CHAPTER 4: CRITERIA FOR CHOOSING MONITORING VARIABLES

4.1 INTRODUCTION

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

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

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

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

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

4.2 GENERIC CRITERIA

4.2.1 Costs as a design criterion

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

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

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

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

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

4.2.2 Site selection options

4.2.2.1 Classification-related monitoring

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

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

4.2.2.2 Priority area monitoring

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

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

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

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

4.2.2.3 Containment monitoring

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

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

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

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

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

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

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

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

4.2.2.4 Source monitoring

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

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

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

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

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

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

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

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

4.2.2.5 Criteria

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

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

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

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

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

4.2.3 Water column, biota and sediments

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

Criteria relating to information content

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

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

Criteria relating to practicalities of monitoring

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

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

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

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

The following justifications are provided:

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

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

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

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

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

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

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

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

4.2.4 Consequences of errors

4.2.4.1 Summary

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

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

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

4.2.4.2 Implications of policy

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

False negatives

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

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

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

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

False positives

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

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

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

4.3 EMPHASIS ON TOXICITY

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

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

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

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

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

4.4 CRITERIA FOR TOXICITY

4.4.1 Classification framework

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

Table 4.5. Broad guidance for choice of toxicity tests.

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

4.4.2 Protective context

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

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

4.4.3 Priority target organisms

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

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

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

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

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

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

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

4.4.4 Ease of monitoring

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

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

Table 4.7. Criteria for ranking ease of monitoring.

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

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

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

For each criterion:

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

4.4.5 Procedure

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

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

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

4.5 CRITERIA FOR TOXICANTS

4.5.1 Introduction

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

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

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

4.5.2 Persistent Organic Pollutants (POPs)

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

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

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

4.5.3 Risk-based approach for additional toxicants

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

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

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

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

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

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

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

4.5.3.1 Severity of impact

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

Table 4.8. Criteria for ranking potential severity of impact.

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

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

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

Severity of impact should include considerations of the following:

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

4.5.3.2 Spatial impact

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

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

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

Spatial impact could include considerations of the following:

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

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

Table 4.9. Criteria for ranking potential spatial impact.

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

4.5.3.3 Temporal impact

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

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

Table 4.10. Criteria for ranking potential temporal impact.

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

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

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

Temporal impact should also include considerations of the following:

- Likelihood of occasional spills.

4.5.3.4 Ease of monitoring

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

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

Table 4.11. Criteria for ranking ease of monitoring.

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

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

To simplify considerations, assume the following:

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

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

4.5.3.5 Risk-based "wish list"

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

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

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

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

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

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

4.5.3.6 Reality-based "practical list"

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

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

4.5.4 Criteria for additional toxicants

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

4.5.4.1 Relative risk

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

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

4.5.4.2 Ease of monitoring

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

4.6 RECOMMENDATIONS

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

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

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

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

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

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