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Summarized water quality criteria

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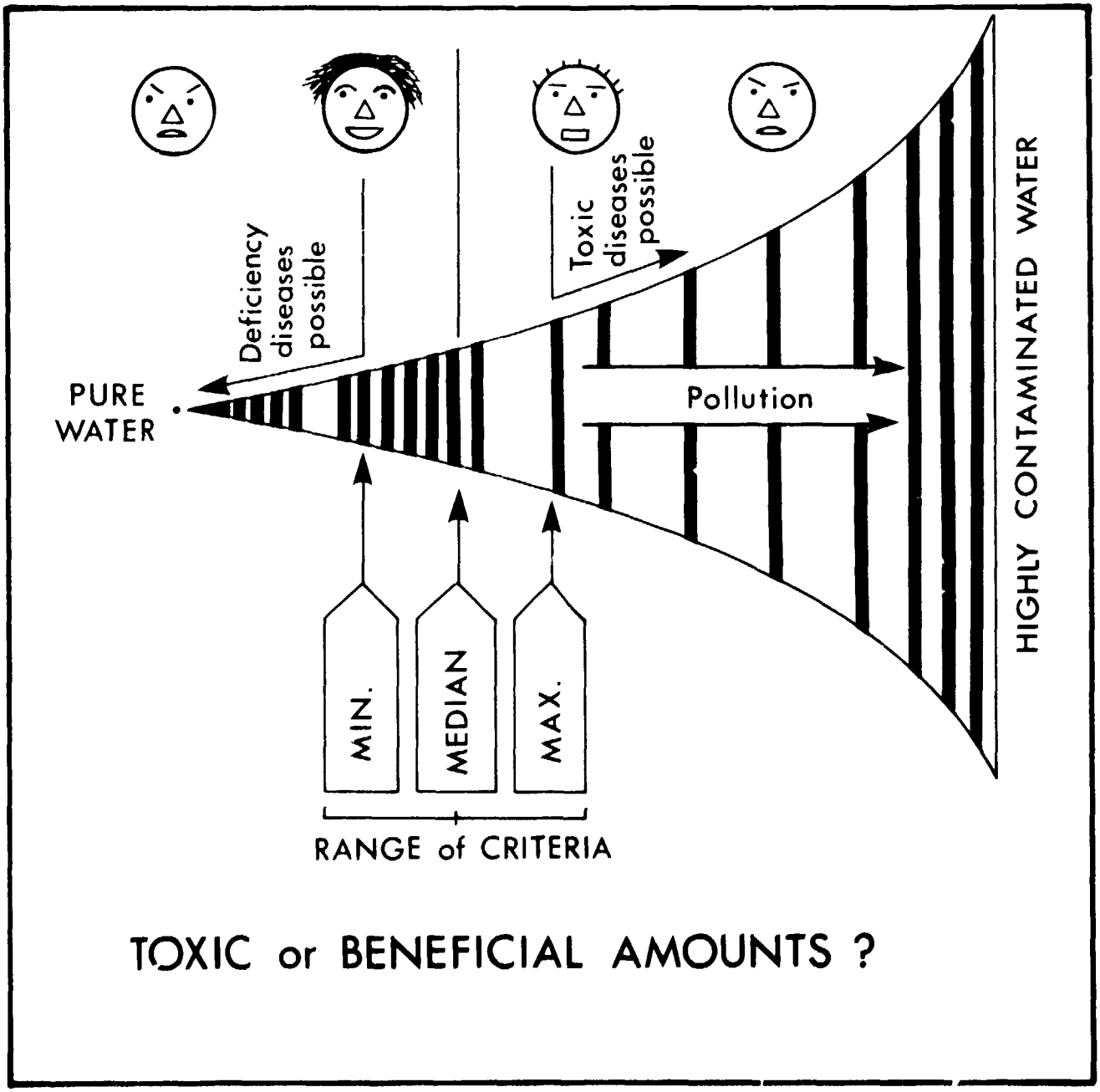
P L Kempster, W A J Hattingh and H R van Vliet



DEPARTMENT OF WATER AFFAIRS, FORESTRY AND ENVIRONMENTAL CONSERVATION

Hydrological Research Institute

Technical Report No TR 108

SUMMARIZED WATER QUALITY CRITERIA

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ERRATA - TR108

1. Front Cover: 'W.A.J. Hattingh' should read ' W.H.J. Hattingh'.

2. Page 14, penultimate line: 'liverstock' should read 'livestock'.

SUMMARIZED WATER QUALITY CRITERIA

by P.L. KEMPSTER
W.H.J. HATTINGH
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ABSTRACT

The available world literature from 27 sources on existing water quality criteria are summarized for the 15 main uses of water.

The minimum, median and maximum specified values for 96 different determinands are included. Under each water use the criteria are grouped according to the functional significance of the determinands e.g. aesthetic/physical effects, high toxic potential, low toxic potential etc. A synopsis is included summarizing salient facts for each determinand such as the conditions under which it is toxic and its relationship to other determinands. The significance of the criteria is briefly discussed and the importance of considering functional interactions between determinands emphasized in evaluating the potential for toxic or beneficial effects. From the source literature it appears that the toxic potential, in addition to being determined by concentration, is also affected by the origin of the substance concerned, i.e. whether from natural sources or from anthropogenic pollution.

CONTENTS

INTRODUCTION

The purpose of this report is to provide an overall picture of the present world opinion as regards the desirable limits for water quality constituents.

Quality criteria from 27 sources are summarized in tabular form for the 15 major uses of water. The summarized tables indicate for each constituent the lowest criterion reported (minimum value), the most commonly reported criterion (median value), and the highest criterion reported (maximum value). Criteria are given for the following water uses:

Table 1 - drinking water
Table 2 - river/dam water (protection of fish etc.)
Table 3 - livestock watering
Table 4 - irrigation
Table 5 - food processing industry
Table 6 - steam generation
Table 7 - brewing industry
Table 8 - paper manufacturing
Table 9 - softdrink industry
Table 10 - textile industry
Table 11 - petroleum industry
Table 12 - chemical industry
Table 13 - recreational purposes
Table 14 - iron and steel industry
Table 15 - tanning industry

The criteria for each use are functionally grouped according to the consequences of exceeding the criteria e.g. for drinking water (Table 1) the criteria are grouped as aesthetic/physical; biological; high toxicity; moderate toxicity; low toxicity and non toxic.

Note that the criteria reported in the tables represent the world opinion as could be gleaned from the literature sources. This does not imply that the authors necessarily agree with the recommended criteria.

Following the 15 tables of summarized criteria is an index to item numbers of determinands in the tables. In the discussion of properties after this index a brief synopsis is given for each determinand indicating salient facts about each one. For more detailed information the source literature should be consulted.

The report concludes with a comment on the significance of the criteria, emphasizing the importance of considering measured values in relation to the natural background in the environment.

SOURCE LITERATURE

(i) ADELAAR, T.F. 1965. Die invloed van brakwater op vee in Suid-Afrika; in Water-referate gelewer voor die afdeling chemie van die S.A. Akademie vir Wetenskap en Kuns, Pretoria. p 76-81.

(ii) AMERICAN PETROLEUM INSTITUTE 1967. Water quality criteria for fresh water. Committee for Air and Water Conservation, American Petroleum Institute, New York.

(iii) BROUWER, W.A.H. 1979. De wettelijke aspekten van de strijd tegen de waterontreiniging in Zwitserland. H_2O - Tijdschrift voor watervoorziening en afvalwaterbehandeling, 12 (22), p 484 to 488.

(iv) CENTRAL WATER PLANNING UNIT 1978. Russian toxicological data for chemicals in sources of drinking water, from Russian Ministry of Public Health toxicological criteria of 1972. Reading Bridge House, Reading, United Kingdom.

(v) DAWSON, G.W. 1974. The chemical toxicity of elements. Water and Land Resources Department, Pacific Northwest Laboratories, Washington; report BNWL-1815-UC-70.

(vi) DEPARTMENT OF HEALTH AND SOCIAL SECURITY 1969. The bacteriological examination of water supplies. Dept. of Health and Social Security, Welsh Office, and Ministry of Housing and Local Government. Report on public health and medical subjects No. 71. Her Majesty's Stationary Office, London.

(vii) ENVIRONMENTAL PROTECTION AGENCY 1972. Water quality criteria. Environmental Protection Agency, Washington D.C.

(viii) ENVIRONMENTAL PROTECTION AGENCY 1976. Quality criteria for water. U.S. Environmental Protection Agency report EPA-440/9-76-023; Washington, D.C. 20460.

(ix) ENVIRONMENTAL PROTECTION AGENCY 1977. National Interim Drinking Water Regulations. U.S. Environmental Protection Agency, EPA report no. 570/9-76-003.

(x) GELDREICH, E.E. (undated). Bacterial criteria for water quality determinations; Environmental Protection Agency, Cincinnati, Ohio, p 1-46.

(xi) GOODMAN, A.H. 1975. E.E.C. Directives on water quality. Severn-Trent Water Authority, STWA-CBI Water and Trade Effluent Group.

(xii) HART, B.T. 1974. A compilation of Australian water quality criteria. Australian Water Resources Research Council, Canberra. Tech. paper no. 7.

(xiii) HENZEN, M.R. en STANDER, G.J. 1962. Drinkwater. CSIR special report no. W16, NIWR, Council for Scientific and Industrial Research, Pretoria.

(xiv) INTERNATIONAL WATER SUPPLY ASSOCIATION 1974. Quality criteria for surface water to be treated to drinking water. IWSA 10th conference, Brighton, 19 to 22 August 1974.

(xv) JAPAN WATER WORKS ASSOCIATION 1970. Guidelines for water works technical management.

(xvi) McKEE, J.E. and WOLF, H.W. 1963. Water quality criteria. California State Water Resources Control Board, publication No., 3-A.

(xvii) McNEELY, R.N., NEIMANIS, V.P. and DWYER, L. 1979. Water quality sourcebook and Addendum; A guide to Water quality parameters. Inland Waters Directorate, Water quality branch, Ottawa, Canada.

(xviii) MINISTRY FOR TRANSPORT AND PUBLIC WORKS 1975. Water quality criteria from The Combat against Surface Water Pollution in the Netherlands.

(xix) MINISTRY OF HEALTH OF THE U.S.S.R. 1971. Maximum permissable concentrations of harmful substances in the water of watercourses used for hygienic and domestic purposes; WHO Expert Committee on Health Criteria for Water Supplies, Geneva, 30th March to 5th April 1971.

(xx) PUBLIC HEALTH SERVICE 1962. Public health service drinking water standards. U.S. Dept. of Health, Education, and Welfare, Washington D.C.

(xxi) SOUTH AFRICAN BUREAU OF STANDARDS 1971. SABS specifications for water for domestic supplies. Report no. SABS 241-1971.

(xxii) STÖFEN, D. 1974. Gesundheitliche höchstwerte für schadstoffe in trinkwasser. Gwf-wasser/abwasser, 115, p 67-71.

(xxiii) UNDERWOOD, E.J. 1971. Trace elements in human and animal nutrition, 3rd edition. Academic press, New York and London.

(xxiv) WEAST, R.C. 1975/76. Handbook of chemistry and physics, 56th edition. CRC press, Cleveland Ohio. pages B5 to B42 and page F195.

(xxv) WESTERN GERMANY 1975. Drinking water standards.

(xxvi) WORLD HEALTH ORGANISATION 1970. European standards for drinking water, 2nd edition, Region office for Europe of the WHO, Copenhagen.

(xxvii) WORLD HEALTH ORGANISATION 1971. International standards for drinking water. 3rd edition. WHO, Geneva.

TABLE 1

QUALITY CRITERIA FOR DRINKING WATER

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Aesthetic/physical				
1	Ammonium (as N)	mg/ℓ	0	0,5	2
2	Chlorine (disinfectn.)	"	0	0,2	0,4
3	Colour	Pt-Co units	5	15	150
4	Conductivity, electr.	mS/m	30	100	200
5	Hydrogen sulphide	mg/ℓ	0	0,05	0,3
6	Iron	µg/ℓ	50	300	1000
7	Manganese	"	10	50	1000
8	Odour	TON	3	3	4
9	Oil and grease	mg/ℓ	0	0,2	0,5
10	Oxygen, dissolved	"	>3	>5	>7
11	pH	pH units	5,0	6,5-9,0	9,5
12	Phenols	µg/ℓ	0,5	1	5
13	Suspended solids	mg/ℓ	25	25	25
14	Taste	subjective		ø	
15	Temperature	°C	15	25	25
16	Turbidity	NTU	0	5	250
	Biological				
17	Coliforms, faecal	Nos/100 mℓ	0	0	2000[x]
18	Coliforms, total	"	0	10	50000[x]
19	Enteroviruses	Nos/10ℓ		0	
20	Streptococci, faecal	Nos/100mℓ	0	20	20000[x]
	High toxicity				
21	Antimony	µg/ℓ	0,2	50	50
22	Beryllium	"	0,2	0,2	1000
23	Cadmium	"	1	10	50
24	Gold	"		20	
25	Lead	"	30	50	100
26	Mercury	"	0,1	2	20
27	Pest., aldrin	"	1	1	17
28	Pest., chlordane	"	3	3	3
29	Pest., dieldrin	"	1	1	17
30	Pest., endrin	"	0,2	0,5	1
31	Pest., heptachlor		0,1	0,1	50
32	Pest., lindane (γBHC)	"	4	5	56
33	Pest., parathion	"	3	35	100

[x] before chlorination

ø see text

TABLE 1 CONT., QUALITY CRITERIA FOR DRINKING WATER

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
34	Pest., toxaphene	µg/ℓ	5	5	5
35	Pest., -2,4,5-TP	"	10	10	30
36	Polychlorobiphenyl	"		1	
37	Polycyclic aromatics	"	0,2	3	5
38	Radium	"		1	
39	Selenium	"	1	10	50
40	Tellurium	"		10	
41	Thallium	"		5	
42	Thorium	"		0,5	
43	Yttrium	"		1	
	Moderate toxicity				
44	Arsenic	"	10	50	500
45	Bismuth	"	100		500
46	Bromine (Br_2)	"	200		3000
47	Chromium	"	30	50	500
48	Cyanide	"	10	200	200
49	Fluoride	mg/ℓ	0,7	1,5	2,4
50	Nickel	µg/ℓ	30	50	1000
51	Nitrate+nitrite (N)	mg/ℓ	6	10	23
52	Pest., DDT	µg/ℓ	42	50	100
53	Pest., malathion	"	50	100	100
54	Pest., methoxychlor	"	10	100	1000
55	Pest., -2,4-D	"	20	100	1000
56	Pest., -2,4,5-T	"	2	100	100
57	Radioactivity ($\alpha+\beta$)	Bq/ℓ	0,15	0,2	1,22
58	Silver	µg/ℓ	10	50	50
59	Tin	"		50	
60	Titanium	"	100	100	100
61	Tungsten	"	100	100	500
62	Vanadium	"	0	100	1000
	Low toxicity				
63	Aluminium	mg/ℓ	0,05	0,15	0,5
64	Barium	"	0,1	1	4
65	Boron	"	1	1	5
66	Cerium	"		2	
67	Cobalt	"	0,05	1	5
68	Copper	"	0,01	1	10

TABLE 1 CONT., QUALITY CRITERIA FOR DRINKING WATER

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
69	Detergents (as MBAS)	mg/ℓ	0,5	0,5	3
70	Iodide	"		10	
71	Lithium	"		5	
72	Molybdenum	"	0,5	0,5	0,5
73	Organic carbon	"	2		8
74	Strontium	"	2		10
75	Uranium	"	0,02	0,6	4,4
	Non toxic				
76	Alkalinity(as $CaCO_3$)	mg/ℓ	30	500	500
77	Calcium	"	75	200	300
78	Chloride	"	100	250	1000
79	Hardness, tot.($CaCO_3$)	"	200	500	1000
80	Magnesium	"	30	150	200
81	Phosphate (as P)	"	0,06	0,10	0,20
82	Phosphate, tot.(P)	"	0,10	0,25	2,0
83	Potassium	"	12		2000
84	Rubidium	"		5,0	
85	Silica (as Si)	"		18	
86	Sodium	"	100	270	1000
87	Sulphate	"	100	250	500
88	Zinc	"	0,2	5,0	15

COMMENTS ON DRINKING WATER CRITERIA (TABLE 1)

It was not always clear in the literature sources whether criteria were meant for drinking water as it appears at the point-of-use, or whether the criteria were for water destined for drinking water use (i.e. before chlorination). The median criteria can be considered as the recommended limits for point-of-use drinking water after chlorination.

Chlorine, hydrogen sulphide, manganese and phenol are placed under the aesthetic/physical grouping, as exceeding these criteria causes objectionable taste/appearance of the water well below levels which would be toxic.

Taste is a subjective criterion, difficult to quantify. The criterion for taste is that it should be 'pleasant'.

For comments on individual determinands see the discussion on p 30.

TABLE 2

QUALITY CRITERIA FOR RIVER/DAM WATER
(PROTECTION OF AQUATIC LIFE)

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Physical				
1	Conductivity, electr.	mS/m		ø	
2	pH	pH units	6,0	6,5-9,0	9,0
3	Suspended solids	mg/ℓ	25		80
4	Temperature	°C		ø	
	High toxicity				
5	Cadmium	µg/ℓ	0,1	3	30
6	Cerium	"		20	
7	Chlorine (disinfectn.)	mg/ℓ	0,002	0,00ɜ	0,01
8	Copper	µg/ℓ	5	5	200
9	Cyanide	"	5	5	5000
10	Hydrogen sulphide	mg/ℓ	0,002	0,002	0,3
11	Lead	µg/ℓ	20	30	100
12	Lithium	"		5	
13	Mercury	"	0,05	0,2	10
14	Pesticide. aldrin	ng/ℓ	1	10	10
15	Pest., chlordane	"	10	25	40
16	Pest.,DDT	"	1	1,5	2
17	Pest., dieldrin	"	1	5	5
18	Pest., endosulphane(α+β)	"	3	3	6
19	Pest., endrin	"	2	2	4
20	Pest., heptachlor	"	1	5	10
21	Pest., lindane (γ-BHC)	"	10	15	20
22	Pest., malathion	"	8	100	100
23	Pest., methoxychlor	"	5	20	30
24	Pest., mirex	"	1	1	1
25	Pest., parathion	"	0,4	8	40
26	Pest., toxaphene	"	5		10
27	Phenols	µg/ℓ	1	1	200
28	Polychlorobiphenyl	ng/ℓ	1		2
29	Selenium	µg/ℓ	5		10
30	Silver	"		10	
	Moderate toxicity				
31	Aluminium	µg/ℓ	100		1500
32	Ammonium (as N)	mg/ℓ	0,016	0,016	124

ø See text

TABLE 2 CONT., QUALITY CRITERIA FOR RIVER/DAM WATER
(PROTECTION OF AQUATIC LIFE)

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Moderate toxicity cont.				
33	Antimony	µg/ℓ	200		2000
34	Arsenic	"	10	200	1000
35	Beryllium	"	11		1100
36	Bromine (Br_2)	"		100	
37	Chromium	"	10	50	100
38	Detergents (as MBAS)	mg/ℓ	0,2		0,5
39	Fluoride	"	1,5	1,5	1,5
40	Iron	µg/ℓ	200	200	1000
41	Manganese	"	100		1000
42	Molybdenum	"		100	
43	Nickel	"	25	50	50
44	Pesticide -2,4-D	"	4	4	4
45	Phthalate esters	"	0,3		3
46	Thallium	"		100	
47	Thorium	"		100	
48	Zinc	"	30	100	100
	Low toxicity				
49	Barium	mg/ℓ	0,5	1	5
50	Cobalt	"		1	
51	Iodide	"		1	
52	Rubidium	"		2	
53	Tin	"		1	
54	Uranium	"	0,1		10
55	Vanadium	"		0,5	
	Non toxic				
56	Alkalinity(as $CaCO_3$)	mg/ℓ	>20	>20	>20
57	Boron	"	1,5		5
58	Calcium	"		1000	
59	Chloride	"	50		400
60	Magnesium	"		1500	
61	Oxygen, dissolved	"	>4	>5	>5,8
62	Phosphate, tot.(P)	"		0,1	
63	Potassium	"		50	
64	Silica (as Si)	"		50	
65	Sodium	"		500	
66	Strontium	"		200	

TABLE 2 CONT., QUALITY CRITERIA FOR RIVER/DAM WATER
(PROTECTION OF AQUATIC LIFE)

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
67	Sulphate	mg/ℓ		1400	
68	Titanium	"		12	
69	Tungsten	"		1	

COMMENTS ON CRITERIA FOR PROTECTION OF AQUATIC LIFE (TABLE 2)

The criteria are for the protection of fresh water aquatic life. Criteria for electrical conductivity and temperature depend on local conditions and on the life species present. Fish are more sensitive to sudden changes in electrical conductivity or temperature than to the absolute values of these determinands.

The minimum and median criteria for mercury are based on the danger to humans of methyl mercury poisoning on eating mercury contaminated fish. The same applies to phenol, although here it is the phenol-taste imparted to the fish fillets which is of concern rather than phenol toxicity.

Item 61 (Oxygen, dissolved) is particularly important for aquatic life. The oxygen levels should exceed the stated criteria.

The toxicity of the metallic elements (lead, zinc, copper etc.) to fish is higher in low calcium content water or in water with a low conductivity: For such waters the minimum criteria rather than the median criteria for metallic elements should be used.

TABLE 3

QUALITY CRITERIA FOR LIVESTOCK WATERING

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Aesthetic/Physical				
1	Conductivity, electr.	mS/m	300	460	1980
2	Iron	mg/ℓ		10	
3	Radioactivity ($\alpha+\beta$)	Bq/ℓ	0,20	0,20	0,20
	Biological				
4	Streptococci, faecal	Nos/100mℓ		40	
	High toxicity				
5	Cadmium	µg/ℓ	10		50
6	Mercury	"	2	3	1
7	Molybdenum	"	10	10	10
8	Pesticide, aldrin	"		1	
9	Pest., chlordane	"		3	
10	Pest., dieldrin	"		1	
11	Pest., endrin	"		0,5	
12	Pest., heptachlor	"		0,1	
13	Pest., lindane (γBHC)	"		5	
14	Pest., toxaphene	"		5	
15	Pest., 2,4-D	"		20	
16	Pest., 2,4,5-T	"		2	
17	Pest., 2,4,5-TP	"		30	
	Moderate toxicity				
18	Arsenic	µg/ℓ	200	200	1000
19	Copper	"	100	500	2000
20	Fluoride	mg/ℓ	1	2	2
21	Lead	µg/ℓ	50	100	500
22	Pesticide, DDT	"		50	
23	Pest., Malathion	"		100	
24	Pest., Parathion	"		100	
25	Selenium	"	20	50	50
26	Vanadium	"	100	100	100
	Low toxicity				
27	Aluminium	mg/ℓ	5	5	5
28	Chromium	"	0,05	1	5
29	Cobalt	"	1	1	1

TABLE 3 CONTINUED, QUALITY CRITERIA FOR LIVESTOCK WATERING

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Low toxicity cont.				
30	Manganese	mg/ℓ		10	
31	Nitrate+nitrite (N)	"	20	45	100
32	Pest., methoxychlor	"		1	
	Non toxic				
33	Boron	mg/ℓ	5	5	5
34	Calcium	"	1000	1000	1000
35	Chloride	"		1500	
36	Magnesium	"	250		500
37	Sulphate	"	500	1000	1000
38	Zinc	"	20	25	25

COMMENTS ON CRITERIA FOR LIVESTOCK WATERING

For livestock the criteria are generally either similar or less stringent than the criteria for drinking water for human consumption. There is, however, a notable exception viz. molybdenum:

The criterion for molybdenum for livestock watering is fifty times more stringent than the criterion for humans. This is because livestock are very sensitive to poisoning by molybdenum. In animal nutrition the metabolism of molybdenum and copper are closely related. The median copper criterion for liverstock is slightly lower than for humans.

TABLE 4

WATER QUALITY CRITERIA FOR IRRIGATION

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Physical/biological				
1	Coliforms, faecal	Nos/100 ml	100		1000
2	Conductivity, electr.	mS/m	28	80	550
3	Nematodes	Nos/l		0	
4	pH	pH units	4,5	4,5-9,0	9,0
5	Plant pathogens, virus	Nos/10 l		0	
6	Streptococci, faecal	Nos/100 ml		20	
	High toxicity				
7	Molybdenum	µg/l	5	10	10
8	Selenium	"	20	20	20
	Moderate toxicity				
9	Arsenic	µg/l	100	100	1000
10	Beryllium	"	100	100	500
11	Boron	"	300	500-750	2000
12	Chloride	mg/l	70	100	150
13	Chromium	µg/l	100	100	1000
14	Cobalt	"	50		200
15	Copper	"	200	200	200
16	Manganese	"	200	500	2000
17	Pesticide-2,4-D	"		700	
18	Radioactivity ($\alpha+\beta$)	Bq/l	0,2	0,2	0,2
19	Vanadium	µg/l	100	100	10000
	Low toxicity				
20	Barium	mg/l		1	
21	Cerium	"		1	
22	Fluoride	"	1	1	15
23	Lead	"	5	5	5
24	Lithium	"	0,075	2,5	2,5
25	Phenols	"		50	
26	Sulphate	"	200	200	200
27	Thallium	"		10	
28	Thorium	"		10	
29	Titanium	"		1,2	
30	Zinc	"	2	2	5
	Non toxic				
31	Aluminium	mg/l	1	5	5
32	Iron	"	1	5	5
33	Magnesium	"		300	

COMMENTS ON CRITERIA FOR IRRIGATION (TABLE 4)

Water quality criteria for irrigation depend both on the plant species being irrigated and on the soil characteristics of the ground.

As a rough rule-of-thumb it can be stated that the heavy metal pollutants are less toxic where fine textured alkaline soils are concerned, and more toxic on coarse textured or acidic soils.

Plant species vary considerably in their sensitivity to certain elements e.g. boron, chloride and lithium. Citrus trees are sensitive to all three of these elements, and for citrus the minimum criteria should be used. Some other plants (especially fruit trees) are sensitive to one or more of these three elements.

TABLE 5

WATER QUALITY CRITERIA FOR THE FOOD PROCESSING INDUSTRY

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Aesthetic/physical				
1	Ammonium (as N)	mg/ℓ		0,4	
2	Colour	Pt-Co units	5	5	20
3	Conductivity, electr.	mS/m	8	77	130
4	Hydrogen sulphide	mg/ℓ	0,2	1	1
5	Iron	µg/ℓ	200	200	200
6	Manganese	"	200	200	200
7	Odour	subjective			
8	pH	pH units	6,5	6,5-8,5	8,5
9	Suspended solids	mg/ℓ	10	10	10
10	Taste	subjective			
11	Turbidity	NTU	1		10
	Biological				
12	Coliforms, faecal	Nos/100 mℓ		10	
13	Coliforms, total	"		100	
14	Streptococci, faecal	"		1	
	Moderate toxicity				
15	Chromium	µg/ℓ		100	
16	Fluoride	mg/ℓ	1	1	1
17	Nitrate+Nitrite (N)	"	2	10	12
	Non toxic				
18	Alkalinity (as $CaCO_3$)	mg/ℓ	30	250	300
19	Calcium	"		100	
20	Chloride	"	250	250	900
21	Hardness, tot.($CaCO_3$)	"	10	250	250
22	Silica (as Si)	"	23	23	23
23	Sulphate	"	250	250	250

COMMENTS ON CRITERIA FOR FOOD PROCESSING (TABLE 5)

Criteria specific for the food processing industry are defined for 23 determinands only. For determinands not in Table 5, the criteria for drinking water (Table 1) should be used.

TABLE 6

WATER QUALITY CRITERIA FOR STEAM GENERATION

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Physical				
1	Colour	Pt-Co units	80		1200
2	Conductivity, electr.	mS/m	0,1	76	450
3	pH	pH units	7,0	8,0-9,5	10
4	Suspended solids	mg/ℓ	0		10
5	Turbidity	NTU	1	20	20
	Chemical				
6	Alkalinity (as $CaCO_3$)	mg/ℓ	0	1-350	350
7	Aluminium	µg/ℓ	5	10	5000
8	Ammonium (as N)	mg/ℓ	0,06		0,6
9	Bicarbonate (as $CaCO_3$)	"	0,5	39-140	140
10	Calcium	"	0		0,4
11	Copper	µg/ℓ	10		500
12	Detergents (as MBAS)	mg/ℓ	0	0,1	1
13	Hardness, tot.($CaCO_3$)	"	0,07	2-80	5000
14	Hydrogen sulphide	"	0		5
15	Iron	µg/ℓ	10		1000
16	Magnesium	mg/ℓ	0		0,25
17	Manganese	µg/ℓ	10		300
18	Oxygen, dissolved	mg/ℓ	$<$ 0,007	$<$0,007	$<$2,5
19	Silica (as Si)	"	0,005		19000
20	Zinc	µg/ℓ	10		10

COMMENTS ON CRITERIA FOR STEAM GENERATION (TABLE 6)

The difference between minimum and maximum criteria for water for steam generation is great. This is because the criteria depend on the type of equipment used. For boilers/turbines operating with high pressure steam the minimum criteria should be used, while the median criteria apply to low pressure boilers. The maximum criteria apply to cooling water.

Of more importance to the environment on the subject of steam/electric-power generation is the pollution of the atmosphere by the burnt products of fossil fuels used to generate the heat. The scale of this pollution is enormous, and the pollutants eventually return to the water sources via rain.

TABLE 7

WATER QUALITY CRITERIA FOR THE BREWING INDUSTRY

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Aesthetic/physical				
1	Colour	Pt-Co units	5	10	10
2	Conductivity, electr.	mS/m		230	
3	Hydrogen sulphide	mg/ℓ	0,2	0,2	0,2
4	Iron	"	0,1	0,3	1
5	Manganese	µg/ℓ	50		100
6	pH	pH units	6,5	6,5-7,0	7,0
7	Turbidity	NTU	0		10
	Biological				
8	Coliforms, faecal	Nos/100 mℓ		100	
9	Coliforms, total	"		1000	
	Moderate toxicity				
10	Fluoride	mg/ℓ	1	1	1
11	Nitrate+nitrite(N)	"	7		10
	Non toxic				
12	Alkalinity(as $CaCO_3$)	mg/ℓ	75		150
13	Calcium	"	100	500	500
14	Chloride	"	100	100	100
15	Hardness,tot.($CaCO_3$)	"	200	250	300
16	Magnesium	"	30	30	30
17	Silica	"	23	23	23
18	Sulphate	"		100	

COMMENT ON CRITERIA FOR THE BREWING INDUSTRY (TABLE 7)

The defined brewing industry water quality criteria are rather sparse. The quality criteria for drinking water for highly toxic and moderately toxic constituents should also be used for the brewing industry.

For ammonium the minimum criterion for drinking water (0 mg/ℓ) should be used for the brewing industry as ammonium tends to dissolve the copper containers which are often used in the brewing industry.

TABLE 8

WATER QUALITY CRITERIA FOR PAPER MANUFACTURING

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Aesthetic/physical				
1	Colour	Pt-Co units	5	5-100	360
2	Conductivity, electr.	mS/m	8	30	76
3	Iron	µg/ℓ	50	100	1000
4	Manganese	"	30	30	500
5	pH	pH units	6,0	6-8,3	10,0
6	Temperature	°C		<35	
7	Turbidity	NTU	0,3	10	100
	Chemical				
8	Alkalinity (as $CaCO_3$)	mg/ℓ	40	75	150
9	Aluminium	µg/ℓ		4	
10	Calcium	mg/ℓ	20	20	20
11	Chloride	"	25	75	1000
12	Chlorine (disinfectn.)	"		2	
13	Copper	µg/ℓ		5	
14	Hardness, tot.($CaCO_3$)	mg/ℓ	8	200	475
15	Magnesium	"	12	12	12
16	Silica (as Si)	"	9	12	47
17	Sulphate	"	7		200

COMMENT ON CRITERIA FOR PAPER MANUFACTURING (TABLE 8)

The criteria for paper manufacturing are few (17 items in all). The range between minimum values and maximum values is rather large. For fine high quality white paper the minimum criteria are applicable, while the maximum criteria apply to low quality brown paper.

TABLE 9

WATER QUALITY CRITERIA FOR THE SOFTDRINK INDUSTRY

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Aesthetic/physical				
1	Colour	Pt-Co units	5	10	10
2	Conductivity, electr.	mS/m		130	
3	Copper	µg/ℓ		100	
4	Hydrogen sulphide	mg/ℓ	0		0,2
5	Iron	µg/ℓ	200		300
6	Manganese	"	50	50	200
7	Turbidity	NTU	1		2
	Biological				
8	Algae, blue-green	mg/ℓ		0	
9	Coliforms, faecal	Nos/100 mℓ		0	
10	Coliforms, total	"		0	
11	Nematodes	Nos/ℓ		0	
	Moderate toxicity				
12	Fluoride	mg/ℓ	0,2		1
	Non toxic				
13	Alkalinity (as $CaCO_3$)	mg/ℓ	70	85	128
14	Chloride	"	250	250	500
15	Hardness, tot.($CaCO_3$)	"	200	250	250
16	Silica (as Si)	"		117	
17	Sulphate	"	250	250	500

COMMENT ON CRITERIA FOR THE SOFTDRINK INDUSTRY (TABLE 9)

Seventeen items in all have criteria specifically defined for the softdrink industry. The quality criteria for drinking water (Table 1) should be used for criteria for constituents not included in Table 9. The criteria for the highly toxic drinking water criteria should in particular also be applied to water for the softdrink industry.

TABLE 10

WATER QUALITY CRITERIA FOR THE TEXTILE INDUSTRY

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Aesthetic/physical				
1	Colour	Pt-Co units	5	5	70
2	Conductivity, electr.	mS/m		15	
3	pH	pH units	2,5		10,5
4	Suspended solids	mg/ℓ	5	5	5
5	Turbidity	NTU	0,3	15	25
	Chemical				
6	Alkalinity (as $CaCO_3$)	mg/ℓ	50	75	200
7	Aluminium	"	2	4	8
8	Bicarbonate (as $CaCO_3$)	"		200	
9	Calcium	"		10	
10	Chloride	"	100	100	100
11	Copper	µg/ℓ	10	50	5000
12	Hardness, tot.($CaCO_3$)	mg/ℓ	0	50	120
13	Iron	µg/ℓ	100	300	1000
14	Magnesium	mg/ℓ		5	
15	Manganese	µg/ℓ	10	50	1000
16	Silica (as Si)	mg/ℓ	9	12	12
17	Sulphate	"	100	100	100

TABLE 11

WATER QUALITY CRITERIA FOR THE PETROLEUM INDUSTRY

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Physical				
1	Colour	Pt-Co units	25	25	25
2	Conductivity, electr.	mS/m		110	
3	pH	pH units	6,0	6,0-9,0	9,0
4	Suspended solids	mg/ℓ	10	10	5000
	Chemical				
5	Alkalinity (as $CaCO_3$)	mg/ℓ	500	500	500
6	Ammonium (as N)	"		33	
7	Bicarbonate (as N)	"		390	
8	Calcium	"	75	75	220
9	Chloride	"	200	300	1600
10	Fluoride	"		1,2	
11	Hardness, tot. ($CaCO_3$)	"	350		900
12	Hydrogen sulphide	"		20	
13	Iron	"	1	1	15
14	Magnesium	"	25	30	85
15	Silica (as Si)	"		40	
16	Sulphate	"		900	

TABLE 12

WATER QUALITY CRITERIA FOR THE CHEMICAL INDUSTRY

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Physical				
1	Colour	Pt-Co units	2	20	500
2	Conductivity, electr.	mS/m		110	
3	pH	pH units	5,5	6,5-8,5	9,0
4	Suspended solids	mg/ℓ	5	15	10000
	Chemical				
5	Alkalinity (as $CaCO_3$)	mg/ℓ	150		500
6	Bicarbonate (as $CaCO_3$)	"	105	205	490
7	Calcium	"	2	50	250
8	Chloride	"	250		500
9	Hardness, tot.($CaCO_3$)	"	250		1000
10	Iron	"	0,02	0,1	10
11	Magnesium	"	2	25	100
12	Manganese	"	0,1		2
13	Nitrate+nitrite	"		10	
14	Silica (as Si)	"		23	
15	Sulphate	"	250		850

TABLE 13

WATER QUALITY CRITERIA FOR RECREATIONAL PURPOSES

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	<u>Aesthetic/physical</u>				
1	Ammonium (as N)	mg/ℓ		0,8	
2	Colour	Pt-Co units		100	
3	Detergents (as MBAS)	mg/ℓ		2	
4	Light penetration	mm	>1000	>1200	>1200
5	Odour	TON		16	
6	Oil and grease	mg/ℓ		5	
7	pH	pH units	5	6-9	9
8	Suspended solids	mg/ℓ		25	
9	Temperature	°C	>20	<30	<30
10	Turbidity	NTU		50	
	<u>Biological</u>				
11	Coliforms, faecal	Nos/100 mℓ	50	100	2000
12	Coliforms, total	"	500		10000
13	Streptococci, faecal	"		200	
	<u>Moderate toxicity</u>				
14	Chromium	µg/ℓ		100	
15	Radioactivity ($\alpha+\beta$)	Bq/ℓ	0,37		0,4

TABLE 14

WATER QUALITY CRITERIA FOR THE IRON AND STEEL INDUSTRY

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Physical				
1	Oil and grease	mg/ℓ	0		1
2	pH	pH units	5	7	9
3	Suspended solids	mg/ℓ	10		25
4	Temperature	°C	<24	<38	<38
	Chemical				
5	Alkalinity (as $CaCO_3$)	mg/ℓ		200	
6	Chloride	"	150		175
7	Hardness, tot.($CaCO_3$)	"	50	100	1000
8	Iron	µg/ℓ		100	
9	Manganese	"		50	
10	Sulphate	mg/ℓ		175	

TABLE 15

WATER QUALITY CRITERIA FOR THE TANNING INDUSTRY

ITEM	DETERMINAND	UNIT	MIN.	MED.	MAX.
	Physical				
1	Colour	Pt-Co units	5	5	100
2	pH	pH units	6,0	6-8	8,0
3	Turbidity	NTU		20	
	Chemical				
4	Alkalinity (as $CaCO_3$)	mg/ℓ	130	135	250
5	Calcium	"	60	60	60
6	Chloride	"	60	250	250
7	Hardness, tot.($CaCO_3$)	"	50	150	510
8	Iron	µg/ℓ	100	100	300
9	Manganese	"	10	200	200
10	Sulphate	mg/ℓ	250	250	250

INDEX TO ITEM NOS. IN TABLES

DETERMINAND	TABLE														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Algae, blue-green									8						
Alkalinity	76	56			18	6	12	8	13	6	5	5		5	4
Aluminium	63	31	27	31		7		9		7					
Ammonium	1	32			1	8					6		1		
Antimony	21	33													
Arsenic	44	34	18	9											
Barium	64	49		20											
Beryllium	22	35		10											
Bicarbonate						9				8	7	6			
Bismuth	45														
Boron	65	57	33	11											
Bromine	46	36													
Cadmium	23	5	5												
Calcium	77	58	34		19	10	13	10		9	8	7			5
Cerium	66	6		21											
Chloride	78	59	35	12	20		14	11	14	10	9	8		6	6
Chlorine	2	7						12							
Chromium	47	37	28	13	15								14		
Cobalt	67	50	29	14											
Coliforms, faecal	17			1	12		8		9				11		
Coliforms, total	18				13		9		10				12		
Colour	3				2	1	1	1	1	1	1	1	2		1
Conductivity	4	1	1	2	3	2	2	2	2	2	2	2			
Copper	68	8	19	15		11		13	3	11					
Cyanide	48	9													
Detergents	69	38				12							3		
Enteroviruses	19														
Fluoride	49	39	20	22	16		10		12		10				
Gold	24														
Hardness, total	79				21	13	15	14	15	12	11	9		7	7
Hydrogen sulphide	5	10			4	14	3		4		12				

INDEX CONT.

DETERMINAND	TABLE														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Iodide	70	51													
Iron	6	40	2	32	5	15	4	3	5	13	13	10		8	8
Lead	25	11	21	23											
Light penetration													4		
Lithium	71	12		24											
Magnesium	80	60	36	33		16	16	15		14	14	11			
Manganese	7	41	30	16	6	17	5	4	6	15		12		9	9
Mercury	26	13	6												
Molybdenum	72	42	7	7											
Nematodes				3					11						
Nickel	50	43													
Nitrate + nitrite	51		31		17		11					13			
Odour	8				7								5		
Oil and grease	9												6	1	
Organic carbon	73														
Oxygen, dissolved	10	61				18									
Pesticide, aldrin	27	14	8												
Pest., chlordane	28	15	9												
Pest., DDT	52	16	22												
Pest., dieldrin	29	17	10												
Pest., endosulphane		18													
Pest., endrin	30	19	11												
Pest., heptachlor	31	20	12												
Pest., lindane	32	21	13												
Pest., malathion	53	22	23												
Pest., Methoxychlor	54	23	32												
Pest., mirex		24													
Pest., parathion	33	25	24												
Pest., toxaphene	34	26	14												
Pest., 2,4-D	55	44	15	17											
Pest., 2,4,5-T	56		16												
Pest., 2,4,5-TP	35		17												
pH	11	2		4	8	3	6	5		3	3	3	7	2	2
Phenols	12	27		25											
Phosphate	81														
Phosphate, tot.	82	62													
Phthalate esters		45													

INDEX CONT.

DETERMINAND	TABLE														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Plant pathogens				5											
Polychlorobiphenyl	36	28													
Polycyclic aromat.	37														
Potassium	83	63													
Radioactivity	57		3	18									15		
Radium	38														
Rubidium	84	52													
Selenium	39	29	25	8											
Silica	85	64			22	19	17	16	16	16	15	14			
Silver	58	30													
Sodium	86	65													
Streptococci	20		4	6	14								13		
Strontium	74	66													
Sulphate	87	67	37	26	23		18	17	17	17	16	15		10	10
Suspended solids	13	3			9	4				4	4	4	8	3	
Taste	14				10										
Tellurium	40														
Temperature	15	4						6					9	4	
Thallium	41	46		27											
Thorium	42	47		28											
Tin	59	53													
Titanium	60	68		29											
Tungsten	61	69													
Turbidity	16				11	5	7	7	7	5			10		3
Uranium	75	54													
Vanadium	62	55	26	19											
Yttrium	43														
Zinc	88	48	38	30		20									

PROPERTIES OF INDIVIDUAL DETERMINANDS

Algae, blue-green

Criteria for blue-green algae are only defined for one of the 15 water uses viz. softdrink industry. Blue-green algae may under certain conditions release toxins e.g. Microcystis. Blue-green algae should also be considered for drinking water as well as livestock watering. Only large quantities of blue-green algae have been implicated in possible poisoning. Insufficient data exist to lay down limits. Note that algae can cause considerable difficulty in the filtration of water (blocking of sand filters).

Alkalinity

Alkalinity is a criterion for 12 of the 15 water uses. Alkalinity is a measure of the acid neutralizing capacity of water. It is mainly due to bicarbonate species. Alkalinity is routinely measured as part of a macro-element analysis of water. It has taste/physical implications and affects stability/corrosive potential of water. The alkalinity of natural water is rarely more than 500 mg/ℓ as $CaCO_3$.

Aluminium

Criteria defined for seven of the 15 water uses. Aluminium is the third most common element in the earth's crust, where it is present combined with silicates. Salts of aluminium are used in water purification as flocculants ('alum') because of the tendency of aluminium to precipitate out of solution around neutral pH. Aluminium is classically regarded as non-toxic because of this insolubility. It should however be regarded as potentially toxic because it can go into solution in strongly acid or alkaline conditions. Soluble aluminium has been implicated as a neurotoxin.

Ammonium

Criteria defined for six of the 15 water uses. The ammonium ion NH_4^+, exists in dynamic equilibrium with free ammonia NH_3, the predominant form depending on pH:

$$NH_4^+ \rightleftharpoons H^+ + NH_3$$

predominates at low pH (acid conditions)	predominates at high pH (alkaline conditions)

The ammonium ion NH_4^+ has low toxicity, while the free ammonia form NH_3 has high toxicity especially towards aquatic life. The criterion for ammonium thus depends on the pH value. In the tables the maximum

criterion applies to low pH water (acid conditions), while the minimum criterion applies to high pH water (alkaline conditions). Common sources of ammonium in water are sewage effluent or agricultural run-off (from nitrogen based fertilizers).

Antimony

Criteria defined for two of the 15 water uses. Antimony is chemically similar to arsenic. Antimony is a cardiac poison. It occurs primarily as an industrial pollutant.

Arsenic

Criteria defined for four of the 15 water uses. Arsenic is classically regarded as highly toxic because of its use in the Middle ages to poison one's enemies. It is however only moderately toxic, and has beneficial effects in small quantities. Arsenic is an antagonist to selenium toxicity (selenosis) in animals. Arsenic was one of the first chemical agents shown to be carcinogenic. Whether a given concentration of arsenic will be carcinogenic, toxic, non-toxic or even beneficial depends very much on the chemical form in which it is present. Arsenic is usually easily removed from water by coprecipitation with excess ferric chloride flocculant.

Asbestos

Criteria as yet undefined. Asbestos is a fibrous silicate mineral. Atmospheric pollution with asbestos is a known cause of lung cancer. Whether it is carcinogenic in water or not is still an unresolved question. Caution should be exercised when asbestos-cement pipes are used to transport water; only waters non-corrosive to cement can be transported with asbestos-cement piping.

Barium

Criteria defined for three of the 15 water uses. Soluble barium is a muscle stimulant: The fatal dose for man is 0,8 g as $BaCl_2$. Barium is readily precipitated from solution (and thus rendered non-toxic) by sulphate. Insoluble barium sulphate is used as a radiological contrast medium (e.g. the 'barium meal' for gastric X-rays).

Beryllium

Criteria defined for three of the 15 water uses. Beryllium is chemically similar to aluminium. Beryllium varies in toxicity from highly toxic to moderately toxic.

Bicarbonate

Criteria defined for four of the 15 water uses, i.e. for steam generation, the textile industry, petroleum industry and chemical industry. Bicarbonate is the main contributor to alkalinity in water.

Bismuth

Criteria defined for one of the 15 water uses, i.e. drinking water. Bismuth is considered to be moderately toxic.

Boron

Criteria defined for four of the 15 water uses. The most important criterion is that for irrigation. Boron is essential for plant growth, but the margin between beneficial amounts and toxic levels is narrow. The toxic level depends on the plant species.

- Sensitive plants such as citrus, most fruit trees and grapes should not be exposed to water containing more than 300 µg/ℓ boron.
- Semitolerant plants such as cereals, potatoes and tomatoes can tolerate up to 750 µg/ℓ boron.
- Some boron tolerant plant species such as beets, onions and lettuces can tolerate up to 2000 µg/ℓ boron.

Boron in water can arise both naturally and from domestic or industrial effluent. It is not readily removed from solution as boric acid and borates are readily soluble at neutral or alkaline pH.

Bromine

Criteria defined for two of the 15 water uses viz. for drinking water and for the protection of aquatic life.

Cadmium

Criteria defined for three of the 15 water uses. Cadmium is a highly toxic and a cumulative poison to higher life-forms. It is mainly an industrial pollutant and is often associated with zinc or lead. It is readily soluble in water and only precipitates at high pH values.

Calcium

Criteria defined for 11 of the 15 water uses. The calcium criteria for industrial uses are low, as calcium can cause scaling e.g. in steam generation; or precipitation of other chemicals (lime i.e. calcium hydroxide is used as a precipitation aid in water purification).

The calcium criteria for water consumption by living organisms are high as calcium is non-toxic. Calcium is an essential element, being an integral part of bone (calcium phosphate). The human body normally needs up to 2g Ca per day.

Calcium reduces the toxicity of heavy metals by hindering their adsorption. This is particularly noticeable in the decrease of the toxic potential of lead or zinc to fish in the presence of high calcium concentrations.

In low calcium content water the minimum criteria values for heavy metals should be used, while in moderate or high calcium content water the median criteria values for heavy metals are applicable.

Cerium

Criteria defined for three of the 15 water uses. Cerium has low toxicity to man but high toxicity to aquatic life. Cerium occurs is association with the other so called lanthanide elements, and is the most common of the lanthanides.

Chloride ($C\ell^-$)

Criteria for chloride are defined for 13 of the 15 water uses. Chloride usually occurs together with sodium in water and bears relation to the salinity of the water. Chloride has low toxicity to those life-forms which have a mechanism for excreting excess chloride. To life-forms which do not have an efficient chloride regulating mechanism e.g. plants, chloride can be toxic. Thus the median criterion for chloride in irrigation water is 100 mg/ℓ as compared to 1500 mg/ℓ for livestock watering.

Chloride is a common domestic and industrial pollutant. Chloride is difficult to remove from water, requiring energy intensive and expensive processes such as distillation, reverse osmosis or ion exchange.

Chlorine ($C\ell_2$)

Criteria defined for three of the 15 water uses. Chlorine is used to chemically disinfect water and thus kill micro-organisms and prevent epidemics. Chlorine is not an ideal disinfectant as chlorinated organic chemicals produced in water through chlorination can be carcinogenic. Chlorine may be replaced in the future by other means of disinfection.

Chromium

Criteria defined for six of the 15 water uses. Chromium is an essential element in human nutrition, without which insulin cannot function. Chromium can be toxic in high concentration. Metal plating and tanning industries are potential chromium polluters.

Cobalt

Criteria defined for four of the 15 water uses. Cobalt is an essential element in human nutrition, but is only needed in minute quantities. Cobalt has a low toxic potential except for irrigation where the toxic potential is moderate.

Coliforms, faecal

Criteria defined for six of the 15 water uses. Faecal coliform bacteria are used as an indicator of faecal pollution.

Coliforms, total

Criteria defined for five of the 15 water uses. Total coliform counts are used as an indication of overall bacteriological quality and to establish the effectivity of disinfection procedures.

Colour

Criteria defined for eleven of the 15 water uses. Common causes of discoloured water ('dirty water') are suspended solids, iron, manganese and humic acids.

Conductivity, electrical (EC)

Criteria defined for twelve of the 15 water uses. Conductivity gives a rough indication of the total dissolved salts (TDS) of a water sample:

$$TDS(mg/\ell) \simeq \text{Conductivity (mS/m)} \times 6,5$$

For the protection of aquatic life a single value for conductivity is impossible to give as the value depends on the species and on local conditions.

Copper

Criteria defined for eight of the 15 water uses. Copper is an essential element and only causes toxic symptoms in high concentration. Water with a high copper concentration has a disagreeable taste. Copper sulphate is often used as an algicide. It should be used infrequently as prolonged elevation of copper concentration promotes the growth of algal species tolerant to copper.

Cyanide

Criteria defined for two of the 15 water uses. Cyanide is more toxic to fish than to humans. Cyanide is rapidly degraded in the environment by bacterial action and is more toxic at low pH (when present as HCN) than at high pH. Free cyanide is more toxic than cyanide complexed to metallic elements (e.g. Fe).

Detergents

Criteria defined for four of the 15 water uses. Detergents cause aesthetic/physical problems e.g. foaming on water surfaces. They can also be toxic, particularly to aquatic life.

Enteroviruses

Criteria defined for one of the 15 water uses i.e. for drinking water. The virus causing poliomyelitis belongs to the enterovirus group.

Fluoride

Criteria defined for eight of the 15 water uses. The median criterion for fluoride in all cases lies between 1,0 and 2,0 mg/ℓ F^- (mean 1,5 mg/ℓ F^-).

Fluoride is one of the elements which helps to prevent dental caries, but it has chronic long term toxicity in concentrations only slightly above the beneficial level. The desirable optimum fluoride concentration in drinking water depends on the average daily intake of water and thus on the average daily maximum air temperature:

For an average maximum air temperature of 16°C the optimum fluoride concentration in drinking water is 1,0 mg/ℓ F^-. For an average maximum temperature of 30°C the optimum fluoride concentration is 0,7 mg/ℓ F^-.

Gold

Criteria defined for one of the 15 water uses i.e. for drinking water. Gold in a soluble form is highly toxic.

Hardness, total

Criteria defined for eleven of the 15 water uses. "Hardness" refers to the soap-neutralizing power of a water. It is caused principally by calcium and magnesium ions which form insoluble stearates with soap. In steam generation hardness is undesirable as it causes scaling.

Hydrogen sulphide

Criteria defined for seven of the 15 water uses. Hydrogen sulphide is a foul smelling gas which characteristically smells like rotten egg. It is highly soluble in water. Although toxic, it imparts unpleasant taste/smell to water at concentrations well below the toxic level. The median criterion of 0,05 mg/ℓ for drinking water is based on the taste threshold.

Iodide

Criteria defined for two of the 15 water uses. Iodide is essential for normal health, being necessary for the production of thyroid hormone. The margin between the essential nutritional requirement and toxic amounts is large for iodide.

Iron

Criteria defined for fourteen of the 15 water uses. Iron is the fourth most common element in the earth's crust. Iron is an essential element, being an integral part of the oxygen carrying red blood pigment haemoglobin. The drinking water criteria for iron are based on aesthetic and not on toxic considerations. Iron in water causes yellowish-brown discolouration. Normally removed by aeration/flocculation/filtration procedures.

Lead

Criteria defined for four of the 15 water uses. Lead is a common industrial pollutant. An important source of pollution is the burning of fossil fuels (coal, oil, petroleum). The lead released to the atmosphere reaches water sources via precipitation (dry or with rain).

Lead is a highly toxic and cumulative poison which affects nerve tissues. The toxicity of lead is inversely related to the calcium content of a water. Lead is more toxic at low calcium concentrations than at high calcium concentrations.

Light penetration

Criteria defined for one of the 15 water uses, i.e. for water used for recreational purposes.

Lithium

Criteria defined for three of the 15 water uses. The lowest criterion is for the protection of aquatic life. Most plants can tolerate lithium. Citrus is however sensitive to lithium, and citrus irrigation water should not contain more than 0,075 mg/ℓ Li.

Magnesium

Criteria defined for ten of the 15 water uses. Magnesium is an essential element for human, animal and plant life. It is non toxic. Together with calcium it is responsible for water hardness.

Manganese

Criteria defined for thirteen of the 15 water uses. Manganese is an essential element for both plant and animal life. The limit for

drinking water is based on aesthetic and not toxic considerations. Manganese, like iron, is a common cause of discoloured water. Prolonged intake of high manganese concentrations can however lead to serious neurotoxicity. Manganese can be removed from water by flocculation at high pH values.

Mercury

Criteria defined for three of the 15 water uses. Mercury is a highly toxic and cumulative poison causing both brain and kidney damage. Mercury is concentrated in the aquatic food chain and transformed to the even more toxic methyl-mercury. For this reason the median mercury criterion for river/dam water is only 0,2 µg/ℓ Hg, whereas the median mercury criterion for drinking water is 2 µg/ℓ Hg. The main danger posed by mercury pollution results from the eating of fish contaminated by mercury. Much controversy still exists about the levels of mercury which are dangerous. This is probably because the toxicity of mercury depends very much on other concomitant elements (i.e. the form in which the mercury is present). The essential element selenium is a known mercury antagonist.

Molybdenum

Criteria defined for four of the 15 water uses. Molybdenum in small quantities is an essential element for plants and animals. Both deficiency and excess cause disease-symptoms. In animal nutrition there is an interaction between molybdenum and copper. The molybdenum criteria for livestock and for irrigation are rather low i.e. 10 µg/ℓ Mo. The drinking water criterion for man is higher i.e. 500 µg/ℓ Mo.

Nematodes

Criteria defined for two of the 15 water uses. Nematodes are worm-like parasites. Adequate filtration/disinfection procedures should remove them from water.

Nickel

Criteria defined for two of the 15 water uses. Nickel is widespread in the environment, being slightly more common than copper in the earth's crust. It is thought to be essential in small quantities for animal and plant life. It can be toxic to certain plants in concentrations exceeding 0,2 mg/ℓ Ni.

Nitrate and nitrite

Criteria defined for five of the 15 water uses. Nitrite is unstable in water, and is readily oxidized by bacterial action to nitrate.

In a chemical analysis of water nitrate + nitrite are generally reported together as mg/ℓ N. Nitrate/Nitrite can cause fatal methemoglobinemia in infants. It is for this reason that the median criterion for nitrate nitrogen is placed at 10 mg/ℓ for drinking water.

Nitrate is the end product of bacterial oxidation of organic nitrogen. Sewage effluents are thus sources of nitrate. Another important source of nitrate is from agricultural runoff (fertilizers).

Odour

Criteria defined for three of the 15 water uses. The unit of measurement is the TON = 'Threshold Odour Number', which signifies the amount of dilution with odour-free water necessary to make the odour of the sample just detectable.

Oil and grease

Criteria defined for three of the 15 water uses. Limit for drinking water and recreational purposes based on aesthetic criteria.

Organic carbon

Criteria defined for one of the 15 water uses, i.e. for drinking water. Organic carbon is a non-specific indicator of the presence of organic compounds in solution.

Oxygen, dissolved

Criteria defined for three of the 15 water uses. For drinking water and for river/dam water the oxygen should exceed the recommended limit; while for steam generation oxygen should be absent (prevention of corrosion).

Pesticides

The organic pesticides are discussed as a group as their toxic effects are similar (neurological/gastrointestinal symptoms). Criteria generally defined for three of the 15 water uses, viz. for drinking water, river/dam water and for livestock watering. For the plant pesticide 2,4-D criteria are in addition defined for irrigation water.

Note that the toxicity of a pesticide when ingested by man is not necessarily due to the pesticide itself, but may arise either from some other highly toxic impurity present as a trace in the pesticide, or from transformation of the pesticide to a toxic metabolite within the body.

Note also that some pesticides are accumulative while other are biodegradable.

The pesticides aldrin, dieldrin, DDT, chlordane and heptachlor are suspected of carcinogenicity (cancer causing).

pH

Criteria defined for thirteen of the 15 water uses. pH is the negative logarithm of the hydrogen ion activity. It is an indication of the acid/base status of the water:

- Water with a pH value less than 7 is acidic.
- Water with a pH value equal to 7 is neutral.
- Water with a pH value greater than 7 is alkaline.

pH must be considered together with Eh (redox potential), temperature, EC (electrical conductivity), oxygen, alkalinity, calcium, sulphate and chloride when evaluating the corrosive potential of a water.

pH influences the solubility of many constituents. Metals tend to dissolve more rapidly in water at low pH (acid conditions). pH also influences the flocculation process used in water purification and the toxicity of many constituents. Two notable examples are cyanide, which is more toxic at lower pH values and ammonium which is more toxic at higher pH values.

Phenols

Criteria defined for three of the 15 water uses. The criterion for drinking water is based on the unpleasant taste of phenols. The fatal dose of phenol for man is estimated at 1,5 g. The limit for fish is low, both because of toxicity and also because of the phenolic taste imparted to fish fillets from phenol polluted water. The toxicity of phenol containing wastes is often due to concomitant cyanide. In contrast to man and animals, phenol has a low toxicity to plant-life.

Phosphates

Criteria for inorganic phosphate defined for one of the 15 water uses; criteria for total phosphate defined for two of the 15 water uses.

Phosphorus is the 11th most common element in the earth's crust, being found as phosphates. Phosphates are an essential nutritional requirement for all life-forms. The higher animals and man require large quantities of phosphates together with calcium to form bone. Phosphates are not toxic.

The primary reasons for defining phosphate criteria are:

(i) phosphate is an algal nutrient, and

(ii) phosphates are indicative of pollution e.g. from detergents, fertilizeres, sewage etc. (i.e. the presence of phosphate is

nearly always associated with the presence of other less desirable pollutants).

Phthalate esters

Criteria defined for one of the 15 water uses i.e. for river/dam water (protection of aquatic life). Phthalate esters are used as plasticizers for plastics. The health implications of phthalate esters are largely unknown.

Plant pathogens (viruses)

Criteria defined for one of the 15 water uses i.e. for irrigation water.

Polychlorobiphenyl (PCB)

Criteria defined for two of the 15 water uses. PCB is used as an insulating fluid in electrical and heat transfer applications. Toxicity suspected to be caused by impurities. The health implications are largely unknown. It is suspected of accumulation in adipose tissue. PCB is difficult to remove from water and is practically non-degradable.

Polycyclic aromatics

Criteria defined for one of the 15 water uses i.e. for drinking water. Polycyclic aromatics arise from incomplete combustion of fossil fuels (coal, oil, tar etc.). Some polycyclic aromatics are extremely carcinogenic e.g. benz(a)pyrene. Water transported through tar coated pipes should be screened for polycyclic aromatics, especially when the pipes are still new.

Potassium

Criteria defined for two of the 15 water uses. Potassium is the 7th most common element in the earth's crust. Potassium is an essential element for life. In large doses potassium is toxic, as it disturbs the electrolyte balance.

Radioactivity ($\alpha+\beta$)

Criteria defined for four of the 15 water uses. Radioactivity is expressed as Becquerels/ℓ (Bq/ℓ) and arises from the radioactive decay of radioactive atoms. The criteria are based on the assumption that long term exposure to low levels of radioactivity poses a cancer risk. The danger posed by radiation depends very much on the type (α,β,γ) of the radiation as well as on the energy of the radiation. Besides the well known naturally radioactive elements uranium, thorium and radium, a number of other natural elements are very slightly radioactive viz. potassium, rubidium, certain lanthanide

elements, zirconium, hafnium, vanadium, tantalum, rhenium, platinum and tellurium. Of these elements, potassium and vanadium are essential nutritional elements.

The literature sources were somewhat conflicting as regards the extent of the danger posed by radioactivity. The danger lies in pollution by artificial radio-elements of high intrinsic radioactivity rather than in radioactivity of natural occurrence.

Radium

Criteria defined for one of the 15 water uses i.e. for drinking water. Radium is a radioactive element. The usual source of radium in drinking water is in groundwater from uranium bearing rocks, radium being one of the decay products of uranium.

Redox potential (Eh)

Criteria undefined. The redox potential although important in evaluating the corrosivity of a water, is seldom measured due to lack of suitable instrumentation.

Rubidium

Criteria defined for two of the 15 water uses. Rubidium is the 16th most abundant element in the earth's crust: Rubidium is as common as chloride and is chemically similar to potassium. Rubidium is non-toxic to man. Natural rubidium is slightly radioactive. Rubidium tends to be concentrated by living organisms. It may possibly play a role in nutrition; very little is however known of the function of this element.

Selenium

Criteria defined for four of the 15 water uses. Selenium is a rare element. It is essential in very small quantities for normal health, serving as an anti-oxidant and involved in vitamin E metabolism. The margin between beneficial levels and toxic levels is narrow. Both absence and excess quantities of selenium result in disease.

Silica

Criteria defined for ten of the 15 water uses. Silica i.e. SiO_2 or sand, is the basic constituent of the earth's crust. It tends to dissolve under alkaline conditions but is non-toxic. The chief problem it poses when present in water is that of scaling where the water is used for steam generation.

Silver

Criteria defined for two of the 15 water uses. Silver is only moderately toxic to man. Its chief toxicity is towards aquatic life. Silver is rapidly immobilized in the environment as insoluble silver sulphide.

Sodium

Criteria defined for two of the 15 water uses. Sodium is an essential constituent of the body fluids. Water containing high sodium levels is undesirable in patients with heart or kidney trouble.

Streptococci (faecal)

Criteria defined for five of the 15 water uses. Faecal streptococci are one of the bacterial types found in faeces. The ratio of Faecal streptococci (F.s.) to Faecal coliform bacteria (F.c.) is indicative of the origin of the faecal pollution. A F.c./F.s. ration of $\geqslant 4,0$ is indicative of human faecal pollution; A F.c./F.s. ration of $\leqslant 0,6$ is indicative of animal faecal pollution.

Strontium

Criteria defined for two of the 15 water uses. Natural strontium has little or no toxicity, in contrast to radioactive strontium-90 arising from nuclear fall-out. Strontium is as common as fluorine in abundance in the earth's crust.

Sulphate

Criteria defined for 13 of the 15 water uses. Sulphate is non toxic to animals and humans except at very high concentration when it exerts a purgative effect. For plant-life sulphate is slightly less toxic than chloride. The sulphate concentration must be considered where concrete is in contact with water, as sulphate promotes the corrosion of concrete.

Suspended solids

Criteria defined for nine of the 15 water uses. Suspended solids cause aesthetic/physical problems. High suspended solids rapidly block sand-filters; for this reason sedimentation and flocculation steps are customarily carried out to remove the major portion of the suspended solids prior to filtration. Sometimes flotation is also used to remove suspended solids.

Taste

Criteria defined for two of the 15 water uses. Taste is a subjective criterion and is difficult to quantify. The taste of water should be 'pleasant'. Taste should also be considered in livestock watering as animals may refuse to drink bad-tasting water. Substances commonly causing bad tastes are chlorine, hydrogen sulphide, phenol, oils and metal ions.

Tellurium

Criteria defined for one of the 15 water uses i.e. for drinking water. Tellurium is a rare-element (similar abundance to gold) and is chemically similar to selenium.

Temperature

Criteria defined for five of the 15 water uses. Although temperature is important for protection of aquatic life, it is difficult to define criteria as these depend on local conditions. Thermal pollution of water bodies is a subject on its own (refer to source literature).

Thallium

Criteria defined for three of the 15 water uses. Thallium has about the same abundance in the earth's crust as mercury. Thallium is similar in toxic potential to arsenic. Thallium sulphate has been used as a rat poison. The danger of thallium pollution is that thallium tends to remain in solution even at high pH values. It is not easily removed from water.

Thorium

Criteria defined for three of the 15 water uses. Thorium is a naturally radioactive element of similar abundance in the earth's crust as molybdenum. Thorium oxide is used in incandescent gas mantles.

Tin

Criteria defined for two of the 15 water uses. Tin is an essential element in animal nutrition and has a moderate to low toxicity, as it tends to precipitate out of solution and is not readily absorbed. Organo-tin compounds are sometimes used to stabilize PVC plastic piping for drinking water distribution.

Titanium

Criteria defined for three of the 15 water uses. Titanium is the 9th most common element in the earth's crust. Titanium does not usually occur in water in high concentration because its oxide is highly insoluble. Titanium oxide is a widely used white pigment.

Tungsten

Criteria defined for two of the 15 water uses. Tungsten is similar in abundance to copper in the earth's crust. Little is known about the health effects of this element.

Turbidity

Criteria defined for nine of the 15 water uses. Turbidity causes aesthetic/physical problems. The unit of measurement is NTU=Nephelometric turbidity unit.

Uranium

Criteria defined for two of the 15 water uses. Uranium is a naturally radioactive element, and is often found in ground water. Uranium in drinking water has a low toxicity, contrary to what might be expected for a radioactive element.

Vanadium

Criteria defined for four of the 15 water uses. Vanadium is an essential nutrient for the growth of plants. Vanadium is suspected as being an essential element in human metabolism. It has an effect on cholesterol metabolism. Vanadium is toxic in excess.

Yttrium

Criteria defined for one of the 15 water uses. Yttrium is reported to be of high toxicity in drinking water. Yttrium is used together with europium in making the fluorescent phosphors of TV-tubes.

Zinc

Criteria defined for five of the 15 water uses. Zinc is moderately toxic to fish and is a common industrial pollutant. The major concern with zinc pollution is the discharge of zinc containing effluents to rivers.

Although zinc is non-toxic to humans, water containing high zinc concentrations should be screened for the highly toxic element cadmium which is a common concomitant with zinc. It is for the latter reason that zinc stabilizers should not be used for stabilizing plastics for drinking water distribution piping.

SIGNIFICANCE OF THE CRITERIA

Water quality criteria should be considered as guidelines only for estimating the water quality of a sample. The criteria can only be as reliable as the body of knowledge existing for a given constituent. The accuracy of this body of knowledge depends in its turn on the reliability and specificity of the analytical methods used to obtain data on the concentrations of the given constituent in the environment. As the state of knowledge advances re the health effects of elements, it is becoming clear that the particular chemical forms and interactions between constituents are as important as the absolute concentrations of constituents. It is also becoming more widely recognized that toxic effects are sometimes due to trace impurities of other substances associated with a given constituent. This is particularly true of the pesticides.

Note that a large number of elements are essential for normal health in small quantities. These same elements can be highly toxic in excess e.g. selenium, chromium. The disease resulting from an elemental deficiency can be as life threatening as that resulting from toxicity with excess of the element. Nutritionists are discovering more and more of the elements to be essential to health in small quantities. The possibility cannot be entirely excluded that some of the naturally occuring radioactive elements are not perhaps essential elements in very small quantities.

Finally it appears from the literature that anthropogenic sources of elements are more likely to be toxic at a given concentration than the same concentration level arising from natural causes (e.g. in the case of arsenic, mercury, chromium). The reason being that the elements are in balance in the undisturbed environment, and that anthropogenic additions tend to disturb the balance. If this last concept is kept in mind we will have gone a long way to safeguarding our water supplies.

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