South African National Water Quality Monitoring Programme Series

National Toxicity Monitoring Programme for Surface Waters

Draft Conceptual Design Framework & Record of Decision Report

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Version 1.23

10 March 2005

ACKNOWLEDGEMENTS

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GLOSSARY

Abiotic. In the absence of living organisms.

Antagonistic effect. Occurs when a mixture of toxicants exhibit an overall toxic effect that is less than the sum of the individual toxic effects when each acts alone.

Bioconcentration. The process of uptake of substances into animal or plant tissue through direct exposure to the substance in the environment.

Biotic. Of or pertaining to living organisms.

Biotoxicology: The qualitative and quantitative study of the adverse effects of chemical pollutants and other anthropogenic materials on organisms.

Carcinogenicity. The extent to which a toxicant can cause cancer.

Chemical pollutants. Chemicals dissolved or adsorbed on biotic or abiotic surfaces that can produce a toxic effect. These include metals or metal ions (*e.g.* lead, mercury, iron, manganese, etc.), inorganic chemicals (*e.g.* nitrate, ammonia, sulfate, fluoride, cyanide, etc.) and organic chemicals (*e.g.* phenols, petrochemicals, pesticides, steroids, algal toxins, etc.). Note that living organisms (*e.g.* faecal coliforms, viruses, parasites etc.) are <u>excluded</u>.

Definitive test. An experimental technique that estimates the concentration of the toxicant at which a specified percentage or number of organisms exhibit a certain response. Typically reports a toxicity endpoint, *e.g.* Lethal Concentration (LC), Effect Concentration (EC), Inhibition Concentration (IC), No Observed Effect Concentration (NOEC), etc.

Ecosystem. The total community of living organisms and their associated physical and chemical environment.

Ecosystem integrity. Aquatic ecosystem integrity is defined as 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 state (*i.e.* unimpaired) characteristics of such an ecosystem. (High ecosystem integrity implies that the structure and functioning of an ecosystem are unimpaired by anthropogenic stresses.)

Endocrine disruption. The extent to which a toxicant mimics natural hormones, inhibits the action of natural hormones or alters the normal regulatory function of the immune, nervous or endocrine systems.

Fitness for use. A scientific judgement, involving evaluation of available evidence, of how suitable the quality of water is for its intended use or for protecting the health (integrity) of aquatic ecosystems [DWAF, 2003a].

Fungicide. A pesticide compound specifically used to kill or control the growth of fungi.

Heavy metal. A metallic element with atomic number greater than 20 (*i.e.* that of calcium).

Herbicide. A chemical pesticide designed to control or destroy plants, weeds, grasses or algae.

Hydrocarbons. A very large group of chemical compounds composed only of carbon and hydrogen. The largest source of hydrocarbons is petroleum crude oil.

Hydrophilic. Having an affinity for water.

Hydrophobic. Repelling water.

Inorganic. Composed of chemical compounds that do not contain carbon as the principal element (excepting carbonates, cyanides and cyanates). Matter other than plant or animal.

Insecticide. A pesticide compound specifically used to kill or control the growth of insects.

Lethality. The extent to which a toxicant can cause death by direct action.

Long-term effect. Any toxic effect (lethal or sublethal) that manifests *over a long period* (4 days or more) as a result of exposure to the toxicant.

Long-term exposure. Exposure of the organism to the toxicant delivered in multiple events or continuously *over a long period*, generally weeks or more. Also referred to as chronic exposure.

Mutagenicity. The extent to which a toxicant can damage or change an organism's or cell's genetic material.

Organic. Composed of chemical compounds based on carbon chains or rings and also containing hydrogen with or without oxygen, nitrogen or other elements.

Persistence. Refers to the length of time a compound introduced to the environment, stays there unchanged.

Pesticide. Substances or mixtures of substances intended (i) for preventing, destroying, repelling or mitigating any pest or (ii) for use as a plant regulator, defoliant or desiccant.

Petrochemicals. Chemicals made from petroleum or natural gas. Examples are ethylene, butadiene, most large-scale plastics and resins and petrochemical sulfur. Also called petroleum chemicals.

Petroleum products. Materials derived from petroleum, natural gas or asphalt deposits. Includes gasolines, diesel and heating fuels, liquefied petroleum gases (LPG and bugas), lubricants, waxes, greases, petroleum coke, petrochemicals and sulfur.

Pharmaceuticals. Drugs and medicinal compounds.

Pollutant. Any physical, chemical or biological object or substance that, when suspended, dissolved or adsorbed on biotic or abiotic surfaces in the water, causes pollution.

Pollution. Defined by the National Water Act as the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it (1) less fit for any beneficial use for which it may reasonably be expected to be used, or (2) harmful or potentially harmful to (a) the welfare, health or safety of human beings, (b) any aquatic or non-aquatic organisms, (c) the resource quality or (d) to property.

Rodenticide. A pesticide compound specifically used to kill or control the growth of rodents.

Screening test. A toxicity test performed on the water or test sample "as is", *i.e.* without dilution. Typically reports a percentage effect or a yes/no result.

Short-term effect. Any toxic effect (lethal or sublethal) that manifests *within a short period* (4 days) as a result of exposure to the toxicant.

Short-term exposure. Exposure of the organism to the toxicant delivered in a single event or multiple events *over a short period*, generally hours or days. Also referred to as acute exposure.

Sub-lethality. The extent to which a toxicant or has short- or long-term detrimental effects to living organisms without causing death.

Surfactant. A soluble compound that reduces the surface tension of liquids, or reduces the interfacial tension between two liquids or a solid and a liquid. Also called a surface-active agent.

Synergistic effect. Occurs when a mixture of toxicants exhibit an overall toxic effect that is greater than the sum of the individual toxic effects when each acts alone.

Target organism. The biological system of concern that will potentially manifest one or more toxic effects.

Teratogenicity. The extent to which a toxicant is capable of causing the formation of congenital anomalies or monstrosities. (Thalidomide is a well-known teratogen.)

Test organism. The organism used in a toxicity test.

Toxicant. A chemical pollutant capable of exhibiting a toxic effect.

Toxic effect. An effect manifest as an impairment of the activity of the organism or the cellular or sub-cellular system. In the current context, these effects are also limited to those that can be detected, either currently or potentially, locally or internationally, by a “toxicity test”, as defined here.

Toxicity. In the current context, the degree to which a water exhibits toxic effects.

Toxicity test. In the current context, a toxicity test is regarded an experimental procedure that measures, under defined conditions in the laboratory or in the field, the toxic effects of chemical pollutants in water on a group of living organisms or a cellular or sub-cellular system.

Trace element. A chemical element that is needed in minute quantities for the proper growth, development, and physiology of an organism.

Waste. Defined by the National Water Act as including any solid material or material that is suspended, dissolved or transported in water (including sediment) and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted.

Watercourse. Defined by the National Water Act as a river or spring, a natural channel in which water flows regularly or intermittently, a wetland, lake or dam into which, or from which, water flows and any collection of water that the Minister may declare to be a watercourse. Furthermore, reference to a watercourse includes, where relevant, its bed and banks.

Water resource. Defined by the National Water Act as including a watercourse, surface water, estuary or aquifer.

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

This document presents the current state of thinking in the design of the National Toxicity Monitoring Programme (NTMP). It will evolve into a final report that will record the design process and, in particular, why certain decisions were taken. It will therefore provide background to, and complement, the formal implementation manual of the NTMP.

The NTMP will involve measurements of toxicity to selected organisms and the concentration of selected toxicants. For reasons given in subsequent chapters, these toxicants have been initially restricted to the so-called persistent organic pollutants (POPs). Other toxicants can be included in future. The intention is to complement other national monitoring programmes by reporting on the status and trends of toxicity in South African inland surface water resources. It is also the intention to extend the degree to which "response-based" monitoring is performed in South Africa (by monitoring toxicity) while also adopting the traditional "stressor-based" approach of monitoring some toxicant concentrations directly.

The overarching framework for the current work is the "Strategic Framework for National Water Resource Quality Monitoring Programmes" [DWAF, 2004a]. This provides general design guidelines and a framework for capacity building.

The current design is specifically restricted to inland surface waters. The intention is to extent this design in future to groundwater and estuaries.

1.2 NEEDS ASSESSMENT

A needs assessment was for the NTMP was performed [DWAF, 2003b]. It recognised a number of reasons why the NTMP was necessary:

- South Africa is a signatory of various international agreements and conventions that mean that such monitoring is necessary.
- The Department recognises a responsibility for keeping abreast of international trends.
- The Department also recognises a responsibility for initialising capacity creation upon which further regional capacity creation can be based.

Some of the issues (like the target users and objectives) are addressed explicitly in the following sub-sections. However, the following summarises other the key recommendations.

- The NTMP should address national issues while anchoring itself at catchment level (within catchment management agencies).
- The choice of toxicants should ideally be based on the following four major categories of information. (1) The nature of the monitoring variable. (2) The nature of potential occurrence (throughout South Africa). (3) The nature of the potential impact (on fitness for use). (4) Nature of the monitoring required.
- The choice of toxicity tests should be based on the outcome of the Water Research Commission funded project that will establish guidelines for the choice of toxicity tests to address the requirements of the National Water Act.

- The degree of assessment of raw data appearing in annual reports should be simple though scientifically sound. They should add value to the raw data, not be misinterpreted, and be as consistent as possible for toxicants and toxic effects.
- The NTMP should not be designed to explicitly establish the sources of toxicants or toxic effects.
- The reporting format should make use of easy-to-understand colour-coded maps that illustrate the status and trends of the nature and extent of toxicants and toxicity nationwide.
- The next phase (*i.e.* the current design phase) of this project should, resources permitting, focus on simultaneously producing monitoring designs for watercourses (including sediments), qroundwaters and estuaries.
- Careful consideration must be given to the capacity creation needs demanded by the ultimate choice of monitoring variables.
- The primary role player in future phases will be DWAF. It will have primary management responsibility but will delegate some of this responsibility to catchment management agencies (CMAs). However, specialist consultant expertise is likely to be necessary to supplement that existing in DWAF. An international funding agency is also likely to be a role player for the pilot study phase.
- The overall project should be planned and executed in a modular way while at the same time being holistic.

As will become evident in the following chapters, all of these issues except one are addressed as recommended. The one exception is that this design phase is restricted to inland surface water resources.

1.3 TARGET USERS

It is important that the ultimate users of the target users ("clients") of the information provided in reports produced by the NTMP are (a) clearly identified and (b) kept in mind at all times during the design of the monitoring programme.

The needs assessment for the NTMP identified the following target users [DWAF, 2003b].

Primary users:

- The Minister of Water Affairs and Forestry
- Water Resource Managers and Water Quality Managers (at DWAF Head Office and Regional Offices, CMAs and Water User Associations)

Secondary users:

- National, provincial and local government authorities
- Non Government Organisations
- All industrial sectors
- Public
- Any other interested party

The primary users are necessarily those that have a direct voice in monitoring design decisions. The secondary users are regarded as having an indirect voice because they may use and benefit from the information generated.

1.4 REVISED OBJECTIVES

Objectives of the NTMP were proposed in the needs assessment [DWAF, 2003b]. Slight changes of emphasis described elsewhere in this document, and a need to be more specific about the scope of the water resources addressed in this phase, have resulted in the following re-wording:

National Toxicity Monitoring Programme
DWAF National Objectives

To measure, assess and report on a regular basis
on the status and trends of the nature and extent of,

first, the potential for toxic effects to selected organisms, and,
secondly, potentially toxic substances
in South African inland surface water resources

in a manner that will
(A) support strategic management decisions
in the context of (1) fitness for use of those water resources
and (2) aquatic ecosystem integrity, and
(B) be mindful of financial and capacity constraints, yet,
be soundly scientific.

It is envisaged that the NTMP will fulfil an auditing function as well as be a basis of communication for informing the public.

1.5 RELEVANT INITIATIVES

1.5.1 Introduction

There are many initiatives within the Department and in other organisations that have a bearing, one way or another, on the design of the NTMP. The following sub-sections summarise some of these, their current status and briefly how they relate to the current design.

1.5.2 Guidelines for toxicity tests

1.5.2.1 Purpose

A project funded by the Water Research Commission entitled "Guidelines for the Selection of Toxicity Tests in Support of the National Water Act (NWA)" is nearing completion. The purpose of this initiative is to provide a facility to the Department and other stakeholders in water resource management that will allow for the objective choice of appropriate toxicity tests in a series of specific NWA contexts.

1.5.2.2 Approach

The management contexts identified are as follows:

Resource Directed Measures

- Classification and Resource Quality Objectives

- Reserve determination – basic human needs
- Ecological Reserve Determination
- Monitoring ecosystem health
- Monitoring compliance with Resource Quality Objectives
- National status and trends monitoring

Source Directed Controls

- Pollution prevention
- Emergency incidents
- Licence conditions

Inland water resources and estuaries are the two water resource types considered. The water body, sediment or groundwater zone can also be chosen. Both fresh and brackish waters are considered for inland water resources.

Only tests considered to be "well established" and reliable are included.

Generic management criteria relating to the following were specified for each management context in collaboration with the Department.

- Legal defensibility
- Effect period (short-term or long-term)
- Target kingdom (animal or plant) – the kingdom to be afforded protection
- Maximum days turnaround time – how quickly results of tests can be obtained
- Maximum costs (low, medium or high)

The facility is embodied in an Excel spreadsheet. The user specifies the nature of the resource of interest and the most relevant management context. The spreadsheet then indicates the suite of toxicity tests that satisfy the criteria. This "shortlist" of tests becomes the point of departure for the final choice of tests most appropriate for the circumstances using other requirements such as the specific organism, the physical nature of the test, analytical and infrastructure requirements, toxicity test endpoint, and so on.

1.5.2.3 Status

The first version is likely to be released in mid-2005 for formal testing.

1.5.2.4 Relevance

Although being more broadly based than only national status and trends monitoring, this facility will almost certainly provide essential input into the design of the NTMP. In particular, it will provide an initial shortlist of applicable toxicity tests that can be further refined (shortened) by imposing other more demanding criteria. These criteria may relate to the following:

- Suitability for nationwide decentralised capacity creation
- Simplicity of application
- Simplicity of assessment of results (in terms of the NTMP objectives)
- Costs
- The degree to which direct analysis of chemical toxicants can be practically undertaken

1.5.3 Environmental Water Quality

1.5.3.1 Introduction

"Environmental Water Quality" (EWQ) is a concept that focuses on understanding how chemical, microbiological, radiological and physical characteristics of water (the "water quality") link to the responses of living organisms and ecosystem processes (the "environment") [Palmer *et al.*, 2003]. There are three kinds of information that underpin this integrated picture:

- The physico-chemical characteristics of water (obtained from chemical and physical analysis).
- The presence, absence and abundance of biota in an ecosystem (obtained from biomonitoring).
- The responses of specific biota to specific concentrations or mixture of components (obtained from ecotoxicology).

1.5.3.2 Integrated Water Resource Management (IWRM)

Strategic Adaptive Management is at the core of IWRM. This involves a cyclical process of four steps: Plan, Implement, Monitor and Adapt.

The "plan" typically involves a catchment assessment study the ultimate purpose of which is to feed into the catchment management strategy. This requires setting the basic human needs Reserve and the ecological Reserve. The latter requires setting the requirements of the ecosystem (the "ecospecs") and the requirements of users (the "userspecs"). EWQ plays a role in a number of contexts:

- Water quality ecospecs can be explicitly based on the EWQ concept.
- The characteristics of a catchment can be described in terms of the above three kinds of information underpinning EWQ.
- This integrated picture can contribute to a better understanding of a catchment during stakeholder engagement and catchment visioning processes.
- The three components of EWQ can contribute directly to the resource classification process since each class can be defined in terms of physico-chemistry, biomonitoring and ecotoxicology.

The "implementation" step focuses on Source Directed Controls (SDCs) that aim to ensure the objectives set for a water resource (the Resource Quality Objectives, RQOs) are achieved. This involves formally authorising (*i.e.* licensing) users for defined water uses, encouraging self-regulation and imposing economic incentives and penalties. All three components of EWQ can be used as licence conditions.

The "monitoring" step can include monitoring the resource and auditing end-of-pipe discharges. All three aspects of EWQ are applicable.

The "adapt" step refers to assessing the results of the monitoring to determine whether the original plan is on track (*i.e.* the RQOs, and hence the assigned management class, is either being maintained or movement towards their achievement is as planned). If indications are otherwise, then changes (*i.e.* management interventions) are required to ensure this happens.

1.5.3.3 Status

Many water use licences involve monitoring the physico-chemistry of water. Some water use licences exist at this time (2004) that require biomonitoring. However, far fewer exist that include toxicity testing. A particular current drawback is that guidelines and standards do not yet exist for toxicity tests so such testing is only recommended, not mandatory.

However, biomonitoring is being carried out in many water management areas.

1.5.3.4 Relevance

Monitoring toxicants directly produces information on the chemical characteristics of the water. Monitoring effects on biota (through toxicity tests, biomarkers or bioaccumulation measurements) provides responses of biota to the presence of chemical components.

The EWQ concept is relevant to the NTMP but only in the context of chemical components. (Microbiological and radiological components, for example, are excluded from the NTMP.) It is particularly relevant at the higher level of providing a framework for thinking when considering how information from the NTMP could complement, for example, the river health programme (which uses biomonitoring). The same kind of thinking could be applied to how the inorganic chemicals national monitoring programme might complement the river health programme.

1.5.4 Resource Directed Measures

1.5.4.1 Introduction

The National Water Act stipulates that the following be defined for each appropriate unit of water resources. Each should be defined through effective stakeholder engagement that is given effect and focus through a catchment visioning process [DWAF, 2003a].

Resource management class

Defining a management class for a water resource can be regarded as the "first line of defence" that ultimately aims at ensuring sustainable development. It captures the most desirable balance between protection of water resources, optimal water use, equity between generations and current equitable access [DWAF, 2003a].

Basic human needs Reserve

The basic human needs Reserve provides for the essential needs of individuals (*e.g.* drinking, food preparation and personal hygiene) served by the water resource in question. It specifically does not include any volume of water for small- or large-scale productive uses.

Ecological Reserve

The ecological Reserve is the quantity and quality of water required to protect aquatic ecosystems of water resources. The specifications of the water quality component of the ecological Reserve on an individual variable basis are called "ecospecs". The degree of “protection” actually afforded to aquatic ecosystems by the Ecological Reserve will depend on the desired degree of protection and the ability of the Department or CMAs to actually ensure that this volume is delivered consistently and in accordance with the requirements laid down in the ecospecs.

Resource Quality Objectives (RQOs)

RQOs are either numerical or narrative expressions of the desired water quality, water quantity and overall resource quality for the management class chosen for a particular water resource.

Resource directed water quality management policy

A draft operational policy exists that is heavily principle-based [DWAF, 2003a]. It proposes hierarchies of enabling principles for all the important principles that underpin resource directed water quality management. Examples are sustainable development, effective stakeholder engagement, various management and governance principles and integrated water resource management. The policy provides a strategic national perspective as well as specific policy statements on all important resource directed issues. These include catchment visioning, catchment assessment, resource directed measures, catchment management strategies and monitoring and auditing.

1.5.4.2 Status

The Class, Reserve and RQOs for each resource unit will be published in the *Government Gazette*. This makes them legally enforceable. However, the Department remains preoccupied with developing appropriate procedures for classification, Reserve determinations and setting RQOs. These efforts are also more heavily focussed on surface water resources than other resources (groundwater, estuaries, wetlands, and impoundments).

It is also the Department's policy to set either narrative or quantitative resource water quality objectives (RWQOs) that are spatially and temporally incremental water quality targets [DWAF, 2003a]. These are management targets that will guide Source Directed Controls and ultimately allow a realisation of the catchment vision in general and the RQOs in particular. However, until RQOs are defined, individual RWQOs necessarily remain undefined. However, procedures for their definition (linking RQOs and effluent discharge licence conditions) are being developed.

Draft recommendations currently exist for many variables comprising the water quality component of the ecological Reserve [Rossouw, 2004]. However, while toxicity tests are acknowledged as being an important biological response variable, methods for their inclusion have not been developed. Methods for categorising the present state of a resource as Natural, Good, Fair or Poor are provided for 15 individual substances (some as a function of hardness) for which South African Water Quality Guidelines for Aquatic Ecosystems are available [DWAF, 1996g]. These are aluminium, ammonia, arsenic, atrazine, cadmium, free chlorine, chromium(III), chromium(VI), copper, cyanide, endosulfan, fluoride, lead, mercury and phenol. Note that only three organic compounds are addressed (atrazine, endosulfan and phenol).

A stakeholder engagement and catchment visioning process would result in the desired state *of the aquatic ecosystem* being expressed as Natural, Good or Fair. Benchmark tables for individual substances (salts, pH, the above toxicants, etc.) translate this desired category into desired numerical ranges of concentration. That is, attaining and maintaining the variables within these ranges (or better) is regarded as ensuring the desired (or better) level of aquatic ecosystem integrity is attained or maintained. (Equivalently, "reserving" these ranges ensures the desired aquatic ecosystem integrity.)

In practice this usually means that upper limits on concentrations are specified. For example, if the desired state in "Natural", then the arsenic concentration would be need to be kept below, say, 0.02 mg/l (unless this benchmark value has been otherwise calibrated because of naturally higher levels). However, the desired state may only be "Fair" (since the water resource may have been accepted by all as being a "working resource" whose ecosystem integrity can be sacrificed to some degree because of other, typically socio-economic, advantages). Then the upper limit may be, say, 0.13 mg/l.

1.5.4.3 Relevance

The RQOs are the ultimate expression of fitness for use of any particular resource (agreed as so by all relevant stakeholders). The objectives of the NTMP state that the monitoring should "support strategic decisions in the context of fitness for use". Some practical connection between the NTMP and RQOs is therefore essential.

There should also ideally be compatibility between the approaches used in the NTMP and those used for specifying the ecological Reserve.

1.5.5 Source classification

1.5.5.1 Purpose

A classification system at national and water management area level has been proposed for sources of pollution [DWAF, 2003d]. Source classification is defined as the "categorising of sources according to the level of threat or risk posed by the source to the water resource". The primary purposes are the following:

- To enable water quality management efforts to be focussed on those pollution sources that pose the greatest risks. In particular, the water use authorisations and the development of Best Practice guidelines can be prioritised.
- To ensure that those sources with the greatest impact (or potential impact) are subjected to scrutiny in respect of the principles of efficiency (*i.e.* wasting of water is minimised) and differentiation (*i.e.* catchment-specific conditions are considered).

1.5.5.2 National level classification

The approaches recognises five main sectors, namely mining, industry, agriculture, settlements (urban and rural/dense) and national infrastructure (*e.g.* contaminated land, railway and shipping activities and natural processes). Each is divided into sub-sectors that are further categorised into activities and processes of similar nature. These are then classified on the basis of the risk or threat posed to water resources, *i.e.* the potential of the source to have a serious detrimental impact on the water quality of the resource.

Various source management options are proposed that depend on the class (A, B or C) assigned to each activity. These options refer to requiring Best Practice guidelines, the degree of co-governance, whether licensing is required or whether a general authorisation suffices, or whether an exemption is appropriate.

1.5.5.3 Water Management Area classification

Classification at this level will be used to ensure the Source Management Plan of the catchment management strategy of each catchment management agency is appropriately focussed. An inventory of sources will be compiled with a description of the relevant processes, substances or activities. These will then be the basis of estimating the risk to the water resource (based on either or both of expert opinion and a semi-quantitative risk-based approach).

A risk-ranking matrix is suggested as one approach. It involves estimating the probability of a problem occurring on a six-point scale (from "not expected to happen" to "expected to occur") and classifying the likely consequences also on a six-point scale (from "very low " to "catastrophic"). The ranking matrix then provides a score from 1 to 20 that is regarded as the level of risk.

1.5.5.4 Status

Full implementation of the source strategy nationwide is only envisaged by 2014 [Bredenhann, 2004, personal communication].

1.5.5.5 Relevance

National status and trends monitoring is traditionally performed on the basis of priority areas. "Priority areas" in the current context are areas in which either (a) the actual water quality is significantly impacted by toxicants or (b) there is a significant risk of such impacts. The source classification approaches have the potential to provide useful information on likely priority areas.

1.5.6 Direct Estimation of Ecological Effect Potential (DEEEP)

1.5.6.1 Approach

Traditional substance-specific assessments of wastewater discharges have limitations. Accordingly, a new approach to assessing the toxicity of whole effluents has been proposed [DWAF 2003c]. Effect-based hazard assessments of effluents can provide insight into the combined effects of both known and unknown hazardous substances (and their interactions, either synergistic or antagonistic) in a mixture.

1.5.6.2 Status

Only the general methodology has been proposed and released for comment [DWAF, 2003c]. Specific tests have not yet been proposed.

1.5.6.3 Relevance

Although the DEEEP approach tests effluents and not water resources, it seems sensible to ensure some degree of compatibility between the two initiatives for a number of reasons:

- Capacity creation could possibly be focussed on satisfying the requirements of both initiatives simultaneously. This could result in considerable cost savings.
- Data assessments from each initiative are more likely to facilitate establishing cause-effect relationships between discharge and resource quality though this is not a deliberate intention of either initiative.

CHAPTER 2:
RESOURCE CLASSIFICATION FRAMEWORK

2.1 INTRODUCTION

The objectives of the NTMP are stated in the Background chapter. The "strategic management decisions" typically relate to the following kinds of issues:

- International responsibilities (overseas as well as neighbouring countries).
- Large scale (spatial and temporal) monitoring of the Department's management efforts.
- Capacity creation as a basis for further regional capacity creation.

The word strategic implies large in scale, both spatial (*e.g.* Water Management Areas and National) and temporal (*e.g.* annual or longer).

A particularly important focus of the objectives is on fitness for use and aquatic ecosystem integrity. National monitoring programmes to date have had similar objectives, although some have been less focussed on ecosystem integrity and more on fitness for use. In order to assess fitness for use they have typically developed their own guidelines against which monitoring data are assessed. The following are some examples:

- The microbial monitoring programme developed *E. coli* and faecal coliform guidelines that assessed the likely health risk associated with a number of sensitive water uses (like drinking untreated water, drinking partially treated water, irrigation of crops eaten raw and recreational use).
- The eutrophication monitoring programme assessed "trophic status" against chlorophyll *a* and total phosphorous concentrations (allowing a classification of impoundments from oligotrophic through to hypertrophic).
- The river health programme has developed indices that report the degree of departure of a water resource from natural (reference) conditions. This programme is primarily focussed on ecosystem integrity and not uses such as domestic, agricultural, industrial, etc.
- The inorganic chemical monitoring programme can assess its results against the South African water quality guidelines. If, for example, the livestock watering guidelines are used, then fitness for this particular use can be assessed.

A central question in the design of the NTMP is exactly what is most usefully and practically meant by "fitness for use". A question that is implied by this is "what guidelines should the NTMP be using to assess its monitoring data?".

The following sections recommend an approach to national status and trends monitoring that addresses these questions.

2.2 ASSESSING ECOSYSTEM INTEGRITY

The approach used in the development of the water quality component of the ecological Reserve [Rossouw, 2004] suggests a way forward. The purpose of this component of the ecological Reserve is to ensure that water of adequate quality is maintained in ecosystems to ensure a certain desired level of integrity.

2.2.1 Ecological category and the Ecological Reserve

The basic level of ecosystem integrity is defined on a resource-specific basis. In particular, an "ecological category" for which water resource managers should aim is defined as Fair, Good or Natural. A Poor state is regarded as unsustainable and is never a desired state. If the present state is Poor, then it should be managed in such a way as to improve it to the desired state.

Importantly, the ecological category need not always be Natural. It must necessarily ultimately relate to the formal classification of the resource unit in question. This also takes account of how stakeholders wish to use the resource. In other words, classifying a resource is equivalent to the stakeholders saying that they wish the resource to (a) maintain a certain degree of ecosystem integrity and (b) enable the water to be used for certain well-defined uses. The latter may vary from recreational, through industrial to various agricultural uses (like livestock watering, aquaculture, irrigation, etc.) and domestic use. The degree of ecosystem integrity and the nature of the uses must necessarily be compatible. For example, if the water is intended to be used for a purpose that inevitably impacts negatively on ecosystem integrity, it may be agreed that the latter may be sacrificed somewhat for the greater socio-economic advantages of the intended use.

It is these concepts that ultimately make the classification and the Reserve the first line of defence against unsustainable development.

2.2.2 Guidelines for the Ecological Reserve

The most fundamental concept to be applied in the determination of an ecological Reserve relating to guidelines is illustrated in the following table.

Table 2.1. Illustration of the most fundamental concept in the ecological Reserve determination relating to toxicants and toxicity. (NOEC = no observable effect concentration; LC_0 = maximum concentration that does not cause lethality.)

Ecological category	Criteria	Toxicity observed	Toxicant concentration (X) observed
Natural	No toxicity of any kind	None	X < NOEC
Fair & Good	No lethality (short- or long-term)	Sub-lethality	NOEC < X < LC_0
Poor (unsustainable)		Lethality	X > LC_0

The following should be noted:

- The original basic concept has been slightly refined and re-defined here to improve clarity and practicality.
- The original wording used the terms acute and chronic. These were defined as meaning lethality and sub-lethality respectively. In order to avoid potential confusion, the words acute and chronic are not used here.
- The ecological Reserve determination goes further than the basic concept illustrated in the table. It must also distinguish between the Fair and Good categories. However, it is recommended that for the NTMP these two categories are grouped together (for simplicity).
- The ecological Reserve concept referred to the terms chronic effect values and acute effect values. These have been re-defined as "no observable effect concentration" (NOEC) and LC_0 (maximum concentration that does not cause lethality) to be more consistent with the "no toxicity" and " no lethality" criteria.

Importantly, the ecological Reserve guidelines will ultimately achieve significant regulatory status in that they will be published in the *Government Gazette*. Accordingly, to be defensible, these values must be based on a significant amount of data and formal analysis [*e.g* Jooste and Rossouw, 2002].

2.2.3 Resource Quality Objectives

Resource Quality Objectives (RQOs) are objectives against which it can be assessed whether or not a water resource is presently in its desired state (or moving towards it). One numerical expression of these are Resource Water Quality Objectives (RWQOs) that may also be defined at a greater spatial and temporal resolution that RQOs. For example, a RQO may express where the resource should ultimately be. RWQOs may state explicitly where in the water resource (and when) certain targets should be achieved in order to ultimately achieve the overall RQO.

The RQOs and RWQOs will necessarily need to be compatible with the variables chosen to monitor the water quality component of the ecological Reserve (and the basic human needs Reserve).

Since RQOs will also be published in the *Government Gazette* (but not so with RWQOs), the RQOs will also have significant legal status and therefore will also necessarily have to be based on defendable data and analysis.

2.2.4 Applicability to the NTMP

2.2.4.1 Monitoring endpoint

The above suggests that, within the context of ecosystem integrity, the NTMP could use the same basic concept as illustrated in the table above (for both toxicants and toxicity). However, one critical and obvious difference would be that the NTMP would not use the same monitoring variables. Nevertheless, the ultimate purpose of the NTMP would still be to specifically assess the following question ("endpoint"):

Is the water resource in an acceptable ecological category?

An "acceptable ecological category" is defined for current purposes as follows:

Table 2.2. Definition of acceptable and unacceptable ecological categories.

Desired ecological category	Acceptable ecological category	Unacceptable ecological category
Natural	Natural	Poor, Fair or Good
Good	Fair, Good or Natural	Poor
Fair	Fair, Good or Natural	Poor

This is, in effect, the same issue addressed by monitoring variables specifically associated with the ecological Reserve. However, the latter monitoring would use the associated "Gazetted" variables while the NTMP would use other specially chosen variables.

2.2.4.2 Monitoring variables

The NTMP monitoring variables would need to have certain properties:

- The NTMP variables would need to complement the information obtained from the ecological Reserve and RQO monitoring variables. However, they need not be based on the same degree of data and formal analysis since "broad brush" national monitoring need not be reporting with the same degree of certainty. (For example, identification of polluters is not an objective of national status and trends monitoring.)

- The NTMP variables can address other issues of national (and international) concern. For example, these variables can help keep abreast of the latest international trends and investigate their relevance to South Africa.

It is conceivable that as more data are collected over the years for NTMP monitoring variables that they may be "promoted" to the level of ecological Reserve monitoring variables or even RQOs. However, this is only likely to be done when the latter variables come up for revision and it is considered appropriate to include other variables to improve the quality and quantity of the more "formal" monitoring RQO-related information provided to resource managers.

The above endpoint suggests a very simple choice of monitoring variables (illustrated in the following tables). (This simplicity is one aspect of the currently proposed approach that makes it very attractive.)

Table 2.3. Choice of toxicity tests and interpretation of guidelines for ecosystem integrity.

		Is resource in an acceptable ecological category?	
Desired ecological category	**Recommended toxicity test**	**If toxicity detected**	**If toxicity NOT detected**
Natural	Sub-lethality	No	Yes
Fair or Good	Lethality	No	Yes

It is proposed that Fair and Good categories be combined into one category for the purposes of national status and trends monitoring. This is regarded primarily as a simplification.

An analogous approach can be used for the concentration of a toxicant based on its NOEC and LC_0:

Table 2.4. Interpretation of toxicant guidelines for ecosystem integrity.

		Is resource in an acceptable ecological category?	
Desired ecological category	**Recommended guideline**	**If concentration > guideline**	**If concentration <or= guideline**
Natural	NOEC	No	Yes
Fair or Good	LC_0	No	Yes

2.2.4.3 Reporting format

The above endpoint suggests a very simple reporting format. A map of an area could reflect each monitoring site and simply report whether or not the present state of the resource is within (or better than) the desired ecological category at each site. If the answer is "yes" a green icon can be used. If the answer is ""no", a red icon is used.

2.3 ASSESSING FITNESS FOR USE

2.3.1 Introduction

An equivalent approach to the above can be adopted for assessing fitness for specific uses. The endpoint in each case could be as follows:

Is the water resource in an acceptable water use class?

An important issue here will be the choice of test organism. It should ideally be one that is representative of target organisms appropriate to the nature of the use, *i.e.* those to be afforded some degree of protection. The table of typical target organisms is reproduced here for convenience.

Table 2.5. Target groups associated with standard water uses [based on Slabbert and Murray, 2004].

Protective context	Most obvious direct target groups	Most obvious indirect target groups
Aquatic ecosystem integrity	Microbes, Fish, Invertebrates, Birds, Mammals, Amphibians, Reptiles, Molluscs, Crustaceans, Plants	Humans
Domestic use	Humans	
Recreational use	Humans	
Industrial use*	Humans	
Agriculture use - irrigation	Plants	Humans, Mammals
Agriculture use - livestock watering	Mammals, Birds	Humans
Agriculture use - aquaculture	Fish, Reptiles, Plants	Humans, Mammals

* Regarded as equivalent to domestic use in the current context.

2.3.2 Water use class

Categories such as Unacceptable, Tolerable, Acceptable and Ideal are used to categorise the degree to which a water resource is suitable for specific uses. These are conceptually equivalent to the above ecological categories. The NTMP will need to recommend guideline values that distinguish (a) Unacceptable from Tolerable and (b) Acceptable from Ideal. As above (and again for simplicity), it is recommended that the categories Tolerable and Acceptable be grouped together. That is, for the purposes of the NTMP, no attempt should be made to distinguish between these two.

For toxicity tests, exactly the same general guidelines could be used as for ecosystem integrity above. That is, the equivalent of the unsustainable Poor ecological state would be assumed to exist if lethality is detected in an appropriate target organism. Similarly, a Natural state would be assumed to exist if no toxicity of any kind is detected.

For toxicants, again the same approach can be adopted. For the specific target organism relevant to the chosen use, a NOEC and LC_0 can be chosen and assessed in the same way as above. To be explicit, the following tables relating to water use class are the equivalent tables to those above for ecosystem integrity.

An "acceptable water use class" is defined as follows:

Table 2.6. Definition of acceptable and unacceptable water use classes.

Desired water use class	Acceptable water use class	Unacceptable water use class
Ideal	Ideal	Unacceptable, Tolerable or Acceptable
Acceptable	Tolerable, Acceptable or Ideal	Unacceptable
Tolerable	Tolerable, Acceptable or Ideal	Unacceptable

Table 2.7. Choice of toxicity tests and interpretation of guidelines for fitness for use.

		Is resource in an acceptable water use class?	
Desired water use class	**Recommended toxicity test**	**If toxicity detected**	**If toxicity NOT detected**
Ideal	Sub-lethality	No	Yes
Tolerable or Acceptable	Lethality	No	Yes

Table 2.8. Interpretation of toxicant guidelines for fitness for use.

		Is resource in an acceptable water use class?	
Desired water use class	**Recommended guideline**	**If concentration > guideline**	**If concentration <or= guideline**
Ideal	NOEC	No	Yes
Tolerable or Acceptable	LC_0	No	Yes

2.4 IN THE ABSENCE OF A CLASSIFICATION

Until the classification system is formally finalised and has been widely applied around the country, resources will not be formally classified. It may take many years before a significant percentage of the nation's water resources are formally classified in respect of both ecological category and water use.

In the interim, either desktop or rapid methods are likely to be necessary. Such methods are being developed. Specifically, guidelines are under development for the determination of Resource Water Quality Objectives [DWAF, 2004b] that can potentially also be defined as formal Resource Quality Objectives. The procedure specifically involves determining an appropriate ecological category and water use class. It is proposed that these procedures be used for the NTMP until formal classification is possible.

2.5 ADVANTAGES

It has been proposed that the ecological state, water use class and management class be related in the following way [DWAF, 2004b] (although this may be revised when the classification system is finalised).

Table 2.6. Potential relationship between ecological category, water use class and management class.

Ecological category	**Water Use Class**	**Management Class**
Natural	Ideal	Excellent
Good	Acceptable	Good
Fair	Tolerable	Fair

By linking the NTMP to the ecological category and the water use class, as described above, the NTMP is implicitly linked to the most fundamental of initiatives within the Department, namely the classification system and the Reserve. These are well recognised as being the most revolutionary concepts of the National Water Act that provide the first line of defence against unsustainable development.

Linking this national status and trends monitoring programme to the classification has the following advantages, and is accordingly strongly recommended:

- It provides unambiguous information that will "support strategic management decisions in the context of fitness for use … and aquatic ecosystem integrity" (the fundamental objective of the NTMP), since the management class is an implicit statement of what is desired for the resource in these two respects.
- It standardises how fitness for use and ecosystem integrity are interpreted in different contexts (specifically the Reserve, classification and national status and trends monitoring). In particular, this approach ensures this by adopting the same basic definition as that used for the ecological Reserve. In other words, the NTMP need not (and arguably should not) develop a different basic philosophy for choosing guidelines (as has been the case in other national status and trends monitoring programmes). Doing so has the danger of introducing inconsistency with the Reserve and the classification system.
- It provides clear guidance on the broad choice of NTMP monitoring variables (*e.g.* when to use lethality or sub-lethality toxicity tests and how to choose guidelines against which to assess monitoring data for toxicants).
- It provides a clear dividing line between variables chosen for the NTMP and those for monitoring the Reserve and Resource Quality Objectives (called "performance monitoring"). This is done by:
  - Explicitly choosing NTMP variables that complement, *i.e.* are not equal to, those chosen for performance monitoring, and
  - Allowing NTMP variables to be chosen that do not necessarily need extensive data availability and formal analysis (since national monitoring programmes need not report with the same demanding degree of confidence as the Reserve and RQOs), and
  - Allowing variables to be chosen that can address national (and international) issues not regarded as the immediate concern of the formal ecological class and water use class (though they may be of potential future concern). That is, there is greater flexibility in choice of monitoring variables in a national status and trends monitoring programme.
- It provides a natural approach to identifying priority resources upon which the NTMP should focus, particularly in the initialisation phase. For example, those water resources whose present state is worse than the management class are ideal initial candidates for the NTMP. These are, by definition, the resources in greatest need of attention and improvement. The more monitoring information that can be obtained about their status and trends the more informed management responses can be.

CHAPTER 3: NULL HYPOTHESES

3.1 INTRODUCTION

The following sections describe the concept of the null hypothesis and associated errors. Specific null hypotheses are proposed for the NTMP that are compatible with a possible resource classification system. The implications of making errors are also described. This provides guidance on the choice of monitoring variables and the guidelines (that are used to assess monitoring data), particularly in the context of sensitivity of tests and possible bias introduced by the guidelines.

3.2 INTERPRETING HYPOTHESES

3.2.1 Terminology

The following sections show how to interpret various null hypotheses (H_0) and the corresponding test or alternative hypotheses (H_a). Usually the alternative hypothesis states what we hope to be true. The null hypothesis states the opposite of this. For example, in respect of toxicity, we would hope that there is not a toxicity problem in a given water resource.

When reporting the results of monitoring, two kinds of errors can be made. These are most usefully referred to as "false negative" and "false positive" results. The word "positive" refers to reporting that the null hypothesis (whatever it might be) is true.

- A "false negative" refers to reporting a negative result (*i.e.* that the null hypothesis is false) when it should have been reported as positive.
- A "false positive" result refers to incorrectly reporting a positive result (*i.e.* the result was actually negative).

These terms are fairly intuitively obvious and therefore should be used in communication. Statisticians refer to these respectively as "Type I errors" (or the Greek letter α) and "Type II errors" (or the Greek letter β). However, these are not useful terms to use as they do not convey any meaning in themselves (except to those who use them frequently) and so will not be used further here.

Statisticians also relate the "confidence level" to the probability of a false negative as follows:

Confidence level (%) = 100 – probability of false negative (%)

This means the higher the required confidence, the lower the probability of a false negative.

Statisticians also talk about "power". This is related to the probability of a false positive as follows:

Power (%) = 100 – probability of a false positive (%)

This means the higher the power, the lower the probability of a false positive.

3.2.2 Causes of errors

A number of factors cause false negative and false positive errors. The following table summarises some of them. It assumes that the null hypothesis is simply "there is a toxicity problem".

Table 3.1. Possible causes of false negative and false positive results.

	Causes of false negative results	Causes of false positive results
Sampling method	Snapshot sampling that may miss toxicant peaks or spikes.	
Sampling site		Sampling in an effluent plume or mixing zone (giving an unrepresentative sample).
Sensitivity	Insensitive tests.	Overly sensitive tests.
Bias	Using toxic criteria that are too lenient.	Using toxic criteria that are too strict.
Variability	Highly variable toxicity test results in the vicinity of the toxic criterion can report no problem when there is actually a problem (see figure).	Highly variable toxicity results in the vicinity of the toxic criterion can report a problem when there is actually no problem (see figure).

The *sampling method* may contribute to false negatives if water samples are taken at times that miss peaks or spikes of toxicant concentrations. In such cases, the measurement (of either toxicants or toxicity) may indicate little or no problem while organisms in the water resource have indeed been impacted by previous peaks.

The choice of *sampling site* is particularly important in our seasonal rivers and when point source effluent discharges create local plumes of high concentrations in the mixing zone.

Sensitivity relates directly to the choice of monitoring variable, particularly toxicity tests. A test organism may be chosen that is very sensitive to a stressor (*i.e.* a toxicant) relative to organisms present in a water resource. This inherently means an increased likelihood of false positive results being reported. They are "false" because although the response of the test organism indicates a problem, the others organisms may indicate no response because they are less sensitive to the stressor.

Similarly, choosing a test organism that is less sensitive to a stressor than other organisms increases the likelihood of a false negative result.

Bias can be interpreted similarly. Using a toxic criterion that is very strict (*e.g.* has been made conservative by application of the precautionary principle) increases the likelihood of a false positive. If it is lenient, then the likelihood of false negatives increases.

Variability can be caused by either of the following:

- Inherent variability of the sampling and analytical procedures. These involve random errors over which one has little or no control.
- Natural variability of the water resource being sampled.

The following figure illustrates how variability in a measurement causes false negative and false positive results. (Hypothetical values have been chosen although such a high variability is possible with certain toxicity tests. The "true value" is also not always in the centre of the range.)

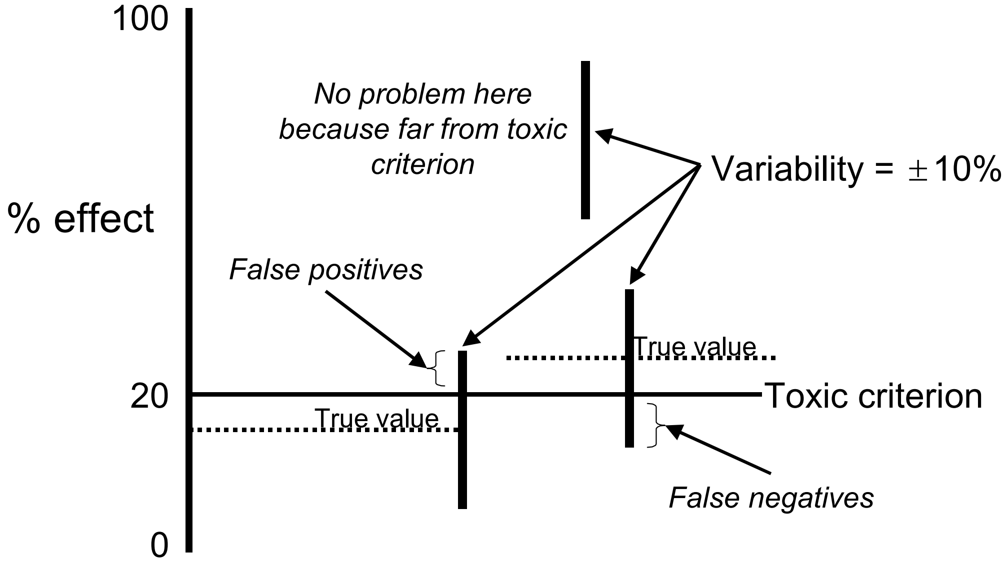

Figure 3.1. Illustration of how variability can cause false negative and false positive results.

3.2.3 Managing errors

Irrespective of which null hypothesis is being tested, false negative and false positive results are errors whose implications should be carefully considered. The following sub-sections describe such implications for some specific hypotheses. However, some generic statements can be made about errors irrespective of any specific hypothesis.

- *Design phase*: In general, the more severe the implications of either a false negative or false positive result, the greater the effort should be to reduce the probability of making such errors in the first place. This requires (a) identifying when specific errors might have unacceptable consequences and (b) designing the monitoring programme to ensure that, under these circumstances, the probability of making the errors is reduced to acceptable levels. This means possible errors need to be addressed before any monitoring takes place, that is, in the design phase.

- *Implementation phase*: When monitoring results begin to be reported, the Department should be aware of the likely uncertainty in any particular result. Specifically it should be aware of the probability of either a false negative or a false positive result. It is therefore in a position to react in a manner appropriate to this known level of uncertainty. The less the uncertainty (*i.e.* the greater the confidence in the result) the more decisive a response by the Department can be. For example, if the probability of a false positive result is 5% or less (and a "positive" result indicates possible problems) then more costly responses would be justified than if the probability was 20%. Equivalently, a high probability of a false positive would suggest greater caution in the response. The same applies to a result that suggests that no action need be taken. This result may be in error. That is, actually a response is required. Again the Department needs to recognise situations when not responding may have serious consequences. As with false positives, the degree to which the Department can be confident that not responding is acceptable depends on the probability of a false negative result.

3.3 SPECIFIC NULL HYPOTHESES

3.3.1 Introduction

Linking the NTMP to the classification system automatically identifies appropriate null hypotheses. It is assumed that it is appropriate to separate the contexts of ecosystem integrity and fitness for use, as indicated in the previous chapter, and identify two null hypotheses addressing status and one hypothesis addressing trends. These are addressed in the following sections.

3.3.2 Null hypothesis for status of ecosystem integrity

3.3.2.1 Definition

The following table defines a possible null hypothesis that allows statements to be made about the status of the ecosystem integrity of a specific water resource. It also defines what is meant by a false negative result and a false positive result.

Table 3.2. Ecosystem integrity null hypothesis.

Null hypothesis	**H_0 = Resource is not in an acceptable ecological category**
Alternative hypothesis	H_a = Resource is in an acceptable ecological category
False negative result	Report resource is in an acceptable category when it is actually in a worse category
False positive result	Report resource is in a worse category when it is actually in an acceptable category

When considering random variability in data only (*i.e.* excluding the sensitivity and bias of measurements and associated toxic criteria), then the following table indicates how different probabilities of the errors can be interpreted.

Table 3.3. Interpretation of different probabilities of a false negative or a false positive result.

	Interpretation
Probability of a false negative	The Department is willing to accept that …
5%	… 1 in 20 times …
10%	… 1 in 10 times …
20%	… 1 in 5 times …
	… it will be reported that the resource is in an acceptable category when it is actually in a worse category
Probability of a false positive	The Department is willing to accept that …
5%	… 1 in 20 times …
10%	… 1 in 10 times …
20%	… 1 in 5 times …
	… it will be reported that the resource is in a worse category when it is actually in an acceptable category

3.3.2.2 Consequences of "false negatives"

The higher the probability of a false negative result, the greater the chances are of reporting that the resource is in an acceptable category when it is actually in a worse category. The NTMP is concerned with providing a degree of protection to selected target organisms and aquatic ecosystem integrity. A high probability of a false negative result increases the chances of such protection not being provided because actual problems are not being detected. The protection is not provided simply because corrective action is not taken because there is apparently no problem. (A "red flag" was simply not raised.)

In essence, an excessive number of false negative results can result in the degree of water resource protection being inadequate to sustain the desired level of ecosystem integrity.

3.3.2.3 Consequences of "false positives"

The higher the probability of a false positive result, the greater the chances are of reporting the resource is in a worse category when it is actually in an acceptable category. The consequences of such an error depend on how (and when) the Department reacts to such information. Many possible scenarios exist.

There may be a response mechanism required for a single sample for which a positive result has just been obtained. The response may be to confirm the result. However, there are again a number of issues that determine whether confirmation is possible and, if so, how it might be done.

- If the result was based on a water sample, should the result be confirmed on the same water sample? Does the water sample still exist? Is it acceptable to use the same sample so long after the sample was taken?
- If the result was based on a biomarker or a bioaccumulation measurement, is the original specimen still available and appropriate to use?
- If the result was based on an active (in stream) measurement, how appropriate is it to repeat the measurement?
- Should the same test be performed or a different one?

An alternative may be to choose not to attempt to confirm individual results. The rationale for this might be that the NTMP takes a strategic perspective with an emphasis on long-term trends and large spatial scale reporting. However, the question still remains that if the individual result is, for example, reported back to the local area it is conceivable that the local stakeholder may decide to take some action. The costs of this action, although now possibly regarded as outside the scope of the NTMP, remain a real consequence of the false positive result. The least that can be done in these circumstances is to report the probability of the result being false to the local stakeholder so that they can use this to make their own judgements on whether to act upon it or not.

An alternative might be to only react to results in an annual report and not to individual measurements. In this case, the results can probably not be confirmed in any way so long after the event. So the individual results would simply be accepted and reported "as is". However, again, their associated probability of being false can be reported.

A possible response might be to act upon an apparent problem by designing and implementing a local monitoring programme with the objectives to (a) confirm there is still a problem and possibly its extent and (b) possibly establish the most likely source. (Note: Such local monitoring programmes are not the direct responsibility of the NTMP.) However, such exercises require considerable resources, both financial and human. The greater the probability of a false positive the greater the chances are that such resources will be wasted because no problem actually existed.

A specific pollution source (say an industrial or agricultural source) may be strongly suspected because such a source exists upstream of the monitoring site at which the apparent problem was reported. Another response may be to confront the suspected polluter with the monitoring results in order to get their involvement in confirming the problem and possibly its extent (even though identification of pollution sources is explicitly NOT regarded as being within the mandate of the NTMP). The greater the probability of a false positive result the greater the chances that such a confrontation would be totally unnecessary since no problem actually existed. Such confrontations would not only again waste resources (this time possibly including that of the suspected polluter) but would almost certainly sour relations somewhat between the suspected polluter and the Department.

There is therefore a wide range of possible scenarios relating to the implications of false positive results. In essence, **an excessive number of false positive results could directly decrease the cost-effectiveness and financial sustainability of the NTMP** because unnecessary resources may be allocated to confirm or follow up apparent problems that are, in reality, not problems.

3.3.3 Null hypothesis for status of fitness for use

3.3.3.1 Definition

The following table defines a possible null hypothesis that allows statements to be made about the status of the fitness for use of a specific water resource.

Table 3.4. Fitness for use null hypothesis.

Null hypothesis	**H_0 = the resource is not in an acceptable water use class**
Alternative hypothesis	H_a = the resource is in an acceptable water use class
False negative result	Report the resource is in an acceptable water use class when it is actually not
False positive result	Report the resource is not in an acceptable water use class when it is actually acceptable

When considering random variability in data only (*i.e.* excluding the sensitivity and bias of measurements and associated toxic criteria), then the following table indicates how different probabilities of the errors can be interpreted.

Table 3.5. Interpretation of different probabilities of a false negative or a false positive result.

	Interpretation
Probability of a false negative	The Department is willing to accept that …
5%	… 1 in 20 times …
10%	… 1 in 10 times …
20%	… 1 in 5 times …
	… it will be reported that the resource is in an acceptable water use class when it is actually not
Probability of a false positive	The Department is willing to accept that …
5%	… 1 in 20 times …
10%	… 1 in 10 times …
20%	… 1 in 5 times …
	… it will be reported that the resource is not in an acceptable water use class when it is actually acceptable

3.3.3.2 Consequences of "false negatives"

A false negative result would report that the resource is fit for use when it is actually not fit for use. This would mean that adequate protection may not be provided to the water users of concern simply because there is apparently no problem. **An excessive number of false negative results increases the likelihood of negative impacts on the water users of concern and hence socio-economic enhancement and optimal water use.**

3.3.3.3 Consequences of "false positives"

A false positive result would report that the resource is not fit for use when it is actually fit for use. The consequences of this depend on how the Department reacts to such a "red flag". However, the same issues as noted above for false positives for ecosystem integrity are likely to apply equally well in this context.

Therefore, as above, an excessive number of false positive results could directly decrease the cost-effectiveness and financial sustainability of the NTMP.

3.3.4 Null hypothesis for trends

3.3.4.1 Definition

This hypothesis requires the current year's statistic being compared with the same statistic from the previous year. The statistic could be:

- The annual mean toxicant concentration at a given monitoring site.
- The annual mean toxicity (*e.g.* % lethality) at a given monitoring site.

These could apply to either ecosystem integrity or fitness for use, depending on which variables are used. The variables chosen for ecosystem integrity necessarily give information on trends in ecosystem integrity. The same applies to fitness for use.

The purpose of comparing one year's statistic with the previous year's statistic could simply be to determine whether there has been a general improvement or worsening in the monitoring site's status over a one-year period.

Table 3.6. Possible trend null hypothesis.

Null hypothesis	**H_0 = the current status is worse than last year**
Alternative hypothesis	H_a = the current status is the same/better as last year
False negative result	Report same/better status when it is actually worse
False positive result	Report status is worse when it is actually the same/better

When considering random variability in data only, then the following table indicates how different probabilities of the errors can be interpreted.

Table 3.7. Interpretation of different probabilities of a false negative or a false positive result.

	Interpretation
Probability of a false negative	The Department is willing to accept that …
5%	… 1 in 20 times …
10%	… 1 in 10 times …
20%	… 1 in 5 times …
	… it will be reported that the current status is the same/better when it is actually worse
Probability of a false positive	The Department is willing to accept that …
5%	… 1 in 20 times …
10%	… 1 in 10 times …
20%	… 1 in 5 times …
	… it will be reported that the current status is worse when it is actually the same/better

3.3.4.2 Consequences of "false negatives"

A false negative result would report that the current status is the same/better as the previous year when it is actually worse. **An excessive number of false negative results can directly:**

- **Result in the degree of water resource protection being inadequate to sustain the desired level of ecosystem integrity, or**
- **Increase the likelihood of negative impacts on the water users of concern and hence socio-economic enhancement and optimal water use.**

3.3.4.3 Consequences of "false positives"

A false positive result would report that the current status is worse than the previous year when it is actually the same/better. The consequences of this again depend on how the Department reacts to such information. Two specific scenarios are envisaged:

- The apparent deterioration in status does not indicate a change to an unacceptable category or class. Although an apparent deterioration has taken place, since the resource remains in the same category or class, this is less cause for concern than the following scenario. No action is therefore somewhat justified.
- The apparent deterioration in status indicates that either the present ecological state or water use class changes to an unacceptable category or class. Since the borderlines between categories and class are, by their very nature, "thresholds of concern", a change from one category/class to a worse one is a significant "red flag". A decisive response by water resource managers would therefore be expected. These may include designing and implementing local monitoring programmes or possibly even approaching suspected polluters. In either case, significant costs may be incurred.

Since the current situation would arise only after an annual report is produced, confirmation of the result would typically not be possible.

As above, an excessive number of false positive results could directly decrease the cost-effectiveness and financial sustainability of the NTMP.

3.4 RECOMMENDATIONS

It is strongly recommended that the implications of false positives and false negatives be carefully considered for each monitoring variable that is chosen for the NTMP. Although it may be difficult, if not impossible, to quantify the real probabilities of these errors occurring, at least some qualitative consideration should be given to them. Furthermore, the above concepts also provide a framework for assessing the ramifications (in terms of sustainable development and sustainability of the NTMP itself) when choosing the sensitivity of test species and the strictness of toxic criteria. It is therefore also strongly recommended that the ramifications are borne in mind when these issues are being considered.

CHAPTER 4: CRITERIA FOR CHOOSING MONITORING VARIABLES

4.1 INTRODUCTION

This chapter summarises the framework and some criteria used for choosing the monitoring variables for the National Toxicity Monitoring Programme (NTMP).

The overall framework dictating the choice of monitoring variables is the resource classification system [see chapter 2, Resource Classification Framework]. However, within that framework, the choice of monitoring variables is based on a series of other criteria. Some apply to toxic effects and others to toxicants. All must ensure that ultimately appropriate information is provided that:

- Allows it to be determined whether the resource is (a) in an acceptable ecological category or (b) in a state desirable for the intended use, and hence
- Addresses the NTMP objectives in respect of supporting strategic management decisions.

The objectives of the NTMP require monitoring of the "nature and extent of, first, the potential for toxic effects to selected organisms, and, secondly potentially toxic substances in South African inland water resources". Toxicants are not necessarily always present in natural waters while others are more common and only become problematic above certain concentrations. On the other hand, some toxicants may occur at extremely low concentrations yet still impact negatively on ecosystem integrity and fitness for use.

This suggests that the design of this monitoring programme may differ fundamentally from others. The following sections address the necessary issues.

4.2 GENERIC CRITERIA

4.2.1 Costs as a design criterion

Monitoring, particularly on a national scale, is expensive. Monitoring toxicants and toxic effects is more expensive (per sample) than monitoring the more common inorganic variables. This is because analytical methods (for toxicants) and toxicity test procedures often require highly specialised equipment and/or fairly well trained personnel. Costs can quickly reach enormous proportions when one realises that many tens of toxicants of concern exist.

A very simple calculation quickly puts costs into perspective. It is quite reasonable to assume an analytical cost of R1000 per organic toxicant (or group of similar organic toxicants) or per toxicity test. The number of sampling sites around the whole of South Africa that might be required to give reasonable coverage of occurrence of a toxicant or toxic effect is unlikely to be a few as ten and unlikely to be as many as 1000. Possibly of the order of 100 sites might ultimately be necessary. Assuming this and assuming monthly sampling (*i.e.* 12 samples per year), this gives a total annual cost of 1000x100x12 = R1,200,000.

This is only for a single monitoring variable (or group of similar toxicants) and reflects analytical costs only. It excludes sampling costs and assumes all necessary capacity exists for such sampling and analysis, and it ignores all other monitoring costs associated with management, national coordination, database management, report preparation and dissemination etc. etc.

It seems quite clear that "traditional" South African approaches to national monitoring could quickly become exorbitantly expensive and completely beyond the capabilities of typical budget allocations. This is particularly true in the light of competition not only with other national programmes but also with many, possibly more pressing, priorities of the Department (like the Reserve and Resource Quality Objectives, water use registration and authorisation, to name but a few). Furthermore, it is often said (with some justification, and not only within the Department) that monitoring is frequently the first to suffer cutbacks when management faces financial pressures.

Two critical issues are central to this problem. The first relates to the number of monitoring sites (and implied in this, their site selection) and the second relates to what is analysed for at each monitoring site. Both of these issues need special attention in order to minimise costs while obtaining a sufficiently accurate picture of toxicity in South African water resources. Furthermore, the choice of monitoring variables cannot be divorced from site selection. The following illustrate some options.

4.2.2 Site selection options

4.2.2.1 Classification-related monitoring

It has been recommended above (in the Resource Classification Framework chapter) that the NTMP be linked to the classification system by aiming to determine whether or not the resource is in the designated class (either as an ecological category or water use class). Monitoring variables related to the resource quality objectives will be the formal variables that will be monitored to determine this. Inevitably the classification system will need to define the locations in the designated water resource where these variables should be satisfied. At this time those developing the classification system have not decided on this level of detail. It is important that the NTMP use a similar approach for choosing monitoring sites in order to firmly anchor the NTMP in the classification system. Until it becomes essential for the NTMP to choose monitoring sites, it is therefore prudent to wait until the classification system has been developed to a point at which guidelines can be obtained for use in the NTMP.

Nevertheless, a number of issues are unique to the NTMP that need to be considered and that may well inform the approach developed for the classification system. Some of these, and other, issues are addressed in the following sub-sections. In particular, the following considerations may well be relevant within the umbrella approach that might be developed for the classification system.

4.2.2.2 Priority area monitoring

An ideal site selection procedure for national monitoring purposes might be the selection of a fine grid of monitoring sites around the country. However, this has not been done in the past because of the associated expenses. In particular, some national monitoring programmes, like the national microbial monitoring programme for surface water, focus on "priority areas". Monitoring sites are chosen in areas known, or suspected, to be contaminated with faecal matter. Although it is acknowledged that this does not provide an ideal national picture (because it is by definition biased towards problematic areas), it is accepted as cost-effective under the circumstances.

Certainly a fine grid of monitoring sites for the NTMP will again be out of the question, for the same reason. Therefore, one approach to monitoring site selection will be to only monitor water resources downstream of known or suspected pollution sites. Further focus, and hence reduction in costs, would be achieved if only suspected toxic effects or toxicants (depending on the nature of the pollution source) are measured at such points.

The downstream monitoring sites may be chosen more on the basis of convenience of access and general health and safety of samplers rather than their proximity to the source. However, identification of potential sources remains a critical requirement. Identification of sources will not be as simple as for faecal pollution. A multitude of possible toxicants can enter water resources from a wide variety of possible sources.

A specific issue that suggests that focussing monitoring near specific pollution sources may be inadequate is that some toxicants, like the persistent organic pollutants, can be distributed through the environment by evaporation and subsequent atmospheric cycling. This suggests that they may occur long distances from their original sources.

4.2.2.3 Containment monitoring

A completely different design for the national microbial monitoring programme for groundwater was recently completed [Murray *et al.*, 2004]. Groundwater monitoring is also expensive and a novel design was developed that focussed on maximising the information obtained from the minimum number of sampling sites (in this case boreholes).

Although the emphasis was on providing information on faecal contamination for aquifers as a whole, use was made of the fact that faecal contamination of groundwater is usually fairly localised. The approach to site selection was to first identify potential significant faecal pollution sources. Then, based on the local geohydrology, "containment" monitoring sites were selected down gradient of the pollution source. These were chosen at a distance behind which (*i.e.* between the borehole and the source) it could be reasonably assumed that faecal contamination would be contained. Detecting no pollution at these sites would allow reasonably confident statements to be made about down gradient aquifer water quality. The zone between the source and the monitoring site is known as a "sacrificial zone" since little or nothing can be said about the water quality in this zone. Given the uncertainties associated with groundwater flow patterns, some degree of "backup" monitoring would also be done at strategic points of use down gradient. This design will be tested between 2004 and 2006.

This approach could, in principle, be adapted under certain circumstances to surface water monitoring of toxicants and toxic effects. The first step would be to identify significant toxicant pollution sources. Obviously, point pollution sources would be the easiest to identify and monitor. Monitoring sites would then also depend on whether the toxicant is persistent or biodegradable. Monitoring for toxicants and/or toxic effects could then be done at the sites indicated in the table.

Table 4.1. Site selection guidelines for monitoring toxicants and/or toxic effects.

	Point source	Non-point source
Persistent	Monitor at the exit point of the catchment	Monitor at the exit point of the catchment
Biodegradable	Choose a monitoring point just beyond the furthermost downstream point (from the discharge point) beyond which no toxicant is expected (based on the typical decay of the toxicant).	Choose a monitoring point just beyond the furthermost downstream point (from the most downstream point of discharge of the non-point source into the resource) beyond which no toxicant is expected (based on the typical decay of the toxicant).

Although the philosophy developed for groundwater faecal pollution monitoring does not seem appropriate for persistent toxicants, the approach may reduce the number of monitoring sites for biodegradable toxicants. However, there remains the problem of flood events (which is not an issue in groundwater). Floods can potentially carry toxicants far downstream, making the choice of containment monitoring site difficult and potentially inappropriate (since this should ideally be as close to the source as possible).

There is a further significant potential disadvantage to applying this approach to toxicants (compared with faecal pollution, that used *E. coli* as the monitoring variable). Monitoring will usually be done at points at which one expects no toxicant. That is, toxicant levels will usually be very low and probably below the detection limits of analytical methods. These methods are often stretched beyond their limits detecting toxicants at the best of times. Burger and Heath (2004) note that the many analytical methods may not be able to meet the low detection limits needed. The success of the approach will therefore be relying on analytical methods at, or beyond, the limits of their capabilities. This is not particularly desirable unless particular methods are known to be sufficiently sensitive (which may be the case in some instances).

On the whole, it seems as though this approach to monitoring in the NTMP is not likely to be very relevant. However, it should be borne in mind should appropriate circumstances exist.

4.2.2.4 Source monitoring

The obvious solution to the disadvantage of having to use analytical methods at the limits of their capabilities is to measure a toxicant concentration at the point at which it is highest. One place at which this occurs is in the effluent.

This approach is in direct conflict with one based on resource classification since the latter refers to monitoring the resource, not the pollutant source. Nevertheless, in the interests of holistic thinking and ensuring that all possible options are considered, this approach is investigated further here, albeit briefly.

The first task will still be to identify pollution sources. Once a source is identified and a toxicant (or series of toxicants) is found likely to occur in an effluent discharged into a water resource, it is likely (or at least ideal) that monitoring of that effluent will become the responsibility of the discharger under the licence conditions associated with that water use. This is, in fact, a very sensible application of the "polluter pays"" principle.

If appropriate licence conditions are defined and adequate (*i.e.* standardised) monitoring is enforced, it may be possible for information on the status and trends of toxicants and toxic effects in water resources to be deduced to an adequate extent from the monitoring of effluents alone. Furthermore, this monitoring would be done and paid for by the polluter. However, the Department would need to assume an auditing role to ensure that such monitoring is performed to appropriate specifications.

In order to specifically achieve the NTMP objectives it is likely that computer models would be necessary. The principle behind these would be relatively simple. They would use flows and discharged loads and persistence/biodegradability information to predict downstream concentrations. It is not difficult to conceive that maps could be produced that could reflect appropriate annual statistics (like medians) at selected points. These maps would be roughly equivalent to, though inevitably have less confidence than, those that would have been produced had (1) adequate funds been available and (2) all the toxicants had been monitored at these selected downstream points and (3) analytical methods where available that could detect the much reduced concentrations at those points.

It is this kind of scenario in which computer models are very powerful. Computer models would typically have no problem whatsoever in predicting concentrations well below the detection limits of analytical methods anywhere in the water resource. In effect this means reporting of toxicant concentrations at any point in a water resource does not depend on these limits. This is particularly useful when detection limits are well above levels at which toxic effects can still manifest. It should nevertheless be noted that the ultimate usefulness of computer models is dependent on the nature of the algorithm (*i.e.* programming) used and the quality of the input data.

As for the groundwater monitoring, a compromise may be possible. Given the inevitable uncertainties associated with (1) identifying all possible toxicant sources and (2) monitoring diffuse sources, it may be appropriate for the Department to perform highly selective "backup" monitoring at a few limited strategic monitoring sites.

The success of this would depend heavily on the successful implementation of what are, in effect, source directed controls.

4.2.2.5 Criteria

The following criteria can be used to establish the most appropriate monitoring approach for a given monitoring variable.

Table 4.2. Criteria indicating when each monitoring approach may be appropriate.

Monitoring approach	Criteria increasing appropriateness of approach
Priority area	• Analytical methods have sufficiently low detection limits
Containment	• Analytical methods have very low detection limits • Toxicants are quickly biodegraded • Water resource not subject to frequent flooding
Source	• Analytical methods do not have sufficiently low detection limits • Downstream behaviour can be conveniently modelled

In all cases it is assumed that it is possible to adequately identify potential pollution sources. In the case of faecal pollution this is often relatively straightforward. However, in the case of toxicants this is not likely to be such a simple matter. It will require *a priori* knowledge relating specific anthropogenic activities to specific toxicants. In many cases this will be possible. However, there may be instances when such knowledge is not available. In these cases, careful consideration needs to be given to the precautionary principle that states that a lack of knowledge should not be used as an excuse for inaction, *i.e.* assuming that the situation is satisfactory.

Finally, it can be repeated here that some problematic toxicants (*e.g.* the persistent organic pollutants) can be transported from their original sources over long distances via atmospheric cycling mechanisms. This means that focussing monitoring in the immediate vicinity of toxicant sources may leave some more distant and possibly problematic areas unmonitored.

4.2.3 Water column, biota and sediments

The following presents a very simple analysis of various factors related to the media that could be sampled in the NTMP. The following specific criteria are considered:

Criteria relating to information content

- *Ability to minimise the monitoring frequency*. Any approach that significantly decreases the monitoring frequency has the significant advantage of greatly reducing sampling and analytical costs.
- *Ability to deal with low concentrations*. As noted above, dilution of water resources can potentially decrease toxicant concentrations (and hence their measurable effects) to very low levels. Any approach that can focus on monitoring media in which concentrations are likely to be high has an inherent advantage over those with naturally low concentrations.
- *Ability to deal with concentration spikes.* Snapshot monitoring is a convenient sampling procedure in which a water sample (whether single or composite) is analysed directly for toxicants or tested for toxicity. The results reflect the quality of the water at the time the sample was taken. A spike of toxicant can easily be missed if the sampling frequency is

low. Any protocol that detects cumulative effects over time will not suffer from this disadvantage.

Criteria relating to practicalities of monitoring

- *Ease of monitoring.* Ease of monitoring is an all-encompassing term including the simplicity (ease) and costs of sampling, analysis and capacity creation. The simpler and cheaper the monitoring is, the more appropriate it is for a national programme.

The following table shows the results of the analysis. The "weights" refer to the relative importance allocated to each factor (1 to 3, 3=most important). The numbers at the head of the media columns (referring to the "suitability to the NTMP") are calculated as the sum over all factors of the weight times the degree to which each factor is addressed (1 to 3).

Table 4.3. Simple analysis of factors relating to sampling and analysis of different media using conventional methods.

	Weight	**Water column**	**Biota**	**Sediments (suspended or bottom)**	
Suitability to NTMP		**41**	**43**	**45**	
Ability to minimise monitoring frequency	3	1	3	3	(1=high, 2=medium, 3=low)
Ability to deal with low concs.	3	1	3	3	(1=low, 2=medium, 3=high)
Ability to deal with spikes	2	1	3	3	(1=low, 2=medium, 3=high)
Ease of monitoring					
Ease of sampling (water or organism)	2	3	1	2	(1=complex, 2=intermediate, 3=simple)
Cost of sampling (water or organism)	3	3	1	2	(1=high, 2=medium, 3=low)
Ease of measurement / analysis & assessment	2	3	1	1	(1=complex, 2=intermediate, 3=simple)
Cost of measurement / analysis & assessment	3	3	1	1	(1=high, 2=medium, 3=low)

The following justifications are provided:

First, it is explicitly noted that the above analysis applies ONLY to those toxicants that are preferentially accumulated in biota and sediments (compared to the water column). For those toxicants that preferentially remain in the water column, monitoring of the water column is considered inevitably more appropriate.

- *Ability to minimise the monitoring frequency*. Because bioaccumulation and bioconcentration in biota, and accumulation in sediments, occurs cumulatively over time, a low monitoring frequency is likely to be satisfactory for biota and sediments.
- *Ability to deal with low concentrations*. Since concentrations in biota and sediments can reach much higher levels than the surrounding water column, analytical detection is easier in biota and sediments.
- *Ability to deal with concentration spikes.* Biota and sediments are more suitable than the water column for the same reason as above given for minimising frequency, namely the time scale of changes is much slower.
- *Ease of monitoring.* Generally speaking analysis of a water sample is simpler (and therefore usually cheaper) than analysing either biota or sediments. More or less the same

applies to sampling, except that sampling sediments may also generally be somewhat simpler than sampling biota.

Using this simple scheme, the overall weighted suitability of each of the three sampling media for the NTMP indicates that sediments are the most suitable, followed by biota and then finally by the water column itself.

This suggests that consideration should be given to identifying those toxicants that preferentially accumulate in sediments and biota. Monitoring these toxicants in these media, particularly sediments, is likely to provide more cost-effective information that if they were monitored in the water column. Equivalently, those that preferentially remain in the water column should be monitored there.

A number of other factors need to be considered if sediment sampling is adopted.

- Sediments do not occur everywhere. This affects the selection of monitoring sites. It may also mean that in some areas that less cost-effective water column sampling is inevitable.
- Sediments can be scoured and transported downstream during flood events. This would need to be taken into account in interpretation of data.
- If trends in toxicant levels in sediments are to be reported, only the top "active" layer of the sediment should be sampled.

The above analysis does not take account of the fact that many organic toxicants form break-down products that can be either more or less toxic than the parent compound.

4.2.4 Consequences of errors

4.2.4.1 Summary

The specific consequences of false negative and false positive errors for each null hypothesis have been discussed in the chapter on Null Hypotheses. The following table summarises the causes and consequences of each type of error. The null hypotheses have been chosen so that the causes and consequences are independent of which null hypothesis is being referred to.

Table 4.4. Summary of causes and consequences of false negative and false positive errors.

	FALSE NEGATIVES	**FALSE POSITIVES**
	CAUSES	
Sampling method	Snapshot water column sampling that may miss toxicant peaks	
Sampling site		Sampling in an effluent plume or mixing zone (giving an unrepresentative sample).
Sensitivity	Test organism less sensitive to stressor than organisms in the water resource	Test organism more sensitive to stressor than organisms in the water resource
Bias	Toxic criterion very lenient	Toxic criterion highly precautionary
	CONSEQUENCES	
Ecosystem integrity	Inadequate protection of water resources	Decreased cost-effectiveness of NTMP
Fitness for use	Increased likelihood of negative impacts on water users (and socio-economic enhancement and optimal water use)	

4.2.4.2 Implications of policy

The resource directed water quality management policy provides important perspectives on false negatives and false positives [DWAF, 2003a].

False negatives

In essence, false negatives ultimately impact negatively on two important principles enabling sustainable development, namely protection of water resources and optimal water use. Sustainable development is one of the core principles to which the Department is committed. The policy also specifically notes the following:

"*The Department regards the resource management class as capturing the most desirable balance between protection of water resources, optimal water use, equity between generations and current equitable access. This balance should be achieved with adequate consideration of environmental integration and application of effective stakeholder engagement. The sustained achievement of the resource management class is then regarded as a minimum requirement to ensure sustainable development.*"

This is the most important perspective in terms of which the causes (and consequences) of false negatives should be interpreted. This perspective is probably the most useful consequence of linking this national monitoring programme to the classification system. The guidelines that define the interface between Poor, Fair & Good, and Natural ecological categories (taking ecosystem integrity as an example) are, in effect, "thresholds of concern". If the present state is not near such an interface, then false negatives are unlikely. (This is the same concept as illustrated in Figure 3.1, which shows how variability can cause false negative and false positive results. In essence, these errors arise only when a measurement is close to the toxic criterion.) The consequence of this is as follows:

If there is any suggestion (from whatever source) that the present state (*i.e.* ecological category or water use class) is close to an unacceptable state, then water resource managers must exercise more caution than when the present state is apparently is not so close, even when the monitoring results suggest that there is no problem. Equivalently, when the present state is apparently comfortably distant from an unacceptable state then false negatives are much more unlikely and inaction by the Department is more acceptable. (***Put simply, if a monitoring result suggests there is no problem, you can have confidence in it if the present state is very much better than the nearest unacceptable state. However, you must have less confidence in a result suggesting there is no problem when you know the present state is close to unacceptable***.)

False positives

A false positive impacts negatively on the principle of financial efficiency and effectiveness, which is an enabling principle of sound financial management [DWAF, 2003a], both principles to which the Department is also specifically committed. The inevitable expense of any national monitoring programme, and of the NTMP in particular, makes this a pertinent principle.

False positives (like false negatives) are more likely to arise when the present state is close to the interface between an acceptable and an unacceptable state.

If there is any question about the relative importance of the consequences of false negatives and false positives, then the policy again provides clear guidance: "*Sustainable development is an overriding principle that should not be violated under any circumstances*" [DWAF, 2003a]. In the current context, this means sacrificing the principle of financial efficiency and effectiveness is preferable to sacrificing sustainable development. That is, broadly speaking, ***the consequences of false negatives are potentially far more severe (and unacceptable) than those of false positives***. Since the chosen management class (or, equivalently, ecological category and water use class) is the "first line of defence" against unsustainable development, deterioration to an unacceptable state is explicitly violating sustainable development.

4.3 EMPHASIS ON TOXICITY

As discussed below, the number of toxicants that can potentially enter water resources is extremely high. It is quite conceivably many thousands of substances. Inevitably, some will be more relevant to national monitoring than others. Ideally (at least in principle), high priority toxicants could be objectively selected by comparing their properties.

However, a survey of readily available sources of data and information on likely toxicity of individual toxicants and of their likely occurrence in South Africa quickly reveals either the scarcity of such data and the difficulty of their interpretation. Accordingly, instead of attempting to start with an all-inclusive list and reducing this in this way to a shorter list of high priority toxicants, it was decided to rather start with a sensible shortlist and add to this according to certain criteria, if necessary.

The initial shortlist chosen included the persistent organic pollutants (POPs) identified in the Stockholm convention of 2001. This is discussed further below.

It was also decided to place more emphasis on toxicity testing in the NTMP rather than analysis of individual toxicants for the following reasons:

- Resource (capacity and financial) limitations would inevitably restrict the number of toxicants being monitored to a very small fraction of the total number of potential toxicants.
- A single toxicity test, if carefully chosen, can provide information that could only be obtained by a great many more chemical analyses for individual toxicants. In other words, in most cases the information:cost ratio is likely to be much higher for a toxicity test than for a measurement of an individual toxicant, and possibly even a series of similar toxicants.
- Toxicity tests are more likely to detect antagonistic, synergistic and cumulative effects.

4.4 CRITERIA FOR TOXICITY

4.4.1 Classification framework

As discussed in the chapter describing the link between the NTMP and the classification system, broad guidance is given for choosing toxicity tests. This is summarised in the following table.

Table 4.5. Broad guidance for choice of toxicity tests.

ECOSYSTEM INTEGRITY		**FITNESS FOR USE**	
Ecological category	**Criteria**	**Water Use Class**	**Criteria**
Natural	No toxicity of any kind	**Ideal**	No toxicity of any kind
Fair & Good	No lethality (short- or long-term)	**Tolerable & Acceptable**	No lethality (short- or long-term)
Poor (unsustainable)		**Unacceptable**	

4.4.2 Protective context

A so-called "protective context" is assumed appropriate. This applies when some target groups of organisms need to be afforded some degree of protection against adverse water quality. In the current context, this adverse water quality would be caused by the presence of toxicants.

However, direct tests on relevant species from a particular target group are often not possible, or at least easy (especially when the target group is humans). Accordingly, the precautionary principle often needs to be applied. For example, this might mean that it is not unreasonable for some concern to be expressed about potential toxicity to humans when a particular water is used, say, for drinking and when toxicity to, say, a particular fish species is demonstrated. Obviously, if a correlation between toxicity to that particular fish species and toxicity to humans has been scientifically demonstrated, then the expressed concern carries more weight.

4.4.3 Priority target organisms

The following table lists some of the more obvious target groups of organisms associated with the various protective contexts.

- A "direct target group" is one affected by direct use of the water resource. In other words, the toxic effect is caused by direct exposure to the water. Domestic use by humans is included here because there are many areas in South Africa where people still use water directly from local water resources, either continuously or occasionally.
- An "indirect target group" is one affected by a primary target group, because the secondary group consumes the primary group. That is, a secondary target group is higher up the food chain and is not in direct contact with the original raw water in which toxicants may have occurred. This group is therefore indirectly affected by the aquatic toxicants.

Table 4.6. Target groups associated with standard water uses [based on Slabbert and Murray, 2004].

Protective context	Most obvious direct target groups	Most obvious indirect target groups
Aquatic ecosystem integrity	Microbes, Fish, Invertebrates, Birds, Mammals, Amphibians, Reptiles, Molluscs, Crustaceans, Plants	Fish, Invertebrates, Birds, Mammals, Amphibians, Reptiles, Humans
Domestic use	Humans	
Recreational use	Humans	
Industrial use*	Humans	
Agriculture use - irrigation	Plants	Humans, Mammals
Agriculture use - livestock watering	Mammals, Birds	Humans
Agriculture use - aquaculture	Fish, Reptiles, Plants	Humans, Mammals

* Regarded as equivalent to domestic use in the current context.

Note that a distinction is made here between two groups of organisms:

- *Target group*: The group of organisms being afforded some degree of protection. Note that it may not be possible for the target group (like humans) to be used as the test group.
- *Test group*: The group to which the organism being used in a toxicity test belongs.

4.4.4 Ease of monitoring

Ranking of simplicity (ease) and costs of sampling, analysis and capacity creation should be restricted to what would be typical for the next three years.

The following table suggests criteria for each issue that can be ranked on a scale of 1 to 3.

Table 4.7. Criteria for ranking ease of monitoring.

Criteria				
Sampling (water or organism)		**Measurement / analysis & assessment**		**Capacity creation**
Ease	**Cost**	**Ease**	**Cost**	**Cost**
1=Complex	1=High	1=Complex	1=High	1=High
2=Intermediate	2=Medium	2=Intermediate	2=Medium	2=Medium
3=Simple/routine	3=Low	3=Simple/routine	3=Low	3=Low

The term "ease" refers to the degree of simplicity of the task. This is related to the degree of expertise required. The cost of capacity creation refers to creating sufficient capacity nationwide, or improving current capacity, within three years.

In all cases a relative ranking is required. The simplest way of achieving this is to do the following:

For each criterion:

- Choose one test that would be ranked at the one extreme of the scale (*e.g.* the highest cost) and mark it with a "1".
- Choose one test that would be ranked at the other extreme of the scale (*e.g.* the lowest cost) and mark it with a "3".
- Rank all the remaining tests relative to these two, marking them with a "1", "2" or "3".

4.4.5 Procedure

It is proposed that the following procedure be used to establish appropriate toxicity tests:

- The spreadsheet facility developed by Slabbert and Murray [2004] should be used to produce a preliminary shortlist of applicable tests since the criteria above correspond closely with those used in that work.
- This preliminary shortlist should be examined in detail to further reduce the list to reflect those that are most likely to succeed in a national monitoring context. The following should be considered:
    - Overall ease of monitoring including both costs and capacity issues.
    - The relation between the test organism and the target organism(s). Although it may be preferable to choose test organisms closely related to the target group, if simpler tests are available that use other organisms these may be preferred.

It is assumed that in the current context of national monitoring of water resource, only screening tests are applicable. A screening toxicity test is performed directly on the water or test sample “as is”, *i.e.* without dilution. A definitive test estimates the concentration of the toxicant at which a specified percentage or number of organisms exhibit a certain response.

4.5 CRITERIA FOR TOXICANTS

4.5.1 Introduction

As noted above, the extremely large number of potential toxicants and the inevitable limitations on resources available for implementation of the NTMP means that not all toxicants can be monitored. Emphasis will therefore be placed on measuring toxicity. However, there are still reasons for monitoring some individual toxicants directly:

- Some toxicants are irrefutably extremely toxic and problematic and their direct detection will allow management responses to be more focussed and immediate.
- Notwithstanding the problems associated with a general lack of data and difficulty in their interpretation for most toxicants, the traditional "substance-specific" approach to managing toxicants (and hence potential toxicity) remains well entrenched. In part this is because it is often easier to identify (and hence manage) polluters if specific substances are identified.

Accordingly, a small core set of toxicants has been chosen as being of highest priority. This approach was adopted because it is extremely resource-intensive to obtain sufficient data (of adequate accuracy) to objectively prioritise long lists of potential toxicants. Starting with a well-defined short list (the POPs) and then adding to this when necessary is considered to be a much more cost-effective approach to choosing appropriate toxicants. Criteria are proposed to enable additional toxicants to be included.

4.5.2 Persistent Organic Pollutants (POPs)

In 2001 a convention was signed in Stockholm, Sweden, with the objective "to protect human health and the environment from persistent organic pollutants". South Africa is one of the signatories. This convention proposed measures to reduce or eliminate releases from intentional and unintentional production and use, and from stockpiles and wastes. The signatories were encouraged, among other things, to monitor POPs in humans and the environment, as well as their effects. The NTMP is an ideal vehicle for monitoring POPs in South Africa's water resources. (See Biotoxicology Chapter in Implementation Manual for more information on POPs.)

The high priority given to these compounds by this convention is driven primarily by their toxicity and the fact that they do not readily breakdown in the environment. They are also soluble in animal tissue. They can therefore bioconcentrate in animals through direct exposure. Being semi-volatile, they can also travel significant distances in the environment through evaporation and atmospheric cycling.

Although the Department of Environmental Affairs and Tourism has primary responsibility for implementation of the terms of the convention, the Department of Water Affairs and Forestry has undertaken to shoulder responsibility for monitoring water resources. These have therefore been chosen to be the core group upon which the NTMP will focus. It should nevertheless be noted that the objectives of the NTMP have a much broader focus. Care should therefore be taken that the NTMP does not become solely focussed on the Stockholm convention.

4.5.3 Risk-based approach for additional toxicants

There are three fundamental types of information that ultimately determine the suitability of including a toxicant in the NTMP.

- The potential impact of the toxicant on ecosystem integrity and fitness for use (should it enter our water resources).
- The probability of the toxicant entering our resources. This relates to the potential spatial and temporal aspects of the impact.

These two factors provide a useful basis for prioritising those toxicants that the Department should be most concerned about and should perhaps ultimately aim to address in the long term. This list might be referred to as the ultimate "wish list".

However, issues related to the practicalities of monitoring must also be considered. This is the third type of information:

- The ease (referring to simplicity, costs and capacity) with which the Department will be able to monitor each toxicant in the next few years.

If this information is overlaid on the wish list, a priority list is obtained of those high priority toxicants that can be monitored in the initial phases of full-scale implementation. This list might be called the "practical list".

The following sub-sections describe how each of the three kinds of information might be obtained. All should be ranked taking into account the current situation in South Africa and how this situation may change in the short and medium term.

4.5.3.1 Severity of impact

This should be ranked on a scale of 1 to 3 as indicated in the following table. The most severe assessment should be chosen when multiple criteria result in different assessments. "Typical uses" and associated organisms are those indicated in the above table of target groups.

Table 4.8. Criteria for ranking potential severity of impact.

	Criteria	
Assessment	**Potential socio-economic impact through typical water uses**	**Potential impact on ecosystem integrity**
1=Low	Low	Low
2=Medium	Medium	Medium
3=High	High	High

Differences in the spatial and temporal impacts and the ease of monitoring of the toxicant should be ignored when ranking the severity of impact. To achieve this assume the following (for all toxicants considered):

- A continuous discharge into all water resources around South Africa.
- Sampling and analytical costs are zero.

Severity of impact should include considerations of the following:

- Persistence and biodegradability.
- Severity of impact of possible breakdown products.
- Degree to which toxicant may partition into sediments.

4.5.3.2 Spatial impact

The spatial impact will primarily be determined by the distribution of typical sources of the toxicant and the likelihood of it entering local water resources. A toxicant that is only likely to appear in surface water resources in a few localised areas (and if it is likely to remain so) should receive a low ranking. On the other hand, a source of toxicants may be localised. However, if discharged toxicants are mobile and persistent, they may be transported over long distances and thus manifest their effects widely. Alternatively, those toxicants like persistent organic pollutants can be transported through the atmosphere for very long distances. In such cases, a higher ranking would be warranted

Differences in the severity of impact, temporal impact and the ease of monitoring of the toxicant should be ignored when ranking the spatial impact. To achieve this assume the following (for all toxicants considered):

- A continuous discharge into those water resources affected.
- Sampling and analytical costs are zero.

Spatial impact could include considerations of the following:

- The solubility and mobility of the toxicant in water.
- Typical flow regimes of water resources.
- The distribution of sources of the toxicant (*e.g.* industry, mining, agriculture, etc.).
- Likelihood of runoff transporting toxicants from points of use to water resources.
- Typical uses and applications of the toxicant (*e.g.* agricultural uses may result in a greater likelihood of toxicants entering water resources.)
- The likely degree of safety typically being applied to such uses. (High levels of safety, *e.g.* in industry, may reduce the chances of the toxicant entering water resources.)

The following table suggests criteria to assign this impact as low, medium or high.

Table 4.9. Criteria for ranking potential spatial impact.

	Criteria
Assessment	**Number of Water Management Areas likely to be impacted**
1=Low	1 to 6
2=Medium	7 to 12
3=High	13 to 19

4.5.3.3 Temporal impact

Temporal impact refers to the periods over which toxicants may enter water resources within one hydrological cycle (*i.e.* one year).

The following table suggests criteria to assign this impact as low, medium or high. The most severe assessment should be chosen when the two criteria result in different assessments.

Table 4.10. Criteria for ranking potential temporal impact.

	Criteria	
Assessment	**Timing throughout one year**	**From year to year**
1=Low	Sporadic, possibly infrequent	Not necessarily every year.
2=Medium	Intermediate	Intermediate
3=High	Continuous or consistently seasonal	Consistently every year

Differences in the severity of impact, spatial impact and the ease of monitoring of the toxicant should be ignored when ranking the temporal impact. To achieve this assume the following (for all toxicants considered):

- A discharge, when it occurs, into all water resources simultaneously around South Africa.
- Sampling and analytical costs are zero.

Temporal impact should also include considerations of the following:

- Likelihood of occasional spills.

4.5.3.4 Ease of monitoring

Ease of monitoring is an all-encompassing term including the simplicity (ease) and costs of sampling, analysis and capacity creation. Ranking of these should be restricted to what would be typical for the next three years.

The following table suggests criteria to assign this impact as low, medium or high.

Table 4.11. Criteria for ranking ease of monitoring.

	Criteria				
	Sampling		**Analysis**		**Capacity creation**
Assessment	**Ease**	**Cost**	**Ease**	**Cost**	**Cost**
1=Low	Complex	High	Complex	High	High
2=Medium	Intermediate	Medium	Intermediate	Medium	Medium
3=High	Simple/routine	Low	Simple/routine	Low	Low

Differences in the severity of impact and spatial and temporal impacts should be ignored.

To simplify considerations, assume the following:

- Costs refer to a single sampling exercise and a single analysis (excluding travelling costs).
- Analysis refers to measurement of the toxicant in water or some other solvent.
- Sediments are excluded.
- Analysis of bioaccumulation is excluded.

A relative ranking approach should be used, as described for toxicity tests.

4.5.3.5 Risk-based "wish list"

The strategy for source management in South Africa [DWAF, 2003d] proposes the use of a risk-ranking matrix to assess risk of individual sources of pollution on local water resources. It is proposed that this is used as the basis for assessing risk in the current context. Their "consequence class" is equivalent to our "severity of impact". Their "frequency class" is equivalent to our combined "spatial and temporal impact".

They use six categories for both dimensions. However, given the complexities and likely lack of data in the current context, it is proposed that these are combined into only three categories (low, medium and high). Averaging the associated risks results in the following risk-ranking matrix:

Table 4.12. Risk-ranking matrix used to assess the risks associated with each toxiciant.

				Severity of impact
	9	16	19	**3 (high)**
	4	9	14	**2 (medium)**
	2	4	7	**1 (low)**
Spatial impact	**1 (low)**	**2 (medium)**	**3 (high)**	
Temporal impact	**1 (low)**	**2 (medium)**	**3 (high)**	

If all toxicants can be ranked in this way, this will provide a risk-based priority list of toxicants. Those with the highest risk are those most desirable to include in the NTMP.

Burger and Heath (2004), in compiling a priority list of endocrine disruptors and other toxicants, did not use the current existence of analytical capacity as a criterion. The latter information was examined independently. It is proposed that this approach be adopted here as well. This has practical advantages. The list produced using the risk-ranking matrix provides a "wish-list" that ignores the existence of current capacity and analytical methods. Taking the latter into account provides a "practical list", as described in the following section.

4.5.3.6 Reality-based "practical list"

The above risk-based "wish list" excludes any consideration of the practicalities of monitoring. It was proposed above that "ease of monitoring" consider the situation over the next three years. If this information in combined with the wish list, this should give a priority list of toxicants that can be practically monitored in the short term. In other words, these would be the toxicants most sensibly monitored in the pilot studies and in the subsequent initial phases of implementation.

The wish list remains the ultimate goal and those high priority toxicants not included because of practical monitoring difficulties are those on which research and development should focus. The intention would then be to gradually introduce these over the years.

4.5.4 Criteria for additional toxicants

The above risk-based approach using the risk-ranking matrix can be used as a means of deciding on the appropriateness of including other toxicants into NTMP. As above, the three basic types of information must be considered, *viz*. severity of impact and probability of entering water resources (these two giving the relative risk) and ease of monitoring.

4.5.4.1 Relative risk

It is recommended that any new toxicant should have a risk of 14 or greater to be included. This is equivalent to requiring the following:

- At least one of spatial impact, temporal impact or severity of impact must be ranked as high (*i.e.* 3).
- All other impacts (other than the one ranked as high), must be medium or high.

4.5.4.2 Ease of monitoring

As above the resources required for sampling, analysis and capacity creation must be considered. If these are within the capabilities of the Department then the toxicant can be included.

4.6 RECOMMENDATIONS

The following recommendations are made on some of the above issues. Other recommendations are made in subsequent chapters.

- The most appropriate approach to monitoring site selection should be based primarily on the framework chosen for the resource classification system. If necessary, issues such as the degree to which the variable is biodegradable, the likely degree of flooding, the degree to which a toxicant is transported via atmospheric cycling and the detection limits of analytical methods should be considered within this framework.

- It is recommended that the consequences of false negatives are regarded as potentially far more severe (and unacceptable) than those of false positives. This is because the former impacts negatively on the Department's ability to achieve sustainable development while the latter impacts on the sustainability of the NTMP itself.

- For a number of reasons, more emphasis should be placed on toxicity tests than on detection of individual toxicants or even groups of similar toxicants. Consideration of toxicants should be restricted to a small group of high priority toxicants (namely the persistent organic pollutants). This is only partly to meet some of South Africa's obligations in respect of the Stockholm convention.

- To choose the most appropriate toxicity tests the spreadsheet facility developed by Slabbert and Murray [2004] should be used as a basis.

- The persistent organic pollutants (POPs) are recommended as the group of toxicants to be included in the NTMP. Since all have a significant potential severity of impact, and a potentially high spatial and temporal impact, all can be regarded as having a roughly equivalent risk. Accordingly, ranking should be based only on ease of monitoring.

CHAPTER 5: SPATIAL & TEMPORAL CORRELATION

5.1 INTRODUCTION

Monitoring data collected at monitoring sites that are too close may vary in a similar way over time. In effect, this means that the data are "correlated" and that if this "spatial correlation" is high, resources may be being wasted because similar information is being obtained from the two sites.

Similarly, data collected at regular intervals from a particular monitoring site may be correlated if the sequential data points vary in a similar way. This is "temporal correlation". For example, if daily sampling is being performed and the data from any particular day varies similarly to that of the previous day, again resources are being wasted because the current day's data contain similar information to that of the previous day.

Both these situations should ideally be avoided. The number of monitoring sites and the sampling frequency impact directly on the total costs of any monitoring programme. On the one hand monitoring sites should be chosen that are sufficiently far apart to be independent. On the other hand, the sampling frequency should be sufficiently low to avoid sequential samples being correlated. The nature of a monitoring variable, in particular the random variability in its measurement, can also place a constraint on sampling frequency (or *vice versa*). In this case it may impose a maximum frequency (*i.e.* a minimum time between samples.) The following sections present a framework that addresses some of the issues.

5.2 NATURE OF MONITORING VARIABLES

5.2.1 Introduction

Before a final choice of monitoring variables can be made, the frequency of sampling must be determined to ensure that associated sampling and analytical costs are not excessive.

The process outlined below allows the estimation of an appropriate maximum frequency considering, primarily, the likely random variation in experimental measurements. Sensitivity and bias are not issues that are considered here (however, see the Null Hypotheses Chapter for the ramifications of these).

The variability determines, for example, the confidence with which statistics can be compared for any given data set. Alternatively, if a specific confidence is required for such comparisons, then this can give guidance on how many samples might be needed (*i.e.* the sampling frequency). A high variability means that more samples are required in order to make such comparisons at a given level of confidence than would be the case if the variability was much lower. This has cost implications.

In essence therefore, we need to ensure that the choice of monitoring variables (some of which may have relatively, and unavoidably, high variabilities) does not place unacceptable demands on the NTMP's ability to report statistically meaningful results.

5.2.2 Maximum monitoring frequency

It is the Department that is ultimately accountable for either action or inaction in response to NTMP reports. The Department is therefore the single most important stakeholder in deciding on acceptable probabilities of both false negative and false positive results. In arriving at these estimates, careful consideration should be given to the implications of the errors for each null hypothesis (as discussed in the chapter on statistical considerations).

Specifically, three factors need to be given attention:

- The acceptable probability of reporting a false negative result.
- The acceptable probability of reporting a false positive result.
- The "effect size". This is defined as the difference between the means being compared divided by the standard deviation (assumed equal for the two samples whose means are being compared).

If each of these can be defined, the table below can be used to obtain the necessary number of data points. Since annual statistics are being assumed for the NTMP, this essentially provides the monitoring frequency. For example, if twelve samples are required, monthly sampling would suffice. It should be noted that a mean may not be the most appropriate statistic to use (a median may be better). However, should means be chosen, then the following analysis could be used.

It was noted above that there exists (a) natural variability and (b) variability inherent in the experimental technique. Natural variability can usually only be quantified by actually measuring changes over long periods (at least one hydrological year). In the absence of information on natural variability, one can, as a preliminary exercise, assume the natural variation is zero. In other words assume all variation arises out of the experimental method.

Experimental variations are easier to quantify and are reasonably well known for many potential monitoring variables. One can then go through the exercise of establishing appropriate monitoring frequencies. Since natural variability has not been considered, these frequencies will be the absolute maximum that is necessary.

If real data on actual natural variations are not available, sensible estimates of this variation should be obtained. The same exercise can then be carried out to obtain an appropriate frequency.

Table 5.1. Recommended minimum number of samples per year as a function of required probabilities of false negative and false positive errors and effect size [Faul and Erdfelder, 1992].

Probability of false positive (%)	Power (β)	Two-tailed tests: Probability of false negative (%)			One-tailed tests: Probability of false negative (%)		
		5%	10%	20%	5%	10%	20%
		α=0.05	α=0.1	α=0.2	α=0.05	α=0.1	α=0.2
		Small effects (size = 0.2)					
5%	0.95	1302	1084	858	1084	858	620
10%	0.9	1054	858	658	858	658	452
20%	0.8	788	620	452	620	452	284
		Medium effects (size = 0.5)					
5%	0.95	210	176	138	176	138	100
10%	0.9	172	140	106	140	106	74
20%	0.8	128	102	74	102	74	46
		Large effects (size = 0.8)					
5%	0.95	84	70	56	70	56	40
10%	0.9	68	56	42	56	42	30
20%	0.8	52	42	30	42	30	20
		Very large effects (size = 1.0)					
5%	0.95	54	46	36	46	36	26
10%	0.9	46	36	28	36	28	20
20%	0.8	34	28	20	28	20	12
		Extremely large effects (size = 2.0)					
5%	0.95	16	14	10	14	10	8
10%	0.9	14	12	8	12	8	4
20%	0.8	12	8	4	8	4	4

As an example, assume the following:

- Acceptable probabilities of false negative and false positive results are 10%.
- The standard deviation representing the variability (from whatever source) is 10 units.
- We want to be able to distinguish meaningfully between means that are 20 units apart.
- The null hypothesis requires us to determine whether one mean is significantly different from another mean.

The effect size is 20/10 = 2. A two-tailed test is required because a difference between means is being assessed (not whether one is greater or less than the other). A monthly monitoring frequency is therefore acceptable (*i.e.* 12 per year).

If the standard deviation was 40 units (perhaps due to large variability) then the effect size would be 20/40 =0.5. So we would need 140 samples per year. This requires sampling almost every two days (2.6 to be more exact). Sampling every three days would not be sufficient.

If natural variability is very much higher than the variability due to experimental methods, then the above exercise will not necessarily restrict the choice of monitoring variables on the basis of their experimental variability (because natural variability will be the main factor to do so). In such a case the above exercise need not be undertaken (in respect of variability due to random errors in experimental method).

However, if experimental variability is equivalent to or higher than natural variability then limits placed on sampling frequency by available resources may restrict the choice of variables to those that are less variable.

5.3 TEMPORAL CORRELATION

Temporal correlation can only be addressed when real data are available. During the design phase of the project, data collected by the project focussing on endocrine disruptor compounds (funded by the Water Research Commission) may be used. Data at each monitoring site will need to be analysed separately to establish a minimum monitoring frequency (*i.e.* maximum time between sampling) required at each site to avoid temporal correlation. This information can be used to obtain better estimates of overall costs and frequencies to be used in the pilot studies.

The pilot studies that will follow this design phase should have as a major objective the collection of sufficient data to ensure sound datasets are obtained to get accurate estimates of minimum monitoring frequencies. Again, different frequencies may be calculated at the different monitoring sites. If the frequencies are similar in magnitude, it may be satisfactory to assume a single average frequency for the NTMP as a whole. However, if there is a large range of frequencies, it may be necessary to consider different frequencies for different monitoring variables (or possibly type of monitoring site). However, the logistical and managerial implications of such a decision would need to be carefully considered.

During the subsequent phased implementation phase it is also possible to examine the data that have been collected for temporal correlation. This should occur during the planned reviews of the monitoring programme as a whole. Again, the appropriateness of a single national average frequency can be weighed against the use of different frequencies under different circumstances.

5.4 SPATIAL CORRELATION

The existence of correlation between monitoring sites can only be established when sufficient data from the sites are available. It is conceivable that this will only be necessary once full-scale implementation has begun (after the pilot studies). Due to the inevitable phased implementation at increasing numbers of sites over the years, it is likely to be relatively easy to avoid spatial correlation initially (using common sense) by placing monitoring sites at significant distances from one another. The emphasis will initially be on obtaining data for a water management area (WMA) as a whole. Completely different river systems are likely to be chosen to achieve this. Therefore, spatial correlation is not highly likely (though should, nevertheless, be specifically borne in mind when choosing sites at this time). However, in subsequent years as more and more sites are added to each WMA to obtain better coverage, spatial correlation will naturally become increasingly likely. Therefore, an examination of spatial correlation should form part of the regular review of the NTMP.

5.5 COMPARISON OF APPROACHES

Statistical approaches are available that can provide information on optimum monitoring frequencies (*i.e.* that deal with temporal correlation) and minimising the number of sampling sites (*i.e.* that deal with spatial correlation). The following two approaches are compared briefly.

5.5.1 Entropy approach

This approach is based on a concept of "entropy" as being a measure of the uncertainty in random processes. Monitoring variables such as toxicant concentrations and degree of toxicity in natural waters can be subject to a wide variety of random processes that ultimately determine the value measured at the time of sampling. To this "natural variability" is then added the "experimental variability" as a result of random variations in the analytical method. Ozkul *et al.* (2000) note that if the primary objectives of the monitoring is to determine variability, then this method can be used to evaluate how informative the data are in time and space dimensions.

It might be noted here that it is not the primary objective of the NTMP to determine variability. It is the primary objective to determine status and trends. Status has been assumed to be represented by some kind of average (like an annual average). However, status could be re-interpreted to include some measure of variability (which could simply be a standard deviation). Nevertheless, such variability is important to the NTMP if only for the reason that the results reported to the water resources manager should reflect the degree of confidence. Typically, this depends on variability.

Ozkul *et al.* (2000) note the following advantages of the entropy method:

- It provides a quantitative measure of information content of any particular site and of an observed time series.
- It can assess the degree to which spatial and temporal correlation exists.
- It gives an indication of the usefulness of the data.
- It can simultaneously assess several features of a monitoring programme (*e.g.* sites, frequencies, variables, and duration).

Although these advantages seem impressive, they also note a major disadvantage of the method. It is sensitive to the choice of multivariate probability function that adequately represents the multivariate nature of the network. As a consequence, they recommend using different techniques in combination in order to investigate network features from different perspectives.

5.5.2 Principal components approach

Another general approach to determining the degree of spatial and temporal correlation involves determining the minimum number of "components" (in a mathematical sense) that adequately reproduces (or models) the total variability of the data. The components that do so are called the "principal components", implying that the other components are less important. This is equivalent to saying that these latter are correlated and therefore provide little or no independent information.

If components are identified as monitoring sites, then this allows redundant sites to be identified and discarded. The approach can also be used to establish temporal correlation at particular sites.

This method has a number of important advantages:

- It is well established and typically available in standard statistical software packages.
- Since it based on a so-called "covariance or correlation matrix", it does not depend on knowing the underlying statistical distributions of the data. (For example, normality need not be assumed.)

5.6 RECOMMENDATIONS

Accordingly, in summary, the following recommendations are made:

- For each monitoring variable chosen for the NTMP, the random experimental variability should be estimated, acceptable probabilities for false positives and false negatives chosen and typical effect sizes estimated. Based on these, the maximum monitoring frequency should be estimated from Table 5.1. It is recommended that the probability of false negatives be more stringent than for false positives.

- The presence of temporal and spatial correlation can only be assessed with real data. Until such time as these are available, common sense should prevail to ensure as far as possible that these are avoided.

- In future when such data become available, it is recommended that the principal components approach be used to assess the degree of correlation.

CHAPTER 6:
CHOICE OF MONITORING VARIABLES

6.1 INTRODUCTION

Having established in previous chapters the framework and some generic criteria for decision-making in respect of monitoring variables, this chapter summarises the actual decisions taken and their justification.

The choices relating to toxicity were made in a workshop attended mainly by local biotoxicologists. All agreed that the overall framework was satisfactory and general consensus was reached in respect of the specific design recommendations.

6.2 TOXICITY

6.2.1 Specific design recommendations

6.2.1.1 Separation of ecosystem integrity and domestic use

Design recommendation: Ecosystem integrity and domestic use will be addressed separately.

Justification: This is consistent with the Department's philosophy of not regarding the ecosystem as a "user".

Implication: No specific attempt will be made to choose toxicity tests that will address both factors simultaneously.

6.2.1.2 Generic tests versus site specific tests

Design recommendation: A limited suite of generic toxicity tests will be chosen that will be applied nationwide.

Justification: Given the costs and likely logistical difficulties associated with nationwide capacity creation in respect of sampling and toxicity testing, allowing for significant site-specificity (and hence possibly a wide range of permitted toxicity tests) is considered likely to be inappropriately demanding. Choosing a few generic tests will also allow better quality control and hence standardisation.

Implication: Local site-specific conditions may occasionally be such that other toxicity tests might be more applicable. However, this will be a limitation of this national programme. It is nevertheless consistent with the broad "strategic" nature of national monitoring programmes. It is not the primary purpose of national programmes to facilitate reporting on specific local conditions. Its scope is defined as broad in both spatial and temporal scales.

6.2.1.3 Coverage of trophic levels

Design recommendation: For protection of ecosystem integrity, toxicity to three trophic levels, plants (algae in particular), invertebrates and fish will be monitored.

Justification: Monitoring only one trophic level can lead to potentially misleading results, in particular false negative results (*i.e.* reporting the resource is in an acceptable ecological category when it is actually not).

Implication: At least three fundamentally different tests will need to be chosen. This may be significantly demanding in respect of capacity creation on a nationwide basis.

6.2.1.4 Simultaneous measurement of lethal and sub-lethal toxicity

Design recommendation: Wherever possible and appropriate, toxicity tests will be chosen that are capable of measuring both lethal and sub-lethal toxicity simultaneously.

Justification: This can greatly reduce the costs of the required tests and limit the necessary capacity creation.

Implication: The number of tests is likely to be smaller than that necessary were different tests chosen for lethal and sub-lethal toxicity.

6.2.1.5 Water column versus biota or sediments

Design recommendation: Unfiltered samples of the water column will be monitored, not sediments or local biota.

Justification: (i) Representative samples of sediments are difficult to obtain. (ii) Assessment of sediment toxicity results is particularly complex. (iii) Inadequate capacity currently exists, and is unlikely to be easily created in the short-term, for such analyses and assessment.

Implications: (i) Concentrations of many, though not all, toxicants are likely to be lowest in the aqueous phase. This will create difficulties relating to detection limits. (However, using unfiltered samples may mitigate this problem to some extent.) Equivalently, the ability of both biota and sediments to accumulate many toxicants is a property that will now not be taken advantage of. (ii) Similarly, the loss of the time-averaging properties of both biota and sediments for many toxicants will mean that for these toxicants there is inherently a reduced ability to detect the effects of spikes of toxicants. (iii) More frequent monitoring may now be necessary (than would be the case had biota and/or sediments been monitored).

6.2.1.6 Active monitoring

Design recommendation: "Active" monitoring (involving equipment and organisms being left in the field for extended periods of time) will not be attempted.

Justification: Vandalism of monitoring equipment is a significant problem in South Africa. Although in some circumstances such monitoring is possible, for a programme of the magnitude of the NTMP loss or damage of equipment is of too great a concern. Adequate protection is unlikely to be feasible in all circumstances.

Implications: (i) Toxicity testing will necessarily need to be performed on samples taken in the field and transported to the nearest laboratory. This may create logistical problems if samples need to reach laboratories within 24 hours. (ii) The advantages of time averaging and accumulation in biota placed *in situ* are now not available. Therefore, one disadvantage of not using active monitoring is that the effects of toxicant peaks may not be detected. (iii) Effectively, this recommendation means that biomarkers of biota placed *in situ* will not be used in the NTMP. (iv) Similarly, so-called "passive samplers" (artificial *in situ* devices that simulate toxicant accumulation properties of biota) will not be used.

6.2.1.7 *Use of biota sampled in situ*

Design recommendation: Local indigenous (or even exotic) biota sampled on site will not be used.

Justification: (i) The practical difficulties of their capture and maintenance are too great for monitoring on a national scale. (ii) There is unlikely to be a single species that occurs in all our waters that will enable sufficiently standardised interpretation of results.

Implication: (i) Laboratory-bred organisms will need to be used in tests. Extrapolation of toxicity test results based on these organisms to likely effects on local indigenous biota may be difficult or at least involve uncertainty. (ii) This effectively precludes the use of biomarkers on locally sampled organisms.

6.2.1.8 Relative sensitivity of aquatic organisms and humans

Design recommendation: Aquatic organisms are assumed generally more sensitive to toxicants than humans.

Justification: This is generally indicated by toxicity data.

Implication: (i) Notwithstanding the above design recommendation not to assume that ecosystem integrity and domestic use should be addressed by the same tests, this recommendation will allow the toxicity data obtained for protection of ecosystem integrity to be assessed in terms of likely impacts on domestic use. Specifically, a toxicity problem detected in an aquatic organism can in general be regarded as a very sensitive test for humans. In essence, false positive results (in respect of humans) have an increased likelihood. Equivalently, if no toxicity is detected in an aquatic organism, the likelihood of a false negative result (in respect of humans) is very low. (ii) Not all possible toxic effects to humans are likely to be covered by a small set of aquatic tests.

6.2.1.9 Use of yeast test

Design recommendation: When the (desired) water use class is "Ideal" or when the (desired) ecological category is "Natural", the yeast test will be used (in addition to the chosen three trophic level tests).

Justification: This is a test that is specific to Endocrine Disrupting Compounds (EDCs). Since this broad group of compounds is of particular concern worldwide, and some of their effects will not necessarily be detected by the "trophic level" tests, this test is seen as an important supplementary test under conditions when the "best" (*i.e.* Ideal or Natural) water quality is desired.

Implication: This is an extra test requiring a further level of capacity creation.

6.2.1.10 Multi-context toxicity tests

Design recommendation: Whenever possible, and only when achieving the NTMP objectives is not compromised, toxicity tests should be chosen that either are currently being used in other contexts or are likely to be used in other contexts.

Justification: Given the significant costs of capacity creation relating to toxicity testing throughout the country, if tests can be used in more than one context then their overall cost-effectiveness increases.

Implications: As noted specifically in the design recommendation, there is a potential danger that when choosing tests, too great an emphasis may be tempted to be given to those that are, or will be, widely used at the expense of those that are more directly suited to the NTMP. This should be avoided. The NTMP should take priority.

6.2.2 Lethality versus sub-lethality

The following is the rationale behind the use of lethality and sub-lethality tests to detect whether the present state has been degraded from a Fair or Good category to Poor and from a Natural to a Fair or Good category, respectively.

- ***Long-term sub-lethality test*** ***for Natural to Fair/Good boundary***: The primary criterion is chosen to be **no toxicity of any kind**. This strictly means either lethality or sub-lethality, short-term or long-term. In effect this means any toxicity test will provide some information. However, **long-term sub-lethality tests** are chosen because it is assumed that these will be more sensitive tests (than lethality tests or short-term tests) and hence allow for more effective protection of ecosystem health.
- ***Long-term lethality test*** ***for Fair/Good to Poor boundary***: The primary criterion is chosen to be **no lethality (either short-term or long-term)**. However, **long-term lethality** tests are chosen again because it is assumed that these are likely to be more sensitive and more relevant to protection of ecosystem health than short-term lethality tests.

6.2.3 Results

6.2.3.1 Database

An initiative relating to guidelines for toxicity tests [see Relevant Initiatives in Background Chapter] provides a useful database upon which to impose the above design recommendations and produce a shortlist of appropriate tests. About 80 toxicity tests were classified as either being appropriate or not appropriate for each of the following criteria:

Table 6.1. Criteria for which toxicity tests were classified.

Screening / Definitive	Lethal
Active monitoring	Sub-lethal
Protective context: Ecosystem integrity	Short-term
Protective context: Domestic use	Long-term
Protective context: Agricultural – irrigation	Water type: Inland water resource
Protective context: Agricultural – stock watering	Water type: Estuarine
Protective context: Agricultural – aquaculture	Water type: Zone=Water body
Test organism: Fish	Water type: Zone=Sediment
Test organism: Amphibians	Water type: Zone=Groundwater
Test organism: Invertebrates	Water type: Fresh
Test organism: Plants	Water type: Brackish
Test organism: Microorganisms	
Test organism: Cellular or sub-cellular	
Test organism: Yeast	

This "inventory of tests" and their classifications exist in an Excel spreadsheet. This allows lists of tests to be created that satisfy multiple criteria. For example, it can list all tests that are (a) screening, (b) do not involve active monitoring, (c) are appropriate to protecting ecosystem integrity, (d) use fish as the test organism, (e) provide a measure of lethality, are (f) long-term tests and are appropriate to (g) the water body of a (h) fresh water of an (i) inland water resource.

6.2.3.2 Initial shortlists

Each of the contexts relating to the classification framework was considered in turn. As noted above, Natural ecological categories were assumed to require long-term sub-lethality toxicity tests while Fair/Good required long-term lethality tests. In order to minimise capacity requirements, the common tests in these two lists were extracted. In other words, tests were chosen that could measure both long-term sub-lethality and long-term lethality in the same experiment (for the same test organism). Such common lists were obtained for all cases except for plants. In the case of plants, only long-term sub-lethality tests were available.

Only screening tests were considered and active monitoring tests were excluded.

The following were the results:

Table 6.2. Initial shortlist for protecting ecosystem health (test organism: fish). These are appropriate for Natural and Fair/Good ecological categories and can determine long-term sub-lethality and long-term lethality in the same test.

Fish (zebra) development (semi-static)
Fish (zebra) development (static)
Fish (rainbow trout) development
Fish (fathead minnow) larval survival and growth
Fish (fathead minnow) embryo-larval survival and teratogenicity

Table 6.3. Initial shortlist for protecting ecosystem health (test organism: invertebrates). These are appropriate for Natural and Fair/Good ecological categories and can determine long-term sub-lethality and long-term lethality in the same test.

Daphnia pulex reproduction
Daphnia magna reproduction and survival
Ceriodaphnia reproduction and survival
Whole Daphnia cellular energy alloc. (lab. test)

Table 6.4. Initial shortlist for protecting ecosystem health (test organism: plants). These are appropriate for the Natural ecological category only (determines long-term sub-lethality only).

Duckweed growth inhibition
Algal 96-well microplate growth inhibition
Algal scintillation well growth inhibition
Algal 24-well microplate growth inhibition
Algal flask growth inhibition - chlorophyll measurement
Algal flask growth inhibition (various measurements)

For completeness, the same was done for domestic use. However, no restrictions were placed on test organism. The following was obtained:

Table 6.5. Initial shortlist for protecting human health (any test organism). These are appropriate for the Ideal and Tolerable/Acceptable water use classes and can determine long-term sub-lethality and long-term lethality in the same test.

Fish (zebra) development (semi-static)
Fish (zebra) development (static)
Frog teratogenicity
Ames Salmonella plate incorporation
Salmonella fluctuation (lab. method)
Salmonella fluctuation (Muta-chromoplate kit)
Umu mutagenicity

Recombinant yeast (hER)
Recombinant yeast (hAR)
Mammalian cell colony formation

6.2.3.3 Discussion of shortlists

Tables 6.2, 6.3 and 6.4 refer to protecting ecosystem health and use fish, invertebrate and plant test organisms respectively. This addresses the design recommendation that three trophic levels are tested.

Note that although individual shortlists were generated for sub-lethal tests (for the Natural ecological category) and lethal tests (for the Fair/Good ecological categories), only the tests common to both are reflected in the tables. That is, the same test can be used to determine both lethality and sub-lethality. This again addresses one of the design recommendations.

Domestic use is addressed as follows: A design recommendation was that protection of humans be assessed from two sources:

- The results of the tests chosen for protecting ecosystem health (*i.e.* chosen from Tables 6.2, 6.3 and 6.4), and
- The yeast test (to be used only when the water use class is Ideal).

In summary, it is Tables 6.2, 6.3 and 6.4 that need to be carefully examined and single tests from each chosen for the protection of ecosystem health in the NTMP. The single yeast test then needs to be added to this list for domestic use.

These considerations comprise the next step and must specifically address issues related to ease of monitoring (namely, costs of sampling, analysis and capacity creation).

6.2.4 Final recommendations

6.2.4.1 Fish toxicity test

Three tests were excluded from those in Table 6.2 for the following reasons:

- Fathead minnow tests: It is considered inadvisable to import these exotic fish for use on such a large scale.
- Rainbow trout test: This fish is associated with colder waters and is therefore considered inappropriate for use on a nationwide basis.

The two remaining tests were then ranked (1-3) on the basis of ease of monitoring. The following table shows the ranking used. Relative weights (1-3) have also been assigned to the five criteria.

Table 6.6. Ranking used for the fish tests.

		Ease of sampling	**Cost of sampling**	**Ease of analysis & assessment**	**Cost of analysis & assessment**	**Cost of capacity creation**
	Rank	1	1	3	3	2
Fish (zebra) development (semi-static)	**22**	2	2	2	2	3
Fish (zebra) development (static)	**18**	2	3	1	2	2

		1=Complex	1=High	1=Complex	1=High	1=High
		2=Intermediate	2=Medium	2=Intermediate	2=Medium	2=Medium
		3=Simple/routine	3=Low	3=Simple/routine	3=Low	3=Low

The recommended fish test is therefore: **Fish (zebra) development (semi-static)**.

6.2.4.2 Invertebrates

Of the four tests in Table 6.3 above, the daphnia magna test was excluded because this species is not currently used in South Africa and it is not prevalent in our waters.

The remaining tests were ranked on the basis of ease of monitoring, using the same relative weighting for the five criteria as above.

Table 6.7. Ranking used for the invertebrate tests.

		Ease of sampling	**Cost of sampling**	**Ease of analysis & assessment**	**Cost of analysis & assessment**	**Cost of capacity creation**
	Rank	1	1	3	3	2
Daphnia pulex reproduction	**21**	2	1	2	2	3
Ceriodaphnia reproduction and survival	**22**	2	2	2	2	3
Whole Daphnia cellular energy alloc. (lab. test)	**19**	2	3	3	1	1
		1=Complex	1=High	1=Complex	1=High	1=High
		2=Intermediate	2=Medium	2=Intermediate	2=Medium	2=Medium
		3=Simple/routine	3=Low	3=Simple/routine	3=Low	3=Low

Although the ceriodaphnia test is marginally better that the daphnia pulex test, it is considered best to choose the latter test because handling and maintenance of daphnia pulex is well established in South Africa.

The recommended invertebrate test is therefore: **Daphnia pulex reproduction**.

6.2.4.3 Plants

Of the six plant tests in Table 6.4, the 96-well test and the scintillation test were excluded because these are tests specifically developed for certain foreign countries and are, in any case, very similar to the 24-well test that is established in South Africa.

The remaining tests were ranked on the basis of ease of monitoring, using the same relative weighting for the five criteria as above.

Table 6.8. Ranking used for the plant tests.

		Ease of sampling	Cost of sampling	Ease of analysis & assessment	Cost of analysis & assessment	Cost of capacity creation
	Rank	1	1	3	3	2
Duckweed growth inhibition	**17**	2	1	2	2	1
Algal 24-well microplate growth inhibition	**27**	2	3	3	3	2
Algal flask growth inhibition - chlorophyll measurement	**18**	2	2	2	2	1
Algal flask growth inhibition (various measurements)	**18**	2	2	2	2	1
		1=Complex	1=High	1=Complex	1=High	1=High
		2=Intermediate	2=Medium	2=Intermediate	2=Medium	2=Medium
		3=Simple/routine	3=Low	3=Simple/routine	3=Low	3=Low

The recommended test is therefore: **Algal 24-well microplate growth inhibition**.

6.3 TOXICANTS

6.3.1 Final recommendations

The persistent organic pollutants (POPs) will comprise the initial "wish list" of toxicant monitoring variables for the NTMP. The following table lists the POPs. The PCBs (polychlorinated biphenyls), dioxins and furans comprise many compounds.

Table 6.6. The "persistent organic pollutants".

Chemical	Pesticide	Industrial chemical	Byproduct	Chemical Abstracts Substance No.
Aldrin	Yes			309-00-2
Chlordane	Yes			57-74-9
Dieldrin	Yes			60-57-1
Endrin	Yes			72-20-8
Heptachlor	Yes			76-44-8
Mirex	Yes			2385-85-5
Toxaphene	Yes			8001-35-2
DDT	Yes			50-29-3
Hexachlorobenzene	Yes	Yes	Yes	118-74-1
PCBs		Yes	Yes	
Dioxins			Yes	
Furans			Yes	

Given the well-established impacts of these compounds on ecosystems and human health (and their obvious international prominence), it is not considered particularly valuable to rank the POPs (among themselves) on the basis of their relative impact. Furthermore, if the NTMP is to be regarded as formally addressing (at least in part) the requirements of the Stockholm Convention, all should probably be monitored irrespective of whether significant sources of them are known to exist in South Africa. The fact that they can be transported by atmospheric mechanisms from neighbouring countries (and those further away) also means that the non-existence of POP sources in South Africa is not necessarily an overriding criterion for their exclusion.

Accordingly, it is recommended that the choice of POPs included for the initialisation phase of the NTMP should be based entirely on criteria related to ease of monitoring. Three main criteria were recommended in Chapter 4:

- Sampling (ease and cost).
- Analysis and assessment (ease and cost).
- Capacity creation (cost).

Ease refers to the simplicity of the task and relates to the degree of expertise required. The cost of capacity creation refers to creating sufficient capacity nationwide (decentralised).

The following general statements can be made:

- Analytical methods do not exist in South Africa at this time for dioxins or furans. A screening test is being developed at Potchefstroom University. However, this is only likely to become available in mid-2005. It might be sometime after that (possibly years) that the test will be sufficiently well established and standardised to enable inclusion in the NTMP.
- A number of analytical laboratories exist that can analyse for the other POPs.
- The analytical method for PCBs and the pesticides involves an extraction then an analysis of the extract using gas chromatography and mass spectrometry (GC-MS). The PCBs and the pesticides may require two different extraction procedures. However, it may be possible to combine them.
- Once the extract has been obtained, a single GC-MS run provides the measurement for all the POP pesticides. If a separate extraction is required for the PCBs, then another GC-MS run will analyse for the PCBs.
- The cost of the analytical method is divided into two main parts: Extraction costs and analytical (GC-MS) costs.
- 1-litre glass sampling bottles are used for the PCBs and pesticides. They should be kept at 4°C and extracted as soon as possible after sampling (preferably within 24 hours).
- The extraction procedures are well documented but need a very reliable technician for consistent results.

From this it can be concluded that for the PCBs and pesticides:

- There is no difference in the sampling procedures (either in terms of ease or cost),
- There is no fundamental difference in the ease or cost of analysis and assessment,
- There is no fundamental difference in the costs of capacity creation.

The following is therefore recommended:

- Dioxins and furans should not be included in the NTMP at this time. This decision should be reviewed in future.
- The PCBs and pesticides should be included in the NTMP and no distinction (in respect of priority ranking) made between them at this time.

6.3.2 Guidelines

As noted in the Resource Classification Framework Chapter (Chapter 2), the two criteria for toxicity that determine the two boundary conditions for the resource classes also suggest the nature of the guidelines that should be used for toxicants. These are:

- No Observable Effect Concentration (NOEC).
- Maximum concentration that does not cause lethality (LC_0).

Values need to be obtained for these that take due consideration of the probabilities of false negative results and false positive results (see sub-section Consequences of Errors in Chapter 4: Criteria for Choosing Monitoring Variables).

6.4 DECISIONS TO BE REVISITED

All monitoring programmes must be revised from time to time to ensure that the original objectives remain valid and that they are being achieved. This should take place, at most, every five years but could be more frequent initially (every three years).

The following issues are recommended as important considerations in the first revision of the NTMP:

- The restriction of toxicity testing to samples of the water column only (*i.e.* excluding sediments). The advantages of sediment sampling should be carefully weighed against the disadvantages (including the costs of capacity creation).
- The inclusion of dioxins and furans if cost-effective decentralised analytical capacity can be created in South Africa.
- Inclusion of active monitoring.

CHAPTER 7: REFERENCES

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