Drinking-water quality criteria with special reference to the South African experience*

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Abstract

Drinking-water quality is discussed and the difference between quality criteria and quality standards is emphasised. Methods for the establishment of criteria/standards are addressed and special reference is made to risk assessment and risk management. A comparison is drawn between the criteria/standards used in the United States, Europe, South Africa and those suggested by the World Health Organisation. Special attention is given to the South African quality criteria, where a three-tier system setting maximum levels for no risk, insignificant risk and low risk has been proposed.

Introduction

The need to take precautions with drinking water to protect public health was recognised as many as 4 000 years ago. According to Baker (1948), as cited by Healey (1986), Francis Evelyn Place, who while in India in 1905, wrote "It is good to keep water in copper vessels, to expose it to sunlight and filter through charcoal". She credited this quotation to a collection of medical lore in Sanskrit approximately 2 000 BC. This recommendation is very appropriate especially when the problem of organic contamination of drinking water is considered.

Today the quality of drinking water is still of primary concern. Microbial contamination remains the most important health risk, but the inorganic compounds are receiving their share of attention. However, the focus has moved to a large extent to the organic compounds. The latter is mainly so because trace quantities of these compounds can now be measured in water, as a result of the development of sophisticated analytical methods.

Drinking water should be fit for human consumption and, therefore, regulation of the environmental contaminants, or at least guidelines in this regard, are necessary. The determination of what substances should be addressed and to what extent they should be reduced or eliminated is, however, a difficult problem. Solving this problem has resulted in a world-wide establishment of various guidelines, criteria, norms, standards, etc.

The purpose of this paper is, firstly, to define drinking-water quality; secondly, to discuss methods for the establishment of criteria/standards and, thirdly, to compare the various authorities' criteria with each other, with special reference to the South African experience.

Definition of drinking-water quality

How is water quality described? In general one can say that drinking water should be consumed in any desired amount without concern for adverse effects on health. One can go a step further and say that the consumer is entitled to a high-quality water which can be described as water that should contain no pathogenic organisms and is free from biological forms that may be aesthetically objectionable. It must be clear and colourless with no objectionable taste or odour. It should not contain concentrations of chemicals that may be physiologically harmful and aesthetically objectionable. Also, it should not be corrosive, nor should it leave deposits on water-conveying structures, including pipes, tanks, water heaters and plumbing fixtures (AWWA, 1987).

It is obvious that the quality of drinking water has to be controlled and managed. In this regard it is necessary to distinguish between certain terminologies.

In general the **criterion** of water being safe to drink means that the concentration of a contaminant should be below a level which is harmful to health (Nicholson, 1983). A number of definitions for a criterion, as applied to water quality, has been proposed. For example, the United States Environmental Protection Agency (USEPA, 1976) define criterion as "a designated concentration of a constituent that when not exceeded will protect an organism or an aquatic community with an adequate degree of safety". Drinking-water quality criteria thus represent the maximum level of a contaminant which can be present in such a concentration that the water can be consumed with adequate safety.

Criteria are not **regulatory requirements** but merely serve as **guidelines**, upon which the regulatory authority may formulate water-quality standards. Criteria to evaluate the safety of drinking water are continually reassessed as new contaminants are identified and health-effects research advances. Drinking-water quality criteria must consider all factors that affect the quality of drinking water, the public health significance of contaminants, and the available technology to treat drinking water. Establishing appropriate criteria, therefore, requires the combined efforts of regulatory agencies, consumers, and the water supply industry (AWWA, 1987).

Criteria are not synonomous with, and should not be confused with standards. It is generally accepted that standards represent **legally enforceable limits**. For drinking water, standards should ideally be identical to criteria to provide the maximum protection for drinking water. However, standards are influenced by practical and political considerations. It is also generally recognised that uniform quality standards for application throughout the world are neither practical nor necessary, because local conditions in each country should be taken into account in establishing the standards or criteria.

Guidelines and criteria are similar in the sense that they are

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not statutorily imposed limits and that they can guide authorities in establishing standards.

Within the framework of criteria and standards various terms are used such as recommended maximum residue limits, maximum permissible concentrations, derived working levels, maximum admissible concentrations, maximum acceptable limits, recommended maximum contaminant levels, maximum contaminant levels, etc. (e.g. Nicholson, 1983).

Establishment of criteria/standards

The task of establishing criteria/standards is not an easy one. The dilemma in this regard is probably best illustrated by the title of a paper "Chemical drinking-water standards, an example of guesswork?" by Berlyne and Yagil (1973). Since then the position has changed dramatically because much more information has become available. However, we now have to consider a whole range of determinands, with categories which were scarely regarded of any significance only a few decades ago, now becoming the focus of concern. Not only are the old limits for old determinands being questioned, but criteria are now being sought for entirely new ones. (Although the terms "constituent" and "contaminant" are also used, the term "determinand" is preferred, but all three terms have the same meaning).

Important determinands

Microbiological determinands

Bacteriological quality is still one of the best established determinands of water. Apart from present determinands (e.g. total coliforms), viruses are receiving more attention and other microbiological issues are also coming to the fore, e.g. *Giardia lamblia* and *Legionella.*

Aesthetic/physical and inorganic determinands

The major inorganic determinands (such as total dissolved solids, hardness, chloride, sulphate, etc.) were long regarded as having primarily aesthetic or industrial significance and being of only marginal health importance (Wells, 1978). However, the position has changed. There are inorganic consituents of more obvious public health significance, e.g. the heavy metals. Determination of criteria in such cases is hampered not only by inadequacy of toxicological information, but also by the occurrence of synergistic phenomena.

Organic chemical compounds

This category is currently receiving the greatest attention, at least in developed countries. The concern in this regard is based on three facts. Firstly, with the increasing sophistication of the chemical industry a significant number of new organic compounds enters the industrial sphere each year and at this stage little is known of their chronic or acute tocixity, or of their fate or the nature of their metabolites in waste-water processes.

Secondly, in developed countries raw water sources for public supply are increasingly derived from rivers containing considerable proportions of effluent from upstream sources. Such effluent will contain materials resistant to normal biological treatment processes, and the effect of increasing concentrations of these compounds in public water supply is unknown.

Thirdly, with the increasing sophistication of analytical equipment, it is now possible to detect old and new compounds, which was not possible previously.

Criteria relating to organic content are of two types: those reflecting total organic concentration, and those relating to single compounds. In the latter case the organic compounds are often, for the purpose of regulation, classified into two further categories, viz. synthetic organic chemicals and volatile organic chemicals. Some authorities even use a third category, viz. the disinfection by-products.

Radionuclides

These compounds are currently receiving much attention and some authorities regard them as priority and include them in regulations (Cotruvo, 1988; Cotruvo and Vogt, 1984; Alston, 1985).

Methods for the establishment of criteria

Each society will have a different legal and procedural framework for making control decisions and determining whether these are advisory or mandatory, depending upon operative laws and tradition. The philosophical bases may be different depending upon the type of contaminant, the mechanism of action, and the significance of the adverse effects.

Among the many bases for establishing control levels are the following: zero or no deliberate addition; no detection by specified analytical methods; natural background level; safe or wholesome level; no unreasonable risk level (taking the average daily intake into consideration); no known adverse effect level with a margin of safety; level consistent with a specified risk or probability of harm; technologically and economically feasible level; level achievable by using the best available technology; marginal benefits are greater than marginal control costs; and costs of achieving the level are low and socially acceptable (Cotruvo, 1987).

When public health is at stake, the ideal goal should be to assure against the occurrence or the potential occurrence of any of the adverse effects, with a large margin of safety. On the other hand, all decisions ultimately must reflect economic and technological feasibility; thus, it is probable that selected control levels will differ from ideal goals. However, risk assessment should be separate and distinct from risk management. Risk assessment is the use of a base of scientific research to define the probability of some harm coming to an individual or population as a result of an exposure. Risk management is the public process of deciding what actions to take when risk has been determined to exist (Cotruvo, 1987).

In all the deliberations on water quality criteria, risk assessment has become the key word. Much has been said about it and it is expected that risk assessment and risk management will receive even more attention in future. It is not the purpose of this paper to address this issue in detail, but a few comments would be appropriate.

Microbial risks from drinking water

The principle risk factors in drinking water are biological in origin as indicated by the reported and projected evidence of waterborne diseases world-wide (Cotruvo, 1987).

Retrospective identification of risk from waterborne infectious diseases is a relatively simple task compared with carcinogenic risks. However, assessments of microbial risks from theoretical projections would be extremely complex. Fortunately,

theoretical exercises in this regard have been obviated by the introduction of two operationally simple and practical treatment techniques: disinfection and filtration.

The removal of microbiological contamination remains the most important consideration in ensuring the safety of public water supplies. The efficient disinfection of water should not be compromised, and chlorination should not be phased out in preference to other methods, unless there is stronger evidence that the by-products produce serious health risks and until the potential hazards of substitute disinfectants are fully explored (Pieterse, 1988).

Risk assessment for chemical agents

Toxicity can be described as the intrinsic quality of a chemical to produce an adverse effect. The toxicology of chemical substances found in drinking water is commonly divided into two broad classes: acute or chronic toxicity (non-carcinogens) and carcinogenicity. The distinguishing characteristic between these categories of effects lies (1) in the probably unverifiable assumption that dose thresholds exist for chronic toxicity effects and (2) in the also unverifiable assumption that dose thresholds do not exist (or have not been demonstrated) for carcinogenic effects (Cotruvo, 1987).

Numerous substances detected in drinking waters are known to induce toxicity but usually at dose levels much higher than those found in water. When appropriate data are available from human epidemiology or animal studies, the use of the acceptable daily intake (ADI) concept is a well-accepted procedure for determining concentration levels for standard and criteria setting. The ADI of a chemical is defined as the dose that is anticipated to be without lifetime risk to humans when taken daily (Cotruvo, 1987).

The ADI is usually derived from a detailed analysis of the toxicology of the chemical being examined. For this purpose the "no observed adverse effect level" (NOAEL) is determined for the most sensitive adverse effect in the test system, and a safety or uncertainty factor is applied to the NOAEL dose to derive the safe level for the general human population (Cotruvo, 1987). NOAEL is also called the "no observed effect level" (NOEL)(Van Dijk-Looyard, 1988; Nicholson, 1983).

It should always be appreciated that the contribution of drinking water as a source of organic matter in general is very low. For example, according to Zoeteman (1985), practically all known organic micropollutants in drinking water contribute less than 1% of the daily intake of these compounds. The only exception is chloroform (Table 1).

TABLE 1
MAIN EXPOSURE ROUTES FOR SOME DRINKING-WATER CONTAMINANTS (ZOETEMAN, 1985).

Substance	% Contribution to total intake			
	Drinking water	Food	Air	Smoking
Fluoride	50	50	<1	—
Lead	32	65	3	—
Magnesium	29	71	<1	—
Calcium	16	83	<1	—
Chloroform	15	77	8	—
Nitrate	14	85	1	—
Trichloroethene	1	5	94	—
Benzo(a)pyrene	1	87	4	8
DDT	<1	100	<1	—
Vinyl chloride	<1	5	95	—
Benzene	<1	56	44	—

There are basically four steps involved in risk assessment (Cotruvo, 1987; Deisler Jr., 1988):

- Hazard identification: qualitative evaluations of the agent's ability to produce carcinogenic effects and the relevance to humans.
- Exposure assessment: the number of individuals likely to be exposed with the types, magnitudes, and durations of the exposure.
- Hazard or dose-response assessment: the attempt to assemble the hazard and exposure information along with mathematical models to estimate an upper bound on the carcinogenic risk at a given dose.
- Characterisation of the risk associated with human exposure.

Numerous mathematical models have been developed in attempts to estimate potential risks to humans from low-dose exposure to carcinogens. Each model incorporates numerous unverifiable assumptions.

A novel approach was followed by Travis *et al.* (1987) in which they suggested regulatory guidelines for the assessment of cancer risk management. These incorporate individual risk, population risk and cost-effectiveness into a single framework, even though they recognise that no absolute rules are possible. They recommend three guidelines, namely the *de manifestis* ('obvious risk') individual lifetime risk, which is a function of population risk (above this level action is necessary); the *de minimis* (for defining an acceptable level of risk that is below regulatory concern) individual lifetime risk, which is a function of population risk (below this risk action is not necessary); and in the region between these two levels regulatory action should be taken if the cost is below $2 million per life saved.

In general it can be said that the process of estimating human cancer risks posed by exposure to chemical carcinogens has been a focus of controversy among toxicologists for at least the past decade (Calabrese, 1987).

According to WD Ruckelshaus, former administrator of the EPA, "risk assessment data can be like a captured spy: If you torture it long enough it will tell you anything you want to know" (Deisler Jr., 1988).

Summary of drinking-water quality criteria as established by various authorities

In this section the quality criteria set by the USEPA, World Health Organisation (WHO) and the European Economic Countries (EEC) are compared. The South African experience in this regard will be dealt with separately.

USA

Landmark legislation, the Safe Drinking Water Act (SDWA), was passed by the USA Congress in 1974 (Sayre, 1988). The act mandated a radical change in the surveillance of drinking-water systems, giving specific roles to federal and state authorities and to public water suppliers. One unique feature of the SDWA is that it requires public water suppliers to notify their consumers if standards or monitoring requirements are not being met. The US Environmental Protection Agency (USEPA) was authorised to set national regulations concerning the maximum permissible levels of certain contaminants, to conduct research, and to oversee implementation of the SDWA.

The SDWA was amended in 1986 to require the USEPA to regulate 83 contaminants by June 1989, and the agency has undertaken a comprehensive reassessment of the interim regulations to identify additional drinking-water contaminants that should be regulated and to establish national primary drinking-water regulations (NPDWRs). In promulgating these, the USEPA must specify recommended maximum contaminant level goals (MCLGs), which are non-enforceable health goals, in addition to maximum contaminant levels (MCLs) — the enforceable standards (Craun, 1988).

Table 2 gives a list of the contaminants to be regulated under the SDWA amendments of 1986.

A treatment technique rather than a MCL can be specified if it is not economically or technologically feasible to ascertain the level of a contaminant in drinking water.

TABLE 2
CONTAMINANTS TO BE REGULATED UNDER THE SDWA AMENDMENTS OF 1986 (SAYRE, 1988).

Inorganics	Organics, continued
Aluminium	Dioxin
Antimony	Diquat
Arsenic*	Endothall
Asbestos	Endrin*
Barium*	Epichlorohydrin
Beryllium	Ethylene dibromide
Cadmium*	Glyphosate
Chromium*	Hexachlorocyclopentadiene
Copper	Lindane*
Cyanide	Methoxychlor*
Fluoride*	Pentachlorophenol
Lead*	Phthalates
Mercury*	Pichloram
Molybdenum	Polychlorinated biphenyls
Nickel	Polycyclic aromatic hydrocarbons
Nitrate*	Simazine
Selenium*	2,4,5-TP*
Silver*	Toluene
Sodium*	Toxaphene*
Sulphate	1,1,2-Trichloroethane
Thallium	Vydate
Vanadium	Xylene
Zinc	
Microbiology and turbidity	**Radionuclides**
Giardia lamblia	Beta particle and photon activity*
Legionella	Gross alpha particle activity*
Standard plate count	Radium-226 and radium-228*
Total coliforms*	Radon
Turbidity*	Uranium
Viruses	
Organics	**Volatile organic chemicals**
Acrylamide	Benzene*
Adipates	Carbon tetrachloride*
Alachlor	Chlorobenzene
Aldicarb	*cis* 1,2-Dichloroethylene
Atrazine	Dichlorobenzene*
Carbofuran	1,2-Dichloroethane*
Chlordane	1,1-Dichloroethylene*
2,4-D*	Methylene chloride
Dalapon	Tetrachloroethylene
Dibromochloropropane	*trans*-1,2-Dichloroethylene
Dibromomethane	Trichlorobenzene
1,2-Dichloropropane	1,1,1-Trichloroethane*
Dinoseb	Trichloroethylene*
	Vynil chloride

*Already regulated

Every public water system will be affected by the far-reaching implications of the new act of 1986. Some of the more salient features are listed below (Sayre, 1988):

- All existing interim and primary regulations are converted to primary regulations.
- As already said, the USEPA must promulgate national drinking-water goals and enforceable standards for 83 contaminants by June 1989. These contaminants are shown in Table 2. Every three years after 1 January 1988, the USEPA must publish an updated list of contaminants that may need regulation.
- To prevent waterborne outbreaks of giardiasis and viral infections, filtration and disinfection of all surface water supplies are mandated, although provision is made for granting exceptions to these requirements under certain circumstances.
- Any pipe solder or flux used for drinking-water systems after June 1986 must be lead-free.
- States must submit a detailed programme for protecting ground water used for public water supplies to the USEPA by June 1989.
- Every public water system, large and small, must conduct a monitoring programme for contaminants, including non-regulated contaminants, at least every five years.

The USEPA has also proposed a list of contaminants that may be appropriate for regulation under the SDWA after the initial 83 contaminants are regulated. These contaminants may have adverse health effects and are known or anticipated to occur in water systems.

The USEPA has indicated that their key priorities in their regulatory agenda are: lead, radionuclides, microbial contaminants, and disinfection by-products (O'Brien and Clemens, 1988; Cook, 1987; Cotruvo, 1988).

A summary of the US primary and secondary regulations appears in Table 3.

World Health Organisation (WHO)

With the advent of the International Drinking Water Supply and Sanitation Decade, 1981-1990, the WHO undertook a revision of the international standards to provide guidance to regulatory agencies responsible for public health and to water treatment operators on water quality that is consistent with the maintenance of good public health. It was recognised that uniform quality standards for application throughout the world were neither practicable nor necessary. It was decided, therefore, that the WHO should publish drinking-water quality guidelines (rather than standards) to be used by countries as a basis for the development of standards (Hickman, 1986).

The guidelines were derived to protect health, assuming lifelong consumption (WHO, 1984). WHO said that in developing national standards based upon the guidelines, it would be necessary to take into consideration local geographical, socio-economical and dietary and industrial conditions. These considerations could lead to national standards that differ appreciably from the guidelines (Cotruvo, 1987).

WHO also stated that the judgement about safety, or what is an acceptable risk level, is a matter in which society as a whole has a role to play. The final judgement as to whether the benefit of adopting any of the proposed guidelines does or does not justify the risk, is for each country to decide. Guidelines were provided for biological quality, aesthetic quality, radioactivity,

inorganic chemicals, and organic chemicals.

Recently a study group, who acted on behalf of the WHO, addressed the WHO guidelines for micro-organic compounds (Van Dijk-Looyard, 1988). This group recommended that the guidelines should be reviewed in view of the latest information on these compounds and that the guidelines for 15 of the present 18 organic compounds in the 1984 WHO guidelines, should be revised. Attention should be given to 29 new compounds or groups of compounds.

A summary of the 1984 WHO guidelines appears in Table 3.

European Economic Community (EEC)

The first effort to develop drinking-water standards for the countries of Western Europe emerged from a study under the auspices of the WHO in the early 1950s (Sayre, 1988). Later the European Economic Community (EEC) independently developed a set of standards in the form of a directive issued in 1980. Under the provisions of the treaty establishing the EEC, all the member countries — Belgium, Denmark, France, West Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and the United Kingdom — had to take the necessary measures to ensure that the quality of water intended for human consumption complied with this directive within five years, i.e. by July 1985. The standards address "maximum admissible concentrations" of water contaminants, including microbiological parameters of less than 1 organism per 100 mℓ, organoleptic parameters, physiochemical parameters, "undesirable" substances in excessive amounts, and toxic substances.

There was consensus that it might be impractical to adopt a single set of standards for all the countries of Europe, but water

TABLE 3A
SUMMARY COMPARISON OF US PRIMARY REGULATIONS WITH EEC AND WHO GUIDELINES (SAYRE, 1988).

Substance	US maximum contaminant level*	EEC maximum admissible concentration+	WHO guideline
Inorganics	**mg/ℓ**	**mg/ℓ**	**mg/ℓ**
Arsenic	0,05	0,05	0,05
Barium	1,0	0,1	NS
Cadmium	0,01	0,005	0,005
Chromium	0,05	0,05	0,05
Fluoride	4,0	NS	1,5
Lead	0,05	0,05	0,05
Mercury	0,002	0,001	0,001
Nitrate	10,0 (N)	50,0 (NO_3)	10,0 (N)
Selenium	0,01	0,01	0,01
Silver	0,05	0,01	NS
Organics	**μg/ℓ**	**μg/ℓ**	**μg/ℓ**
2,4-D	100	NS	1
Endrin	0,2	NS	NS
Lindane	0,4	NS	NS
Methoxychlor	100	NS	1
Pesticides (total)	NS	5	NS
Toxaphene	5	NS	NS
2,4,5-TP silvex	10	NS	NS
Trihalomethanes	100	1	30 ($CHCl_3$ only)
Volatile organic chemicals	**μg/ℓ**	**μg/ℓ**	**μg/ℓ**
Benzene	5	NS	10
Carbon tetrachloride	5	NS	3
1,1-Dichloroethylene	7	NS	3
1,2-Dichloroethane	5	NS	10
para-Dichlorobenzene	75	NS	NS
1,1,1-Trichloroethane	200	NS	NS
Trichloroethylene	5	NS	30
Vinyl chloride	2	NS	NS
Microbials			
Coliforms – organisms/100 mℓ	<1	0	0
Turbidity – NTU	1-5	0-4	<1
Radionuclides			
Beta particle and photon activity	4 mrem	NS	1,0 Bq/ℓ
Gross alpha particle activity	15 pCi/ℓ (0,56 Bq/ℓ)	NS	0,1 Bq/ℓ
Radium-226 + radium-228	5 pCi/ℓ (0,19 Bq/ℓ)	NS	NS

*Enforceable
+ Non-enforceable
NS = Not specified
NTU = Nephelometric turbidity units
1 Ci = 3,7 × 10^{10} Bq

TABLE 3B
SUMMARY COMPARISON OF US SECONDARY REGULATIONS WITH EEC AND WHO GUIDELINES.

Substance	US secondary maximum contaminant level*	EEC		WHO guideline value
		Guide level*	Maximum admissible concentration	
Chloride	250 mg/ℓ	25 mg/ℓ	NS	250 mg/ℓ
Colour	15 CU	1 mg Pt-Co/ℓ	20 mg Pt-Co/ℓ	15 CU
Copper	1 mg/ℓ	100 μg at treatment plant: 3 000 μg after 12h in piping	NS	1,0 mg/ℓ
Corrosivity	non-corrosive		Water should not be aggressive.	
Fluoride	2 mg/ℓ		Varies according to temperature, e.g. 1,5 mg/ℓ (8-10°C)	1,5 mg/ℓ
Foaming agents	0,5 mg/ℓ		NS	NS
Iron	0,3 mg/ℓ	0,05 mg/ℓ	0,3 mg/ℓ	0,3 mg/ℓ
Manganese	0,05 mg/ℓ	0,02 mg/ℓ	0,05mg/ℓ	0,1 mg/ℓ
Odour	3 TON	0 dilution number	2 dilution number at 12°C	
pH	6,5-8,5	6,5-8,5	NS	6,5-8,5
Sulphate	250 mg/ℓ	25 mg/ℓ	NS	400 mg/ℓ
Total dissolved solids	500 mg/ℓ	NS	NS	1 000 mg/ℓ
Zinc	5 mg/ℓ	100 μg at treatment plant: 5 000 μg after 12h in piping	NS	5,0 mg/ℓ

*Non-enforceable
NS = Not specified
CU = Colour units
TON = Threshold odour number

experts deemed the EEC directive an adequate starting point. Nevertheless, the directive states firmly: "Member states shall fix values applicable to water intended for human consumption for the parameters shown . . ." (Sayre, 1988).

The difficulties of applying a single set of enforceable standards among all the countries of the EEC are exemplified by the controversy the United Kingdom is currently encountering. The Commission contends that the UK has failed to implement certain portions of the directive, e.g., the EEC has challenged the use in the United Kingdom of average values instead of maximum admissible concentrations (Sayre, 1988).

The EEC maximum admissible concentrations are summarised in Table 3.

The South African experience

There are no legally enforceable drinking-water standards in South Africa. Until very recently the quality of drinking water was guided by specifications established by the South African Bureau of Standards (SABS). The SABS Specification No. 241 of 1984 lays down the minimum physical, chemical and bacteriological requirements for 26 determinands for the purity (as delivered to the consumer) of water for domestic supplies (SABS, 1984). The requirements are classified in two categories, viz. "recommended" and "maximum allowable" limits. Methods for the sampling and determination of these determinands are also described. A summary of the quality limits appears in Table 4.

Proposed new aesthetic/physical and inorganic determinands

The Department of National Health and Population Development (hereafter called the Department of Health) is the responsible authority in South Africa for issues on water quality as far as it relates to human health. This Department is considering the introduction (and has already accepted the basic philosophy) of certain drinking-water quality guidelines based on recommendations by the Council for Scientific and Industrial Research (CSIR) (Aucamp and Vivier, 1987). These criteria refer to 56 aesthetic/physical and inorganic chemical determinands, 30 more than covered in the SABS specification.

In formulating their criteria, Kempster and Smith (1985) used the following approach:

- Existing world criteria were used together with criteria proposed by Smith (1980) as well as data on the toxicities of elements (Berman, 1980) and normal dietary intakes (Underwood, 1977; IAEA, 1980).
- For the potentially toxic elements, a drinking water contribution of from 10 to 20% of the total dietary intake was taken as a safe working level, except where water is known to be the main vehicle of intake (e.g. fluoride) or where the element has a low toxicity via the oral route (e.g. barium).
- Regional climatic, geochemical and hydrological differences were taken as far as possible into account.
- The criteria were established to be in agreement with the SABS criteria (SABS, 1984).
- Three criteria levels have been proposed, viz. a "recommended" (working limit); a "maximum permissible limit" and a "crisis limit".

The three-tier system

The first level of the three-tier system is the **recommended or working limit.** This is the limit which should ideally not be exceeded. It is also called the **maximum level for no risk** by the Department of Health (Aucamp and Vivier, 1987). This is the goal, or ideal, which should be aimed at and is the fundamental water-quality criterion. This limit closely follows the **recommend-**

ed levels set by the USEPA, EEC, WHO and SABS. Drinking water conforming to these levels is considered to be safe for a lifetime's consumption, while concentrations less than these maximum levels are considered to be inside the **safe or no risk range.**

As the recommended limit is often exceeded in practice by one or more determinands in a given water sample, it was necessary to propose less stringent limits.

The secondary or less stringent criterion is called the **maximum permissible level** or **maximum allowable limit.** It is also referred to as the **maximum level for insignificant risk** (Aucamp and Vivier, 1987). The range between the maximum limit for no risk and this level is considered to be the **insignificant risk range.** In this range the authority responsible for water supply and treatment, is also solely responsible for decisions regarding the quality of the drinking water supplied.

The third level is referred to as the **crisis limit,** that limit where extreme action must be taken (Kempster and Smith, 1985). The Department of Health refers to this as the **maximum level for low risk** (Aucamp and Vivier, 1987). The range between this third level and the previous levels is considered to be the **low risk range.**

The definition of the **crisis limit** (or maximum level for low risk) represents a new departure in water quality criteria. There is consequently no literature and the concentration values for the **crisis limit** had to be defined *de novo.* As an interim measure the **crisis limit** value for each determinand was originally defined as twice the risk limit value, except for dissolved oxygen, pH and temperature (Kempster and Smith, 1985). The appropriate crisis level will, however, largely be determined by the toxicological characteristics of the individual determinand.

In the past, the "maximum permissible limit" criterion has been regarded especially by the general public, as a magic number, which, even if exceeded by a fraction of a per cent, immediately means that the water concerned is poisonous and quite unfit for drinking. For instance, where the maximum permissible limit for fluoride is 1,5 mg/ℓ, and a given water sample contained 1,6 mg/ℓ fluoride, then such water would have been condemned immediately without further question. This state of affairs was obviously undesirable as the transition from a "safe" concentration to a "poisonous" concentration is a gradual transition and is not a sharp cut-off limit as suggested by the water-quality criteria. In order to foster the awareness of this gradual transition from a "safe" concentration to a "poisonous" concentration, the "crisis limit" was defined as a limit where "extreme action"

TABLE 4
SABS SPECIFICATION FOR WATER FOR DOMESTIC SUPPLIES (SABS, 1984).

Determinand	Unit	Recommended maximum limit	Maximum allowable limit
Colour	mg/ℓ Pt	20	NS
Odour and taste	Shall not be objectionable		
Turbidity	NTU	1	5
pH	pH unit	6-9	5,5-9,5
Conductivity	mS/m	70	300
Macro-determinands	**mg/ℓ**		
Hardness, total	$CaCO_3$	20-300	650
Magnesium	Mg	70	100
Sodium	Na	100	400
Chloride	Cl	250	600
Sulphate	SO_4	200	600
Nitrate and Nitrite	N	6	10
Fluoride	F	1	1,5
Zinc	Zn	1	5
Micro-determinands	**μg/ℓ**		
Arsenic	As	100	300
Cadmium	Cd	10	20
Copper	Cu	500	1 000
Cyanide	CN	200	300
Iron	Fe	100	1 000
Lead	Pb	50	100
Manganese	Mn	50	1 000
Mercury	Hg	5	10
Phenolic compounds	Phenol	5	10
Selenium	Se	20	50
Bacteriological requirements			
Standard plate count	per 1 mℓ	100	NS
Total coliform	per 100 mℓ	0	5
Faecal coliform	per 100 mℓ	0	0
Radio-activity	If present shall be within the limits laid down by the International Commission for Radiological Protection		

NS = Not specified
NTU = Nephelometric turbudity units

should be taken (Kempster and Smith, 1985).

The philosophy behind the creation of the "crisis" limit is to prevent unnecessary panic when a given determinand's concentration exceeds the "maximum permissible limit". As long as the concentration does not exceed the "crisis limit", the parties concerned can take urgent, yet carefully planned and thought-out measures to reduce the troublesome determinand's concentration to below the "maximum permissible limit".

In applying these criteria, the crisis limit should be treated as a tentative guideline only, and not applied rigidly, except in the case of extremely toxic determinands, such as cyanide, where the risk associated with elevated concentrations is high. For the aesthetic determinands of low toxicity, where there is only a slight risk at elevated concentrations, the crisis limit should be used with discretion and may be relaxed where circumstances warrant.

The three-tier system also allows health authorities to approve water of a poorer quality under certain very specific conditions with more ease and confidence, than with other systems which involve fixed maximum concentrations. In a paper by Aucamp (1988) case studies in connection with nitrates, fluorides and manganese, illustrating the three-tier system, are presented.

Limits for the proposed new aesthetic/physical and inorganic (and microbiological) determinands appear in Table 5.

TABLE 5
PROPOSED DRINKING-WATER CRITERIA UNDER CONSIDERATION FOR APPLICATION IN SOUTH AFRICA (KEMPSTER AND SMITH, 1985; AUCAMP AND VIVIER, 1987).

Determinand	Unit	A	B	C
Physical and organoleptical				
Colour	mg/ℓ Pt	20	—	—
Conductivity	mS/m (25°C)	70	300	400
DOC	mg/ℓ C	5	10	20
Dissolved oxygen	% Sat.	70	30	10
Odour	TON	1	5	10
pH	pH unit	6,0-9,0	5,5-9,5	<4,0 or >11,0
Taste	TTN	1	5	10
Temperature	°C	<25	<30	<40
Turbidity	NTU	1	5	10
Microbiological				
Standard plate count	per 1mℓ	<100	1 000	10 000
Total coliform	per 100 mℓ	0	5	100
Faecal coliform	per 100 mℓ	0	1	10
Clostridium perfringens	per 100 mℓ	0	10	100
Coliphages	per 100 mℓ	0	10	100
Enteric viruses	per 10 ℓ	0	1	10
Micro-elements	μg/ℓ			
Antimony	Sb	50	100	200
Arsenic	As	100	300	600
Beryllium	Be	2	5	10
Bismuth	Bi	250	500	1 000
Cadmium	Cd	10	20	40
Chromium	Cr	100	200	400
Cobalt	Co	250	500	1 000
Cyanide	CN	200	300	600
Gold	Au	2	5	10
Lead	Pb	50	100	200
Mercury	Hg	5	10	20
Molybdenum	Mo	50	100	200
Nickel	Ni	250	500	1 000
Selenium	Se	20	50	100
Silver	Ag	20	50	100
Tellurium	Te	2	5	10
Thallium	Tl	5	10	20
Tin	Sn	100	200	400
Titanium	Ti	100	500	1 000
Tungsten	W	100	500	1 000
Vanadium	V	250	500	1 000

A = Recommended limit (maximum limit for no risk)
B = Maximum permissible limit (maximum limit for insignificant risk)
C = Crisis limit (maximum limit for low risk)
TON = Threshold odour number
TTN = Threshold taste number
NTU = Nephelometric turbidity units

TABLE 5 (Continued)
PROPOSED DRINKING-WATER CRITERIA UNDER CONSIDERATION FOR APPLICATION IN SOUTH AFRICA (KEMPSTER AND SMITH, 1985; AUCAMP AND VIVIER, 1987).

Determinand	Unit	A	B	C
Macro-elements	mg/ℓ			
Aluminium	Al	0,15	0,5	1,0
Ammonia	N	1,0	2,0	4,0
Barium	Ba	0,5	1,0	2,0
Boron	B	0,5	2,0	4,0
Bromide	Br	1,0	3,0	6,0
Calcium	Ca	150	200	400
Cerium	Ce	1,0	2,0	4,0
Chloride	Cl	250	600	1 200
Copper	Cu	0,5	1,0	2,0
Fluoride	F	1,0	1,5	3,0
Hardness	$CaCO_3$	20-300	650	1 300
Iodide	I	0,5	1,0	2,0
Iron	Fe	0,1	1,0	2,0
Lithium	Li	2,5	5,0	10,0
Magnesium	Mg	70	100	200
Manganese	Mn	0,05	1,0	2,0
Nitrate	N	6,0	10,0	20,0
Potassium	K	200	400	800
Sodium	Na	100	400	800
Sulphate	SO_4	200	600	1 200
Uranium	U	1	4	8
Zinc	Zn	1	5	10

A = Recommended limit (maximum limit for no risk)
B = Maximum permissible limit (maximum limit for insignificant risk)
C = Crisis limit (maximum limit for low risk)

Microbiological determinands

The microbiological quality of water is receiving on a continuous basis a high priority in South Africa and a well established expertise for the assessment of the microbiological quality has been developed (Grabow, 1986). A variety of microbiological determinands are being addressed in research and monitoring programmes and the establishment of new criteria is being investigated. The limits as specified in the SABS specification are still generally applied as the guideline criteria but the Department of Health is now also considering the adoption of three additional determinands in the three-tier system, viz. for *Clostridium perfringens,* coliphages and enteric viruses (Aucamp and Vivier, 1987)(Table 5).

Organic compounds

The presence of organic compounds in drinking water is also receiving much attention in South Africa and in this regard various research and monitoring programmes are in progress.

There are specific research programmes aiming at the establishment of criteria for organic compounds, for future use in South Africa. The SABS specification only privides for phenolic compounds in this category (SABS, 1984).

Radionuclides

According to the SABS specification "radio-activity, if present, shall be within the limits laid down by the International Commission for Radiological Protection" (SABS, 1984). The radioactivity issue is also receiving attention.

Conclusions

The consumer has little opportunity to exercise choice in relation to the water that he or she drinks and it is, therefore, important that the water should be fit for human consumption and that regulation of environmental contaminants, or at least quality guidelines, exist.

Drinking-water quality criteria or guidelines should not be confused with drinking-water quality standards. Whereas standards represent legally enforceable limits, criteria only serve as guidelines. Most countries use criteria to ensure that an acceptable water quality is maintained but not all have enforceable standards. However, many countries have developed some form of enforceable drinking-water standards and in many of those that have not yet done so, the pressure is mounting to adopt standards ensuring the integrity of public water supplies.

No single set of standards could be applicable to all nations, but there is a remarkable degree of agreement about which contaminants should be regulated and at what levels.

The first priority of water suppliers in all countries is to ensure that drinking water is microbiologically safe. Once this has been accomplished, attention could be given to other contaminants.

The establishment of drinking-water quality criteria or standards can be a very laborious process and once standards are adopted the problems associated with implementing and enfor-

cing them satisfactorily, must be faced. This could also include the adoption of increasingly sophisticated treatment techniques in most of the industrialised nations.

The process of setting standards involves risk assessment and risk management. This is no easy task and risk assessment is often fraught with many uncertainties and management decisions must be made in the light of those uncertainties as well as social demands and economic and technological realities. Numerous assessment methodologies are available to decision makers.

Regardless of all their weaknesses, quantitative extrapolation techniques are at present the only means of attempting to project the consequences (in terms of probabilities) of environmental exposures to potential toxicants.

Current criteria values represent the best estimates which can be made with the present knowledge and toxicological data. Further information on the effects of chemicals, especially carcinogens at low doses, is needed in order to develop a more realistic model. At the same time epidemiological studies need further refinement.

The development of drinking-water quality criteria must be a continuous and dynamic process. The process should anticipate additional health-effects research, better documentation of risk assessment, and available treatment technology.

It should also be kept in mind that in general water constituents represent only a very small proportion of the daily dietary intake of chemicals.

Although South Africa does not have enforceable drinking-water quality standards, well defined criteria/guidelines are used to ensure a high quality of potable water supply. These criteria compare, as far as the microbiological and inorganic/aesthetic determinands are concerned, very favourably with the USEPA, WHO and EEC regulations. However, South Africa's drinking-water quality criteria do not yet provide for organic compounds and detailed radio-active limits. These issues are receiving attention.

A novel approach of a three-tier system for setting maximum levels for no risk, insignificant risk and low risk in South Africa, is currently under consideration. With this system it is endeavoured to be more pragmatic and rather to impose the concept of health risk ranges for the various water-quality variables. It is the explicit aim to ensure health control by applying realistic criteria.

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