ECOLOGICAL RISK ASSESSMENT: RESEARCH PRIORITIES

M Claassen

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by

M Claassen (Editor)

Division of Water, Environment and Forestry Technology,
CSIR
PO Box 395, Pretoria, 0001

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Ecological Risk Assessment: Research Priorities

Edited by: **M Claassen**

Contributors: **PJ Ashton, S Jooste, CG Palmer, L Phillips, DJ Roux, P-A Scherman, L Slabbert, GJ Steyn, PW Wade, V Wepener**

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by

Division of Water, Environment and Forestry Technology,

CSIR

P O Box 395, Pretoria, 0001

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ABSTRACT

The purpose of ecological risk assessment (ERA) is to contribute to the protection and management of the environment, through scientifically credible evaluation of the ecological consequences of such changes. Risk assessment consists of probabilistic analyses in the context of variability and uncertainty, and linking outcomes to decisions. Goods and services provided by water resources rely on hydrological, biological and ecological processes, and thus require an assessment method that can deal with the complexities. The dilemma for water resource managers is that decisions must be made while knowledge about ecosystems and their response to stresses are incomplete. This problem is compounded by the stochastic nature of natural systems, which makes accurate predictions very difficult. The advantages of being able to deal with variability and uncertainty, coupled with the need for effective resource utilisation, justifies the application of risk assessment to water resource management.

The United States EPA guidelines for ERA are referred to in international applications of ERA, but were found lacking in two areas. Firstly, the guideline document is not explicit in following a rigorous scientific process. More specifically, it does not specify the evaluation of stated hypotheses. Secondly, the EPA guideline document discusses inputs, processes, outputs, activities and issues, without making clear distinctions as to their relative roles and importance. The South African ERA guideline document was developed to address these issues.

Within the context of the National Water Act, assessment and management approaches need to be developed to support the implementation of the Act. Sufficient protection measures to ensure sustainable use in an integrated management framework need to be established and accepted. The development of methods for the rapid determination of a preliminary Reserve is underway but methods to determine more comprehensively the resource quality required for protecting aquatic ecosystems for different classes and for different resources needs to be developed. Classification is a key concept in the NWA and risk concepts can be used effectively to define the classes. Setting management objectives and determining classes are areas where a risk-based approach can be very useful. A very powerful feature of

risk assessment is the ability to assess the risks of various development options. Risks can then be ranked to serve as decision support.

In analysing the application of risk concepts to water resource quality management, it was found that risk assessment may reasonably be used to aid water resource quality management decisions and activities in the following areas:

- Basis for water quality criteria: The current South African Water Quality Guidelines (aquatic ecosystems) was derived from toxicological data and some qualitative assumptions regarding exposure. These criteria are limited because expected effect differing from substance to substance, co-occurrence of different stressors are not considered, and the criteria do not necessarily relate to the same ecological effect. Setting criteria on a risk basis would induce a measure of transparency into the interpretation of such criteria.
- Site-specific criteria: Applying risk to the site-specific adaptation of criteria supplies a rational basis for incorporating new or locally significant data in a manner that is open to peer review.
- Resource management classification: The provision in the National Water Act for the classification of water resources can be linked to risk concepts. Management objectives may be expressed in terms of allowable risk to the Reserve. This provides an explicit communality between the receiving water quality/risk objectives and the reserve as well as effluent criteria and/or standards.

1. Objectives

The overall objective of the three-year project (1998-2000) was to focus the techniques for ecological assessment of water resources to address research needs within the new regulatory context. The developed ecological risk assessment (ERA) process should facilitate the coordination of the ecological contributions towards predictive assessments (EIAs, criteria and permits), regulatory processes (compliance monitoring), sustainable development issues (SEA, IEM and ICM) and retrospective analyses (restoration).

The first task was to determine research priorities for ERA. The approach followed for the assessment is outlined in **Figure 1**. The task objective of identifying research priorities for ERA is at the top of the diagram, with intermediate objectives required to reach the objective presented in a hierarchical structure.

The method followed for the assessment included:

- A literature survey on ERA and risk-based decision making
- A survey of existing ERA technologies and applications at
    - US EPAs' National Centre for Environmental Assessment (NCEA)
    - US EPA Region 9
    - Oak Ridge National Laboratory
- A workshop with representatives from government, academia and industries
- Interviews with individuals
- An assessment, integration and reporting phase

The report structure follows the rationale presented in **Figure 1**, with the context of water resource management investigated first, followed by the identification of protection-based water resource management issues, applications for ERA in South African water resource management and the identification of research priorities for ERA.

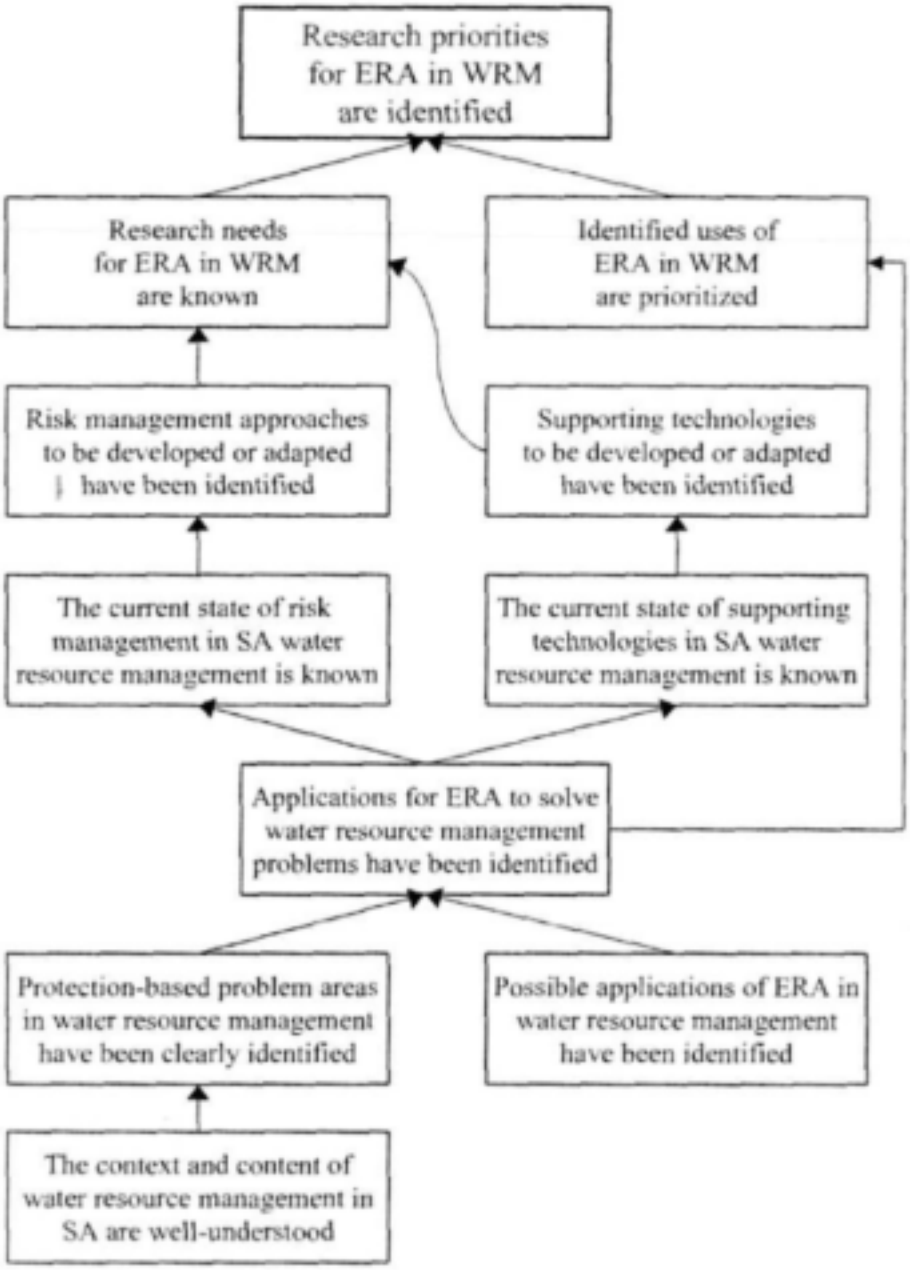

Figure 1: Intermediate objectives diagram for identifying research priorities.

2. Introduction to Ecological Risk Assessment and Risk Management

2.1 Risk assessment

Risk assessment originated in the insurance domain. Brokers traded in a market where the outcomes of transactions were uncertain. The occurrence, frequency, timing and magnitude of events such as death or property loss effected claims, but could not be predicted. Actuarial techniques were developed to determine the probability of such events occurring and their associated magnitudes. Willet defined risk assessment in 1901 as the "objectified uncertainty regarding the occurrence of an undesired event" (quoted in Suter, 1993). Today risk is still considered to be the probability of an undesired effect, expressed in the context of associated uncertainties (Suter, 1993; EPA, 1998).

An important distinction is to be made between deterministic and probabilistic assessment paradigms. Both of these are closely linked to the mathematics of sets or Boolean algebra. The analysis of set theory presented in **Appendix A** is fundamental to further analysis of probabilistic analysis. Whereas deterministic analysis describes an element's membership to a set as binary (member or non-member), probabilistic analysis takes uncertainty into account when expressing the likelihood that an element (event) belongs to a set. Risk is described as the likelihood of the occurrence of an undesired effect, given an event.

The use of a risk-based approach has specific implications for management. If we consider the use of probability in the actuarial domain, it would not make sense to painstakingly determine probabilities and consequences of events and then not use it to manage risk. The most important characteristic of risk management is the integration of risks from different sources. Decisions should then be based on the combined risk of undesired consequences. Risk ranking is also a key aspect of risk management, where the aspects contributing most to the risk can be identified and managed.

2.2 Ecological risk assessment process

The impacts of developments on natural resources have been the focus of many studies. Environmental assessments cover a range of activities that support objectives such as identification of effects, comparisons of actions, damage assessment, hazard prioritization, stop/go evaluation, scalar regulation, etc. The methods used for these assessments have, however, been debated. ERA is a process for determining the nature, likelihood and uncertainties pertaining to such environmental consequences. The purpose of ERA is to contribute to the protection and management of the environment, through scientifically credible evaluation of the ecological effects of such changes. The assessment involves identification of the hazard and using measurement, testing and mathematical or statistical models to quantify the relationship between the event and its effects. The role of ERA in environmental decision-making is mainly to provide a quantitative basis for comparing and prioritising risk. As all alternative management options have hazardous properties, the characterization of these hazards is essential for making the best possible (and defendable) decision.

The traditional approaches to assessing and reducing environmental risks, have relied on chemical-by-chemical, medium-by-medium and, sometimes, risk-by-risk strategies. These approaches ignore the interdependence of environmental components and investigate risks associated with individual chemicals instead of environmental mixtures of chemicals. Moving towards integrated environmental management requires a risk management framework that can engage a wide range of stakeholders and address the interdependence and cumulative effects of various problems. The approach must have the capacity to address various media, contaminants, and sources of exposure and an array of public values, perceptions, and ethics. It should be sufficiently understandable to be adopted and used by risk managers in a wide variety of situations and lead to acceptable and effective decisions. It should also be flexible so that its use can be matched to the importance of the decisions to be made. A systematic, comprehensive risk-management framework should be used to reduce environmental, health, and safety risks. A framework for risk management proposed by the Commission on Risk Assessment and Risk Management (1997) comprises six stages (**Figure 2a**): formulating the problem in broad context, analysing the risks, defining the options, making sound decisions, taking actions to implement the decisions, and evaluating the effects of the actions taken. The framework can be used iteratively and embraces collaborative involvement of stakeholders.

The first step of the framework for ERA in **Figure 2b** (US EPA, 1998) deals with problem identification in a holistic context. In the problem-formulation stage, the environmental values to be protected and the goals of the assessment should be defined. In addition, the appropriate level of ecological organization (such as individual species, population, or community), the end points or potential receptors of stress, and the ways to measure the end points must be identified. One of the ERA framework's greatest strengths is that it is sufficiently flexible to apply to a broad range of environmental problems, in particular to broaden the conceptual approach beyond a perceived narrow view of risk assessment as the evaluation of a chemical's effect on a few species. An important characteristic and potential strength of the ERA framework is its introduction of the term "Problem Formulation" in place of "Hazard Identification" to characterize the nature of initial activities that should occur as part of the risk assessment process. Problem formulation is the most critical step in ecological risk assessment because it provides direction for the analysis and should take into account the ecological, societal and political issues related to the questions being addressed.

The US EPA (1998) guidelines for ERA are referred to in international applications of ERA, but when analysed by Murray and Claassen (1999), were found lacking in two areas. Firstly, the guideline document is not explicit in following a rigorous scientific process. More specifically, it does not specify the evaluation of stated hypotheses. Secondly, the EPA guideline document discusses inputs, processes, outputs, activities and issues, without making clear distinctions as to their relative roles and importance. A summary of the ERA process, as described by Claassen *et al.* (2001), is herewith discussed according to the phases in **Figure 2b**.

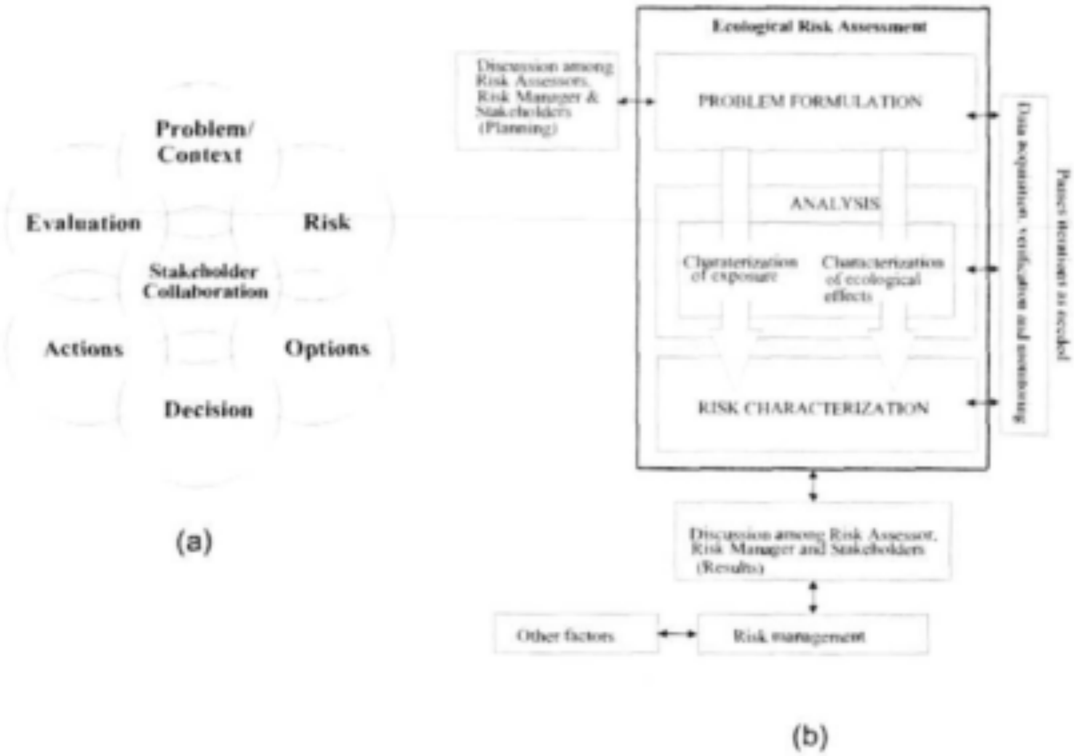

Figure 2: Framework for risk management (a) and ecological risk assessment (b).

A dialogue between the risk manager and the risk assessor should begin with a planning process preceding the formal assessment. The following are actions that are part of the process of agreeing on the objectives;

- Agree on management goals
- Define management decisions
- Ensure risk assessment is appropriate
- Agree on scope of risk assessment
- Produce summary report

The formulation of the analysis plan is the first formal stage of an ecological risk assessment, in which the risk assessor needs to carry out the following actions;

- Integrate available information
- Select what to protect
- Identify potential assessment endpoints
- Confirm ecological relevance
- Confirm management relevance

- Define assessment endpoints
- Hypothesise responses

The analysis phase as the second formal stage of an ecological risk assessment comprises the following actions;

- Critically evaluate information
- Evaluate uncertainty
- Measure new data if necessary

During exposure characterization ;

- The stressor source is described (with relation to spatial and temporal distributions)
- The exposure is described

The response characterization requires the assessor to;

- Identify applicable effects of the stressor on the ecosystem
- Perform an ecological response analysis.

The final task of the analysis phase is to;

- Integrate the results into a stressor-response profile (as a summary of what has been learned)
- Information gathered at this stage may necessitate returning to an improved formulation of the analysis plan, for example, to modify the endpoints selected.

The risk characterization is the final formal stage of an ecological risk assessment. It comprises the following actions;

- Test hypotheses and estimate the risk
- Assess the risk
- Report the risk

The results of the risk assessment should be presented clearly and concisely. It should include a degree of detail appropriate to the kinds of management decisions that need to be taken.

In the risk management phase the risk assessor and risk manager must perform the following;

- Discuss the results of the assessment
- Make environmental management decisions

The risk manager uses the results along with other relevant social, legal, political or economic information to make decisions on how to proceed. This may include invoking mitigation measures, monitoring progress and communicating results to the public.

2.3 Aspects of ecological risk assessment

Hazard assessment

A risk assessment is distinctly different from a hazard assessment. Hazard assessment has historically been the most commonly use method for evaluating the effects of chemicals in the environment. In a hazard assessment the expected environmental concentration and the estimated toxic threshold are used to give an indication of the acceptability of the expected concentration (Suter, 1993). The South African water quality guidelines (DWA&F, 1996) are hazard-based. Various sources of information were used to derive concentrations of chemicals that would ensure adequate protection of aquatic ecosystems (Target Water Quality Range), protection against chronic and acute effects (Chronic - and Acute Effect Values) and identify situations where the aquatic ecosystems are threatened. The use of the guidelines is hazard-based, since ambient or expected environmental concentrations are compared with the effect threshold values.

Ecosystem aspects

Ecosystem targets are defined in terms of two possible views: (Calow and Forbes, 1997)

1. Ecosystem health paradigm

Ecological systems have coherence and integrity that depend upon certain states. The ecological assessment needs to be expressed in terms of these states. The ecosystem health paradigm requires that ecology and ecologists play a dominant role in not only carrying out the assessment but in defining the criteria by which risks are evaluated.

2. Ecosystem service paradigm

Ecological systems do not only have intrinsic coherence, but what society gets from them depends on their structure and function. The ecosystem service paradigm suggests that social needs and values are as important as scientific ones and so emphasizes the need for interaction between scientists and society at large in defining ecological risk criteria.

Bartell (1997) argues that ERA opens the door for sophisticated applications of systems analysis and ecological modeling, in part, because the foci of ERA are precisely ecological systems that defy simple analytical or brute force statistical description. A limitation of the current assessment process is the oversimplification of ecological concepts and assessment methods of unknown performance. Munkittrick and McCarty (1995) argues that the difference in spatial and temporal scales between population and community changes and single species effects make single-species toxicity test results of very doubtful value for predicting impacts at a higher level of biological organization. One challenge in realizing the potential of ERA lies in interjecting modern ecology and the environmental sciences into the decision-making process and regulatory arena. ***Here ecological principles are often poorly understood or communicated, and social, economic and political considerations enter unequally into environmental decision-making.***

The goal of an ERA for chemical stressors is to determine those situations in which the likely exposure concentration overlaps with the concentration likely to cause biological effects (Calow and Forbes, 1997). In practice ecological risk is often defined in terms of the probability of:

- mortality in a fraction of a population
- extinction of a species or a fraction of a species; or
- loss of a certain fraction of ecosystem process and/or service.

For physical or biological stressors, similar endpoints can be used, but evidence of causality is typically based on functional impacts (breeding, predation, migration, etc.) rather than physiological changes (toxicity).

Tiered approach

ERA can, and has been, used in a wide range of applications. An ERA approach that is often used consists of the following three tiers (Cardwell *et al.*, 1993):

Tier 1- Screening level risk assessment;

Tier 2- Risk quantification with generic data;

Tier 3- Risk quantification with application-specific data.

Uncertainty

In predicting the nature and extent of harm to ecosystems, uncertainties arise from errors, ignorance, and the stochastic nature of natural systems. There are two major areas of ecological uncertainty (Calow and Forbes, 1997):

- uncertainty in predicting effects on organisms in field situations from their response in controlled laboratory test systems and;
- uncertainty about the roles of different species in ecosystems (the point at which damage to species or populations can be considered as damage to the community or ecosystem).

A key question posed is: "What does the lack of knowledge about ecological systems and lack of replications imply for ecological risk assessment?" (Power and Adams, 1997). Safety or uncertainty factors are a conservative approach for dealing with uncertainty related to assessing risk. These factors have little or no relevance to actual uncertainty, but they do greatly reduce the probability of underestimating risk. They consequently also greatly increase the possibility of overestimating risk and may (and often does) lead to unrealistic answers in hazard and risk assessments (Chapman *et al.*, 1998). The selection of the magnitude and type of safety factor to use is primarily a policy decision and not necessarily science-based.

Safety factors

The precautionary principle has been suggested as the only means presently available to deal with cumulative impacts. This approach involves taking protective action even when scientific evidence does not prove causal links between emissions and effects. Intraspecies safety factors of 10x are generally considered appropriate for aquatic ecosystems. For conversion between acute and chronic assays Abt Associates (1995) cautiously concluded that an uncertainty factor of 10x should account for most difference in test duration. LOEC-to-NOEC extrapolation is more difficult, as the low-dose section of the dose-response curve is important, but invariably not known. Also the data is often unbounded, which makes analyses particularly difficult. The safety factor of 10x used by the US EPA was cautiously endorsed by Abt Associates (1995), arguing for best professional judgement. The debate as to the correct numeric size of safety factors is somewhat futile, as no one set of data will be universally applicable. Responses to chemical stressors are dependent on both genetic and environmental factors. The European Union and other assessment schemes, (following Cairns *et al.*, 1979) reduce safety factors as data become available. One method of using science in the precautionary approach is to stress statistical type-II errors and power analyses over traditional type-I errors. The following principles are suggested for safety factors:

1) Data supersede extrapolation
2) Extrapolation requires context
3) Extrapolation is not fact
4) Extrapolation is uncertain
5) All substances are not the same
6) Unnecessary overprotection is not useful

Statistical analysis

Traditionally experimental design has focused on minimizing the incidence of false positives (type-I error). However, to maximize the probability of protecting the environment, it is more appropriate to guard against false negatives (type-II error) (Calow and Forbes, 1997). Proving no risk (rejecting the alternative hypothesis) has become the norm for ecological risk assessments. Risk assessments are thus fraught with type-II errors, while spending the majority of effort to minimize type-I errors. One major weakness that exists in any sort of ecological risk assessment is the lack of prediction validation (Holdway, 1997).

Type-I & II errors

A Type-I error is rejecting the null hypothesis when the null hypothesis is true.
- eg. condemning an exposure that actually is safe

A Type II error is accepting the null hypothesis when the null hypothesis is false
- eg. absolving an exposure that actually does harm

Societal values

A variety of criticism of ERA relates to the role of values. The risk assessors are often called on to adopt a particular set of values, but as they are neither democratically appointed nor elected, their values don't have a particular standing in a democracy (Suter and Efroymson, 1997). Another argument states that decisions made by risk assessors are value-laden, thus they function as risk managers, although the distinction between these roles is clearly defined in the ERA process (EPA, 1998).

2.4 Risk management

Environmental assessments are often conducted to assess the impacts of anthropogenic activities. It is generally understood that these assessments are not a precise statements of the outcome, but rather represent the likelihood of certain consequences, based on available knowledge (Suter, 1993, DEA&T, 1998). Gentile (1998) stated that information on social values should be combined with technical information about ecological relationships to frame questions about what is important in an assessment and how much change society is willing to tolerate.

In the European Union, ERA is a well-developed tool used primarily as an input into the decision-making process governing chemical regulation. In Europe ERA is a pragmatic response to the need to mitigate and control the most obvious impacts of pollution (Van Leeuwen, 1997). ERA methods have also been developed to provide quantitative and objective measures of ecological risk for natural populations exposed to mixtures of chemical contaminants (Logan and Wilson, 1995). Hart (1998) and Hart *et al.* (1999) pointed out that the application of a risk-based approach to the development of water quality guidelines and management in Australia should provide an effective means of protecting biodiversity and ecological integrity. Benefit assessment has been advocated as preferable to risk assessment in large ecological units or in evaluating ecological alternatives. Suter and Efroymson (1997) agree that benefits should be assessed prior to decision-making, but not because of an ERA limitation specific to large scales. ERA is commonly used as one of several options for the consideration of alternative remedial choices. An alternative to the risk paradigm is to shift the relative emphasis from assessment to management. This may be the preferred option when the economic or social stakes are high, or the cost of ERA is high because of insufficient knowledge. Risks should still be estimated though, so that managers can select trials on the basis of estimated risk, leading to fewer errors. It is argued that ecological risks, particularly at large geographical scale or at higher levels of organization, are difficult to quantify, characterize generally, or predict at all. Suter and Efroymson (1997) contend that this may hold true for quantifying the value-laden concept of ecosystem health, but that ERA has been used successfully in many assessments at these levels. If asked where most ERAs could be improved (aside from assuring basic competence), Suter and Efroymson (1997) points to failures to obtain site-specific information.

Risk-based assessments of ecological effects also support the use of multi-criteria decision analysis (MCDA), through the explicit statements of uncertainty. MCDA approaches are especially appropriate in participatory democracies where decision-making methods need to allow for direct input from those affected (Joubert, *et al.* 1997).

2.5 Ecological risk assessment applications in the US

ERA at the National Centre for Environmental Assessment

The mission of the National Center for Environmental Assessment (NCEA) is to focus on the process of human health and ecological risk assessment; to integrate dose-response, and exposure data and models for risk characterization; and to link between the Office of Research and Development (ORD) activities and regional offices. The key roles of the NCEA include; Conducting assessments of contaminants and sites of national significance, developing assessment methods for human health and ecological impact, and provide methods and guidance to risk assessors (guidelines, data bases, consultation and training). The purpose of ERA, according to NCEA (EPA, 1998), is to organize and present information to improve decision-making. There have also been shifts in agency policy from; point source to non-point, command control to voluntary compliance, and single stressor to multiple stressors. The Framework for Ecological Risk Assessment (EPA, 1992) dealt with individual stressors, but not multiple stressors. The risk assessment forum including the Office of Water and the ORD develop tools and processes for catchment scale assessments. The Office of Water is specifically interested in catchment protection, through adopting a catchment approach and implementing it as a component of the National Water program.

Five specific catchments were selected in 1993 and teams were formed to do the assessments. The catchment ERA will help resource managers predict how changes in land use and river flow will affect biological communities in the watershed. This will enable resource managers to make decisions based on more information. The five watershed level ecological risk assessment case study sites are Big Darby Creek (Ohio), Clinch Valley Watershed (Virginia), "Middle" Platte River Wetlands (Nebraska), Waquoit Bay Estuary (Massachusetts) and "Middle" Snake River (Idaho). Details about these studies are provided in **Appendix B** (EPA, 1997).

The planning of the assessments is done through community-based management goals. The goals are derived from pre-established goals, laws, meetings and surveys. Objectives are the developed to help select assessment endpoints and conduct the assessments. Within the objectives, the focus, scope and complexity of the risk assessment is determined.

Lessons were learned in developing management goals and objectives, selecting assessment endpoints, developing conceptual models, and developing risk hypothesis and analysis plans. For the integration of ecological and economic assessments the key questions are:

- What economic information is needed for catchment ERAs?
- Can economic analysis and ecological risk assessment processes be mutually supportive?

Some of the goals and benefits derived from catchment ecological risk assessments were:

- Coordinates activities
- Powerful communication tool
- Improves understanding of impact and stressors
- Identifies further research needs
- Estimates change associated with management actions
- Scientific approach for more informed decision making

Water Body and Effluent Standards in EPA Region IX (California EPA, 1998)

The US Clean Water Act is not explicitly risk-based, but has as its goals to:

- restore and maintain chemical, physical and biological integrity,
- the protection and propagation of fish, shellfish and wildlife and recreation in and on the water, and
- consider the use and value of water

The catchment management process is designed to monitor and assess water quality and habitat, set water quality standards, develop catchment management plans and implementation plans. The setting of ambient water quality standards is a state function, which considers beneficial uses of the water in setting water quality criteria. The anti-degradation policy means that the quality can't be allowed to degrade below its current level. The beneficial uses that are considered are protection of aquatic life, protection of wild life, protection of public health, agriculture, livestock watering, and other industrial uses. The protection of aquatic life includes vertebrates, invertebrates and plants at both acute levels (survival) and chronic levels (propagation). The protection of wild life addresses survival, propagation and bioaccumulation. For public health considerations, drinking water supply, fishing, primary contact recreation and secondary contact recreation are included in an assessment. The resultant water quality criteria are then designed to protect the designated uses. The criteria could be narrative (nuisance growth etc.) or numeric, pollutant specific, and include acute and chronic measures. The implementation of catchment management plans includes discharge permits for point sources (all point sources including industrial, municipal and storm water) and voluntary programs for non-point sources. The discharge permits are either technology-based, water quality based or designed to protect beneficial uses of a water body. Technology-based effluent standards are uniform, industry-wide standards that are specific to 50 industrial categories. The water quality based effluent standards are more stringent than technology-based standards, and are typically translations of numeric or narrative water quality criteria. These standards can include toxicity and are based on total maximum daily loads (waste load allocations).

In a review of risk assessment in California's EPA (Risk Assessment Advisory Committee, 1996) the following needs were identified in the general recommendations:

- Providing advice and oversight in the areas of risk assessment, risk assessment-risk management interactions, and risk communication.
- Agency-wide consistency and harmonization.
- Identification, evaluation, and promotion of new or existing knowledge, which can improve the scientific basis for risk assessment in California.
- Formalized program for peer review.
- Input into the risk assessment process from risk managers and from external stakeholders.
- Effective and efficient mechanisms for participation by the general public and interested stakeholders.
- Bring together risk assessment and risk management personnel to better translate emerging methods in risk assessment into risk management policy.
- Evaluation of the various scientific disciplines required for risk assessment should be conducted
- An approach in conducting chemical risk assessments that balances the level of effort and resources with the importance of the risk assessment.

In the specific recommendations the following issues were raised:

Hazard Identification

• Develop and explicitly state provisions for re-evaluating past decisions on individual agents as well as processes used.

• Standardize the collection and submission of pertinent information, and the content and construction of the hazard identification document.

Dose-Response Assessment

• Explore alternative ways, other than using large uncertainty factors, to bridge gaps in toxicity data.

• Guidelines on the appropriate use of uncertainty factors, and provide guidance on how severity of effect should be taken into account in setting these factors.

Exposure Assessment

• Integrate fate and transport modelling efforts with human exposure assessment.

• More emphasis on receptor-based exposure assessment when it is appropriate and cost-effective.

Risk Characterization

• Improve the characterization of uncertainty and variability in its risk assessments and in the communication of this information.

• Extent and depth of analyses should be responsive to the needs of the decision-maker and to the decisions they are intended to support.

Data Management Issues

• Review present data collection/data management efforts and initiate measures to minimize overlap and to improve accessibility and quality of data.

3. Water Resource Management in South Africa

3.1 Regulatory framework

The context for the use and management of water resources in South Africa has been set in the constitution (Act 108 of 1996). The Bill of Rights (Chapter 2) specifies among others that every person shall have the right to:

- equality before the law and that no person shall be unfairly discriminated against (section 9),
- life and respect for and protection of his or her dignity (sections 10 and 11),
- an environment which is not detrimental to his or her health or well-being and to have the environment protected (section 24),
- have access to sufficient food and water (section 27), and
- access to all information held by the state or by another person and that is required for the exercise or protection of any rights (section32).
-

The Act also specifies aspects related to co-operative governance in Chapter 3, which refers to infrastructure and mechanisms for water resource management.

The framework for water resource management is largely provided by the National Water Act (Act 36 of 1998), with implications also from other environmental policies (DEA&T, 1996a and 1996b). The purpose of the National Water Act (NWA) states, among others, that:

"2. The purpose of this Act is to ensure that the nation's water resources are protected,

used, developed, conserved, managed and controlled in ways which take into account amongst other factors—

(a) meeting the basic human needs of present and future generations;

....

(d) promoting the efficient, sustainable and beneficial use of water in the public interest;

....

(g) protecting aquatic and associated ecosystems and their biological diversity;

...."

Within this context, assessment and management approaches need to be developed to support the implementation of the Act. Methods to define *"sufficient water"* need to be established and accepted as well as sufficient protection measures to ensure *"sustainable use"* in an integrated management framework. In defining **pollution**, the NWA specifies *it not be "less fit for any beneficial purpose"* or *"harmful or potentially harmful"*. Furthermore, **protection** is defined in terms of *"ecologically sustainable use"*, *"prevention of degradation"* and *"rehabilitation"*. We would therefore have to decide what constitutes unacceptable change and develop methods to measure, assess, predict and manage these aspects. **Resource quality** is defined as:

"the quality of all the aspects of a water resource including:
the quantity, pattern, timing, water level and assurance of instream flow;
the water quality, including the physical, chemical and biological characteristics of the water;
the character and condition of the instream and riparian habitat; and
the characteristics, condition and distribution of the aquatic biota"

The management of resource quality would, thus, mean the ability to define these aspects, measure them and provide information that could be used to support decisions (typical multi-criteria) in an integrated water resource management framework. The framework developed for water resource management allows for the implementation of risk-based technologies, although the specific areas where it will be useful will have to be determined, and the risk-based technologies need to be suitably developed for these applications.

3.2 Protection-based water resource management

The protection of water resources receives specific attention in Chapter 3 of the NWA. The first stage in the protection process is the development of a **system to classify** the nation's water resources as specified in the Act (section 12).

> **12.***(2) "The system for classifying water resources may-*
> *(a) establish guidelines and procedures for determining different classes of water resources;*
> *(b) in respect of each class of water resource-*
> *(i) establish procedures for determining the Reserve;*
> *(ii) establish procedures to satisfy the water quality requirements of water users as far as reasonably possible, without significantly altering the natural water quality characteristics of the resource;*
> *(iii) set out water uses for instream or land-based activities which must be regulated or prohibited in order to protect the water resource; and*
> *(c) provide for any other matters relating to the protection, use, development, conservation, management and control of water resources, as the Minister considers appropriate."*

Water resources will be grouped into classes representing different levels of protection according to the classification system. The protection required for a specific class is expressed as the risk of irreversible damage to the system. This provides the context for balancing development options (risk) against long-term protection of a water resource. A system comprising a few protection classes has been recommended (MacKay, 1998). The highest class (highest protection, lowest risk) will include water resources of high conservation importance or because they support very important and sensitive uses. The lower classes (more utilization, high risk) would be applicable to resources where there are high demands on water for socio-economic development and where the conservation value of the system is not very high.

The classification of a water resource should be a formal process of negotiation and consensus-seeking among all stakeholders. Stakeholder groups should be represented by water user sectors, industrial sectors, agricultural sectors, public sectors, special interest groups, local and regional government as well as other government departments responsible for resource development and protection (MacKay, 1998). The stakeholders should come to agreement on the level of protection that will be afforded to the resource, with an understanding of the limitations and opportunities that the agreed level of utilization hold.

The **resource quality objectives** (RQO's) of all or part of water resources considered to be significant is then determined. In determining resource quality objectives a balance must be sought between the need to protect and sustain water resources on the one hand (related to the Reserve), and the need to develop and use them on the other. Assessment methods should thus provide information that would support management decisions in this context. The RQO's are defined in the NWA as:

"The objectives determined under subsection (1) may relate to-

- *the Reserve;*
- *the instream flow;*
- *the water level;*
- *the presence and concentration of particular substances in the water;*
- *the characteristics and quality of the water resource and the instream and riparian habitat;*
- *the characteristics and distribution of aquatic biota;*
- *the regulation or prohibition of instream or land-based activities which may affect the quantity or quality of the water resource; and*
- *any other characteristic,of the water resource concerned."*

The next section (Part 3) in the NWA is to determine **the Reserve**, which is defined in two parts:

"The basic human needs reserve provides for the essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene.

The ecological reserve relates to the water required to protect the aquatic ecosystems of the water resource.

The Reserve refer to both the quantity and quality of the water in the resource, and will vary depending on the class"

The Reserve refers to both the quantity and quality of the water in the resource, and will vary depending on the class of the resource. The development of a process for the determination of a preliminary Reserve is underway but methods to determine more comprehensively the resource quality required to protect aquatic ecosystems for different classes and for different resources still needs to be developed.

The NWA provides for the development of strategies to facilitate the proper management of water resources, including the development of a national water resource strategy and catchment management strategies. This approach would call for compatible criteria to be used on a national and at regional levels. The strategy for the implementation of catchment management is further discussed in a strategic plan (DWA&F, 1998).

4. The Role of ERA in Water Resource Management

The protection philosophy was entrenched in the fundamental principles and objectives for a new water law in South Africa (DWAF, 1997), with Principles 9 and 10 stating:

(9) "The quantity, quality and reliability of water required to maintain the ecological functions on which humans depend shall be reserved so that the human use of water does not individually or cumulatively compromise the long term sustainability of aquatic and associated ecosystems."

(10) "The water required to meet the basic human needs referred to in Principle 8 and the needs of the environment shall be identified as "the Reserve" and shall enjoy priority of use by right. The use of water for all other purposes shall be subject to authorisation."

The white paper on water policy (DWAF, 1997) supports the philosophy of water resource protection, stating that:

"Only that water required to meet basic human needs and maintain environmental sustainability will be guaranteed as a right. This will be known as the Reserve."

This approach initiated in the principles has subsequently been enacted (NWA, Act 36 of 1998), with Part 3 of the National Water Act (NWA) stating:

"the ecological reserve relates to the water required to protect the aquatic ecosystems of the water resource. The Reserve refers to both the quantity and quality of the water in the resource, and will vary depending on the class of the resource."

Section 18 of the NWA compels responsible authorities to:

"...give effect to the Reserve as determined in terms of this Part when exercising any power or performing any duty in terms of this Act"

The Reserve is, however, determined in accordance with a class, which allows a balance to be sought between the need to protect and sustain water resources on the one hand and the need to develop and use them on the other. The ecological reserve can be described as ecological specifications that provide a specific level of protection to a water resource. The level of protection is related to the goods and services that society derives from the resource, and the potential for the resource to provide such goods and services for future generations.

Jooste and Claassen (2000) investigated the application of risk concepts to water resource quality management and concluded that risk may reasonably be used to aid water resource quality management decisions and activities in, amongst others, the following areas:

- Basis for water quality criteria: The current South African Water Quality Guidelines (aquatic ecosystems) was derived from toxicological data and some qualitative assumptions regarding exposure. These criteria are limited because expected effect differing from substance to substance, co-occurrence of different stressors are not considered, and the criteria do not necessarily relate to the same ecological effect. Setting criteria on a risk basis would induce a measure of transparency into the interpretation of such criteria.
- Site-specific criteria: Applying risk criteria to the site-specific adaptation of criteria supplies a rational basis for incorporating new or locally significant data in a manner that is open to peer review.

- Resource management classification: The provision in the National Water Act for the classification of water resources can be linked to risk concepts. Management objectives may be expressed in terms of allowable risk to the Reserve. This provides an explicit communality between the receiving water quality/risk objectives and the reserve as well as effluent criteria and/or standards.
- Hazard ranking: In some situations, it is neither necessary nor feasible to calculate absolute risks. In the case where different hazards within the same scenario or hazards in different scenarios need to be compared, risk is often a suitable basis for comparison.

The relationship between risk and water resource classification is fundamental to the application of risk assessment to water resource management. The classes (eg. A-F) are based on the protection of ecological integrity, with increasing risk of losing basic ecosystem processes (structure & function; **Figure 3**). Management objectives can be set along this continuum. In accordance with **Figure 3**, class D is defined as habitat conditions and biological integrity deviating significantly from that associated with *ecotype under normal conditions*, basic *ecosystem processes* (structure & function) being intact and indicator species representing the ecotype still occurring. Class A represents natural conditions. The provision of goods and services are linked to the classification system, with an A-class river providing non-consumptive services and having the maximum potential to provide consumptive goods and services. D-class rivers provide the maximum goods and services that can be delivered on a sustainable basis, albeit at higher risk. Classes E and F provide goods at a rate that poses high (unacceptable) risk to basic ecosystem processes. For this study, the risks associated to the different classes are based on the probability that basic ecosystem processes (structure & function) will be irreversibly damaged in a given year. In an A-class, this risk is one in a million, which would typically be due to long term natural change such as interglacial cycles and relate to geological time. In a D-class, the risk is one in a thousand with the system being sensitive to small disturbances at the level of ecological succession processes.

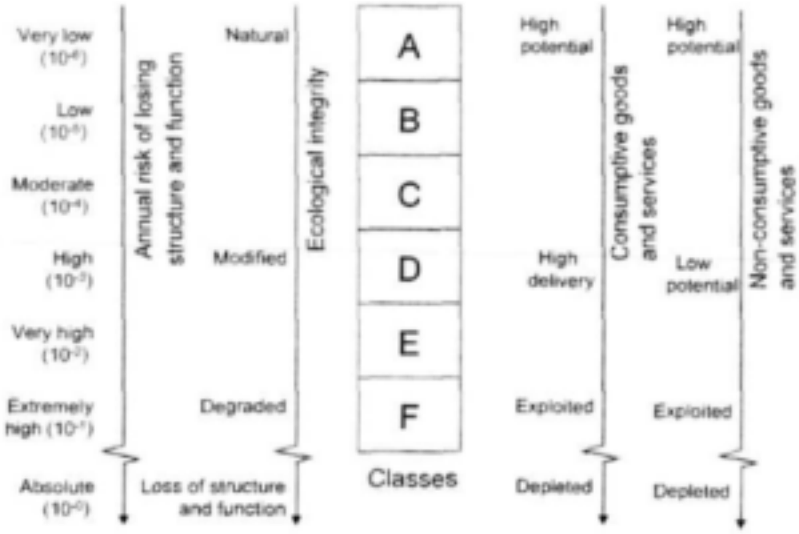

Figure 3: Relation between risk and water resource classification

5. Application of Specific Water Resource Assessment Technologies to ERA

ERA is not a tool for classification *per se*, but can rather be used to assess constraints to development. An important distinction to make is between hazard and risk. A hazard is related to the occurrence of an event (such as pollution), whereas the risk describes the likelihood of it having an effect (such as fish kills). The risk determination includes factors that would affect exposure to the event (such as isolation of the pollutant). The development of a classification system, the process for determining the reserve and the development of a risk-based policy framework are first steps to developing an approach for risk assessment (development of a risk management framework). Setting management objectives and determining classes are areas where a risk-based approach could be very useful. A very powerful feature of risk assessment is the ability to assess the risks of various development options. Risks can then be ranked to serve as decision support. The numeric output from risks assessments can be used for communicating options and decisions.

The following issues were identified in a workshop were the requirements for successful implementation of the protection aspects on the NWA were discussed:

 # 1 Reliable classification system

 # 2 Process for consensus seeking & effective communication at all levels

 # 3 Capacity (people)

 # 4 Reserve determination

- *Process for determining*
- *Process of consensus seeking*

 # 5 Understanding Water Resource Management process

 # 6 Understanding rules for changing classification (Role of National Strategy)

 # 7 The development of policy (risk based-)

 # 8 Enforcement

- *ERA policy & DSS*
- *Enforcement*

In the area of policy development, techniques are also needed to provide inputs into the process. The policy should also be analyzed and feedback provided. Scenario-based planning can again play an important role. During the implementation of policy it is critical to view risk management and risk assessment as two distinctly different processes. Risk management is normally done in the wider context and involves values (soft issues), whereas risk assessment is the technical practice of objectively determining risks of various options. A risk-based management framework needs to be developed that would cater for such implementation, but a prerequisite to that is an understanding of ERA concepts and possibilities.

Possible other applications of ERA are:

- to assess levels of vulnerability to classes and,
- prioritize monitoring and control in different classes

Management action as a result of a hazard should be dependant on the risk attached to the hazard.

In addition to the issues previously defined, the following issues are considered important for protection.

 # 9 Assign RISKS to HAZARDS for classes

- *For monitoring, control & enforcement*
- *Managements' response to Hazard is dependant on Risk*

 # 10 Dependant on the development of ERA and Risk Management competence

The roles of environmental chemistry, toxicology and ecotoxicology in applying ERA to water resource management are discussed in **Appendix C**.

6. Research Needs

Within the context of the National Water Act (Republic of South Africa, 1998), assessment and management approaches need to be developed to support the implementation of the Act. Methods to define **sufficient water** as referred to in the Act would need to be established and accepted, as well as sufficient protection measures to ensure **sustainable use** in an integrated management framework. We would therefore have to decide what constitutes unacceptable change and develop methods to measure, assess, predict and manage these aspects.

The first stage in the protection process is the development of a **system to classify** the nation's water resources. The **class** and **resource quality objectives** of all or part of water resources considered to be significant is then determined. The next section in the NWA is to determine **the Reserve**. The development of methods for the rapid determination of a preliminary Reserve is underway but methods to determine more comprehensively the resource quality required for protecting aquatic ecosystems for different classes and for different resources needs to be developed.

Classification is a key concept in the NWA. The approach focuses on the current status of *significant water resources* and defines *future desired states* (management objectives). Risk concepts can be used effectively to define the classes. The ability to reliably classify water resources will be key to its successful implementation. Methods will also have to be developed for consensus seeking and communication of results.

From the classification the Reserve needs to be determined for significant water resources. The Reserve determination is technically even more challenging than resource classification. Communication is important, both for involved people involved in the process and to bring new people on board. A common understanding around the process and techniques is important, especially between scientists. Scientists need to understand the management framework and process as the context to the technical developments.

Setting management objectives and determining classes are areas where a risk-based approach can be very useful. A very powerful feature of risk assessment is the ability to assess the risks of various development options. Risks can then be ranked to serve as decision support. The quantitative output from risks assessments can be useful for communicating options and decisions. Possible other applications of ERA are:

- to assess levels of vulnerability to classes and,
- prioritize monitoring and control in different classes

Management action as a result of a hazard should be dependant on the risk attached to the hazard.

An important issue is whether we set biological criteria to what (and when) change is acceptable. It would be necessary to identify individuals, communities, populations or ecosystems and assess their resilience. If this is the case, we can predict ecosystem-level effects to say where ecosystems will respond in a specific way.

It is also important to understand how societal values affects overriding policies in the management of water resources. An iterative process is needed to for bringing risk into common knowledge. In this process stakeholders will have to be identified and convinced through the development of demonstration material and communication. The key aspect for developing capacity in risk-based approaches is training. It is critical that resources be allocated to support this. There then has to be a translation of risk into policy and decision support to achieve enforcement. A protocol (standardized practice) for decision-making in the risk-paradigm is also required. This process will feed back into policy around acceptable limits. As part of the demonstration stage, a pilot application will familiarize resource management practitioners with the concepts and provide support for initial choices for water resource management.

A weakness of ERA lies in the simplistic assumptions and gross oversimplifications required to create the present generations of ecological risk assessment models (Holdway, 1997). These issues together with those raised by various other authors (summarized by Adams and Power, 1997) are:

1. Toxicity testing
   - Implications of toxicity tests for ecosystems are unknown
   - Extrapolation from single species acute toxicity tests to population impacts
   - Using single substance toxicity tests to address complex mixture toxicity
   - Assumptions of simple additive effects

2. Ecological assessment
   - Ecological concepts are oversimplified in ERA
   - Due to a lack in understanding ecosystem structure, function, and processes, extrapolating across multi-trophic levels is a major limitation
   - ERA predictions are not validated
   - Lack of ecological realism and sophistication in the conception and practice of ERA

3. General
   - A pressing need for the improvement of the knowledge-base
   - Prediction from community effects using data from experiments utilizing inappropriate time and spatial scales
   - Assumptions regarding the importance of indirect effects.

Since ecological principles are often poorly understood or communicated, and social, economic and political considerations enter unequally into environmental decision-making, the key question for the integration of ecological and economic assessments are:

- What economic information is needed for catchment ERAs?
- Can economic analysis and ecological risk assessment processes be mutually supportive?

The two major areas of uncertainty about ecological processes need to be addressed (Calow and Forbes, 1997):

- Uncertainty in predicting effects on organisms in field situations from their response in controlled laboratory test systems and;

- Uncertainty about the roles of different species in ecosystems (the point at which damage to species or populations can be considered as damage to the community or ecosystem).

Some of the needs identified by California EPA (Risk Assessment Advisory Committee, 1996) are also relevant to South African water resource management. These are:

- Consistency in risk assessment
- Supporting new or existing knowledge to improve the scientific basis for risk assessment
- Formalized peer review
- Input from risk managers
- Mechanisms for participation by the public and stakeholders
- Translation of emerging methods in risk assessment into risk management policy
- Evaluation of the various scientific disciplines required for risk assessment
- Balancing the level of effort and resources with the importance of the assessment
- Integrate fate and transport modelling efforts with human exposure assessment
- Improve the characterization of uncertainty and variability in risk assessments
- The analyses should match the needs of the decisions they are intended to support

7. Capacity Building

A full list of people benefiting from the project through participation and attendance of courses are provided in **Appendix D**.

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Appendix A: Set theory

A set can be described as a well-defined collection of objects (Hays, 1969), where "objects" may refer to entities, phenomena or outcomes of an experiment.

Important set descriptors are:

equal A = B when A = {1,2,3,4,5} and B={1,2,3,4,5}

subsets $A \supseteq B$ or $B \subseteq A$

when A = {a|a is an integer and $1 \le a \le 20$} and B = {1,4,5,6,12}

proper subsets $A \subset B$ or $B \supset A$ when B contains at least one element that is not in A

The mathematics of such sets may involve their union, intersection, complement or difference where:

if A = {x|x is an integer and $x \le 10$}, and
B = {x|x is an integer and $6 \le x \le 15$}, and
x denotes elements that are members of a universal set,

then
union $A \cup B$ = {x|x is an integer and $x \le 15$}
intersection $A \cap B$ = {x|x is an integer and $6 \le x \le 10$}
complement $\bar{A}$ = {x|x is an integer and $x > 10$}
$\bar{B}$ = {x|x is an integer and $6 > x > 15$}
difference A - B = {x|x is an integer and $x < 6$}
B - A = {x|x is an integer and $10 < x \le 15$}

For deterministic analyses, the objective is to establish whether a given element (or outcome) is a member of a specified set or not. Consider the following example:

where A = {x|x is an integer and $x \le 10$}
for $i = 3$ *then* $i \in A$, but,
for $i = 12$ *then* $i \notin A$,

The analysis thus results in a binary output *viz.*
$i \in A$ or $i \notin A$ (*i* is a member of A or *i* is not a member of A)

Conversely, probabilistic analyses is concerned with the likelihood of any specific outcome. In this case, the sample space (***S***) denotes the set of all possible outcomes of an experiment. Within the sample space, a set consisting of all the possible subsets in ***S*** is defined as ***Q*** (the family of events in ***S***). The number of members in ***Q*** will be 2^N, where N is the number of possible outcomes. For example, for the throw of a dice:

if $\boldsymbol{S} = \{x|x \text{ is an integer and } x < 7\}$, then
$\boldsymbol{Q} = \{A|A \text{ is all unique subsets of } \boldsymbol{S}\}$

A probability function (p) is then associated with each event (A) in $\boldsymbol{Q}$, such that:

$0 \leq p(A) \leq 1$,
$p(\boldsymbol{S}) = 1$ and
$p(\bar{A}) = 1 - p(A)$

Furthermore, where A and B are two mutually exclusive events in the sample space $\boldsymbol{S}$:

if $A \subseteq B$, then $p(A) \leq p(B)$, and
$p(A \cup B) = p(A) + p(B)$ (Hays, 1969)

It is, however, important to remember that probabilities are assigned to *events*, and that the one is meaningless without the other, therefore the notation p(A).

For simple experiments, such as the throw of a dice, it is often true that the elementary events have the same probability of occurrence. In this case, the probability is merely the number of events in a defined subset, divided by the total number of possible events. In the example of the dice, the probability of throwing a number higher than two can then be described by:

if: $\boldsymbol{S} = \{1,2,3,4,5,6\}$ (sample space)
$\boldsymbol{Q} = \{A|A \text{ is all possible subsets of } \boldsymbol{S}\}$
$A_1 = \{3,4,5,6\}$ (the defined subset which is an element of $\boldsymbol{Q}$)
then: $p(A_1) = 4/6 = 0.66'$

Most real-world scenarios are more complex than the examples used thus far. In natural systems specifically, different events often don't have the same probability of occurrence. Frequency distributions are used to describe such systems, where the elementary events often have different probabilities of occurrence. Building on the previous example, we could consider the probability of a predator taking a specific prey species. If the relative abundance of prey species is 130, 25, 3 and 42 respectively and there is no particular bias towards a specific species being preyed on then:

$\boldsymbol{S} = \{x|x \text{ is 200 individuals that are prey}\}$ (sample space)
$\boldsymbol{Q} = \{A|A \text{ is all unique subsets of } \boldsymbol{S}\}$ (family of events)

We are, however, interested in four specific events (subsets defined by species) in ***Q***, defined as A_1, A_2, A_3 and A_4. The probabilities of the predator taking a subset of individuals (an event) are given as:

$$p(A) = \frac{number\ of\ elementary\ events\ in\ A}{total\ number\ of\ elementary\ events\ in\ S}$$

thus the respective probabilities for an individual from the specific species being taken are:

$$p(A_1) = \frac{130}{200} = 0.65$$

$$p(A_2) = \frac{25}{200} = 0.125$$

$$p(A_3) = \frac{3}{200} = 0.015$$

$$p(A_4) = \frac{42}{200} = 0.21$$

This specific view of probability is based, at least in theory, on the outcome of an infinite number of repetitions of the same experiment under the same conditions. James Bernoulli first described this concept in the early eighteenth century. "Bernoulli's theorem" is as follows:

> *"If the probability of occurrence of the event X is p(X), and if N trails are made, independently and under exactly the same conditions, then the probability that the relative frequency of occurrence of X differs from p(X) by any amount, however small, approaches zero as the number of trails grows infinitely large."*

Probability in this case is considered to be a mathematically calculable number, based on the properties of available data.

The more general use of the term probability refers to one's expectation of the outcome. One might say: "It will probably rain tomorrow. ", thereby not inferring an experimental calculation of probability, but merely an expectation. In this sense, it is not always based on empirical data, but rather a subjective expression based on knowledge of a specific system and its behaviour. An expression of probability under these conditions would be dependent on system knowledge and views in a given context and may change as a result of acquired knowledge, different views or in another context.

A further approach in Boolean algebra that has been proposed for use in ERA is fuzzy logic (Suter, 1993). Fuzzy subset theory was designed to deal with reality, not by forcing it into rigid mathematical models, but rather to represent our understanding of the truth through assigning fuzzy bounds to memberships. Using the example of a predator taking prey from a system. In this case, we may be interested in the probability of a large individual being taken.

Then:

$\boldsymbol{S}$ = {x|x is 10 individuals that are prey} (sample space)

$\boldsymbol{Q}$ = { $\underset{\sim}{A}$ | $\underset{\sim}{A}$ is all unique subsets of $\boldsymbol{S}$} (family of events)

$\underset{\sim}{A}_1 = \{(x_1 \mid 0.1), (x_2 \mid 0.2), (x_3 \mid 0.4), (x_4 \mid 0.7), (x_5 \mid 0.8), (x_6 \mid 0.8)\}$

Where:

$\underset{\sim}{A}$ is a fuzzy subset indicating the event's membership to the subset.

The membership rule to $\underset{\sim}{A}$ is: "Members of **S** that are big"

The membership in this case can be a subjective judgement of what is considered big, and how much each member of **S** fits the definition. The probability of a large individual being selected by the predator can be calculated as:

$$p(\underset{\sim}{A}) = \frac{sum\ of\ memberships\ to\ A}{sum\ of\ memberships\ to\ S}$$
$$= \frac{3}{10}$$
$$= 0.3$$

Appendix B: Watershed Ecological Risk Assessment in the US

The Agency has placed increased emphasis on community and place-based approaches to environmental management. These efforts represent a fundamental change from traditional single media-based approaches for environmental regulation to a concern for the impact of multiple stressors over a broad range of spatial scales. ORD needs to provide communities the processes and tools that communities are able and willing to use to determine what ecological resources are at risk and how best to protect those resources through management action. Ecological risk assessment could play a major role in bringing science into these place-based decisions.

The purpose of place-based research is to develop and demonstrate methods to assess the impact of multiple chemical, physical and biological stressors at several different ecological scales. The way communities, ecosystems, and entire ecosystems respond to stress will be studied. Research may be able to define the "acceptable" impacts upon ecosystems, including the watershed scale significance of stressors and management actions. The research will develop and demonstrate techniques and methods to quantify uncertainties associated with risk assessment.

The Office of Water (OW) and the Office of Research and Development (ORD) cosponsored five prototype watershed ecological risk assessment case studies in five different ecological and geographic regions, in July 1993. For each of these studies case study teams were assembled which included participants from Federal and State agencies and environmental organizations. These organizations are now all supporting the risk assessment effort initiated by OW and ORD because of the gain it will provide for ecological resource management decision-making.

There are advantages to using the ecological risk assessment paradigm in place based assessments that these activities are anticipated to illuminate. One advantage is that using an ecological risk assessment process provides resource managers with predictions of what ecological changes will occur from the stressors associated with alternative management decisions. This can convince a risk manager as to why a particular protective action should be taken because anticipated results and the associated uncertainty is described as well as the time frame in which results would be achieved. Finally, it is anticipated these case studies will refine the approach so it can ultimately be adopted for use by other regions, states and local organizations in their watersheds.

By applying the ecological risk assessment framework in watersheds we are clarifying the definition and application of management goals, assessment endpoints, and conceptual model development; expanding the concept of measures; and identifying the explicit need for analysis plans.

Approach

NCEA and OW are applying the theoretical principles outlined in the Ecological Risk Assessment Guidelines to improve decision-making in five watersheds. These ecological risk assessments were undertaken to address local or state concerns and analyze stressors and resulting ecological effects. This approach applies the scientific principles espoused by the guidelines for the benefit of local human and ecological communities. Evaluating these demonstrations will facilitate making improvements to the methods used for place-based assessments. Simultaneously, the approach brings numerous organizations together to address and analyze an environmental problem, and stimulates public awareness and participation in decision-making for reducing ecological risks.

All five watershed case study problem formulations were presented to the Science Advisory Board for review in June 1996. The review requests NCEA on the process used to 1) obtain watershed management goals; 2) interpret the goals for the risk assessment; and 3) define the problem at the landscape scale for multiple stressors, including a plan for analyzing data and characterizing risk. The five watershed level ecological risk assessment case study sites are:

Big Darby Creek, Ohio. - A watershed relatively free of pollution that is highly valued for its scenic beauty, its high water quality and for recreational opportunities. The Big Darby watershed is also widely recognized for its species diversity, including many rare and endangered freshwater mussels and fish. The watershed is subjected to urbanization, through westward expansion from Columbus, agricultural nonpoint sources and permitted discharges. Management issues relate to future land use and implementation of best management practices.

Clinch Valley Watershed, Virginia- The assemblage of fish and freshwater mussel species in the rivers in this watershed is among the most diverse in North America. Recent surveys by biologists show a declining abundance of most rare species in this region from anthropogenic stressors such as mining, forestry, agriculture, cattle grazing, municipal septic tanks, and spills.

"Middle" Platte River Wetlands, Nebraska- The Platte River provides water for agricultural irrigation, electric power production, recreation, fish, wildlife and community and industrial water supplies. The middle segment of the river is the major resting area for migratory waterfowl, including the sandhill crane. The water usage has reduced the volume of the waterflow disturbing the required habitat of resident and migratory birds.

Waquoit Bay Estuary, Massachusetts- A shallow Cape Cod estuary fed by groundwater and freshwater streams Waquoit Bay is prized by residents and visitors for its aesthetic beauty and recreational opportunities. The bay provides a permanent or temporary home for many fresh- and salt water aquatic species as well as terrestrial species. The Bay has also been designated as a National Estuarine Research Reserve.

"Middle" Snake River, Idaho- The west-central Snake River plain of southern Idaho (called the Middle Snake in this case study) is the most degraded stream reach of the Snake River. Water use demands on the water flowing into this river segment include upstream impoundments and demands for energy, irrigation and dairy feedlots. Many aquatic benthic and pelagic species in this area that require cold, swiftly flowing water are either extinct or threatened. This activity is being expanded into a larger scale place-based assessment because it was found that the problems of the Middle Snake could be better addressed by studying the upstream inputs to this ecosystem and a wider scale (statewide) management plan is more appropriate.

BIG DARBY CREEK WATERSHED

Why is Big Darby Creek special?

The Big Darby watershed is a freshwater, aquatic ecosystem encompassing 1,443 sq km (557 square miles) in central Ohio. It is drained by Big Darby Creek, Little Darby Creek and a dozen smaller tributaries. The watershed is an example of a high quality ecosystem relatively free of pollution. A significant portion of Big Darby Creek is an Ohio State Scenic River and National Scenic River. The 129 kilometer (80 mile) long stream is widely recognized as home to an exceptional variety of species, including many rare and endangered freshwater mussels and fish. Big Darby Creek has been designated by The Nature Conservancy - an international conservation organization - as one of the "Last Great Places" in the western hemisphere. Awareness of the value of this unique resource, and growing concern about its future, has resulted in a partnership of over forty public agencies and private organizations. The partners share the goal of developing a cooperative approach toward the protection and maintenance of this valuable resource.

How can this valuable resource be protected?

This ecological risk assessment will analyze the stressors and resulting ecological effects in the Big Darby Creek watershed. The assessment promotes community awareness of ecological problems in the watershed and will provide information to resource managers, including government officials, organizations and the public. These activities promote environmentally beneficial results.

How is the ecological risk assessment being done?

Interested organizations collectively developed a management goal and developed a scientific study approach. The ecological risk assessment brought together numerous organizations to analyze the impact of stressors on the watershed. Measurements of watershed condition will be plotted on maps and related to land use within the watershed. Relationships between the stressors caused by land use activities and effects on fish and aquatic invertebrates will be examined. This will provide information to estimate risks associated with land-use decisions. A report describing the management goals for the watershed and the analysis plan for the assessment will be available upon completion of the analysis described above.

Key stressors being evaluated in the ecological risk assessment are: sedimentation, nutrient enrichment, changes in water flow, changes in the physical characteristics of the stream channel, loss of tree cover adjacent to the stream and chemical contamination.

How will the results be used?
The Big Darby Creek Watershed Ecological Risk Assessment will help resource managers predict how changes in land use and river flow will affect biological communities in the watershed. This will enable resource managers to make decisions based on more information. This project is co-sponsored by the US EPA's Office of Water and Office of Research and Development as an effort to bring the science of risk assessment into the local community decision-making process.

CLINCH RIVER WATERSHED

Why is the Clinch River special?
The Clinch River above Norris Lake is one of the largest free-flowing segments of the Tennessee River drainage basin with a length of 320 kilometers (200 miles). At Norris Lake the Clinch is joined by the Powell River, and continues to flow in a southwesterly direction, eventually joining the Tennessee River near the town of Harriman, TN. The watershed drains approximately 7,600 square km (2900 square miles). The assemblage of fish and freshwater mussel species in the Clinch river is among the most diverse and unique in North America. In fact, many of the native mussel species are found nowhere else. The Clinch River harbors at least four fish and 18 mussel species that are either federally endangered, threatened or are candidates for protection under the Endangered Species Act. The Nature Conservancy-- an international resource conservation organization -- has established the Clinch Valley Bioreserve to conserve biological diversity in the Clinch River watershed while continuing to meet social and economic needs. A partnership has been formed between public and private organizations that share a goal of preserving or restoring the valuable natural resources of the watershed while maintaining its economic uses.

How can this valuable resource be protected?

This ecological risk assessment will analyze the stressors and resulting ecological effects in the Clinch River watershed. The assessment promotes community awareness of ecological problems in the watershed and will provide information to resource managers, including government officials, organizations and the public. These activities promote environmentally beneficial results.

How is the ecological risk assessment being done?

Interested organizations collectively developed a management goal and a scientific study approach. The ecological risk assessment brought together numerous organizations to analyze the impact of stressors on the watershed. Measurements of watershed condition will be plotted on maps and related to land use within the watershed. Relationships between the stressors caused by land use activities and effects on fish and aquatic invertebrates will be examined. This will provide information to estimate risks associated with land-use decisions. A report describing the management goals for the watershed and the analysis plan for the assessment will be available upon completion of the analysis described above.

Key stressors being evaluated in the ecological risk assessment are habitat disruption, sedimentation and chemical contamination

How will the results be used?

The Clinch River Ecological Risk Assessment will help resource managers predict how changes in land use and river flow will affect biological communities in the watershed. This will enable resource managers to make decisions based on more information. This project is co-sponsored by the US EPA's Office of Water and Office of Research and Development as an effort to bring the science of risk assessment into the local community decision-making process.

"MIDDLE" PLATTE RIVER WATERSHED

Why is the middle Platte River special?

The Platte River flows eastward across Nebraska providing water for irrigation, electric power, recreation, fish, wildlife, and community and industrial water supplies. The middle segment of this river has national and international environmental importance. It is the major staging (resting) area for one-half million sandhill cranes and several million ducks and geese that migrate annually through the area. Many other species of mammals, birds and fish (such as the whooping crane) use the water, woodlands and remaining native grasslands and wet meadows in the middle Platte River valley. Surface and groundwater flows from this segment of the Platte River system are also important to the economic stability of central Nebraska by irrigating about two million acres of land, mostly for corn production.

The volume and variability of water flows to the middle segment of the Platte River have been reduced from dams in Colorado, Wyoming and Nebraska along with irrigation and other water withdrawals. Cultivated agriculture has replaced most of the native prairie and river-dependent vegetation that once occupied the middle Platte River watershed. Reductions in quality and quantity of water and habitat have prompted concern for the welfare of the sandhill crane, other migratory bird populations, and threatened and endangered fish and bird species. American Rivers, a national river conservation organization, has designated the Platte River as one of the ten most endangered rivers in America.

How can this valuable resource be protected?

Interested organization collectively developed a management goal and a scientific study approach to evaluate the environment of the middle Platte River. An ecological risk assessment will analyze the stressors and resulting ecological effects in the middle Platte River watershed. The assessment promotes community awareness of ecological problems in the watershed and will provide information to resource managers, including government officials, organizations and the public. These actions promote environmentally beneficial results.

How is the ecological risk assessment being done?

The landscape in the middle Platte River watershed is a mosaic of interdependent habitats that support biological communities. The ecological risk assessment brought together numerous organizations to analyze the impact of stressors on these habitats and the wildlife populations in the watershed. A report describing the management goals for the middle Platte River watershed and the analysis plan for the assessment will be available upon completion of the analysis described above.

Key stressors being evaluated in the ecological risk assessment are changes in the magnitude, timing and frequency of middle Platte River flows, loss or disturbance of critical wildlife habitat, changes in stream channel characteristics and degraded water quality due to agriculture-related activities

How will the results be used?

The middle Platte River Ecological Risk Assessment will help resource managers predict how potential changes in land use and river flow could affect the biological communities in the watershed. This will enable resource managers to make decisions based on more information. This project is co-sponsored by the US EPA's Office of Water and Office of Research and Development as an effort to bring the science of risk assessment into the local community decision-making process.

WAQUOIT BAY WATERSHED

Why is Waquoit Bay special?

Waquoit Bay is a shallow Cape Cod estuary fed by groundwater and freshwater streams. Because the Bay is close to the mixing zone between the warm waters of the Gulf Stream and the colder waters of the Labrador Current, many important fish species are found in the Bay. Alewives, bluefish, striped bass, winter flounder, menhaden, and tautogs all reside in the Bay for at least part of the year. The Commonwealth of Massachusetts has designated Waquoit Bay as an Area of Critical Environmental Concern. The Bay has also been designated as a National Estuarine Research Reserve. These designations help reduce existing and future human disturbances to the Bay's watershed. Federal, state and local resource agencies, various regional and local citizen interest groups, and academic organizations are working together to preserve and restore the quality of the Waquoit Bay estuary and its associated freshwater ponds and rivers.

How can this valuable resource be protected?

The waters of Waquoit Bay and its associated rivers and ponds show signs of degradation such as eutrophication, habitat loss and resource depletion. Stressors in the Waquoit Bay watershed result from land use along the coast and from upland areas. This ecological risk assessment will analyze the stressors and resulting ecological effects in the Waquoit Bay watershed. The assessment promotes community awareness of ecological problems in the watershed and will provide information to resource managers, including government officials, organizations and the public so they can make more ecologically informed decisions. These activities promote environmentally beneficial results.

How is the ecological risk assessment being done?

Interested organizations collectively developed a management goal and a scientific study approach. Because many of the ecological effects observed in the Waquoit Bay watershed are related to loss of the once extensive eelgrass beds, the risk assessment research will focus on the causes of this loss, and ways to halt or reverse it. Relationships between nutrient enrichment and eelgrass loss are being analyzed. This will provide information to estimate risks associated with land-use decisions. A report describing the management goals for the Waquoit Bay watershed and the analysis plan for the assessment will be available upon completion of the analysis described above.

Key stressors under evaluation are nutrient enrichment (nitrogen loading), suspended sediments, changes in water flow patterns, inputs of toxic chemicals and physical alteration of habitat

How will the results be used?

The Waquoit Bay Ecological Risk Assessment will help resource managers predict how changes in land use and human activity in the watershed will impact eelgrass growth. This will enable resource mangers to make decisions based on more information. This project is co-sponsored by the US EPA's Office of Water and Office of Research and Development as an effort to bring the science of risk assessment into the local community decision-making process.

MID-SNAKE RIVER

Why is the Mid-Snake River special?

This case study covers the middle reach of the Snake River which runs about 100 kilometers (62 miles) from Milner Dam to King Hill. The watershed includes 22,326 square kilometers (8600 square miles) of land. The Snake River has long been valued as a source of water for irrigation and for generating hydroelectric power. Prior to impoundment of the river approximately 24 native fish species were found below Shoshone Falls, including chinook salmon, Pacific lamprey, steelhead trout and white sturgeon.

This exceptional stream is threatened by many stressors from the day-today activities of people within the watershed. Dams and other diversion structures, and land use practices in the watershed have reduced flow rates allowing aquatic weeds and algae to choke the river. The native fish and invertebrates that require cold, swiftly flowing water have been lost or severely reduced in number. Currently eight invertebrates species are classified as either endangered or threatened.

How can this valuable resource be protected?

This ecological risk assessment will analyze the stressors and resulting ecological effects in the Mid-Snake River watershed. The assessment promotes community awareness of ecological problems in the watershed and will provide information to resource managers, including government officials, organizations and the public. These activities promote environmentally beneficial results.

How is the ecological risk assessment being done?

Interested organizations collectively developed a management goal and developed a scientific study approach. The ecological risk assessment brought together numerous organizations to develop a goal to maintain and restore conditions that support the native cold-water biota of the Mid-Snake River, while also maintaining the river's economic value. The ecological risk assessment uses a water quality model and field studies to analyze the impact of stressors on the watershed. Water quality will be examined to determine relationships between land and water use within the watershed and what effects are seen in the river. By evaluating current and past condition, forecasts can be made about future risks associated with land and water use decisions. A report describing the management goals for the Mid-Snake River watershed and the analysis plan for the assessment will be available upon completion of the analysis described above.

Key stressors being evaluated are changes in water flow, nutrient enrichment and sedimentation

How will the results be used?

The Mid-Snake River Ecological Risk Assessment will help resource managers predict how potential changes in land use and river flow will affect the biological communities in the watershed. This will enable resource managers to make decisions based on more information. This project is co-sponsored by the US EPA's Office of Water and Office of Research and Development as an effort to bring the science of risk assessment into the local community decision-making process.

Appendix C: Role of water resource assessment technologies in ERA

Ecological Risk Assessment Guidelines and Application in Water Resource Management : The Role of Aquatic Toxicology

- Prof. Carolyn G Palmer

The aim of this document is to indicate where and how a toxicological approach fits into the process of Ecological Risk Assessment as described by Murray and Claassen (1999), and as discussed at the workshop "Risk-based objectives" (Grahamstown 8-10 February 2000).

Agree on objectives

Agree on management goals

Task Description

Identify relevant resource quality objectives.
Link these resource quality objectives to related ecosystem characteristics and functions.
Confirm that management goal include the management of chemical factors that could compromise resource quality objectives.

Task Motivation

In order to visualize whether toxicology will be useful in the ERA it is necessary to list the aspects of ecosystem function that are important - a list of resource quality objects will provide this.
It is then useful to link these objectives to specific ecosystem functions so that later the choice of test organism can be linked back to ecosystem function, and from there back to the resource quality objective.
Finally, for toxicology to be of use there must be chemical stressor/s (hazard/s) that could affect the ecosystem.

Key Characteristics of the task

Identification of the potential for chemical stressors to require management

Define management decision

Task Description

Define the kinds of decisions that will be made about the chemical stressor/hazard.

Task Motivation

Definition of probable management decisions will assist in experimental planning.

Key Characteristics of the task

Make sure management will require toxicological data.

Agree on scope of risk assessment

Task Description

Identify whether an experimental assessment of biotic responses to chemical stressor/s is a key, or desired aspect of the ERA.
Identify the likely range of stressors to be tested.
Identify the desired level of environmental realism.
Identify whether acute of chronic response data are needed.
Identify whether this is a site-specific application.

Task Motivation

It is important to identify whether chemical stressors are the main source of risk, or an incidental source of risk. Decisions can then be made as to whether toxicology will add value to the ERA
The cost of different kinds of toxicity tests varies - in assessing the scope of the study it is useful to know which kinds of chemicals are to be tested, as well as whether the results are requited with a high degree of environmental realism. This will allow an assessment of which test and test organism are likely to be needed
The nature of the chemical stressor - i.e. whether a single substance, and suite of single substances, or a complex effluent (and if so, the nature of the complex effluent) will allow an evaluation of the scope of toxicological testing that would be required.
There are time and cost implications, as well as suitability for extrapolating the data in deciding on acute (short-term) versus chronic (long term) testing.
For site-specific applications it may be work using more expensive tests. The level of knowledge usually pays off in the level of protection that can be specified.

Key Characteristics of the task

Identify whether it is important to quantify biotic responses to chemical stressors, and if so, how many and what sort of chemicals?

Formulate analysis plan

Integrate available information

Task Description

List chemical stressors.
Establish the water chemistry of the receiving water.
Identify the test organisms that will best serve as surrogates for the ecosystem characteristics.

Use the above information to decide on:
- test taxa
- test system
- experimental design
- diluent
- end-point
- test duration.

Decide on the application of the data.

Task Motivation

At this stage is essential to decide on the range of chemical stressors acting on the environment and to select those to be tested. These may be one or more single substances, or one or more complex mixtures. Both the risk assessor and the risk manager should know the form in which the final data are reported i.e. a single substance will be reported as a concentration at which a particular response is elicited; a complex mixture will be reported as a % dilution at which as particular response is elicited.
Water chemistry data about the receiving environment need to be evaluated as this chemistry will affect the chemical reality of the stressor in the environment relationship. If no data are available it will be necessary to decide if water chemistry monitoring is need, or whether data can be extrapolated from a similar system.
A range of toxicity test organisms is available, including: microbial systems, algae, standard test invertebrates and fish, and wild indigenous populations of invertebrates or fish. It is also possible to use multi-species systems where process rates are measured. Standard test organisms give less variable results, wild populations give variable results with a higher degree of environmental realism. Certain taxa are particularly sensitive to, for example, metals, or to pesticides. All this must be considered in the selection of the test organisms.
In addition it must be remembered that it is an ecosystem that is being managed - so there is an assumed relationship between the test organism and ecosystem function. This link is formalized through stating resource quality objectives which may relate to ecosystem structure (e.g. biodiversity), or function (e.g. food webs and therefore organic waste processing). There should be a record of the reasoning in this linkage so that management decisions can be linked to toxicity results.
Toxicity testing involves a wide range of decisions and all accrued information is used to make decisions on the following alternatives:
- test taxa - one or more species/species-system/ laboratory-bred/wild populations;

- test system - flow-through/static/static renewal/recirculating, microcosm/mesocosm/macrocosm;
- experimental design - replicated with an ANOVA/unreplicated with a regression analysis
- diluent
- end-point - lethal/sub-lethal
- test duration - chronic/sub-chronic/short-term chronic/chronic.

Key Characteristics of the task

Information is needed on the chemistry of the receiving water, and the chemical to be tested. This is used to decide on the kind of test to be undertaken

Select what to protect

Task Description

Make a statement that links the selected test organism to the aspect of the ecosystem that needs to be protected. For example the test organisms may be cited as a "sensitive taxon" - and act as a surrogate fro a 95% species protection; or may be cited as "keystone" species - indicative of a crucial process such as leaf litter processing. Even standard test organisms can be used in this way as long as the assumption of associated between the test organism and the aspect of ecosystem protection is stated and is reasonable. (For example, one of the reasons for using wild populations of riverine invertebrates in studies which aim to protect rivers, is that the standard test invertebrate *Daphnia* spp. Is a standing water animal. Flow is known to be an important habitat determinant in rivers, so it might be reasonable to use flowing water rather than standing water test organisms.)

Task Motivation

Without a stated link between the test organism and the management objective, the toxicity test will fail the "so what?" question.

Key Characteristics of the task

Link the toxicity test process to the ecosystem management objective.

Hypothesise responses and collect data and information

Task Description

Specify the ecosystem end-point.
Specify responses (e.g. species/community abundance, presence of all life-history stages, and/or species survival).
Develop a system-specific stressor-response index (i.e. the concentration at which one of the responses occurs. In a simple toxicity test this could be concentration at which a particular mortality rate is recorded).

Calibrate the sressor-response index.

Task Motivation

The end point is that which is seen to be at risk, and against which risk is evaluated. A endpoint might be "deviation from the natural condition" - and the risk of such a deviated is evaluated.
The responses provide the next level of link between the test species and the ecosystem. By including abundance, life history stages and survival a wider range of species response s can be linked to the ecosystem level of organization. Responses can be qualitatively described e.g "negligible, low, medium, high".
The quantified stressor-response data are the basis of the role of toxicity testing in ERA. These are the results of toxicity tests that are undertaken. This is a key, central action.
Calibration of the stressor response index is the process of quantifying what a specified response - e.g. the concentration at which there is a 95% probability that less than 1% of the population will did - with the qualitative response "e.g ' a negligible chance that population abundances with change".

Key Characteristics of the task

Identify the toxicity tests that need to be undertaken, and once they have been undertaken record the hazard/stressor response data. Link this quantified response to selected ecological criteria such as population abundances, life history stages or species/individual mortalities..

Analyse Information

Task Description

Analyse toxicity-test data

- toxicity test data may be based on a replicated design and analysed using ANOVA,; or an unreplicated design and analysed using Probit or Logit programmes (Parametric statistics), or trimmed Spearman Karber analysis (Non-Parametric statistics).

Task Motivation

Experimental design depends on the for m of analysis selected so all options should be considered.

Key Characteristics of the task

Select appropriate statistical analysis, which then dictates experimental design.

Critically Evaluate Information

Task Description

identify existing information.
Evaluate gathered information.
Consider the variability of the available data, distinguish variability and uncertainty, and decided on requirements for further tests.

Task Motivation

There may be existing toxicity-based information (for example the Water quality guidelines for Aquatic Ecosystems are based on toxicological studies).
Evaluate the data gathered from toxicity-testing - it may be that additional tests are necessary.
Depending on the kinds of testing undertaken a better description of variability may be possible, but there may also remain important areas that are unknown- or areas of uncertainty. If this s the case additional testing may be considered..

Key Characteristics of the task

Collect all existing toxicological information/data.

Characterise exposure

Task Description

Describe experimental exposure.
Model environmental exposure.
- one approach to this is to develop a time series of the stressor in the environment.
Note "leaps of faith".

Task Motivation

The conditions of experimental exposure will determine the way in which experimental results can be calibrated and related to ecosystem conditions.
The actual environmental exposure of the ecosystem to the stressor needs to be modeled so that experimental results can be appropriately applied.

- A time series of the stressor in the environment allows an comparison of the "natural" time series of this chemical variable, with the "altered" time series of the chemical variable of concern. Or if this is a complex effluent, the natural would be zero, and the time series of concentration in the environment would be the measure of deviation for the natural. This allows an assessment of the chance or risk of encountering the selected end-point.

Where there is uncertainty about the ecological significance of measurable end-point, this must be recorded. For example, it may not be known at which point a change in the abundance of a particular species will results in a shift in ecosystem health.

Key Characteristics of the task

Understand the exposure chemistry in the experiment and in the environment
Undertake some sort of modeling that allows an assessment of the duration of particular events in the environment..

Characterise responses

Task Description

Use experimental results, calibration and ecosystem exposure to provide the best possible description of the ecosystem response to exposure.

Task Motivation

This is the integration of experimental toxicological information and exposure modeling - it is the link which allows risk assessment.

Key Characteristics of the task

Link experimental data, exposure modeling and ecosystem understanding.

Characterise risk

Task Description

Describe the likelihood of the chemical hazard causing the selected endpoint (e.g. was is the probability that a range of concentrations or dilutions of a chemical stressor will occurs, and what is the degree of response expected.).

Task Motivation

This is the step of integrating the results of the toxicological testing what is known about exposure and ecosystem response.

Key Characteristics of the task

Apply toxicological data in a risk paradigm.

Established Toxicity Tests And Their Use In Aquatic Risk Assessment - Laetitia Slabbert

GENERAL CONCEPTS REGARDING TOXICITY TESTING

Toxicity is a characteristic of a chemical (or a group of chemicals) that causes adverse effects in organisms. Adverse effects include lethality or those effects limiting an organism's ability to survive in nature. Such effects can be acute or chronic, and refer to the length of time organisms are exposed to toxicants before adverse effects are observed. Acute means a stimulus severe enough to rapidly induce an effect. An effect observed within 96 h or less is usually considered acute. Chronic means a stimulus that continues for a relatively long period of time and refers to long-term effects of small doses and their accumulative effects over time (Slabbert *et al.*, 1998a,b).

Toxicity is determined by means of a toxicity test (also called a toxicity assay, a biological toxicity test/assay, a bioassay or a biotest). A toxicity test is a technique that determines the effect of a chemical/mixture of chemicals using living organisms or cellular/subcellular systems and defined test/laboratory conditions (Slabbert *et al.*, 1998a,b). Most tests are static or static-renewal tests. In a static test solutions are manually added at the start of a test. A static-renewal test is a variation of the static test where solutions are replaced on a predetermined basis, e.g. 24 h intervals. Fresh samples are usually collected for renewal. In flow-through tests samples are mechanically renewed throughout the day.

Toxicity can be measured directly in a screening test by exposing organisms to a single concentration (for example 100% effluent or a water sample). In this case results are expressed as a percentage effect. Toxicity is also measured by observing the responses of organisms to increasing concentrations of a chemical/effluent. This type of application is called definitive testing. The measured effects are usually brought into relationship with the corresponding chemical concentrations or percentages of an effluent using statistical calculations or graphic methods (US EPA, 1991). Acute toxicity endpoints commonly include lethal concentrations (LC's). The LC is the point estimate of the toxicant concentration at which a certain percentage of the test organisms die, e.g. LC_{10} (10% lethality) or LC_{50} (50 % lethality). Chronic toxicity endpoints normally include the no observed effect concentration (NOEC), the lowest observed effect concentration (LOEC) and the effect concentration (EC). The NOEC and LOEC are derived from concentrations tested while the EC is the point estimate of the toxicant concentration at which a certain percentage of test organisms would be affected (growth, reproduction, etc), e.g. EC_{10} (10% effect) or EC_{50} (50% effect).

TOXICITY TESTS

During the past two decades a variety of toxicity tests have been established in South Africa for use in the water field (Slabbert *et al.*, 1998a,b). The tests employ organisms from various levels of the aquatic food chain (fish, frogs, *Daphnia*, protozoa, algae and bacteria) as well as cellular (mammalian cells) and subcellular (enzymes) systems. In addition to acute effects (lethality) sublethal responses such as growth and metabolism are measured. Chronic toxicity is evaluated in terms of genotoxicity/mutagenicity, embryo development (teratogenicity) and cell transformation (potential carcinogenicity). Traditional aquatic chronic toxicity tests, measuring growth and reproduction, are still lacking. The following tests are available:

Traditional acute aquatic toxicity tests

- 96-h fish (*Poecilia reticulata* - guppy and *Oreochromis mossambicus* - tilapia) lethality test
- 48-h water flea (*Daphnia pulex*) lethality test
- 72-h algal (*Selenastrum capricornutum*) growth inhibition test

Rapid acute toxicity tests

- 10-min microbial (protozoan *Tetrahymena pyriformis*; bacterium *Pseudomonas putida*; activated sludge) oxygen uptake inhibition test
- 6-h bacterial (*P. putida*) growth inhibition test
- 30-min urease enzyme inhibition test (selectively sensitive to heavy metals)
- 30-min acetylcholinesterase enzyme test (selectively sensitive to organophosphate and carbamate pesticides

Acute mammalian cell tests

- Buffalo green monkey (BGM) kidney and Chinese hamster V79 cell cloning efficiency tests

Chronic toxicity tests

- Ames *Salmonella typhimurium* mutagenicity test
- Frog (*Xenopus laevis*) embryo teratogenicity test
- Hamster embryo transformation test (potential carcinogenicity)

The toxicity tests are described and discussed in a Water Research Commission (WRC) Report entitled **Development of guidelines for toxicity bioassaying of drinking and environmental waters in South Africa** (Slabbert *et al.*, 1998a). The methodologies are either based on, or similar to, international protocols (e.g. US EPA, EEC, OECD), or have been locally developed. The tilapia lethality test protocol was recently established (Slabbert *et al.*, 1999).

TOXICITY TEST APPLICATION

The type of test applied will depend on the envisaged purpose of an evaluation. Some tests are more suitable for screening purposes, others for regulatory requirements, and others for predictive hazard assessment. Each of these applications have a different set of requirements with reference to precision, test organism/test material choice, exposure time and cost. Each type of test has its own merits when properly used in the correct context.

The South African tests are used for human health as well as aquatic life protection (Slabbert *et al.* 1998a,b). Tests are applied in battery form so that tests can complement each other and thus provide optimal protection. The main focus of the tests is complex (whole) sample (water, effluent, extracts, leachates) testing. Toxicity tests such as the *Daphnia* lethality test, bacterial growth inhibition test, urease enzyme test and the mutagenicity test have been extensively used in routine evaluations of drinking water and drinking water treatment systems (human health protection). Other tests applicable to drinking water include the fish test, mammalian cell culture tests, other rapid assays and the frog embryo teratogenicity test. The fish, *Daphnia* and algal tests have been found to be the most suitable for effluent and surface water testing (aquatic life protection). The rapid tests are also applicable if rapid screening is required or if chemicals such as metals or pesticides are expected to be present. If effluent discharge can impact on drinking water sources, tests for human health protection should also be included. Selected batteries of tests have also been applied to groundwater, extracts of materials/products/sediments and leachates.

Selected toxicity tests have also been used for chemical testing. The acute fish, *Daphnia*, and algal tests have been applied to a number of local pesticide products to obtain ecotoxicological data for international registration purposes. The *Daphnia* test is frequently used to establish the toxicity of chemical products used and/or produced by local industries. The Ames mutagenicity test is applied to products to investigate potential human health effects.

Fish, *Daphnia* and algal tests have been used in a study to establish site-specific guidelines for copper and manganese. *Daphnia* tests have also been applied for a number of years in metal speciation studies.

TOXICITY TESTS AND AQUATIC RISK ASSESSMENT

Toxicity tests are often used for effects assessment during the first and second formal stages of risk assessment, namely problem formulation (or hazard assessment) and information analysis. (Murray and Claassen, 1999). The assessment endpoints (e.g. aquatic organisms and characteristics likely to be affected, position in food chain, value of organism, etc) will determine which toxicity tests will be most applicable. It is important that the test organisms are representative of the aquatic species of concern. Toxicity test measurement endpoints of importance include lethality, growth and reproduction.

Where possible existing ecotoxicity data for single chemicals will be used in aquatic risk assessments. However, if data is limited or lacking, or specific species are of concern, appropriate local tests can be applied. Locally established toxicity tests that are applicable for aquatic risk assessment include the fish and *Daphnia* lethality tests, the algal and bacterial growth inhibition tests, and the frog embryo lethality/teratogenicity test. Fish, *Daphnia* and algal tests are also used by other countries for this purpose. All the test organisms used in the local tests, except guppies (surrogate test organism), are indigenous and are, therefore, representative of some of our aquatic organisms.

Toxicity testing usually follows a stepwise, tiered approach, progressing from simple short-term tests to more complex and sophisticated longer-term tests based on the results of previous studies. Criteria and logic about issues such as severity of effects are used to move from one tier to the next. The tests mentioned above are typical examples of simple short-term tests. We currently lack short-term and the more traditional long-term chronic toxicity tests, as well as bioconcentration tests. Following a tiered approach, simulated or experimental microcosm and mesocosm studies maybe used at an intermediate level before commencing with actual field studies. After each tier an assessment is made in the light of the exposure data (Rand and Zeeman, 1998). Higher tier testing is conducted if the previous assessment indicates a low margin of safety and a potential for risk. Biomarkers in fish are currently receiving attention in a WRC project, and should be useful attributes to field studies.

Whole Effluent Toxicity (WET) testing (and other complex sample testing) is used to identify hazard (inherent properties of contaminants to cause harm), and thus fit the first stage of risk assessment. Further stages of an aquatic risk assessment require additional information, which can be obtained via the tiered approach. A toxicity identification evaluation (TIE) is seen as part of the tiered approach.

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Issues Relevant to Conducting Exposure Assessments Within Ecological Risk Assessments in South Africa

- Dr Peter Wade

1. Introduction
2. Exposure Assessment Overview
3. Planning an Exposure Assessment
4. Exposure characterization using model simulations
5. Gathering and Developing Data for Exposure Assessments
6. Developing the Exposure Profile
7. References

1. Introduction

1.1 Terms of Reference

This report was commissioned as a contribution to identify existing water resource assessment methods for ERA.

1.2 Objectives of the report

The report encapsulates the issues relevant to conducting the Exposure Assessment module of the Ecological Risk Assessment process.

1.3 Scope and limitations

The study was restricted to issues of exposure assessment as detailed in publications by the US EPA, and as published in peer-reviewed journal articles in *Environmental Toxicology and Chemistry*.

The most sophisticated exposure protocols deal with human health exposure assessments. Information was drawn from these documents, and transformed to fit the ecological risk assessment paradigm.

1.4 Sources of information

The sources of information are principally documents available on the US EPA website. Case studies were taken from the *Environmental Toxicology and Chemistry* journal.

2. Exposure Assessment Overview

Exposure characterisation describes the contact (or co-occurrence) of stressors with ecological receptors, and is based on measures of exposure and of ecosystem receptor characteristics [2].

The Exposure Characterisation module discussed in this document rests in the "Analyse Information" box in Figure 2 of Murray and Claassen (1999). This is the second formal stage of the Ecological Risk Assessment, the first being the Problem Formulation phase.

2.1 Inputs and Outputs of Exposure Assessments

Inputs

The Exposure Assessment is performed after effects assessment end points are decided upon, and after responses have been hypothesised [2]. These end-points are the definitive measures that scientifically and ecologically represent broader management concerns, and are therefore a significant input into the Exposure Assessment phase.

Scenarios under which exposure to receptors might occur are decided upon in the Problem Formulation phase, and are fed into the Exposure Assessment phase.

In a tiered ecological risk assessment, the scope and level of detail of the current Exposure Assessment iteration must be made clear to the personnel undertaking the Exposure Assessment.

Data Quality Objectives (DQO's) are also input into the Exposure Assessment phase.

The nature or Exposure assessment output information should be decided beforehand, because it needs to be dovetailed with Effects assessment information in the Risk Characterization phase. Therefore, an input into the Exposure Assessment phase will be the nature of the Effects data (units of intensity, timing, duration, spatial extents) that the Exposure assessment will be compared with in the Stressor-Response profile emanating from the entire ecological risk assessment.

Outputs

The final output of the Exposure Assessment phase of the Ecological Risk Assessment is the Exposure Profile. This profile identifies the receptor and the pathways by which a stressor moves from source to receptor. The magnitude of contact or co-occurrence of stressor and receptor is described in terms of the dimensions of intensity, and spatial and temporal extent.

Variability and uncertainty estimates of all dimensions of accompany the Exposure Profile.

2.2 Characteristics of Exposure Assessment Methodologies

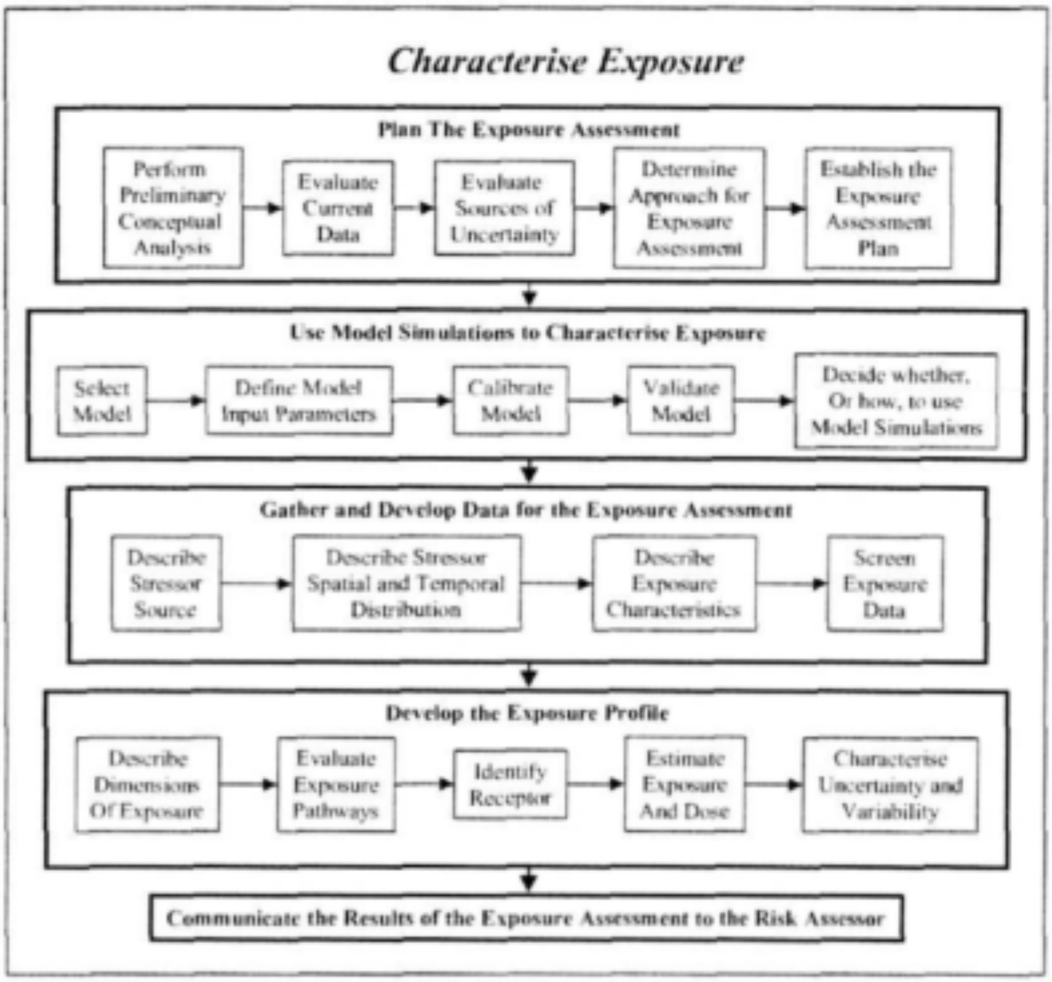
Exposure assessments can be Prospective, in which an exposure is estimated as a result of a future event, and Retrospective, in which the impacts of past exposures are assessed.

Exposure assessment methodologies need to be internally consistent. There is sometimes difficulty when the scope of the Exposure Assessment covers ambits of different regulatory frameworks [4].

The methodologies need to be based on sound scientific knowledge, methods and practices. Exposure assessors need to keep up with latest developments in science, and to readily adopt new concepts and methodologies as they become available [4].

Exposure Assessment studies can be Site- or Facility-specific, e.g. within the United States' CERCLA act, Superfund Amendments and Reauthorisation Act, or they can be chemical-specific, such as Exposure assessments associated with Pesticide usage, or associated with setting Water Standards or to deal with Toxic Air Contaminants

2.3 Basic Elements of Exposure Assessment in Ecological Risk Assessments



3. Planning an Exposure Assessment

This phase is the link between Problem Formulation and Exposure Assessment. The Exposure Assessor should be involved in both phases.

The two products of the planning phase are the Work Plan, or WP, and the Sampling and Analysis Plan (SAP) [8].

The following actions are necessary to define the Work Plan.

3.1 Performing Preliminary Conceptual Analysis

The purpose of the exposure assessment should be very clear. Exposure assessments can be used in risk assessments, or for determination of status and trends, or for epidemiological studies [1,2].

Knowledge of the scope of the assessment is critical. Scope can be understood as "comprehensiveness", for example, where exposure to multiple chemicals, perhaps considering only certain significant chemicals may yield the same risk estimates as a very detailed analysis.

Knowledge of the purpose of the risk assessment usually helps define the scope [1].

Risk assessments usually follow a tiered approach, in which the scope if the assessment is narrowed upon successive iterations [4].

The level of detail, or depth of the assessment is measured by the amount and resolution of data used, and the sophistication of the analysis employed [1].

3.2 Evaluating Current Data

Data needs are determined in the Problem Formulation step. Current data must be compiled to avoid duplication, and to assist in the formulation of the modelling and sampling plans.

3.3 Evaluating Sources of Uncertainty

Uncertainty evaluation occurs throughout the analysis phase. At all times, efforts must be made to establish what is known, and what is not known, about the stressors and receptor contacts.

Sources of uncertainty are tabulated in Reference [2a] pg 58.

3.4 Determining the approach for the exposure assessment

The intended use and acceptable uncertainty will generally favour one approach to quantifying exposure over others. Some approaches include the Point of contact approach; the Scenario evaluation approach; and the Reconstruction of dose approach [1].

3.4.1 Scenario planning

An exposure scenario is a set of behaviours that describes the interaction of stressors and receptors in an ecosystem [4]. Scenarios are received from the Problem Formulation phase of the Ecological Risk Assessment. The planning phase of the Exposure Assessment develops the assessment according to the input scenarios.

3.4.2 Simplifying assumptions

Some simplifying assumptions that can be used are: [4]

- Exclusion of factors that have relatively small impacts
- Exclusion of factors that may significantly reduce exposures, but are highly uncertain.
- Assumption of consistent parameter values over considerable periods of time.
- Application of similar assumptions to all locations in the study.

3.5 Establishing the exposure assessment plan

The Exposure Assessor determines the scope, level of detail, and approach for assessment, and translates these into a set of objectives. The objectives are the foundation for the exposure assessment plan [1].

In developing the exposure assessment plan, the Assessor adheres to DQO's and to requirements for co-located sampling of field sites, and establishes confounding factors, e.g. changing field conditions and unexpected nature of contaminants (e.g. more contaminated than expected).

3.5.1 Planning an exposure assessment as part of a risk assessment

Exposure information must be clearly related to hazard identification and to dose-response (or exposure response) relationships. Toxic endpoints in the Effects Assessment phase guide decisions on collection and analysis of exposure information. Other aspects of hazard identification include limited versus repeated exposures, dose-rate considerations, reversibility of toxicological processes, and composition of exposed population [1].

3.5.2 Establishing the modelling strategy

Modelling is used to estimate pollutant concentrations at exposure points. Modelling helps to refine questions.

The following are the actions to establish the modelling strategy:

- Setting the modelling study objectives
- Characterization and model selection
- Obtaining and installing the computer code
- Calibrating and running the model
- Model validation

3.5.3 Establishing the sampling strategy

The product of this step is the Sampling and Analysis Plan (SAP) [8].

The following issues are dealt with in the SAP.

- Data quality objectives
- Sampling plan
- Quality assurance samples
- Background levels
- Quality assurance and quality control (QAQC)
- QAQC for previously generated data
- Selection and validation of analytical methods

4. Exposure characterization using model simulations

Modelling was recommended by US EPA regulatory workshops ARAMDG and the FIFRA Exposure Modelling Work Group as potentially valuable tools with respect to pesticide registration. The US EPA Office of Pesticide Programs proposes greater use of models as opposed to field measurements.

If the decision is made to base the Exposure Assessment entirely on analytical results, the modelling phase is recommended to assist in refining the questions to ask.

Modelling can tell what data are missing, and what the most important data are (sensitivity analysis).

4.1 Model selection

Common models used in risk assessments are Surface Water Models and Contaminant Fate and Transport Models (Groundwater and vadose-zone; Atmospheric fate and transport; Inter-media (multi-media) Fate and Transport).

4.2 Model input parameters

Model input parameters include:

- Field site measurements – measurements taken from field site during experimental study
- Best available nearby sources - E.g. temperature data from nearby weather stations
- Environmental fate summaries by producers, e.g. Physicochemical properties such as Koc and Henry's law K
- Partitioning coefficients, E.g. Kd in soil and sediment
- Half-lives from aerobic and anaerobic metabolism studies
- Plant uptake efficiency factors

4.3 Model calibration

Model calibration is essential. In one case of pesticide fate and transport prediction, Solomon et al. [5] found order of magnitude errors using uncalibrated pesticide fate models.

Models should be calibrated in phases, with calibration of chemical fate models preceding calibration of transport models, as in reference [5].

Included in the model calibration should be a sensitivity analysis, in which physicochemical parameters are varied to determine the relative influences on predicted fate and transport.

4.4 Model Validation

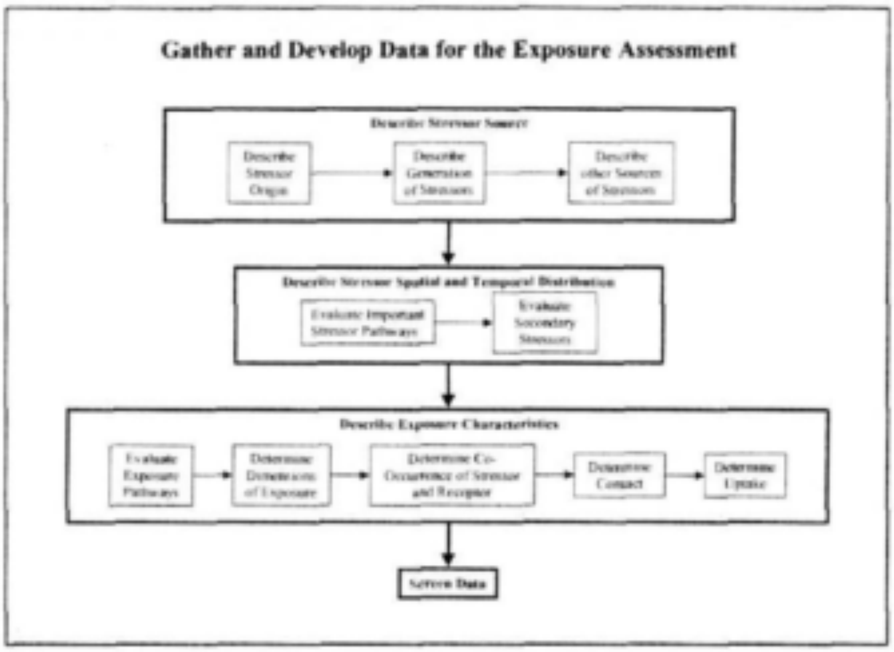
Models should be validated with respect to field measurements, if possible [4, 8].

4.5 Decision on whether, or how to use model simulations

Model validation problems can lead to the decision not to use models in the study.

5. Gathering and Developing Data for Exposure Assessments

The information generated in the exposure assessment depends on the approaches selected in the planning stage. Examples of types of measurements to characterise exposure-related media and parameters can be found in reference [1], pp 75-78.



5.1 Obtaining chemical concentration information

Chemical concentration information can be obtained by direct measurement, or by using transport and dispersion models.

Determining concentration information by measurement

If concentration information is obtained by direct measurement, the measurements should be taken as close to the suspected point of contact of stressor and receptor as possible, as certainty in data generally decreases with distance from this point [1].

While most exposure assessments are source-based, receptor-based exposure assessments are more relevant to risk estimates. In receptor-based exposure assessments, exposure data is measured directly at the site of action, e.g. metal loading on fish gills, as opposed to the traditional method of predictive exposure assessment (measure at source, model resulting impacts) [4].

If concentrations in the environment cannot be directly measured, as is the case with prospective risk assessments, they can be estimated by using related measurements and models [1]. In this case, source characterization data are used as input into transport and transformation models (environmental fate models). In exposure assessments, environmental fate models are used extensively to calculate point concentrations, concentrations in different environmental media, distribution of contaminants over space and time [1].

Selection of models for environmental concentrations

In selecting a model for use in an exposure assessment, the prime consideration should be the objective and scope of the exposure assessment. The assessor should consider the objectives of the study, the technical capabilities of the models, how readily the models may be obtained, and how difficult each is to use [9].

5.2 Describing Stressor source

Source identification is important, as it assists in finding when and where stressors will be found. Also many management practices will focus on modifying the source, e.g. biological stressors (nonindigenous organisms), in which case it is critical to identify the source of the stressors [2].

The stressor source can be defined as the first component of exposure pathway [2], or the place where the stressor is released or the action that produces the stressor [3]. Sometimes the original source no longer exists, in which case the source is then considered to be the current origin of stressors, e.g. contaminated sediments.

In probabilistic ecological risk assessments, the probabilistic intensity/duration profile is used. This is the most sophisticated form of source description [3].

A list of Ecological problem areas, stressors and sources can be found in reference [6] pg 2.3-15, Table 2.3.1.

5.2.1 Describe Stressor Origin

Is the source one of the following? [2]

- Anthropogenic Source
- Natural Source
- Point Source
- Diffuse Nonpoint Source

5.2.2 Describe generation of stressors

To describe the generation of stressors, one aims for quantitative measurements or modelling information, but sometimes it is only possible to yield a qualitative description.

Questions to ask when generating stressor information are described in reference [2a], Page 26.

The following actions are required to describe generation of stressors:

- Describe type of stressor (Chemical, Physical, Biological)
- Describe Intensity (Chemical - Dose or concentration; Physical - Magnitude or extent of physical disruption; Biological - Density or population size)
- Describe mode of action - How stressor acts on receptor.
- Describe Location
- Describe initially receiving environmental medium
- Describe timing and duration

- Describe influences of other constituents
  - Transport
  - Transformation
  - Bioavailability

5.2.3 Describe Other sources of stressors

Options to describe other sources of stressors are (in order of complexity) [2]:

- Focus only on the source under evaluation, and calculate incremental risks attributable to that source.
- Consider all sources of a stressor and calculate the total risks attributable to that stressor. Relative source attribution is a separate step.
- Consider all stressors influencing an assessment endpoint and calculate the cumulative risks to that endpoint.

If secondary stressors are identified that are of concern, exposure and effects analyses are conducted iteratively [2].

5.3 Describing Stressor spatial and temporal distribution

Once the source of the stressor has been identified and described, the next step is to describe distribution of stressor in the environment [2].

Measurements, models, or a combination of the two can describe this distribution. Retrospective risk assessments primarily use measurements. Risk assessments of intended activities usually require predictive modelling.

The description of the environmental distribution of stressor can assist in estimating contact or co-occurrence of stressor with organisms. Sometimes the extent of contact is known *a-priori*, and describing the distribution helps identify potential sources, and helps to ensure that all-important exposures have been addressed.

5.3.1 Evaluate Important Stressor transport pathways

The route that the stressor takes to the receptor is important. Some physical stressors, e.g. flooding, burial, etc, may not, however, involve pathways. In this case, the secondary stressors are of interest [2].

Some important pathways are summarised in reference [2a] pg 64.

Stressor pathways can take the following forms, and determining them constitute the following actions:

Environmental Partitioning (chemical stressors) - Assessment of media between which stressor will partition.

- Determine Physicochemical properties of stressor
- Assess Ecosystem characteristics (media) influencing transport/partitioning
  - Guided by physicochemical properties of stressor.
  - Chemical mixtures may change in composition along flow path due to differential partitioning of constituents.
- Evaluate Fate and Transport of stressors

Physical attributes (physical stressors) - E.g. size of suspended solids.

Physical stressors that eliminate parts of ecosystems, e.g. logging or draining wetlands, may not have a transport pathway. In this case secondary stressors must be evaluated.

- Assess Ecosystem characteristics influencing transport

Dispersion (biological stressors)

Assess the modes of propagation - Propagation of biological stressors can be via diffusion, which is a gradual spread from the source by reproduction and motility, or jump-dispersal, which consists of erratic spreads over time, usually via a vector, e.g. shrimp virus, cosmos plant, etc.

Assessment of the modes of propagation of biological stressors involves the following actions:

- Assess availability of vectors
- Assess natural dispersal attributes
- Assess habitat or host needs
- Assess ecosystem characteristics influencing transport (survival and reproduction)
  - Substrate preferences
  - Habitat needs
  - Reproduction rates
  - Predators
  - Competitors
  - Diseases

5.3.2 Evaluate secondary stressors

Secondary stressors can be formed by biotic or abiotic transformations, and may have more, or less, impact than the primary stressor [2].

Some examples and guidance can be found in Reference [6] pg 2-3, 13-14.

Secondary Stressor evaluation must be coordinated firmly with the ecological effects characterisation. If secondary stressors are important, the ecological risk assessment can become iterative [2].

Secondary stressors can have the following characteristics:

- Chemical (Note - in the field it may be difficult to distinguish between transformation and transport).
  - Transformation, e.g. degradation of oil constituents by micro organisms
  - Metabolite, e.g. Mercury is microbially transformed to methyl-mercury.

- Degradation products
  - Biochemical
  - Geochemical
- Complex interactions, e.g. Dissolved oxygen decrease due to increase in plant primary production due to injection of nutrients.
- Transport, e.g. volatilisation of oil constituents

- Physical (E.g. removal of riparian vegetation can increase nutrients, stream temperatures, sedimentation and stream flow).
  - Formation
  - Transport

- Biological
  - Migration and displacement

5.4 Describing Exposure Characteristics

In order to adequately describe the exposure characteristics, the Work Plan (WP) and Sample Analysis Plan (SAP) must have been completed in the planning stage [8].

Exposure characteristics include the extent and pattern of co-occurrence or contact between a stressor and a receptor. The data emanating from this phase has to describe the intensity and extent (spatial and temporal) of exposure such that the risk assessor may develop a stressor-response profile. This information must be in the form that is coherent with that of the data from the Effects Characterization.

The terms of the exposure characteristics description depend on the hypothesized stressor effects on the receptor.

The outputs of this phase are exposures described in terms of intensity, time and space, in units that can easily be combined with the Effects Assessment. The assessor should be able to distinctly trace the paths of stressors from source to receptors.

In probabilistic risk assessments, estimates should be "most likely" as opposed to "worst-case" scenarios, which is often the case in single ratio estimates [6].

The personnel executing this phase of the exposure assessment should be aware of potential confounding factors, e.g. changing field conditions and unexpected nature of contaminants (e.g. more contaminated than expected) [8].

5.4.1 Evaluate Exposure Pathways

These activities involve determining the possible routes by which a stressor might reach a receptor. This includes evaluation of data on: [7]

- Environmental fate/transport of contaminants
- Ecological characteristics at site (habitat and potential receptors)
- Magnitude and extent of stressor distribution (spatial and temporal scales)

5.4.2 Determine Dimensions of Exposure

In determining these dimensions, the assessor must strictly adhere to Data Quality Objectives (DQO's) defined in the planning phase, and to requirements for co-located sampling of field sites [8].

Relevant dimensions are intensity or magnitude of stress; temporal, which include duration, frequency and timing, and spatial extent - local, regional, global, habitat-specific or ecosystem-wide, or movement of the stressor through the environment [2].

The following table summarizes the types of dimensions corresponding to the types of stressors:

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Stressor Type</td></tr>
<tr><td>Chemical</td><td>Physical</td><td>Biological</td></tr>
<tr><td colspan="2">Intensity</td><td>Dose or concentration</td><td>Magnitude or extent of physical disruption</td><td>Density or population size</td></tr>
<tr><td colspan="2">Spatial</td><td>Fate and Transport</td><td>Movement of physical structures</td><td>Life history dispersal characteristics</td></tr>
<tr><td rowspan="3">Temporal</td><td>Duration</td><td>How long does stressor persist? Does it bioaccumulate?</td><td>Irrecoverable habitat alteration?</td><td>Will stressor reproduce and proliferate?</td></tr>
<tr><td>Frequency</td><td colspan="3">Isolated, episodic, or continuous?
Subject to natural daily, seasonal or annual periodicity?</td></tr>
<tr><td>Timing</td><td colspan="3">Timing and sequence of exposure events.
When does it occur in relation to critical organism life cycles or ecosystem events?</td></tr>
</table>

5.4.3 Determine Co-occurrence

The distribution of the stressor is compared with the distribution of the receptor, e.g. using maps [6].

To effect this, the stressor and receptors must be characterized on similar spatial and temporal scales [8].

5.4.4 Determine Contact

Contact can be understood as Potential Dose. This is the amount ingested, inhaled, or applied to skin. If it is assumed that a chemical is well mixed (i.e. receptor doesn't occupy a microenvironment in a heterogeneous system), contact can be quantified as environmental concentration. This assumption is commonly used for respired media, e.g. water or air.

The following are important measures in determining contact:

- Amount of stressor in medium
- Behaviour of receptor
- Duration of contact through:
  - Observation and survey data
  - Other estimates of duration of contact
  - Frequency distributions

The US EPA is moving towards measurements of actual exposure and frequency distributions of exposures to populations [4].

5.4.5 Determine Uptake

Uptake can be understood as the Internal dose. It can be estimated from the potential dose via absorption factors and bioavailability estimates. It can also be estimated using pharmacokinetic models.

There is significant possible interaction between the factors, e.g. to determine the concentration of the bioavailable form of a metal, the ecosystem characteristics need to be known in order to predict the chemical form of the metal.

Uptake is often assessed by modifying an estimate of contact with a factor indicating the proportion of the bioavailable form of stressor absorbed.

The following actions are included in determination of uptake of a chemical:

- Determine Physicochemical properties of stressor
- Assess Ecosystem characteristics (media) influencing transport/partitioning
  - Guided by physicochemical properties of stressor.
  - Abiotic factors may increase or decrease the amount of stressor contacted and taken up by receptors (e.g. by modifying behaviour).
  - Chemical mixtures may change in composition along flow path due to differential partitioning of constituents.
- Evaluate Permeability of Stressor/Receptor barrier
- Evaluate condition (behaviour) of receptor
- Use Pharmacokinetic models
- Use Biomarkers
- Use Tissue residues or Body Burdens

5.5 Screening Data

Data types emanating from the Exposure Assessment must dovetail with the procedures in the Effects Assessment.

The following considerations were published by Solomon et al [5], when screening data

In the case of discrete exposure data, one might have to normalize for irregular sampling. Often sampling has not occurred for periods where concentrations are expected to be very low. Solomon et al. [5] used "boxcar moving average" or "window technique" to normalize data for pesticide runoff exposure estimates.

If environmental sampling data does not have the same period as those used in the Effects Assessment, it can be transformed to an approximation of the required information by assigning time windows, or "boxcars" to instantaneous observations, that are 4-d and 21-d wide. A data set of duration (n) days will yield (n-3) 4-day averages, and (n-20) 21-day averages [5].

6. Developing the Exposure Profile

The final product of the Exposure Assessment is the Exposure Profile, which is a summary of w
Assessor must state and defend how dimensions of exposure were evaluated. Variability in receptor attributes or stressor levels must be described.

6.1 Concepts of Exposure, Uptake and Dose

6.1.1 Contact

Contact, in the case of chemical stressors, is understood as chemicals crossing physiological boundaries. Two types of contact can occur [1]:

- Intake, being inhalation or ingestion (eating or drinking) of the bulk medium containing the chemical.
- Absorption, in which the chemical is removed from carrier medium, and in which the medium is not absorbed at same rate as chemical

6.1.2 Exposure

Exposure is related to the condition of the chemical contacting the outer boundary of the receptor. The chemical concentration at point-of-contact is the exposure concentration.

Exposure can be described over period of time as the time-dependent profile of exposure concentration. The area under the curve is the magnitude of the exposure in concentration-time units [1].

6.1.3 Dose and Bioavailability

There are a number of different interpretations of dose:

Applied dose

The applied dose is the amount of chemical at the physiological barrier, which is available for absorption. Sometimes one can calculate relationship between the applied dose and the internal dose (i.e. through Bioaccumulation Factors, or BAFs).

Potential dose

Total potential dose is the amount of chemical in contact with the receptor. This concept is useful if the exposure is to discrete amount, e.g. ingestion of a matrix or application of a chemical to the epithelium [1].

Internal dose

The internal dose is the amount of chemical absorbed that is available for interaction with biological receptors. In order to calculate the internal dose one needs to have data on absorption, metabolism, storage, excretion or internal transport of a chemical. The amount of chemical transported to the organ (site of action) is the internal dose.

The delivered dose may be small part of the internal dose. The bioactive dose may be small part of the delivered dose. Pharmacokinetics tell us the relationships between delivered dose and effective dose [1]. Most current risk assessments of environmental chemicals use dose-response relationships based on potential (administered) dose, because pharmacokinetic studies have not yet been done on the specific receptors.

Bioavailability and chemical speciation

When calculating the effective dose to aquatic organisms, or in determining the bioavailable fraction of a chemical in blood plasma, it must be noted that the total concentration of the chemical in the environment is not always the concentration of the chemical in the form necessary for uptake. Chemical speciation calculations can assist in understanding how much of the applied dose is bioavailable.

6.2 Relationships of exposure and dose to risk

6.2.1 Individual risk

Individual risk is the risk of adverse effects borne by a single individual in a population [1]. While human health exposure assessments focus almost always on individual risk, this risk formulation is rarely used in ecological risk assessments.

6.2.2 Population risk

Population risk refers to the estimate of the extent of harm for the population or subpopulation of the receptor [1].

6.2.3 Risk descriptors

Exposure and dose information developed as part of an exposure assessment are used in constructing risk descriptors. A typical risk descriptor is the proportion of a population thought to experience more than a threshold level of risk. Sometimes data is evaluated for both highly exposed sub-populations, and highly sensitive sub-populations.

6.3 The role of exposure scenarios in exposure assessment

Exposure scenarios are tools to help the risk assessor develop estimates of exposure, dose and risk. Estimates derived from scenarios can be used to develop a series of exposure and risk descriptors. Exposure scenarios can often assist risk managers in estimating possible impact of certain mitigation or control options [1].

Scenarios may have a limited ability to accurately characterise exposures, and scenarios may be developed with policies in mind that are not readily apparent to the risk manager. There is a need for very clear communication on the dynamics underlying the scenarios [4].

Scenarios can be used to quantify exposure and dose; as input of estimates into risk descriptors, and as a tool for option evaluation.

Reference [1] describes general methods for estimating exposure and dose, and details using estimates for developing descriptors

6.4 Describing dimensions of exposure

The first practical step in developing the exposure is the description of the dimensions of exposure, i.e. the Intensity, the temporal extent (duration, frequency and timing and sequence of exposure events), and the spatial extent.

6.5 Evaluating Exposure Pathways

In this step, the following actions are performed:

- Describe pathways
- Verify Pathways
- Rank Pathways by contribution to total exposure.

6.6 Identifying Receptor

The receptor of the stressor should be identified, in order to assist in estimating exposure.

6.7 Estimating exposure and dose

Exposure assessments can be from the perspective that begins with a biological receptor, or it can be from the complimentary perspective of the contaminant emission into the environment, or observation that contamination exists at certain sites [4].

In the latter Emission-based exposure calculations, exposure is estimated using concepts of contaminant fate and transport, or by use of monitoring data for retrospective risk assessments. Models are usually used, based on monitoring data [4].

In the former Receptor-based exposure calculations, the exposure data required are as follows:

Point-of-contact data

These are concentrations determined or inferred at the point of contact of stressor and receptor.

Reconstruction of Internal Dose

Exposure is estimated after it has taken place (average past exposure rate). Measure internal body indicators (body burdens or biomarkers) and back-calculate dose:

- Potential dose for intake processes (inhalation and ingestion)
- Internal dose for uptake processes (dermal route)
- Internal dose for intake processes (respiratory and oral)

Estimate from scenario evaluation

Characterization of concentrations of chemicals and time of contact are usually done separately.

Chemical concentration characterization

Estimates of exposure concentration are typically accomplished indirectly by measuring, modelling or using existing data on concentrations in bulk media, as opposed to at point of contact. Assuming the total concentration in the bulk medium is the exposure concentration is a source of potential error, and must be discussed in the uncertainty analysis.

Exposure time characterization

This involves frequency and duration exposure estimates. Exposure time characterisation is usually done indirectly using demographic data, survey statistics, behaviour observation, activity diaries (human exposure), activity models, and assumptions about behaviour in the absence of more substantive information [1].

6.8 Issues of Data Handling

6.8.1 Use of data in making inferences for exposure assessments

The following issues need to be resolved before data can be used in exposure assessments:

- Relevance of data for exposure assessment
- Adequacy of data for exposure assessment
- Evaluation of analytical methods
- Evaluation of analytical data reports (evaluation of censored data sheets and of blanks and recovery).
- Combining measurement data sets from various studies
- Combining measurement data and modelling results

6.8.2 Dealing with data gaps

The following strategies may be used to deal with data gaps [1]:

- Collect new data
- Narrow scope of assessment
- Use more conservative assumptions
- Use models to estimate values and check on how conservative assumptions are
- Use surrogate data

6.8.3 Strategies for Difficult Data Analyses.

The following strategies are described in Reference [5].

Insufficient monitoring data
Relatively few values, or sample time info not available.
Distributions plotted, and 90th percentile concentrations obtained by regression.

Datasets non- log-normal, or of seasonal sampling
Estimate non-parametrically from time-weighted data.

Large and complete datasets

Normalize for irregular sampling. Often sampling has not occurred for periods where concentrations are expected to be very low. Solomon et al. (1996) used "boxcar moving average" or "window technique" to normalize data.

Assign time windows, or "boxcars" to instantaneous observations, that are 4-d and 21-d wide. A data set of duration (n) days will yield (n-3) 4-day averages, and (n-20) 21-day averages.

Sort "normalised" exposure values in decreasing order of concentration.

Plot as a function of cumulative time represented by samples. Determine probability of exceedance from percentiles of the data with reference to total time, and without using regression. Because 4- or 21-day averages represent an equal interval of time, no time weighting is required.

6.9 Characterizing Uncertainty and Variability

Analysis of uncertainty is an integral part of the Exposure Characterization [6].

6.9.1 Variability

Variability is a natural spread of a variable, as opposed to uncertainty, which is lack of knowledge of the true value of a variable.

Variability can be expressed as Probability-Density Functions, as Cumulative-Distribution Functions, or as Point estimates on Distribution Functions.

6.9.2 Types of uncertainty

There are four types of uncertainty.

- Model uncertainty
- Scenario uncertainty
- Parameter uncertainty
- Within-population-variability versus estimate uncertainty

6.9.3 Uncertainty handling

- Identify key assumptions
- Discuss magnitude of sampling / measurement error
- Identify significant variables in sensitivity analysis
- Identify uncertainties that can be reduced by:
    - Sensitivity analysis
    - Analytical uncertainty propagation
    - Probabilistic uncertainty analysis
    - Classical statistical methods

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Appendix D: Capacity development

Participants of ERA lectures presented at the Biomonitoring short course (Rhodes)

	Females		Males	
	Black	White	Black	White
1999	3	7	11	12
2000	6	8	13	11

Government officials participating in the 3-day course on ERA presented in Lesotho, August 2001

Bulane L
Hlabana M
Hoohlo Q
Lesemane L
Linko T
Majara N
Mabote M
Mafatle
Maliehe L
Mahlaha
Makuta M
Malachamela F
Maloi M
Matlanyane T
Matli M
Matsepe K
Moeletsi
Mohapeloa M
Mokose M
Molapo L
Molapo M
Moonyane
Moreboli M
Moremoholo M
Ntlale
Nkotsi I
Nonyana M
Puling B
Sekamane M
Senoko T
Sethati M
Setsabi I
Thamae
Thamae L
Thamae S
Tjela M
Tsasanyane T
Tsotetsi L
Williams T

Other related WRC reports available:

Feasibility of using a risk-based approach to set integrated environmental objectives for the protection of water resources

Jooste S • MacKay HM • Scherman P-A • Muller WJ

The report produced comprises 3 sections. The first section assesses the feasibility of using a risk-based approach for setting integrated environmental objectives for the protection of water resources. The second and third parts are the proceedings of workshops. **Part 2** deals specifically with the use of risk-based objectives (RBO) in water resource management, and **Part 3** covers the findings of a workshop where RBOs were used to set flow requirements for rivers.

In **Part 1**, against a background of resource quality objectives (RQOs), the concept of risk, and the feasibility of using RBO for the management of RQO is examined. This necessitates the integration of risk objectives and risk criteria with ecological and management objectives.

The proceedings of the workshop on RBOs in water resource management highlighted the need for information on stressor-response relationships. The experimental work is normally done on a single species using a single stressor (e.g. toxin, etc). The result is then extrapolated to ecosystem scale, often involving other species. Without the knowledge of the stressor-response relationship, it is difficult to know how much confidence to place on the results.

In **Part 3**, the proceedings of the workshop using RBO to set flow requirements tested 2 methods of setting the quantity component of the ecological reserve. These were:

- The *less frequency/assurance* method
- The *less depth* method.

The former generates different assurances of maintenance flows for different ecological management classes (EMC), i.e. maintain the depth, velocity, etc., but alter the assurance. The latter gives a way of motivating for higher or lower flows for different EMCs.
These were used on a range of rivers for which data were available, and there was no generic preference for one or the other as they offer different products.
Finally, two papers (by Hughes and O=Keeffe respectively) make a first attempt at developing a framework for defining the different levels of flow-related stress for instream fauna

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