Needs assessment and development framework for a tested implementation plan for the initialisation and execution of a National Toxicants Monitoring Programme (NTMP)

Final Report

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April 2003

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EXECUTIVE SUMMARY

This needs assessment and development framework forms the first phase of a larger phased project. The latter will ultimately deliver a well-tested implementation plan for full-scale implementation of a national monitoring programme for toxic substances ("toxicants") and toxic effects.

The specific purpose of this needs assessment phase is the following:

To perform a thorough and systematic needs assessment that will form the basis of the development of a modular implementation plan for initialisation and sustained execution of a National Toxicants Monitoring Programme (NTMP) that meets the requirements of the National Water Act.

The needs of the Department of Water Affairs and Forestry (DWAF) were captured in a series of in-depth meetings involving an eight-member steering committee and consultations with other relevant parties at DWAF head office. This report contains the outcome of those meetings as well as numerous principles upon which future development should take place. This report contains three sections, each summarised in the following subsections.

Background

As the public trustee of South Africa's water resources, it is the responsibility of DWAF to develop national monitoring programmes. It is also DWAF's responsibility to establish national information systems, of which monitoring programmes form one aspect. The provision of such data and information is required by the National Water Act. This is reiterated in the National Water Resource Strategy.

The detailed design of a national toxicants monitoring programme will need to take very careful account of the considerable complexity of this field. An extremely wide range of potential toxicants can occur in water resources. Each of these can potentially exhibit a range of toxic effects on a wide variety of organisms ranging from plants, invertebrates, fish, mammals, birds to humans.

Monitoring of toxicants in water resources in other countries is also at a relatively early stage of implementation. The United States Geological Survey has only as recently as last year (2002) reported on the widespread prevalence of some toxicants in the US. One reason for this is that only recently have analytical methods been developed for the detection of some of the toxicants. However, another reason, relevant worldwide, has been the preferred focus of monitoring toxicity of effluents and hazardous wastes. That is, prevention is sensibly seen as better than cure. Once toxicants have entered the natural environment, they are much more difficult to monitor.

Biotoxicology

The section summarising biotoxicology is intended to be a section in the ultimate implementation manual. It will provide background information on many of the scientific aspects of this monitoring programme, especially for people that are not experts in this field.

Biotoxicology is the qualitative and quantitative study of the adverse effects of chemical pollutants and other anthropogenic materials on organisms. The envisaged national monitoring programme only concerns itself with a part of this very broad field.

Toxicants comprise individual chemicals or classes of chemicals including inorganic and organic compounds. The latter include pesticides, petroleum products, petrochemicals, surfactants and pharmaceuticals.

Many interrelated factors affect the extent to which such toxicants occur in natural waters and sediments (*i.e.* their concentrations). These include those due to the type of toxicant (it's chemical and physical properties) and the properties of the environment in which it finds itself.

The experimental measurement of the concentration of a toxicant can vary from simple and standard (in the case of many inorganic compounds) to complex, expensive and requiring specialist expertise (*e.g.* for pesticides and pharmaceuticals). Some such expertise exists in South Africa though only in a few specialised laboratories.

Toxicity, on the other hand, is concerned with the adverse effects of these substances (or mixtures of them) on living organisms. These toxic effects can manifest in a short period of time (within days) or be cumulative effects that manifest over much longer periods. They can result in the death of the organism (a "lethal" effect) or simply impair some activity of the organism without killing it (a "sublethal" effect).

The extent to which this toxic effect manifests itself depends on many factors, only one of which is the concentration of the toxicant to which the organism is exposed. It also depends on properties of the toxicant itself, various exposure factors (like the time exposed) and organism factors that determine the susceptibility of that organism to the toxicant.

Measuring the extent of toxicity can be done *in situ* or in the laboratory. Many "toxicity tests" exist that can measure short- and long-term effects, both lethal and sublethal. Although some have been used for many years, many lack the degree of standardisation that exists for the analytical methods that measure the concentrations of toxicants.

Design decisions

It is intended that the National Toxicants Monitoring Programme (NTMP) ultimately provide information primarily to the Minister of Water Affairs and Forestry and Water Resource Managers and Water Quality Managers (at DWAF Head Office and Regional Offices, CMAs and non-DWAF organisations).

Preliminary expressions of perceived needs by DWAF were eventually crystallised into a series of formal decisions and recommendations. These are not repeated here but appear in the RECOMMENDATIONS section towards the end of this report. Considerable effort was expended on understanding and defining the objectives of the NTMP. This was deemed a critical task since this defines the scope of the NTMP. In particular, it will ensure that the next design phase is well focussed.

CONTENTS

1 INTRODUCTION

This needs assessment is the first phase of a larger project that ultimately aims at full-scale implementation of toxicant and toxicity monitoring of South African water resources. The phases are as follows.

- Phase 1: This needs assessment.
- Phase 2: The development of an appropriate design for the monitoring programme that addresses stated monitoring objectives. The design will be captured in a prototype implementation manual that will describe in detail how the national monitoring programme should be initialised and implemented fully. No significant pilot testing will take place in this phase. However, this phase will include preparing proposals for international funding for some of the pilot studies in the next phase.
- Phase 3: This will involve a series of carefully planned pilot studies that will test the design and the effectiveness of the implementation manual itself. The result will be a final properly tested and refined implementation manual.

Upon completion of the necessary pilot studies, full-scale implementation can start.

The general purpose of this needs assessment phase is as follows:

To perform a thorough and systematic needs assessment that will form the basis of the development of a modular implementation plan for initialisation and sustained execution of a National Toxicants Monitoring Programme (NTMP) that meets the requirements of the National Water Act.

Specifically it will include the following:

- Defining the target users of the information provided by the NTMP (within DWAF);
- Defining the national monitoring information needs of DWAF in respect of toxicants and/or toxicity (*e.g.* should this be a 'status and trends' programme);
- Determining whether monitoring (a) the toxicants *per se* (*i.e.* the *presence* of pesticides, heavy metals, etc.) or (b) the toxicity (*i.e.* the *effects* of the toxicants) or (c) both is necessary to meet these national needs.
- Defining the monitoring objectives of the NTMP at a national level (*e.g.* status and trends);
- Defining the scope of the term 'toxicants' (*e.g.* classes of substances to be included) and of the term 'toxicity' (if the latter is monitored);
- Defining the scope of the water resources to be included (watercourses, groundwater, estuaries, etc.);
- Defining the generic format in which that information is required by the target group;
- Identifying the primary role players that should contribute to the development of the ultimate implementation plan;
- Describing the extent to which capacity, particularly among previously disadvantaged individuals, can begin to be created in support of ultimate implementation; and
- Describing in sufficient, though not excessive, detail enough technical background on toxicity-related concepts to support the future implementation plan.

The BACKGROUND chapter provides a perspective on the general complexity of the field, how such monitoring is approached in other countries as well as some of the preliminary perceived needs within South Africa.

The BIOTOXICOLOGY chapter is a summary of the basic principles of the general field of biotoxicology. It is intended that this chapter will appear verbatim in the ultimate implementation manual. It will serve as a basic reference to those involved in implementation, particularly those who are not experts in the field of toxicity.

The DESIGN DECISIONS chapter also presents various perceived needs. However, it addresses various specific aspects of monitoring design that create a sound foundation upon which to proceed with the detailed design phase (that follows this needs assessment phase).

2 BACKGROUND

2.1 The National Water Act

The Department of Water Affairs and Forestry (DWAF) is the public trustee of South Africa's water resources. As such it must ensure that waters remain fit for use on a sustainable basis. The National Water Act No. 36 of 1998 specifically requires that national monitoring systems be established (Chapter 14, Part 1). Furthermore, the Minister is also required to establish national information systems regarding water resources (Chapter 14, Part 2). A national water quality monitoring system is one source of information feeding into such an information system.

The requirement for the envisaged national monitoring programme relating to toxicants and toxicity is therefore firmly based on requirements of the National Water Act. This programme is but one in a series of such national programmes. The others are at different stages of development and implementation. The oldest and most well established is the programme monitoring inorganic compounds (including common metal cations and inorganic anions). Others include biomonitoring, microbial monitoring, eutrophication monitoring, and radioactivity monitoring.

2.2 Consideration of the complexity

The design of any national monitoring programme is complex. It involves a wide range of issues ranging from identifying monitoring variables, choice of monitoring sites, monitoring frequency, analytical methods, quality control and assurance, data management, data assessment and reporting. However, the design of one aiming at monitoring the occurrence of toxic (or potentially toxic) compounds is particularly complex. It is important to be fully aware of the extent of the problems facing such a design before proceeding. The problems include the following.

- There is an extremely diverse range of classes of toxicants.
- There is an extremely diverse range of individual toxicants in each class.
- There is an even wider range of potential negative impacts since each individual toxicant can exhibit a range of effects on a range of target organisms (including plants and animals). These effects also depend on many environmental variables.
- Many toxic or potentially toxic chemicals released into the environment degrade or are metabolised into a range of other chemicals, each of which may be toxic in its own right.
- Partly because of the former issue, many toxicants will exhibit non-conservative behaviour in the environment. However, many are particularly persistent.
- Direct chemical analysis for many toxicants can be difficult and expensive.
- Although a range of toxicity tests are available, many are relatively difficult to apply and interpret, particularly compared to typical standard analyses for the more common chemicals such as calcium, sulfate, etc. used in such programmes as the National Chemical Monitoring Programme.

It is important that each design decision relating to the NTMP take full account of these issues.

2.3 Monitoring in other countries

The following account is a brief summary of some toxicity related monitoring activities in a few other countries for which information was readily available.

Slabbert *et al.* (1998a) have summarised the general policies and strategies on the use of biological toxicity tests in the United States, Canada and some member states of the European Union. However, the authors' emphasis is primarily on effluent toxicity testing, not water resource testing which is the current context. The report also does not consider direct measurements of toxicant concentrations. It is nevertheless a useful summary of some of the historical approaches adopted to address the general issue of managing toxicity of waters in those countries.

A summarised review of the international use of toxicity tests in 38 countries indicated that the majority of countries do not have any regulations for the use of toxicity tests to monitor effluent discharges [Dutka, 2000]. Although a few years out of date, the results (see Table 1) give an interesting perspective, although some aspects seem questionable (like the appearance of the United Kingdom in the first column).

Emphasis worldwide has tended to be mainly on toxicity testing of effluents and hazardous waste. Formal national monitoring of water resources has received less attention, though this is now increasing. This is no doubt due to at least two main factors.

- The preferred (and sensible) focus on prevention rather than cure.
- The inherent difficulties associated with monitoring toxicants once they have entered the environment (compared to monitoring point sources).

Table 1. Survey of 38 countries with and without toxicity test regulations for effluents and hazardous wastes [Dutka, 2000].

Countries with no toxicity test regulations		**Countries with toxicity test regulations**
Not using toxicity tests	**Using toxicity tests**	
Algeria	Australia	Argentina
Chile	Mexico	Czech Republic
China	New Zealand	France
Colombia	South Africa**	Hawaii, USA
Cuba	Switzerland	Lithuania
Egypt		Rep. of Kazakhstan
Fiji		Russia
Hong Kong		Sweden
Israel		Ukraine
Lebanon		United States of America
Morocco		
Panama		
Portugal		
Singapore		
Solomon Islands		
Syria		
Tonga		
United Kingdom*		
Vanautu		
Viet Nam		
Zimbabwe		

* Regulations now in place. ** Only at one factory in 2000.

2.3.1 *United States*

A national programme called Biomonitoring of Environmental Status and Trends (BEST) exists that has the following goals [Olsen *et al.*, 1999]:

- Determine the status and trends of contaminants and their effects on natural resources;
- Identify and assess the major factors affecting observed conditions and trends;
- Identify needs for prevention and reduction of impacts;
- Where possible, predict future conditions and cumulative impacts; and
- Provide summary information to decision makers to guide efforts, recommendations and/or decisions pertaining to impact prevention, remediation, restoration and enhancement of fish and wildlife resources.

The monitoring focuses on a few indicator fish and birds species, samples of which are analysed for target chemicals.

The Environmental Monitoring and Assessment Programme (EMAP) was established in response to the US EPA's Science Advisory Board which, in 1988, recommended that EPA [Olsen *et al.*, 1999]

- Implement a monitoring programme to report on status and trends in environmental quality;
- Explicitly develop and use monitoring systems to identify emerging environmental problems; and
- Place greater emphasis on the development and use of ecological indicators.

EMAP is applied to estuaries and surface waters. In respect of the latter, the monitoring objectives address the following questions.

- What is the present extent and geographic distribution of the Nation's inland surface water ecological resources?
- What is the ecological condition of these resources?
- What proportion of these resources is degrading or improving, where, and at what rate?
- What are probable causes of adverse conditions and trends?

Indicators are categorised as follows [Olsen *et al.*, 1999].

- Response indicators (fish assemblages, benthic macroinvertebrate assemblages, zooplankton assemblages, trophic state and semi-aquatic wildlife assemblages);
- Exposure/habitat indicators (physical habitat structure, water quality, sediment toxicity, chemical contaminants in fish and biomarkers in fish); and
- Stressor indicators (land use and land cover, human and livestock population density, chemical use, pollutant loadings, flow and channel modification, introduced species and stocking and harvesting records).

The National Water-Quality Assessment Program (NAWQA) in broad terms answers the following questions: "Is the river and ground water quality of the nation getting better or worse?" and "Why?". More specifically it "is designed to assess the status and trends in the quality of the Nation's ground- and surface-water resources and to link the status and trends with an understanding of the natural and human factors that affect the quality of water" [Olsen *et al.*, 1999].

Data collected includes the following.

- Water quality characteristics including dissolved oxygen, pH, temperature, major ions and metals, nutrients etc.
- Additional water-quality constituents such as trace elements and organic components including pesticides.
- Habitat characteristics and identification of biological communities.
- Additional biological water-quality characteristics such as bacteria.
- Hydrogeologic information and land cover data.

Sixty "study units" where chosen that represent major hydrogeologic catchments comprising 60-70% of the Nation's water use and cover 40% of its area. All study units measure a common set of physical variables, inorganic constituents and organic compounds. Other variables and information recorded at each study site depend on the local factors.

In the 1970s the US EPA chose a series of contaminants for regular monitoring. The choice was based on the following criteria:

- Availability of reference standards;
- The amount of compound manufactured; and
- The number of locations at which the compound was found.

It is only fairly recently that the United States Geological Survey (USGS) has reported on the prevalence of pharmaceuticals and other everyday organic products in U.S. waters [Erickson, 2002]. The main reason for this is that it is only recently that analytical methods have become available that can detect the very low concentrations at which these compounds occur in natural waters. They concentrated on some 95 contaminants from industrial, human and agricultural wastewater sources in 139 U.S. streams. Importantly, they focussed mainly on sites susceptible to contamination such as those downstream of urban areas and livestock production. There were nevertheless some sites that were regarded as "less developed". In some cases as many as 38 of the 95 compounds were detected in a single water sample.

This study was little more than a snapshot in time. The intention is to monitor at regular intervals in future.

The following comments can be made in respect of related monitoring in the United States.

- Broadly speaking, national "status and trends" monitoring programmes have objectives rather similar in many respects to those of South African national programmes. The exception is that they explicitly include establishing the causes of problems.
- US national programmes seem less modular than the South African national programmes. This is in the sense that each South African national programme tends to focus on a more restricted series of related monitoring variables. For example, there are chemical, microbial, eutrophication, biomonitoring (and now radioactivity, toxicants and toxicity) national programmes. The US programmes tend to more all-encompassing by monitoring a wide range of variables from land use, through explicit water quality variables to ecological impacts. It is difficult to judge which might be the fundamentally better approach. Each will have its own pros and cons. However, the modular South African approach does suggest that if it is ultimately desirable that water resources can be characterised as sufficiently "fit for use" (whatever the use or uses might be), then two issues need to be taken into account. First, an overarching assessment stage is necessary that uses results from many national programmes, that is independent of any individual national programme (*i.e.* it must be modular). Secondly, to ensure that such an assessment stage is possible, the monitoring variables in individual national programmes must be carefully considered

and appropriately complementary (*i.e.* must provide all the necessary information when combined).
- In the US, besides the more focused (and more recent) effort of the USGS, monitoring of toxicants and toxicity is done to some extent in a number of different national monitoring programmes.

2.3.2 *Canada*

There are four important statutes in Canada relating to chemical constituents that potentially cause adverse short- and long-term effects on animals and humans. These include: the Canadian Environmental Protection Act (CEPA), the Fisheries Act, the Pest Control Product Act, and the Transport Act (Transportation of Dangerous Goods Regulation).

Canada is actively applying ecotoxicology for the protection of aquatic ecosystems [Blaise, 2001]. The three major functions of environmental protection agencies are cognitive (knowledge of effects through bioassays followed by cause identification), curative and preventive. The impression is given that considerable emphasis is given to preventative measures, particularly with respect to known pollutants and new substances of less well-known behaviour. Toxicity tests are used to assess toxicity of liquid and solid media, including sediments.

They have a toxicology test method development programme. It aims to develop standardised methods to ensure the following:

- Proper use for legislative requirements
- National consistency in testing
- Quality assurance for clients
- Sound biological components in ecotoxicological hazard assessment schemes.

Standardised methods include fish, invertebrate, micro-algal and bacterial methods. Documents also exist for sediment sample collection, preparation and testing. Canada also has a biological testing laboratory accreditation programme.

2.3.3 *Asia-Pacific region*

A particular focus in this region since the mid-1990s has been on persistent organochlorines. Marine mussels were used as a biological indicator in the coastal waters of Asian countries such as Cambodia, China, Hong Kong, India, Indonesia, Japan, Korea, Malaysia, Philipines, Far East Russia, Singapore and Vietnam [Monirith *et al.*, 2003]. The later review is the first comprehensive report on monitoring organochlorine pollution in the Asia-Pacific region. Although involving marine waters, Monirith *et al.* (2003) note that DDT concentrations in mussels near developing countries were higher than those near developed countries. The opposite trend was found for polychlorinated biphenyls (PCBs) which are industrial chemicals. Similar trends in other parts of the world have been noted by Goldman and Tran (2002).

Wong (2003) has noted that the choice of some monitoring variables in Hong Kong's toxicant monitoring programme was simply based on the degree of public concern or pressure from concerned groups.

2.3.4 *Netherlands*

National monitoring in the Netherlands has been well summarised by Breukel (1999). A chemical monitoring programme exists that is referred to as a "Nation-wide ambient monitoring programme". Ambient monitoring involves "the observation of water systems with standardised methods over a long period (years), to establish status and trends for the purpose of enabling policy makers to make tactical and strategic decisions with water management, for the testing of standards and calculation of loads".

Among other variables, this programme includes monitoring inorganic pollutants (including heavy metals), organic pollutants, some ecotoxicological variables, radioactivity and microbiology. They include measurements in samples of filtered and unfiltered surface water, suspended solids, sediments and biota (fish and mussels).

The Netherlands also has hydrological and biological monitoring programmes.

Ad hoc studies have been done since the early 1980s on monitoring toxicity in the Meuse and Rhine rivers [Sloof *et al.*, 1983]. They used a fish (guppy) test and found large variations in toxicity in time and space. They attributed this to seasonal effects and variations in pollutants discharges.

2.4 Perceived monitoring needs in South Africa

The needs of this national programme as perceived in preliminary discussions with DWAF are captured in this section. Many are examined in more detail and defined more precisely in later sections.

- The NTMP is regarded as a "status and trends" monitoring programme in essentially the same sense of the National Microbial Monitoring Programme (NMMP) and the National Eutrophication Monitoring Programme (NEMP). Such programmes are also referred to as "assessment monitoring programmes".

- The NTMP is a national programme in the sense that it intends to provide a national picture of the status and trends of water quality relating to toxicants and toxicity. This may be in the form of an annual report containing a national map and regional (Water Management Area) maps indicating areas of concern (for example where high concentrations of toxicants or high toxicity occur). These reports should also allow a comparison with previous years, that is, allow some degree of assessment of trends.

- The NTMP will not concern itself with providing sufficient data to establish cause and effect relationships. The NTMP is intended to highlight areas of concern so that, for example, strategic decisions can be made regarding national and regional resource allocation. Should the NTMP indicate an area of concern and DWAF needs to establish who or what is causing the toxicity, then this is outside the scope of the NTMP.

- Although the reports of the NTMP should not strictly be regarded as representing the "State of the Environment" (in the usual sense in which that term is used), this is in fact more or less the overall nature of the intended NTMP report. The temporal scale is primarily annual. However, it is possible that more frequent reports might be issued to local and regional parties (as is done in the National Microbial Monitoring Programme). The spatial scale of the NTMP is national and regional.

- The NTMP should be able to report on the "nature and extent" of the problem in the sense of reporting **what** agent or effect might be cause for concern (*i.e.* what toxicants, toxicant classes or toxic effects). It is not concerned with monitoring specific sources of toxicants.

Various other national monitoring programmes exist or are being designed. In respect of these, it is important that the NTMP satisfy the following criteria:

- The NTMP must complement the data and information provided by other national programmes;
- The NTMP reporting protocol and format should be compatible with other existing protocols; and
- The NTMP must not duplicate existing efforts in other programmes.

The NTMP can complement the national chemical monitoring programme in a number of ways. The chemical monitoring programme is, by its very nature, a "substance-specific" approach. It analyses for the existence and concentration of conventional chemicals (calcium, sulfate, etc.). However, such monitoring variables are inadequate for characterising toxicity. This is particularly so when complex solutions are involved. These problems arise because a substance-specific approach depends on knowledge of

- the composition of the solution (which may be difficult, costly or even impossible to characterise sufficiently well); and
- the individual effects of each component (which often incorrectly assumes different toxicants act independently).

Therefore the NTMP can detect and report the existence and/or concentration of individual toxicants or classes of toxicants that are not already included in the chemical monitoring. Secondly, the NTMP can report the actual toxicity. This, by definition, examines effects (not what is causing them).

The biomonitoring ("river health") programme can detect (amongst other things) the effects of deteriorating water quality (due, for example, to the presence of toxicants). However, the nature of the biomonitoring indicators is such that

- the observed effects cannot easily be linked directly to the presence of toxicants; and
- the time from the sudden appearance of toxicants (from whatever source) to measured impact can be too long (possibly weeks or months).

Providing toxicant concentrations or toxicity measurements will therefore increase the possibility of being able to identify the agents causing any observed deterioration in ecosystem health (as reported by the biomonitoring programme). In this context, the NTMP complements this programme.

3 BIOTOXICOLOGY

3.1 Introduction

Biotoxicology is the qualitative and quantitative study of the adverse effects of chemical pollutants and other anthropogenic materials on organisms. The current national monitoring context only concerns itself with a subset of this extremely broad field.

Aquatic toxicology, in particular, is a multidisciplinary science that integrates expertise from biology (biological structure and function of aquatic ecosystems) and relates to establishing the concentration of toxicants in the aquatic environment. Establishing the concentration requires expertise in the distribution and fate of toxicants. This is a function of physical factors (*e.g.* solubility, volatility, etc.), chemical factors (hydrolysis, photolysis, oxidation and reduction etc.) and biological factors (*e.g.* bioaccumulation, biotransformation, biodegradation) [Rand and Petrocelli, 1995].

An important basic principle of toxicology is that no chemical is completely safe and no chemical is completely toxic [Rand and Petrocelli, 1995]. Even apparently harmless chemical substances can have toxic effects when taken up by an organism in sufficient amounts. Conversely, uptake of small amounts of toxic chemicals may result in no apparent toxic effect. Typically the effect on an organism depends on both the quantity of the chemical to which the organism is exposed and the duration of that exposure.

3.2 Toxicants

3.2.1 *The nature of toxicants*

Toxicants in general can occur in a very wide variety of physical forms, including dusts, fumes, mists, vapours and gases, liquids and solids [Sax, 1974]. In the current context, toxicants are confined to *chemical* pollutants capable of exhibiting a toxic effect.

Monitoring to establish the specific source of the toxicants is explicitly not included in the monitoring objectives of the NTMP. However, for the sake of completeness, this adjacent table summarises a few typical sources of some toxicants. Organic compounds comprise the widest variety of toxicants, some classes of which also appear in the table.

Table 2. Examples of potential sources of various toxicants in natural waters.

Toxicant	Typical sources
Heavy metals	Mining industry, chemical industry, tanning
Inorganics	Mining industry
Pesticides	Pesticide manufacture and formulation; Agriculture
Petroleum products	Petroleum industry
Petrochemicals	Petrochemical industry
Surfactants	Household aqueous waste, industrial laundering and other cleansing operations
Pharmaceuticals	Pharmaceutical industry, agriculture, hospitals

The following subsections describe briefly some of the classes of chemical pollutants of potential concern. It might be noted that these classes are not mutually exclusive (as roughly illustrated in

Figure 1). That is, some specific toxicants may appear in more than one class. Nevertheless, these classes are defined and used here because they are classifications that are in common use. Examples of toxicants are given for each class.

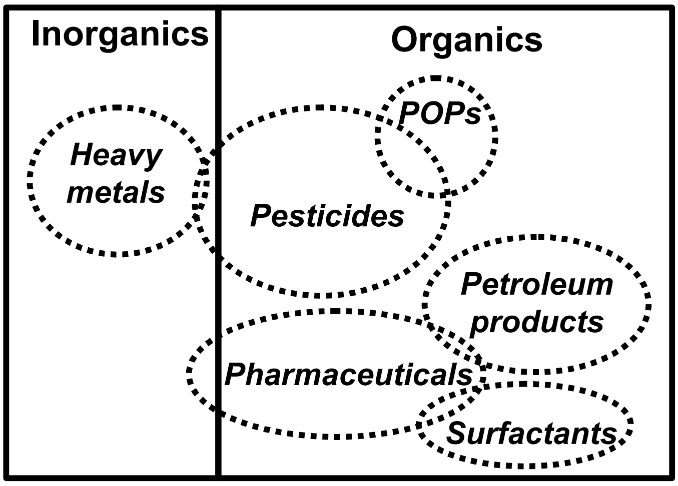

Figure 1. Illustration of the overlap between some classes of toxicants (POPs = Persistent Organic Pollutants).

Inorganic substances

Heavy metals are defined as metallic elements with atomic number greater than 20 (*i.e.* that of calcium) [World Bank, 1999]. The heavy metals are highlighted in the adjacent periodic table.

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	**Sc**	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Ga**	**Ge**	As	Se	Br	Kr
Rb	**Sr**	**Y**	**Zr**	**Nb**	**Mo**	**Tc**	**Ru**	**Rh**	**Pd**	**Ag**	**Cd**	**In**	**Sn**	**Sb**	Te	I	Xe
Cs	**Ba**	*L*	**Hf**	**Ta**	**W**	**Re**	**Os**	**Ir**	**Pt**	**Au**	**Hg**	**Tl**	**Pb**	**Bi**	**Po**	At	Rn
Fr	**Ra**	*A*															
		L	**La**	**Ce**	**Pr**	**Nd**	**Pm**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
		A	**Ac**	**Th**	**Pa**	**U**	**Np**	**Pu**	**Am**	**Cm**	**Bk**	**Cf**	**Es**	**Fm**	**Md**	**No**	**Lr**

Figure 2. The elements typically regarded as “heavy metals” (highlighted in bold).

Most of the lanthanides (the so-called “rare earths”, from La to Lu) and the actinides (from Ac to Lr) are particularly uncommon and not likely to be relevant in a national monitoring programme. However, some, like uranium (U), are potential toxicants that could feasibly occur in South African aquatic environments. However, it might be reasonably suggested that uranium is better dealt with in the national radioactivity monitoring programme. Accordingly, it is suggested that the lanthanides and actinides be excluded from the scope of “heavy metals” for the NTMP. An operational definition of heavy metals in the current context would then include the metals indicated in the following figure.

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	**Sc**	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Ga**	**Ge**	As	Se	Br	Kr
Rb	**Sr**	**Y**	**Zr**	**Nb**	**Mo**	**Tc**	**Ru**	**Rh**	**Pd**	**Ag**	**Cd**	**In**	**Sn**	Sb	Te	I	Xe
Cs	**Ba**	*L*	**Hf**	**Ta**	**W**	**Re**	**Os**	**Ir**	**Pt**	**Au**	**Hg**	**Tl**	**Pb**	**Bi**	**Po**	At	Rn
Fr	**Ra**	*A*															
		L	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
		A	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Figure 3. Operational definition of the 44 “heavy metals” for the NTMP (highlighted in bold).

In the current context, elemental forms of the metals are not usually an issue. One exception is mercury, Hg, which is significantly soluble in water in its elemental form, Hg^0, as well as occurring in other charged and neutral forms. Most metals tend to exhibit their toxicity when they occur as ions. Metals can occur in aquatic environments in various forms.

- They can be dissolved hydrated cations (*i.e.* the positively charged metal ion surrounded by water only, like Fe^{2+} or Cd^{2+}).

- The dissolved cation may bind to other dissolved inorganic or organic compounds forming “complexes” or adsorb onto the charged solid surfaces. These dissolved complexes may be negatively charged (like $Fe^{II}PO_4^-$), positively charged (like $HgCl^+$) or neutral (like $PbCO_3$). The degree of binding depends on the relative concentrations, the inherent strength of the bonds formed and various properties of the water such as pH, oxidation potential and salinity.

- Some heavy metals commonly occur as negatively charged ions, like molybdate ($Mo^{III}O_4^{2-}$) or chromate ($Cr^{III}O_4^{2-}$), which can bind to other positively charged metal ions or surfaces.

- Some heavy metals, like mercury (Hg), can also occur as organometallic compounds, like methylmercury (CH_3Hg).

- Many metals are very stable in precipitated (solid) forms, particularly in suspended solids and sediments. For example, iron and manganese forms various oxides and oxyhydroxides. Unless the conditions (*e.g.* of pH and reduction potential) of the aquatic environment change, iron and manganese can remain in some solid forms indefinitely.

It might finally be noted that the metal aluminium (Al), although strictly not a heavy metal, can also be toxic.

Other inorganic compounds include many that are anions (*i.e.* have a negative charge). These are typically comprised of non-metallic elements, as indicated in the following figure.

H																	He
Li	Be											**B**	**C**	**N**	**O**	**F**	Ne
Na	Mg											Al	**Si**	**P**	**S**	**Cl**	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	**As**	**Se**	**Br**	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	**Te**	**I**	Xe
Cs	Ba	*L*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	**At**	Rn
Fr	Ra	*A*															
		L	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
		A	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Figure 4. Non-metallic elements present in many inorganic compounds.

It should be noted that although carbon (C) is the defining element for something being "organic", when in its higher oxidation states it is typically regarded as an inorganic substance, *e.g.* as in carbonate (CO_3^{2-}), cyanide (CN^-) or cyanate (CNO^-).

Typical examples of inorganic substances that are known to exhibit significant toxicity to certain organisms are the following:

Cyanide (CN^-), ammonia (NH_3), chloride (Cl^-), arsenic (usually as arsenate, $As^VO_4^{3-}$), borate ($B(OH)_4^-$), fluoride (F^-), nitrate (NO_3^-), nitrite (NO_2^-), selenate (SeO_4^{2-}), sulfide (S^{2-}).

Like metals, the inorganic ions exist in the aquatic environment in various forms. These include dissolved forms that are unbound to anything (except the surrounding water) or complexed to metal cations, adsorbed onto solid surfaces or precipitated.

Organic compounds

Organic compounds all contain carbon (C) in one or more of its more reduced oxidation states and usually hydrogen (H) and sometimes other elements like oxygen (O), nitrogen (N) and sulfur (S). The number of organic compounds is enormous. They are used in a very wide variety of applications, many of which result in their entering the natural environment. Many degrade naturally, albeit at vastly different rates. However, many can produce breakdown products that are themselves toxic.

"Organic compounds" is such a broad classification that it is more appropriate to deal with the various classes separately. This is done in the following subsections.

Pesticides

Pesticides are 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 [World Bank, 1999]. They are usually organic compounds, but may also contain inorganic substances.

The major chemical groups that are formulated (by combining active ingredients) include [World Bank, 1999]:

- Insecticides (organophosphates, carbamates, organochlorines, pyrethroids, biorationals and botanicals).

- Fungicides (dithiocarbamates, triazoles, morpholines, pyrimidines, phthalamides and inorganics).
- Herbicides (triazines, carbamates, phenyl ureas, phenoxy acids, bipyridyls, glyphosates, sulfonyl ureas, amide xylenols and imidazole inones).
- Rodenticides (coumarins).

The synthesis of the active ingredients used in pesticides involves chemical manufacturing processes. Internationally, the major chemical groups manufactured include [World Bank, 1999]:

- Carbamates and dithiocarbamates (carbofuran, carbaryl, ziram and benthiocarb).
- Chlorophenoxy compounds (2,4-D, 2,4,5-T and silvex).
- Organochlorines (dicofol and endosulfan).
- Organophosphorous compounds (malathion, dimethoate, phorate and parathion methyl).
- Nitro compounds (trifluralin).
- Miscellaneous compounds such as biopesticides (like *Bacillus thuringiensis* and pherhormones), heterocycles (like atrazine), pyrethroids (like cypermethrin) and urea derivatives (like diuron).

The World Bank (1999) urges that special attention be given to certain restricted substances. These include hexachlorobenzene, toxaphene, chlordane, aldrin, DDT, mirex, dieldrin, endrin and heptachlor.

Persistent Organic Pollutants (POPs)

POPs are organic toxicants that are of particular concern because of their significant persistence in the natural environment. Twelve – all chlorinated compounds – have become the focus of international action through the convention signed on POPs in Stockholm in May 2001: Polychlorinated biphenyls (PCBs), dioxins, furans, aldrin, dieldrin, DDT, endrin, chlordane, hexachlorobenzene (HCB), mirex, toxaphene and heptachlor [Goldman and Tran, 2002].

PCBs are industrial chemicals. Dioxins and furan are unwanted by-products of various technological processes, but were never produced commercially and have no intended use. Aldrin, dieldrin, DDT, endrin, chlordane, HCB, Mirex, toxaphene and heptachlor were initially developed as pesticides [Goldman and Tran, 2002].

Petroleum products

Petroleum products comprise another extremely wide range of chemicals that occur in, or are derived from, petroleum. Petroleum itself consists of a range of hydrocarbons usually classified in terms of the number of carbon atoms in the molecules, as indicated in table 3.

Hydrocarbons are typically hydrophobic. This means they do not dissolve in water like heavy metals and charged organic compounds. Their concentrations in the aquatic environment are therefore usually low. However, such compounds usually have an affinity for fatty tissues. They can thus be stored and concentrated in animal tissues by a process referred to as "bioaccumulation".

Table 3. Petroleum constituents [Morrison and Boyd, 1987].

Fraction	Distillation temperature (°C)	Carbon number
Gas	Below 20 °C	1-4
Petroleum ether	20-60 °C	5-6
Ligroin (light naphtha)	60-100 °C	6-7
Natural gasoline	40-205 °C	5-10 & cycloalkanes
Kerosene	175-325 °C	12-18 & aromatics
Gas oil	Above 275 °C	12 and higher
Lubricating oil	Non-volatile liquids	Long chains and cyclic structures
Asphalt	Non-volatile solids	Polycyclic structures

Surfactants

A surfactant combines in a single molecule a strongly hydrophobic group with a strongly hydrophilic group. They tend to congregate at the interfaces between the aqueous medium and the other phases of the system such as air, oily liquids and particles, thus imparting properties such as foaming, emulsification and particle suspension [Standard Methods, 1998].

The hydrophobic group is generally a hydrocarbon containing about 10 to 20 carbon atoms. Hydrophilic groups are of two types, those that ionise in water (positively or negatively charged) and those that do not [Standard Methods, 1998].

Pharmaceuticals

Pharmaceutical compounds comprise drugs and medicinal chemicals used for both humans and animals. Some are isolated from natural sources (plant, animal or mineral). Many are synthesised in industrial processes for reasons of economy, purity and adequacy of supply. Although such chemicals are developed for therapeutic (*i.e.* beneficial) reasons for specific organisms, they can also be toxic.

Pharmaceuticals can enter natural waters through sewage effluent and landfill leachates and present an unknown risk to aquatic species [Pascoe *et al.*, 2003].

Some examples of pharmaceuticals are the following: antibiotics, hormones, pain killers, steroids.

Besides the final products themselves, the pharmaceutical manufacturing industry uses a wide variety of organic chemicals that can occur in their wastewaters, and hence potentially enter natural waters. The US EPA has published effluent limitations guidelines that list many specific organic compounds [US EPA, 1998]. They include the following:

- Alcohols (amyl alcohol, ethanol, isopropanol, methanol)
- Aldehydes (isobutyraldehyde)
- Alkanes (n-heptane, n-hexane)
- Amines (diethylamine, triethylamine)
- Aromatics (benzene, toluene, xylenes, chlorobenzene, o-dichlorobenzene)
- Chlorinated alkanes (chloroform, methylene chloride, 1,2-dichloroethane)
- Esters (ethyl acetate, isopropyl acetate, n-amyl acetate, etc.)
- Ethers (tetrahydrofuran, isopropylether)
- Ketones (acetone, 4-methyl-2-pentanone)

Naturally occurring toxicants

Many compounds that can exhibit toxicity occur naturally in the environment. These include many heavy metals, other inorganic substances and various organic compounds. The inorganic substances (including heavy metals) appear in the natural environment through contact between natural waters and the local geology. They simply dissolve, or are weathered, out of the local rocks and soils.

A particularly important class of organic toxicants is the cyanotoxins. They are released into the water when the cells of cyanobacteria (also called blue-green algae) are ruptured (*e.g.* by decay or algicides). Passive release can also occur [DWAF 2002b]. The appearance of cyanobacteria is one symptom of eutrophication of natural waters caused by increasing nutrient loads. Some degree of monitoring for cyanotoxins is carried out in the National Eutrophication Monitoring Programme [DWAF, 2002b].

3.2.2 *Factors affecting their extent*

The extent to which a toxicant occurs in the aquatic environment is represented by its concentration. This concentration depends, on the one hand, on the nature of the toxicant and various properties of it and, on the other, various properties of the aquatic environment in which it finds itself. Some of these properties are illustrated in the adjacent figure.

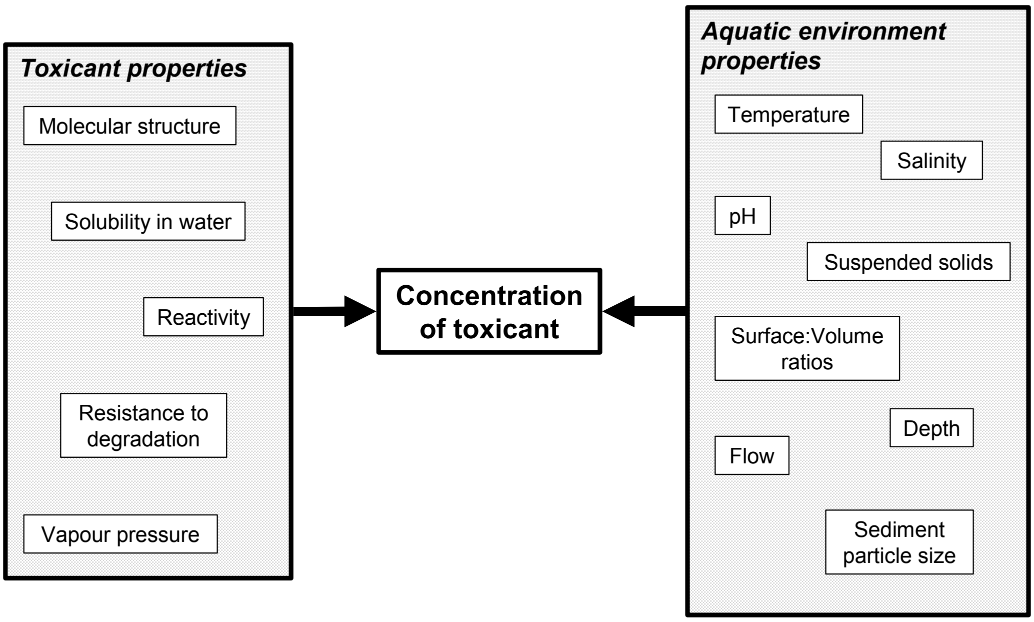

Figure 5. Properties of the toxicant and aquatic environment that determine the concentration of the toxicant.

3.2.3 *Measurement of their extent*

The analytical measurement of the concentration of toxicants depends primarily on the nature of (i) the toxicant and (ii) the medium in which it occurs. In the current context, three media are possible, namely water, sediment and biological organisms (like fish).

Water is the most common non-gaseous medium in which toxicants occur and is the medium for which most analytical techniques have been developed. The concentration of the toxicant is a well-defined quantity expressed as the amount (usually as mg) per unit volume (usually litre).

In respect of sediments and organisms, toxicants are often thought of as “accumulating” in these media. Sediments can act as “sinks” in which toxicants can gradually increase in concentration over time, even though the concentration in the bulk water (with which it is in contact) might remain fairly constant. Nevertheless, even sediments have an upper limit of solubility. As long as the environmental conditions (both chemical and physical) do not change, these higher concentrations in sediments can remain stable and the toxicant is effectively trapped. However, these situations are sometimes referred to “time bombs” because there is often no guarantee that the conditions will indeed remain constant indefinitely. For example, flooding can scour out sediments, mixing them with the bulk water and thus potentially “releasing” the toxicants into the water and transporting them downstream.

The toxicant typically needs to be extracted from the sediment into a liquid phase (often water). This liquid phase is then subjected to analytical measurement.

Accumulation of toxicants in the organs and tissues of biological organisms is referred to as “bioaccumulation”. For example, some fish accumulate pesticides and heavy metals.

Various reference methods for some toxicants are suggested in the South African Water Quality Guidelines [DWAF, 1996a-g]. For more detail these guidelines should be consulted. For details on individual analytical methods, the latest Standard Methods (1998) should be consulted.

Inorganic substances

Analytical methods for heavy metals and inorganic compounds, including sample preservation methods, are well known, standard and widely practised [Standard Methods, 1998]. The most common analytical methods for heavy metals use Atomic Adsorption Spectrometry (AAS) and the Inductively Coupled Plasma (ICP) technique. The other inorganic substances usually make use of classical “wet chemical” techniques and automated variations of them as well as more modern instrumental techniques like ion chromatography [Standard Methods, 1998].

In most cases, the total concentration of a heavy metal or other inorganic substance will be measured and little or no attention given to the forms in which it exists (*i.e.* its “speciation”). However, filtering of samples can separate solid forms from dissolved forms, allowing this distinction to be made relatively easily.

Pesticides

Standard techniques are available for organochlorine pesticides and chlorinated phenoxy acid herbicides [Standard Methods, 1998]. Local capacity exists (*e.g.* at the ARC) for analysing for pesticides using a range of chromatographic methods. Both organisations are capable of determining a wide range of individual pesticides as well as classes of pesticides.

Petroleum products

At present some standard procedures are available for determining "oil and grease" and hydrocarbons [Standard Methods, 1998]. Local capacity also exists (*e.g.* at the SABS) for analysing for "total petroleum hydrocarbons", "diesel range organics" (10-28 carbons) and "gasoline range organics" (6-10 carbons).

Pharmaceuticals

Regarding many of the organic chemicals used in the pharmaceutical manufacturing industry, the US EPA has published guidance on appropriate analytical methods [US EPA, 1999]. Procedures that can be used include biological (using *Hydra vulgaris*) [Pascoe *et al.,* 2003] spectrofluorometrical [Manzoori and Amjadi, 2003], spectrophotometrical and chromatographical [Schellen *et al.,* 2003].

Surfactants

Standard techniques are currently available that determine surfactants [Standard Methods, 1998].

Bioaccumulation analyses

Bioaccumulation analyses are used to determine the degree to which a toxicant accumulates in an organism when subjected to long-term exposure [Rand and Petrocelli, 1995]. A bioconcentration factor can be determined that reflects the ratio between average concentration of the toxicant in the tissues of the organism to the average concentration in the water to which they are exposed.

3.3 Toxicity

3.3.1 *The nature of toxicity*

For a toxicant to produce a toxic effect on aquatic or other organisms, the following must occur.

1) The toxicant must come into contact with the organism.
2) It must react with an appropriate receptor site on the organism (a) at a high enough *concentration*, and (b) for a *sufficient length of time*.

Toxicants can affect organisms on land, in the air and in natural waters. However, the current context is restricted to those organisms, including humans, which use or rely on South African fresh and estuarine water resources.

This section addresses toxic effects only. It does not necessarily try to link specific toxicants with these effects. However, it is sometimes possible to use specific toxicity tests to detect specified toxicants like estrogen mimics and some heavy metals.

The organisms

The types of organisms of interest would typically include at least those reasonably associated with the various water uses for which water quality guidelines have been developed (even if not for toxicants *per se*). The following table suggests such an association.

Table 4. Target organisms associated with the standard water uses

Water use	Most obvious target organisms
Domestic	Humans
Recreational	Humans
Industrial*	Humans
Aquatic ecosystem organisms	Fish, invertebrates, birds, mammals, plants
Agriculture - irrigation	Humans, plants
Agriculture – livestock watering	Mammals
Agriculture – aquaculture	Fish, reptiles, plants

* Equivalent to domestic use in the current context.

Human health is obviously a primary concern in the context of national toxicants monitoring. However, impacts on certain animals in agriculture (livestock, fish, etc.) are also important considerations as are potential impacts on general ecosystem health. Therefore, the range of organisms that can potentially exhibit toxic effects is very large.

The toxic effects

The reader is referred to the glossary for definition of many of the terms used here. To many of the above organisms, the nature of the toxicity can be reported in the following three contexts.

Short-term versus long-term effect: One broad classification of toxic effect relates to the time required for the effect to manifest itself. The term "short-term effect" can refer to those toxic effects that manifest relatively quickly (within days). On the other hand "long-term effects" can refer to those that take longer to manifest. These terms are also commonly referred to as acute and chronic effects.

Reporting toxic effects as short-term or long-term is useful to a water quality manager. If water from a particular river reach exhibits acute toxicity to fish, this serves as a red flag in respect of the general health of fish populations and diversity in that area. If that river reach is being monitored by the national biomonitoring programme, this toxicity information would be useful to compare with their observations. In this way the NTMP would complement other monitoring programmes.

Lethal or sublethal: The next most obvious distinction that one can make in respect of the nature of toxic effects is whether the effect is lethal or not (*i.e.* "sublethal"). Lethality is usually a short-term effect.

Type of sublethal effect: If the effect is sublethal, then the type of effect can be reported. Sublethal effects include a very wide variety of adverse responses to exposure to toxicants.

Typical sublethal effects in aquatic organisms include the following [Rand and Petrocelli, 1995]:

- *Biochemical and physiological effects.* These include studies of enzyme inhibition, clinical chemistry, haematology and respiration.

- *Behavioural effects.* Typical behavioural effects include locomotion and swimming, attraction-avoidance, predator-prey relationships, aggression and territoriality and learning.
- *Histological effects*. These relate to structure and chemical composition of the animal or plant tissues as related to their function.

Some biochemical and physiological effects can also apply to humans and other mammals. These include mutagenicity, carcinogenicity, tumour promotion, teratogenicity, oestrogenicity and endocrine disruption.

3.3.2 *Factors affecting the extent*

The degree of toxicity (*i.e.* the extent to which the toxic effect manifests itself) is determined by various properties of the toxicant and complex interactions between exposure and organism-specific factors. Some are illustrated in the adjacent figure. Note that the degree of toxicity depends directly on the concentration of the toxicant. Factors determining this concentration are discussed above.

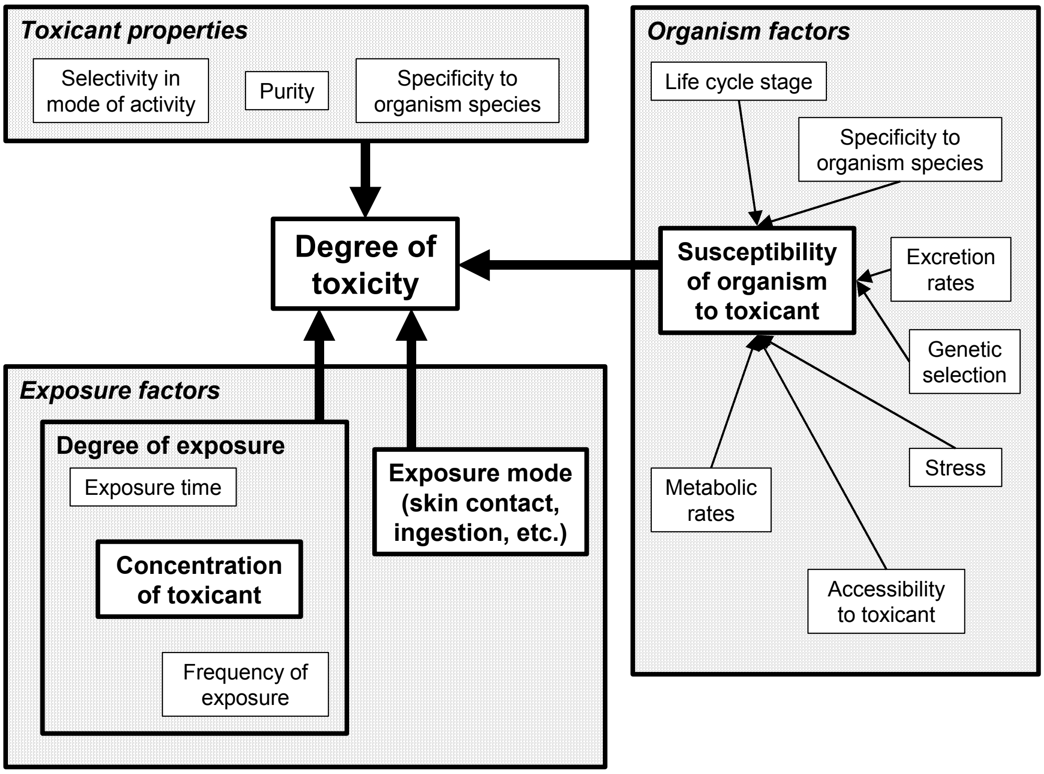

Figure 6. Toxicant properties, exposure and organism factors determining the degree of toxicity.

3.3.3 *Measurement of the extent*

"Toxicity tests" (see glossary) measure directly the degree (*i.e.* extent) of toxicity on specific target organisms. Slabbert et al. (1998a) should be consulted for more detailed information on toxicity test methodologies. A wide variety of scenarios and issues are relevant when choosing an appropriate toxicity test.

In situ versus in laboratory: Some tests are designed to take place in the natural water itself while others require water samples to be transported to a laboratory where the test takes place. Most single-species tests are conducted in the laboratory. Such tests are convenient because they allow a much greater degree of control than those performed in the field. However, the usefulness of tests done in the laboratory will depend on the criteria used to choose the organism. One limitation of such tests is that the effects observed in the laboratory may not occur in exactly the same way in the natural environment.

Toxicity tests performed in the natural environment are more likely to determine effects that are more representative. However, difficulties are created by natural variability in the environment. This can make it difficult to establish that an observed effect is really due to a chemical toxicant.

In the current context of long term monitoring of water resources, the most applicable tests are those in which the test organism is directly exposed to the water with no dilution. However, it is also possible to concentrate water samples, thus increasing the concentration of the toxicants to which test organisms are exposed. This can increase the detection potential of a test.

A significant issue in laboratory toxicity testing is the variability in measurements. This applies to both control samples and test samples. This therefore creates some degree of uncertainty in reporting. Generally, a lethal effect requires at least a 10% effect for the effect to be regarded as lethal. Sublethal effects typically require a 20% effect.

Short-term versus long-term effect: Some tests are specifically designed to measure effects over the short term and others over the long term. Common short-term tests include measuring fish and invertebrate lethality or algal growth over a fixed period of time [Rand and Petrocelli, 1995]. Long-term tests typically can involve exposing organisms to the toxicant over an entire reproductive cycle or part of it and measuring growth and reproduction [Rand and Petrocelli, 1995].

Lethal versus sublethal: Lethality can be measured in terms of the percentage of a selection of test organisms that die within the test period. The degree to which sublethal effects manifest themselves is also usually reported quantitatively, most commonly as a percentage effect. In particular, this usually refers to the percentage of organisms (or activity) affected.

4 DESIGN DECISIONS

4.1 Introduction

Given the perceived needs as noted above and many other considerations, the following sections summarise specific design decisions upon which future development should be based.

4.2 Monitoring programme name

It is proposed for simplicity that the programme be named in a way consistent with the other national status and trends monitoring programmes. These programmes are named as follows:

National X Monitoring Programme

Examples of X are microbial, eutrophication, chemical and so on. In the current context (namely toxicity), a number of options are available. These include the following

National Toxicants Monitoring Programme
National Toxicity Monitoring Programme
National Pollutants Monitoring Programme
National Priority Pollutant Monitoring Programme

Both “toxicants” and “toxicity” seem adequate. On the face of it, there seems little that distinguishes between these two words. Monitoring “toxicants” implies that “toxicity” is an issue since the presence of toxicants implies the potential presence of toxicity. Equivalently, the presence of “toxicity” implies the potential presence of toxicants. One issue that distinguishes slightly between “toxicants” and “toxicity”, is that “toxicity” is a more emotive word than “toxicants”. For this reason only, “toxicants” seems the slightly more preferable word.

An alternative phrase (to “toxicants” or “toxic pollutants”) was proposed in the US as long ago as the early 1970s, namely ‘priority pollutants’ [Erickson, 2002]. This phrase was chosen mainly because of the lack of sound toxicological data. In other words, emphasis was placed more on the presence of a “pollutant” (whether a toxic effect could be associated with it or not). A “priority pollutant” (in their context) would then be either of the following.

- A known toxicant (*i.e.* a chemical agent with a known toxic effect); or
- A chemical agent that is suspected of having toxic effects.

Given the definition of “pollution” in the National Water Act (see Glossary), a pollutant can refer to a broader range of problematic agents than simply those that cause toxicity. This may therefore make the use of the word ‘pollutant’ unsatisfactory in a South African context. The true intention thus far seems to lean towards ‘chemical pollutants’ in particular (see Glossary) and specifically those that exhibit or *can potentially exhibit* a toxic effect. Importantly, it seems preferable to allow for the inclusion of agents that are of concern but are not yet proven to exhibit toxic effects.

Therefore “toxicants” and “toxicity” seems preferable terms to “pollutants” or “priority pollutants”.

Finally, it might be noted that if separate implementation manuals are produced for the different water resource types, then it will be necessary to distinguish between them in the programme name. For example, one might have the following:

National Toxicants Monitoring Programme for Watercourses
National Toxicants Monitoring Programme for Groundwaters
National Toxicants Monitoring Programme for Estuaries

It is not deemed necessary to include the phrase “Water Quality” in the programme name since the following more complete generic description exists that encompasses all national programmes relating to water quality (and, for example, has been used on the cover page of existing implementation manuals):

South African National Water Quality Monitoring Programmes Series

4.3 Target users

The following are potential users of the information provided in the reports produced by the NTMP.

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.

4.4 Monitoring objectives

The following is proposed as defining the objectives of the NTMP. The wording is largely based on similar wording used in the other national programmes. However, in some respects it does present an improvement in understanding, in particular in respect of defining the management objectives (that are intended to be supported by the monitoring).

National Toxicants 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, potentially toxic substances in South African water resources
(watercourses, groundwaters and estuaries), and,
secondly, the potential for toxic effects to selected organisms

in a manner that
will support strategic management decisions
in the context of fitness for use of those water resources,
be mindful of financial and capacity constraints, yet,
be soundly scientific.

The following summarises the meaning of the various terms. Some issues are discussed in more detail elsewhere.

National: The use of the word "national" in the title of this monitoring programme refers to a number of contexts.

First, the primary responsibility for the monitoring programme lies with the Department of Water Affairs and Forestry (DWAF), a *national* department.

Secondly, as a national department, DWAF has various *international* responsibilities relating to the following.

- South Africa is signatory to various international agreements and conventions.
- Participation in global monitoring programmes.

Typically descriptions of the "state of the environment" at *national* level are required for the above contexts.

Thirdly, DWAF also recognises various national responsibilities. These include the following.

- A responsibility to keep abreast of international trends in emerging problems. (The field of endocrine disruption is one example.) A national monitoring programme can then raise "red flags" if and when problems occur, typically triggering action (like more detailed monitoring) at regional level. This "early warning system" is therefore seen to be large in spatial scale (*i.e.* regional and national) and in time (perhaps annual but possibly more frequently).
- Creation of monitoring capacity upon which further region-specific capacity creation can be based when Catchment Management Agencies become operational.

Measure: This means “perform an experimental measurement of some property of the water resource”. In the current context this measurement might be the concentration of a specific toxicant (or class of toxicants), or simply their presence or absence. It might also mean a measurement of toxicity using a “toxicity test”. Such measurements will comprise the raw data of the monitoring programme.

Assess: This means “add value to the raw data by providing information based on that raw data and perhaps specific knowledge relating to the source or other site-specific issues”. A common and simple mechanism of assessment of monitoring data is comparison of a measurement with a guideline value (if one exists). Such guidelines are typically specific to the kind of water use.

Report: Monitoring data must never be collected for the sake of having data. It (or assessment of it) must always be reported to well-defined target users in an appropriate format at appropriate intervals.

On a regular basis: Monitoring is not a once-off activity. The measurements, assessments and reporting should be done at regular intervals, or at intervals determined by the target users. In the current context, the temporal scale is annual. This means that reports must be prepared and submitted annually to the target users. These reports are usually based on data collected at an appropriate frequency.

Status: This refers to the current situation relating to the nature and extent of the problem. Since the temporal scale is annual, this refers to the current year.

Trends: These are the statistically significant changes in the status from one reporting period (*i.e.* year) to the next, or shorter period if necessary to meet the monitoring objectives.

Nature: This word refers to the type of problem.

For toxicants, nature refers to the following:

- Classes (types) of the toxicants (*e.g.* pesticides, heavy metals), or
- Individual toxicants (*e.g.* DDT, mercury).

For toxic effects, nature refers to the following:

- The kind of toxic effect (*e.g.* fish lethality or endocrine disruption).

For both toxicants and toxic effects, if guidelines exist then a further characterisation of the “nature” of the problem (or potential problems) may be possible, depending on the exact nature of the guidelines.

Note that ‘nature’ does not include establishing the source of the toxicants (*i.e.* who or what activity is causing the problem). This would require a specialised monitoring design that is not seen as part of this national programme. However, when it is possible to make scientifically sound statements regarding actual or potential sources (e.g. distinguishing between natural and anthropogenic sources), then this can be done in the annual assessment report.

Extent: This word refers to the degree or severity of the problem.

In the first instance, extent refers to the *spatial* extent (*i.e.* the areas that are affected).

For toxicants, the extent also refers to the following:

- The concentration of the toxicant.

For toxic effects, the extent refers to the following:

- The degree of toxic effect (like percentage effect in the case of toxic effects).

For both toxicants and toxic effects, if guidelines exist then a further characterisation of the “extent” (*i.e.* severity) of the problem (or potential problem) may be possible depending on the exact nature of the guidelines.

Potentially toxic substances: This phrase is used deliberately to allow for inclusion of toxicants known to have toxic effects as well as those that are only suspected (but not proven) as having toxic effects. The term “toxic substance” is synonymous with “toxicant”.

South African water resources: For the purposes of this monitoring programme, these include watercourses, groundwater and estuaries.

The potential for toxic effects: This phrase refers to the following two contexts:

- First, an actual toxic effect can be reported. This refers to a specific observation (measurement) of the impairment of activity of a well-defined organism, cellular or sub-cellular system (the “test organism or system”). This would often be reported as a percentage effect, referring to the specific organism, cellular or sub-cellular system.
- The “*potential* for toxic effects” refers to extrapolating the above measurement to potential toxic effects to an organism or system *other than the one tested* (the “target organism or system”). This “extrapolation” to a different organism or system should only be done when it is scientifically sound (see below). That is, it should have been demonstrated experimentally that an observed effect in the test organism or system is correlated with an effect in the other organism or system. For example, toxic effects manifest in water flea (*Daphnia*) should not simply be interpreted as meaning that humans will show similar responses. (“Extrapolating” from water flea to humans is inappropriate.) However, a toxicity test using mammalian cells may be more appropriate if humans are regarded as a critical target organism.

Selected organisms: This refers to a suite of organisms specially selected for this national monitoring programme according to particular criteria. Since resource quality objectives relate, amongst other things, to water users, these organisms should represent these water users.

Support strategic management decisions: The ultimate objective of the monitoring is to allow informed decision making by those responsible for management of water resources. In particular, *strategic* decisions are defined as those that are large in scale, both spatially and temporally. A large spatial scale refers to regional (water management area) and national scales. A large temporal scale refers to decisions that have implications over periods of a year or more.

In the context of fitness for use of those water resources: *This issue, in effect, refers to the core mandate of DWAF. They are the public trustees of the nation's water resources and must ensure their sustainable fitness for use.*

The above-mentioned international and national responsibilities are contexts in which higher-level decision-making is required (that this programme will support). However, such lofty goals have the danger of being somewhat vague and being of little or no specific use at lower levels of water resource management. If the objectives include specific lower-level issues, this will not only make the national programme better defined (and hence easier to design) but also more amenable to buy-in by regional and local organisations. Such buy-in is important because DWAF alone is unlikely to be able to provide all the necessary resources for a national monitoring programme.

Water quality management at catchment level functions within the general context of resource directed measures, including classification of resources, setting the reserve and ultimately, setting resource quality objectives. The ultimate management objective is therefore defining these resource quality objectives and managing resources accordingly.

The NTMP can anchor itself firmly at this lower level by including an objective that involves prioritising water resources within the context of this RDM process (ultimately leading to setting resource quality objectives).

This can be achieved as follows. First, the NTMP can help prioritise water resources to be subjected to the RDM process by identifying problem areas. Secondly, the same NTMP monitoring should continuously provide a consistent national picture of toxicity-related problems, even in those areas where resource quality objectives have been set and where their compliance is being monitored (by another monitoring programme). This will provide a useful standard reference against which the priority of the remaining areas (*i.e.* those still without resource quality objectives) can be assessed. In this way continuity of the NTMP is ensured.

In summary, the ultimate *management objectives* supported by the NTMP involve addressing national and international responsibilities while simultaneously addressing one of the needs at catchment level, namely prioritising water resources for application of the RDM process.

Mindful of financial and capacity constraints: It is important that the monitoring that takes place is cost-effective. This is in respect of both financial resources and the existence and creation of the necessary capacity to perform all the required tasks (like sampling, analysis, database management, reporting etc.).

Soundly scientific: It is essential that the monitoring is based on sound science. Frequently, this may apparently manifest itself as a conflicting requirement with being mindful of financial and capacity constraints. However, this need not be so. If the "scientifically ideal" monitoring design cannot be achieved, this must simply be reflected in the reported assessment (unless the data are obviously totally inadequate). For example, less data may mean information is more uncertain. As long as this increased uncertainty is properly reported, the user of the information is still in a position to make an informed decision, albeit with greater risk.

Both the design of the monitoring programme and its implementation will need to be scientifically sound. The scientific soundness of the above objectives refers more to the implementation. In essence this may mean little more than not deviating from the design. However, tasks like choosing sampling sites and, in particular, assessing the data will require decisions to be made before and during implementation over which the design manual can only provide general guidance. It is at these times that special care should be exercised that decisions are made that are absolutely defensible in terms of scientific observation. Indeed, it may be useful to imagine that the decision might need to be defended in court. This may provide a useful incentive for decisions being scientific.

4.5 Addressing low-level management objectives

This section describes in some detail how the NTMP can address the lower-level management objectives relating to the RDM process and ultimately setting resource quality objectives.

The National Water Act describes Resource Directed Measures (RDM) of water quality management as involving a three-stage process of classification of water resources, setting the Reserve for those resources and finally setting Resource Quality Objectives (RQOs). This is a lengthy and costly process that will take many years to implement fully.

It is sensible practice to implement this in a phased way, choosing areas of greater importance first. Obviously this national monitoring programme only concerns itself with toxicity-related issues. However, it can provide a national picture to DWAF on the nature and extent of toxicity-related problems in South Africa. In particular, this national picture will identify areas of concern (or “hot spots”) as being those with high concentrations of toxicants or toxicity. DWAF can then combine this information with that obtained from other national programmes (for example relating to ecosystem health, microbial pollution, eutrophication problems, etc.) in order to prioritise areas for applying the RDM process.

Once an area has been chosen by DWAF as deserving of attention in respect of the ultimately establishing resource quality objectives, this monitoring programme has fulfilled its initial purpose. Typically, monitoring of compliance with these resource quality objectives would be implemented by DWAF in such an area. That monitoring is not the responsibility of this national programme however. It is independently designed and implemented and may include monitoring variables different from those used in the NTMP. It may also monitor at a different frequency.

This scenario raises the question of what the role of the NTMP will be once compliance monitoring has been implemented in an area. It is proposed that the monitoring that had been done up to that point be continued during the execution of the RDM process and after resource quality objectives have been set. The reasons are the following.

On the one hand, the compliance monitoring may not include toxicity-related variables (for whatever reason). In this case, the NTMP serves the useful purpose of providing on-going monitoring that will detect changes in the *status quo* relating to toxicity. This includes detecting emerging problems (where none existed before) or changes in existing problems (whether worsening or improving). This information remains relevant to general water quality management and can still serve the purpose of helping DWAF prioritise areas, in this instance, requiring changes to resource quality objectives or to the compliance monitoring thereof.

On the other hand, compliance monitoring may be implemented and include toxicity related monitoring variables. Compliance monitoring is necessarily catchment-specific (or, for groundwater, based on groundwater management units) and its objectives are entirely local in extent. Irrespective of the degree of compliance monitoring, there remains a need for a *national* picture of the nature and extent of toxicity-related problems in water resources. In particular, there remains a need for continuity and consistency over the years in *national* reporting of toxicity-related problems. The context of prioritising areas for ultimate setting of resource quality objectives remains valid. Over the years, an increasing number of areas will have their resource quality objectives defined and have compliance monitored. However, the proper prioritisation of the *remaining* water resources will continue to need all water resources to be characterised in the same way so that valid comparisons of the degree of toxicity-related problems can be made.

In essence, although at face value there is apparently potential for duplication of monitoring effort, this is not the case. The NTMP should provide a continuous national perspective on toxicity-related problems at all times in support of managing resources within the context of their resource quality objectives, whether defined or not and whether their compliance is being monitored or not.

4.6 Choice of monitoring variables

The toxicants and toxic effects chosen for the NTMP must provide data and information that allow the stated national objectives to be achieved.

The NTMP should include monitoring variables that include an appropriate selection of

- toxicants (possibly individual chemicals but more likely classes of toxicants or indicators of them); and
- toxic effects.

4.6.1 *General considerations*

The choice of which toxicants and which toxic effects to be included in the NTMP should be based on a number of considerations.

Consideration 1: The DSR framework

It is worthwhile noting the generic kinds of indicators that are used for monitoring. A useful framework that has been proposed for sustainability indicators is the “Driving Force – State – Response (DSR)” framework by the United Nations. There are three kinds of indicators:

- *State indicators*. These assess the condition of resources as a result of pressures. They answer the question “What is happening to the resource?”.
- *Driving force indicators*. These measure the human activities that impact on the resource. They answer the question “Why is it happening?”.
- *Response indicators*. These relate to the response of society to the impacts. They answer the question “What is society doing about it?”.

The current suite of national monitoring programmes tends to concentrate on state indicators by this definition. They specifically do not monitor causes (*i.e.* the driving forces) or the responses of society.

However, as noted above, the Environmental Monitoring and Assessment Programme in the US refers to ‘response’, ‘exposure/habitat’ and ‘stressor’ indicators and define these terms differently (and less broadly). By these definitions, the South African biomonitoring programme monitors a combination of response and exposure/habitat indicators. The chemical, microbial and eutrophication monitoring programmes monitor exposure/habitat indicators.

To be consistent with the other programmes, the NTMP should restrict itself to exposure/habitat indicators. By the US definition, this would specifically include indicators that reflect water quality, toxicity (including that of sediment) and possibly chemical contaminants and biomarkers in fish.

Consideration 2: Avoidance of duplication

Not all agents causing toxic effects should be automatically included in the NTMP. For example, the NTMP should not duplicate the sampling for, and analysis of, toxicants already being done in another national monitoring programme. However, it is conceivable that it may be appropriate to report an *NTMP-related assessment* of the raw data for toxicants monitored in other programmes in NTMP reports. This is particularly so if the inclusion of such toxicants leads to a more complete reporting of toxicants in general. It is likely that such toxicants will be reported in the other programmes within the context of those programmes (for example, not in the context of toxicity). Therefore, reporting an assessment of such data within the context of the NTMP does not necessarily represent a duplication of effort.

This issue will not apply to toxic effects since no national programme exists at present that monitors toxicity directly.

Avoidance of duplication of effort can also apply in another context. Consider the case of a particular toxicant (identified as one of concern) that has a well-known and measurable toxic effect that can be fairly unambiguously associated with only that toxicant. Measuring both the concentration of the toxicant and its toxic effect in this case is duplication of effort. In such a case, one or the other can be chosen (*i.e.* either measure the concentration of the toxicant or measure its toxic effect). If the concentration is measured, then the toxic effect can be inferred from this. On the other hand, if the toxic effect is measured, the concentration can be inferred from this measurement. These inferences would necessarily be reported in the assessment report.

Another way of expressing this is that the choice of toxicants and toxic effects must be complementary.

Consideration 3: Availability of experimental techniques

The number of potential toxicants and toxic effects is enormous. Experimental techniques can be highly specialised and expensive, if they exist at all. The choice of toxicants and toxic effects for national monitoring should take account of the existence, expense and complexity of available techniques. Ideally widely accepted and preferably standard methods should be used. The expense of the technique may also be a factor in determining how frequently monitoring occurs.

If expertise to perform an experimental technique does not exist in South Africa, a number of options are available. If an appropriate technique is being applied elsewhere in the world, then the applicability of the transfer of this technology to South Africa should be investigated.

If an experimental technique does not exist anywhere for a particular toxicant of interest, an alternative option would be to establish whether a toxic effect typically associated with that toxicant could be measured. If so, then this may be adequate. However, it must be remembered that toxicity tests usually detect combined effects of many different toxicants. However, some individual tests can work fairly well for specific classes of toxicants.

If an appropriate toxicity test does not exist, this should not necessarily preclude the inclusion of the particular toxicant. If the toxicant is regarded as particularly important, then recommendations can be made in respect of a proposed research project that will develop an appropriate method (either to measure the toxicant concentration or its toxic effects). In other words, choice of monitoring variables should not be based solely on currently available experimental techniques. It can help identify important gaps in existing analytical capacity and thus help focus future research efforts on local needs.

Consideration 4: Screening versus comprehensiveness

Given the diverse nature of toxicant and toxic effect monitoring, it is quite conceivable that the implementation costs could quickly become prohibitive.

One approach to minimising costs will be to apply commonly used and cheaper toxicity tests to screen waters for potential toxicity. Some toxicity tests have the advantage of being able to detect the effects of a range of toxicants.

The results of such a simple screening test can be dealt with is two ways, depending on the priority of the water resource.

- A high priority resource can be defined as one reasonably expected to contain certain toxicants or exhibit certain toxic effects, based on local land use practices. The detection of a toxic effect in a high priority water resource could be followed by analyses that aim to identify individual toxicants or toxicant classes to obtain more information on the nature of the problem. Cost savings arise because these extra and possibly expensive tests are only being applied when a problem is indicated by the screening test.
- A low priority water resource would be one not reasonably expected to exhibit such problems. In waters that are considered least likely to exhibit toxicity related problems, a toxicity test result could be taken at face value and simply reported as such.

Another approach would be to decide on a shortlist of toxicants and/or toxic effects most likely to occur in a particular water resource based on the local land use. In the regular reviews of the overall monitoring programme, the land use practices would need to be examined to determine whether they have changed. If so, a different set of monitoring variables may be necessary.

It is important to note that any approach that attempts to limit the number or type of monitoring variables is, by its very nature, incomplete and likely to give a false sense of security. However, this may be a necessary deficiency if financial resources are particularly restrictive. In such cases, users of the information (*i.e.* the water resource managers) must fully understand and acknowledge this deficiency and manage the water resource accordingly.

Consideration 5: Transience and persistence of pollutants

Some toxicants may persist for very long periods in the environment, some accumulating in living organisms (bioaccumulation) while others may degrade in much shorter periods. Toxicants that are persistent in the environment will generally be easier to detect in a monitoring programme than those that are short-lived. If certain short-lived toxicants are deemed important to include in the NTMP, monitoring frequencies may need to be much shorter or even event-based if appropriate.

Consideration 6: Choice of test organism or system

Generally, in the field of aquatic toxicology, the choice of organisms for toxicity tests is based on a number of criteria [Rand and Petrocelli, 1995]. The following relate to the suitability of the species to laboratory analysis.

- Availability and abundance of the species.
- Amenability to routine laboratory maintenance and availability of techniques for culturing and rearing them in the laboratory.
- Availability of background information on the species (*i.e.* its physiology, genetics and behaviour). This allows data to be more easily interpreted.

Other criteria relate to how representative the species is.

- Sensitivity of the species. Since sensitivities vary among species, species representing a broad range of sensitivities should be used whenever possible.
- Ideally indigenous species should be studied which are representative of the ecosystems that may be impacted.
- The recreational, commercial or ecological importance of the species.

The current context of national monitoring puts particular emphasis on some of these criteria and less on others. Since nationwide sampling and analysis is envisaged, many laboratories will need to develop the capacity to perform toxicity tests. This places particular importance on those criteria related to the suitability of the species to laboratory techniques. Techniques need to be as simple, standard and as foolproof as possible.

The choice of test organism may also be determined by the toxic effect of interest. For example, there are widely used tests using bacteria, frogs, etc. that are applicable when one is interested in measuring such effects as mutagenicity and teratogenicity.

How representative an organism is depends primarily on the use to which the water is put (which is one factor in setting resource quality objectives). Obviously, one or more uses of the water can exist at any single point in a water resource and uses may vary from one point to the next and one catchment to the next. Use therefore is, by its very nature, highly site specific. The consequence of this is that resource quality objectives will also be site specific.

Some user categories are defined in the South African Water Quality Guidelines [DWAFa-g]. These are

- Domestic water use
- Recreational water use
- Industrial water use
- Agricultural water use: Irrigation
- Agricultural water use: Livestock watering
- Agricultural water use: Aquaculture
- Aquatic ecosystems

Of particular concern are toxicants and toxic effects that have or potentially will have significant negative impacts on the fitness for use of the water resource in any of the above categories.

Consideration 7: Choice of toxicity test

A Water Research Commission funded project is currently underway to develop guidelines for choosing the most appropriate toxicity tests to address specific requirements of the National Water Act. One such context is the present one, namely national status and trends monitoring. Specific toxicity-related information requirements are being defined for each context. An inventory of toxicity tests is being compiled that will ultimately be matched with the chosen information requirements. This process will objectively identify the most appropriate toxicity tests to perform in the current monitoring context.

The preliminary information requirements being considered with their current classifications are the following. Those deemed appropriate to national monitoring are highlighted in bold.

- Legal defensibility (Classification: good or **fair**.)
- Indicator or targeted: (Classification: **indicator** or targeted)
- Toxic effect (Classification: Lethality, any sublethal effect, specified sublethal effect, any of the above)
- Target organism (Classification: Humans, **fish**, **invertebrates**, other animals, plants (like **algae**))
- Observation frequency (Classification: single unit of time, high frequency, **low frequency**)
- Sample-to-report turnaround time: (Classification: unit of time, fast, **slow**)
- Level of expertise required (Classification: **minimal**, moderate, high)

It is recommended that the outcome of that project be carefully examined and used as a basis for making the final choice of toxicity tests.

4.6.2 *Recommended approach*

Toxicants

Toxicants or classes of toxicants should be included that are as relevant as possible to each major water use, as defined by the South African Water Quality Guidelines. There are four major categories of information required to make a sensible choice of toxicants or toxicant classes. These are as follows.

- The nature of the monitoring variable.
- The nature of potential occurrence (throughout South Africa).
- The nature of the potential impact (on fitness for use).
- Nature of the monitoring required.

For each such individual toxicant or toxicant class, questions relating to these categories should be answered. The following table contains some typical questions. Columns can be added for each toxicant or toxicant class and the table completed. Each issue or question has various ramifications, all of which are not captured in the table. However, the table serves as an illustration of how one can begin to approach the problem of choosing the most appropriate toxicants to monitor.

When such tables have been completed for a sufficient number of toxicants, a comparison of the tables should facilitate the choice of the best ones to include in the NTMP. It is likely that a suite of toxicants or toxicant classes will be required that are representative of a number of important water uses.

Table 5. Typical questions to be considered when deciding on monitoring variables.

Toxicant monitoring variable:
Nature of monitoring variable
Is the variable an individual chemical or a class of chemicals? (Individual/Class)
Can this monitoring variable be used in a screening context (*i.e.* an indicator of possible problems, though requiring confirmation)? (Yes/No) Explain.
Can this monitoring variable be used as an indicator of the presence of other toxicants? (Yes/No) Explain.
Do appropriate water quality guidelines exist (locally or internationally) that can be used to assess the raw data and hence address the stated objectives of the NTMP? (Yes/No). Explain.
Nature of potential occurrence
What is the expected spatial distribution of this toxicant or toxicant class throughout South Africa?
What are the major factors likely to affect this distribution? (Increasing number of sources, bioaccumulation, accumulation in sediments, etc.)
What is the likely degree of persistence in water resources?
Nature of potential impact
Relevant water use (Domestic, recreational, industrial, agricultural: aquaculture, agricultural: irrigation, agricultural: livestock watering, aquatic ecosystems).
Describe briefly the potential impact and relative severity for that water use.
Nature of the monitoring required
Is it already being monitored in another national monitoring programme? (Yes/No)
Describe briefly the analytical methods required, the degree to which capacity exists in South Africa, the availability of the method internationally (if not currently local), the capacity required (approximate initial capital costs, operating costs and human resource costs)
Given the likely potential spatial occurrence throughout South Africa and its potential impacts if present, is this variable a good candidate for monitoring throughout the country? Alternatively, should it rather only be monitored in areas where it is most likely to occur?
Can the presence of this particular monitoring variable be better monitored using a toxicity test (rather than direct measurement)?

Toxicity

The recommended approach for choosing the most appropriate toxicity tests is to base the choice on the outcome of the above-mentioned Water Research Commission project that will provide guidelines for choice of toxicity tests.

Furthermore, the choice of toxicity test should complement, or be complemented by, the choice of toxicants or classes of toxicants.

4.7 Degree of assessment

An important issue will be the degree to which an assessment of the raw data will be done and reported. It is not recommended that raw data be reported explicitly. Raw data will need to be stored in a single central database facility, like the Water Management System at IWQS. It is therefore always available to anyone who wants to perform more in depth analyses.

It is not deemed the responsibility of the NTMP to perform highly sophisticated data assessments. The potential for complexity in this monitoring programme is enormous. This is primarily because of the wide variety of toxicants and potential toxic effects. Accordingly, the following are suggested as criteria for choosing an appropriate level of assessment.

- The emphasis should be on 'lowest common denominator' assessments. By this is meant simple analyses and simple readable presentation of the results (like colour-coded maps) that can be understood by people who are not experts in the field of either monitoring or toxicity.
- The presentation of results should be as consistent as possible for the different toxicants and for the toxicity results.
- The assessments must nevertheless add value to the raw data and this added value must be scientifically sound.
- The reporting format must ensure that the results cannot be misinterpreted. This is relevant when either numerical or narrative results are presented.

In summary, assessments should be simple and sound.

Another aspect of assessment relates to making statements about the possible sources of toxicants or toxicity. First, it must be reiterated that it is explicitly not an objective of this monitoring programme to enable unambiguous identification of who or what activity is causing the problem. However, often information about local land use and geology is available and well known. When a toxicant or a toxic effect is detected in a water resource and statements can confidently be made about the source, then such statements add useful value and should be made. In particular, if the distinction can reasonably be made between the source being natural or anthropogenic, then this should be done. However, since the monitoring programme is not specifically designed to link sources and effects, the wording of such statements should be carefully considered. They must always be defensible and scientifically sound.

The following gives some examples in respect of assessment of toxicant concentration data only.

Single analytical results at any one sampling time provide information on the concentrations of toxicants at that single time. However, it is conceivable that if sufficiently frequent sampling and analysis takes place, it may be possible to report results in terms of "short-term exposure" or "long-term exposure" (see glossary). If toxicants occur consistently at particular sites over long periods, this could be reported as long-term exposure to organisms that are known to occur in, or that use, those waters. Note that the existence of an actual toxic effect is not being reported, nor implied. All that is being reported is that the specified organism has been exposed to the toxicant for a short period (up to days) or long period (weeks or more).

Since a period of days is the threshold between short- and long-term, strictly sampling frequency would need to be almost daily to enable absolutely certain statements to be made about the real extent of exposure. Such a frequency may well be beyond the capacity of a national programme. However, if sampling occurs weekly or even monthly, it may still be possible to draw some conclusions in this context. For example, it may occur that, at a particular site, monthly monitoring of the water reveals the consistent occurrence of a particular toxicant (say mercury) over a period of a year. It is not unreasonable to report this as "*potential* long-term exposure of fish to mercury". The word "potential" implies some uncertainty, created by the fact that data is only available on a monthly basis. The further implication is that if the mercury concentration is constant at monthly intervals, the mercury is probably at the same concentration in the period between sampling. Of course, this would only be assumed if there were no reason to think that mercury concentrations might be fluctuating (say because of known sporadic effluent discharges upstream).

It might be noted that it is not the responsibility of the NTMP to report results in a way directly related to fitness for use (for example, using phrases such as "drinkable"). The reason for this is that to be able to confidently make such a statement, the results of a number of different monitoring programmes may be necessary. In other words, reports that are required to assess water quality in this way are at a higher level than those produced by any single monitoring programme.

Besides visual presentation of results (like in colour coded maps), reporting formats should also provide a narrative description of the nature and extent of the problems. This narrative description should make use of unambiguous short simple phrases. However, it must be remembered that most people reading such reports perceive a literal meaning of such phrases (that may differ from one person to another). They must therefore be very carefully thought through and tested if possible (by asking a range of people what they understand by the phrases). Phrases that can be misinterpreted (even if defined in a glossary!) should be avoided because these phrases can easily be (and probably will be) used out of context. A survey should be conducted of organisations (like water boards) that report water quality data to ensure lessons learned by them are properly applied to the NTMP.

4.8 Reporting format

At the highest level of reporting, colour-coded maps can be presented that indicate the **nature** of the problem on a national basis as well as the **extent** of the problem.

The **nature** of the problem can be presented using different maps for different classes of toxicants. ‘Extent’ refers to two factors, the concentration and the spatial extent. The spatial extent is represented by shading on the map. The concentrations of the identified toxicants can be colour coded to indicate the extent of the problem with that class of toxicant in particular spatial areas (*e.g.* red=worst, green=no problem, blank=no data).

Similarly, for toxicity, the **nature** of the problem can be presented using different maps for different kinds of toxic effects. Each map can again be colour coded to indicate the quantitative and spatial **extent** of the measured effect.

4.9 Scope of water resources

Water resources are defined in the National Water Act as including watercourses, estuaries and aquifers. It should be noted that watercourse includes its beds and banks. This implies that toxicants and/or toxicity in sediments are strictly included in this national programme. Given the fundamentally different nature of watercourses, estuaries and aquifers, the monitoring designs are likely to have significant differences (though also significant aspects in common). This has ramifications regarding future development not only in respect of expertise required but financial resources as well.

Simultaneous versus in series

Assuming it is ultimately desirable that all water resource types be included in the NTMP, a number of options are possible regarding how the individual implementation plans for each type of resource could be developed.

- **Simultaneously**: This would involve considering all resource types in parallel and designing specifically for each. This would probably have the advantage of reaching an all-encompassing design sooner (if there are no significant unexpected pitfalls that seriously affect all the designs). However, it has the disadvantage of requiring more resources in a shorter period (*i.e.* there are cash flow issues). It will also not be possible to establish experience with a design for a single resource type so that the design for the remaining types can avoid unexpected pitfalls. Project management will be also complex because a number of disciplines (*e.g.* focussed on watercourses, groundwaters and estuaries) will need to be kept focussed and synchronised.

- **Staggered**: Development of a design for each resource type can overlap but be staggered over time. However, unless actual implementation (even at pilot scale) is done for the first resource type chosen, there can be no guarantee that unexpected pitfalls will not exist. The complexity of this project (created by the very nature of the plethora of toxicants and potential toxic effects) means that a significant time period could elapse before being confident enough to proceed with the design for a new resource type. In effect, this makes this option almost equivalent to designing them in series.
- **In series**: A design for each can be done in sequence, a full design for a single resource type being developed first, followed by the others. If the most complex resource type is chosen first and carried through to at least pilot scale implementation, then the design for the remaining types should be able to proceed relatively quickly and confidently. However, the disadvantage is that the overall time required to develop designs for all types is very likely to be much longer than if they are done simultaneously. On the other hand, this has the advantage of spreading the necessary resources over a longer period. Project management will be simpler because fewer disciplines will need to be kept synchronised at any one time.

Table 6. Summary of pros and cons of designing a monitoring programme for the different resource types simultaneously and in series.

Option	Time to include all resource types	Cash flow implications	Project management complexity	Ability to rely on previous experience with toxicants monitoring
Simultaneously	6 yrs	Worst (but manageable?)	Worst (but manageable)	Worst
In series	10 yrs?	Best	Easier (more modular)	Best

The National Microbial Monitoring Programme was developed first for surface fresh waters and is now being extended to include groundwaters (*i.e.* was done in series). The National Eutrophication Monitoring Programme was also developed first for surface fresh waters only.

At face value, the above analysis suggests that developing designs in series is better. However, it is suggested that the time to include all resource types is an issue that overrides the others. A critical strategic decision for DWAF to take is how long it is prepared to wait until it has included all resource types in this national monitoring programme. It is suggested that 10 years (or more) is unreasonable.

It is therefore proposed that a simultaneous approach be adopted for the *development of the design*. When these designs are sufficiently advanced then decisions can be made (based on the same criteria as above) whether pilot studies should be implemented for each resource type and in what order. In effect, this defers the necessity for the above decision (relating to including all resource types) for a few years.

The pilot studies should be modular in any case. That is, each should be squarely focussed on well-defined and different areas of the overall monitoring design. For example, if watercourses are deemed of greatest priority, the initial pilot studies can focus on these alone. One advantage of this is that experience thus gained may well also lead to refinements in monitoring design for other resource types (without them having been pilot-tested explicitly). More importantly, go/no-go decisions can be made after the initial series of pilot studies are completed on implementation of pilot studies that test the other resource types, say, groundwaters and estuaries.

In other words, it is recommended that *design phases occur simultaneously* for all water resource types though *pilot testing should be partly simultaneous and partly in series*.

Prioritisation of water resources

The issue of prioritising the resource types will also need to be addressed to decide which resource type should be processed first. The following factors would need to be considered. (The term "affected water" refers to water observed to be either containing toxicants or exhibiting a measurable toxic effect.)

- The number of people potentially impacted by affected water.
- The strategic importance and number of ecosystems potentially impacted by affected water.
- The degree to which existing infrastructure and expertise exists that can contribute to the implementation of the NTMP (either pilot scale or full scale).

These tend to suggest that watercourses should be processed before groundwater and then estuaries.

4.10 Primary role players

The primary role player in future phases is DWAF. DWAF will also need to ensure that appropriate expertise is available in specialised areas such as geohydrology and estuarine water quality. Therefore, consultants with expertise in national monitoring design and water quality in the chosen water resource types (*e.g.* a geohydrologist) will need to be appointed if the expertise does not exist within DWAF.

Another important role player (at least envisaged for the pilot studies) will be an international funding agency.

The following parties are regarded as stakeholders in future phases. However, their needs are secondary to those of DWAF.

National Department of Environmental Affairs and Tourism
National Department of Health
National Department of Agriculture

4.11 Capacity creation

The minimal expertise that currently exists in South Africa for (1) measuring concentrations of many toxicants and (2) applying toxicity tests (for measuring toxic effects) is likely to be inadequate for full-scale national monitoring. The need for significant capacity creation will therefore be inevitable. However, this can only begin once the detailed design of the monitoring programme has been decided.

It is premature at this time to recommend specific capacity creation initiatives. This can only reasonably be done when specific decisions have been made on the monitoring variables to be used in the NTMP. These variables must include both toxicants and toxicity and, therefore, capacity is likely to be required in both areas. Capacity creation in respect of toxicity will inevitably involve attendance at courses given by local experts in this field. The nature of capacity creation in respect of analytical methods for detection of the more uncommon toxicants like pesticides and pharmaceuticals is more difficult to imagine. Some of these techniques involve the use of very expensive equipment by people specially trained to use that equipment. Careful thought will need to be given by the designers of the monitoring programme to whether the establishment of new capacity, which may require the acquisition of such equipment, is warranted. This will have to be weighed against the possible use of simpler indicators of the presence of toxicants by possibly less accurate though cheaper methods. This is a delicate balancing act that will have major ramifications for NTMP implementation. This needs assessment report lays the foundation for such decisions to be made.

4.12 Modularity

The development of an internally consistent design for monitoring toxicants and toxic effects will be complex. This in itself is a good reason to approach the development of the overall design in a modular fashion.

‘Modular’ means consisting of modules. A ‘module’ should be regarded as a self-contained unit. In the context of monitoring design, a module may take various forms.

- A module may be a well-defined project (or sub-project) in which certain inputs are required, a series of tasks is performed and outputs (deliverables) are produced. All these occur within a specified period of time.
- A module can also be more conceptual. It can be a less well-defined period during which focus is concentrated on one task or a series of related tasks to the exclusion of others. In other words, modularity can be more a way of thinking than a well-defined set of rules, dates and tasks.

Modularity has a number of advantages.

- Planning the execution of the overall monitoring design project in a modular fashion greatly simplifies project and financial planning. It not only allows managers but also the people executing the project to plan their affairs more easily.
- The time frame envisaged for the overall project is of the order of 6 years. Predicting resource availability so far ahead is difficult. Executing the project in well-defined tasks (*i.e.* in a modular way) is highly conducive to an adaptive management style. This allows flexibility in planning the future execution of tasks. This is particularly relevant to the series of pilot studies that will test the prototype implementation manual.
- Executing one module at a time allows all involved to focus on one thing at a time. This creates an environment in which greater depth of analysis and understanding can be achieved. Although some human beings can “process in parallel” fairly well, they can achieve more if not forced to do so. Of course, all involved need to be aware that the different modules need to be consistent with each other and therefore while working on one module, one should not lose sight of the big picture.

5 CONCLUSIONS

A few general conclusions can be drawn from this work.

- The design of a national toxicants monitoring programme will be complex. The most challenging aspect of the forthcoming design will be the choice of the most appropriate monitoring variables. There are many potential variables, including individual toxicants, indicators of toxicant classes and toxic effects (on a variety of potential organisms). Very careful and focussed thought will be required to ensure that the stated monitoring objectives are met.

- The nature of the measurement of many of the monitoring variables (toxicity tests and analyses for chemicals like pesticides) is such that it is likely that resource constraints will be a primary factor in limiting the variables chosen for the programme.

- The particular nature of toxicants, their toxic effects and their likely varying behaviour in different water resources (including their sediments), suggests that specialist expertise in these areas will be essential to sound monitoring design. It also suggests that different designs are likely to be necessary for the different water resource types.

6 RECOMMENDATIONS

The following recommendations are made:

- The monitoring programme should be called the “National Toxicants Monitoring Programme” (NTMP).

- The following should be adopted as the objectives of the programme.

> **National Toxicants 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, potentially toxic substances in South African water resources
> (watercourses, groundwaters and estuaries), and,
> secondly, the potential for toxic effects to selected organisms
>
> in a manner that
> will support strategic management decisions
> in the context of fitness for use of those water resources,
> be mindful of financial and capacity constraints, yet,
> be soundly scientific.

- The NTMP should address primarily national responsibilities of DWAF while anchoring itself firmly at catchment level. The latter can be achieved by making it a lower-level objective of the NTMP to permit strategic prioritisation of water resources within the context of the RDM process (which has the ultimate objective of setting resource quality objectives). This should also facilitate buy-in of regional and local organisations.

- The NTMP should complement the data and information provided by other national monitoring programmes. In particular, it should ultimately enable a high level integrated assessment of monitoring data from all such programmes to be performed.

- The NTMP should monitor both toxicants (*i.e.* individual chemicals or classes thereof) and toxicity (*i.e.* toxic effects) to selected organisms.

- The choice of toxicants or toxicant classes should 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. Use of the proposed structured template of questions relating to these issues is encouraged.

- 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. National “status and trends” monitoring is one such context.

- 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. However, the assessment of raw data should make references to the possible natural or anthropogenic sources if this can reasonably be done in a sound and scientific way. This would typically make use of information that is available from sources outside the monitoring programme itself (*i.e.* not determined by the NTMP).

- 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 of this project should, resources permitting, focus on simultaneously producing monitoring designs for watercourses (including sediments), qroundwaters and estuaries. The main motivation for this is to ensure that elapsed time to monitoring all resource types is not excessively long. Pilot scale testing should then proceed in a following (third) phase. Decisions can be taken at the end of the (second) design phase regarding the relative priority of the three water resource types and hence which to include in the pilot scale testing (or in what order).

- Careful consideration must be given to the capacity creation needs demanded by the ultimate choice of monitoring variables. This can only be done effectively in the following phase in which the detailed design of the NTMP will be decided.

- The primary role player in future phases will be DWAF. 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. This will simplify project planning, be conducive to adaptive management and allow greater depth and understanding.

GLOSSARY

Abiotic. In the absence of living organisms.

Acute effect. See short-term effect.

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 excluded.

Chronic effect. See long-term effect.

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

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.

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 or grasses.

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. Also referred to as a chronic effect.

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.

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.

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. Also referred to as an acute effect.

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.

Sublethality. The extent to which a toxicant is detrimental 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.

Target organism. The biological system of concern that will potentially manifest one or more toxic effects. In the present context the relevant targets systems are defined as humans, fish, invertebrates, other animals, and plants.

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

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.

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.

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