# A FURTHER INVESTIGATION INTO USING A RISK-BASED APPROACH FOR SETTING INTEGRATED ENVIRONMENTAL OBJECTIVES FOR THE PROTECTION OF WATER RESOURCES

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Report to the Water Research Commission
KV No:  154/04
ISBN N0.:  1-77005-229-1

OCTOBER 2004

# FINAL REPORT TO THE WATER RESEARCH COMMISSION
# JANUARY 2000 - DECEMBER 2001


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**Contract K8/350** entered into between the Water Research Commission and the Institute for Water Research, Rhodes University.

# EXECUTIVE SUMMARY

During 1998 the Water Research Commission (WRC) funded a project to investigate the feasibility of using a risk-based approach for setting Resource Quality Objectives (RQO) for the protection of water resources (Jooste *et al.*, 2000). The investigation intended to provide direction for future, more detailed research in order to support, develop and implement the protection-based classification system for water resources, as undertaken by the Department of Water Affairs and Forestry (DWAF) in order to meet the objectives of the National Water Policy (DWAF, 1997) and National Water Act (No. 36 of 1998). This project formed Phase I of the risk-based objectives study, with the findings of the current report being Phase II. Both Phases I and II attempted to investigate and evaluate risk-based methodologies, which could effectively incorporate the uncertainty and variability inherent to biological systems and biological data. While Phase I reviewed research into setting objectives for water quantity, water quality, habitat integrity and biotic integrity requirements of water resources; investigated possible approaches to incorporate risk concepts into the protection of water resources, and identified future research directions; Phase II focussed on linking stressors and responses to an identifiable end-point, and integrating stressor responses for co-occurring stressors.

The primary focus of Phase II was therefore a specialist workshop held in February 2000, with the overall aim of linking stressors and associated responses to an identified end-point, and integrating stressor responses for co-occurring stressors. The stressors considered were changes to flow (water quantity), water quality and habitat. The following discussion points were identified and defined to lead the workshop:

- If the aim is to integrate stressor effects, a common end-point (e.g. the sustainability requirements of the Ecological Reserve) must be defined.
- How should stressors be defined so that a given response can be linked to the stressor stimulus, and can the response be related in some way to the identified end-point?
- What techniques, procedures or protocols already exist to determine stressor exposure and effects?
- Can risk-based objectives (quantitative or semi-quantitative) reasonably be derived for use within the present regulatory framework?

Outcomes of discussions surrounding these identified questions are detailed in Sections 3.2 to 3.5 of the report, with Chapter 4 listing identified gaps and recommendations.

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# GLOSSARY

This glossary of terms is amended from Jooste *et al.* (2000).

| | |
|---|---|
| **Acute effect (exposure) value** | The concentration at and above which statistically significant acute adverse effects are expected to occur (DWAF, 1996). |
| **Analysis** | A formal, usually quantitative, determination of the effects of an action (as in risk analysis and impacts analysis) (Suter, 1993). |
| **Assessment** | The combination of analysis with policy-related activities such as identification of issues and comparison of risks and benefits (as in risk assessments and impacts assessment) (Suter, 1993). |
| **Biodiversity** | The diversity of living things found in the natural world. The concept usually refers to the different species, but also includes ecosystems and the genetic diversity within a given species (Bush, 1997). |
| **Criterion** | The level of exposure (concentration and duration) of a contaminant in a particular medium that is thought to result in an acceptably low level of effect on populations, communities, or uses of the medium (e.g. water quality criteria, air quality criteria) (Suter, 1993). |
| **Chronic effect (exposure) value** | The concentration limit, which is safe for all or most populations even during continuous exposure (DWAF, 1996). |
| **Deterministic analysis** | An analysis in which all population and environmental parameters are assumed to be constant and accurately specified (Suter, 1993). |
| **Ecological integrity** | The ability of an ecosystem to support and maintain a balanced, integrated composition of physico-chemical habitat characteristics, as well as biotic components, on a temporal and spatial scale, that are comparable to the natural (i.e. unimpaired) characteristics of such an ecosystem. High ecological integrity implies that the structure and functioning of an ecosystem are unimpaired by anthropogenic stresses) (Murray, 1999). |
| **Ecological risk analysis** | Determination of the likelihood (usually expressed as probability) and magnitude of adverse effects of environmental hazards (chemical, physical, or biological agents occurring in or mediated by the ambient environment) on nonhuman biota (Suter, 1993; Jooste, 2001). |
| **Ecological risk assessment** | The process of defining and quantifying risk to nonhuman biota and determining the acceptability of those risks (Suter, 1993). |

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|---|---|
| **Ecological Water Requirements** | Ecological Reserve |
| **Ecosystem** | A biotic community and its interaction with the abiotic environment (Bush, 1997). |
| **Effects assessment** | The component of an environment risk analysis that is concerned with quantifying the manner in which the frequency and intensity of effects increase with increasing exposure to a contaminant or other source of stress (Suter, 1993). |
| **Endpoint, assessment** | A quantitative or quantifiable expression of the environmental value considered to be at risk in a risk analysis, e.g. a 25% reduction of a particular species (Suter, 1993). |
| **Environmental risk analysis** | Determination of the probability of adverse effects on humans and nonhuman biota resulting from an environmental hazard (a chemical, physical or biological agent occurring in or mediated by the environment) (Suter, 1993). |
| **Hazard** | A state that may result in an undesired event, the cause of risk (Suter, 1993). |
| **Hazard assessment** | Determination of the existence of a hazard.<br>(a) In predictive risk assessments, it is a preliminary activity that helps to define assessment endpoints by determining which environmental components are potentially exposed to toxic concentrations and how they might be affected.<br>(b) An alternate assessment method that determines whether a hazard exists by comparing the magnitude of expected environmental concentrations to toxicological test endpoints for a contaminant (Suter, 1993). |
| **Instream Flow Requirements** | Some flows within a total flow regime in a river are more important than others for maintenance of the river ecosystem. These flows can be identified and described in terms of their timing, duration and magnitude. These identified flows can be combined to define a recommended modified flow regime specific for that river and constitutes the instream flow requirement (King and Louw, 1998). |
| **Mesocosm** | Medium-sized multi-species system in which physical and biological parameters can be altered and subsequent effects monitored. They may be field- or laboratory-based and are thought to mimic responses of organisms in the field more realistically than single-species test systems (Palmer and Scherman, 2000). |
| **Model** | A formal representation of some component of the world. Models may be mathematical, physical or conceptual (Suter, 1993). |

**Parameter uncertainty** — The component of uncertainty associated with estimating model parameters. It may also arise from measurements or extrapolation (Suter, 1993).

**Reserve** — The quantity and quality of water required -
(a) to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No. 108 of 1997), for people who are now or who will, in the reasonably near future, be -
 (i) relying upon;
 (ii) taking water from; or
 (iii) being supplied from,
 the relevant water resource; and
(b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource (National Water Act, No. 36 of 1998).

**Resilience (ecological)** — Resilience measures the rate of return to a predisturbance state after a perturbation, and is directly related to ecosystem recovery (Suter, 1993).

**Resource** — A water resource includes a watercourse, surface water, estuary or aquifer (National Water Act, No. 36 of 1998).

**Resource base** — The base level of ecological integrity and function which must be maintained in order to protect the ecological resilience of a water resource, so that the capability of the resource to supply services or meet the needs of humans can be maintained in the long term (National Water Act, No. 36 of 1998 - Part 1, Section 1.3.4).

**Resource quality** — The quality of all the aspects of a water resource including
(a) the quantity, pattern, timing, water level and assurance of in-stream flow;
(b) the water quality, including the physical, chemical and biological characteristics of the water;
(c) the character and condition of the in-stream and riparian habitat; and
(d) the characteristics, condition and distribution of the aquatic biota (National Water Act, No. 36 of 1998).

**Resource Quality Objective** — A numerical or descriptive statement of the conditions, which should be met in the receiving water resource to ensure that the resource is protected (National Water Act, No. 36 of 1998 - Part 1, Section 1.2.4).

**Risk** — The likelihood (usually expressed as probability) of a prescribed undesired effect. If the level of effect is treated as a number, risk is a function of the likelihood and frequency of effect. Risk results from the existence of a hazard and uncertainty about its expression (Suter, 1993).

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|---|---|
| **Risk assessment** | The process of assigning magnitude and likelihood to the adverse effects of human activities or natural catastrophes (Suter, 1993). |
| **Risk characterization** | The process of (a) integrating the exposure and effects assessments to estimate risks and (b) summarizing and describing the results of a risk analysis for a risk manager or other stakeholders (Suter, 1993). |
| **Risk management** | The process of deciding what actions to take in response to a risk (Suter, 1993). |
| **Stochastic** | Randomly determined; that follows some random probability distribution or pattern so that its behaviour may be analysed statistically but not predicted precisely (Brown, 1993); that which cannot be determined uniquely, but can only be expressed in terms of likelihood. |
| **Stress** | The proximate cause of an adverse effect on an organism or system (Suter, 1993). |
| **Stressor** | Any physical, chemical or biological entity or process that can induce an adverse response (Murray and Claassen, 1999). |
| **Sustainability (ecological)** | The need to maintain ecological structures, functions or ecological integrity (Simonovic, 1996). |
| **Toxicity** | (1) The harmful effects produced by exposure of an organism to a chemical;<br>(2) The property of a chemical that causes harmful effects in organisms (Suter, 1993). |
| **Uncertainty** | Imperfect knowledge concerning the present or future state of the system under consideration; a component of risk resulting from imperfect knowledge of the degree of hazard or of its spatial and temporal pattern of expression (Suter, 1993). |
| **Xenobiotic** | A toxicant or foreign substance (Rand, 1995). |

# LIST OF ACRONYMS

This list of abbreviations is amended from Jooste *et al.* (2000).

| | |
|---|---|
| **AEV** | Acute Effect (Exposure) Value |
| **BAT** | Best Available Technology |
| **BATNEEC** | Best Available Technology Not Exceeding Excessive Cost |
| **CAP** | Continuous Assessment Paradigm |
| **CEV** | Chronic Effect (Exposure) Value |
| **CSIR** | Council for Scientific and Industrial Research |
| **CV** | Criterion Value |
| **DEAT** | Department of Environmental Affairs and Tourism |
| **DRIFT** | Downstream Response to Imposed Flow Transformations |
| **DSS** | Decision Support System |
| **DWAF** | Department of Water Affairs and Forestry |
| **EC** | Environmental Concentration |
| **EIA** | Environmental Impact Assessment |
| **EMC** | Ecological Management Class |
| **EMP** | Environmental Management Plan |
| **ERA** | Ecological Risk Assessment |
| **ERBM** | Ecological Risk-Based Management |
| **ECR** | Ecological Reserve Category |
| **FS-R** | Flow Stressor-Response |
| **I&APs** | Interested and Affected Parties |
| **IEM** | Integrated Environmental Management |
| **IFR** | Instream Flow Requirement |
| **IWQS** | Institute for Water Quality Studies |
| **IWR** | Institute for Water Research |
| **FDC** | Flow duration curve |
| **LC50** | Concentration that kills 50% of the test population |
| **LOEC** | Lowest Observed Effect Concentration |
| **LT50** | Lethal time |
| **NER** | No Effect Range |
| **QAP** | Quantal Assessment Paradigm |
| **PEC** | Predicted Environmental Concentration |
| **PNEC** | Predicted No observed Effect Concentration |
| **RBO** | Risk-based objectives |
| **RQO** | Resource Quality Objectives |
| **RQS** | Resource Quality Services |
| **RU** | Rhodes University |
| **SSR** | Stressor Response Relationship |
| **TDS** | Total Dissolved Solids |
| **TSS** | Total Suspended Solids |
| **TWQR** | Target Water Quality Range |
| **UCT** | University of Cape Town |
| **UCEWQ** | Unilever Centre for Environmental Water Quality |
| **US EPA** | United States Environmental Protection Agency |

# ACKNOWLEDGEMENTS

Thanks to those who participated in the workshop that formed the focus of this project. Participants were the following:

*Water quantity group*
Prof J H O'Keeffe, IWR, RU
Prof D Hughes, IWR, RU
Ms D Louw, IWR Source-to-Sea, Pretoria
Mr A Birkhead, Streamflow Solutions

*Water quality group*
Prof C G Palmer, UCEWQ, RU
Mr N Rossouw, Ninham Shand
Dr S Jooste, RQS, DWAF
Dr H Malan, Freshwater Research Unit, UCT
Dr P Ashton, Environmentek, CSIR

*Habitat group*
Dr N Kleynhans, RQS, DWAF (*water quantity and habitat*)
Dr J King, Southern Waters, UCT (*water quantity and habitat*)
Mr N Kemper, Pretoria
Dr R Wadeson, Pietermaritzburg
Prof K Rowntree, Geography Department, RU

*General*
Mr M Claassen, Environmentek, CSIR: liaison with the WRC ERA project
Dr P-A Scherman, previously of the IWR, RU: will also participate in *water quality* group
Dr WJ Muller, UCEWQ, RU: will also participate in *water quality* group

We would also like to thank the persons who served as an *ad hoc* steering committee for the project, that is Dr SA Mitchell, Mr M Claassen, Mr R Hattingh, Mr M van Veelen and Mr G McKonkey. Finally, our thanks to the Water Research Commission for funding the project; Mrs J MacLean of the IWR for efficient financial services; and our organizations, the Institute for Water Research, Resource Quality Services, DWAF, and Coastal & Environmental Services, for their support.

# CHAPTER 1

# THE RISK ASSESSMENT FRAMEWORK IN SOUTH AFRICA

## 1.1 INTRODUCTION

The fundamental differences between hazard and risk-based approaches can be described as follows: A hazard-based approach emphasizes the *potential* for causing an effect, while risk-based approaches define a realistic *expectation* of effect. It is important to understand the difference between these approaches before a risk-based approach to resource management can be undertaken.

A risk-based approach generally refers to a process whereby a desired outcome is set as management objective relating to specific risk levels, and all stressors on a system are managed so as to achieve these objectives (Claassen and Wade, 2001). The cumulative impact of stressors is therefore managed. This approach presents a shift from present management strategy, where individual stressors are normally managed independently of their combined impacts.

The incorporation of risk concepts into water resource management is still in its infancy in South Africa. The concept of Ecological Risk Assessment (ERA), and its application to informed decision-making, is embodied in a text by Claassen *et al.* (2001). This document provides a background to the ERA process, and provides a set of guidelines by which an ERA can be undertaken. Although this Water Research Commission-funded study has demonstrated the usefulness of risk-based procedures, the Department of Water Affairs and Forestry (DWAF) is still drafting its risk policy document. It is assumed that the availability of such a policy document, which is envisaged to cover concepts such as risk-based decision-making and building capacity within the field of risk assessment, will further clarify the role of risk concepts in water resources management in South Africa.

The South African National Water Act (No. 36 of 1998) recognizes that the water resource needs to be used to the benefit of the population, but also needs to be protected. Water use (including the discharge of wastes) is necessary for the economic development of the country and its people, while protection of the resource is needed so that this use as well as the other goods and services provided by the resource, will be available to future generations. Therefore, risk and risk-based management is conceptually well-suited to resource management in this country. Risk not only takes cognisance of the potential effect of human activity, but also considers the environment in which this activity takes place. It is able to provide an objective, focussed evaluation of impact that, if used properly, provides the basis for balanced management decision. Risk-based management of the water resource has been used in water quantity supply management for many years by DWAF. The application of risk-based management now needs to be extended to water quality management.

Furthermore, the concept of risk is incorporated in the approach followed, and methods and tools used, for determining the Ecological Water Requirements (EWR) for aquatic water resources. This is fundamental to the process as the Ecological Reserve concerns aquatic ecosystems, which are inherently variable. Some of the methods used, e.g. the stressor-response approach used for flow determinations, incorporate risk concepts more than others, e.g. the approach used for water quality assessments, which is still largely hazard-based. All EWR methods are however moving toward an effective incorporation of risk concepts.

The development of a classification system for the country's rivers is still being undertaken, and will be based on the risk of irreversible damage to the resource base. The concept is therefore risk-based, but again methods incorporating risk must be developed or present methods refined.

This chapter of the report therefore serves to describe and define risk-based methods, and provide some background to the current status and use of these methods.

### 1.2 ECOLOGICAL RISK ASSESSMENT: AN OVERVIEW

*This summary is based largely on the work of Claassen and colleagues, as described in their document published in June 2001, and attempts to capture the main points of ERA in South Africa.*

To achieve effective resource management and decision-making, often in the absence of adequate data, an approach is needed which can incorporate the uncertainty and variability inherent to biological data.

Basic characteristics of risk are as follows (Jooste and Claassen, 2000):

- An **expression of likelihood**. This may be in the form of probability or possibility.
- A **subject** (hazard or stressor) which initiates the consideration of risk.
- An **object** (target) upon which the stressor or hazard is expected to have an effect.
- The **type** (or consequence) and **magnitude** of effect of impact being assessed (i.e. the probability of something happening to the object).

Differences between risk and hazard can therefore be expressed as follows (Jooste and Claassen, 2000). **Risk** is the likelihood or expectation of a specified effect and incorporates both the relationship between the stressor and its expected response, as well as the expectation of the exposure to that stressor. It accepts that the some relationship exists between the stimulus applied to a system and the response of that system, and that this response is practically continuous above a possible threshold stimulus. Uncertainty and variability becomes part of the expression of risk. Risk as an assessment tool is therefore used most effectively in a risk management framework.

**Hazard** focuses on the potential of a stressor to cause an effect which is seldom explicitly specified. It is not explicitly concerned with the uncertainty and variability within the effects on the system under consideration. The concept of a criterion is the focus of this approach. The outcome of the assessment is only concerned with the confidence with which compliance to the criterion can be expressed. The assessment result is therefore essentially dichotomous or binary (e.g. complies / does not comply).

In 1997, Skivington produced a guide for assessing risk from point sources of pollution. Concurrently, the United States Environmental Protection Agency (US EPA) developed guidelines for the application of ERA in America. These guidelines were published in 1998. The US EPA approach formed the basis for the method developed by Murray and Claassen (1999) for use within South Africa.

An ERA therefore determines the likelihood that undesirable ecological effects may occur, or are occurring, as a result of exposure to one or more stressors. The approach developed by

Murray and Claassen (1999) incorporates the following abbreviated steps (Claassen and Wade, 2001):

- **Agree on objectives**: this phase requires extensive liaison and agreement regarding objectives, acceptable levels of uncertainty, goals, and resources (financial, human and data) availability.

- **Formulate analysis plan**: Technical data gathering e.g. stressor sources and potential impacts, system at risk, assessment end-points, and possible exposure routes. The risk hypotheses are therefore developed at this point.

- **Analyse information**: Quantify exposure and effects characteristics, and identify data uncertainty and variability. Collect additional data if required, and address all aspects of the stressor(s). Prepare a stressor-response profile, which generates the following information.

  - Stressor level – represents any stressor that may have an adverse effect on the end-point. (Alternative terminology for *end-point* is *target population* or *receptor*. The latter terms are used widely in the US and UK as the biotic entity involved is the end-point (Jooste, RQS, pers. comm.)).
  - Exposure profile – indicates the probability of the end-point being exposed to different levels of the stressor.
  - Effects profile – shows a cumulative distribution of effects on the end-point, given specific exposures.
  - Risk profile – quantifies the co-occurrence of the exposure and effects.

  A number of tools are available for use during the analysis phase of an ERA. Examples of *risk assessment models* include the following (DEAT, 2000):

  - APPRAISE: database and calculation tool to assess the environmental impact of industrial releases (UK).
  - RBCA: Risk-based Corrective Action Tool Kit for contaminated land and water (UK).
  - REFEREE: ERA using effect models linked to ecological and ecotoxicological databases (Netherlands).
  - CalTOX: A multimedia total exposure model for hazardous waste sites (USA).

  Examples of *fate and transport models* (used to determine the effective dose with which the end-point (e.g. ecosystem) will be in contact) are the following (DEAT, 2000):

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

  *Effects* can be determined using the following tools (DEAT, 2000):

  - Pulsed exposures.

- Population models.
- Sensitivity distributions.
- Sediment toxicity evaluations.
- Chronic toxicity tests.
- Mesocosms and microcosms.
- Behavioural toxicity tests.

A number of databases are available for use, e.g. the International Register of Potentially Toxic Chemicals (UNEP), Integrated Risk Information System (US EPA) and Ecotox Thresholds Software (US EPA).

- **Characterise and communicate risk**: The likelihood of adverse ecological effects is determined by integrating exposure and effect data, and evaluating associated variability and uncertainties. Risk hypotheses are tested, and the results of the risk assessment are presented in the appropriate manner. Risk hypotheses are therefore predictions of relationships between stressor, exposure and the response of the assessment end-points.

- **Manage risk**: Results are discussed with the risk manager, and decision-making commences. An iterative approach to risk assessment may be followed.

Fundamental to risk assessment is therefore the hazard or stressor that is eliciting the risk (and its associated exposure pathway), and the probability of effect due to that exposure, i.e. the stressor-response relationship.

## 1.3 RISK AND RESOURCE MANAGEMENT

The concepts of hazard and risk are used extensively in resource management, particularly water resource management. Examples of how hazard and risk can be incorporated into environmental management and water resource management are shown in Sections 1.3.1 and 1.3.2 respectively.

### 1.3.1 Integrated Environmental Management (IEM)

Risk-based approaches can be used for a wide number of applications, including environmental studies such as EIAs (Environmental Impact Assessment) and EMPs (Environmental Management Plans).

The risk assessment process is becoming more common in industry because of the use of ERA in regulation and management practises. A risk management plan is usually developed after a detailed risk assessment process, to evaluate alternative risk reduction and prevention measures and to implement cost-effective options. ERA can assist managers in tasks such as compliance with legislation, financial planning, site-specific decision-making, prioritisation and evaluation of risk reduction measures, and precautionary or remediation actions (DEAT, 2000).

There is a substantial overlap in the ERA and EIA process, meaning that the ERA framework can be integrated with the generic EIA procedure. Examples of overlap and the use of ERA within an EIA process are as follows (DEAT, 2000):

- Hazard identification takes place within an EIA. If significant uncertainties are identified, the EIA may need to be extended to include an ERA.
- ERA can be used to determine the magnitude, extent, severity, uncertainty and variability of significant impacts identified by the EIA.

ERA applications that can be used within a risk framework therefore include the following (DEAT, 2000):

- Site-specific decisions.
- Comparative risk analysis and determining alternative risk options.
- Determining acceptable risks to develop environmental standards or benchmarks.

The value of ERA within the EIA structure can therefore easily be validated and its usefulness demonstrated. Areas that require clarification and support are the role of stakeholder involvement, and the interactive approach between government, interest groups and public participation (DEAT, 2000). The establishment of government institutions or divisions to support the integrated use of EIA and ERA within an IEM framework are critical.

### 1.3.2 Ecological Water Requirements: Resource Quality Objectives and ecospecs

The current approach by which Ecological Water Requirement (EWR) studies are conducted are conceptually risk-based, but the practical application of a risk-based methodology still has to be formulated and implemented.

Resource Quality Objectives (RQOs) are set for components of the resource during an EWR study and relate to certain risk levels. Where resources need a high level of protection, a strict set of objectives that will represent a low risk of damage to the system, will be set. Adopting a risk-based approached to EWR therefore provides a nationally uniform basis for deciding on the acceptability of impacts, while at the same time allowing natural site-specific differences to be taken into account by setting resource-specific objectives (Jooste *et al.*, 2000).

Ecospecs (ecological specifications) are clear and measurable specifications of ecological attributes that define the Ecological Reserve Category (ERC) and serve as an input to RQO. Ecospecs refer explicitly and only to ecological information, whereas RQOs also include economic and social objectives (IWR Environmental, 2003).

The critical components of the RQOs are:

- Requirements for water quantity, stated as flow requirements for a river reach or estuary, and/or water level requirements for standing water or groundwater, and/or requirements for groundwater level in order to maintain spring flow and base flow in rivers and other ecological features.
- Requirements for water quality (chemical, physical, and biological characteristics of the water).
- Requirements for habitat integrity, which encompass the physical structure of instream and riparian habitats, as well as the vegetation aspects.
- Requirements for biotic integrity that reflect the health, community structure and distribution of aquatic biota.

The specialist workshop conducted during this investigation (i.e. Phase II) therefore focussed on the physical drivers as components of the RQOs, i.e. water quantity, quality and habitat integrity.

### 1.3.3 General

For effective management, determining the risk associated with a specific hazard is vital, as the manager's response to the hazard must depend on the risk it poses (Claassen and Wade, 2001). It is therefore essential to develop an understanding of risk management and risk procedures among water resource managers, with risk management being the action when a decision is based on knowledge of the likelihood of events and their consequences.

# CHAPTER 2

# AIMS AND OBJECTIVES OF THE RISK-BASED OBJECTIVES STUDY

The aims and objectives of both Phases I (Jooste *et al.*, 2000) and II (current study) of the risk-based objectives (RBO) study are presented, with the links between the studies elucidated.

## 2.1 PHASE 1: 1998-1999

Specific aims of the Jooste *et al.* (2000) study, i.e. Phase I, were to:

- review and consolidate research into setting objectives for water quantity, water quality, habitat integrity and biotic integrity requirements of water resources, as these relate to the designation of the Ecological Reserve;
- investigate new and emerging trends in using risk concepts for setting environmental objectives;
- identify possible approaches to incorporate concepts of risk into setting integrated Resource Quality Objectives for protecting water resources; and
- identify research direction(s) addressing the development of methodologies for setting integrated objectives for water resource protection, in order to provide a key component of the current DWAF project to develop and implement a national protection-based classification system for water resources in South Africa.

Although the process for classifying water resources is currently under review, with two classification systems currently available (categories A-F, and descriptive categories such as *natural*, *good*, *fair* and *poor* (see Appendix 1 for the relationship between the two systems) (Scherman *et al.*, 2003)), the use of a risk-based approach for classification is applied in both classification systems. The following factors are inherent to the classification project and set the framework for the initiation of the risk-based objectives project (Jooste *et al.*, 2000):

- Not all water resources have the same level of protection, with each Ecological Reserve Category (ERC) and Ecological Management Class (EMC) carrying specific levels of protection or levels of *risk* of damage to the sustainability of the ecosystem.
- Resource Quality Objectives will be set for each water resource. RQOs are a statement (numerical or descriptive) of requirements for a given level of protection, and will be set for water quantity, water quality, habitat integrity and aquatic biota, as they relate to the designation of the Ecological Reserve.

The report for Phase I (Jooste *et al.*, 2000) was presented in three parts, with Part 1 comprising background literature on risk concepts and the feasibility of using of a risk-based approach for water resource management. The integration of risk objectives and risk criteria (acceptable risk), with ecological and management objectives, was discussed. Part 1 concluded with identifying research needs for the effective use of a risk-based approach to set integrated environmental objectives. Subjects covered included the need for risk management structures and policy, and the importance of understanding risk concepts and improving its accessibility to practitioners and managers. The integration of co-occurring stressors was identified as an important research area. The value and importance of collecting fundamental southern African biological and ecological data, in order to improve our understanding of ecosystems and stressor-response relationships, was also emphasized.

Parts 2 and 3 of Jooste *et al.* (2000) summarised the findings of two specialist workshops. For the first workshop (Part 2) literature was reviewed for information on functional relationships that exist between selected stressors and biotic response, i.e. can the occurrence of a stressor be related to an observable biotic effect. The following variables were selected for review:

- water quantity (flow)
- water quality, in the form of:
  - toxics
  - nutrients - nitrate, nitrite, ammonia, phosphate, iron, manganese
  - system variables - pH, electrical conductivity, salinity, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), temperature
- habitat

Part 3 documented the discussion and findings of a workshop on using risk-based objectives to set flow requirements for rivers. The selection of flow as the first parameter under discussion was due to the Instream Flow Requirement (IFR) team already implicitly following a risk-based approach when determining water quantity requirements during flow estimates and Ecological Water Requirements studies. Documents written by Hughes and O'Keeffe were included as a first attempt at developing a framework for determining the water quantity Reserve, and defining different levels of flow-related stress for instream riverine fauna. The stressor-response method explored in this section has been finalized and published (O'Keeffe *et al.*, 2002).

## 2.2 PHASE II: 2000-2001

One of the key features of a risk assessment, particularly in characterizing and evaluating the probability of effect, is information on *stressor-response relationships (SRR)*. Conventionally, the effect of a stressor is measured in a controlled laboratory environment using a single species or few selected species, i.e. toxicological information. As this information is then extrapolated from one species in the laboratory to the same species in the river, and to many other species, populations, communities and the ecosystem, it is important that stressor-response information be available, and relationships be characterized and quantified. SRR therefore need to include the involvement of the end-point, and the direction of change in both stressor and response. As SRR were developed for flow during Phase I of the RBO study, water quality and habitat were the focus of Phase II, although flow relationships were also discussed.

The primary focus of Phase II of the RBO project was therefore a workshop held during February 2000 with the overall aim of *linking stressors and associated responses to an identified end-point, and integrating stressor responses for co-occurring stressors.* The stressors considered were changes to *flow (water quantity)*, *water quality* and *habitat.*

The following *discussion points* were identified and defined to lead the workshop:

- If the aim is to integrate stressor effects, a common end-point (e.g. the sustainability requirements of the Ecological Reserve) must be defined.

- How should stressors be defined so that a given response can be linked to the stressor stimulus, and can the response be related in some way to the identified end-point?
- What techniques, procedures or protocols already exist to determine stressor exposure and effects?
- Can risk-based objectives (quantitative or semi-quantitative) reasonably be derived for use within the present regulatory framework?

Outcomes of discussions surrounding these identified questions are detailed in Sections 3.2 to 3.5.

# CHAPTER 3

# PHASE II: RISK-BASED OBJECTIVES WORKSHOP

## 3.1 INTRODUCTION

South Africa has traditionally dealt with stressors on an individual basis, e.g. setting water quality guidelines for toxic chemicals. Although valuable, this approach has shortcomings as integrated, cumulative, antagonistic or synergistic effects of individual chemicals (for example) are not managed or monitored. Effect-specific criteria, and not only substance-specific criteria, therefore need to be developed. By implementing water resource strategies that focus on impacts on the resource, e.g. resource directed measures, a risk-based approach is implemented and resource-based management objectives are set. However, for the management of co-occurring stressors, it is important to define stressor-response relationships for individual and co-occurring stressors. Before these relationships can be evaluated, a number of fundamental questions need to be answered. Workshop results are reported as a report-back per identified question.

Jooste and Claassen (2000) produced a discussion document to lead the workshop. To focus thinking, the *minimum requirements for undertaking risk assessments*, were identified.

- The assessment should support the management decisions to be made. This alignment should be explicit in the risk assessment planning phase and be evident in the assessment results.
- The end-point(s) selected for the assessment should be appropriate in terms of both its ecological importance and its relevance to the management objectives.
- A risk hypothesis should be formulated that includes the stressor source and exposure routes, exposure-effect relationships, ecological end-points and ecosystem processes.
- An analysis plan should be drawn up and reviewed in terms of its alignment with management needs and scientific rigour.
- A critical evaluation of all available information should be conducted to assess weaknesses and identify areas where more information needs to be collected. Variability and uncertainties should be explicitly assessed and accounted for throughout the assessment.
- The characterisation of exposure should include descriptions of the pathways, spatial and temporal attributes and account for variability and uncertainties.
- The characterisation of effects should establish causality between exposure and effects and have clear links to the end-points.
- The estimation of risk should integrate the exposure and effects information and provide a sound basis for evaluating the hypothesis. Different lines of evidence should be evaluated to support the conclusions.
- Communication of the results should be clear and provide sufficient information on all the phases of the assessment to allow for peer review.
- Scientific rigour should be upheld throughout the assessment.

## 3.2 QUESTION 1: DEFINE A COMMON END-POINT

During a risk study, it is essential to define and describe the ecosystem or factors at risk according to structural or functional relationships. Co-occurring stressors, e.g. flow, toxics, habitat, must therefore all be assessed to the same common end-point in order for risk-based objectives to be applied. In general, end-points should (Jooste and Claassen, 2000):

- reflect important ecological characteristics of the system;
- be susceptible to known or potential stressors; and
- be relevant to management goals.

Once a common end-point has been determined for co-occurring stressors, i.e. the entity considered to be of ecological value, potential assessment end-points need to be identified, i.e. characteristics of the entity that are at risk. *Assessment end-points are therefore the definitive measures that scientifically and ecologically represent broader management concerns* (Claassen *et al.*, 2001). The next step would be to determine measurement end-points, e.g. specific values generated by field or laboratory tests, such as LC50s (i.e. the lethal concentration responsible for the mortality of 50% of a population).

For the purpose of discussion at the workshop, the common end-point was identified as the sustainability requirements of the Ecological Reserve (see Section 1.3 of Jooste *et al.* (2000) for a discussion around concepts of sustainability and resilience). As each Reserve category has a characteristic profile of ecological integrity and set of objectives, it is necessary to define exactly what is meant by the *sustainability requirements of the Ecological Reserve.* Debate ensued around the meaning and application of this concept, e.g. is it the risk of moving from an assigned category to a lower category, and therefore not maintaining the ecological function associated with the assigned category; is it the risk of impacting on the resource base (that is, that level below which recovery will not be possible); is it the risk of not meeting RQOs per category; or is it the risk associated with the uncertainty of defining the Ecological Management Class (EMC). It must be emphasized that these are management risks rather than ecological risks, although the EMC is derived from ecological considerations.

The final conclusion reached by the workshop was that as Ecological Reserve Categories are defined as deviation from the natural state (or the natural stress profile), the risk would be that of changing category or losing ecological function, and the ecological end-point is to maintain conditions as required by the assigned category (therefore incorporating the *probability* of changing to a lower category).

### 3.3 QUESTION 2: HOW SHOULD STRESSORS BE DEFINED SO THAT A GIVEN RESPONSE CAN BE LINKED TO THE STRESSOR STIMULUS, AND CAN THE RESPONSE BE RELATED IN SOME WAY TO THE IDENTIFIED END-POINT

A hazard is an event (e.g. concentration of a chemical) that is detrimental, while stressors also have natural stress profiles. The hazard therefore causes a degree of deviation from the natural stress profile (or reference condition). The degree of deviation is considered as the end-point or *effect*, which is measured as the *response* (e.g. change in abundance, life-stage or survival). Responses should be recorded at the highest available level of organisation – extrapolation will still be needed if this is at the level of organism.

The aim was therefore to develop a *stress index* for each variable identified by the workshop groups, and develop a *descriptor* for each stress level. This approach was developed during Phase I of the RBO project for flow, and is encapsulated in a research paper by O'Keeffe *et al.* (2002). Further development of the approach gave rise to the Flow Stressor-Response (FS-R) method used to determine low flows during EWR studies. The principles of this method are shown in Section 3.3.1. The aim of this component of the workshop was therefore to develop a similar stressor-response relationship for variables other than flow.

**Comment:** The use of the term *stressor* in this chapter is not in complete agreement with the definition in the glossary and international usage. In this chapter a *stressor* is understood to not always have a negative effect, and only when the magnitude and frequency of a stimulus exceeds its safe bounds does it become a stressor. However, according to international literature, a stressor is already assumed to be causing an adverse effect.

### 3.3.1 Water quantity: Flow Stressor-Response method for determining low flows - an overview

The excerpt regarding this method is taken from IWR Source-to-Sea (2004) and O'Keeffe *et al.* (2002).

The FS-R method was designed to guide the evaluation of the ecological consequences of modified flow regimes, based on the principles of ERA, and uses an index of flow-related stress. Some of the indicators used in assessing the levels to which a river is stressed are fish, invertebrates and vegetation (O'Keeffe *et al.*, 2002). As the impact of too little or too much flow at the wrong phase of the hydrological cycle is the stressor, the focus is on flow-dependent biota. The FS-R method recognises natural stress, as low-flow episodes are part of the natural disturbance regime of a river.

The basis of this method is the application of a generic stress index from 0-10 (see Table 3.1 for selected stress levels and associated descriptions), which describes the progressive consequences of flow reduction to the flow-dependent biota and river processes. The stressor, i.e. unnatural flow patterns at the wrong times, and resultant hydraulics and habitat changes, are related to biotic stress responses in terms of abundance, life stages and persistence / survival. These relationships are translated into a stress profile for any flow regime, in terms of magnitude, frequency and duration. Examples of the stress index development for flow-dependent biota are shown in Table 3.1.

**Table 3.1** Selected levels of the generic dimensionless stress index developed by O'Keeffe *et al.* (2002).

| Stress Index | Stressors | | Responses | | |
|---|---|---|---|---|---|
| | **Flow** | **Habitats** | **Abundance** | **Life-stage** | **Survival** |
| 0 | Very fast, very deep. | All very abundant. | All very abundant. | All healthy. | All species. |
| 2 | Fast, deep, but slightly reduced. | Critical habitats not abundant. | Slight reduction for rheophilic species. | All healthy in some areas. | All species. |
| 5 | Moderate / slow, few deep areas. | Critical habitat very reduced. | Remnant populations of all rheophilic species. | Critical life stages of sensitive species non-viable. | All species. |
| 7 | Slow, shallow. | No critical habitat. | All rheophilic species rare. | All life-stages of sensitive species at risk or non-viable. | Sensitive species disappear. |
| 10 | No surface water. | Sub-riverbed refugia only. | Only specialist survivors. | Virtually no development. | Only specialist survivors. |

The use of the FS-R method therefore broadly consists of the following steps (IWR Source-to-Sea, 2004):

- A stress index of 0-10 is described for each element of the biota (fish, invertebrates, riparian vegetation) in relation to stresses experienced by specific flow-dependent organisms / processes under different flow conditions, and attached to responses to changing flow and habitat conditions.
- Each stress value is attached to a specific flow per site, via the hydraulic calibrations for the site.
- Natural and altered low-flow time series are converted to stress time-series, and then to stress duration curves and spell analyses. This information is used to evaluate any low-flow scenario provided.

**Comment**: As the method is reported in O'Keeffe *et al.* (2002), it is only informally risk-based. Further developments may include a description of what flow characteristics result in what level of impact on the target, e.g. a wet season flow of more than 20% lower than the normal flow may result in a small loss of individuals in flow-sensitive species, and 50% below normal flow may result in a significant loss in flow sensitive species. From these data and the likelihood of the occurrence of these flow conditions, the risk is calculated.

It should be noted that studies such as the Thukela EWR study have created the opportunity for a number of these developments to take place. The data therefore exists for risks to be calculated.

### 3.3.2 Water quality workshop session

Workshops held as part of Phase I of the RBO project highlighted the dearth of information on functional relationships between water quality stressors and responses. Problems identified during Phase I were as follows (Jooste *et al.*, 2000).

- Most toxicological data are produced using small groups of individuals from a species. Few data exist that relate to effects on a whole population, meaning that extrapolation is required.
- Most studies concentrate exclusively on sensitive or susceptible life-stages of organisms.
- Only a few end-points are well reported, e.g. the most widely used end-points of mortality and fertility for invertebrates, and biomass density for bacteria and phytoplankton.

In the water quality field most data is therefore hazard-based, and incorporates only a minimal component of frequency and duration. The focus of the water quality component of the workshop was therefore to attempt to develop a stress index and investigate stressor-response relationships for selected variables, following the method used by the flow team, i.e. Section 3.3.1. The degree of deviation from the *reference condition* or *natural stress profile* (possibly more accurately called a *natural stimulus profile*, according to internally accepted definitions of a stress (see comment in Section 3.3)) (which will not be an instantaneous measurement, but probably a median of the relevant data record) was acknowledged to be the end-point or effect, with the (anthropogenic) hazard causing the degree of deviation and the end-point measured as responses to the hazard. The aim was to specify *instantaneous levels* of hazards (normally at a particular flow) for the following stressors (see list below), and to integrate rate of change and duration at a later stage. It was also recognized that specific descriptors need to be developed for each stress level.

- toxics
- system variables
- nutrients

Information was generated for selected stress levels only i.e. 0, 2, 5, 7 and 10 – those levels where greatest changes are thought to take place. The same responses are assumed as shown in Table 3.1. Surrogates (e.g. algal responses for nutrient index) and best available knowledge was used in developing the stress tables, which affects the uncertainty of the result.

**Note**: The system-specific calibration of these indices is essential, as the stress index is meaningless without calibration. The information reflected here was based on a single workshop event, and data have therefore not been tested or refined.

**Stress Index: Toxics**

Table 3.2 represents a first attempt at developing a stress index for toxics.

**Table 3.2** Stress index levels and qualitative descriptions of the associated toxic levels.

| Stress Index | Qualitative description of the stressor / hazard |
|---|---|
| 0 | Level of toxic is the same as natural / reference condition. |
| 2 | Negligible level of toxic as compared to natural / reference condition. |
| 5 | Low level of toxic as compared to natural / reference condition. |
| 7 | Moderate level of toxic as compared to natural / reference condition. |
| 10 | High level of toxic as compared to natural / reference condition. |

Note: *Negligible, low, moderate* and *high* must be calibrated and will be system-specific.

**Stress Index: Nutrients**

Table 3.3 represents a first attempt at developing a stress index for nutrients. Algal responses are used as a surrogate for nutrient responses.

**Table 3.3** Stress index levels and qualitative descriptions of the associated nutrient levels.

| Stress Index | Qualitative description of the stressor / hazard |
|---|---|
| 0 | Characteristic natural levels that represent algal productivity in terms of magnitude and ratio. |
| 2 | Nutrient levels that do not cause a change in primary producers, i.e. nutrient LOEC (lowest observed effect concentration). |
| 5 | Nutrient levels causing a change in heterotrophs. |
| 7 | Nutrient levels causing a change in habitat and heterotrophs. |
| 10 | Nutrient levels causing a system change. |

**Stress Index: System variables**

Table 3.4 represents a first attempt at developing a stress index for system variables, e.g. pH, electrical conductivity, dissolved oxygen.

**Table 3.4** Stress index levels and qualitative descriptions of the associated levels of system variables.

| Stress Index | Qualitative description of the stressor / hazard |
|---|---|
| 0 | Level of system variables is the same as natural / reference condition. |
| 2 | Negligible deviation from natural / reference condition. |
| 5 | Low deviation from natural / reference condition. |
| 7 | Moderate deviation from natural / reference condition. |
| 10 | High deviation from natural / reference condition. |

**Note**: *Negligible, low, moderate* and *high* must be calibrated and will be system-specific. Populating these values (Tables 3.3 and 3.4) will follow a different approach to toxics as they represent ranges, and responses to changing levels of nutrients and system variables are U-shaped (U-shaped responses may have to be split as, for example, high or low nutrients will have very different impacts). A number of databases exist with toxics data, but very little work has been conducted on determining functional relationships for system variables or nutrients. This need was identified as **critical**.

**Approach for conducting a water quality assessment utilizing the concepts of stress and risk**

The following preliminary water quality approach was developed – see Figure 3.1:

Use the generated Stress Index and calibrate on a system-specific basis. Produce system-specific hazard levels.

↓

Apply to the system to produce a reference condition stress profile.

↓

Produce a reference condition duration curve.

↓

Assess altered stressor levels to derive the altered stressor time-series (using the flow-concentration relationship for the variable under evaluation).

↓

Produce the altered Stress Index time-series.

↓

Produce the altered Stress Index duration curve.

↓

Compare this information with the reference condition duration curve to assess the degree of deviation. This difference is the *hazard*.

**Note**: To calculate risk, set conditions for duration and the probability of exceedence.

**Figure 3.1** A preliminary approach for assessing water quality using stressor-response functional relationships.

The following **knowledge gaps** were identified during the water quality process:

- A link is needed between primary and secondary producers.
- Reference conditions for water quality must be specified.
- Need to relate the degree of response to the degree of change.
- Need to define what a degree of deviation means in ecological terms.
- Developing flow-concentration relationships and models (however, the method developed by Malan and Day (2002a, b; Malan *et al.*, 2003) is available for use).
- Need to bridge the fundamental gap between water quality and quantity, i.e. water quality uses 0 stress as reference condition, while quantity does not use reference condition in its definitions.
- Water quality is represented by three separate stress indices, and not an integrated water quality index.
- Experimental research and an assessment of international databases (particularly for toxics) are needed for calibrating qualifiers of the stress index table.

### 3.3.3 Water quantity and habitat workshop sessions

The aim of this session was to produce stress-flow relationships for a number of components, i.e. fish, macroinvertebrates, riparian vegetation and geomorphology (functions such as channel maintenance and sediment transport), and evaluate the influences of *high and low flows* on each component. A generic rule table(s) (i.e. define stress levels 0-10 per component) therefore needed to be produced which incorporates site-specific hydraulic characters and produces stress-flow relationships. Due to the different impacts of high and low flows, it might be necessary to separate out the flows and produce generic tables for each. In some instances, seasonal stress relationships will also need to be identified and incorporated.

It was agreed that the derivation of these generic stress tables would incorporate the habitat component as well, as the interaction between flow and geomorphology (i.e. channel shape and structure) defines the habitat in which in-stream biota occur.

Examples of descriptors that could be used to populate stress tables for the different components, were as follows:

- Fish: migration and breeding rate
- Riparian vegetation: growth and recruitment
- Geomorphology: channel maintenance and sediment transport.

As for water quality, the quantity team also identified the need to interpret deviations from the stress profile in ecological terms. It was felt, however, that defining deviations in ecological terms was already incorporated in the thinking of the IFR / BBM (Building Block Methodology) approach, as well as the DRIFT (Downstream Response to Imposed Flow Transformations) approach.

The following **knowledge gaps** were identified by the water quantity (flow) and habitat groups:

- Ecological interpretation needs to be included, and further developments need to define relationships in terms of ecological end-point.
- Physical impacts on habitats, e.g. bulldozing, need to be addressed in some way. It may be possible to use available data to generate stressor-response metrics.
- An integrative methodology may be needed for the DRIFT and BBM approaches.

It is important to note that a number of the points mentioned in this section are currently being addressed by existing projects, including refinement and development during Ecological Water Requirements studies, e.g. the Thukela study initiated in 2001.

## 3.4 QUESTION 3: WHAT TECHNIQUES, PROCEDURES OR PROTOCOLS ALREADY EXIST TO DETERMINE STRESSOR EXPOSURE AND EFFECTS

These requirements have largely been identified as knowledge gaps, and are being covered by a range of projects currently being conducted or completed. See Section 1.2 for a number of tools available internationally.

A focus for all projects is to identify tools, methods, research and information in relation to ecological functioning, stressors and ecological effects.

## 3.5 QUESTION 4: CAN RISK-BASED OBJECTIVES (QUANTITATIVE OR SEMI-QUANTITATIVE) REASONABLY BE DERIVED FOR USE WITHIN THE PRESENT REGULATORY FRAMEWORK

With the river classification system (and associated resource-directed measures for management) being conceptually risk-based, a regulatory environment has been established that is accommodating of risk-based assessment and management. The use of source-directed controls could however benefit from a risk assessment approach, particularly in developing scenario-based decision support systems (Jooste and Claassen, 2000). The risk-based approach is therefore essentially an extension of the precautionary approach as adopted by DWAF.

Although risk-based objectives can be used in the following process;

- identify hazard,
- quantify the hazard, and
- express the likelihood of effect on the identified end-point,

the question remains as to its application and usefulness. It was felt that the usefulness of this approach is largely dependent on current management approaches and thinking (although current thinking is in line with current approaches, e.g. to EWR assessments). Risk communication and the development of a risk policy, were identified as essential management requirements.

# CHAPTER 4

# RECOMMENDATIONS AND IDENTIFIED GAPS

- More focus is required on the definition of stressors. Some fundamental research on the water quantity and quality conditions that arise naturally without negatively impacting on biota, as well as those conditions which do affect biota, needs to be identified. Since this would likely involve observations in real ecosystems, it poses a real challenge to the research- and funding communities, but one that would be well worth its investment in improving confidence in resource management.

- Develop ecosystem knowledge and understand the behaviour of ecosystems and their response to stressors. This knowledge arises from monitoring, experimentation or modelling (among other methods), and must incorporate the impact of the environment on the behaviour of the stressor. A good knowledge of the system quantifies variability, increases confidence in results, and improves the predictability of the assessment.

- Cause-effect diagrams facilitate understanding of the study. Factors such as sources, stressors, exposure routes, end-point, response, measure and ecosystem links must therefore be defined (Claassen *et al.*, 2001).

  Examples modified from Claassen *et al.* (2001) include the following:

| | |
|---|---|
| **Sources** | Effluent discharge |
| **Stressors** | Heavy metals |
| **Exposure routes** | Speciation / transport |
| **End-point** | Aquatic invertebrates |
| **Response** | Mortality |
| **Measure** | Presence – absence |
| **Ecosystem links** | Fish |

- Introducing hazard assessment to an extensive site / situation-specific risk assessment approach: It is recommended that a *tiered assessment approach* be adopted. The criteria to move from tier to tier needs to be formulated, and although such approaches have been developed (e.g. Direct Estimation of Ecological Effects Potential (previously known as TEHA or Toxicity-based Ecological Hazard Assessment)), the adoption of such approaches has not yet taken place although being investigated (Jooste and Claassen, 2000).

- Most risk assessment protocols allow for participation by *Interested and Affected Parties* (I&APs). Guidelines need to be established to decide the extent and representation in the risk management process (Jooste and Claassen, 2000).

- Management decision on fundamental *assessment hypothesis:* The statistical foundations of risk assessment allows for different hypotheses in assessing stressor impacts. On the one hand, it can be assumed that an effect or a risk exists until the contrary is proven, or conversely, it can be assumed that no effect or risk exists until the contrary is proven. This would need to be reflected in management policy (Jooste and Claassen, 2000).

- Setting of *bright lines* in the risk continuum to denote points or levels corresponding to, for example, clearly trivial (*de minimis*) risk and clearly unacceptable (*de manifestos*) risk. This would serve to divide the risk continuum into action domains, and will largely be a matter of policy, possibly in consultation with I&APs (Jooste and Claassen, 2000). There exists a considerable body of knowledge in both the USA and Europe on the psychology of risk criteria and how these could be developed, but these need to be adapted to South African conditions.

- *Peer review* is an objective of the risk assessment process, and is relevant particularly in the case of disputes (Jooste and Claassen, 2000).

- A gap that was identified during the workshop was the need for a *pilot application using actual generated data*, i.e. calibrating hazard or stressor-response relationships using real data. This gap therefore concerns a need to validate methods so as to set stressor-response functions for all variables

- The impact of *biological stressors* have not been evaluated, e.g. exotic species, introduced species (e.g. via water transfers), and genetically modified organisms. These impacts are of particular importance in a management framework.

- How will *mixtures* be dealt with? It may be possible to develop a generic stress index for some key effluents, e.g. textile and pulp and paper effluents; even on a site-specific basis. Care should be taken in calibrating such a stress index, due to the variability of effluents.

- The link between risk assessments and other resource-based approaches such as river health and ecosystem integrity will have to be defined, so as to assess the validity of a risk assessment approach.

- A large gap in thinking is still the development of *co-integrating the effects of stressors towards defining ecological risk*. More research needs to be undertaken to distinguish mechanistic issues from expectation issues, as risk is essentially an expectation issue. Methods exist in which expectations can be integrated (Jooste, 2001), but these need to be validated. However, the different stressors (each of an innumerable number of water quality-related stressors, flow, a number of habitat-related stressors, as well as a number of biotic stressors) may share mechanistic ecosystem pathways. This would mean that mechanistic phenomena such as additivity, supra-additivity (synergism) and infra-additivity (antagonism) might be involved. These issues should be investigated so that SRR for not only each individual stressor can be derived, but also changes to the SRR in the presence of other stressors.

# REFERENCES


Brown, A.C. (1993) Variability in biological systems. *S. A. J. Sci.*, **89**, pp308-309.

Bush, M.B. (1997) *Ecology of a changing planet.* Prentice Hall, New Jersey, pp434.

Claassen, M., W.F. Strydom, K. Murray and S. Jooste (2001) *Ecological risk assessment guidelines.* Water Research Commission Report No. TT 151/01. Pretoria, South Africa.

Claassen, M. and P.W. Wade (2001) Ecological risk assessment in water resource management. *A. J. Aq. Sci*. **26** (2), pp131-134.

DEAT (2000) *Ecological risk assessment, integrated environmental management.* Information Series 6. Department of Environmental Affairs and Tourism (DEAT), Pretoria, South Africa.

Department of Water Affairs and Forestry (1996) *South African water quality guidelines* (Second edition). Pretoria, South Africa.

Department of Water Affairs and Forestry (1997) *White paper on a national water policy for South Africa*. Pretoria, South Africa.

IWR Environmental (2003) *Mhlathuze catchment: Ecological Reserve and monitoring programme. Mhlathuze monitoring report.* Prepared for the Department of Water Affairs and Forestry, South Africa.

IWR Source-to-Sea (2004) *Instream Flow Requirements Report. Thukela Water Project Decision Support Phase. Reserve Determination Module - Thukela System.* Prepared for the Department of Water Affairs and Forestry, South Africa. DWAF Report No. PBV000-00-10307.

Jooste, S. and M. Claassen (2000). Discussion document produced for RBO workshop held in Grahamstown, 2000.

Jooste, S., H.M. MackKay, P-A. Scherman and W.J. Muller (2000) *Feasibility of using a risk-based approach to set integrated environmental objectives for the protection of water resources.* Water Research Commission Report No. 914/1/00. Pretoria, South Africa.

Jooste, S. (2001) *Risk as a tool in water resource management.* Ph D thesis, University of Pretoria.

King, J. and D. Louw (1998) Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology. *Aq. Ecosyst. Health Manage.*, **1**, pp109-124.

Malan H.L. and J.A. Day (2002a) *Development of numerical methods for predicting relationships between stream flow, water quality and biotic responses in rivers*. Water Research Commission Report No. 956/1/02. Pretoria, South Africa.

Malan H.L. and J.A. Day (2002b) *Linking discharge, water quality and biotic responses in rivers: a literature review*. Water Research Commission Report No. 956/2/02. Pretoria, South Africa.

Malan H.L., A. Bath, J. Day and A. Joubert (2003) A simple flow-concentration modelling method for integrating water quality and water quantity in rivers. *Water SA,* **29** (3), pp305-311

Murray, K. (1999) *National Aquatic Ecosystem Biomonitoring Programme: National Implementation Assessment.* NAEBP Report Series No 8. Institute for Water Quality Studies, Department of Water Affairs and Forestry. Pretoria, South Africa.

Murray, K. and M. Claassen (1999) An interpretation and evaluation of the US Environmental Protection Agency ecological risk assessment guidelines. *Water SA*, **25** (4), pp513-518.

National Water Act (NWA) No. 36 of 1998. *Government Gazette* **398** (19182), pp1-201.

O'Keeffe, J., D. Hughes and R. Tharme (2002) *Linking ecological responses to altered flows, for use in environmental flow assessment: the flow stressor-response method*. Verh. Internat. Verein. Limnol. **28**, pp84-92.

Palmer C.G. and P-A. Scherman (2000) *Application of an artificial stream system to investigate the water quality tolerances of indigenous, South African, riverine macroinvertebrates*. Water Research Commission Report No. 686/1/00. Pretoria, South Africa.

Rand, G.M. (Ed.) (1995) *Fundamental of aquatic toxicology: Effects, environmental fate, and risk assessment*. Second edition, Taylor and Francis, Washington, pp1125.

Scherman, P-A., W.J. Muller and C.G. Palmer (2003). Links between ecotoxicology, biomonitoring and water chemistry in the integration of water quality into environmental flow assessments. *Riv. Res. Appl.* **19**, pp1-11.

Simonovic, S.P. (1996). Decision support systems for sustainable management of water resources: general principles. *Wat. Intl.*, **21**, pp223-232.

Skivington, P. (1997). *Risk assessment for water quality management*. Water Research Commission Report No. TT 90/97. Pretoria, South Africa.

Suter, G.W. (II) (Ed.) (1993). *Ecological risk assessment*. Lewis Publishers, Michigan. pp538.

# APPENDIX 1

The table below shows the relationship between the alternative descriptions for river health categories (Scherman *et al.*, 2003).

| Ecological Condition Categories | Ecological Management Classes |
|---|---|
| A | Natural |
| B | Good (A/B, B, B/C) |
| C<br>D | Fair (C, C/D, D) |
| E<br>F | Poor |