



Integrated Environmental Management Information Series

*Ecological Risk
Assessment*

6



Department of
Environmental Affairs and Tourism

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ISSUED BY

Department of Environmental Affairs and Tourism
Private Bag X447
Pretoria
0001 South Africa

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ENQUIRIES AND COMMENTS

All enquiries and comments should be addressed to:
The Director: Environmental Impact Management
Department of Environmental Affairs and Tourism
Private Bag X447
Pretoria
0001 South Africa

REFERENCING

When referencing this document, it should be cited as follows:
DEAT (2002) Ecological Risk Assessment, Integrated Environmental Management, Information Series 6, Department of Environmental Affairs and Tourism (DEAT), Pretoria.

ISBN 0797039767

PREFACE

This document is one of a series of overview information reports on the concepts of, and approaches to integrated environmental management (IEM). IEM is a key instrument of South Africa's National Environmental Management Act (NEMA). South Africa's NEMA promotes the integrated environmental management of activities that may have a significant effect (positive or negative) on the environment. IEM provides the overarching framework for the integration of environmental assessment and management principles into environmental decision-making. It includes the use of several environmental assessment and management tools that are appropriate for the various levels of decision-making.

The aim of this document series is to provide general information on techniques, tools and processes for environmental assessment and management. The material in this document draws upon experience and knowledge from South African practitioners and authorities, and published literature on international best practice. This document is aimed at a broad readership, which includes government authorities (who are responsible for reviewing and commenting on environmental reports and interacting in environmental processes), environmental professionals (who undertake or are involved in environmental assessments as part of their professional practice), academics (who are interested and active in the environmental assessment field from a research, teaching and training perspective), non-governmental organizations (NGOs) and interested persons. It is hoped that this document will also be of interest to practitioners, government authorities and academics from around the world.

This document has been designed for use in South Africa and it cannot reflect all the specific requirements, practices and procedures of environmental assessment in other countries. It is recommended that the current document be read in conjunction with the following document: Claassen et al. (2001) Ecological Risk Assessment Guidelines, WRC Report Number TT 151/01. The WRC document clarifies many of the technical issues dealt with in this text.

This series of documents is not meant to encompass every possible concept, consideration, issue or process in the range of environmental assessment and management tools. Proper use of this series of documents is as a generic reference, with the understanding that it will be revised and supplemented by detailed guideline documents.

ACKNOWLEDGEMENTS

We wish to thank the following individuals and organizations for their contributions to this study: Dr Glenn W. Suter II (ORNL), Ms Anne Sergeant (US EPA) and Dr Bill van der Schalie (US EPA) for their support of the USA-SA bilateral collaboration, which led to the establishment of ERA in South Africa, as well as the CSIR, WRC and NRF for funding various aspects of the development of ERA.

Principal Authors:	Marius Claassen and Joy Leaner
Project Managers:	Mark Gordon (DEAT) and Nigel Rossouw (CSIR)
Editorial Review:	DEAT: Wynand Fourie, Johan Benade and Danie Smit CSIR: Patrick Morant and Michelle Audouin
Peer Review:	Heather Mackay, CSIR

SUMMARY

Ecological risk assessment and risk management have been used extensively in the economic, social and political arenas to promote environmental sustainability and improve the quality of life of humans. The objectives of this document are to describe the concepts and approaches for ecological risk assessment (ERA) globally and within the integrated environmental management (IEM) framework. A broad overview of the ERA paradigm and tools from North America, Europe, Asia/Pacific and developing countries were considered. Overall, the ERA approach followed by the North American countries and South Africa is best used when performing hazard identification and prospective risk assessment.

The approaches followed by the United Kingdom, Sweden, Australia/New Zealand and East Asia follows the precautionary principle, and are conservative approaches

to hazard identification and risk assessment. In developing countries, e.g. the Czech Republic and Lithuania, the ERA approaches used are either adopted from the US EPA, or formal risk assessment procedures are completely lacking. The guidance documents that have been produced are specific to the legislative frameworks in the respective countries, and this should be considered when using the guidance documents to perform ERAs. The risk assessor, risk manager, and interested and affected parties should identify the best practices and tools for performing specific risk assessments. For the ERA framework to be successfully implemented within the IEM procedure, both approaches should incorporate involvement from stakeholders, interested and affected parties, regulatory agencies and the public.

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1. Introduction to Ecological Risk Assessment

1.1 Concepts and principles of ERA

Decisions are often made in environments where information is incomplete, outcomes are uncertain and driving forces are variable. Risk assessment has historically been used in the gambling, actuarial and engineering fields to deal with these difficulties. The main elements of risk assessment are therefore defined as probabilistic analyses and the characterization of uncertainty and variability. The objectives of such assessments are determined in the context of social, economic and environmental issues, and decisions are made by considering these issues. The actual technical risk assessment should, however, not be biased or compromised by societal values or economic drivers. Risk assessment is carried out to enable a risk management decision to be made. Risk management is the decision-making process and associated actions through which choices are made between different options, which would achieve the set objectives. The application of risk assessment principles to environmental assessment gained momentum in the 1980s, with applications in impact assessment, remediation and regulation.

The evaluation of risks to ecosystems is particularly appealing, since it can deal with the complexities of such systems, including natural variability and uncertainty. Uncertainty describes the nature and extent of unknowns in a risk assessment. The sources of uncertainty include a lack of data about the types of stressors and the exposure to them, inadequate information about cause-effect relationships, a poor understanding of distributions over time and space, and uncertainty about the methods used to calculate risk (US DoE, 1995). Variability describes the expected distribution of stressor measures, exposure scenarios, cause-effect relationships, cumulative effects and indirect effects resulting from stochastic or random processes and associated diversity.

Risk in the context of ecological risk assessment and management is defined by the following necessary components (Claassen *et al.*, 2001b):

Subject:

A hazard or stressor that initiates risk, including an exposure pathway (“Affected by what”).

Object:

The target (receptor) upon which the stressor or hazard is expected to have an effect (“The effect on what”).

Effect:

The type, magnitude and characteristics of the effect being assessed (the response of the receptor given a specific stressor).

Expression of likelihood:

Probability of effect or other expression of expectation appropriate to the assessment.

1.2 Definitions of ERA

Willet defined risk assessment in 1901 as the “objectified uncertainty regarding the occurrence of an undesired event” (quoted in Suter, 1993). Views from a century later expanded slightly on this notion, stating that “risk assessment defines the probability of an undesired effect, expressed in the context of associated uncertainties” (US EPA, 1998). Ecological risk assessment “evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of one or more stressors” (US EPA, 1992). Risk analysis is “a two-step process of evaluating risks and making decisions based on the evaluation and other input” (Frantzen, 2002). Risk management is the process of “implementing specific actions in response to the risk”.

2. Role and Use of ERA within Integrated Environmental Management

Ecological risk assessment has been used in risk management by decision-makers who integrate the results of the risk assessment with economic and socio-political considerations to improve the lives of humans (Kwiatkowski, 1998). The risk assessment has traditionally been a function of policy and regulatory agencies and most development has taken place in these fields. Currently the risk assessment process is becoming more common in industry because of the use of ERA in regulation and in management practices. The risk management plan usually evolves after a detailed risk assessment process, to evaluate alternative risk reduction and prevention measures and to implement those that appear cost-effective.

Environmental risk assessment is used to assist management in:

- compliance with legislation
- financial planning
- site-specific decision-making
- prioritization and evaluation of risk reduction measures
- precautionary or remediation actions.

The ERA framework can be integrated with the generic environmental impact assessment (EIA) procedure. There is an overlap in the basic principles of the generic EIA procedure and the ERA framework (Table 1, Figure 1) that makes the integration possible at all levels of policy and regulation. For example, both procedures:

- aim to balance socio-economic development objectives with environmental quality and ecological functions to promote sustainable development,
- assist in the development, implementation and evaluation of policies that promote sustainable development,
- can be applied to different levels of analysis (e.g. local, regional, continental and global scales), and
- are adaptive and considers problem assessment, policy priorities, formulation and implementation of policies through adequate tools, and takes into account the perspectives of the stakeholders involved (Atunes and Santos, 1999).

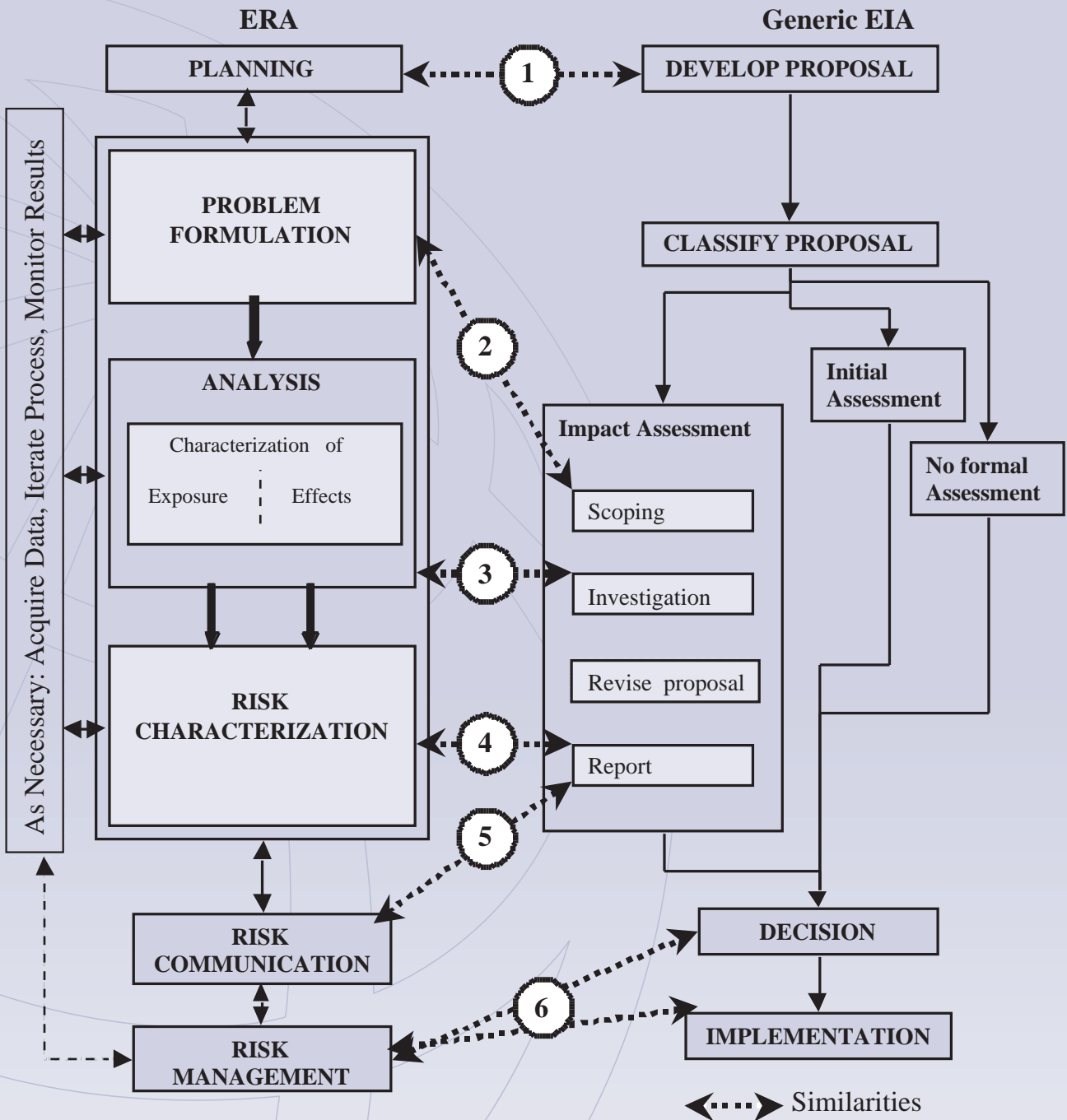
The two processes are complementary in that the EIA addresses all the identified issues in a specific development, whereas the ERA is a structured approach to dealing with ecological impacts. Because the ERA is based on the general principles of risk assessment, the approach is already relevant at the planning stage, where potential risks are identified. The risk-based approach followed in an ERA ensures that the process is rigorous and scientifically sound. The ecological contribution to the EIA can then be evaluated alongside social and economic aspects.

The IEM procedure as a whole promotes a holistic and interconnective approach to managing environmental systems through a goal-oriented, strategic process (Antunes and Santos, 1999). This philosophy is also supported in the ERA process.

The EIA procedure encompasses several tasks that are similar to those followed during assessment practices, and has been applied successfully in coastal zone and catchment management (Argent *et al.*, 1999). Similarly, the techniques used in ERA have a wide range of application, which can be used within the EIA procedure. For example:

- in determining acceptable risks to develop environmental standards or benchmarks,
- in site-specific decisions (hazard identification or land-use planning), and
- in comparative risk analysis (compare different types of risks, make alternative risk options).

Figure 1: Comparison of the ERA framework (US EPA, 1998) and the generic EIA procedure



- 1 Consultation (I&APs, Stakeholders, Assessors); Management plan and options
- 2 Evaluates the extent of & approach of investigation, determines the procedures to be followed and the requirements
- 3 Provides data and information that facilitates decision-making
- 4 The findings of the analysis or investigation are described or documented
- 5 Assessment is discussed and environmental management decisions may be made
- 6 Once satisfied, management makes decisions and implements them

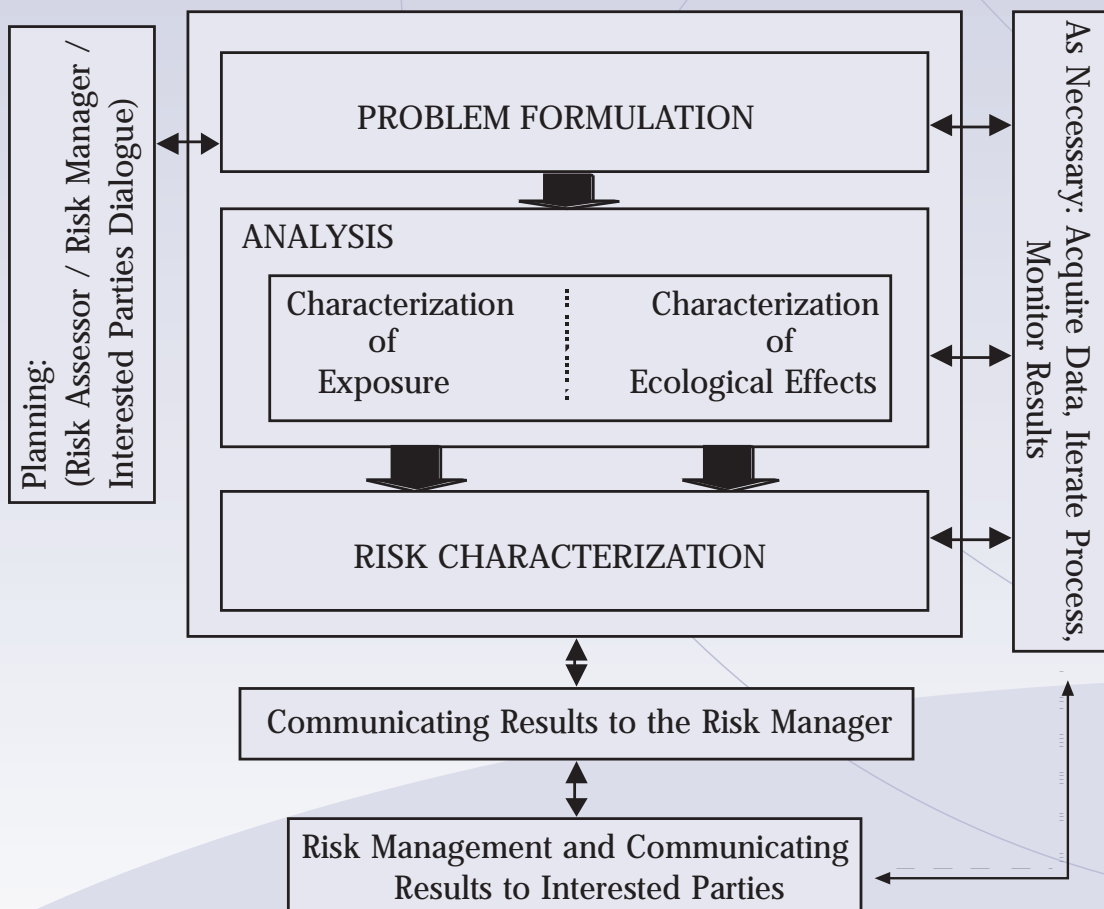
Table 1: Similarities in the basic principles of the EIA procedure and the ERA framework

Generic EIA Process	Ecological Risk Assessment
Accountability for information and decisions taken.	Risk manager is accountable.
Open, participatory approach.	Participatory approach from planning to risk communications.
Consultation with interested and affected parties.	Risk communication occurs with interested and affected parties.
Considers alternative options.	Alternative options are considered in remediation approaches.
Ensures social costs of developing proposals will be outweighed by social benefits.	Includes cost-benefit analysis.
Opportunity for public and specialist input in decision-making.	Risk communication between risk managers and public/I&APs in decision-making.
Includes uncertainty.	Includes uncertainty.

Although ERA has emerged as a specific area in its own right, it is complementary to the EIA process within the general IEM procedure (Figure 2). For example:

- Hazard identification is part of the preliminary assessment for EIA, but if significant uncertainties are identified and unresolved, then the EIA needs to be extended to include an ERA.
- Impacts that may be significant are identified early in the EIA process. ERA can then be employed to determine magnitudes, severity, extent, uncertainties and variability in a structured way.

Figure 2: The ecological risk assessment framework developed by the US Environmental Protection Agency (US EPA, 1998)



2.1 Strengths and Limitations

- The ERA process can be retrospective or prospective.
- The ERA process results in probabilistic expressions that highlight uncertainties about the outcome of a project.
- It quantifies effects, determines significance and has a degree of confidence in prediction, which aids in decision-making.
- The ERA process predicts possible outcomes, and hence adverse effects can be prevented or mitigated.
- There is a limited provision for consultation and feedback during impact quantification.
- It does not explicitly establish legal, policy or administrative requirements - information related to environmental policy and management is evaluated during problem formulation.
- The framework does not incorporate a classification of the proposal stage.

Values that should be integrated when making good risk management decisions are:

- i. the sustainable use of environmental resources (integrate environmental concerns into social and economic decision-making processes);
- ii. people-centred development (integrate population concerns, promote social justice, reduce unsustainable consumption).

The application of ecological risk assessment within IEM has to incorporate continuous involvement of stakeholders, interested and affected parties, and regulators for the integrated ERA approach to be successfully implemented. In addition, strict attention has to be paid to social issues related to the ERAs, so that user expectations can be developed and met in a way that decision-makers use the best information available.

2.2 Future developments for ERA framework in EIA procedure

Claassen (1999) evaluated the applicability of the ERA framework within the EIA procedure. Stakeholder and interested party involvement is fundamental at all stages of the EIA procedure, and the establishment of adequate governance institutions is essential for the success of the EIA procedure (Atunes and Santos, 1999), since this will affect the uncertainty and decision-making process. Similarly, stakeholder involvement in ERA is critical to the success of the assessment. Margerum (1999) indicates that an interactive approach between government, interested groups, public participation, and non-government authorities creates a better understanding of ecological, social and economic systems. Current thinking in South Africa (DEAT, personal communication), however, indicates that extensive stakeholder and interested party involvement at the preliminary stage (i.e. screening report) in the EIA procedure is not mandatory. The role of stakeholder involvement in the EIA procedure needs to be clarified.

3. Approaches to ERA

3.1 International review of ERAs

There are several approaches to performing ecological risk assessment. The types of risk assessment approaches followed differ between countries, and usually support the environmental legislation of that country (Table 2). A comparative review of ERA frameworks for the international regions is presented in Table 3.

- North America (United States of America, Canada)
- Europe (United Kingdom, Netherlands, Sweden, Belgium)
- Asia/Pacific (Australia/New Zealand, South East Asia, Japan)
- Developing countries (Czech Republic, Eastern Europe, South Africa)

(See Appendix 1 for more details on the specific ERA approaches followed in each country.)

Table 2: A comparison of ERA approaches in different countries.

Country	Document	Comments
<i>North America:</i>		
United States of America (USA): United States Environmental Protection Agency	Guidelines to Ecological Risk Assessment (US EPA, 1998).	Core document in USA. Specific to USA legislation. ERA framework (Figure 2) includes three phases: problem formulation, analysis, and risk characterization. Process is iterative. Describes risk quantitatively and qualitatively.
Oak Ridge National Laboratory	Produced a portfolio of screening benchmark reports and guidance documents (Appendix 1).	ERA approach is similar to US EPA (Figure 2). Includes hazard identification. Performs screening at preliminary stage. Follows site-specific risk assessment.
California/EPA	Produced various guidelines on hazard identification, dose response, and exposure assessment (Appendix 1).	ERA approach is similar to US EPA (Figure 2). Does not address risk management decisions.
Superfund	Ecological Risk Assessment Guidance for Superfund (US EPA, 1997).	ERA approach is EPA-approved. Follows site-specific ERAs. Uses semi-quantitative data.
Canada: Environment Canada (EC)	Framework for Ecological Risk Assessment at Contaminated Sites in Canada (EC, 1994).	ERAs are similar to US EPA (Figure 2). Key components are: problem formulation, exposure and toxicity assessment, receptor and risk characterization. Specifies a tiered approach. Decision-making tools evaluate risk reduction alternatives (Figure A1).
<i>Europe:</i>		
European Environmental Agency	EnviroWindows: (http://service.eea.eu.int/) contains various reports (Appendix 1).	ERA approach in the EU consists of four steps, viz. effects assessment (hazard identification and dose-response assessment), exposure assessment, and risk characterization.
United Kingdom	Guide to Risk Assessment and Risk Management for Environmental Protection (UK DOE, 1995).	ERA framework has 5 stages (Figure A2) which leads to risk estimation, viz. description of intention, identification of hazard and consequences of hazard. Risk is estimated from a combination of magnitude and probability of consequences, which lead to risk perception.
Netherlands	Premises for Risk Management (MHPPE, 1989).	ERA used in development of environmental policy objectives. Management framework (Figure A3) provides for: estimation of magnitude, probability of hazard occurrence, acceptability of risks, and prevention or maintenance of acceptable risks.
Sweden	Key legal framework: The Environmental Code (Swedish EPA, 1999).	Swedish EPA interprets environmental laws. Environmental policy objectives follow the precautionary principle and are based on exposure, rather than effects.

Country	Document	Comments
Belgium	No formal document - Has a general framework for contaminated site management (Figure A4).	Management framework integrates risk assessment approaches and defines investigation procedures. ERAs follow remediation and site-specific approaches.
<i>Asia/Pacific:</i>		
Australia/New Zealand	Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites (ANZECC/ NHMRC, 1992)	The framework (Figure A5) identifies prevention of site contamination and recommends protection of the entire environment, incorporates a risk assessment approach that is similar to that of the US EPA (Figure 2). ERA is iterative, and emphasizes both qualitative and quantitative approaches to determining risks.
East Asia	Environmental Risk Assessment Manual -A practical guide for tropical ecosystems (GEF/UNDP/IMO, 1999).	Provides an integrated ERA framework (Figure A6) that has three phases, viz. problem formulation, retrospective and prospective risk assessment, and risk management. Framework objectives are based on exposure, rather than effects. Follows precautionary approaches to assessing risks.
Japan	No formal guidelines on ERA; the Pollutant Release, Transfer and Registration Act (Japanese Government, 2000) is the key legal framework.	Places emphasis on risk management. Various modelling approaches and case studies have been used to assess risks (e.g. Tokai and Nakanishi, 2001).
<i>Developing Countries:</i>		
Czech Republic	No formal document, but performs risk assessments based on European Union methodologies and retrospective approaches (Holoubek et al., 2001).	Performs ERAs in the IDRIS project. ERA is retrospective and site-specific. ERA includes hazard identification, eco-toxicological properties and assessment in the field and sites with known influence of stressors.No risk communication process is undertaken in the IDRIS project.
Eastern Europe	No formal documents.	Russia follows the US EPA's methodology for performing ERAs (Korobitsin and Chukanov, 2001). The ERAs in Lithuania, Armenia and Romania are performed by scientists who communicate the results at scientific meetings (see Appendix 1).
South Africa	Ecological Risk Assessment Guidelines (Claassen <i>et al</i> 2001a).	The ERA framework is modelled on that of the US EPA (Figure 2). The ERA approach has three formal stages, viz. plan assessment, analyze and describe risk, followed by a discussion between risk assessor and manager, who communicates with interested parties (Figure A7).

Table 3: Comparison of the key elements of the different ERA approaches.

	Qualitative	Quantitative	Guidance	Site-specific	Remediation	Preventative	Hazard ID	Retrospective	Prospective	*Cumulative	*Comparative	Exposure	Effects	Iterative
USA	✓	✓	✓		✓	✓	✓		✓			✓	✓	✓
ORNL	✓	✓	✓	✓	✓		✓		✓			✓	✓	✓
Cal/EPA	✓	✓	✓		✓	✓	✓		✓			✓	✓	✓
Canada	✓	✓	✓		✓	✓	✓		✓		✓	✓	✓	✓
UK	✓	✓	✓			✓	✓		✓					✓
Sweden				✓		✓	✓		✓			✓		
Netherlands	✓			✓	✓		✓	✓				✓		
Belgium		✓	✓	✓	✓			✓						✓
A/NZ	✓	✓	✓	✓	✓	✓		✓				✓	✓	✓
East Asia	✓	✓	✓	✓		✓		✓	✓					✓
Czech Republic				✓			✓	✓	✓					
South Africa	✓	✓	✓						✓			✓	✓	✓

* The lack of procedures for cumulative and comparative assessment is evident. Both are important for a balanced approach towards sustainable development.

3.2 Identification of Best Practice

The selection of specific approaches should consider the context and specific requirements of the assessment. Table 4 presents the approaches that have become the standard for ecological risk assessment in different applications, and the associated methods.

Table 4: Approaches for ERA and associated methods

Ecological risk assessment process	US EPA Guidelines for Ecological Risk Assessment (US EPA, 1998)
Risk management	Risk Assessment and Risk Management in Regulatory Decision-Making, (CRARM, 1997)
Restoration of contaminated sites	Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments (US EPA, 1997)
Petroleum clean-up	Risk-based Corrective Action (ASTM, 1995)
Hazardous materials	Risk-based Decision-making in the Hazardous Materials Safety Program (US Department of Transportation, 1998)
Cumulative risk assessment	Guidance on Cumulative Risk Assessment (US EPA, 1997)

4. Tools for Ecological Risk Assessment

ERA can be described as a philosophy rather than a specific method, and is based on the principles described in the introduction. These principles can be met through the application of different combinations of processes (previous chapter) and assessment tools. These tools are often not specific to ERA, and have often been developed to support other processes, such as predicting the fate of chemicals in the environment and understanding ecosystem processes. These tools, however, may not always meet the requirements of ERAs. A common problem is that predictive tools do not always deal explicitly with variability and uncertainty, and where they do, they seldom allow a separate analysis of these attributes. Furthermore, probabilistic analysis (determination of likelihood) is not always supported by the available tools. It is thus important to consider the limitations of the available tools before selecting one or more of these for use in an ERA. The phases of an ERA and some of the tools available are as follows:

Objectives

Agreeing on the objectives of an assessment generally does not rely on numeric tools, but rather less technical approaches in the management and social science domain. It is, however, important that the chosen approach is compatible with risk-based analysis. The following tools (or combinations of these) are routinely used in risk assessment and risk management:

- Visioning.
- Multi-criteria decision analysis.
- Cost-benefit analysis.
- Adaptive resource management.

Planning

Planning is the scientific activity of deciding what to do and how to do it. The general approach should be compatible with the scientific method (Popper, 1959; Lakatos & Musgrave, 1968). A change of emphasis in risk assessment is that hypotheses are not just evaluated to reject (or accept) them, but that it is rather a process of gathering, evaluating and presenting evidence about different scenarios.

In addition to the methods available for scientific analysis, the following are some of the tools that are available for specific aspects of planning:

- Guidelines for selecting endpoints (US EPA, 2000).
- Data quality objectives (Barnhouse and Suter, 1996).
- Developing conceptual models for ecological risk assessments (Suter, 1996a).
- Guidelines for exposure assessment (US EPA, 1992).

- ORNL ecotoxicological screening benchmarks (Sample *et al.*, 1998).
- Dose rates to freshwater biota exposed to radionuclides (Blaylock, *et al.*, 1993).
- Guidelines for testing of chemicals (OECD, 1994).

Analysis

Several tools are available for exposure assessment, dose-response analysis and effects assessment. The different types of tools are discussed, and are illustrated with specific examples.

Various risk assessment models are available, although most just string together specific aspects of a risk assessment, rather than to deal with the process in its entirety. Examples of such models are:

- APPRAISE: Database and calculation tool to assess the environmental impact of industrial releases (UK).
- DOE#1: Risk assessment and risk management methodology (USA).
- RBCA: Risk-based Corrective Action Tool Kit for contaminated land and water (UK).
- REFEREE: Ecological risk assessment using effect models linked to ecological and ecotoxicological databases (Netherlands).
- DIAS: Dynamic Information Architecture System - predicts the magnitude and extent of ecological risks and evaluates remedy effectiveness in a timely and cost-effective manner (Sydelko *et al.*, 2001).
- PROTEUS: A technical and management model for aquatic risk assessment of industrial spills (Netherlands) (Stam *et al.*, 2000).
- RISC: Risk Assessment Model for Soil and Groundwater Applications (New Zealand).
- API-DSS: American Petroleum Institute - Decision Support System Software (USA).
- CalTOX: A multimedia total exposure model for hazardous waste sites (USA).

The characterization of point sources of pollution is in the engineering domain, with process models often being used to determine probable stressors and stressor levels. Determining the effective dose with which the endpoint (ecosystem) will be in contact can be done through chemical fate and transport models for chemical stressors and variable-specific models for biological and physical stressors. Examples of fate and transport models and resources are the following:

- Wildlife Exposure Factors Handbook (US EPA).
- Wildlife Contaminant Exposure Model: Estimate wildlife exposure to substances (US EPA).
- Air quality management system - contaminant dispersion in air (UK).
- AQUA: Groundwater flow and contaminant transport model.
- Groundwater flow and contaminant transport model (USA).
- EXAMS II: Exposure simulation model looking at the

effect of a chemical on an ecosystem, concentrations, fate and transport (USA).

- PLUMES: Dilution/dispersion model for pollution plumes in marine and freshwater (USA).
- WASP: Water Quality Analysis Simulation Programme models; contaminant fate and transport in surface waters (USA).

Non-point source pollution can be characterized with models developed specifically for such applications. These include:

- HSPF - Hydrological Simulation Programme—Fortran) (USGS).
- BASINS - Better Assessment Science Integrating Point and Non-point Sources (US EPA).

Once the effective dose has been established (for prospective analyses) the effects can be determined with the tools mentioned below, among others (Giddings & Hendley, 1998). For retrospective and comparative analyses the effects assessment models are used to determine the likely stressor levels.

- Time-to-event analysis.
- Pulsed exposures.
- Population models.
- Sensitivity distributions.
- Sediment toxicity evaluation.
- Chronic toxicity tests.
- Mesocosms and microcosms.
- Behavioural toxicity tests.

Databases include CHEMBANK (UK), CHEMTOX (USA), Environmental Chemicals Data and Information Network (EC), Integrated Risk Information System (US EPA), International Register of Potentially Toxic Chemicals (UNEP), RISKLINE (Sweden), Oak Ridge National Laboratory Benchmarks (USA), Cal/Ecotox (USA), and Ecotox Thresholds Software (US EPA).

Risk characterization

Risk characterization is most often a quantitative (statistical) procedure for which mathematical approaches based on probability theory may be employed. For qualitative analysis, interpretive techniques may be used. Some of the tools available for risk characterization are:

- Preliminary Remediation Goals for Ecological Endpoints; and
- Risk Characterization for Ecological Risk Assessment of Contaminated Sites (Suter, 1996b).

Risk Communication

The target audience for the information should be well defined. When information about the risk assessment is communicated, appropriate attention to the associated complexities and uncertainties will promote effective

communication. One should ensure that the message is well formulated, effectively conveyed, correctly understood and that it results in meaningful actions.

Specific applications

Tools are also available for specific applications, such as Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments (US EPA, 1997) and Risk-based Correction Action (petroleum clean-up).

With the broad range of tools available, it is important to match the specific tool with the objectives of the assessment and the requirements for risk assessment. This will ensure that the results promote effective decision-making and environmental management.

5. Information Requirements

Much has been written about the data requirements for ecological risk assessment (US EPA, 1998, GEF/UNDP/IMO, 1999). What follows is a summary of the specific data and information requirements for the various stages of an ERA, as presented above, and comments on the characteristics of data (and information) used in ecological risk assessments.

5.1 Specific data requirements

Objectives

The single most important source of information for an ecological risk assessment is a clearly stated and well-articulated objective. When wrong questions are asked, it is inevitable that it will lead to wrong answers, irrespective of a thorough analysis of the questions. It is the joint responsibility of the decision-maker (risk manager) and risk assessor to formulate the study objectives. The most important questions that should be addressed when stating objectives are as follows:

- What is the problem, and why?
- What is the manager's perception of the problem?
- What are the management options/goals?
- What is the scope of the assessment?
- How much uncertainty can be tolerated?
- What resources are available to assess and manage the risk?
- How much time is available to assess and manage the risk?
- How should the risk be communicated?

The social, economic and political context of the problem should be considered when agreeing on the objectives.

Planning

During planning, generic knowledge about the type of problem is required, in other words *what* is affecting/being affected and *what* are the mechanisms for the process. This allows a conceptual model to be constructed and more detailed data requirements to be identified. It is during this phase that a lack of basic understanding of the processes and mechanisms will have significant time and resource implications.

Data that can be usefully employed during this stage include:

- national and regional data on stressor sources (e.g. emissions inventory)
- spatial data on ecosystem characteristics (e.g. Red Data species)
- general data on stressor-response relationships (e.g. ecotoxicological benchmarks)
- information about ecosystem structure and function (e.g. ecosystem studies).

Analysis

The analysis phase is concerned with *how* and *to what extent* the effects are being induced or expressed. Here, depending on the level of the assessment, the emphasis is on predicting the effects (prospective), identifying the source (retrospective) or evaluating alternatives (comparative). The data required should be quite specific to the problem, i.e. deal with the specific sources, pathways, stressors, ecological targets (end points), and ecosystem responses. This phase is inevitably the most data-intensive of an ERA, although the value of the assessment is often not driven by the data itself, but rather by an understanding of processes and interrelationships.

Examples of data and knowledge required for the analysis phase are:

- detailed spatial, temporal and magnitude distribution of stressor release and/or occurrence
- understanding exposure and effects mechanisms

- site-specific and system-specific knowledge of stressor-response relationships
- ecosystem-specific structure and function knowledge.

Risk characterization

The risk characterization phase does not require more information than that collected during the analysis phase, but requires an understanding of statistics and/or probability theory and practice. This requires the integration of information regarding exposure and effects to estimate risks.

Risk management

During risk management information is required on all the factors that may affect the risk or may be affected by the risk. The risk manager must consider the costs and benefits of avoiding the risks, as well as the legal and regulatory constraints, and all relevant social, economic and ecological information.

5.2 Data characteristics

Uncertainty

An objective of ERA is to achieve a balance between the cost of the analysis and the benefit accruing from using the results. There is a strong correlation between data availability and uncertainty in the output. A screening assessment may use only limited data, and will probably have a wide range of uncertainty (Figure 3a). A more detailed analysis may yield more reliable predictions, but usually comes at the cost of having to source more data (Figure 3b). Optimization of the relationship can mainly be achieved through sensitivity analysis. The variables that have the biggest influence on the uncertainty should be the focus of more detailed analyses. This will reduce the cost and optimize benefits.

Uncertainty is compounded in the analysis, where relatively little data uncertainty, model uncertainty, uncertainty about cause-effect relationships and uncertainty in interpretation may add up to unacceptable uncertainty.

Figure 3a: Low confidence prediction

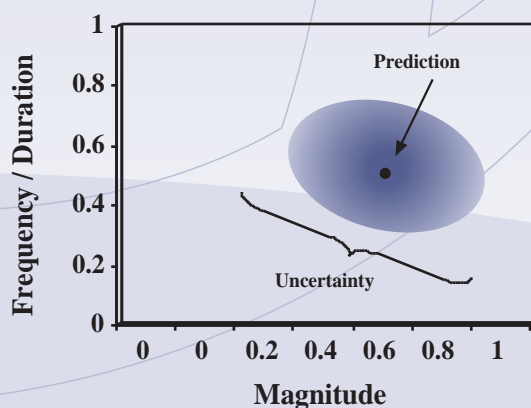
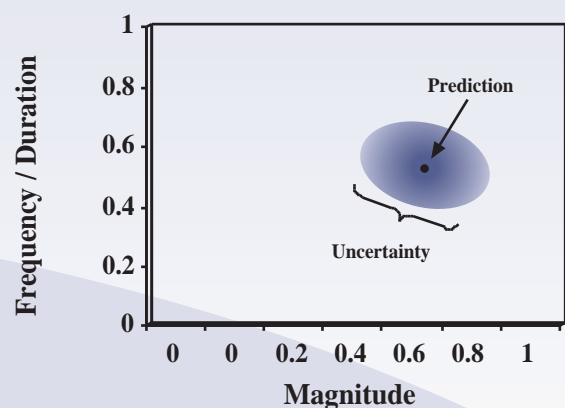


Figure 3b: High confidence prediction



Variability

A strength of risk-based approaches is that variability can be incorporated in the assessment. Variability may be related to the source of a stressor, the stressor itself, the actual exposure, the response of the ecosystem to the stressor, or knock-on effects. The variability is most often a function of natural stochasticity. Expressing the variability allows the risk manager to weigh up potential future scenarios and to make an informed decision. Statistically, variability can be dealt with in the same way as uncertainty, but the two (distinctly different) attributes should preferably be reported separately. This will also facilitate future analyses, since variability cannot be reduced by knowing more, whereas uncertainty is directly dependent on knowledge of the specific system.

Variability is often characterized as a normal distribution, which is often associated with a natural stochastic process. The distribution may, however, be logarithmic, exponential, bimodal, or approximate another distribution. The lack of diagnostic data or knowledge of the specific driving processes often reduces the expression of variability to a “flat” distribution ($x \pm y$).

Assumptions

Assumptions should be noted during analyses and stated clearly when reporting the results of the assessment (as is the case with all scientific procedures). Sensitivity analyses should be employed to characterize the potential impact of assumptions on the analysis. The assumptions should also be supported by theory and/or fact and motivated accordingly.

6. Conclusions

The consistent application of the ERA process and associated tools will ensure that scientific rigor prevails. This will strengthen the ecological assessment and increase the confidence in decisions based on the assessment. The expression of ecological risks in probabilistic terms, while

explicitly stating uncertainties, also provides a “common currency” through which ecological, social and economic information can be integrated to support integrated environmental management.

Overall, it is evident that the US EPA framework is used most often for performing risk assessments in North America and in other countries, where the concepts of the framework has been modified to meet the needs of the specific country in question. Many countries in the developing world lack formal ecological risk assessment processes, and perform scientific studies using general risk assessment methods. Formal approaches to risk assessment are needed in all countries, and there is a clear determination in the legislative structures of the different countries to achieve this goal. The ecological risk assessment framework is developing in its own right, and this framework is comparable with the integrated environmental management procedure. The need for involvement of stakeholders, interested parties, and regulatory agencies should be emphasized and is fundamental to the success of the integrated assessment approaches.

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APPENDIX 1

INTERNATIONAL REVIEW OF ERA APPROACHES:

North America

United States of America

US EPA

Document: *Guidelines for Ecological Risk Assessment (US EPA. 1998)*

- ERA framework (Figure 2):

- Initial dialogue between risk assessor, risk manager, and interested parties.
 - Phase I: Problem Formulation - identifies, refines goals and objectives by integration of available data; produces assessment endpoints and conceptual models which lead to an analysis plan to ensure sufficient information for decision-making.
 - Phase 2: Analysis - fundamental interactions of analysis are: (i) exposure characterization - determines how much exposure to stressor is likely to occur; (ii) effects characterization - determines likelihood and types of effects; produces stressor-response profile.
 - Phase 3: Risk Characterization - integrates exposure and effects analyses to yield risk estimates; evaluates any associated uncertainties due to data and knowledge gaps; interprets and discusses ecological risks; evaluates lines of evidence supporting or refuting risk estimates.
 - Risk communication between risk assessor, risk manager, and interested parties is fundamental to ERA.
- Iterative process leads to more precise risk estimation.
- Exposure and effects data are integrated to quantitatively or qualitatively describe risk.
- Inexplicitly provides a tiered approach to risk assessment, the onus of which lies with risk assessor.

Oak Ridge National Laboratory (ORNL)

Documents: ORNL has developed a broad portfolio of screening benchmark reports and guidance documents, including *Toxicological benchmarks for screening potential contaminants of concern, 1994*; *Approach and strategy for performing ERA for USDoE*; and *Preliminary assessment of ecological risk to wide-ranging wildlife species on the Oak Ridge Reservation, 1996*.

- Documents provide benchmarks for hazard identification.
- Risk assessor decides on screening benchmark.
- Documents produced cover exposure models, data quality objectives, and guidance to developing preliminary remediation goals.

California/ EPA

Document: Various guidelines on hazard identification, dose response, and exposure assessment have been compiled by Cal/EPA, including *Guidelines for assessing ecological risks posed by chemicals - Development plan (Cal/EPA, 1996)*, *A review of the California Environmental Protection Agency's Risk Assessment Practices, Policies and Guidelines*

- Recommendations from the risk assessment advisory committee include the following:
 - The need for early input from risk managers and stakeholders.
 - Improvement on hazard identification, dose response and exposure assessment.
 - Cal/EPA should improve characterization of uncertainty and variability in risk assessment and communication with risk managers and public.

Superfund

Document: *Ecological Risk Assessment Guidance for Superfund (US EPA, 1997)*

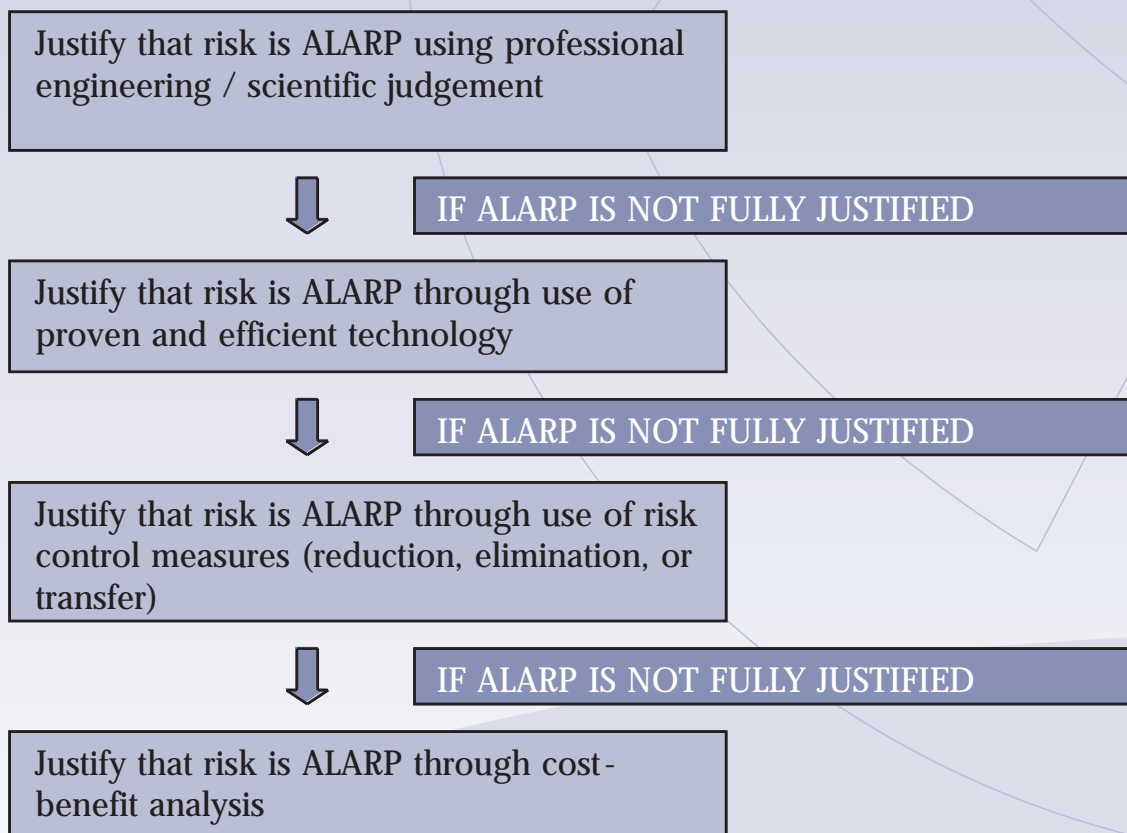
- Risk assessment approach is EPA-approved.
- Semi-quantitative comparative ecology data are used to provide direct measure of impacts.
- Document contains extensive checklists for ecological sampling and guidance on conducting literature reviews, statistical uncertainty, biological sampling methods and data analysis.

Canada

Document: *Framework for Ecological Risk Assessment at Contaminated Sites in Canada: Review and Recommendations (Environment Canada, 1994)*

- The approach promotes site-specific assessment and remediation in Canada, and explicitly screens pathways, contaminants and receptors to produce a conceptual model.
- Incorporates more stakeholder, risk manager and interested and affected parties communication.
- Explicitly recommends a tiered approach (Levels I - III) to risk assessment, recognizes that risk perception influences risk acceptability and categorizes risk.
- The tiered approach is as follows:
 - Level I: screening and characterization process occurs by qualitative or comparative methods.
 - Level II: leads from Level I, semi-quantitative data are obtained, and increased emphasis is placed on data collection.
 - Level III: includes site-specific data and predictive modelling to obtain quantitative information.
- Provides decision-making tools for evaluating risk reduction alternatives (Figure A1).

Figure A1: Recommended procedure to justify risk reduction: As Low as Reasonably Possible (ALARP) (Environment Canada, 1994).



Europe

European Environmental Agency

The European Environmental Agency (EEA) is a central body of the extended European Environment Information and Observation Network.

Document: *Enviro Windows* (<http://service.eea.eu.int/>) - contains reports on corporate environmental management, environmental best practices and approaches for selecting ecological sensitive solutions at the business and local authority level.

- ERA process used in new and existing substances in the EU consists of four steps:
 - Effects Assessment (incorporates hazard identification and dose-response assessment) - identifies and characterizes the hazard, and estimates the Predicted No Effect Concentration (PNEC).
 - Exposure Assessment - calculates the Predicted Environmental Concentration (PEC) using monitoring data and modelling techniques; considers transport and fate mechanisms.
 - Risk Characterization - calculates a quotient (PEC/PNEC) - if ratio is less than 1, the substance is considered to present no risk.
- The EEA aims “to support sustainable development and to help achieve significant and measurable improvement in Europe’s environment through provision of timely, targeted, relevant and reliable information to policy-making and the public.”

United Kingdom

Document: *Guide to Risk Assessment and Risk Management for Environmental Protection* (UKDOE, 1995)

- Follows a unique risk assessment and risk management approach.
- UKDOE ERA framework (Figure A2):
 - Five stages lead up to risk estimation: description of intention (analogous to problem formulation), identification of the hazard, and identification of the consequences of hazard.
 - If hazard unidentified, then magnitude and probability of consequences are inferred or estimated.
 - A combination of magnitude and probability of consequences yields an estimation of risk (Table A1).
 - An evaluation of the estimated risk is identified, and leads to risk perception, leading to risk assessment and risk management.
 - Informs risk-monitoring (e.g. risk manager, interested parties) system.
 - Risk assessment must contribute to UK’s sustainable development strategy; the framework assesses whether sustainability is affected.
- Decision-making assesses the best possible science information and risk analysis, and is strongly influenced by risk perception.
- Risk assessment follows the precautionary principle, and critically evaluates risk estimates.
- The risk assessment approach is iterative, and follows quantitative/qualitative analyses.

Figure A2: The risk assessment and risk management framework as described by the UK Department of the Environment (UK-DOE, 1995):

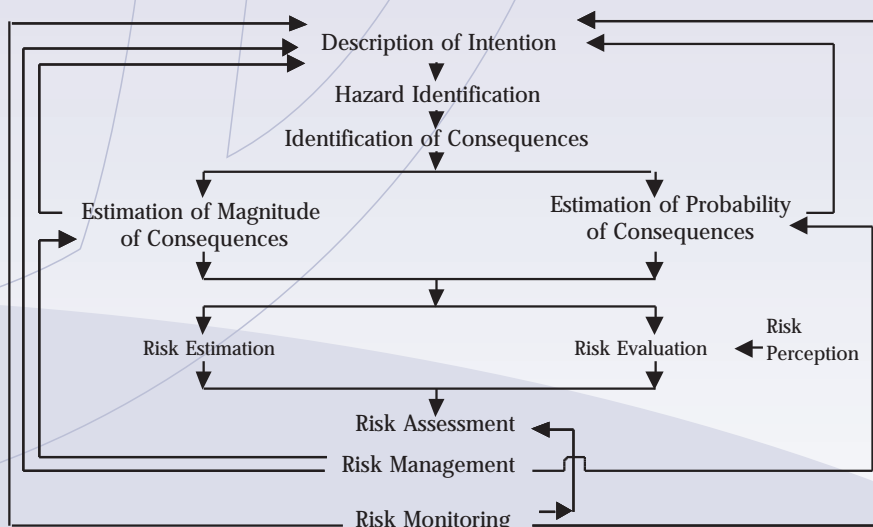


Table A1: Estimation of risk from consideration of magnitude of consequences and probabilities (UK DOE, 1995).

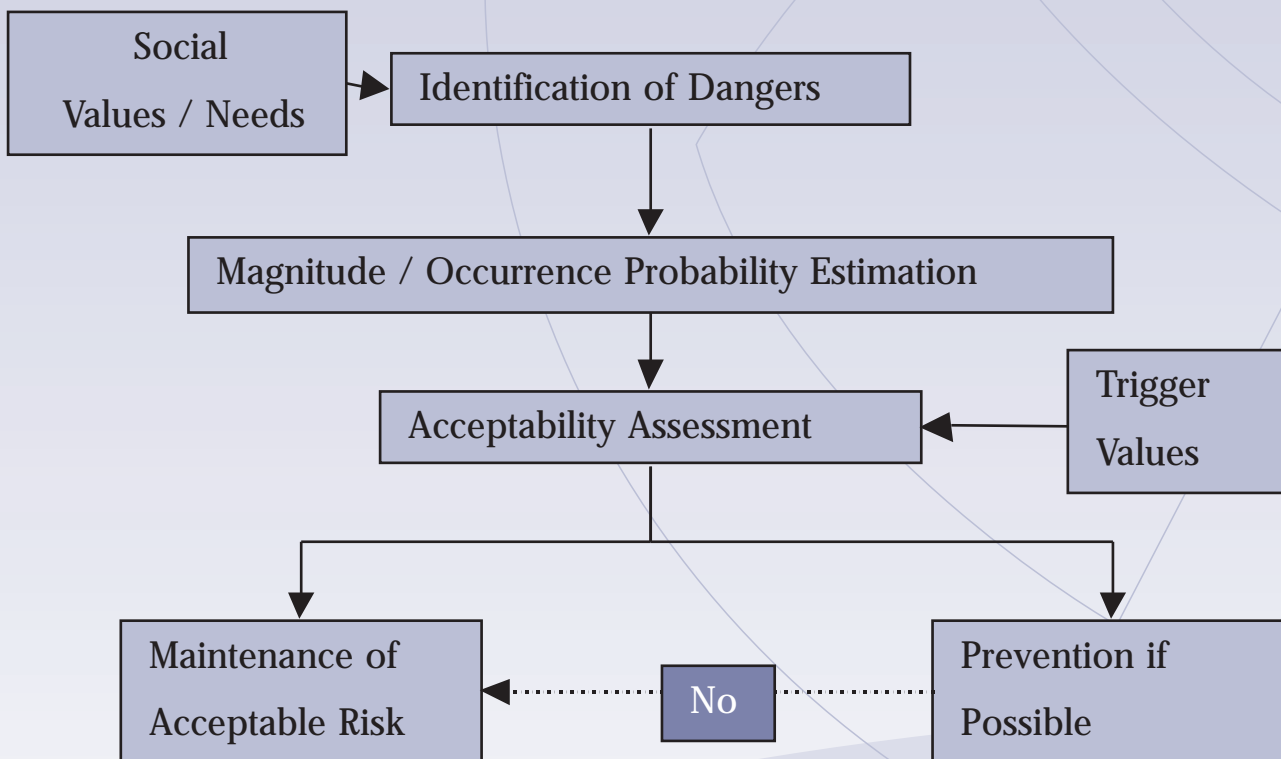
-	Consequences			
	Severe	Moderate	Medium/Low	Negligible
Probability	-	-	-	-
High	High	High	Medium / Low	Near Zero
Medium	High	Medium	Low	Near Zero
Low	High/Medium	Medium/Low	Low	Near Zero
Negligible	High/Medium/Low	Medium/Low	Low	Near Zero

The Netherlands

Document: *Premises for Risk Management* (MHPPE, 1989)

- The management framework (Figure A3):
 - provides for an estimation of *magnitude and probability of hazard occurrence*, and is followed by an assessment of *acceptability of risks*, and *prevention or maintenance of acceptable risk*
 - determines whether hazard prevention is possible or not
 - recommends implementation of remediation action.
- Risk assessment defines limits for stressor, and there is increased separation between receptor and source.
- Risk assessment allows comparison of risks from agent/s and prioritization of actions (McCarty and Power, 2000).
- Risk assessment is quantitative, and uncertainties are discussed qualitatively (Clarkson *et al.*, 2001).
- Framework is not useful for development of specific management action (Power and McCarty, 2002).

Figure A3: The main elements of the risk management framework defined in the *Premises for Risk Management* (1989) of the Netherlands Ministry of Housing, Physical Planning and Environment



Sweden

Document: *The Environmental Code (Swedish EPA, 1999)* is the key legal framework that amalgamates the rules contained in 15 acts, including the Environmental Protection Act of 1969.

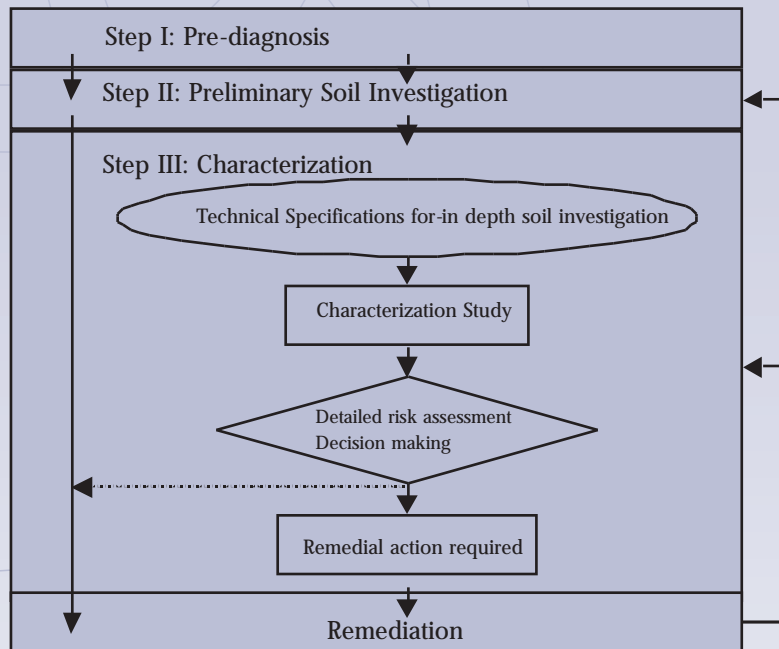
- National License Board: issues licence for integrated pollution control; defines guidelines for potential pollution activities.
- Companies are responsible for compliance to legislation regarding risks (Johannesson et al., 1999).
- Policy objectives:
 - follow precautionary principle: the environment is protected through the elimination of hazardous substances
 - do not directly confront the issue of what should be protected (McCarty and Power, 2000).

Belgium

Document: No formal document - Halen *et al.* (2001) proposed a general framework for contaminated site management, which integrates risk assessment approaches (Figure A4).

- Risk assessment establishes remedial and investigation priorities, and follows site-specific approaches.
- The approaches ensure early decision-making, based on risk acceptance of contaminated data.
- Risk characterization and remediation practices are quantitative and iterative.

Figure A4: Tiered frame proposed for the general management of contaminated sites of the Walloon region, Belgium, modified from Halen *et al.* (2001)



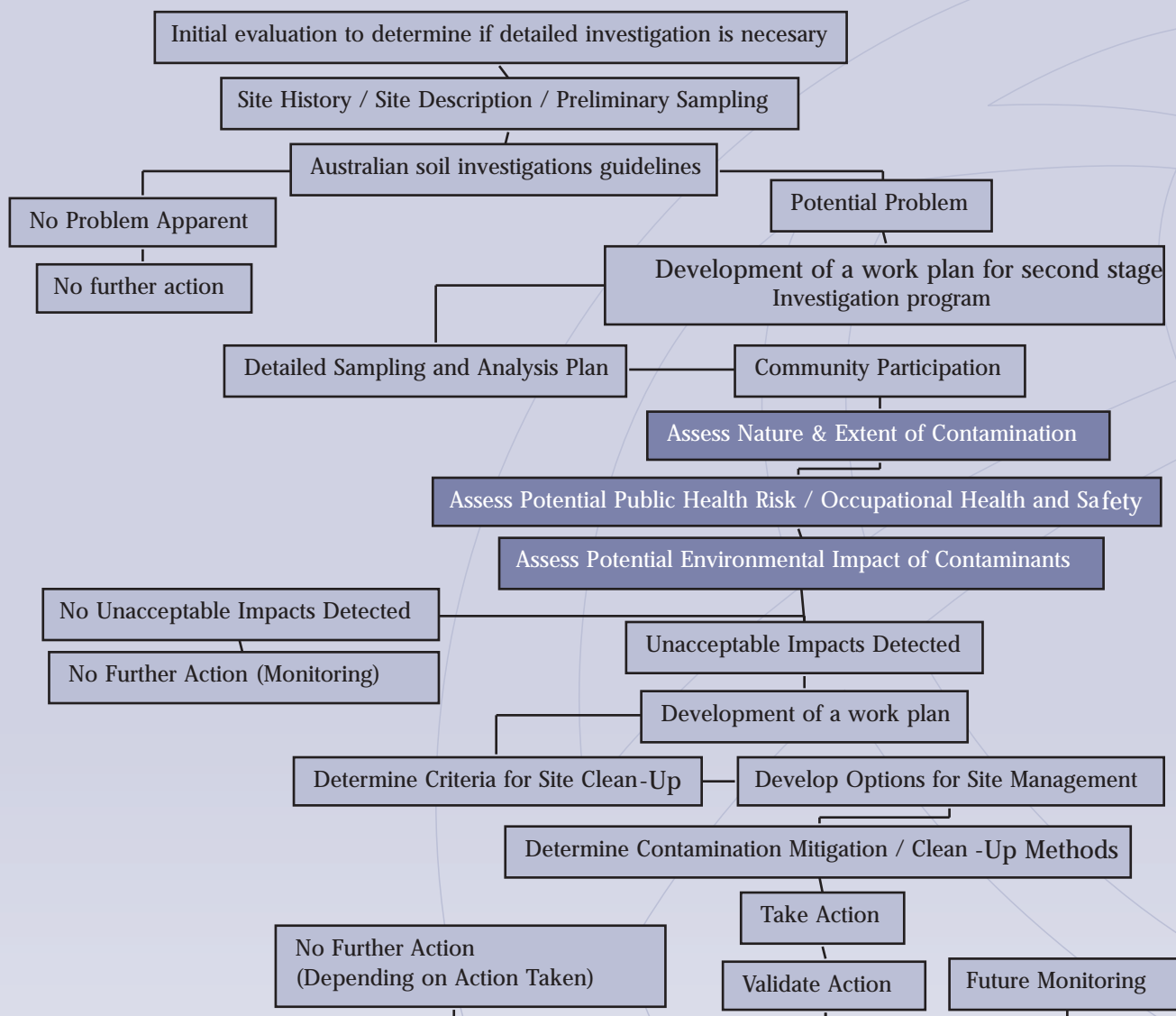
Asia/Pacific

Australia/New Zealand

Document: Australian and New Zealand guidelines for the assessment and management of contaminated sites (ANZECC and NHMRC, 1992)

- The framework (Figure A5):
 - identifies the prevention of site contamination
 - recommends protection of the entire environment
 - provides a multi-disciplinary approach for remediation of contaminated sites.
- Community involvement at the preliminary stages of contaminated site management is fundamental to the policy, legislation, and assessment procedures.
- The recommended approach to the assessment and management of a potentially contaminated site (Figure A5) incorporates a risk assessment approach that is technically similar to that of the US EPA (Figure 2).

Figure A5: Recommended approach to the assessment and management of a potentially contaminated site (ANZECC / NHMRC, 1992)



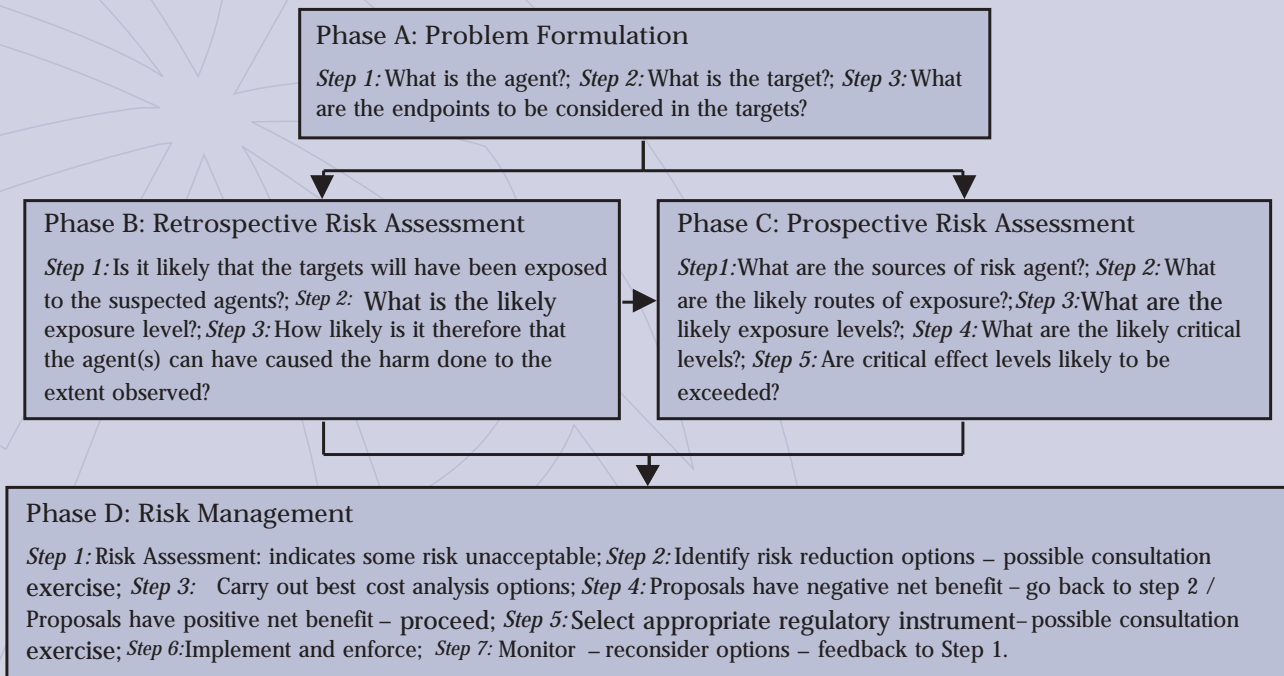
East Asia

Document: *Environmental Risk Assessment Manual - A practical guide for tropical ecosystems* (GEF/UNDP/IMO, 1999). This is the general guidance document in the East Asian region for the prevention and management of marine pollution at national and subregional level.

- Document recognizes the need for a thoroughly planned and developed assessment into an efficient and integrated ERA framework (Figure A6).
- ERA framework is divided into three phases:
 - an identification of the agents, targets, endpoints and the scale at which the assessment must be carried out in the problem formulation phase; followed by
 - a retrospective and prospective risk assessment procedure, where the effects and likelihood of an undesirable effect is assessed, respectively.
 - The risk assessment process progresses to the risk management phase, which is an iterative process involving the monitoring and management of risk.
- The framework's objectives are based on exposure, rather than effects.
- Includes a precautionary approach as part of the risk assessment.
- Guidelines provide examples on:

- performing comparative risk assessment
 - uncertainty assessments
 - benefit-cost analysis.
- Limitations of the risk assessment process is presented.

Figure A6: Basic approach to risk assessment/risk management for tropical ecosystems (GEF / UNDP / IMO, 1999).



Japan

Document: No formal guidelines on risk assessment, uncertainty analysis, nor risk communication programs in Japan (Clarkson *et al.*, 2001) - The Pollutant Release, Transfer and Registration Act (Japanese Government, 2000) is the key legal framework.

- Much emphasis is placed on risk management.
- A focus on developing appropriate remediation technologies and clean-up standards has been identified for the future (Clarkson *et al.*, 2001).

Developing Countries

Czech Republic

Document: No formal document, but performs risk assessments based on European Union methodologies and on retrospective approaches to risk assessment within the IDRIS project (Holoubek *et al.*, 2001).

- IDRIS is the main research project involved in risk assessment.
 - Approaches followed are as follows:
 - hazard identification and ecotoxicological properties of environmental compartments
 - hazard identification and assessment in the field
 - risk assessment focused on sites with known influence of stress factors.
- Risk assessment is retrospective, and site-specific practices are followed.
- No risk communication process is undertaken within the IDRIS project.
- The need for region-specific and prospective risk assessment methodologies was identified as critical to the risk assessment process, and is included in the second part of the project (IDRIS II), executed by the Czech Ministry of the Environment (Holoubek *et al.*, 2001).

Eastern Europe

From a review of the proceedings of the NATO Advance Research Workshop on Assessment and Management of Environmental Risks (2001), it is evident that the most East European countries lack formal guidelines to performing risk assessments. For example:

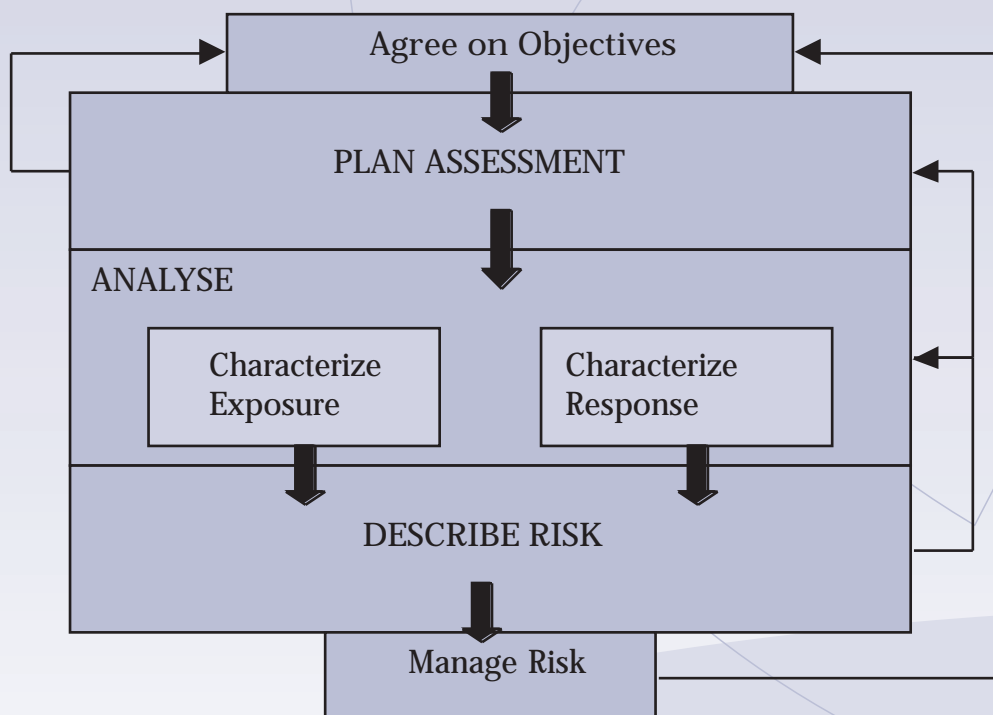
- Russia follows the US EPA's methodology for ERA (Figure 2) (Korobitsin and Chukanov, 2001), and
- the risk assessments of Lithuania, Armenia and Romania are performed by scientists who communicate the results at scientific meetings (Grazuleviciene *et al.*, 2001; Sargsyan, 2001; Constantinescu and Bugoi, 2001).

South Africa

Document: *Ecological Risk Assessment Guidelines* (Claassen *et al.*, 2001a).

- The risk assessment process in South Africa is modelled on the ERA framework of the US EPA (Figure 2), although the stages of the ERA process were interpreted and/or reworded to ensure appropriate dialogue of the concepts between risk assessors, risk managers and interested parties (Claassen *et al.*, 2001).
- ERA framework: follows three formal stages (Figure A7):
 - *Stage 1: Plan Assessment* - is technically similar to problem formulation, where information is collected, hypotheses are developed, scientific information is collated.
 - *Stage 2: Analyze* - information is critically evaluated, and exposure and responses are characterized.
 - *Stage 3: Describe Risk*, is technically similar to risk characterization, where hypotheses are evaluated, and risk is assessed, evaluated and reported.
 - The final stage leads to a discussion of the risk assessment results between the risk assessor and risk manager, who, in turn, communicate the results to the public.
- The ERA process is iterative.
- Comparative risk assessment approaches evaluate various risk hypotheses and enable the risk manager to set risk-based priorities (Claassen *et al.*, 2001b).

Figure A7: Process for ecological risk assessment in South Africa (Claassen *et al.*, 2001b)



APPENDIX 2

CASE STUDIES:

From Claassen *et al.*, 2001a

CASE STUDY OUTLINE A: Industrial Effluent

Agree on objectives

Management goals

Stakeholders were concerned about the perceived impacts of Egoli Industries' effluent on Hugen Park. Specific concerns were related to the *Goldie sp.* Egoli Industries' goals were to:

- determine the risk posed by their effluent on downstream ecosystems.
- manage their effluent to protect the *Goldie sp.*
- maintain a good relationship with stakeholders.

Management options

Egoli Industries had several management options. These were to:

- optimise their manufacturing process to attain minimum waste production
- use the best available technology to reduce metal levels in effluent
- negotiate with water users to reduce abstraction in order to increase the dilution of effluent
- employ other methods of waste disposal, e.g. recycling, drying, export, etc.

Appropriateness of ERA

ERA was considered to be appropriate, because:

- it provides managers with an evaluation of various management options;
- social, economic and ecological issues can be compared, because the probability, magnitude and characteristics of combined effects are determined;
- it realistically addresses the complexity of problems through explicitly evaluating variability and uncertainty.

Scope of the study

The study was bounded by the following parameters:

- o Spatial:
The Egoli industrial site and downstream Hugen National Park.
The resolution was at the level of ecological communities.
- o Temporal:
The study included historical data and considered the industry's lifetime.
- o Detail:
The site-specific study considered weekly water quality, the population status of *Goldie sp.* and relevant toxicological data (specifies resolution of data in exposure and effects).
- o Financial:
The study had to be completed by three project members within two months. Local expertise was used where possible.

Summary report

This was a detailed record of the preceding "Agree on Objectives" discussions.

Plan Assessment

Information

The following information was collected:

- Management context: Egoli Industries supports pro-active environmental management.
- The legislation on biodiversity is the key regulatory consideration.
- Egoli Industries' metal-containing (M+) effluent is discharged into the river.
- The river transports M+ to Hugem Park. M+ can undergo chemical transformation during transport.
- The impacts are due to effects on fecundity and mortality of sensitive species.
- The high conservation importance of Hugem Park is due to the occurrence of the *Goldie sp.*
- The cause-and-effect relationships are presented in the following diagram.



Hypotheses

The following risk hypotheses were considered:

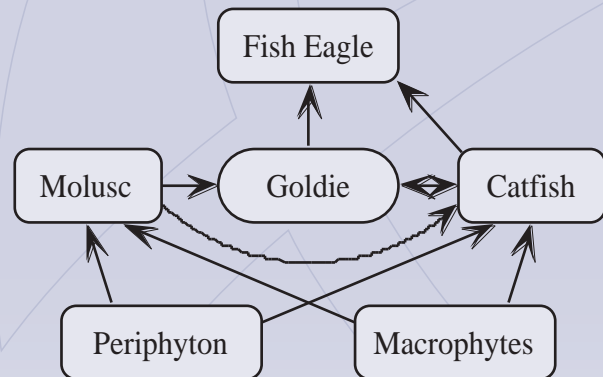
“Current metal levels in the river do not pose an unacceptable threat to the *Goldie sp.*”

“Future metal levels in the river will not pose an unacceptable threat to the *Goldie sp.*”

What to protect

The *Goldie sp.* was selected as the assessment end point, because:

- it integrates ecological impacts, confirming its ecological importance (ecosystem diagram →)
- it is sensitive to the effects of the metal
- its status renders it important for biodiversity and providing goods and services.



Plan to evaluate risk hypotheses

- The current status was evaluated through compiling and comparing data on effluent quality, river water quality, toxicology and ecosystem structure.
- Fate and transport modelling and predictions based on ecotoxicology data were used to evaluate a range of possible future impacts.

Data and information

Data that were collated included:

- M+ concentrations in the effluent and the river
- chemical characteristics of the diluent water
- observed laboratory transformations of M+ species (literature)
- surveys of the *Goldie sp.* and associated ecosystems
- toxic response of similar species to M+
- The details of the management options.

Analyze

Evaluate information

- Historical data were available on M+ concentrations (and other important water quality determinants) in the effluent and the river. Data were collected at a weekly interval through acceptable analytical procedures. Possible reductions in M+ were determined from the details of the management options.
- The status of the *Goldie sp.* and associated ecosystems prior to development was assessed. The current status

of the *Goldie sp.* and associated ecosystems, the river flow and M+ concentrations in Hugem Park was measured in this task.

- Fecundity and mortality data (toxicology) were available for the taxonomic group representatives.

Exposure

As an aquatic species, the *Goldie sp.* is directly exposed to water (dermal, gills, digestive tract) and ingests contaminants together with food. The concentration of the bioavailable form of M+ in the water is presented in the accompanying graph. The potential future M+ concentration was calculated through fate and transport modelling. It can range from 4 to 12 M+ units at the site where *Goldie sp.* occurs, depending on the management action.

Responses

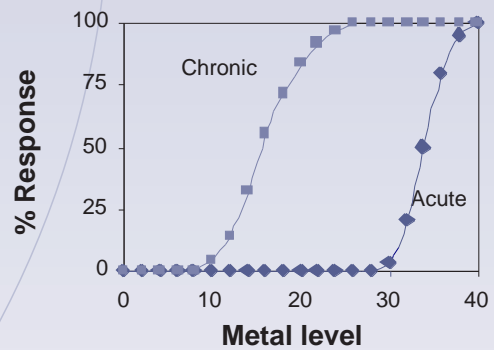
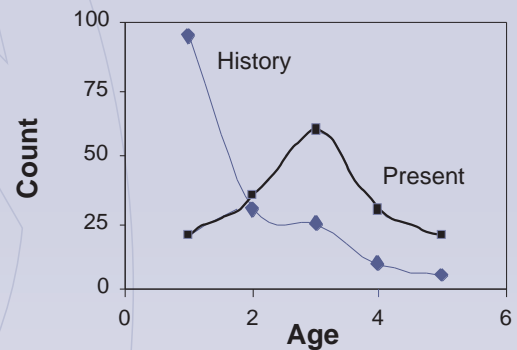
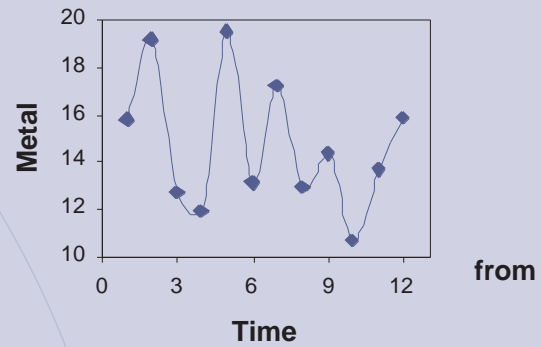
The historical (prior to industrial activity) and present *Goldie* population structures are presented in the adjacent figure. Although the abundance is the same, the population structure is different.

The dose-response relationship for other species in the taxonomic group of *Goldie sp.* is presented in the adjacent figure. Chronic (inhibition of fecundity at age 3-4) and acute (mortality of age 1) effects are shown.

Describe Risk

Risk hypotheses

The risk hypothesis of present conditions was evaluated by comparing historical and current population data. The present abundance of *Goldie sp.* was similar to historical records. The acute toxicity data supported the trend, with acute toxicity being indicated above 30 M+ units. The marked difference in population structure suggested chronic impacts. The evaluation was further supported by toxicological data, where chronic effects on species in the taxonomic group were observed above 10 M+ units, with 100% effect on fecundity at 25 M+ units. Present metal values fluctuate between 10 and 20 units. This supported the evaluation that the current metal levels affect the population structure. If the current trend continued, the *Goldie sp.* population would not be viable in 3 to 5 years' time. The same data indicated that possible future levels would only affect fecundity at metal levels between 10 and 12 units. Acute effects were not expected under potential future scenarios. (Various statistical methods could be employed to quantify the risk.)



Evaluate risk

The evidence suggested that the current metal levels had a significant effect on the *Goldie sp.* population structure. No acute effect on the *Goldie sp.* population was indicated. Egoli Industries could institute management actions to limit the in-stream metal concentration to 10 units.

Report risk

The preceding evaluation was reported in a format appropriate for the target audience.

Uncertainties were due to extrapolation between *spp.* and ecosystem, another gene pool used for toxicology, lack of analytical precision, lack of data on Goldie biology, adsorptive capacity of in-stream particulates and sediments and a sampling error.

Variability was affected by river flow, effluent quality, other abstractions, seasonal trends, diurnal fluctuations in pH, temperature, DO and EC and *Goldie sp.* susceptibility to M+.

The variability is accounted for in the determination of risk, while the uncertainties are not such that the confidence in the assessment is compromised.

Manage Risk

Discussion

The results were discussed to ensure that the risk manager was clear on the study characteristics and the significance and limitations of the results.

Decision

The results of the assessment informed effective decision-making. No further analyses were thus suggested. The manager was able to implement decisions based on appropriate ecological and other relevant information.

CASE STUDY OUTLINE B: Sustainable Utilisation

Agree on Objectives

Management goals

A state-owned property sustains a unique biome, which includes endemic species. The neighbouring community has been harvesting Fetchit for the past 10 years, but due to the increasing needs of the community, the demand for Fetchit has risen sharply. The conservation status of the area is high, with significant ecotourism potential. The management goal is to “balance the development needs of the local community with ecotourism potential and

conservation priorities.”

Management options

- Stop or control the harvesting of Fetchit.
- Restock/replace Fetchit in the area.
- Provide an alternative source of Fetchit.

Appropriateness of ERA

ERA could be used to inform decision-making because:

- different development options could be evaluated
- cumulative effects could be assessed
- it would provide an objective scientific evaluation.

Scope of study

- Data availability: very little was known about the specific area and associated ecosystems.
- Scientific knowledge: studies have been done on ecosystems with similar ecological characteristics.
- Spatial scale: the local community’s property, the ocean and agricultural areas bounded the study.
- Temporal scale: the study was to consider long-term effects (50-100 yrs).
- Uncertainty: because of the critical nature of the resource, very little tolerance (uncertainty) could be accommodated in the decision.

Summary report

A detailed record of preceding discussions was documented.

Plan Assessment

Information on context

Legislation regarding the protection of endemic species existed. The act proposed sustainable development as the minimum requirement.

The frequency of harvesting and mass taken was recorded. Harvesting methods may have had an impact on species that utilised a similar habitat.

Cause-effect

Fetchit harvesting ► Reduced production and abundance
► *N. demic* reduced

What to protect

A functional ecosystem model was developed to decide what to protect.

The function of Fetchit in the ecosystem was summarised as follows:

- Food source for *S. entails*.
- Competes for resources with *N. demic*.
- Competes for habitat (niche) with *A. monarch*, *M. poster*.
- Creates habitat for *K. ritters*, *D. gers*, *N. demic*.
- Helps with dispersal of *D. rifters*.

Selected end points were Fechit and *N. demic*.

- Fechit attributes: abundance, production and reproduction.
- *N. demic* attribute: abundance.

Develop risk hypothesis

The assessment evaluated whether Fechit could be harvested without compromising the sustainability of Fechit and *N. demic* populations.

Plan to evaluate hypothesis

1. Describe relationship between harvesting and Fechit:
 - Harvesting data (kg/ha + frequency)
 - Detailed surveys (kg/ha)
 - Pilot studies (harvesting vs. production)
 - Ecosystem modelling (sustainability of populations)
2. Describe relationship between Fechit and *N. demic*:
 - Detailed surveys
 - Functional relationship (qualitative model)
 - Pilot studies (Fechit : *N. demic*).

Collate data

- Harvesting data were available.
- Survey methods were known and accepted.
- Need to collect other data - used accepted methods to ensure <5% error in measurements.

Analyze

Evaluate information

- Measure new data.
- Detailed surveys.
- Pilot studies.

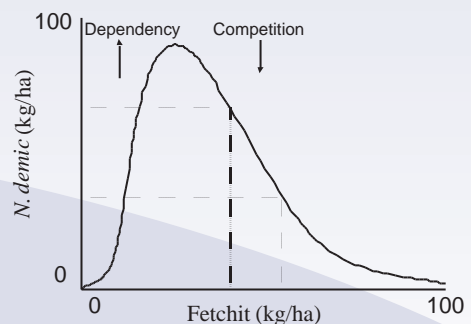
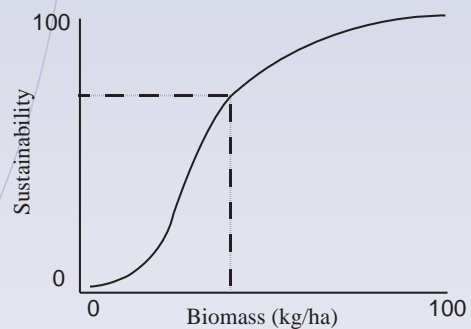
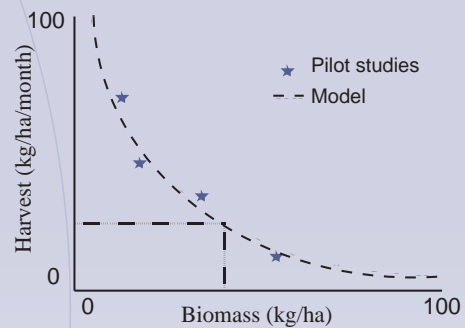
Characterize exposure

- Current harvesting:
- 50kg/ha, once monthly
- Potential harvesting:
- 15kg/ha, weekly or 700 kg/ha, annually

Characterize response

An inverse relationship exists between harvesting and biomass production of Fechit. The top figure shows modelled and measured data. The sustainability of the Fechit population is affected by the biomass, with the relationship indicated in the middle figure.

N. demic is dependent on Fechit for habitat, but also competes for resources with Fechit. The relationship is depicted in the adjacent figure, with the optimal range indicated between the dotted lines.



Describe Risk

Assess risk

- 1: Harvesting at 20kg/ha/month will ensure a biomass of acceptable sustainability.
- 2: For optimal *N. demic* population, 300-700kg Fetchit/ha needs to be maintained (then *N. demic* = 10-25 kg/ha)

Uncertainties that should be considered when making use of the assessment include:

- long-term trends
- seasonality
- genetic diversity.

Report risk

The preceding evaluation was reported in a format that was appropriate for the target audience.

Manage Risk

Discussion

The results were discussed to ensure that the risk manager was clear on the study characteristics, significance of the results and limitations.

Decision

The manager was able to make effective decisions based on appropriate ecological and other relevant information. The results met the brief of the assessment and, therefore, could inform a decision. No further analyses were suggested.

Notes:

*The evaluation of exotic or invasive species could also be assessed in a similar way.
Other biological stressors include disease and genetic modification.*

CASE STUDY OUTLINE C: Marine Pollution

Agree on objectives

Management goals

An increasing incidence of crude oil spills threatened vulnerable coastal ecosystems. A management plan needed to be developed to:

- reduce the likelihood of spills
- minimise vulnerable ecosystems' exposure to spilt oil
- optimise the remediation of exposed ecosystems.

Management options

The Maritime Safety Authority and the relevant government department had the following options:

- Specify routes whereby potentially dangerous cargo can be transported.
- Control entry of high-risk vessels to sensitive areas.
- Reduce potential exposure to vulnerable ecosystems in the event of a spill.
- Mitigate impacts on vulnerable species in the event of exposure, including contingency plans.

Appropriateness of ERA

An ERA would enable effective management decision-making because:

- the hazard could be characterized, which would lead to the institution of appropriate preventive actions
- the evaluation of exposure routes and mechanisms would allow for the development of an optimal hazard management programme
- the integration of potential ecosystem responses and consequences would support the development of mitigation actions.

Scope of the study

The study was bounded by the following parameters:

- Spatial:
A 500 km buffer around two vulnerable coastal populations.
- Temporal:
The study considered of current and potential future impacts.
- Detail:
The study was conducted at a detailed level, allowing the collection of site-specific information and the development of simulations.
- Financial:

8 experts and 20 support staff members completed the study in 14 months.

Summary report

A detailed record of the preceding *Agree on Objectives* discussions was produced.

Plan Assessment

Information

The following information was collected:

- Global demand and supply of crude oil.
- Frequency and timing of vessels passing through the study area.
- Safety records of three classes of cargo vessels.
- Characteristics of crude oil transported.
- Ocean currents and characteristics that could affect spilt oil dispersion.

- Susceptibility of two coastal populations to crude oil.
- *Rocky* is dependent on habitat, which is adversely affected by spilt oil.
- *Diver* is directly affected through the toxic effects of crude oil.

Hypotheses

The following hypothesis was evaluated: "Vessels carrying crude oil do not pose an unacceptable risk to *Diver* and *Rocky* populations."

- "Unacceptable" was defined as the probability of adverse effects being more than 1×10^{-3} (one in a thousand) annually.
- "Adverse effects" were defined as fatality to more than 5% of an exposed population or chronic effects in more than 25% of exposed populations.

The causal relationship between an oil spill and adverse ecological effects was presented in the adjacent figure.

What to protect

- *Diver* was selected as an assessment end point because it has a high conservation status, integrates effects in the food chain (predators) and it is sensitive to crude oil exposure.
- *Rocky* was selected as an end point due to its importance as a food source for local communities and its dependency on habitat of good integrity.

Plan to evaluate hypotheses

- The likelihood of a spill (the hazard) occurring was determined through evaluating the safety records of three classes of vessels (failures/1000 km travelled).
- The probability of exposure was determined through modelling the dispersion of spilt oil in the ocean. Pollutant levels that would induce acute and chronic effects were determined from historical and modelled information.

Data and information

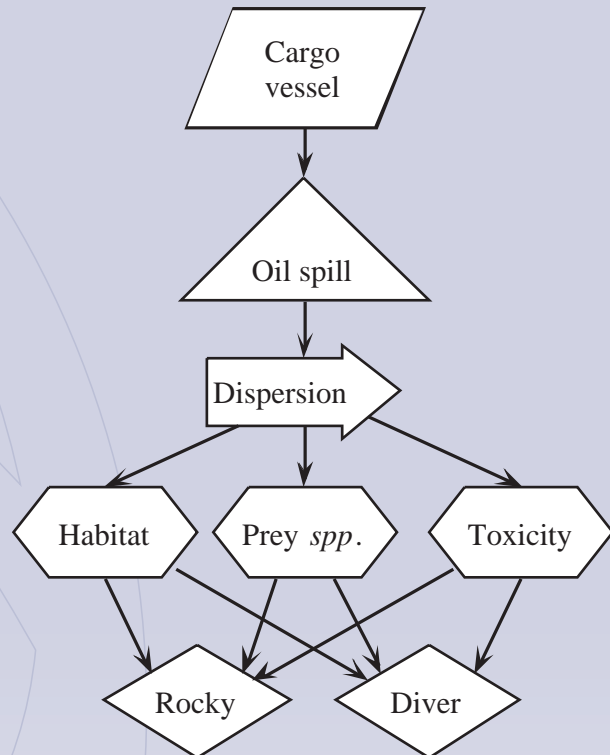
Data that were collated included:

- current and potential shipping routes, frequency of use and cargo type
- safety records of vessels carrying crude oil
- oceanographic and climate information
- a suitable simulation model and parameters
- *Diver* and *Rocky* sensitivity to crude oil.

Analyze

Evaluate information

- Data were available at the required resolution and confidence for shipping routes and safety records and magnitude of spills.
- The simulation model was calibrated to predict the



dispersion and fate of spilt oil in the study area.

- There was uncertainty about the effect of global climate change on local conditions.
- Assays were conducted to evaluate the susceptibility of *Diver* and *Rocky* to crude oil.

Exposure

The probability of a significant oil spill (> 10⁶ units) was determined as follows:

- (Vessels per annum * Failures per 1000 km travelled)
 - o Class A : (100 * 0.00001) = 0.001
 - o Class B : (240 * 0.00005) = 0.012
 - o Class C : (35 * 0.0013) = 0.0455
- Summed probability of a significant spill (per annum) = 0.0585

The oil concentrations that would reach the *Diver* and *Rocky* habitats could be simplified (hypothetically) to: $C = V/\pi r^2$ + (wind + current - biodegradation)

- Where: C = Oil concentration (units/km²) V = spilt volume
 r = Population's distance from spill $\pi = 22/7$
 Wind + current - biodegradation = distribution functions accounting for variability
- The *Diver* population was 30 km and *Rocky* 28 km from the shipping route.

Responses

The populations' toxicological response to oil was described as follows (units oil/km²):

- No Observed Effect Concentration (NOEC)
 - *Diver* = 2x10¹ *Rocky* = 1x10²
- Lowest Observed Effect Concentration (LOEC)
 - *Diver* = 8x10¹ *Rocky* = 3x10²
- Concentration lethal to 5% of population (LC5)
 - *Diver* = 1x10³ *Rocky* = 5x10²
- Concentration that induced chronic effects in 25% of population (EC₂₅)
 - *Diver* = 4x10² *Rocky* = 6x10²

Describe Risk

Risk and hypotheses

- The probability of a significant spill in the study area was 0.0585.
- Significant exposure to the populations were:
 - Diver*: 4x10² units/km² (chronic effects)
 - Rocky*: 5x10² units/km² (acute effects)
- The expected exposures in the event of a spill was thus:
 - C = $V/\pi r^2$ + (wind + current - degradation)
 - Diver* = 10⁶/(22/7)*30² + (± distribution)
 - = 353 units/km² (± distribution)
 - Rocky* = 10⁶/(22/7)*28² + (± distribution)
 - = 378 units/km² (± distribution)
- The probabilities of significant effects were calculated through incorporating the distribution functions for wind, current and degradation (through Monte Carlo simulations):
 - Diver*: Probability of > 4x10² units/km² = 0.03
 - Rocky*: Probability of > 5x10² units/km² = 0.001
- The risks posed by crude oil vessels to the respective populations were calculated as the products of the likelihood of the hazard occurring and the probabilities of significant effects if they do.
 - Diver*: 0.0585 * 0.03 = 1.76 x 10⁻³
 - Rocky*: 0.0585 * 0.001 = 5.86 x 10⁻⁵

Evaluate risk

- The risk posed by crude oil vessels to the *Diver* population is higher than the acceptable risk of 1x10⁻³.
- The risk posed to the *Rocky* population is acceptable in the context of the management thresholds.
- The risk to the *Diver* population was mostly affected by class C vessels and driven by chronic response.

Report risk

- The calculated risks, together with the associated uncertainties, were reported in a clear, yet concise, format.

Manage Risk

Discussion

During discussions of the results, it was clear that the study provided adequate information on which to base a decision.

Decision

- The regulations for class C vessels were upgraded to reduce the risk.
- Mitigation actions were put in place to rehabilitate the *Diver* population in the event of a spill.

8. Glossary

Definitions:

ALARP (As Low as Reasonably Possible) - A methodology for justifying if risk control measures reduce risks to reasonable and practical levels.

Assessment endpoint - An explicit expression of the environmental values that is to be protected - identified during initial discussions between risk assessor and risk manager, and ecologically relevant receptor/s at risk. For example: fish is a valued ecological entity, reproduction of fish is a specific attribute. Together they form an assessment endpoint.

Comparative risk assessment - compares risks across different contaminants based on exposure scenarios.

Conceptual model - identifies how risks may form, based on information on stressors/contaminants, receptors, potential exposure pathways, and predicted effects on the assessment endpoints.

Ecological risk assessment - The application of risk assessment techniques to assessing risks to plants, animals and ecosystems. Evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. The assessment may describe the type, magnitude and probability of the effect and relate to a specific spatial and temporal context.

Exposure assessment - The process of measuring or estimating the intensity, frequency, and duration of exposures to an agent currently present in the environment, or of estimating hypothetical exposures that might arise from the release of new chemicals into the environment.

Hazard - A state or set of conditions that may result in an undesired event; the cause of risk. In environmental toxicology, the potential for exposure of organisms to chemicals at potentially toxic concentrations constitutes the hazard.

Hypothesis - A statement of condition that can be tested in the assessment. The conventional approach is to falsify the hypothesis, thus rejecting it. The hypothesis can also be accepted.

Likelihood - An expectation of a specific outcome. It could be based on quantitative analyses, qualitative assessments, expert opinion or perception.

Lines of evidence - Information derived from different sources or by different techniques that can be used to evaluate risk hypothesis(/es).

Prospective risk assessment - assesses the likelihood of an undesirable effect on an ecological system, given the specific exposure to a stressor.

Qualitative risk assessment - The likelihood or the magnitude of the consequences are expressed in qualitative terms

(i.e. not quantified).

Quantitative risk assessment - The probability or frequency of the outcomes can be estimated and the magnitude of consequences is quantified so that risk is calculated in terms of probable extent of harm or damage over a given period.

Receptor - The ecological entity (e.g. plant, animal or ecosystem) exposed to the stressor. Generally asks the question, "What might be affected by contamination and in what way?"

Retrospective risk assessment - assessment that recognizes that an undesirable effect on an ecological system has occurred.

Risk - The chance of something happening that will have an undesired impact. It may be an event, action, or lack of action. It is measured in terms of consequences and likelihood.

Risk characterization - A synthesis and summary of information about a hazard and associated effects, so that it addresses the needs and interests of decision-makers and interested and affected parties. Generally answers questions such as "What contaminant? What pathway? What receptor? What exposure? and What effect?"

Risk management - The systematic application of management policies, procedures and practices to the tasks of analyzing, evaluating, controlling and communicating risk.

Risk perception - the overall view of risk held by a person or group; includes both feeling and judgement.

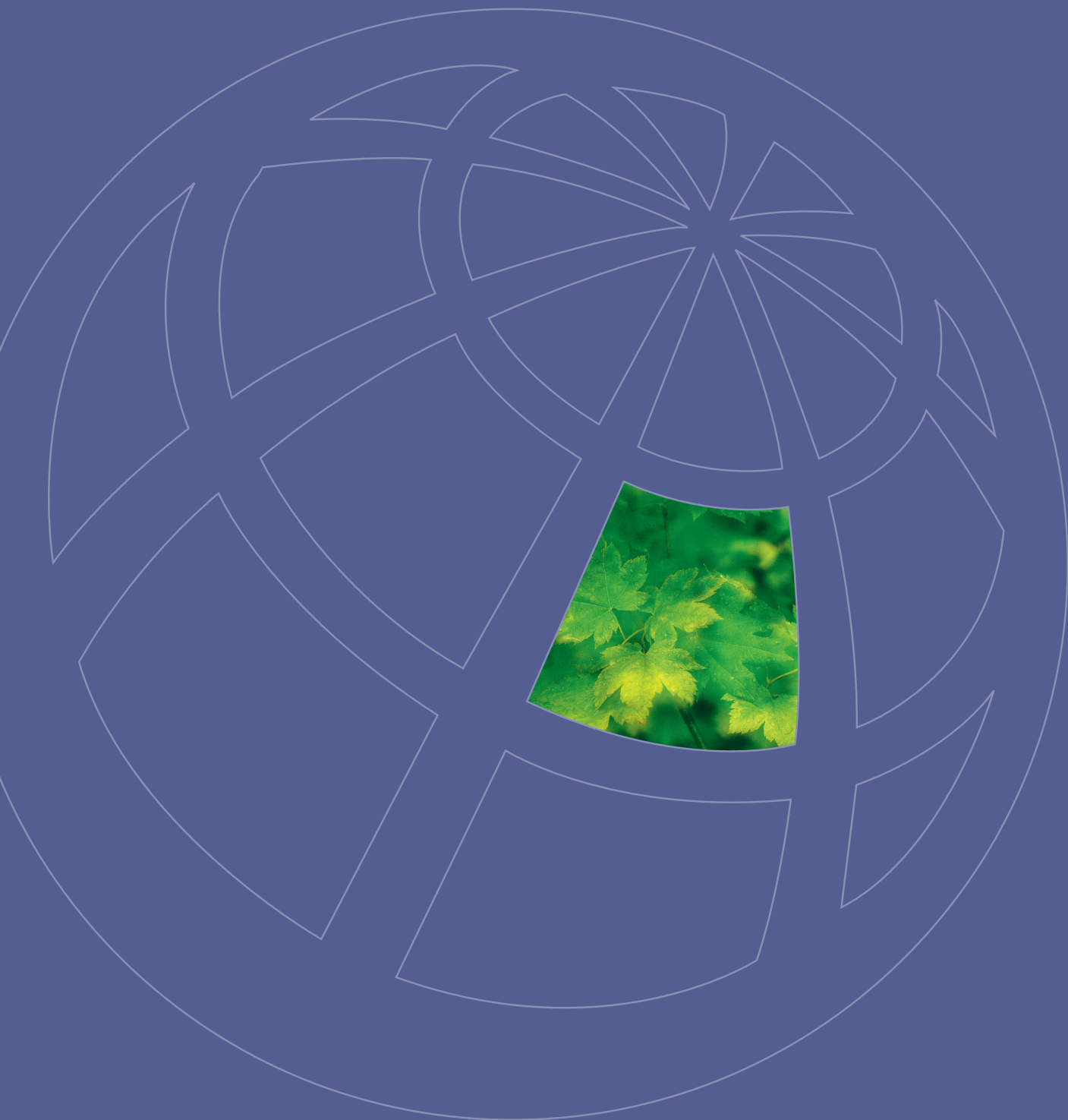
Stressor - A physical, chemical or biological entity that can induce an adverse response.

Sustainable development - the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Toxicity assessment - The overall process of evaluating the type and magnitude of toxicity caused by a hazardous substance. It involves determining the toxicity of the contaminants, and establishes the sensitivity of the ecological receptor(s). Asks for example "What potential effects might the contaminants cause and at what concentration?"

Acronyms:

ALARP	As Low As Reasonably Possible
ANZECC / NHMRC	Australian and New Zealand Environment and Conservation Council / National Health and Medical Research Council
A / NZ	Australia / New Zealand
Cal/EPA	California Environmental Protection Agency
CRARM	Congressional Commission on Risk Assessment and Risk Management
DEAT	Department of Environmental Affairs and Tourism
EEA	European Environmental Agency
EPA	Environmental Protection Agency
ERA	Ecological Risk Assessment
IDRIS	Identification of ecological RISks
IEM	Integrated Environmental Management
GEF/UNDP/IMO	Global Environment Facility/United Nations Development Programme/International Maritime Organization
NMHPPE	Netherlands Ministry of Housing, Physical Planning and Environment
OECD	Organization for Economic Cooperation and Development
WRC	Water Research Commission
US EPA	United States Environmental Protection Agency
UK DOE	United Kingdom Department of the Environment
US DoE	United States Department of Energy



Department of
Environmental Affairs and Tourism

Private Bag X447, Pretoria, 0001, South Africa, www.environment.gov.za