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THE DEVELOPMENT OF SOUTH AFRICAN WATER QUALITY GUIDELINES FOR THE NATURAL AQUATIC ENVIRONMENT

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ABSTRACT

This paper describes the progress made by the Department of Water Affairs and Forestry in the development of documented water quality guidelines for aquatic ecosystems in South Africa, which will be able to take into account local and site-specific conditions. Proposed guidelines for toxic substances, nutrients and physico-chemical variables are described.

KEYWORDS

Acute Exposure Valve; agricultural; Continuous Exposure Valve; domestic; industrial; in-stream water quality guidelines; recreational.

INTRODUCTION

With regard to management of the natural aquatic environment in South Africa, the policy of the Department of Water Affairs and Forestry (DWAF) has evolved significantly and rapidly in recent years. For example in 1986, the statement was made that the water demand for environmental management would be met from developed sources, but only if surplus water was available (DWAF, 1986).

By 1992 (DWAF, 1992) this position had changed, and the natural environment was afforded recognition as a legitimate water user, although "in competition with other user sectors for a scarce resource". The department relied upon conservation groups, academic institutions and official bodies such as park boards to represent the water-related interests of the natural environment.

The current policy of the department is encapsulated in the White Paper of 1994 (DWAF, 1994), where it is stated that the environment is "the base from which the [water] resource is derived"; this environment must be "protected and sustained".

This paper describes the progress made by DWAF in the development of documented water quality guidelines for aquatic ecosystems in South Africa, which will be able to take into account local and site-specific conditions.

PROPOSED APPROACH TO DEVELOPMENT OF WATER QUALITY GUIDELINES

For the purposes of deriving water quality guidelines, the natural aquatic environment can be defined as the abiotic and biotic components, habitats and ecological processes contained within the outer edges of the riparian zones, in the case of rivers, or inside the fringing vegetation zones of reservoirs, lakes and wetlands. Terrestrial biota which depend on aquatic ecosystems for essential life support are included, such as fish eagles, fishing owls, hippo and otters; man is not included. Groundwater, subsurface water and water in bank storage are not included.

Domestic, industrial, agricultural and, to some extent, recreational water users can make a decision on their water quality requirements which is tempered by technical feasibility and the costs of off-stream treatment. The decision is based on quantitative knowledge of the physiological, aesthetic or economic effects of worsening or improving water quality. The water quality guidelines (DWAF, 1993) for these users have been stated as effects associated with several concentration ranges of key water quality constituents.

In contrast, there is relatively little available scientific information, and even less predictive ability, to quantify the effects of changes in water quality on ecosystem processes as well as the physiology of biota. Hence water quality guidelines for the natural aquatic environment in South Africa will be stated in the form of single-level values or single ranges.

The approach taken in guideline development will be a protective one, focused on aquatic biota, since there is more scientific information available on water quality requirements for this component than for ecological processes and habitats. Through the derivation of conservative guidelines for the protection of aquatic biota, it is considered that some measure of protection can also be extended to aquatic habitats and processes. This is intended to minimise the risk of unforeseen, possibly irreversible, damage to the resource base. The protective approach is similar to those which have been adopted and are currently being applied in the United States, Canada and Australia (USEPA, 1986; CCREM, 1987; ANZECC, 1993).

THE CONCEPT OF A NATIONAL GUIDELINE

The national guideline is the concentration level or range which is considered to afford long-term protection to the biota, processes and habitats within the water compartment of the natural aquatic environment. If it is exceeded there is a risk of chronic or acute toxicity to biota, or of adverse effects on ecosystem structure, composition and functioning. The national guideline value or range may be modified on a site-specific or region-specific basis, according to a prescribed methodology, which takes into account the required level of protection for the water resource, and regional or site-specific aspects of the aquatic environment such as "background" water chemistry, hydrology, physical and biological characteristics.

CATEGORISATION AND DERIVATION OF GUIDELINES

For the natural aquatic environment, water quality guidelines have been categorised broadly into two classes: (i) substance-specific guidelines, and (ii) guidelines for complex mixtures. Complex mixtures are those such as effluents which contain several constituents, where the individual effects of each constituent on the natural aquatic environment cannot be resolved. In such cases, guidelines should be developed site-specifically, using an approach of assessing whole effluent toxicity (which is not discussed further in this paper).

Substance-specific guidelines can be subcategorised according to the different properties or effects of each substance. The preliminary subcategorisation is:

- toxic substances (including inorganic substances such as heavy metals, and organic substances such as pesticides);
- nutrients (inorganic forms of nitrogen and phosphorus):
- physico-chemical constituents and properties.

In all of these categories, the concept of protective national guidelines, with site-specific modifications allowed on a controlled and limited basis, can be applied. However, the methods for derivation of guidelines differ between categories.

Toxic substances

The results of acute and chronic toxicity tests, conducted in laboratories and with single species populations, are the norms used for deriving national guidelines for toxic substances.

Although the toxicity of individual toxic substances often depends on the chemical characteristics of a water body, it is intended that national water quality guidelines should be set at levels which will protect all or most water bodies. Aquatic biota may be exposed to elevated concentrations of toxic substances that vary in the timing, duration and frequency of occurrence. The use of national guidelines represents an attempt to provide a reasonable and adequate amount of protection, with only a small possibility of considerable overprotection or underprotection.

National guidelines for each toxicant of concern can be expressed as two concentrations, which are termed an Acute Exposure Value (AEV) and a Continuous Exposure Value (CEV).

The AEV refers to the concentration at and above which some acute adverse effect will occur. If exceedance of the AEV is limited and lasts for a short period only, aquatic organisms and their uses should, however, not be affected permanently and populations will recover. The AEV is not a compliance level, but rather a danger level indicating where acute adverse effects can be expected.

The CEV refers to the concentration which is safe for all or most populations even during continuous exposure. It can also be termed the no-unacceptable-biological-effects-concentration for long-term or permanent exposure. The CEV represents the concentration of a substance which should not be exceeded in order to protect fish, invertebrates, phytoplankton and aquatic plant communities in freshwater ecosystems (streams, rivers, lakes and reservoirs) against unacceptable long-term and short-term effects.

Some adverse effects, e.g. reduction in growth or reproduction of a particular species may occur at, and even below, the CEV. If maintained continuously, any concentration above the CEV is expected to cause an ecologically unacceptable effect. However, the concentration of a substance in a body of water can be above the CEV without causing an unacceptable effect if:

- the magnitude and duration of the excursions above the CEV are appropriately limited, and
- there are compensating periods of time during which the concentrations remain below the CEV.

Calculation of the AEV is based primarily on the results of acute toxicity tests, while calculation of the CEV is based on results of chronic toxicity tests and/or the ratios between acute and chronic results (acute:chronic ratios).

The derivation of a CEV and AEV for a particular toxic substance is a rigorous calculation procedure, based upon the method used by the United States Environmental Protection Agency (USEPA, 1986). The procedure relies upon data generated from the results of toxicity tests on at least eight different families of freshwater animals, and at least one freshwater alga or vascular plant. Because of the general lack of data for indigenous South African species, information from two international databases, Assessment Tools for the Evaluation of Risk (ASTER) (USEPA, 1994a) and the Aquatic Toxicity Information Retrieval Database (AQUIRE) (USEPA, 1994b), has been used. These databases comprise data obtained from peer-reviewed publications, with enough supporting information to indicate that acceptable test procedures were employed and that the results are reliable.

Only data on freshwater species were used in deriving of guideline values. Data on cold and warm water fish include species which are represented by reproducing wild populations in South African waters. If not indigenous to South Africa, species were selected on the basis of their commercial or recreational importance (e.g. rainbow trout, brown trout, largemouth bass and common carp).

Table 1 shows the preliminary national guideline values derived for mercury.

Table 1. Preliminary national guideline values for mercury in the natural aquatic environment

	Continuous Exposure Value	Acute Exposure Value
Mercury	2.2 $\mu g/\ell$	4.1 $\mu g/\ell$

Nutrients

In some aquatic systems, the natural levels of inorganic nitrogen and phosphorus may result in only moderate growths of nuisance plants, causing no environmental damage and with no loss of fitness for use. In other similar ecosystem types, the same concentrations of these elements can result in significant nuisance growths of algae and aquatic plants. It is also clearly inappropriate to attempt to control nutrient inputs into naturally eutrophic systems, since this would result in changes to the natural structure and functioning of such ecosystems.

Most aquatic organisms are tolerant of high (> 40 mg NO_3-N/l) nitrate concentrations, although such concentrations are very seldom found in natural waters. Nitrate toxicity is therefore not considered to be an important norm for setting nitrate water quality guidelines for protection of the natural aquatic environment. Nitrite and ammonia, however, do have toxic effects on aquatic biota, and these effects should be taken account of in the derivation of site-specific guidelines.

The secondary effects of inorganic nitrogen, namely its influence with phosphorus in creating eutrophic conditions through nuisance growths of algae and other water plants, are considered to be far more important. However, it must be remembered that site-specific conditions are critically important in modifying the influence of nitrogen on eutrophication.

Generally, inorganic nitrogen concentrations in the range of 0.4 to 1.0 mg N/l are considered to be low enough to limit eutrophication. However, in the presence of sufficient available phosphorus, nitrogen-fixing organisms will be able to fix molecular nitrogen to make up for any deficit caused by low inorganic nitrogen concentrations.

It is not possible to recommend a single set of inorganic nitrogen and phosphorus concentrations that will prevent nuisance growths of algae and aquatic plants in South African freshwater systems. Therefore, site-specific studies should be conducted on each aquatic system of interest to determine the appropriate nitrogen and phosphorus concentrations that can be tolerated within each system.

Physico-chemical constituents and properties

The physico-chemical category includes physical or chemical substances, properties or indicators which are naturally present in almost all surface waters, but which may have adverse effects when present in excessive amounts or at levels significantly different from natural (unimpacted) conditions. Variables in this category include.

- temperature and dissolved oxygen, which are essential "drivers" of ecosystem processes, structure and composition. Natural ranges and cycles in these variables tend to be determined by local climatic and topographical factors and by biological activity;

- turbidity (suspended solids), pH, hardness (alkalinity), total dissolved solids (TDS), major dissolved ions (calcium, magnesium, potassium, sodium, chloride, sulphate). Natural levels or ranges of these variables tend to be determined by geochemical processes within a river catchment, and depend on the structure and composition of rocks and soils. Cycles of variability are usually determined by local climatic and hydrological conditions.

Many of the physico-chemical constituents and properties have adverse physiological or behaviourial effects on biota at very high or very low levels, and the response to such extreme levels can be tested in the laboratory in the same manner as for toxic metals and inorganic variables. However, accuracy is limited by the varying sensitivities of biological populations adapted to different local conditions, and to different rates of change in the concentrations of variables. In addition, certain biota show a tendency to become acclimated to changes in concentrations if these changes do not occur rapidly.

It is in the determination of "safe" continuous exposure levels that difficulties arise. Many local ecosystems evolve over geological timescales, in such a way that the biota and the ecological processes are adapted to the natural levels or cycles of physico-chemical variables. Small changes from "natural" levels can lead to significant changes in biological community structure and composition, often as a result of disturbance to the reproductive, spawning, growth or migratory cycles of key species. The onset of such changes, their nature and extent, the consequences and possible reversibility, are all extremely difficult to predict accurately under field conditions.

For the physico-chemical category, therefore, stringent single-level national guidelines are not presented. Rather, national recommended ranges or levels are used. These give an indication of conditions which should not lead to adverse physiological effects on most biota.

Protection of local ecosystem processes, structure and functioning can only be ensured by the derivation of site-specific guidelines. These guidelines will depend on knowledge and understanding of local physical, chemical and biological conditions. Therefore, factors which must be considered in the derivation of site-specific guidelines are also included as key information for each constituent or property. In some cases, the guideline is stated entirely in terms of site-specific natural conditions.

The proposed approach to be used in developing the recommended ranges or values is as follows:

- International criteria for the constituent/property in question are reviewed.
- If considered appropriate, these criteria are adopted as guidelines for South African conditions. If reliable local information is available, it should be incorporated, and the recommended range or value should be modified if necessary.
- The proposed range or value, and the method of derivation, should be submitted to stringent review by members of the local scientific community.

Table 2 shows the proposed National Recommended Range for dissolved oxygen, as an example of the approach for this category.

Table 2. Proposed national recommended range for dissolved oxygen in the natural aquatic environment

<table>
<tr><th></th><th>Concentration</th><th>Condition</th><th>Application</th></tr>
<tr><td>National Recommended Range</td><td>80%-120% of saturation</td><td>6 a.m. sample or lowest instantaneous concentration recorded in a 24-hour period.</td><td>Intended to protect all life stages of most Southern African aquatic biota which are endemic to, or adapted to, aerobic warm water habitats.</td></tr>
<tr><td>National Recommended Minimum Values</td><td>> 60% of saturation</td><td>7-day mean minimum value</td><td rowspan="2">The 7-day mean minimum and the 1-day minimum must apply together. These will protect sensitive life stages which may last for only a few days, and will take into account the resilience of aquatic biota to short-duration oxygen depletion. Violation of these minimum values is likely to cause severe adverse effects on the natural aquatic environment.</td></tr>
<tr><td></td><td>> 40% of saturation</td><td>1-day minimum value</td></tr>
<tr><td>Site-specific modifications allowed</td><td colspan="3">Local natural conditions
Site-specific modifications may be considered in:
• naturally eutrophic systems, which have abundant natural sources of nutrients, and in which dissolved oxygen minima may be very low due to high rates of respiration;
• deep lakes in which oxygen depletion or anoxia of the hypolimnion is a regular, usually seasonal, occurrence resulting from lake morphology and local climate.
The expected range in dissolved oxygen must be determined by measurement at a site over several consecutive 24-hour cycles, repeated in each season to take account of climatic influences.

Where natural physical, chemical or ecological processes lead to dissolved oxygen concentrations which fall below the national recommended minimum values, then the minimum acceptable site-specific concentration can be set at a level which is related to the measured natural minimum concentration.

Specific biota
Some upland reaches of Southern African streams, in mountainous areas such as Lesotho and the Drakensberg range, can be considered cold-water habitats, usually with high natural dissolved oxygen levels. The dissolved oxygen requirements of biota adapted or introduced into South Africa (such as trout) may be more stringent than the national recommended range. In such cases, key species of recreational, commercial or conservation importance should be identified. Site-specific guidelines should be derived according to the needs of these species.</td></tr>
</table>

APPLICATION OF WATER QUALITY GUIDELINES

Water quality guidelines are intended to be an important tool in the process of management of the natural aquatic environment. They are not designed to be prescriptive at a national level: rather it is proposed that they be used for guidance, and that they be incorporated into a decision-making process at a local or regional level. At this level, stakeholders can make informed decisions based on the water quality guidelines and on advice from technical specialists. The end point of the process would be to allow the development of environmental quality objectives which are appropriate to a local situation, and which are agreed to by all stakeholders.

CONCLUSIONS

The development of national water quality guidelines for the natural aquatic environment should be of great value in the integrated management of water resources. This information will fill a gap which has led to much public and institutional concern in the past, when no accepted South African criteria or methods for derivation of criteria were available.

A protective approach has been followed in the development of guidelines for the natural aquatic environment. This reflects the water quality management policies of DWAF, and is well integrated with the pollution prevention approach and the use of the precautionary principle.

The development of accepted procedures for derivation of guidelines will assist in directing research into the responses of Southern African species to toxic substances, and in ascertaining the tolerances of local biotic communities to changes in concentrations of other water quality variables.

The application of in-stream water quality guidelines is necessary but not sufficient for the maintenance of aquatic ecosystem health at an acceptable level. Other issues which need to be considered are the assurance of an adequate quantity of water to sustain ecosystem processes and functioning, and the maintenance of habitat quality, particularly in the sediment and riparian compartments. These aspects are being addressed in other current research and management initiatives. Ideally, all three factors should eventually be integrated within a policy framework for management of the ecological health of water resources.

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