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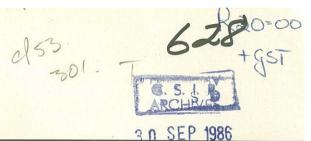NATIONAL INSTITUTE FOR WATER RESEARCH

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SYNOPSIS

Using existing criteria from other countries, in conjunction with data on element toxicities and normal dietary intakes, drinking-water criteria for 56 aesthetic/physical and inorganic chemical determinands are proposed for the Republic of South Africa. Three limits are given, viz. a 'recommended' limit, a 'maximum permissible' limit, and a 'crisis' limit, defined in most cases as twice the maximum permissible limit. The properties of and limits assigned to each determinand are discussed, and suitable sampling and analytical frequencies are suggested. Lists of recommended methods of analysis and sample collection and preservation procedures are also included.

OPSOMMING

Drinkwaterkriteria vir 56 estetiese/fisiese en anorganiese chemiese determinante word vir die Republiek van Suid-Afrika voorgestel deur gebruik te maak van ander lande en bestaande kriteria, tesame met gegewens oor toksisiteit van elemente en normale dieëtopnames. Drie perke word gedefinieër, naamlik, 'n 'aanbevole' perk, 'n 'maksimum toelaatbare' perk, en 'n 'krisisperk': Laasgenoemde word in die meeste gevalle op tweekeer die 'maksimum toelaatbare' perk bereken. Die eienskappe van elke determinant en die perke wat daarvoor vasgestel is, word bespreek en geskikte bemonsterings- en ontledingsfrekwensies voorgestel. Lyste van aanbevole ontledingsmetodes en bemonsterings- en preserveringsprosedures word ook gegee.

ACKNOWLEDGEMENTS

CONTENTS

1. INTRODUCTION

Kempster, Hattingh and van Vliet (1980) have shown that a wide divergence exists in the drinking-water criteria of different countries. Flessinger (1980) believes that drinking-water standards should be the same in all countries. While a measure of uniformity is desirable, however, drinking-water standards should take regional climatic, geochemical and hydrological differences into account. In formulating the criteria which follow for use in South Africa, existing world criteria were used (Kempster *et al.*, 1980) together with the 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). During the preparation of this report, certain determinand criteria were modified slightly so as to be in full agreement with the applicable criteria in the recently revised South African Bureau of Standards (SABS) Specification for Water for Domestic Supplies (SABS, 1984).

Three criteria levels have been suggested for each of 56 determinands, viz. a 'recommended' (working)limit, a 'maximum permissible' limit, and a 'crisis' limit. The nomenclature of this three-tier system in relation to the international nomenclature on water quality criteria is discussed in Appendix 1. The criteria proposed for aesthetic/physical determinands are listed in Table 1, while Table 2 lists the criteria for the other inorganic chemical determinands. Recommended methods of analysis and recommended sampling and sample preservation procedures are given in Appendix 2. Suggested sampling and analytical frequencies are shown in Appendix 3.

Criteria as opposed to standards are not legally binding. These criteria should therefore be seen as guidelines. They are provisional criteria, not yet adopted as official policy.

These criteria were prepared under the auspices of the National Institute for Water Research (NIWR) Steering Committee for 'Health Aspects of Water Supplies'. Separate reports, in which suitable microbiological and organic chemical criteria are proposed, have been prepared by other working groups under the auspices of the same committee.

2. APPLICATION OF THE CRITERIA

The recommended or working limit is the limit which should ideally not be exceeded. The recommended limit has a built-in safety factor, and thus no immediate danger exists where this limit is exceeded, provided the maximum permissible limit is not exceeded.

The maximum permissible limit is still safe, but should not be exceeded. Where the concentration of a particular determinand exceeds the maximum permissible limit, then planning/action to reduce the concentration of this pollutant should be instituted without delay.

In addition, it is suggested that a limit be set on the amount by which the concentration of a determinand may exceed the maximum permissible limit before extreme action need be taken. This crisis limit was originally defined as twice the maximum permissible concentration limit shown in Tables 1 and 2. Thus, for example, the crisis limit for turbidity would be 10 NTU, i.e. twice the maximum permissible limit of 5 NTU. However, this definition of the crisis limit as twice the maximum permissible limit was only used as an initial part of departure, and was changed in several cases as the criteria were updated.

For certain determinands such as dissolved oxygen, pH and temperature, the crisis limit requires different definition. The suggested crisis limits for the latter three determinands are as follows:

(i) A dissolved oxygen of less than 10% of saturation

(ii) A pH value of less than 4,0 or greater than 11,0

(iii) A water temperature of greater than 40 °C.

Note that no crisis limits are defined for colour or free residual chlorine.

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, as well as for 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.

TABLE 1: Limits for determinands having aesthetic/physical implications

Determinand	Unit	Recommended limit	Maximum permissible limit	Crisis limit	Effects other than aesthetic
Colour	mg/ℓ Pt	20	NS	NS	If of industrial origin, may be toxic
Electrical conductivity	mS/m (25 °C)	70	300	400	Influences corrosive potential of water
Odour	TON	1*	5	10	May be indicative of toxic substances
Oxygen, dissolved	% saturation	70% min	30% min	10% min	Influences corrosive potential of water
pH	pH unit	6,0 – 9,0**	5,5 – 9,5**	<4,0 or >11,0	Influences corrosive potential of water
Taste	TTN	1*	5	10	May be indicative of toxic substances
Temperature	°C	25 °C max.	30 °C max.	40 °C max	Influences corrosive potential of water
Turbidity	NTU	1,0	5,0	10,0	Disinfection problems when turbidity high
Chloride	mg/ℓ Cl	250	600	1200	Undesirable in irrigation water
Chlorine, free residual***	mg/ℓ Cl	0,2 – 5,0	<0,2 or >5,0	–	Disinfectant properties of chlorine. For disinfection should not be less than 0,2 mg/ℓ Cl

TABLE 1: (continued)

Determinand	Unit	Recommended limit	Maximum permissible limit	Crisis limit	Effects other than aesthetic
Methylene blue active substances (MBAS)	mg/ℓ LAS	0,5	1,0	2,0	Measures most reducing substances
Sulphate	mg/ℓ SO$_4$	200	600	1200	Cathartic action on new users
Dissolved organic carbon (DOC)	mg/ℓ C	5,0	10,0	20,0	May have toxic implications
Copper	µg/ℓ Cu	500	1000	2000	Essential nutritional element
Hydrogen sulphide	µg/ℓ H$_2$S	100	300	600	Indicative of bacterial activity
Iron	µg/ℓ Fe	100	1000	2000	Can be used as an indicator of proper flocculation/filtration
Manganese	µg/ℓ Mn	50	1000	2000	Essential nutritional element
Phenols	µg/ℓ Phenol	5	10	40	--
Zinc	µg/ℓ Zn	1000	5000	10000	Screen samples with >1000 µg/ℓ Zn for concomitant Cd or Pb

* Taste and odour must be acceptable
** Note that chlorine is not an effective disinfectant at pH values greater than 8,5
*** If chlorine used as disinfectant

NS : Not specified
TON : Threshold Odour Number
TTN : Threshold Taste Number
NTU : Nephelometric Turbidity Units
LAS : Linear alkylate sulphonate

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TABLE 2: Limits for other inorganic determinands

Determinand	Unit	Recommended limit	Maximum permissible limit	Crisis limit	Effects other than aesthetic
Ammonia	mg/ℓ N	1,0	2,0	4,0	Toxic to goldfish
Calcium	mg/ℓ Ca	150	200	400	Essential nutritional element
Fluoride	mg/ℓ F	1,0	1,5	3,0	Related to incidence of caries
Hardness, total	mg/ℓ CaCO$_3$	20 min 300 max	min NS 650 max	min NS 1300 max	Causes scaling of boilers, pipes etc.
Lithium	mg/ℓ Li	2,5	5,0	10,0	More toxic to plants than man
Magnesium	mg/ℓ Mg	70	100	200	May cause diarrhoea in new users
Nitrate	mg/ℓ N	6,0	10,0	20,0	Responsible for infant methaemo-globinaemia
Potassium	mg/ℓ K	200	400	800	Cathartic
Sodium	mg/ℓ Na	100	400	800	Chronic, long-term toxicity
Aluminium	µg/ℓ Al	150	500	1000	Can be used as an indicator of proper flocculation/filtration
Antimony	µg/ℓ Sb	50	100	200	Emetic and cardiotoxin
Arsenic	µg/ℓ As	100	300	600	Nutritionally essential in small quantities. Toxic in excess
Barium	µg/ℓ Ba	500	1000	2000	Low toxicity via oral route
Beryllium	µg/ℓ Be	2	5	10	May be carcinogenic
Bismuth	µg/ℓ Bi	250	500	1000	Neurotoxic

TABLE 2: (continued)

Determinand	Unit	Recommended limit	Maximum permissible limit	Crisis limit	Effects other than aesthetic
Boron	$\mu g/\ell$ B	500	2000	4000	More toxic to plants than man
Bromide	$\mu g/\ell$ Br	1000	3000	6000	–
Cadmium	$\mu g/\ell$ Cd	10	20	40	Accumulative poison. Concomitant of zinc
Cerium	$\mu g/\ell$ Ce	1000	2000	4000	–
Chromium	$\mu g/\ell$ Cr	100	200	400	Nutritionally essential. Absence causes diabetes
Cobalt	$\mu g/\ell$ Co	250	500	1000	Nutritionally essential. Toxic in excess
Cyanide, free	$\mu g/\ell$ CN	200	300	600	Toxicity decreased by chlorination
Gold	$\mu g/\ell$ Au	2	5	10	Only soluble salts toxic
Iodide	$\mu g/\ell$ I	500	1000	2000	Nutritionally essential. Toxic in excess
Lead	$\mu g/\ell$ Pb	50	100	200	More toxic in soft than hard waters
Mercury	$\mu g/\ell$ Hg	5	10	20	Organic complexes neurotoxic
Molybdenum	$\mu g/\ell$ Mo	50	100	200	High toxicity to animals
Nickel	$\mu g/\ell$ Ni	250	500	1000	Nutritionally essential
Selenium	$\mu g/\ell$ Se	20	50	100	Nutritionally essential. Toxic in excess. Protects against mercury toxicity

TABLE 2: (continued)

Determinand	Unit	Recommended limit	Maximum permissible limit	Crisis limit	Effects other than aesthetic
Silver	µg/ℓ Ag	20	50	100	Causes argyria (bluish discoloura-tion of skin)
Tellurium	µg/ℓ Te	2	5	10	Chemically related to selenium
Thallium	µg/ℓ Tl	5	10	20	Metabolic poison
Tin	µg/ℓ Sn	100	200	400	Low toxicity. Nutritionally essen-tial
Titanium	µg/ℓ Ti	100	500	1000	Only soluble salts potentially toxic
Tungsten	µg/ℓ W	100	500	1000	Only soluble salts potentially toxic
Uranium	µg/ℓ U	1000	4000	8000	Causes brownish discolouration of water
Vanadium	µg/ℓ V	250	500	1000	Nutritionally essential

NS = Not specified

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3. DISCUSSION OF PROPERTIES OF AND LIMITS ASSIGNED TO THE DETERMINANDS

The rationale used in formulating individual criteria is discussed briefly below:

(1) Aluminium

The normal total dietary aluminium intake is 20 to 30 mg per day. Most of this aluminium is derived from fruit and vegetables (Underwood, 1977). Soluble aluminium salts may exhibit neurotoxicity (Berman, 1980). The concentration of aluminium in drinking-water can serve as an indicator of the efficacy of the flocculation/filtration process. It is desirable that the dissolved aluminium concentration be kept low, especially where aluminium sulphate is used as a flocculant, because break-through of aluminium into the drinking-water may be associated with impurities in the flocculant such as arsenic. For South Africa it is proposed that the world median criterion of 150 µg/ℓ be adopted for the 'recommended' limit for aluminium (Kempster *et al.* 1980), with the 'maximum permissible' limit set at 500 µg/ℓ .

(2) Ammonia

The primary importance of ammonia, apart from its measurement as a pollution indicator, is its use together with chlorine in water disinfection.

It is difficult to set a criterion for ammonia as its potential toxicity depends very much on pH. Ammonia is toxic to goldfish at a concentration of 2 mg/ℓ (as N). Ammonia may also dissolve copper from piping and appliances (McKee and Wolf, 1963). The suggested criteria for ammonia in drinking-water are a 'recommended' limit of 1 mg/ℓ (as N) and a 'maximum permissible' limit of 2 mg/ℓ (as N).

(3) Antimony

The total dietary antimony intake is between 34 and 1 300 µg per day (Underwood, 1977). Antimony acts as an emetic and cardio-toxin at high concentrations. The acute lethal dose is around 50 mg (McKee and Wolf, 1963). The world median criterion for antimony is 50 µg/ℓ (Kempster *et al.* 1980).

The suggested drinking-water criteria for South Africa are a 'recommended' limit for antimony of 50 µg/ℓ with a 'maximum permissible' limit of 100 µg/ℓ .

(4) Arsenic

Arsenic is an essential nutritional element, toxic in excess. The mean dietary intake for arsenic is 1 000 µg per day, with a normal range of 100 µg to 3 000 µg per day (Underwood, 1977; IAEA, 1980). It is proposed that the 'recommended' limit for South Africa be set at 100 µg/ℓ, a concentration at which no adverse health effects from arsenic have been reported (EPA, 1977). The proposed 'maximum permissible' limit is 300 µg/ℓ arsenic. The world maximum criterion is 500 µg/ℓ (Kempster *et al*, 1980). Adverse effects in sensitive individuals have,

however, been noted at drinking-water concentrations above 300 µg/ℓ (EPA, 1977).

Note that arsenic can be present as a concomitant impurity in flocculants used for water purification, thus the rationale for setting relatively low limits for iron and aluminium. The possibility of heavy metal concomitants should also be kept in mind when criteria are defined for polyelectrolytes.

(5) Barium

The normal dietary intake of barium is 500 µg per day. Barium has a relatively low toxicity via the oral route. The major dietary sources of barium are plants and nuts (Underwood, 1977). Soluble barium salts are more toxic than insoluble salts (Berman, 1980). Little is known of barium metabolism in man apart from the fact that barium is a metabolic antagonist for potassium.

A 'recommended' limit for barium in drinking-water of 500 µg/ℓ with a 'maximum permissible' limit of 1 000 µg/ℓ is proposed for South Africa. The Environmental Protection Agency sets a maximum contaminant level for barium of 1 000 µg/ℓ (EPA, 1977).

(6) Beryllium

The normal total dietary beryllium intake is probably less than 15 µg per day (IAEA, 1980). Beryllium toxicity is characterized by disturbances of the immunological system. Beryllium may be carcinogenic. The world criteria range from 0,2 µg/ℓ to 1 000 µg/ℓ . (Kempster *et al*, 1980). The suggested criteria for South Africa's drinking-water are a 'recommended' limit for beryllium of 2 µg/ℓ and a 'maximum permissible' limit of 5 µg/ℓ .

(7) Bismuth

Total dietary intake is unknown, but is probably less than 5 µg per day (IAEA, 1980). Bismuth can cause both renal and neuro-toxicity (Berman, 1980). The world criteria range from 100 µg/ℓ to 500 µg/ℓ (Kempster *et al*., 1980). The suggested tentative limits for South Africa are a 'recommended' limit for bismuth of 250 µg/ℓ with a 'maximum permissible' limit of 500 µg/ℓ .

(8) Boron

The normal dietary intake of boron is 3 000 µg per day (Underwood, 1977). Like aluminium, the harmlessness/toxicity of boron is greatly dependent on the chemical form in which the element occurs. Certain forms of boron are relatively toxic to man (Berman, 1980). As drinking-water is also used for irrigating plants, which are more sensitive to boron toxicity than humans, it is proposed that criteria suitable for plants be adopted viz., a 'recommended' limit for boron of 500 µg/ℓ and a 'maximum permissible' limit of 2 000 µg/ℓ .

(9) Bromide

The normal dietary intake is 8 to 24 mg per day (Underwood,

1977). The suggested tentative drinking-water limits for bromide are a 'recommended' limit of 1 mg/ℓ and a 'maximum permissible' limit of 3 mg/ℓ . The world criteria range from 0,2 to 3 mg/ℓ for bromide (Kempster *et al*, 1980).

(10) Cadmium

Cadmium is an accumulative heavy metal poison. It may be essential in very small quantities, but causes high blood pressure in excess. The normal total dietary intake is around 70 µg per day (Underwood, 1977). A 'recommended' limit for South African drinking-water of 10 µg/ℓ is proposed with a 'maximum permissible' limit of 20 µg/ℓ . Note that acute cadmium toxicity closely mimics the symptoms of microbial food poisoning (Berman, 1980). Cadmium is a common concomitant of zinc, and any water sample with a zinc concentration in excess of 1 mg/ℓ should be screened for cadmium.

(11) Calcium

The normal total dietary calcium intake (English diet) is 1,4 g per day (IAEA, 1980). There is an inverse correlation between calcium intake and heart disease. Note also that heavy metals are more toxic at low calcium concentrations (soft waters). High calcium concentrations are, however, undesirable as they contribute to scaling in boilers and pipes. For South African drinking-water criteria a 'recommended' limit of 150 mg/ℓ is proposed for calcium, with a 'maximum permissible' limit of 200 mg/ℓ . The world criteria range from 75 to 300 mg/ℓ (Kempster *et al*, 1980).

(12) Cerium

The normal total dietary cerium intake is unknown. Very little is known about the toxicity or metabolism of cerium. The world median criterion for cerium in drinking-water is 2 000 µg/ℓ (Kempster *et al*. 1980). The suggested drinking-water criteria for South Africa are a 'recommended' limit of 1 000 µg/ℓ and a 'maximum permissible' limit for cerium of 2 000 µg/ℓ .

(13) Chloride

A chloride concentration above 250 mg/ℓ imparts a salty taste to water (EPA, 1979). High chloride concentrations promote corrosion. The 'maximum allowable' limit for chloride set by the SABS (1984) is 600 mg/ℓ . A 'recommended' limit for chloride of 250 mg/ℓ is proposed, with a 'maximum permissible' limit of 600 mg/ℓ .

(14) Chlorine, free residual

Chlorine in drinking-water is predominantly present as hypochlorous acid (HOCl) or in the dissociated form as the hypochlorite ion OCl⁻ (Van Leeuwen, undated). Very little of the 'free chlorine' is present as Cl_2 at the pH range of drinking-water. Chlorine gas reacts with water as follows:

$$Cl_2 + H_2O \rightleftharpoons HOCl + HCl$$

Although present as HOCl and HCl, the residual chlorine is

conventionally expressed as mg/ℓ Cl or mg/ℓ Cl_2 (numerically equivalent). The most commonly cited aesthetic drinking-water criterion for free residual chlorine is a chlorine concentration of 0,2 mg/ℓ Cl (Kempster *et al*, 1980). The proposed drinking-water limits for South Africa are a 'recommended' limit for free residual chlorine of 0,2 to 5,0 mg/ℓ Cl and a 'maximum permissible' limit of less than 0,2 or greater than 5,0 mg/ℓ Cl.

(15)   Chromium

Chromium is an essential nutritional element needed for the proper functioning of insulin. The normal total dietary chromium intake varies between 5 and 320 µg per day (Underwood, 1977: IAEA, 1980). In view of the relatively low toxicity of chromium and the probability of chromium deficiencies in Western diets (EPA, 1977; Underwood, 1977) it is difficult to see why the chromium limit is customarily set at 50 µg/ℓ . A 'recommended' limit of 100 µg/ℓ for chromium is proposed for South African drinking-water, with a 'maximum permissible' limit of 200 µg/ℓ .

(16)   Cobalt

Cobalt is an essential nutritional element with low intrinsic toxicity. The normal dietary intake is between 10 µg and 1 800 µg per day. Cobalt can cause cario-toxicity in sensitive individuals (Underwood, 1977).

The suggested drinking-water limits for South Africa are a 'recommended' limit for cobalt of 250 µg/ℓ and a 'maximum permissible' limit of 500 µg/ℓ .

(17)   Colour

Colour in water is generally due to organic compounds (humic acids) together with colloidal iron and/or manganese. Coloured water on chlorination produces more trihalomethanes than water with zero colour (EPA, 1979). A 'recommended' limit of 20 Pt units* for colour is tentatively suggested, with a 'maximum permissible' limit being unspecified. The world median criterion for colour is 15 Pt units* (Kempster *et al*, 1980). Waters with high concentrations of humic acids can have a colour reading in excess of 50 Pt units*. Such naturally coloured waters are not harmful *per se*, unless industrial pollution or pollution from agricultural runoff is present, as humic acids can act as carriers of potentially toxic heavy metals.

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*(Colour Pt units expressed as mg/ℓ Pt)

(18)   Copper

Copper is an essential nutritional element, the normal dietary intake being around 3 mg per day (Underwood, 1977). Copper in water may cause taste/staining problems at concentrations of 1 mg/ℓ . Above 2 mg/ℓ, taste/staining problems become marked (EPA, 1979). A 'recommended' limit for South African drinking-water of 0,5 mg/ℓ and a 'maximum permissible' limit of 1 mg/ℓ copper is proposed.

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(19) Cyanide, free

A cyanide intake of 50 mg or more in a single dose can be fatal.
Less than 10 mg in a single dose is non-injurious (EPA, 1977).
The EPA states, in addition, that on chlorination cyanide is
converted to cyanogen chloride which is an order of magnitude
less toxic than cyanide. A cyanide criterion of 300 µg/ℓ
provides at least a ten-fold safety factor. The suggested
'recommended' limit for drinking water is a cyanide concentra-
tion of 200 µg/ℓ with a 'maximum permissible' limit of 300 µg/ℓ
for prechlorinated water. In chlorinated water cyanogen
chloride should be measured.

(20) Dissolved Organic Carbon (DOC)

Dissolved organic carbon (DOC) can affect the taste of water,
particularly on chlorination. Organic carbon arising from soil
acids (humic acids) is harmless. Organic carbon arising from
industrial or sewage effluents, however, is undesirable. For
South African drinking-water a 'recommended' limit for DOC of
5 mg/ℓ (as C) and a 'maximum permissible' limit of 10 mg/ℓ (as
C) is tentatively suggested.

(21) Electrical conductivity

The use of electrical conductivity (EC) rather than total
dissolved salts (TDS) as a measure of salinity is recommended
because EC is amenable to more rapid and accurate measurement
than TDS. The measurement of EC at 25 °C rather than at 20 °C
is recommended in view of our temperate climate. The approxi-
mate TDS concentration can be calculated from the formula:

$$TDS \ (mg/\ell) = EC \ (mS/m) \times 6,5$$

A 'recommended' limit for EC of 70 mS/m (TDS = 455 mg/ℓ) and a
'maximum permissible' limit of 300 mS/m (TDS = 1 950 mg/ℓ) is
proposed. The EPA recommended limit for TDS is 500 mg/ℓ, which
corresponds to an EC of 77 mS/m (EPA, 1979). The WHO set an
excessive limit for TDS of 1 500 mg/ℓ in 1958 (McKee and Wolf,
1963). The latter corresponds to an EC of 230 mS/m . Note that
the conversion factor for converting from EC to TDS, as given in
the above formula, is approximate, the factor varying from 4,0
to as much as 9,0 depending on the composition of the specific
water.

(22) Fluoride

The normal total dietary fluoride intake is between 0,5 and 3 mg
per day. Tea is a major fluoride contributor to the diet, and
tea drinkers consume in excess of 1 mg fluoride per day from tea
alone. A small amount of fluoride in drinking-water decreases
the incidence of caries. Unfortunately the margin between
beneficial and toxic levels of fluoride is small. The concen-
trations of maximum benefit with maximum safety is said to be
around 1,0 mg/ℓ fluoride (Underwood, 1977). The maximum safe
fluoride concentration decreases with an increase in the annual
mean of the maximum daily air temperature (EPA. 1977). The

proposed 'recommended' limit for South Africa is 1,0 mg/ℓ
fluoride, with a 'maximum permissible' limit of 1,5 mg/ℓ
fluoride.

(23) Gold

The total dietary gold intake is probably less than 7 µg per day
(IAEA, 1980). Soluble gold salts are toxic to many organ
systems (Berman, 1980). The suggested drinking-water limits for
South Africa are a 'recommended' limit of 2 µg/ℓ with a 'maximum
permissible' limit of 5 µg/ℓ .

(24) Hardness, total

Although a total hardness of less than 100 mg/ℓ (as $CaCO_3$) is
desirable to avoid excessive scaling of pipes, a total hardness
of up to 300 mg/ℓ (as $CaCO_3$) is quite acceptable from a health
viewpoint. Note the inverse relationship between total hardness
and the toxic potential of heavy metals. The suggested maximum
value for the 'recommended' limit for total hardness for South
Africa is 300 mg/ℓ (as $CaCO_3$) with a 'maximum permissible' limit
for drinking water of 650 mg/ℓ (as $CaCO_3$). In view of the
desirability of some hardness in water as a protective factor
against heart disease, a minimum limit of 20 mg/ℓ (as $CaCO_3$) is
additionally suggested.

(25) Hydrogen sulphide

Hydrogen sulphide imparts an unpleasant taste/odour to water.
The minimum detectable concentration for unpleasant odour is
50 µg/ℓ . The maximum allowable concentration in the world
criteria is 300 µg/ℓ (Kempster et al., 1980). The EPA (1979)
considers a separate criterion for hydrogen sulphide
unneccessary, provided that the threshold odour number (TON) is
measured. A 'recommended' limit for South Africa of 100 µg/ℓ
for hydrogen sulphide is proposed, with a 'maximum permissible'
limit of 300 µg/ℓ (as H_2S).

(26) Iodide

The normal total dietary iodide intake is 200 µg to 2 000 µg per
day. Intakes greater than 2 000 µg per day or less than 200 µg
per day can result in thyroid disease (Underwood, 1977). The
suggested 'recommended' limit for South Africa for iodide in
drinking-water is 500 µg/ℓ, with a 'maximum permissible' limit
of 1 000 µg/ℓ . Note that both high fluoride intake and high
arsenic intake increases the nutritional requirement for iodide.

(27) Iron

Iron is an essential nutritional nutrient with a recommended
total dietary intake of 10 mg per day (Underwood, 1977). While
iron in high concentration is potentially toxic, especially
towards infants (Berman, 1980), its aesthetic undersirability
manifests well below potentially toxic concentrations. An iron
concentration in water above 300 µg/ℓ is aesthetically undesir-
able, giving rise to discolouration, staining and taste
problems. As dissolved iron is often present in raw waters, and
is in addition used as a flocculant in water purification, the

iron concentration in drinking-water serves as an indicator of the efficacy of the flocculation/filtration process. The ferric salts used as flocculant are never pure, consequently break-through of iron into the drinking-water may be accompanied by the presence of other less desirable metals (e.g. arsenic).

Iron in drinking-water can also arise from corrosion in the distribution system, where the presence of iron may be asso-ciated with e.g., high lead concentrations.

Because of the usefulness of iron as one of the indicators of proper flocculation/filtration, it is proposed that the 'recom-mended' limit for iron be set at a relatively low concentration, viz., 100 µg/ℓ, with a 'maximum permissible' limit of 1 000 µg/ℓ .

(28) Lead

Lead is an accumulative poison, which produces a great variety of symptoms. In view of the recent discovery that the chemi-cally closely related element tin is nutritionally essential (Underwood, 1977), the possibility that lead is beneficial in small quantities remains an open question. The normal total dietary lead intake is around 300 µg per day (Underwood, 1977). Lead is potentially more toxic in soft than in hard waters. The proposed South African drinking-water limits for lead are a 'recommended' limit of 50 µg/ℓ lead, and a 'maximum permissible' limit of 100 µg/ℓ . As lead may accompany zinc, samples with a zinc concentration in excess of 1 mg/ℓ Zn should be screened for lead.

(29) Lithium

The normal total dietary lithium intake is around 0,1 mg per day (IAEA, 1980) but may be as much as 2 mg per day (Underwood, 1977). Lithium is more toxic to plants than to man (Kempster *et al*, 1980). The suggested drinking-water limits for South Africa are a 'recommended' limit of 2,5 mg/ℓ and a 'maximum permis-sible' limit of 5 mg/ℓ .

(30) Magnesium

The normal dietary magnesium intake (English diet) is 250 mg per day (IAEA, 1980). Magnesium imparts an unpleasant taste to water in concentrations exceeding 100 mg/ℓ (McKee and Wolf, 1963). It can also cause diarrhoea in new users. The proposed South African drinking-water limits are a 'recommended' limit of 70 mg/ℓ and a 'maximum permissible' limit of 100 mg/ℓ .

(31) Manganese

Manganese is an essential nutritional element, the normal dietary intake being around 4 000 µg per day (Underwood, 1977). Colour/staining problems can arise when the manganese concentra-tion in water exceeds 50 µg/ℓ (EPA, 1979). Manganese commonly occurs in elevated concentration in raw waters and can thus, like iron, be used as an indicator of purification efficacy. A 'recommended' limit for manganese of 50 µg/ℓ and a 'maximum permissible' limit of 1 000 µg/ℓ is proposed for South African drinking-water.

(32) MBAS (expressed as LAS)

The measurement of MBAS (methylene blue active substances), expressed as linear alkylate sulphonate (LAS), is customarily used as an indicator of the presence of foaming agents (detergents).

The MBAS measurement also includes reducing substances other than detergents. Detergents can impart both undesirable taste and foaming to water at concentrations above 0,5 mg/ℓ (as LAS). As detergents may be associated with other more toxic substances (McKee and Wolf, 1963; EPA, 1979) it is suggested that the 'maximum permissible' limit be set at 1 mg/ℓ (as LAS). A 'recommended' limit of 0,5 mg/ℓ (as LAS) is proposed.

(33) Mercury

The total dietary intake of mercury is as follows:

(a) Diet with no sea foods   =   4 µg per day

(b) Normal diet (some sea foods) =   9 µg per day

(c) Diet rich in sea foods   =   20 µg per day

The total tolerable safe dietary uptake is 40 µg mercury per day, of which not more than 27 µg should be methyl mercury (Underwood, 1977).

The suggested 'recommended' limit for South African drinking-water is a mercury concentration of 5 µg/ℓ with a 'maximum permissible' limit of 10 µg/ℓ .

(34) Molybdenum

The normal total dietary molybdenum intake in man is 130 µg per day (IAEA, 1980). The world median criterion for molybdenum in drinking-water of 500 µg/ℓ assumues a low toxic potential for molybdenum in man. This assumption may not be true in view of the high toxicity of molybdenum to animals and the paucity of data for man (Underwood, 1977). In view of these facts it is suggested that the South African drinking-water 'recommended' limit for molybdenum be set at 50 µg/ℓ with a 'maximum permissible' limit of 100 µg/ℓ .

(35) Nickel

Nickel is an essential nutritional element. The normal total dietary intake is between 300 and 500 µg nickel per day. Nickel is relatively non-toxic as it is poorly absorbed from the gastro-intestinal tract (Underwood, 1977). The suggested drinking-water limits for South Africa are a 'recommended' limit of 250 µg/ℓ and a 'maximum permissible' limit of 500 µg/ℓ .

(36) Nitrate

Nitrate is relatively non-toxic to adults. Concentrations in excess of 100 mg/ℓ (as N) cause mucous membrane irritation in adults. Nitrate is, however, potentially lethal to infants and

fatal methaemoglobinaemia can occur at nitrate concentrations in excess of 10 mg/ℓ nitrate (as N). Even below 10 mg/ℓ nitrate (as N) infant methaemoglobinaemia can still occur, but this is uncommon (EPA, 1977; McKee and Wolf, 1963).

The International Standing Committee on Water Quality and Treatment (1974) concluded that at nitrate levels of less than 10 mg/ℓ (as N) methaemoglobinaemia was uncommon, and that a completely safe level was 6 mg/ℓ (as N). Their findings have subsequently been adopted by the European Economic Community (1980), where a guide level for nitrate in water of 25 mg/ℓ (as NO_3) is specified. This is equivalent to approximately 6 mg/ℓ (as N). This directive has also been adopted by Britain (White, 1983).

The proposed South African drinking-water limits are a 'recommended' limit of 6 mg/ℓ nitrate (as N) and a 'maximum permissible' limit of 10 mg/ℓ (as N).

(37) Odour

Odour is quantified in terms of the threshold odour number (TON) as described in Standard Methods (1980). The world median criterion for TON is 3. At a TON of 3, a water sample must be diluted with twice its volume of odour free water to render the odour just detectable. A TON of 1 is proposed for the 'recommended' limit. A TON of 5 is tentatively suggested for the 'maximum permissible' limit.

(38) Oxygen, dissolved

Dissolved oxygen is usually expressed in units of mg/ℓ (Kempster et al, 1980). As the solubility of oxygen is dependent on both pressure and temperature, however, reporting dissolved oxygen as a percentage of the saturation value is more meaningful. Water with a dissolved oxygen of less than 70% saturation tastes slightly flat, while a dissolved oxygen of less than 30% saturation imparts an unpleasantly flat taste to water. The proposed 'recommended' limit for South African drinking-water is a dissolved oxygen saturation greater than 70%. A saturation greater than 30% is proposed as the 'maximum permissible' limit. Thus the oxygen saturation should not be less than 30%.

(39) pH

Only extremes of pH affect the taste of water undesirably. The acid-base status influences the corrosivity of water as well as the disinfection efficiency of chlorine. Lower pH values favour disinfection but encourage corrosion. Higher pH values make disinfection more difficult but protect against corrosion (McKee and Wolf, 1963). The proposed 'recommended' limit for pH is that the pH be in the range 6,0 to 9,0 pH units. For the 'maximum permissible' limit the pH range 5,5 to 9,5 is suggested. As far as corrosion is concerned, there is no universally applicable index (EPA, 1979). The Langelier Saturation Index is the index most commonly used for estimating the corrosivity of drinking-water.

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(40) Phenols

      Phenols impart unpleasant taste/odour to water, particularly
      after chlorination, as the taste threshold for chlorinated
      phenols is at least an order of magnitude lower than for
      unchlorinated phenols (McKee and Wolf, 1963). The world
      criteria for phenols range from 0,5 to 5 µg/ℓ (Kempster et al,
      1980). The suggested 'recommended' limit for phenols for South
      Africa is 5 µg/ℓ with a 'maximum permissible' limit of 10 µg/ℓ
      (expressed as phenol).*

      ─────────────────────────────────────
      *A relatively high phenol limit is proposed, as unpolluted
       surface water in South Africa often gives phenol readings of
       around 10 µg/ℓ .

(41) Phosphate

      The normal dietary phosphate intake (English diet) is around 2 g
      phosphate per day, expressed as P (IAEA, 1980). Inorganic
      phosphate has a very low toxic potential. Note, however, that
      phosphate can interfere with flocculation processes and also
      stimulates algal growth. Phosphate from agricultural runoff can
      be accompanied by other concomitant fertilizer impurities such
      as arsenic or cadmium. As far as inorganic phosphate itself is
      concerned, however, there is no toxicological reason for
      defining a drinking-water limit. McKee and Wolf (1963) state
      that 450 g sodium orthophosphate can be ingested by man without
      danger. Note that while phosphate is non-toxic, elemental free
      yellow phosphorus is extremely toxic.

(42) Potassium

      The normal dietary potassium intake (English diet) is 2 800 mg
      per day (IAEA, 1980). Potassium gives water an unpleasant taste
      at concentrations above 340 mg/ℓ . Potassium salts are also
      cathartic (McKee and Wolf, 1963). The suggested drinking-water
      limits for South Africa are a 'recommended' limit of 200 mg/ℓ
      and a 'maximum permissible' limit for potassium of 400 mg/ℓ .

(43) Rubidium

      The normal dietary intake of rubidium is between 2 and 5 mg per
      day. The world criteria define a median limit for rubidium of
      5 mg/ℓ for drinking-water and 2 mg/ℓ for protection of aquatic
      life (Kempster et al, 1980). Very little is known of the
      metabolic effects of rubidium. It is apparently practically
      non-toxic to man (Underwood, 1977). In view of the sparse
      information on this element a realistic limit cannot be defined.

(44) Selenium

      Selenium is an essential nutritional element, being an integral
      part of the enzyme glutathione peroxidase. Selenium protects
      against mercury toxicity and there is strong evidence that it is
      an anti-carcinogen (Underwood, 1977). Selenium is, however,
      toxic in excess. The normal total dietary selenium intake is
      100 to 200 µg per day. High sulphate intake increases the
      selenium requirement. The proposed drinking-water limits for

                                                                    17

selenium are a 'recommended' limit of 20 µg/ℓ and a 'maximum permissible' limit of 50 µg/ℓ .

(45) Silica

The total dietary silica intake (English diet) is estimated at 1 g (as Si) per day (IAEA, 1980). Silica in solution is for all practical purposes non-toxic to man (Underwood, 1977). This is in marked contrast to silica breathed in via the air. The primary objection to silica in water is in boiler feed water used for steam generation. No limit needs to be set for drinking-water as far as the health effects are concerned.

(46) Silver

The normal total dietary silver intake is 27 µg per day (IAEA, 1980). The EPA (1977) set a maximum allowable silver concentration in drinking-water at 50 µg/ℓ, which is a safe concentration if argyria (bluish discolouration of the skin) is to be avoided. The suggested drinking water limits for South Africa are a 'recommended' limit of 20 µg/ℓ silver and a 'maximum permissible' limit of 50 µg/ℓ silver.

(47) Sodium

Sodium is predominantly ingested by man as sodium chloride (table salt). The total daily sodium chloride intake by man varies from 0,5 g/day to as much as 30 g/day. Many studies have been conducted on the long-term toxicity of sodium in recent years, and it is now widely recognized that elevated sodium intake leads to serious health disturbances, one of which is high blood pressure. The nutritional requirement for sodium is around 0,5 g/day (Battarbee and Meneely, 1978). A drinking-water sodium concentration of 100 mg/ℓ would supply 20% of the nutritional requirement of sodium for a 1 litre/day intake. In hot climates, where a 2 litre/day intake is common, 40% of the sodium requirement would be supplied by water at this concentration. The suggested sodium limits for South African drinking-water are a 'recommended' limit of 100 mg/ℓ and a 'maximum permissible' limit of 400 mg/ℓ . The taste threshold for sodium in drinking-water is 290 mg/ℓ for the bicarbonate salt and 135 mg/ℓ for the chloride salt. Note, however, that the primary reason for defining a recommended sodium limit of 100 mg/ℓ is based on health implications and not on any taste effects.

(48) Strontium

The normal dietary strontium intake is 1 to 5 mg per day (Underwood, 1977). Strontium has a low level of toxicity comparable to calcium (McKee and Wolf, 1963). As high strontium intakes tend to inhibit absorption of toxic radio-strontium 90 from nuclear fall-out, high natural-strontium levels in water are desirable. For this reason it is suggested that no contaminant level for natural strontium be defined for drinking-water.

(49) Sulphate

Above a sulphate concentration of 250 mg/ℓ adverse taste effects are likely to occur (EPA, 1979). In addition, elevated sulphate

concentrations have a laxative effect on new users. A sulphate concentration above 600 mg/ℓ has a laxative effect on the majority of users. In addition to its aesthetic undesirability, sulphate concentrations above 250 mg/ℓ enhance the corrosivity of water, especially towards cement-concrete or asbestos-cement pipes.

Sulphate has traditionally been regarded as non-toxic by the bodies responsible for laying down water quality criteria. There is some doubt, however, as to the validity of this assumption, as animal data show that sulphate can be deleterious and may lead to deficiencies of essential trace elements such as copper and selenium, with consequent health effects in the long-term (Bird, 1978).

The normal total dietary sulphur intake is around 3 g/day (as sulphate) for the average English diet (IAEA, 1980). For the proposed South African drinking-water criteria, a 'recommended' limit for sulphate of 200 mg/ℓ and a 'maximum permissible' limit of 600 mg/ℓ is suggested. With these limits water would supply 10% and 30% respectively of the normal total dietary intake for a water consumption of 1,5 litre/day. The range of international criteria for sulphate is from 100 mg/ℓ to 500 mg/ℓ with a median of 250 mg/ℓ . The median value is, however, based on the international criteria over the past two decades, with the present trend being towards lower values (Kempster *et al*, 1980).

(50) Taste

It is generally stated that the taste of water should be 'pleasant'. For objectionable tastes, a threshold taste number (TTN) can be defined in an analagous way to the threshold odour number (Standard Methods, 1980) as follows:

The threshold taste number (TTN) = the ratio by which the sample must be diluted with 'taste-free' water for the objectionable taste of the sample to be just detectable. By 'taste-free' water is meant water without the objectionable taste in question. Where A = mℓ sample and B = mℓ taste-free water, then:

$$TTN = (A + B)/A$$

The suggested criteria for taste are a 'recommended' TTN of 1 and a 'maximum permissible' limit (tentative) for TTN of 10.

(51) Tellurium

The normal dietary intake of tellurium is unknown. However, the normal tellurium concentration in blood is less than 1 µg/ℓ (IAEA, 1980). The world median criterion for tellurium in drinking-water is 10 µg/ℓ (Kempster, *et al*, 1980). The suggested drinking-water limits for South Africa are a 'recommended' limit of 2 µg/ℓ and a 'maximum permissible' limit of 5 µg/ℓ . A lower limit than the world median criterion is suggested in view of the uncertainty as to the safe limit for tellurium.

(52) <u>Temperature</u>

Temperature is primarily an aesthetic criterion for drinking-water, although it does affect the corrosivity, growth of micro-organisms, and the rate of chlorine disinfection of water (McKee and Wolf, 1963). The ideal temperature for drinking-water is 10 °C, although the most commonly cited criterion is 25 °C (Kempster *et al*, 1980). The proposed 'recommended' limit for South African drinking-water is a temperature of 25 °C (maximum) with a 'maximum permissible' limit of 30 °C (maximum).

(53) <u>Thallium</u>

The normal dietary thallium intake (English diet) is less than 2 µg per day (IAEA, 1980). Thallium is a neurotoxin which interferes with potassium metabolism (Berman, 1980). Alopecia is a late symptom of thallium toxicity. The suggested drinking-water limits for South Africa for thallium are a 'recommended' limit of 5 µg/ℓ and a 'maximum permissible' limit of 10 µg/ℓ . The world median criterion is 5 µg/ℓ (Kempster *et al*, 1980).

(54) <u>Tin</u>

The total dietary tin intake ranges from 190 µg per day to 17 000 per day (Underwood, 1977). While inorganic tin is relatively non-toxic, some organic complexes of tin are highly toxic (Berman, 1980). The world median criterion for tin is 50 µg/ℓ (Kempster *et al*, 1980). The suggested drinking-water limits for South Africa are a 'recommended' limit of 100 µg/ℓ and a 'maximum permissible' limit of 200 µg/ℓ .

(55) <u>Titanium</u>

The total dietary titanium intake is around 1 mg per day (IAEA, 1980). Toxicology is unknown. Titanium is not normally present in water. Titanium may serve as an indicator of industrial pollution. The world median criterion for titanium in drinking-water is 100 µg/ℓ (Kempster *et al*. 1980). The suggested drinking-water limits for South African are a 'recommended' limit of 100 µg/ℓ and a 'maximum permissible' limit of 200 µg/ℓ .

(56) <u>Tungsten</u>

The daily dietary tungsten intake is unknown. The health effects are also largely unknown. It is suggested that the world median and maximum drinking-water critera for tungsten of 100 µg/ℓ and 500 µg/ℓ respectively be adopted for the South African 'recommended' and 'maximum permissible' limits (Kempster *et al*, 1980).

(57) <u>Turbidity</u>

Although turbidity affects the aesthetic quality of water, its primary importance is in relation to water disinfection. In the absence of particulate matter (zero turbidity) disinfection is

readily achieved with a minimal chlorine dose. The amount of chlorine required for disinfection increases as the turbidity increases (EPA, 1979). The benefits of zero turibidity are many:

(a)   Minimum quantity of chlorine needed for disinfection. Thus minimal formation of chloro-carbons and taste/odour problems are less likely to occur.

(b)   Even without adding chlorine, the bacterial count in zero turibidity water is low. Zero turbidity is thus an extra safeguard against water-borne bacterial diseases.

(c)   The chance of having potentially carcinogenic asbestos fibres in water with zero turbidity is low. Asbestos measurements are difficult and costly to carry out, whereas turbidity is easily measured.

(d)   The heavy metal load of water is reduced when particulates are completely removed.

Because of the many advantages of low turbidity, and the ease with which continuous turbidity measurement can be made, it can serve as a monitoring determinand for potential water quality problems.

For the above reasons the turbidity standard should be made stringent. A recommended limit for turbidity of 1 NTU and a 'maximumum permissible' limit of 5 NTU is proposed for South African drinking-water. These limits are in agreement with those of the EPA (1977).

(58)   Uranium

The total dietary intake is uncertain. Uranium has a relatively low toxicity in water and drinking-water limits are based on the brownish discolouration uranium imparts to water rather than any radiological hazard. The median and maximum world criteria for uranium are set at 600 and 4 400 $\mu g/\ell$ uranium respectively (Kempster et al, 1980). The figure of 4 400 $\mu g/\ell$ U corresponds to 5 000 $\mu g/\ell$ expressed as UO_2. The suggested drinking-water limits for South Africa are a 'recommended' limit of 1 000 $\mu g/\ell$ U and a 'maximum permissible' limit of 4 000 $\mu g/\ell$ U.

(59)   Vanadium

The normal dietary vanadium intake is between 1 000 and 4 000 $\mu g/\ell$ per day. Vanadium has a relatively low toxicity to man (Underwood, 1977). The median world criterion for vanadium in drinking-water is 100 $\mu g/\ell$ with a maximum criterion of 1 000 $\mu g/\ell$ (Kempster et al, 1980).

Vanadium lowers blood cholesterol and is suspected as being a nutritionally essential element. Vanadium is also reported to have an anti-caries effect (McKee and Wolf, 1963). The suggested drinking-water limits for South Africa are a 'recommended' limit for vanadium of 250 $\mu g/\ell$ and a 'maximum permissible' limit of 500 $\mu g/\ell$.

(60) <u>Zinc</u>

Zinc imparts an astringent taste to water at concentrations exceeding 5 mg/ℓ (McKee and Wolf, 1963). Zinc itself is an essential nutrient, the normal total dietary intake being around 15 mg per day (Underwood, 1977; IAEA, 1980). Zinc in water may, however, be accompanied by potentially toxic lead or cadmium, particularly where the source of the zinc is from corrosion of galvanizing or from industrial pollution. In view of the danger of the concomitance of lead or cadmium, the 'maximum permissible' limit for zinc should be set at 5 mg/ℓ . A 'recommended' limit for zinc of 1 mg/ℓ is proposed. Note that samples containing more than 1 mg/ℓ zinc should be screened for lead and cadmium.

4.   <u>CONCLUSIONS AND RECOMMENDATIONS</u>

In applying drinking-water criteria, discretion should be exercised both as regards analytical frequency and the range of determinands routinely measured. The nature and type of industrial and agricultural pollution in the catchment of each sewage treatment works should be known, as this can facilitate the identification of significant pollutants requiring routine analysis. In addition, the type of treatment chemicals/flocculants being used should also be considered when deciding on which determinands should be selected for routine analysis. Thus, for example, if ferric chloride is one of the treatment chemicals used, iron should be determined in the final water. If aluminium sulphate is used, the aluminium should be determined.

In conclusion, the importance of routinely taking note of the three aesthetic determinands colour, odour and taste, should be emphasized. Objectionable colours, odours or tastes may be the first pointers to potential treatment problems.

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NOMENCLATURE OF THE LIMITS FOR THE AESTHETIC/PHYSICAL
AND INORGANIC DRINKING-WATER CRITERIA

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INTRODUCTION

The primary water quality limit is the so-called 'recommended limit' ('aanbevole grens'). This is the limit which 'should ideally not be exceeded' (Kempster and Smith, 1982). This is the goal, or ideal, which should be aimed at and is the fundamental water quality criterion. Other names used elsewhere for this limit are the 'streefwaarde' (Netherlands) and the 'objective' (Canada) – see Hattingh (1983).

As the recommended limit is almost always exceeded in practice, however, by one or more determinands in a given water sample, it is necessary to define less stringent limits.

The secondary or less stringent criterion has been given a large variety of names, of which the best known is the 'maximum permissible level' as used, for instance, in the World Health Organization's International Standards of 1971 and thereafter (Hattingh, 1983).

This report summarizes the decisions with regard to the naming of the limits reached at the 8 February 1983 meeting of the Water Quality Criteria Sub-Committee of the NIWR Steering Committee for 'Health Aspects of Water Supplies.'

EQUIVALENT TERMINOLOGY

The terminology equivalent to the original names given to the criteria limits for the preliminary South African drinking-water criteria (Kempster and Smith, 1982) are given in Table 1. This table was compiled with the help of the note on nomenclature prepared by Hattingh (1983) for the sub-committee meeting of 8 February 1983.

TABLE 1:   Equivalent terminology

Kempster and Smith (1982)	Other nomenclature (Hattingh, 1983)
'Recommended limit'	- 'Aanbevole grens' (SABS, 1971) - 'Streefwaarde' (Netherlands, 1975) - 'Guide level' (EEC, 1975) - 'Objective' (Canada, 1979) - 'Suggested No Adverse Response Level, SNARL' (EPA, 1982)
'Risk limit'	- 'Maximum permissible level' (WHO, 1971) - 'Highest desirable level' (WHO, 1971) - 'Maximum allowable limit' (SABS, 1971) - 'Maksimum toelaatbare grens' (SABS, 1971) - 'Maximum concentration limit' (Zimbabwe, 1971) - 'Maximum admissible concentration' (EEC, 1975) - 'Maximum contaminant level' (EPA, 1977) - 'Maximum acceptable limit' (Canada, 1979)
'Crisis limit'	(There is no equivalent nomenclature – see text)

The secondary, or less stringent limit (risk limit) has been given many names by the various authorities (Table 1). The secondary limit

has been generally known in South Africa as the 'maximum allowable limit' ('maksimum toelaatbare grens'), as the latter terminology has been used in SABS specification 241 (SABS 1971) for many years. The sub-committee originally decided to call the secondary limit the 'risk' limit rather than the 'maximum allowable' limit due to the implications of the word 'allowable'. The latter (and similar) terms are so entrenched, however, that the sub-committee decided on 8 February 1983 to use the term 'maximum permissible limit' as the confusion in the naming of the secondary limit is already somewhat great. The sub-committee decided that it was best not to add to the plethora of names.

During the formulation of the preliminary inorganic water quality criteria for drinking-water, an early decision of the sub-committee was that a tertiary limit should also be defined. The tertiary limit, originally named the 'crisis limit' was defined as (Kempster and Smith, 1981): 'that limit where extreme action must be taken' - the crisis limit thus represents the level at which serious health effects may occur if the water concerned is consumed for any length of time. As the term 'extreme action' is contained in the definition of the crisis limit, the term 'action limit' has been suggested for this tertiary limit.

Note that the definition of a tertiary limit represents a new departure in water quality criteria. There is consequently no equivalent terminology in the overseas 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, 1982). The appropriate 'crisis level' for each determinand will, however, largely be determined by the toxicological characteristics of the individual determinand. Thus, the definition of the 'crisis limit' value as 'twice the risk limit' must be regarded as an interim definition.

As there is no equivalent in the overseas criteria for the 'crisis limit', the sub-committee decided to keep to the nomenclature 'crisis limit' until a more suitable alternative is proposed.

RECOMMENDATION OF SUB-COMMITTEE

The recommendation of the sub-committee on 8 February 1983 was that the term 'risk limit' be replaced by the older term 'maximum permissible limit'. The term 'recommended limit' shall remain unchanged. The term 'crisis limit' will be kept until a more suitable term is proposed. The recommended names, together with the original names (Kempster and Smith, 1982) are summarized in Table 2.

TABLE 2: Change in nomenclature of South African drinking-water criteria as agreed upon at NIWR sub-committee meeting of 8 February 1983

Former term	Nomenclature agreed upon	
	English	Afrikaans
Recommended limit	recommended limit	aanbevole grens
Risk limit	maximum permissible limit	maksimum toelaatbare grens
Crisis limit	crisis limit	krisis grens

PHILOSOPHY OF THE 'CRISIS LIMIT'

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 percent, 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 contains 1,6 mg/ℓ fluoride, then such water has immediately been condemned without further question. This state of affairs is 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 sub-committee originally proposed the definition of the 'crisis-limit' as a limit where 'extreme action' should be taken.

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'.

At the sub-committee meeting held on 8 February 1983, there was a tentative suggestion that the 'crisis limit' should be called the 'action limit'. As it was rightly pointed out, the 'action' should already start at the 'risk' or 'maximum permissible' concentration limit. The original definition of the 'crisis' limit was the limit of 'extreme action' (e.g. turn off the taps).

CONCLUSIONS

1. The nomenclature of the primary limit viz., 'recommended limit' ('aanbevole grens') remains unchanged.

2. The nomenclature of the secondary limit, i.e., 'risk limit', is changed to 'maximum permissible limit' ('maksimum toelaatbare grens').

3. The nomenclature of the tertiary limit, viz., 'crisis limit' (or limit of extreme action) will remain unchanged until a more suitable term is proposed. The Afrikaans equivalent is 'krisis grens'.

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RECOMMENDED METHODS OF ANALYSIS AND

RECOMMENDED SAMPLING AND SAMPLE PRESERVATION

PROCEDURES

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PRETORIA
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TABLE 1: Recommended methods of analysis

Determinand	Unit	Method	APHA (1980)	EPA (1979)
Colour	mg/ℓ Pt	Visual comparison – (Platinum-cobalt standards)	204A	110,2
Electrical conductivity	mS/m (25 °C)	Wheatstone bridge conductimetry	205	120,1
Odour	TON	Threshold odour test	207	140,1
Oxygen, dissolved	% saturation at 760 mm	Iodometric (azide modification) Membrane electrode	421B 421F	360,2 360,1
pH	pH units	Electrode	423	150,1
Taste	TTN	Threshold taste test	211A	–
Temperature	°C	Mercury-filled Celsius thermometer	212	170,1
Turbidity	NTU	Nephelometric (formazin standard)	214A	180,1
Chloride	mg/ℓ Cl	Titrimetric (silver nitratre) Titrimetric (mercuric nitrate) Potentiometric (silver nitrate) Colorimetric, automated (ferricyanide)	407A 407B 407C 407D	- 325,3 - 325,1
Chlorine, free residual	mg/ℓ Cl	Iodometric Amperometric Titrimetric (DPD–FAS) Colorimetric (DPD)	408A,B 408C 408D 408E	330,2 330,1 330,4 330,5
Methylene blue active substances	mg/ℓ LAS	Colorimetric (methylene blue)	512A	425,1
Sulphate	mg/ℓ SO$_4$	Gravimetric (barium chloride) Turbidimetric (barium chloride) Colorimetric, automated (methylthymol blue) Colorimetric, automated (chloranilate)	426A 426C 426D –	375,3 375,4 375,2 375,1

TABLE 1: (continued)

Determinand	Unit	Method	Method ref. no. APHA (1980)	Method ref. no. EPA (1979)
Dissolved organic carbon	mg/ℓ C	Combustion/oxidation – infra-red/flame ionization	512A	425,1
Copper	µg/ℓ Cu	Atomic absorption (direct flame)	303A	202,1
		Atomic absorption (chelation/solvent extraction)	303B	–
		Atomic absorption (furnace)	–	220,2
		Colorimetric (neocuprine)	313B	–
		Colorimetric (bathocuprine)	313C	–
Hydrogen sulphide	µg/ℓ H_2S	Colorimetric (methylene blue)	427C	376,2
		Titrimetric (iodine)	427D	376,1
Iron	µg/ℓ Fe	Atomic absorption (direct flame)	303A	236,1
		Atomic absorption (chelation/solvent extraction)	303B	–
		Atomic absorption (furnace)	–	236,2
		Colorimetric (phenanthroline)	315B	–
Manganese	µg/ℓ Mn	Atomic absorption (direct flame)	303A	243,1
		Atomic absorption (chelation/solvent extraction)	303B	–
		Atomic absorption (furnace)	–	243,2
		Colorimetric (phenanthroline)	319B	–
Phenols	µg/ℓ Phenol	Distillation, followed by:		
		Colorimetric (4–AAP, with chloroform extraction)	510B	420,1
		Colorimetric, automated (4–AAP)	–	420,2
		Colorimetric, (MBTH, with chloroform extraction)	–	420,3
Zinc	µg/ℓ Zn	Atomic absorption (direct flame)	303A	289,1
		Atomic absorption (chelation/solvent extraction)	303B	–
		Atomic absorption (furnace)	–	289,2
		Colorimetric (dithizone)	328B,C	–
		Colorimetric (zincon)	328D	–

TABLE 1: (continued)

Determinand	Unit	Method	Method ref. no. APHA (1980)	Method ref. no. EPA (1979)
Ammonia	mg/ℓ N	Nesslerization	417B	–
		Colorimetric (phenate)	417C	–
		Colorimetric, automated (phenate)	417F	350,1
		Electrode	417E	350,3
Calcium	mg/ℓ Ca	Atomic absorption (direct flame)	303A	215,1
		Titrimetric (EDTA)	311C	215,2
Fluoride	mg/ℓ F	Electrode	413B	340,2
		Distillation, followed by:		
		Colorimetric (SPADNS)	413C	340,1
		Colorimetric, automated (complexone)	413E	340,3
Hardness, total	mg/ℓ CaCO$_3$	Calculation	314A	–
		Titrimetric (EDTA)	314B	130,2
		Colorimetric, automated (EDTA)	–	130,1
Lithium	mg/ℓ Li	Atomic absorption (direct flame)	303A	–
		Flame photometric	317B	–
Magnesium	mg/ℓ Mg	Atomic absorption (direct flame)	303A	242,1
		Calculation	318C	–
Nitrate	mg/ℓ N	Cadmium reduction; colorimetric (diazotization)	418C	353,3
		Colorimetric (chromotropic acid)	418D	–
		Colorimetric (brucine)	–	352,1
		Devarda's alloy reduction	418E	–
		Colorimetric, automated cadmium reduction (diazotization)	418F	353,2
		Colorimetric, automated, hydrazine reduction (diazotization)	–	353,1
Potassium	mg/ℓ K	Atomic absorption (direct flame)	303A	258,1
		Flame photometric	322B	–

TABLE 1: (continued)

Determinand	Unit	Method	APHA (1980)	EPA (1979)
Sodium	mg/ℓ Na	Atomic absorption (direct flame)	303A	273,1
		Flame photometric	325B	–
Aluminium	µg/ℓ Al	Atomic absorption (direct flame)	303C	202,1
		Atomic absorption (chelation/solvent extraction)	303D	–
		Atomic absorption (furnace)	–	202,2
		Colorimetric (Eriochrome cyanine R)	306B	–
Antimony	µg/ℓ Sb	Atomic absorption (direct flame)	303A	204,1
		Flame photometric	–	204,2
Arsenic	µg/ℓ As	Atomic absorption (hydride generation)	303E	206,3
		Atomic absorption (furnace)	–	206,2
		Colorimetric (SDDC)	307B	206,4
Barium	µg/ℓ Ba	Atomic absorption (direct flame)	303C	208,1
		Atomic absorption (furnace)	–	208,2
Beryllium	µg/ℓ Be	Atomic absorption (direct flame)	303C	210,1
		Atomic absorption (chelation/solvent extraction)	303D	–
		Atomic absorption (furnace)	–	210,2
		Colorimetric (aluminon)	309B	–
Bismuth	µg/ℓ Bi	Atomic absorption (direct flame)	303A	–
Boron	µg/ℓ B	Colorimetric (curcumin)	404A	212,3
		Colorimetric (carmine)	404B	–
Bromide	µg/ℓ Br	Titrimetric (PAO or sodium thiosulphate)	–	320,1
		Colorimetric (phenol red)	405	–

TABLE 1: (continued)

Determinand	Unit	Method	Method ref. no. APHA (1980)	Method ref. no. EPA (1979)
Cadmium	µg/ℓ Cd	Atomic absorption (direct flame)	303A	213,1
		Atomic absorption (chelation/solvent extraction)	303B	-
		Atomic absorption (furnace)	-	213,2
		Colorimetric (dithizone)	310B	-
Cerium	µg/ℓ Ce	*	-	-
Chromium	µg/ℓ Cr	Atomic absorption (direct flame)	303A	218,1
		Atomic absorption (chelation/solvent extraction)	303B	218,3
		Atomic absorption (furnace)	-	218,2
		Colorimetric (diphenyl carbazide)	312B	-
Cobalt	µg/ℓ Co	Atomic absorption (direct flame)	303A	219,1
		Atomic absorption (chelation/solvent extraction)	303B	-
		Atomic absorption (furnace)	-	219,2
Cyanide, free	µg/ℓ CN	Colorimetric (chloramine T)	412D	335,2
		Electrode	412E	-
		Colorimetric, automated (chloramine T)	-	335,3
Gold	µg/ℓ Au	Atomic absorption (direct flame)	303A	231,1
		Atomic absorption (furnace)	-	231,2
Iodide	µg/ℓ I	Colorimetric (leuco crystal violet)	414A	-
		Catalytic reduction; colorimetric (potassium thiocyanate)	414B	-
		Titrimetric (PAB or sodium thiosulphate)	-	345,1
Lead	µg/ℓ Pb	Atomic absorption (direct flame)	303A	239,1
		Atomic absorption (chelation/solvent extraction)	303B	-
		Atomic absorption (furnace)	-	239,2
		Colorimetric (dithizone)	316B	-

TABLE 1: (continued)

Determinand	Unit	Method	APHA (1980)	EPA (1979)
Mercury	µg/ℓ Hg	Atomic absorption (cold vapour)	303F	245,1
		Colorimetric (dithizone)	320B	–
Molybdenum	µg/ℓ Mo	Atomic absorption (direct flame)	303C	246,1
		Atomic absorption (furnace)	–	246,2
Nickel	µg/ℓ Ni	Atomic absorption (direct flame)	303A	249,1
		Atomic absorption (chelation/solvent extraction)	303B	–
		Atomic absorption (furnace)	–	249,2
		Colorimetric (heptoxime)	321B	–
Selenium	µg/ℓ Se	Atomic absorption (hydride generation)	303E	270,3
		Atomic absorption (furnace)	–	270,2
		Colorimetric (diaminobenzidine)	323B	–
Silver	µg/ℓ Ag	Atomic absorption (direct flame)	303A	272,1
		Atomic absorption (chelation/solvent extraction)	303B	–
		Atomic absorption (furnace)	–	272,2
		Colorimetric (dithizone)	324B	–
Tellurium	µg/ℓ Te	*	–	–
Thallium	µg/ℓ Tl	Atomic absorption (direct flame)	303A	279,1
		Atomic absorption (furnace)	–	279,2
Tin	µg/ℓ Sn	Atomic absorption (direct flame)	303A	282,1
		Atomic absorption (furnace)	–	282,2
Titanium	µg/ℓ Ti	Atomic absorption (direct flame)	303C	283,1
		Atomic absorption (furnace)	–	283,2
Tungsten	µg/ℓ W	*	–	–

TABLE 1: (continued)

Determinand	Unit	Method	Method ref. no. APHA (1980)	EPA (1979)
Uranium	µg/ℓ U	Fluorometric	**	-
Vanadium	µg/ℓ V	Atomic absorption (direct flame)	303C	286,1
		Atomic absorption (furnace)	-	286,2
		Colorimetric (gallic acid)	327B	-

APHA (1980) : Standard Methods for the Examination of Water and Wastewater, 15th Edition, APHA, Washington D.C., 1980
EPA (1979) : Methods for Chemical Analysis of Water and Wastes, EPA, Cincinnati, Ohio, 1979
* : No recognized standard methods
** : Selected analytical methods approved and cited by the U.S. EPA, p. S.36. Supplement to 'Standard Methods, 1981

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TABLE 2: Recommended sampling and sample preservation procedures

Determinand	Minimum Volume required (ml)	Container	Preservation	Holding time
Colour	50	P,G	Cool, 4 °C	24 h
Elect. cond.	100	P,G	Cool, 4 °C	24 h
Odour	200	G	Cool, 4 °C	24 h
Oxygen, dissolved	300	G	Electrode – determine on site Iodometric – fix on site	None 4 – 8 h
pH	25	P,G	Determine on site	6 h
Taste	200	G	Cool, 4 °C	24 h
Temperature	1000	P,G	Determine on site	None
Turbidity	100	P,G	Cool, 4 °C	7 days
Chloride	50	P,G	None	7 days
Chlorine, free residual	200	P,G	Determine on site	None
MBAS	250	P,G	Cool, 4 °C	24 h
Sulphate	50	P,G	Cool, 4 °C	7 days
DOC	25	G	Cool, 4 °C; H_2SO_4 or HCl to pH <2	24 h
Sulphide	500	P,G	4 ml 2N zinc acetate solution/ℓ	24 h
Phenols	500	G	Cool, 4 °C; H_3PO_4 to pH <4, 1 g $CuSO_4/\ell$	24 h

TABLE 2: (continued)

Determinand	Minimum Volume required (mℓ)	Container	Preservation	Holding time
Ammonia	400	P,G	Cool, 4 °C; H₂SO₄ to pH <2	24 h
Fluoride	300	P,G	None	7 days
Hardness, total	100	P,G	Cool, 4 °C, HNO₃ to pH <2	6 months
Nitrate	100	P,G	Cool, 4 °C	24 h
Bromide	100	P,G	Cool, 4 °C	24 h
Cyanide	500	P,G	Cool, 4 °C: NaOH to pH 12	24 h
Iodide	100	P,G	Cool, 4 °C	24 h
Mercury	100	G	2 mℓ 20% (W/V) potassium dichromate solution (prepared in 1:1 HNO₃)/ℓ	38 days
All other metals	100	P,G	HNO₃ to pH <2	6 months

P = plastic, polyethylene or equivalent. G = glass.

References: (1)   Standard Methods for Examination of Water and Wastewater, 15th Edition, APHA, Washington, D.C. (1980)

(2)   Methods for Chemical Analysis of Water and Wastes, EPA, Cincinnati, Ohio (1979)

SUGGESTED SAMPLING AND ANALYTICAL

FREQUENCIES FOR DRINKING-WATER

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INTRODUCTION

The desired analytical frequency for a substance in drinking-water is primarily governed by a determinand's concentration <u>relative</u> to the recommended and maximum permissible drinking-water limits. Thus where a given determinand's concentrations is consistently less than the recommended limit, a low analytical frequency is sufficient. If on the other hand, the concentration exceeds the maximum permissible limit, a high frequency of analysis is desirable.

The purpose of measuring water quality in relation to its health aspects differs fundamentally from the measurement of water quality in relation to modelling studies. In the latter type of study, high analytical frequencies are generally needed irrespective of the magnitude of the measured concentration. For drinking-water purposes high frequencies are only needed where a determinand is measured for process control purposes or where it's concentration is near to or exceeds the maximum permissible criterion limit, as mentioned above. This argument must be qualified, however, with the proviso that where no prior measurements have been made, a high frequency of analysis must initially be used to establish the nature of the source water's variability.

The purpose of this report is to provide an initial guideline, especially as regards the frequency of analysis of the more toxic metals and of determinands often useful in process control. Such a guideline is urgently needed in South Africa, where widespread industrial and agricultural pollution occurs in conjunction with limited volume water resources, with a consequent strain on the older conventional methods of water purification for potable use.

The proposed frequencies should be used with discretion, especially in relation to the nature and type of pollution occurring in the catchment of the relevant treatment works and also in relation to the past history of the raw source water. The type of source should also be considered. Thus, for example, borehole water sources generally need considerably lower frequencies of analysis than surface waters.

FREQUENCY GUIDELINE

As an initial guideline, the determinands have been divided into five frequency groups (Tables 1 to 5):

1. <u>Group A</u>: Indicator or process control determinands with a suggested frequency of at least 1 per day.

2. <u>Group B</u>: Determinands with relatively narrow margins of safety and high toxicity, with a suggested frequency of a least 1 per month.

3. <u>Group C</u>: Determinands with relatively wide margins of safety or low short term toxicity, with a suggested frequency of at least 1 per quarter (i.e., 4 per year).

4. <u>Group D</u>: Potentially toxic determinands not often found in drinking-water, with a suggested frequency of at least 1 per year.

5. <u>Group E</u>: All other potential elemental pollutants and radioactive elements, for which multielement screening analyses should be carried out at least once every 5 years.

TABLE 1: Group A determinands

```
INDICATOR OR PROCESS CONTROL DETERMINANDS.

SUGGESTED FREQUENCY = AT LEAST DAILY


    Alkalinity              (i)        Magnesium            (ii)
    Aluminium               (ii)       Manganese            (ii)
    Ammonia                 (ii)       Odour
    Calcium                            Oxygen, dissolved
    Chloride                (ii)       pH
    Chlorine, free residual            Sulphate             (ii)
    Colour                             Taste
    Electrical conductivity            Temperature
    Hardness, total         (ii)       Turbidity
    Iron                    (ii)

Notes

(i) Alkalinity, electrical conductivity, temperature, pH and calcium must
    be measured in order to estimate the corrosive potential of water by
    e.g. the Langelier index.

(ii) These determinands fall under group A only if used in the treatment
     process or in control of the treatment process.  If chemicals
     containing these determinands are not used in the treatment process,
     then they fall under group C.
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TABLE 2: Group B determinands

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DETERMINANDS WITH RELATIVELY NARROW MARGINS OF SAFETY.   SUGGESTED
FREQUENCY = AT LEAST MONTHLY


Arsenic                              Cadmium
Cyanide          (i)                 Gold           (i)
Lead                                 Mercury
Selenium                             Silver

Note
(i) Only in gold mining areas, otherwise group D.
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TABLE 3:   Group C determinands

DETERMINANDS WITH RELATIVELY WIDE MARGINS OF SAFETY.   SUGGESTED
FREQUENCY = AT LEAST QUARTERLY

Aluminium	(i)	Ammonia	(i)
Barium		Boron	
Chloride	(i)	Chromium	
Cobalt		Copper	
Dissolved organic carbon (DOC)		Fluoride	
Hardness, total	(i)	Hydrogen sulphide (ii)	
Iron	(i)	Magnesium	(i)
Manganese	(i)	Methylene blue active substances (MBAS)	
Molybdenum			
Nickel		Nitrate	
Phenols	(ii)	Potassium	
Sodium		Sulphate	(i)
Vanadium		Zinc	

Notes

(i) If compounds containing these determinands are used in the treatment
     process, then they should fall under group A.

(ii) These determinands only need measurement if taste and odour problems
     occur.

TABLE 4:   Group D determinands

POTENTIALLY TOXIC DETERMINANDS NOT OFTEN FOUND IN DRINKING-WATER.
SUGGESTED FREQUENCY = AT LEAST ANNUALLY

    Antimony
    Bismuth
    Lithium
    Thallium
    Tin

TABLE 5:   Group E determinands

SUGGESTED FREQUENCY = AT LEAST ONCE EVERY 5 YEARS

    This group comprises other potential elemental pollutants, unusual
    elements and radioactive elements.   As complete an analysis as
    possible should be done on the raw and treated water every 5 years
    using a combination of suitable multi-element screening techniques,
    such as Inductively Coupled Plasma Optical Emission Spectroscopy,
    Neutron Activation Analysis and Ion Chromatography.

INTERPRETATION OF ANALYSIS

As indicated previously, the degree of health safety can be gauged by the magnitude of a determinand's concentration relative to the 'recommended' or 'ideal drinking-water limit. To facilitate this gauging process, the maximum permissible limit and 'crisis' limit were suggested. As the concentration of a determinand in the real life situation fluctuates about a mean, however, a statistical test should be included in the present proposal.

With these requirements in mind, a set of rules was constructed with which to compare analysed concentrations with the criteria limits (Table 6).

The establishment of whether the mean of n results complies with criteria or not is made by using the formulae given in Table 7 in conjunction with the rules given in Table 6. The rationale behind the calculation of the minimum number of statistically meaningful results, n, is given below. Note that in applying the rules in Table 6 the sign of the inequalities must be reversed for dissolved oxygen, as well as for the recommended, maximum permissible and crisis levels for the lower (acidic) pH limits. The upper (alkaline) pH criteria limits can be treated similarly to the other determinands.

TABLE 6:   Comparison of analyses with the proposed drinking-water limits

CASE 1:   Measured concentration (M) greater than or equal to crisis limit (i.e., $M \geq$ twice maximum permissible limit *)

Suggested actions:

(a) Reanalyse sample and check analytical method;

(b) and simultaneously resample and reanalyse immediately.

(c) If still case 1, then institute urgent measures to decrease concentration to below maximum permissible limit and to discover source of pollution. The frequency of analysis should be increased to at least 12 per day. The relevant authorities should be informed immediately, and an urgent investigation into the cause of the pollution started without delay. The problem can only be considered solved when the mean concentration of n independent samples is less than the maximum permissible limit, where n is calculated as shown in Table 7.

* except for pH, temperature and dissolved oxygen.

Note that in order to place the NIWR criteria into full agreement with the revised SABS 241 Specification, the general rule that the crisis limit is twice the maximum permissible limit is no longer valid in all cases.

CASE 2: Measured concentration (M) greater than or equal to maximum permissible limit but less than crisis limit.

Suggested actions:

(a) Reanalyse sample and check analytical method;

(b) and simultaneously resample and reanalyse immediately

(c) If still case 2, then shift determinand concerned to group A (i.e., increase frequency of analysis to at least once per day) until problem solved. If determinand is aready in group A, then increase frequency of analysis above that already used. Institute measures to decrease concentration below maximum permissible limit and institute investigation into the source and cause of the pollution. Inform the relevant authorities of the pollution. The given determinand's concentration can only be considered to be below the maximum permissible limit after the mean concentration of n independent samples is below the maximum permissible limit, where n is calculated as shown in Table 7.

CASE 3: Measured concentration (M) greater than or equal to recommended limit, but less than maximum permissible limit.

Suggested actions:

(a) Check to see whether the mean concentration of n independent samples lies between the recommended and maximum permissible limits, where n is calculated as shown in Table 7. If the mean is less than the recommended limit, then no further action need to be taken. If the mean does indeed lie between the recommended and maximum permissible limits then proceeded to point (b):

(b) If the determinand lies in group B, then the analytical frequency should be increased to at least once per week. If the determinand lies in Group C or D, then it should be shifted to group B.

(c) Institute measures to decrease the determinand's concentration and endeavour to discover and control the source of pollution.

(d) The urgency with which measures are taken to reduce the determinand's concentration to below the recommended limit depends on its toxic potential.

TABLE 6: (continued)

CASE 4: Measured concentration (M) less than recommended limit.

Suggested actions:

(a) If the mean concentration of n independent samples is less than the recommended limit, where n is calculated as shown in Table 7, then the water complies with the ideal limit as far as the given determinand is concerned and no action need be taken.

Note, however, that:

If the mean concentration of the given determinand is consistently less than the recommended limit, then the determinand may be analysed at less frequent intervals provided the following conditions are met:

   (i)   There is not significant pollution by the given determinand in the source water.

   (ii)   The determinand is not an indicator or process control determinand (i.e., a group A determinand).

   (iii) The given determinand's concentration remains constant over long periods (this is often the case with borehole water).

TABLE 7: Calculation of the number of independent samples (n) needed to determine the magnitude of the measured concentration relative to a drinking-water limit (P $\geqslant$ 0,95)

(a) Calculate the difference (D) between the maximum permissible and recommended drinking-water limits:

D = (maximum permissible limit - recommended limit)

(b) Calculate n according to the formula*:

$$n = \left[\frac{6VM}{100D}\right]^2 + 1$$

Where V is the coefficient of variation (expressed as a percentage) of the determinand's concentration and M the mean concentration in the water concerned. In practice these two variables can only be estimated. At least 6 independent samples are needed to determine M and V. See Table 8 for calculation of V.

(c) If 'n' as calculated by the formula in point (b) is less than 6, then let n = 6.

Note: 'V' is the coefficient of variation (%) of the determinand's concentration in the water supply being tested, and not the coefficient of variation of the analytical method.

* Based on a single-tailed t-test with a 95% confidence interval of one third D.

TABLE 8: Formula for calculation of coefficient of variation

(a) $V = (\frac{s}{M} \times 100)$ %

    where V = coefficient of variation (%),

             M = mean (average) concentration,

             s = standard deviation.

(b) The standard deviation is given by:

$$s = \sqrt{\frac{\Sigma(c_i - M)^2}{N - 1}}$$

where N = number of concentration values (c_i) used in calculating the average concentration M.

(c) The mean concentration is given by:

$$M = \frac{\Sigma c_i}{N}$$

STATISTICAL REQUIREMENTS

At the outset it is important to realise that the statistical procedure used depends on the nature of the question to be answered. In modelling studies, trend analysis, or where absolute determination of the concentration of a determinand is required, the ususal two-tailed statistical tests should be used. Thus, for example, the formula for determining the minimum number of analyses, n, required for determining a determinand's concentration with 95% confidence is given by:

$$n = \left[\frac{2 \times 1,96 \times s}{L}\right]^2 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (i)$$

where s is the standard deviation and L is the confidence interval (ISO, 1980).

Formula (i) can also be expressed as an equivalent formula in terms of coefficient of variation V (%) and mean (M):

$$n = \left[\frac{2 \times 1,96 \times V \times M}{100 \times L}\right]^2$$

$$n \cong \left[\frac{VM}{25L}\right]^2 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (ii)$$

Formulas (i) and (ii) are only valid, however, for large n (>30) and for normal distribution.

For smaller values of n the t-statistic can be used to calculate n:

$$n = \left[\frac{2 \times t \times \sigma}{L}\right]^2 + 1 \quad \dots\dots\dots\dots\dots\dots\dots \quad (iii)$$

Where t is the t-statistic value, L is the confidence interval, and σ is the standard deviation of the population (Downie and Health, 1974).
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Formulas (i) and (iii) are both two-tailed in concept, as they include both extremes of a distribution. They are thus used in determining absolute values for a determinand. In determining compliance of a water source with drinking-water criteria limits, however, a one-tailed statistical test is sufficient as we are only concerned when a determinand is greater than a limit. For this purpose a one-tailed t-statistical test can be used to calculate n:

$$n = \left[\frac{t \times \sigma}{L}\right]^2 + 1 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (iv)$$

Where t is the t-statistic value, σ is the standard deviation of the population and L is the desired confidence interval (Downie and Health, 1974). For practical purposes, a value of L equal to one-third of the difference (D) between the maximum permissible and recommended limits of a determinand is suggested, and a value of t equal to 2,0 for a 95% one-tailed confidence level for a minimum of 6 samples (Downie and Health, 1974).

Formula (iv) then reduces to:

$$n = \left[\frac{6 \times \sigma}{D}\right]^2 + 1 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (v)$$

As the standard deviation σ can also be expressed in terms of the coefficient of variation V, where:

$$V = \left[\frac{\sigma \times 100}{M}\right]\%$$

M being the mean concentration, formula (v) can be expressed as an equivalent formula using the coefficient of variation of the population instead of the standard deviation:

$$n = \left[\frac{6 \times V \times M}{100 \times D}\right]^2 + 1 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (vi)$$

The formula (vi) is the one given in Table 7.

In using either of the two equivalent formulas (v) or (vi), it is important to remember that V, M and σ are the coefficient of variation, mean and standard deviation respectively of the population from which the samples are drawn. The corresponding values of V. M and σ calculated from the samples are only estimates of the true population values. Where prior data for the water concerned is available, the historical value of V or σ should be used in calculating n, together with the current value of M.

The most serious statistical limitation in applying the formula in Table 7 lies in the requirement that the samples drawn must be independent, i.e., there must be no 'memory effects' between samples. Where this condition is not met, the values of σ and V calculated from the samples drawn are very poor estimates of the true population standard deviation and coefficient of variation. The net result is that 'n' will be under-estimated.

In practice, so far as the treated water is concerned, two samples can be considered independent when they are drawn at greater time intervals than the retention time of the works. Where samples are analysed at more frequent intervals than the retention time, then the values should be

grouped (averaged), and the grouped means used in the formula in Table 7.
The value of n calculated will then represent the number of grouped
samples required. Note, also, that much analytical time and cost can be
saved by integrating dependent samples prior to analysis.

For the raw source water, ensuring statistical independence is a difficult
task, especially as the time interval varies with different determinands
and with flow rates, as well as with local conditions. As an initial
guideline, where only limited data on a source water is available and a
sampling programme must be planned for future trend analysis, the general
rules given in Table 9 can be used. Note that statistical calculations
should always be interpreted with caution, as the samples analysed only
represent a very small fraction of the water source sampled. Consequently
no amount of statistical manipulation will ever correct for bad sampling
techniques. This difficulty is further compounded by the assumption of
independence between samples. This latter assumption is not required for
the sampling technique *per se*, but is required for statistical treatment
of the data, and it is one of the most problematical aspects in the use of
statistics for environmental water quality data reduction. The reason for
this difficulty is that the major body of statistical theory was developed
to describe populations consisting of <u>discrete</u> units whether people, dice
or examination marks, where the individual units are independent of one
another. The independence assumption is violated to a lesser or greater
degree when statistics are applied to continuous non-discrete systems such
as water bodies.

It cannot be emphasized too strongly that a thorough knowledge of the
behaviour of the raw source water and of the type of pollution in the
catchment is of equal, if not of more importance, in determining the
appropriate frequency than any statistical calculation. This is parti-
cularly so where there are cyclic variations in the source water. Many
statistical formulae are suggested in the literature in analysing
environmental sampling data. Standard texts on statistics should be
consulted for further information.

TABLE 9: <u>Sampling requirements where trend analysis is contemplated</u>

(a) The minimum number of independent concentration values n required to
establish a 95% confidence interval of L mg/ℓ over the total period
of observation is given by:

$$n = \left(\frac{VM}{25L}\right)^2$$

where V = coefficient of variation (expressed as %) of the deter-
minand's concentration,

M = mean (average) concentration,

L = desired confidence interval i.e., the acceptable error
range, in concentration units, that one wishes to achieve.

Note: The value of L chosen is usually much smaller than M. Very
large values of n are thus often needed for reliable trend
analysis.

TABLE 9: (continued)

(b) The minimum time interval TI between the n concentration values in
    (a) required for independence is as follows:

        (i)   For industrial effluents TI   =   5 hours
       (ii)   For river water samples TI   =   6 days
      (iii)   For reservoir samples TI   = 29 days
       (iv)   For treated water TI   =   retention time of
                                                   treatment works.

(c) Where large fluctuations in a determinand's concentration occur
    during the interval TI, then additional samples should be taken
    during each time interval TI, and the results averaged over each
    interval TI. The averaged results can be used for trend analysis by
    e.g. linear regression.

(d) Trend analysis can be done on the n concentration values obtained
    using conditions a, b and c above, using standard linear regression
    techniques. Most pocket calculators with scientific packages have
    linear regression facilities.

CONCLUSIONS AND RECOMMENDATIONS

As the quality of knowledge regarding the health aspects of inorganic
elemental determinands in drinking-water is improving very rapidly with
each decade, provision should be made in the envisaged legislation for
updating the criteria, especially as regards the determinands included in
group B. Arsenic and cadmium are, at present, pollutants of serious
environmental concern. Other elements may become important in the future,
thus the importance that the group E screening analysis carried out every
5 years for potential pollutants be as comprehensive as possible.

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