Sodium, Chlorides, and Conductivity in Drinking-Water

Report on a WHO Working Group

The Hague
1 — 5 May 1978

WHO WORKING GROUP ON SODIUM, CHLORIDES, AND CONDUCTIVITY IN DRINKING-WATER

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INTRODUCTION

A Working Group on Sodium, Chlorides and Conductivity in Drinking-Water was convened in Voorburg (The Hague) from 1 to 5 May 1978 by the WHO Regional Office for Europe in collaboration with the Netherlands Ministry of Health and Environmental Protection.

In the 1977 Working Group on Health Hazards from Drinking-Water, held in London, several participants suggested that there should be further discussion on sodium and related parameters in drinking-water. This recommendation was adopted by the Regional Office for Europe and the Government of the Netherlands extended its hospitality. The National Institute for Water Supply and the Department of International Affairs of the Ministry of Health and Environmental Protection played major roles in organizing the meeting.

The aim of the meeting was to establish recommended upper limits or recommendations in relation to sodium, chlorides and conductivity in drinking-water. As part of its mandate the Working Group also had to consider the feasibility of the recommendations and suggest possible measures.

The meeting brought together experts on:

— internal medicine

— environmental health

— environmental hygiene (technical as well as chemical)

— drinking-water production.

The meeting was attended by 20 experts from 12 countries, as well as by staff members from the WHO Regional Office for Europe and from the Commission of the European Communities.

With the exception of the plenary sessions, the Working Group was split up into a medical and a technical group.

The meeting was opened by Dr L. Ginjaar, Minister of Health and Environmental Protection, who emphasized that the consumer has no choice but to accept the quality of drinking-water offered him. This places a heavy burden of responsibility on the authorities.

Dr J. Meilof was elected Chairman of the meeting, Dr R.F. Packham Chairman of the technical group, and Dr V. Beneš Chairman of the medical group. Mr C.H. Elzenga and Dr G.K. Matthew were appointed rapporteurs to the technical group and the medical group respectively. Dr F.J.J. Brinkmann coordinated the group reports and prepared the final report.

Only lately has attention been paid to the health aspects of sodium and also sodium in drinking-water. Much more attention is now being paid to this ion, especially in the USA, but also in the Netherlands, USSR, UK, and other countries. In the USA and also in the Netherlands recommendations on sodium in drinking-water have been formulated in the last few years.

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Chloride is listed in the 1971 International Standards with a recommended limit of 200 mg/l and a maximum permissible limit of 600 mg/l. These limits are based on organoleptic and technical considerations. Though conductivity is not listed in the 1971 International Standards, it is reasonable to assume that the values for conductivity can be used as an alternative to the values for Total Dissolved Solids which do form part of the International Standards list.

The parameters sodium, chloride and conductivity are linked together. Chloride is often the counter-ion of sodium, and both ions increase the conductivity of water.

SODIUM

Introduction

Until recently relatively little importance was attached to the occurrence of sodium in drinking-water. More attention was paid to the counter-ion, chloride, as an indicator of the salt content and as a cause of corrosion, poor flavour and other problems.

Several factors now indicate, however, that attention must be paid to the effects of sodium on human health. The relationship with hypertension, in particular, has led to recommendations that dietary sodium intake should be reduced.

A short-term goal of 6 g NaCl daily intake with an ultimate target of 3 g per day has been proposed by the US Committee on Nutrition (1977).

In the most recent literature on drinking-water, also, more attention has been paid to sodium. In its publication *Drinking water and health* the Research Council of the US National Academy of Sciences estimated that at least 40% of the population would benefit if total sodium intake were kept below 2 g (5 g NaCl) per day. From this value, assuming that 2 litres of water are consumed per day and that drinking-water contributes 10% of the total intake of sodium, a sodium concentration of up to 100 mg/l has been calculated as acceptable.

Another reason why attention must be paid to sodium in drinking-water is the substantial increase in sodium content of water during the last few decades, due not only to increased pollution of surface and ground water but also to water treatment processes at waterworks as well as processes used in domestic water softening.

Sources of Sodium in Drinking-Water

Natural sources

The sodium ion is a ubiquitous constituent of natural waters. It is derived geologically from the leaching of surface and underground deposits of salts such as sodium chloride, from the decomposition of sodium aluminium silicates and similar minerals, from the incorporation of evaporated ocean spray particles into rainfall, and from the intrusion of sea water into fresh-water aquifers. Salt spray from the sea is often the largest contributor of sodium ions within 50−100 miles of sea coasts. Some soils exhibit the property of ion exchange, whereby calcium ions in water are replaced by sodium ions during normal leaching.

Sea water contains about 10.5 g/l sodium and an almost equivalent amount of chloride, but wide fluctuations in concentration are known to occur. Seas which are virtually enclosed and have a high surface water input, such as the Baltic and Black Sea, are far fresher, as may also be the case with sea adjacent to the mouths of major rivers. Some virtually enclosed seas with little fresh-water input and high evaporation rates or salt beds beneath them may have far higher salinities. Inland seas and terminal sinks may be virtually salt water.

Because of the high sodium content, the contamination of fresh water by sea water, as in the case of sea-water intrusion, can lead to a very marked rise in sodium levels. High sodium levels in ground water can also result from geological deposits of sodium chloride.

Pollution

Human activities also contribute sodium ions to natural waters. The sodium chloride used for de-icing roads enters water supplies as runoff from both roads and storage depots. The quantity of sodium ions from this source has increased 10- or 20-fold since 1945 (*1*). This added sodium chloride is most heavily concentrated around metropolitan areas (*2,3,4,5*).

Municipal use of water typically results in the addition of 20−50 mg/l of sodium ion, primarily from urine and detergents.

Industry

Another major cause of the increased sodium concentration in surface water is the increased pollution by industrial activities. As an example, some figures are given for water from the Rhine, which is used as the water source for millions of people. As Fig. 1 shows, the five-year average of sodium concentration in the Rhine at Lobith between 1963/67 and 1972/76 rose from 82 mg/l (3.6 mmol/l) to 119 mg/l (5.2 mmol/l) (*6*). In Canada, sodium is

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Fig. 1. Five-year average concentrations of Na$^+$ in the Rhine at Lobith.
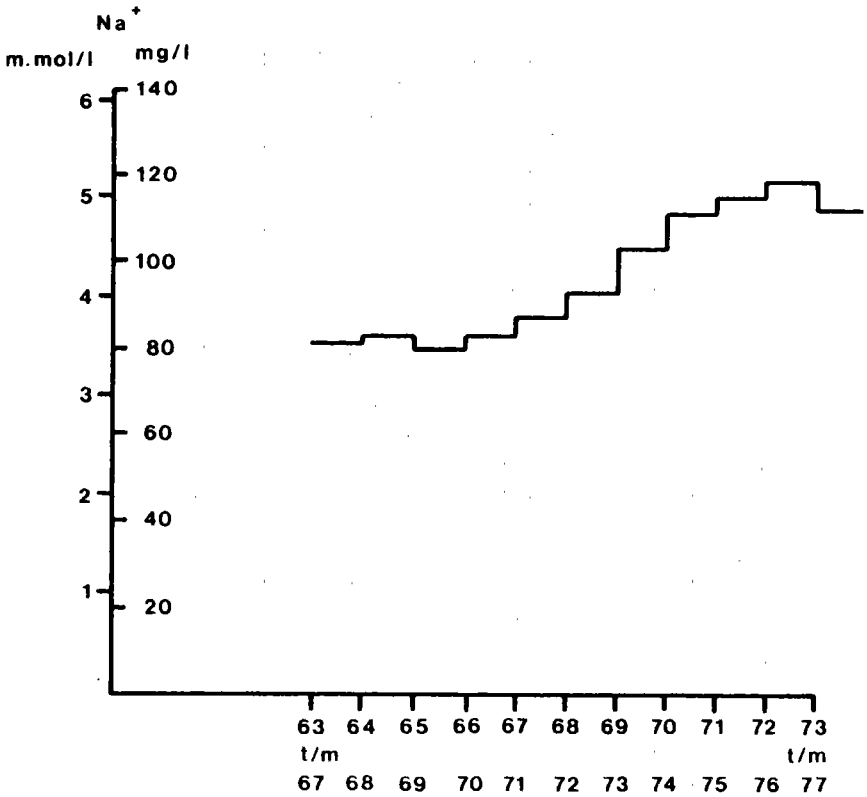
encountered primarily as sodium chloride (salt or halite) and sodium sulfate (salt cake). The major sources are the underground salt deposits of Saskatchewan, Alberta, Nova Scotia and south-western Ontario and the naturally occurring brines of the southern Alberta and Saskatchewan lakes. Canadian production for 1974 amounted to approximately 5.7 million short tons of salt (7) and 0.6 million short tons of sodium sulfate (8). In Canada, sodium sulfate is used mainly in the pulp and paper, glass and glass-wool, and soap industries. It is also employed in lesser amounts in the manufacture of pigments and colours, in base metal smelting, in the manufacture of medicines and other industrial chemicals and as a mineral feed supplement (7). Sodium

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chloride is used as a feedstock in the chemical industry for the production of sodium hydroxide and chlorine, sodium carbonate, sodium chlorate, sodium bicarbonate and sodium hypochlorite. Significant quantities are also used in food processing, slaughtering and meat packing, and in the dairy, fishing, grain and brewing industries (9).

Road salt

In North America one of the principal uses of sodium chloride is for the control of ice and snow on roads. The quantities of salt applied per year vary widely, depending on weather conditions, traffic density and type of road. Generally, major highways and main city roads receive more salt than less used roads. In many parts of the United States and Canada it has become the practice to maintain bare pavement on all major roads. Data gathered in 1965—70 from cities in Ontario, Canada, and from the north-eastern United States indicate that from 8.5 to 55 tons of salt were used per lane mile, per year, with an average of about 20. In Canada it has been estimated that salt consumption for snow and ice control rose from 1.6 million tons in 1968 to 2.5 million tons in 1974. In the United States, salt consumption for road de-icing increased from about 0.5 million tons in 1947 to 9 million tons in 1970 (1). It has been estimated that 25—50% of the salt used on a road infiltrates the ground water.

In the Netherlands, 110 000—500 000 tons of road salt were used in the years 1965—70 (10). The amount of road salt used in Denmark has been estimated at about 250 000 tons per year in recent years. In the winter of 1969—70, 200 000 tons of sodium chloride were used on Danish highways, and are thought to have caused pollution of ground water as well as surface water (11).

It is reported that use of sodium chloride for de-icing roads causes the death of trees and increases the sodium concentration in the soil to as much as 20 times the normal concentration (12).

Sewage

Sewage effluents normally have a sodium concentration at least 20 mg/l higher than the public water supply to the same community. Many lowland rivers used for public supply show an increase in sodium levels from source to mouth reflecting the degree of indirect re-use of the water, and these increased levels will affect the corresponding water supplies. Elevated sodium levels due to re-use are found particularly during periods of low river flow. Industrial recycling of water, which is actively encouraged as a means of water conservation, can also lead to elevated sodium levels, but the magnitude of this effect is dependent on the process used.

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Processes for the preparation of drinking-water

Various treatment processes are an important source of sodium in drinking-water. These range from large amounts of sodium-containing chemicals in public water supply processing to the domestic water softener of the ion-exchange type. Public water supplies are treated by softening and purification. The lime soda process may produce significant quantities of sodium if there is substantial noncarbonate hardness to be removed. Several sodium-containing chemicals are used in other processes: sodium fluoride (NaF) or sodium silico-fluoride ($Na_2 SiF_6$) for fluoridation; sodium hydroxide (NaOH), sodium carbonate ($Na_2 CO_3$) and sodium bicarbonate ($NaHCO_3$) for corrosion control; sodium hypochlorite ($NaHClO_3$) for disinfection and certain coagulants. Taken individually the sodium contribution is not large, but collectively it can be significant.

Table 1 shows data obtained in Massachusetts by Calabrese & Tuthill of the University of Massachusetts (1977).

Table 1. Increase in sodium due to drinking-water treatment

Community	Sodium content Raw Finished mg/l		Amount of sodium added mg/l	Increase %
A	1.9	21.0	19.1	1005
B	40	130	90	225
C	7.7	48	40.3	523
D	33	87	54	164
E	20	38	18	90
F	27	60	33	122
G	5.7	13	7.3	128

It should be noted that all but one of the waters exceeded 20 mg/l Na, the limit suggested by some authorities.

Recent investigations in the Netherlands Waterworks Testing and Research Institute, in collaboration with the municipal drinking-water supply authority of Amsterdam, have shown that the lead solvency of drinking-water prepared from the Rhine can be reduced by at least 50% by pH correction from pH 7.9 to 8.9. Copper solvency can be reduced by 75%.

From a technical point of view this can be carried out in practice quite easily, in combination with partial desoftening of the water with pellet softeners and sodium hydroxide. Capital investments are relatively low and the technical reliability is high.

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This treatment process increased the sodium content of the water by approximately 30 mg/l. Whereas the untreated drinking-water has a pH of 7.9 and a total hardness of 100 mg, as $CaCO_3$, the treated water after partial desoftening has a pH of 8.9 and a total hardness of 45 mg. The use of iron salts for coagulation and pH correction also entails the use of calcium or sodium hydroxide. In the latter case an increase of sodium in the order of 12 mg/l, depending on the buffer capacity of the water, may be expected for treatment of Rhine water.

Domestic water softeners are also a source of sodium. A domestic water softener commonly used in the USA is the synthetic white zeolite ion exchange type which, for each mg of Ca or Mg hardness (expressed as $CaCO_3$) removed, adds about 1 mg of sodium. In a recent case, a home in Massachusetts had raw water with a sodium content of 120 mg/l and a hardness of about 660 mg/l. After "softening" the hardness was reduced to 16 mg/l but the sodium rose to 434 mg/l. In theory, for every 40 mg calcium per litre exchanged, the sodium concentration in the treated water will increase by 46 mg/l. Two sodium ions are added for each ion of calcium or magnesium removed.

Table 2 shows the chemicals discharged by cationic or anionic ion exchangers for each 20 mg calcium exchanged.

Table 2. Compounds discharged by ion exchange of 20 mg calcium

| | In mg/l | | | |
	NaCl	$CaCl_2$	$NaCl + CaCl_2$	HCl
Strong cationic ion-exchangers in the Na-form	100[a]	60	160	—
Strong cationic ion-exchangers in the H-form	—	—	36	20
Weak cationic ion-exchangers in the H-form	—	—	36	10
Strong anionic ion-exchangers in the Cl-form	100[a]	—	100	—

[a] Corresponds to 40 mg Na.

Statistics on the total numbers of domestic softeners in use in the Netherlands, the Federal Republic of Germany, Belgium and France were collected

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Table 3. Number of domestic softeners.

	Total softeners present end 1973	Total softeners installed in 1973	Number of households × 1 000	Number of softeners end 1973 per 1 000 households	Increase during the year 1973 per 1 000 households
Netherlands	5 000	1 000	3 986	1.25	0.25
Germany, Federal Republic of	30 000	3 000	22 852	1.31	0.13
Belgium	30 000	10 000	3 233	9.28	3.09
France	155 000	40 000	15 778	9.83	2.54

by the Dutch Health Council (13). Table 3 gives an estimate of the number of domestic softeners at the end of 1973 and the number of softeners installed in 1973.

Levels in Drinking-Water

United States of America

A survey of 2 100 water supplies, covering approximately 50% of the population of the United States, was carried out in 1963–66 by the Heart Disease Control Program of the Division of Chronic Diseases and the Water Supply Section of the Division of Environmental Engineering, both belonging to the US Public Health Service. The distribution of sodium ion found in this survey ranged from 0.4 to 1 900 mg/l, as shown in Table 4. Some 42% of the supplies had sodium ion concentrations in excess of 20 mg/l and nearly 5% had concentrations greater than 250 mg/l. Similar results were shown in the 1975 report of Chemical Analysis of Interstate Carrier Water Supply Systems. For 630 systems, sodium ion concentration ranged from <1 to 402 mg/l. A total of 42% had concentrations greater than 20 mg/l and 3% had concentrations greater than 200 mg/l.

Table 4. Sodium ion concentration in drinking-water

Sodium ion concentration mg/l	Number of samples	Percentage of samples
0 – 19.9	1 194	58.2
20 – 49.9	391	19.0
50 – 99.9	190	9.3
100 – 249.9	178	8.7
250 – 399.9	74	3.6
400 – 499.9	10	0.5
500 – 999.9	14	0.7
1 000 or higher	2	0.1
Total	2 053	100.1

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Netherlands

In the Netherlands a Committee of the Health Council drafted a report on the maximum permissible concentration of sodium in drinking-water (6). Since 1949, the sodium content of drinking-water in the Netherlands has in general increased considerably, as can be seen from Fig. 2a, b, c. This increase particularly concerns surface water supplies, but ground water supplies are also affected.

Fig. 2a, b, c. Distribution of total drinking-water supplies, according to sodium content, in (a) 1949, (b) 1963, (c) 1973.

Class I:	0 — 50 mg Na/l	(0 —2.2 mmol/l)
Class II:	50 —100 mg Na/l	(2.2 —4.4 mmol/l)
Class III:	100 —150 mg Na/l	(4.4 —6.5 mmol/l)
Class IV:	>150 mg Na/l.	
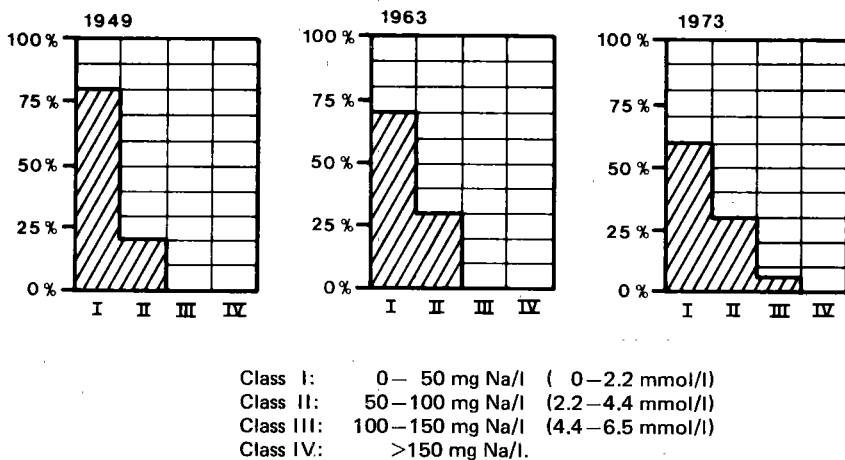
Source: National Institute for Water Supply, Voorburg.

The sodium levels in drinking-water vary between 6 and 143 mg/l (National Institute for Water Supply, 1976). Sixty-two per cent of water supplied contains sodium below 50 mg/l, 30% contains between 50 and 100 mg/l, and 7.5% exceeds 100 mg/l.

United Kingdom

Sodium levels in water sources supplying the larger towns (population 50 000) in the United Kingdom are shown as a histogram in Fig. 3. The levels shown are five-year means for the period 1969—73. The highest sodium levels in England are found in coastal ground water sources affected by sea-water intrusion (14).

Fig. 3. Frequency distribution of sodium levels in water sources
supplying large towns in the United Kingdom
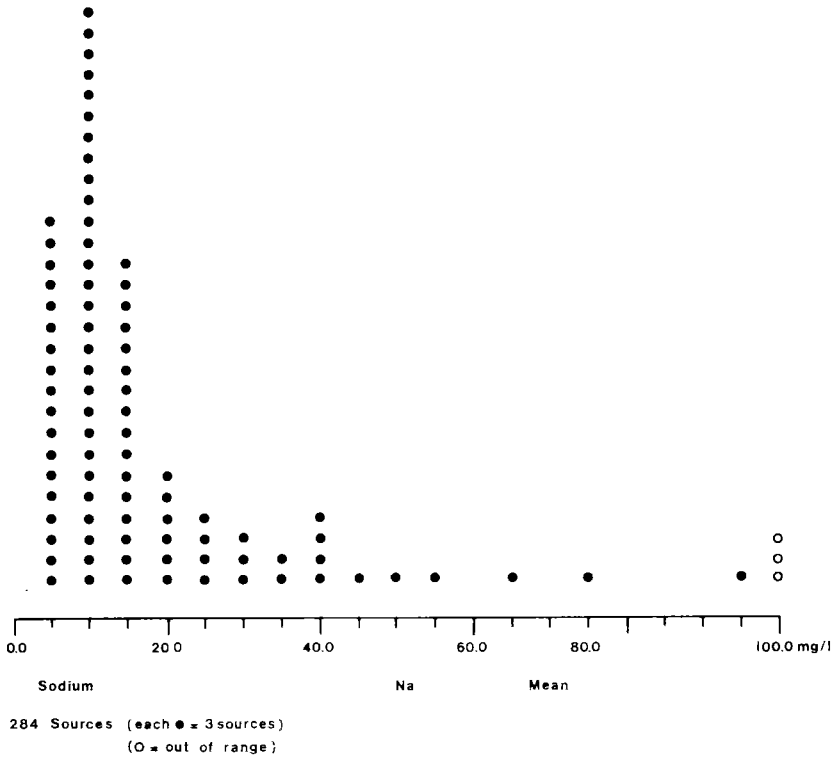
Canada

Canadian data, comprising 176 determinations from 71 stations, gave a
mean of 8.8 mg/l (range 0.2 to 470 mg/l) for a number of Alberta, British
Columbia and Nova Scotia supplies; 173 of these determinations showed
levels less than 50 mg/l (*15*). The use of water softeners could of course
drastically increase these concentrations. For example, the sodium sulfate
content of the Edmonton water supply was found to rise from 8 mg/l in
summer to 56 mg/l in winter because of the use of lime-soda ash for soften-
ing (*15*); the highest level recorded (470 mg/l) was for well water treated

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with a water softener. A survey (reported in 1961) of 300 drinking-water samples from southern Alberta showed that a considerable proportion of well waters contained extremely high sodium levels, exceeding in some instances 3 g/l (16). This can be attributed to the high salt content of the soils, as discussed previously. The sodium content of supplies derived from surface waters in this area was generally in the range 0—50 mg/l.

Hungary

In some communities in Pest and Bacs-Kiskun counties, where the drinking-water supply is obtained from wells 100—300 m deep, for geological reasons (salt deposition) the sodium content of drinking-water exceeds 200 mg/l. No epidemiological data are available (17).

France

Sodium concentrations of 200—230 mg/l are reported in several instances in a table showing waters which contain more sodium than calcium.

Sodium Intake from Food, including Drinking-Water

Total sodium intake

Sodium occurs naturally in all foods. Natural levels vary considerably for different types of food, and food processing can have a noticeable effect on these levels. For example, fresh peas have a sodium content of 9 mg/kg, drained canned peas — 2.3 g/kg and frozen peas — 1 g/kg. Fresh fruit and vegetables contain from $<10 \mu g/g$ to 1 mg/g whereas cereals and cheeses may contain from 10 mg/g to 20 mg/g. Sodium concentrations in bottled mineral waters in the European Economic Community ranged from 5 to 1 800 mg/l (18, 19, 20).

In Belgium, bread is reported to contain 13.3 g NaCl/kg, in Spain 14.2 g/kg, and in Bangkok and Nepal 4—5 g/kg. In some regions of Italy bread often contains no salt at all. In Belgium it was estimated that approximately 3 g salt per day was ingested in bread. Milk contains approximately 1.5 g/l (21).

Assessment of daily sodium intake is difficult because of the wide variations in concentrations in foods and the habit that many people have of adding salt. Salt is often added both during food preparation and at the table. Adequate data on the impact of cooking on the salt content of food is also lacking. Most data that have been reported are based on measurement of sodium excretion in urine. Wide variations occur between individuals and in the same individual from day to day (22). In western Europe and North

America, present sodium chloride consumption is estimated to be 5 – 20 g per day, with an average of approximately 10 g per day (see Table 5).

Table 5. Daily intake of sodium chloride.

Population	NaCl Average	(g/day) (Range)	Reference	
United States	10	(4 – 24)	USEPA	(23)
United States	6 – 8		Nat. Health Survey	(6)
Belgium	± 12		Joossens et al.	(6)
Cook Islands	± 8		Prior et al.	(6)
Wales	± 8		Miall	(6)
Canada + USA	2.5 – 18		Nat. Res. Council	(9)
Canada	± 9		Nutrition Canada	(8)

Water consumption

Average contribution of different water intake routes

It is generally assumed that an average adult requires 2 500 ml of water per day (*24, 25, 26, 27*). Part of this quantity, approximately 300 ml, is obtained from oxidation of food (*25*). The remaining 2 200 ml is obtained from tap-water-based fluids and foods, including drinking-water, and from other fluids and foods, such as milk, wine, citrus juice, meat, vegetables and eggs.

Table 6 shows that in the countries of the European Community most of the human water intake is derived from tap water (*19*).

Table 6. Survey of human water intake routes in the countries of the European Community

Route	Mean estimated quantity (% of total)
Local tap water (drinking, coffee, tea, soup, boiling, baking, etc.)	60
Non-local drinking-water (beer, soft drinks, mineral water)	10
Non-drinking water (milk, wine, citrus juice, meat, vegetables, eggs)	30

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Owing to differences in consumption habits, relatively large national differences in fluid-intake patterns can be observed.

According to a recent study among 3 073 adults in the Netherlands (see Table 7), an average of 1.26 litres of tap water is consumed daily per capita (*28*).

Table 7. Water consumption in the Netherlands.

Type of tap water consumed	Average quantity consumed daily (l/head)
Total at home	1.02
Total (at home and elsewhere)	1.26

Preliminary results of a drinking-water consumption study being conducted in Canada among 342 households also indicate that the majority of Canadian adults drink approximately 1.3 litres of tap water per day, as is shown in Table 8 (*29*).

Table 8. Distribution of average weekly tap-water consumption
by commodity, 467 males, 503 women
(in litres)

Item	Male		Female	
	Summer	Winter	Summer	Winter
Tea	1.2	1.4	1.7	1.7
Coffee	1.9	2.2	2.0	2.3
Milk	0.6	0.7	0.3	0.5
Reconstituted juice	1.7	1.5	1.4	1.4
Home-made beer/wine	0.5	0.3	0.2	0.1
Water	2.9	2.7	2.5	2.6
Ice	0.2	0.2	0.2	0.2
Soup	0.5	0.7	0.4	0.7
Popsicles	0.1	0.05	0.1	0.05
Baby formula	0.02	0.06	0.05	0.02
Total	9.5	9.7	8.9	9.5

Individual differences in daily water intake

Factors that influence individual water intake include climate, physical exertion, amount and kind of food consumed, health, age, body size and weight, and individual preferences.

It is commonly recognized that high environmental temperature is associated with suppression of food intake and an increase in fluid intake. It has been suggested that under normal living conditions, water intake increases directly with temperature (*30*).

Children born and raised in places where the mean annual temperature is 21°C consume about twice as much water as children living in areas where the mean temperature is 10°C (*31*). For six-year-olds living in Prince George, British Columbia, Canada (*31*), total fluid intake averages 1.0 1/day (0.35 – 3.0). The volume of fluids consumed in cooler climates varies more with individual preferences. It has been suggested that this is due to the lack of a constant fluid demand which is imposed by perspiration in warmer climates (*32*).

It was found that the average fluid intake in the desert was 5.90 litres per day with a standard deviation of ±2.03 whereas average fluid intake in the tropics was 3.26 litres with a standard deviation of ±1.09. This was among men engaged in normal activity, including truck driving, guard duty, hiking, etc. Five per cent of the men in the tropics drank as little as 1 1/day.

In the Netherlands it was found that females generally consume about 10% less tap water than males, as illustrated for different age categories in Table 9 (*33*).

Table 9. Average total daily consumption of drinking-water (including coffee and tea) in relation to age and sex

Age category (years)	Daily volume of water (litres) consumed per capita	
	Males	Females
0 – 4	0.62	0.56
5 – 17	0.95	0.85
18 – 55	1.27	1.19
over 55	1.37	1.21

Of even more importance is that group of the population which normally consumes relatively large amounts of tap water and consequently runs the greatest risk.

The Dutch study showed the distribution of total daily tap-water intake among different parts of the population, as given in Table 10.

Table 10. Daily average consumption of tap water in the Netherlands

Proportion of the population (%)	Consumption above 1 l/day
50	1.1
10	1.9
5	2.3
1	3.2

It seems reasonable to assume daily consumption of 2 litres or less, as this figure applies to more than 90% of the population. A wide variation in consumption was also observed in the Canadian Water Consumption Survey (29) (Table 11).

Contribution of water to total sodium intake

The contribution of tap water to an individual's total intake of sodium can vary widely but is usually relatively small. If a person consumes 10 g/day

Table 11. Canadian drinking-water consumption survey.

SUMMER

| Age (years) | Litres per week | | | |
| | Males | | Females | |
	Range	Mean	Range	Mean
under 3	0–12	3.3	0–11	4.4
3–5	0–21	6.1	0.6–21	6.0
6–17	0–30	9.4	0–22.5	6.5
18–34	0.6–30	9.9	1.1–30	8.8
35–54	0–30	9.8	0–30	11.4
over 54	1.1–30	10.9	2.1–30	10.6

Table 11 (contd)

WINTER

| Age (years) | Litres per week | | | |
| | Males | | Females | |
	Range	Mean	Range	Mean
under 3	0–11	3.7	0–14.5	5.2
3–5	1.6–11.5	6.5	0.6–18.5	5.9
6–17	0.6–30	8.3	0–30	7.5
18–34	0–30	10.2	1.1–30	9.8
35–54	1.1–30	10.8	1.6–30	11.4
over 54	2.6–30	11.4	2.1–30	11.3

of salt from food while consuming 2 litres of water with the relatively high sodium concentration of 100 mg/l (250 mg/l as NaCl) then the water will contribute 2.44% of his total intake.

Assuming that salt intake from food ranges from 5 to 20 grams and water consumption from 0.5 to 3.0 litres per day, the following minimum and maximum contributions can be calculated for various concentrations of sodium in water (Table 12).

Table 12. Contribution of water to total sodium intake

| Concentration in water | | Contribution from water | |
| Na^+ | NaCl | Minimum water consumption Maximum intake from food | Maximum water consumption Minimum intake from food |
mg/l	mg/l	%	%
20	50	0.125	2.91
40	100	1.25	5.66
100	250	0.62	13.04
200	500	1.24	23.08
400	1 000	2.44	37.50
1 000	2 500	5.88	60.00

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Although the highest percentage contributions are unlikely to occur, it is clear that water can substantially contribute to sodium intake, although in relatively uncommon circumstances.

Physiology of Sodium

Sodium plays an important part in the regulation of body fluids. Most of the sodium in the human body is present in the extracellular fluid, i.e., in the interstitial fluid between cells, or in blood plasma. Chloride is its anion. Cells have the capacity to maintain high gradients of sodium and potassium across their membranes, potassium being the predominant cation within cells. Sodium is the main single cation in the extracellular space and has a predominant effect on the amount of water held in that space. Plasma contains about 142 mmol of sodium chloride per litre (8.3 g/l); this concentration is normally maintained within close limits, more than 150 mmol/l usually being found only in cases of disease. A very precise control of sodium balance is therefore essential to maintain an extracellular volume appropriate to the circumstances.

Sodium balance is maintained by the control of the amount of sodium and water excreted daily and not by the control of absorption. Fluid is normally excreted as follows:

(a) by transpiration through the skin: approx. 250 ml per day;

(b) in faeces: approx. 150 ml per day;

(c) in urine: approx. 1 500 ml per day.

The concentration of sodium chloride in the transpired fluid varies from 20 to 50 mmol/l. Between 5 and 12.5 mmol of sodium chloride is therefore excreted through the skin each day. The amount of sodium chloride excreted in faeces ranges from 0.25 to 8 mmol per day. However, 90−96% of all the sodium chloride that leaves the body is excreted in the urine. Regulation of the sodium content and osmolality of the extracellular space is thus achieved through control of sodium chloride excretion by the kidneys.

During acclimatization to heavy work in hot climates, there is initially a substantial loss of salt in the perspiration with the risk of ill effects and even death. If the salt intake is not adequate to cover this loss, the concentration of salt in the perspiration subsequently falls − markedly so if the intake is relatively low.

The first step in the excretion process, which also has the purpose of eliminating waste products from the blood, consists of an ultrafiltration process in the renal glomeruli in which low-molecular-weight substances such as salts and urea are removed from the plasma. The second step is a substantial reabsorption of sodium chloride, other salts and water from the kidney

tubules into which the filtrate has passed. This reabsorption prevents substantial loss of the salts while enabling waste substances to be concentrated into and discharged with the urine.

Normally about 170 litres of blood plasma per day are filtered by the kidneys of adults and about 99% of the filtrate is reabsorbed by an active process against a concentration gradient. In infants, however, the ability of the kidney to reabsorb fluid against such a gradient is not yet fully developed.

The intake of sodium is not physiologically controlled: more than 90% of the sodium in food is absorbed. Intake is therefore dependent on food composition and on eating and cooking habits. Much less is needed than is commonly taken. In some non-European populations, for example, less than 1 g of sodium chloride is consumed per day without a sodium deficit occurring. Indeed, the minimum requirement for sodium chloride is estimated to be only about 2 mmol per day (120 mg NaCl per day). That the human organism is capable of maintaining sodium balance with a very low consumption of sodium chloride is confirmed by observations on patients on strict salt-restricted diets, who excrete less than 10 mmol of sodium per litre of urine.

As already noted, Europeans have an intake of up to about 20 g of sodium chloride per day. In the healthy adult the excess, i.e., the greater part of the intake, is excreted, largely by the kidneys, without any apparent ill effects. In infants, because of the immature function of their kidneys, and in a number of diseases, affecting some 3% of the population, a high sodium intake can be detrimental (see p. 20). The possibility that insidious ill effects occur more widely, however, is the main reason for concern about sodium intake.

Adverse Effects of Sodium on Health

Acute effects

Because of the efficiency with which the kidneys excrete it, sodium is not an acutely toxic substance. The LD_{50} of sodium chloride in rats is said to be 3 000 mg/kg (USDHEW) or 3 750 mg/kg (34). Hypertonic solutions produce violent inflammation of the gastrointestinal tract, leading to vomiting and elimination of much of the salt. Effects in animals include convulsions, muscular twitching and rigidity, cerebral and pulmonary oedema, stupor and death.

The immaturity of the infant kidneys means that acute effects are most likely to occur in small children. Death is reported in 6 of 14 infants given a formula to which, by mistake, salt was added instead of sugar; the concentration reached was 21.140 mg/l (35). A dose of 1 g of kitchen salt per kilogram body weight can be lethal in small children (36).

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Severe deterioration of chronic congestive heart failure can naturally result from (excessive) salt intake. Ill effects due predominantly to drinking-water high in sodium have been documented. One patient was admitted to hospital when he changed his source of water to one containing 4 200 mg/l of sodium. Another patient, whose health repeatedly deteriorated at home, was found to be drinking water containing 3 300 mg Na/l.

Hypernatraemia and "sudden infant death"

Fluid loss without adequate replacement, for instance in infants with gastrointestinal infections, leads to dehydration with raised sodium concentration and increased osmolality in the plasma (hypernatraemia with hyperosmolality). A severe haemorrhagic encephalopathy is a characteristic post-mortem finding in infants dying in that condition. The long-term consequences of hypernatraemia have been investigated and evidence has been found of permanent neurological damage in a high proportion of cases (37).

In recent years it has been suggested that modern feeding practices (and the sodium content of drinking-water) may cause, or at least contribute to, hypernatraemia and hyperosmolality. The use of powdered cows' milk, and the early introduction of solid feed, presents the artificially fed infant with more protein and higher concentrations of sodium than occur with breast feeding. Cows' milk contains over 500 mg/l of sodium, about three times as much as human milk, although the modified feeds now available, when reconstituted with distilled water, keep sodium content below 300 mg/l. The protein content of cows' milk is also higher, so that more urea has to be excreted. With the increased solute load, the resulting obligatory urinary water excretion is higher with artificial than with breast feeding although the intake of water is the same. The infant's margin of safety in the face of fluid loss is therefore less (38). Matters are worse if mothers prepare over-concentrated feeds, as is common, or if powders are made up with water containing high concentrations of sodium.

As already noted, the immature kidney of the infant is not as effective as that of the adult in maintaining plasma osmolality in the face of a heavy solute load. Higher mean plasma osmolality has been demonstrated in artificially-fed than in breast-fed infants, with even higher figures for those who are already on solid food. Forty per cent of the last group exceeded 300 mOsm/l plasma, the conventional level of hyperosmolality (39).

One important adverse feature of hyperosmolality is that an infant can become critically deprived of water without the usual signs of dehydration being apparent. Treatment may therefore be delayed.

A number of important questions arise. Does hyperosmolality with hypernatraemia, due to artificial feeding or high sodium intake, lead to more severe illness in infants who happen to develop gastrointenstinal infections etc.? May it be responsible for death or permanent neurological damage

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in such infants? May it be a cause of the unexplained deaths which sometimes occur in infancy? If the answer to any of these questions were affirmative, the key question would be: does the sodium in drinking-water contribute to these effects?

The hypothesis that hypernatraemia may be associated with "sudden infant death" was examined some years ago (40). The concentrations of sodium, urea and other substances in the vitreous humor of the eye were measured at necropsy in 40 infants who had died unexpectedly. In 17 infants sodium concentrations were above the range expected, with a similar figure for urea. A higher proportion of those in whom no other major abnormalities were found showed increased concentrations, while all 5 children who had no reported symptoms before death had markedly increased concentrations. Control values were not reported.

The medical group of the Working Group noted that evidence that a raised sodium intake is a factor in "sudden infant death" is limited and indirect and is not generally thought to be at all conclusive. Given that regulations requiring a reduction of sodium in infant feed have been widely introduced, the group agreed that there is no adequate evidence on this point at present on which to base a recommendation for a standard or guideline for sodium in drinking-water. For healthy infants, babies and children, the group simply recommended that total sodium intake be kept as low as possible. It also recommended that research should be undertaken to determine whether hypernatraemia and hyperosmolality are more common in places with a high concentration of sodium in tap water.

Sodium and the prevention of primary hypertension

Introduction

The role of sodium in the pathogenesis of hypertension has been a matter of scientific controversy for some time. The evidence comes from various sources, viz:

(a) experimental findings in animals;

(b) experimental findings in human volunteers;

(c) epidemiological studies;

(d) clinical studies of reduced sodium intake in established hypertension.

The medical group discussed the evidence primarily on the basis of reviews and reports (6, 41, 42, 43, 44). Original scientific papers individually considered during the meeting will be referred to in the following account.

Experiments in animals

It has been repeatedly demonstrated that a high intake of sodium chloride induces hypertension in rats within a few months. The effect has also

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been demonstrated in dogs and monkeys but not in rabbits (45). Independent, critical reviews of the original papers in a number of countries put the validity of the evidence virtually beyond doubt.

The experimental work has also demonstrated a genetic factor in the pathogenesis of raised blood pressure in rats; selective breeding has developed sodium-sensitive and sodium-resistant strains.

There is some evidence of a dose-response relationship, but although it has been indicated that the effect of sodium on blood pressure may be manifest from above minimal doses of sodium (42), the relationship is actually very difficult to quantify. The evidence suggests in fact that sodium-sensitive strains do not develop hypertension on a standard diet. There is some evidence that even brief exposure to a sodium-rich diet in very young sodium-sensitive animals leads to hypertension.

The pathophysiological changes during excess sodium intake in experimental animals occur in two successive phases. Phase 1 is characterized by expansion of extracellular fluid, including plasma, with an increase in cardiac output and a decrease in total peripheral vascular resistance. There is only a small rise in arterial pressure, if any, because of a corrective response by the baroreceptors. Phase 2, occurring after one to several weeks, shows a gradual rise in arterial pressure together with a reversal of the initial rise in cardiac output. Sodium and fluid balance is partly restored in this period. This conversion of an increased flow pattern into an increased resistance pattern is thought to be due to a self-correcting mechanism related to tissue perfusion; the increased flow is no longer accepted by the organs and tissues, which respond by an increase in total peripheral vascular resistance. The strength of this delayed response overcomes the initial baroreceptor effect and blood pressure is allowed to increase. The partial restoration of sodium and fluid balance is due to increased excretion of urine by the kidneys because of the raised blood pressure. Thus the chronic phase of salt hypertension is characterized by raised blood pressure with normal cardiac output and practically normal body fluid volumes. Plasma sodium content is not significantly different from normal.

The medical group acknowledged that results of experiments in animals can never be extrapolated completely without reservation to man. However, in the view of the group, the number of species affected, the consistency of the effects and the relationship of dose and length of exposure to effect gave considerable grounds for confidence that the findings are likely to be applicable to man. It was therefore the consensus view that the evidence of the animal work, even taken alone, should be accepted as strongly suggestive of an effect of sodium intake on the development of hypertension in man. The group was less confident about extrapolating from the important finding of increased sensitivity in immature animals, until this had been more widely confirmed. Nor was it prepared, on the basis of the animal work, to hazard conclusions about the threshold of any effect in man.

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Studies in human volunteers

Some reports in the literature "indicating that large daily intakes of NaCl will increase the blood pressure of nonhypertensive individuals" have been referred to, but these also comment that "failure to see such acute elevations appears to have been a more common experience" (*42*). The medical group considered recent work (*46*) in which 8 volunteers took high, medium and low salt diets for at least 4 weeks each, without effect on their blood pressure. The authors themselves comment "that the stimulus may not have been applied for long enough and that the individuals selected may have been relatively salt insensitive". They go on to point out that "most people in western societies ingest a high salt diet from infancy yet persistent hypertension is uncommon until the fourth decade". Acute experiments in volunteers are unlikely to be helpful and it is questionable whether prolonged experiments in communities where a low salt intake is common would be proper. Although some rise in mean pressure does occur before the fourth decade, it may be noted here that in respect of latency the animal data and the occurrence of severe hypertension in humans show different patterns.

Epidemiological studies

The majority of studies reviewed correlate blood pressure with measures of total sodium intake rather than the concentration of sodium in drinking-water and are of course based on population groups rather than on individuals.

Cross-cultural comparisons. A very low prevalence of hypertension and no increase of blood pressure with age are features of a striking range of non-westernized population groups scattered across at least five continents; the National Academy of Sciences report comments on studies in 19 groups. These groups contrast with westernized populations in very many ways but one of the most constant features is a low consumption of salt. When salt intake has been measured, it has generally been below 2 g per day, although the diets of the groups vary greatly in other ways. Some of the studies have contrasted "low-salt" groups with generally similar neighbouring groups with a "high-salt" tradition or have compared members of a group who have adopted western customs, including a high salt intake, with their traditionalist fellows. In all the studies reviewed, the higher salt intake is associated with a greater prevalence of hypertension, increasing with age. Several studies have taken account of other factors which may influence blood pressure, but factors such as obesity, nutritional deficiency or debilitating disease do not appear to be clearly related to prevalence of hypertension.

A number of studies include information on groups with salt intake intermediate between the "low-salt" and westernized "high-salt" patterns.

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The Working Group noted that a very rough and ready dost-effect relationship was suggested by this group of studies, starting (very approximately) from an intake of 3 −4 g salt per day.

Some striking results have been published (*43, 47, 48*). Six groups were studied in the Solomon Islands, closely related in origin, but now westernized to different degrees: different prevalences of hypertension correlated closely with salt intake but not body weight. The Pukapukas were compared with the Rarotongas on the Cook Islands: the first group had an intake of 3.5 g per day, blood pressure was raised in 3% of males and there was no rise with age; among the second group, with double the intake, 28% of males had an increased blood pressure and an increase with age of the same order as would be expected in Europe. There were no significant differences in weight or health between the groups.

Although observations cannot be fully controlled for other factors in this form of study, the Working Group noted the very strong consistency of the findings across a variety of cultures and climates and the apparent uniformity of the effect of acculturation.

Studies of total intake in individuals. A number of studies in Europe and the USA have compared salt usage in patients with hypertension with salt usage of controls or have measured blood pressure in groups consisting of low and high salt users (often crudely assessed). Although a positive result has been reported, it is admitted that this has not been generally confirmed. It is suggested that this may be due to the relatively high intake of virtually all westerners and many individuals being genetically insusceptible. It is also suggested that it may be intake in childhood which is critical; no studies on this important point are reported in the reviews.

Studies of sodium intake from drinking-water. Reports of two direct epidemiological studies claiming to demonstrate the differences in average blood pressure levels in communities supplied respectively with water of high and low sodium content were considered. One of these studies is reporting the blood pressures of high school pupils in two communities in Massachusetts (*49*). The other is reporting the blood pressures of those between 16 and 60 in two communities in the Soviet Union (*50*). Even drinking-water with a high sodium content provides only a relatively small proportion of the sodium intake of Europeans and North Americans who are not on a salt-restricted diet and, even assuming that sodium intake and hypertension are related, it would not be readily anticipated that an association of blood pressure with the concentration of sodium in water would be demonstrable. These two studies suggest a strong relationship, however.

The full report of a study by Calabrese & Tuthill (*51*) is not yet published but was seen by the Working Group. These workers studied two neighbouring communities, alike in most ways but with sodium in their

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drinking-water at respectively 8 and 108 mg/l. They chose to study high school children in order to avoid many of the confounding factors to be expected in an adult population. Detailed information was obtained from each individual on factors known to be associated with variations in blood pressure and on consumption of salty foods. Several precautions were taken to obtain valid blood pressure measurements. The data were analysed in two separate ways to eliminate the effect of the other risk factors.

Some 300 individuals were studied in each community. Mean blood pressures were higher in the high sodium community. The differences between the means in the two communities, adjusted for 18 other variables in a one-way analysis of covariance, and the associated probabilities are reproduced in Table 13.

Table 13. Difference in blood pressure between two communities, with 8 and 108 mg NaC/l respectively in drinking-water

	Difference of means Hg	p value
Female systolic	4.82	< 0.01
Female diastolic	4.31	< 0.001
Male systolic	4.78	< 0.001
Male diastolic	1.77	< 0.078

The authors advocate caution in interpreting the results. Other factors, particularly other substances in water, may have been missed and they are not satisfied that they avoided bias in the observers. Further work is under way on metal-ions in the water. The study is to be repeated in another group of students and diet is likely to be studied in greater detail.

The report of the other study (50) available to the Working Group gives less detail. A comparison was made between 1 809 individuals using well water within the WHO limit for chloride and 1 448 using water which exceeded that limit by 2–5 times. Hypertension (BP 160/95 in those over 20) was present in 12.4% of the second group but in only 3.4% of the first. A p value of less than 0.001 is reported. No control for other factors is mentioned.

A study in Romania has shown a similar result (52).

A study from Texas was reported briefly to the Group; in this study a high sodium/calcium ratio, rather than a raised sodium level as such, appeared to be related to an increase in blood pressure.

The Working Group agreed that conclusions should not be drawn from these studies taken in isolation. The possibility that water with a high sodium content encourages a taste for a high-salt diet, or that some other factor in water is responsible for the results reported, requires further study.

Clinical studies

It has long been accepted that severe restriction of sodium intake is an effective treatment of hypertension but it must be noted that this is true of other forms as well as of primary hypertension. The Working Group concluded that while evidence from studies of patients with hypertension is compatible with the hypothesis that high sodium intake induces hypertension in susceptible individuals, it is in no way a proof.

The mechanism whereby diuretic drugs reduce blood pressure is controversial and no conclusions about the role of sodium in the pathogenesis of hypertension can be drawn from the effectiveness of these drugs.

Sodium in the pathogenesis of hypertension – conclusions

The clearest evidence comes from the animal studies. Positive results have not been obtained in all species in which hypertension can be induced by some means, however, and there is the usual doubt about whether the results can be extrapolated to man. The cross-cultural studies in man are very striking but no studies give clear evidence of an effect of total sodium intake on the pathogenesis of hypertension within the western culture. The studies of the effect of sodium intake in water are also striking, but limited and open to alternative interpretations.

The Group nevertheless agreed that the aggregate evidence of an effect from sodium is impressive and must be taken seriously.

The question whether sodium exerts an effect entirely or principally in infancy or childhood, or whether it continues to act throughout life, is a vital one in determining preventive measures but on this point the evidence is inadequate.

The Group agreed that any preventive measures would predominantly fall to those concerned with diet and with food processing, and that involvement of those groups and of clinical scientists with a special knowledge of hypertension, in addition to toxicologists and epidemiologists, was essential in reaching a judgement on the evidence and recommending appropriate action. Any action relating to sodium in water, with which the Group was primarily concerned, would be a secondary matter. For its part, however, the Group agreed that there were now persuasive arguments in favour of beginning a progressive stepwise reduction of total sodium intake; for example, those responsible might plan initially for a reduction to an intake of 6 g/day, perhaps with a long-term goal of 3 g/day for adults, depending on

the results of further research. In this situation it was necessary to consider whether action should be taken on sodium contributed by drinking-water.

The Group noted the argument in one of the reports (6) that sodium from water should be limited to 10% of total intake. It was accepted that if the population were persuaded to cut down on salt in its diet, it might well resent high levels of sodium in its drinking-water. It is clear, however, that the suggested figure of 10% is arbitrary.

In these circumstances the Group agreed that it should not recommend any specific standard for sodium in water. Its view was that because every community must use the drinking-water locally available, sodium concentrations should be maintained at the lowest practicable level and action to reverse the trend towards increasing sodium in water supplies should be encouraged everywhere. The precise level of sodium to be tolerated in a water supply, and the actions to be taken to observe that level, would vary according to local circumstances. The level might be calculated as in the following example. If the above-mentioned goals of 6 and 3 grams for total daily intake of sodium chloride were accepted, and if it were decided that the contribution of water to total intake should be (for example) not more than 10%, then the maximum quantity of sodium (as the ion) in each litre would be 120 mg and 60 mg respectively. To illustrate the principle further, Table 14 gives examples of the sodium concentrations which would be acceptable in drinking-water according to the goal chosen (in any community) for total sodium chloride intake and according to the maximum contribution which water is allowed to make to total intake.

Table 14. Sodium contributed by drinking-water — mg Na ion[a]

% contribution from drinking-water	Goal for total intake 6 gram NaCl per day		Goal for total intake 3 gram NaCl per day	
	daily intake from Na mg	Na mg/l in tap water[b]	daily intake from Na mg	Na mg/l in tap water[b]
1.0	24	12	12	6
10.0	240	120	120	60
20.0	480	240	240	120
50.0	1 200	600	600	300

[a] These figures are expressed as sodium ion; the quantity of sodium chloride is approximately 2½ times greater.

[b] Assuming an intake of 2 litres per day.

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The Group considered whether separate supplies of low-sodium water should be made available for small children, because of the possibility that critical events in the pathogenesis of hypertension take place at an early age and because small children consume more water, and therefore more sodium, in relation to body weight than do adults. The consensus of opinion among the Group was that it would be psychologically harmful, and liable to undermine public confidence in the water supply, if advice were given, generally or locally, not to use tap water for children.

In deciding that it could not on medical grounds specify a figure applicable in all circumstances related to the pathogenesis of hypertension, the Working Group did not imply that the concentration of sodium in drinking-water is a matter of indifference. Some waters contain high concentrations which should be widely regarded as unacceptable. The Group emphasized that, in the present state of knowledge and in fairness to those who choose to adopt a low salt intake, and also because tap water is used for those who may be critical groups, such as children, concentrations should be maintained at the lowest levels practicable. An appropriate limit, however, depends on policies concerning, for instance, salt in processed food and public relations considerations. Even where a limit is decided on, water suppliers should be encouraged to reduce sodium as far below that limit as is practicable.

Further research

Research should continue to be conducted to clarify the relative roles of sodium and other factors which may contribute to the pathogenesis of hypertension in westernized societies, with emphasis on their interactions. As already indicated, however, the Group does not consider that the first stages of action should await the completion of such research.

The Group recommended that every effort should be made to devise thorough and coordinated programmes of research which would have as good a chance as possible of resolving the questions at issue. At the same time a reasonable replication of findings is needed.

Research should be directed at individuals, properly selected so as to be representative of a variety of defined populations. Cross-sectional studies at the ages when the tendency to hypertension becomes manifest should be complemented by long-term prospective studies which measure sodium intake from infancy. All forms of intake should be determined quantitatively. Studies should allow for proper control of other "risk factors" involved in hypertension. A special study should be made of groups or individuals in western society who have a habitual salt intake below 3 g/day (or as near as possible to this level) and do not differ genetically or in their life style, etc. In particular, studies of siblings with different salt consumption patterns would be especially desirable.

The effects of programmes to reduce sodium intake should be carefully evaluated. Every effort should be made to conduct controlled trials of low salt intake in the apparently healthy, either where local medical or general opinion does not support a full programme, or else to investigate the effects of a more severe reduction of intake than forms part of such a programme.

In spite of the difficulties, studies of the effects of limiting salt intake in infancy should be given priority.

The effects of the sodium content of water on salt preference and consumption should be studied.

If the case for a severe reduction of total sodium intake becomes fully established as a result of further epidemiological research, it will probably be necessary to reduce sodium concentrations in a significant number of water supplies, but this will not be easy to achieve. In the Group's opinion, such an outcome of further research is not at all improbable. It is therefore recommended that those concerned should already take steps in preparation for such an outcome, so that action could be taken speedily when the findings become available, should they justify it. Such steps might, for example, involve the support of research and development on methods of desalination and of limiting contamination by sodium compounds.

Sodium and the prevention of other diseases

Coronary heart disease, heart failure, stroke, renal failure and intermittent claudication are especially common in people with hypertension. It might be that elimination of one cause of hypertension would lessen morbidity and mortality from these other diseases, although the evidence is clearcut only in the case of stroke. The point simply emphasizes the importance of the prevention of hypertension. There is conflicting evidence on the association between sodium in drinking-water and deaths from cardiovascular disease. A note from the US Environmental Protection Agency, which was made available to the Group, quotes a review (53) in which an association between high sodium and soft surface waters is reported. The note speculates that the protective effect of hard water could in fact be an adverse effect of sodium. The note also reports that, during a three-year period when the city of Dallas in Texas used a hard but high-sodium water, heart disease deaths for all categories rose, while there was no such change in a neighbouring city whose water supply remained unchanged. However, work in progress in the United Kingdom so far shows no statistically significant association between sodium in water and deaths from cardiovascular disease, in contrast to a relationship of such deaths with soft water. Analyses employing mortality statistics, which are the only statistics of illness that are available in detail on a representative basis, obviously cannot distinguish between effects due to an increased incidence of hypertension and effects due to increased severity, nor between these effects and independent effects

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on heart disease, for which hypertension is a risk factor. A prospective study of middle-aged men, which should resolve some of these questions, has recently been started in the United Kingdom.

Taste

General considerations

According to the WHO definition, health implies not only the absence of disease or infirmity but also the physical, mental and social wellbeing of individuals. In this context the taste of drinking-water is an essential aspect of the health effects of water constituents. Furthermore, it has been shown that persons rating the taste of their drinking-water as bad consume only half as much as those assessing the taste as good (28).

It is generally agreed that drinking-water should be tasteless to the majority of consumers (27). For this purpose it has been shown that the salt composition of drinking-water should to some extent resemble the salt content of saliva to which the taste buds in the oral cavity are adapted (54). Changes in the salivary salt content will alter the detectability of salt in water (55). The average sodium content of saliva is 300 mg/l (13 mmol/l), ranging from 78 to 600 mg/l (3.4 – 26 mmol/l) (56).

As taste sensitivity varies widely from person to person, any maximum acceptable level of taste impairment should not be based on the "average member" of the population served by a supply, but on the most sensitive minority within that population.

Taste threshold concentrations of different sodium salts in water

The Taste Threshold Concentration (TTC) for the sodium ion depends on the corresponding anion, as shown in Table 15. Sodium carbonate has the lowest TTC and sodium hydrocarbonate the highest TTC of the sodium salts which may be present in appreciable amounts in drinking-water.

It should be noted that the result of the TTC determination can be influenced by the salt concentration of the water used for rinsing, which is not usually indicated adequately, and the combined presence in drinking-water of different sodium salts as well as other salts can result in additivity or masking effects (59).

Relationship between taste assessment and sodium concentration

The taste assessment was investigated of distilled water to which different amounts of sodium salts were added; the water was assessed by a panel of 52 judges, with a 5-category taste scale (60). The categories ranged from "good" via "not perceptible", "weak, hardly offensive" and "offensive"

Table 15. Taste Threshold Concentrations, in water, of some
sodium salts (*57, 58*)

Type of salt	TTC mg/l	Average TTC of the sodium ion	
		mg/l	mmol/l
Sodium carbonate	30— 80	21	0.9
Sodium chloride	320— 350	152	6.7
Sodium nitrate	700	189	8.2
Sodium sulfate	370—1 000	220	9.6
Sodium hydrocarbonate	1 100	422	18.3

to "bad". To these categories the following taste scale values could be attributed respectively: 0.00, 0.74, 1.41, 2.07 and 2.87.

The results for sodium chloride and sodium hydrocarbonate, as shown in Fig. 4, indicate that an optimal taste is obtained for $NaHCO_3$ at below 1.5 mmol/l. The taste of these salts was assessed as "offensive" by the average

Fig. 4. Taste assessment of aqueous solution of NaCl and $NaHCO_3$
by a panel (*60*)
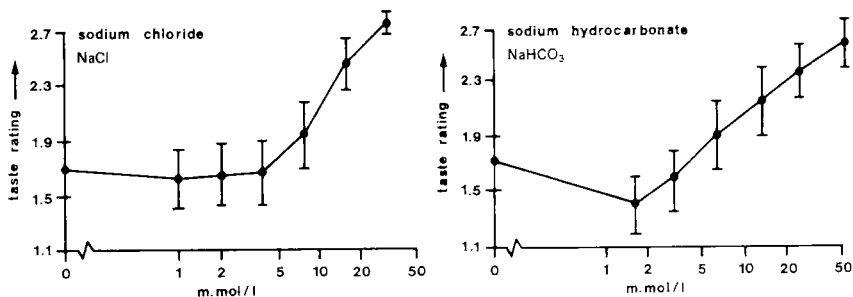
panel member at a NaCl concentration in distilled water of 465 mg/l (184 mg Na/l) and a $NaHCO_3$ concentration of 630 mg/l (230 mg Na/l). Furthermore, the relationship between taste assessment and salt concentration is quite different for different salts.

Guidelines for setting a standard for sodium in drinking-water to prevent taste impairment

Although the average sodium content of saliva is reported to amount to 300 mg/l, in water the Taste Threshold Concentration of sodium present in salts such as sodium chloride and sodium sulfate has been reported to be 130–140 mg/l. On the other hand a minimal quantity of about 35 mg/l of sodium seems to be required to prevent the water from having a flat taste.

For taste reasons it is desirable that a minimum concentration of salts (including sodium salts) is present in drinking-water, but sodium should be limited to levels below 184–230 mg/l. This limit seems desirable in view of the fact that at 184–230 mg Na/l a panel of 52 judges found the taste of normally present sodium salts (NaCl and $NaHCO_3$) offensive, and in view also of the need to base standards on the most sensitive minority within the population. Generally, drinking-water should not contain more than about 200 mg sodium per litre if it is not to have an offensive taste.

Salt Restriction as a Medical Treatment

The needs of patients

A salt-restricted diet is an established treatment for patients with hypertensive disease, congestive heart failure and some less common diseases. It is effective even for heart failure which is not due to hypertension, as well as for hypertension of various known causes, and the issue is to some extent separate from the role of sodium in the pathogenesis of these conditions. There is general agreement that a salt-restricted diet is effective, and the only controversial points are whether sufficiently severe diets are practicable and whether diets or diuretic drugs form the treatment of choice. Diets are reported to be effective in some cases of drug-resistant hypertension. In any case salt-restricted diets are widely used in some countries, and because of the very low intakes which may be involved, the needs of these patients in relation to water supply must be given separate consideration.

Some 2% of the Dutch population (6) and 3% of Americans (44) are said to be on salt-restricted diets. In one view, as much as one-third of these should be on strict restriction to not more than 500 mg sodium (1 250 mg as salt) per day (61).

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It is not practicable to provide an adequate diet that contains less than about 460 mg of sodium per day. It follows that the maximum contribution of water to sodium intake must be set at 40 mg per day. Assuming consumption of 2 litres per day, the water consumed by these patients must not contain more than 20 mg of sodium per litre. Furthermore, a concentration as close to zero as possible, to allow more scope for variety in the diet, is obviously desirable.

For those on a less severely restricted diet, the requirement cannot be so closely defined. For some patients restriction of intake to 3 or 6 grams of salt is sufficient, and for them the considerations are those already set out in relation to prevention.

Information of health organizations

The Group considered whether to put the figure of 20 mg/l of sodium forward as a recommended guideline. It was suggested by some members that guidelines should relate only to the needs of the healthy. The general view, however, was that although suppliers could never hope to meet all special needs, they should be expected to endeavour to meet the needs of those with very common diseases. On the other hand a concentration of 20 mg/l would be totally impracticable for a large number of suppliers and there would be nothing to be gained by defining such a guideline.

It seems likely that physicians are not always aware that there may be relatively high concentrations of sodium in water. Steps should be taken to rectify this. The Group recommended that where sodium is above a critical concentration in a water supply, or is liable to rise above it from time to time, the water supply organization should inform the appropriate health organization of this situation and a record of the current concentration should be made available in a place convenient for individual physicians. The Group thought that 20 mg/l was an appropriate critical level but it might vary from place to place in the light of local medical practice and diet.

In the Group's view, the needs of these patients reinforce the case for achieving the lowest concentration of sodium in water supply that is practicable in local circumstances.

Control

Source selection

The careful siting and testing of wells can be very important in controlling sodium levels in water. To prevent the use of high sodium and chloride waters it is essential to select and protect a suitable water supply source. As civilization has progressed the selection of pure water sources has become

more difficult; even ground water sources have become contaminated. It is usually still possible to locate water sources, but at ever increasing cost.

We must protect the sources we have from road drainage, industrial and municipal effluent, and spills of toxic chemicals. The price of so doing is high and continuing vigilance is essential. Strict measures are required to control pollution, and staffs of responsible agencies must be adequate to ensure high standards. There is no substitute for frequent on-site inspections.

Controlled pumping

Salt water intrusion into underground aquifers is a common reason for failure of wells near bodies of salt water. Along the sand bars on which many coastal communities are built the common water supply source is the drilled or gravel packed well. Through overpumping many of these have become saline and often been abandoned; this has necessitated drilling of a new well or provision of a costly desalination process. Salt water intrusion can be prevented by underpumping, development of additional sources and natural and artificial recharge. An example of underpumping is the British system of monitoring the encroachment of sea water into test wells and using the sensing elements to control the rate of pumping from the producing wells.

Artificial recharge

Salt water intrusion can be countered by a system of natural and artificial recharge. In Long Island, New York, for instance, large concrete surfaces have been constructed to catch rainwater and return it to the sandy soil. Long Island communities have depended upon small sewerage systems rather than large central sewage treatment plants and trunk sewers which would convey ultimately irreplaceable effluent to the ocean. By using intermittent sand filters as the last treatment unit, with the effluent entering the underlying ground, Long Island remains a source of good-quality ground water.

In the dune area of the Netherlands salt water intrusion from the sea was aggravated by overpumping in response to increased demand for drinking-water. Pre-treated river water is now being artificially recharged on a large scale.

Surface sources

A variation of salt water intrusion is the encroachment of salt water in tidal estuaries and rivers. Especially in times of low flow the sodium and chloride content of the water can be increased to an unacceptable level at intakes situated downstream. A common method of low flow augmentation to control salinity is the provision of reservoirs from which certain amounts of water can be released. The other possibility is to re-site the intake upstream.

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Especially in highly urbanized and industrialized areas the sodium content of the main rivers is increased by pollution. When these rivers are used for extraction of drinking-water, measures must be taken to cut down pollution.

Alternatives to heavy use of salt for de-icing roads

As has been described elsewhere, a major source of sodium in drinking-water has been the use or rather misuse of road salt. Three methods of minimizing this are:

(1) to use a substitute for sodium chloride;

(2) to change the pattern of use of sodium chloride;

(3) to exercise care in storing salt.

Let us consider the last method first. In a small town in Massachusetts huge piles of salt were for many years stored on bare ground at a low spot behind a public works building. Recent tests have shown that individual water supplies within a 1 000-foot radius from that spot are contaminated with sodium to levels of 230 mg/l and chlorides to 600 mg/l. The town is now required to store the salt on a concrete platform and cover it with plastic sheeting. This is not an isolated case.

Changes can easily be made in salt application and snow removal practices. For example the "bare pavement" philosophy need not be followed if lower speed limits are adopted and enforced. Snow removal crews can be so managed that they start work at the first snowfall, not after it has been snowing for hours. It has also been found that road surfaces can be cleared even when the amount of salt mixed with sand is significantly reduced. Similarly, there is no need to spread raw salt on damp road surfaces in anticipation of freezing conditions: plain sand is quite effective. Alternative chemicals which offer an economical and permanent solution have not yet been found. Calcium chloride has admittedly superior de-icing properties but is more expensive. Glycols have been used at airports but the greater quantities needed for highway safety make them too expensive for this purpose. There is a pressing need for a safe, economical alternative to salt.

Desalination

For the purposes of this discussion the desalination of sea water will not be covered except to say that by distillation units fresh water of very low sodium and chloride content can be produced at fairly low cost, with electricity as byproduct. Costs vary with the availability and cost of fuel. In the Middle East, where waste oil is readily available, costs could be lower. Water thus produced will frequently need to be blended or otherwise treated in order to overcome corrosivity. Pure water can also be produced by solar distillation of brackish water.

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However, conventional or solar distillation may not be the most economical (or desirable) method for desalination of brackish water. Alternative methods are zeolite (Z), ion exchange (IX), reverse osmosis (RO) and electrodialysis (ED), used singly or in combination. For the purposes of this discussion brackish water is considered to contain more than 1 000 mg/l TDS. Table 16 illustrates the results as well as the comparative costs of demineralizing water by the methods indicated. The communities in question are in the USA and costs are projected in terms of 1977 currency.

Table 16. Demineralization costs in a number of communities
in the USA, using different methods

City	Method	Raw water quality		Treated water quality		Cost c/m³ (US$)
		TDS	Hardness	TDS	Hardness	
A	Z–RO	2 163	1 248	430	5	30.1
B	IX–ED	2 720	1 547	481	100	50.4
C	RO	2 417	1 033	246	125	55.2
D	RO	1 643	725	385	72	34.3
E	RO	3 236	1 512	981	194	25
F	ED	1 100	207	500	90	20
G	IX–RO	1 135	503	400	100	11

European practice demonstrates comparable results.

Sampling and Methods of Analysis

The sodium concentration at the consumer's tap is the ruling factor. Because sodium is a "conservative" parameter not to be changed during distribution, measurement of the sodium content of the water before entry into the distribution system will usually be sufficient, but in cases where the distribution system is supplied by more than one source, the water quality has to be analysed at a number of well chosen delivery points.

The frequency of analysis required depends on the consistency of the water quality at the source and on the treatment process.

If sodium compounds are used in the processing, for instance for softening purposes or pH correction, the quality of the finished water has to be monitored very frequently (daily). If sodium compounds are not used in the processing but the source varies in quality in relation to sodium, frequent monitoring of the source is necessary together with less frequent monitoring

of the purified water. If the source is of a constant quality and no chemical containing sodium is used during the treatment, less frequent analysis (once every 3 months) of the purified drinking-water will be encouraged. In this case the raw water can be monitored instead of the purified water.

Methods of analysis

The accuracy of measurement depends on the sodium level present. To detect trends it is desirable that the accuracy of the method used is 1 mg/l up to a level of 50 mg/l. Above this level the accuracy must be at least 5 mg/l. The detection limit must be 1 mg/l or lower.

In the *Standard methods for the examination of water and waste water* (*62*) two methods are mentioned:

(1) the flame photometry method;

(2) the gravimetric method, in which sodium is precipitated as zinc uranylacetate hexahydrate

$$Na \cdot C_2 H_3 O_2 \cdot Zn(C_2 H_3 O_2)_2 \cdot 3 UO_2(C_2 H_3 O_2) \cdot 6 H_2 O$$
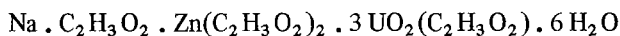
The flame photometry method will satisfy the required detection limit (*63*) but the gravimetric method will not meet this limit and can only be used for higher concentrations.

Other methods are:

(3) atomic absorption spectophotometry, which satisfies the requirements for detection limit and accuracy but is not as sensitive as flame photometry;

(4) the use of ion selective electrodes. This method has the disadvantage of sensitivity to interference. It meets the requirements for detection limit. The method is especially applied in the continuous determination of sodium in unpolluted waters and can be used for monitoring purposes after treatment of water with sodium compounds.

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CHLORIDES

Introduction

The chloride content of water can be an indication of pollution. If the chloride content of surface or ground water is higher than that of surrounding waters, the possibility of contamination has to be considered.

It is impracticable to remove chloride either from a natural source or from polluted water. In conventional drinking-water purification processes the chloride content is not reduced.

Because of its conservative character and because it is easily identified analytically, chloride is often the parameter used in calculating the dimensions of storage reservoirs and other infrastructural works in relation to drinking-water supply. The chloride content of drinking-water, irrigation water or industrial water in most cases is a nuisance. Moreover, it impairs the taste of drinking-water. The chloride ion is obviously one of the parameters that must be determined in drinking-water.

Sources of Chloride in Drinking-Water

Natural

Chloride is widely distributed in nature, generally as sodium (NaCl), potassium (KCl) and calcium $(CaCl_2)$ salts; it constitutes approximately 0.05% of the lithosphere (1).

By far the greatest amount of chloride in the environment is present in the oceans as sodium chloride. Underground, bedded and dome salt deposits have been found in many places in the world.

Pollution

Sodium chloride is used widely in the production of industrial chemicals such as chlorine, sodium chlorite, and sodium hypochlorite. Sodium chloride, calcium chloride and magnesium chloride are extensively used in snow and ice control, and potassium chloride is used in the production of fertilizers (1,2). The presence of chloride in natural waters can be attributed to dissolution of salt deposits (3), salting of highways to control ice and snow (4—8), effluents from chemical industries (9), oil well operations (10) and sewage (11), irrigation drainage (12), refuse leachates (13) and sea water intrusion in coastal areas (1). Each of these sources may result in local contamination of surface water and ground water.

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Processes

Chloride is not removed by conventional water treatment processes.

The chloride concentration of water may rise markedly when chlorine is added for oxidation or disinfection purposes. The use of aluminium or iron chlorides for flocculation purposes will also result in an increased chloride concentration.

Conclusions on treatment processes

For ground water with a low content of organic compounds, ammonium and iron (II) only, addition of 0.1 to 0.6 g/m^3 of chlorine will be sufficient for disinfection. When ground water containing much iron (II) or surface water heavily polluted with colloids is to be purified, considerable amounts of chlorine and iron and aluminium salts (usually chlorides) have to be added, namely up to 40 g/m^3 chlorine, corresponding to 40 mg/l chloride, and up to 0.6 mol/l iron or aluminium, usually corresponding to about 63 mg/l chloride. To avoid a considerable increase in chloride content, flocculation can be carried out for instance with aluminium hydroxychlorides or sodium aluminate.

Instead of breaking-point chlorination, treatments such as aeration and sand filtration can be applied to remove ammonium (*14*).

Levels in Drinking-Water

In many countries a trend towards increasing chloride levels in ground and drinking-water has been noticed. This is also the case for a number of waterworks using surface water from urbanized areas for drinking-water supply. Some examples from European countries are given below.

The chloride content of Amsterdam drinking-water was found to be 50 mg/l in 1948, 112 mg/l in 1963 and 170 mg/l in 1973. For another Dutch town, Leiden, the figures were 44 mg/l in 1948, 98 mg/l in 1963 and 176 mg/l in 1973 (*15*). A considerable increase in concentrations was also found in analysis of drinking-water from Antwerp (Belgium): in 1968 the average chloride concentration was 43 mg/l, increasing in 1976 to 88 mg/l with a minimum of 57 mg/l and a maximum of 131 mg/l (*16*). In Denmark, levels between 0 and 200 mg/l with a dozen stations up to 845 mg/l have been reported (*17*). In the 1976 statistical review of the Austrian Water Supplies, concentrations between 0.3 and 60 mg/l and a maximum of 134 mg/l are reported (*18*). The statistical review (1975) of the Swiss Water Supplies shows chloride concentrations generally between < 0.5 and 25 mg/l and some as high as 70 mg/l (*19*).

Some data from other continents are also available. In the USA, for instance, chloride levels in the 100 largest cities, in 1962, ranged from 0 to 540 mg/l, with an average of 13 mg/l (*20*). A survey in 1969 revealed a chloride range of 0 − 1950 mg/l, with an average of 27.6 mg/l (*21*). Drinking-water data for several Canadian provinces indicate generally low chloride concentrations, often less than 10 mg/l. Of 127 stations in Saskatchewan analysed in 1975, only 1 recorded a chloride concentration higher than 50 mg/l; no stations recorded a level greater than 250 mg/l (*22*).

The South Africa Rand Water Board reported very low levels, between 6 and 19 mg/l (*23*).

Effects on Health

Toxicological effects

The toxicological doses of the chlorides depend on the cations of the salts. Some data are listed in Table 1 (*24*). Apart from these data and the knowledge that the toxicity of chloride salts depends on the cation of the compound, the toxicological information on chlorides is rather sparse.

Less than 1 g sodium chloride per kg body weight has been reported to be lethal in a 9-week-old child (*25*). Gleason et al. report the symptoms of sodium chloride poisoning (*26*). The LD_{50} (rats, 8.5 ± 5.3 hrs) is reported to be 3.75 ± 0.43 g/kg. Hypertonic salt solutions can produce violent inflammatory reactions in the gastrointestinal tract. Symptoms include convulsions, diarrhoea, muscular twitching and rigidity, prostration and death. Dehydration and congestion occur in most internal organs, particularly in the meninges and brain. Death may occur from respiratory failure secondary to acute encephalopathy.

Human infants also show vomiting, thirst, fever and respiratory distress. A distinctive microscopic lesion of the kidney is described: parenchymatous dehydration produces conspicuous shrinking in the convoluted tubules of the renal cortex. Some toxicological data in relation to fish and lower aquatic organisms are also avilable. The acute toxicity level for fish lies between 8.5 and 12 g chloride per litre and for lower organisms a value of 1.3 − 2.3 g/l is reported (*27*).

Organoleptic effects

Chloride ions in high concentration as part of the total dissolved solids in water can be detected by taste and may be objectionable to consumers.

According to the EPA Water Quality Criteria the median chloride concentrations detected by taste, with a panel of 10 to 20 persons, were 182, 160 and 372 mg/l for sodium, calcium and magnesium salts respectively. The detailed results are listed in Table 2 (*28*).

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Table 1. Toxicological data

Compound	Animal	Exposure	Dose	
$CaCl_2$	rat	oral	LD_{50}	1000 mg/kg
	mouse	intraperitoneal	LD_{50}	280 mg/kg
	rat	intraperitoneal	LDL_0	500 mg/kg
$MgCl_2$	rat	oral	LD_{50}	2800 mg/kg
	mouse	intraperitoneal	LD_{50}	342 mg/kg
	rat	intraperitoneal	LDL_0	225 mg/kg
$BaCl_2$	rat	oral	LD_{50}	150 mg/kg
	mouse	intraperitoneal	LD_{50}	54 mg/kg
	man	oral	LDL_0	80 mg/kg
$NaCl$	rat	oral	LD_{50}	3000 mg/kg
	mouse	intraperitoneal	LD_{50}	2602 mg/kg
	man	oral	TDL_0	8200 mg/kg 23d
KCl	guinea pig	oral	LD_{50}	2500 mg/kg
	mouse	intraperitoneal	LD_{50}	552 mg/kg
	rat	oral	LDL_0	2430 mg/kg
NH_4Cl	rat	oral	LD_{50}	1650 mg/kg
	mouse	intraperitoneal	LD_{50}	1300 mg/kg
$CdCl_2$	rat	oral	LD_{50}	88 mg/kg
	rat	intraperitoneal	TDL_0	3 mg/kg
$PbCl_2$	guinea pig	oral	LDL_0	2000 mg/kg

TDL_0 : The lowest dose of a substance reported to produce any toxic effect.

LDL_0 : The lowest dose of a substance reported to cause death in animals when exposed for 24 hours or less.

LD_{50} : The dose which causes death of 50% of an entire population of an experimental animal species.

Table 2. Range of concentration of various salts detected by taste in drinking-water by a panel of 10 to 20 persons.

| | Median | | Range | |
	Salt	Anion	Salt	Anion
KCl	525 mg/l	250 mg/l	350 – 600 mg/l	167 – 286 mg/l
NaCl	300 mg/l	182 mg/l	200 – 450 mg/l	121 – 274 mg/l
CaCl$_2$	250 mg/l	160 mg/l	150 – 350 mg/l	96 – 224 mg/l
MgCl$_2$	500 mg/l	372 mg/l	200 – 750 mg/l	149 – 560 mg/l
Sea water	–	1300 mg/l	–	1150 – 1600 mg/l

The median concentration identified by a larger panel of 53 adults was 395 mg/l for sodium chloride. When compared with distilled water a difference in taste was perceived at a median concentration of 61 mg/l. Coffee was affected in taste when brewed with water containing 210 and 222 mg/l chloride from sodium and calcium chloride respectively.

Data obtained by Lockhard et al. are listed in Table 3 (29).

Table 3. Taste threshold concentration, in mg/l, of salt and ions in water.

	Salt	Cation	Anion
NaCl	345 mg/l	135 mg/l	210 mg/l
KCl	650 mg/l	340 mg/l	310 mg/l
CaCl$_2$	347 mg/l	125 mg/l	222 mg/l

A recent study by Zoeteman (30) concerns the taste assessment of different concentrations of 9 salts in water. The results for NaCl are presented in Fig. 1.

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Fig. 1. Taste assessment of aqueous solutions of sodium chloride.
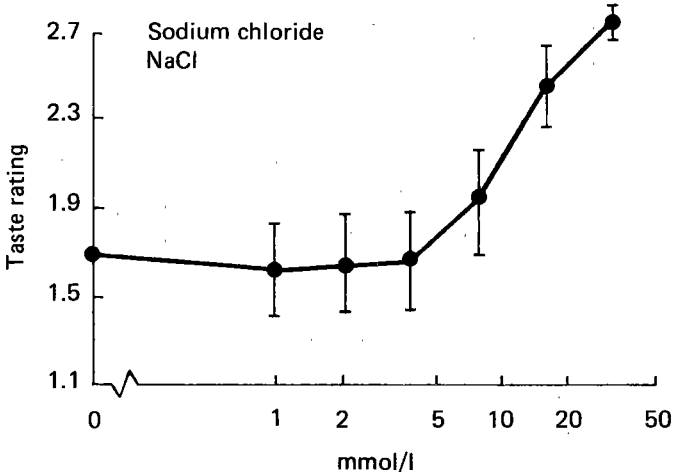
Taste scale:

0.00	Good taste
0.74	No perceptible taste
1.41	Weak, hardly offensive taste
2.07	Offensive taste
2.87	Bad taste

From these data a threshold value of 200 mg/l of chloride can be estimated, above which an objectionable taste is imparted to water.

Other Effects

Effects of water quality on metal distribution systems

The chloride content of water usually has an important effect upon its corrosive character. The chloride ion is small and mobile and contributes greatly to the electrical conductivity of the water. Since corrosion processes involve passage of an electric current through water, the higher the conductivity of the water the more easily this part of the process proceeds. The chloride as such is also of importance. It forms soluble salts with many metal ions, so that no film which could prevent further corrosion is formed on the

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metal surface. It does not, however, follow that the higher the chloride content, the more corrosive the water will be to all metals. For example, aluminium shows widespread slight corrosion in water of high chloride content but severe local pitting corrosion in water of lower chloride content. Pitting corrosion in copper tends to be more localized, and consequently deeper, in water of very low chloride content.

Besides the occurrence of pitting corrosion, the metal solvency of water can be affected by the chloride content owing to the formation of metal chlorides and/or complex metal polychlorides.

Considerations in Relation to Standards or Recommended Limits

As pointed out before, there is from a medical point of view no hard evidence of a direct need for a standard. However, secondary effects may have an impact on public health, such as increased metal concentrations, taste effects, and damage to materials used for transport due to corrosion.

From this point of view it is recommended that the chloride level will not be in excess of 200 mg/l.

This recommendation is to a certain extent in line with the *WHO International standards for drinking-water* (1971) which give a highest desirable level of 200 mg/l chloride for drinking-water. The Group found no evidence to support a maximum permissible level of 600 mg/l and recommended that its use should be discouraged.

Sampling and Methods of Analysis

Sampling

Under usual circumstances the chloride concentration remains constant during distribution.

Chlorine compounds used for disinfection purposes may cause slight changes in the chloride content of distributed water. When there is leakage from the distribution system, however, the chloride content of the distributed water can change considerably.

When measured at the end of the treatment process, the chloride content at the consumer's tap will be usually known also. If the distribution system is supplied by more than one source and if the products of these sources differ in chloride content, the chloride content of the distributed water must be measured at a number of well chosen delivery points.

If chlorine and/or its compounds are used in processing, the chloride content of the purified water must be monitored frequently, e.g. in cases of breaking-point chlorination and iron (III) chloride coagulation. Otherwise

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analysis of the raw water for chloride will suffice. The frequency of this measurement depends on whether the quality of the source is relatively constant, but must be at least three-monthly.

Methods of analysis

The accuracy of measurement depends on the chloride level. To detect trends it is desirable that the accuracy of the method used is 1 mg/l up to 50 mg/l. Above 50 mg/l the accuracy must be at least 5 mg/l. The detection limit must be 1 mg/l.

In *Standard methods for the examination of water and waste water (31)* four methods are given:

(1) The argentometric method (following Mohr), using K_2CrO_4 as indicator, is suitable for use in relatively clear waters when 0.15 to 10 mg Cl^- are present in the portion of the sample titrated.

(2) The mercuric nitrate method. Chloride is titrated with mercuric nitrate, forming the soluble but slightly dissociated mercuric chloride. The excess mercuric ions react with the indicator 2,8-diphenylcarbazone, giving a purple complex.

(3) The potentiometric method. Chloride is titrated with silver nitrate solution with a glass and silver-silver chloride electrode system. During titration an electronic voltmeter is used to detect the change in potential between the two electrodes. The end-point of the titration is that instrument reading at which the greatest change in voltage has occurred for a small, constant amount of silver nitrate added.

(4) A method based on the following principles for application in dynamic automated analysers. The chloride ion displaces the thiocyanate ion from mercuric thiocyanate. The displaced thiocyanate ion then reacts with the ferric ion to give a red-coloured complex, ferric thiocyanate. The concentration of the coloured complex, which is proportional to the original chloride concentration, is measured spectrophotometrically at 480 nm. The range of measurement is $1 - 100$ mg/l chloride.

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CONDUCTIVITY

Introduction

Electrical conductivity is a physico-chemical property of water. It cannot be associated with any one substance in water, since all ions present in water contribute. Since inorganic substances dissociate into ions, electrical conductivity is an excellent overall indicator of the salt content of a water sample.

Conductivity and Compounds Contributing to it

Equivalent conductivity rates of ions

The ions present in water contribute to its electrical conductivity in proportion to their mobility, which increases as the temperature rises (by some 2.5% per $°C$ in the case of HCO_3^- ions and by some 1% per $°C$ in the case of H_3O^+ ions). A reference temperature is therefore chosen ($20°C$), and the values found at other temperatures are converted to the value that would have been found at that temperature.

The ions interfere with each other's mobility, with the result that conductivity does not rise in proportion to increases in the ion concentration. This effect is taken into account by using conductivity coefficients when, for instance, the completeness of an analysis is being checked with the help of conductivity (1).

The conductivity of the ions is referred to a mol/l equivalent in infinitely diluted solution (equivalent conductivity, conductivity factors) and indicated for $18°C$ (scientific purposes), $20°C$ (Federal Republic of Germany) or $25°C$ (USA) (see Table 1).

The conductivity of water can be calculated with the formula:

$$K = \Sigma \, (m_i \, z_i \, \Lambda_i \, f_i)$$

z_i is the valency of ion i,

m_i is the concentration in mol/l of the particles i,

Λ_i is the equivalent conductivity (S/m) (l/mol),

f_i is the conductivity coefficient.

The conductivity coefficient is dependent on the ion concentration. On the other hand it is possible to draw a conclusion from conductivity changes when the ions concerned are known. The conductivity coefficient in the measuring range can be determined by adding known amounts of the ions in question.

Table 1. Equivalent conductivity (S/m) (l/mol).

Cations	18°C	25°C	Anions	18°C	25°C
Na^+	4.26	5.01	HCO_3^-	3.82	4.45
K^+	6.37	7.35	$\frac{1}{2} CO_3^{2-}$	6.05	8.6
NH_4^+	6.36	7.37	Cl^-	6.63	7.63
$\frac{1}{2} Ca^{2+}$	5.04	5.95	NO_3^-	6.26	7.14
$\frac{1}{2} Mg^{2+}$	4.46	5.31	$\frac{1}{2} SO_4^{2-}$	6.87	7.98
H_3O^+	31.5	35.0	OH^-	17.4	20.0

Correlations with other physico-chemical properties

The following four parameters correlate with the solid particles dissolved in water:

(a) electrical conductivity (K);

(b) osmotic pressure (p);

(c) solid residue from evaporation, i.e. total dissolved solids (TDS);

(d) ion strength (I).

Because of the changing interrelations, no strict correlation is possible between the four parameters, but water from a known source often has a consistent qualitative composition, even if the concentrations of the individual substances vary. This applies — as is well known — to ground water and also to certain rivers (2). In such cases factors can be discovered empirically which make possible an approximate recalculation of the parameters.

The following recalculation factors are discussed for:

K in mS/km, TDS in g/m^3 and I in mol/m^3

$$TDS \sim K/6 \text{ or } K/10 \qquad (2,3,4)$$

$$I \sim K/5.6$$

Extensive data from the United Kingdom demonstrate wide fluctuations in conductivity. These are shown graphically in Fig. 1.

Fig. 1 further shows the close correlation between conductivity and TDS and this suggests the use of conductivity measurements as a rapid and reasonably accurate alternative to the tedious conventional determination of TDS.

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Fig. 1. Correlation between conductivity and total dissolved solids

Conductivity (Millisiemens/m³) = 0.548 + 0.143 × TDS
Conductivity (Mhos/cm³) = 5.48 + 1.43 × TDS
Using source means (208)
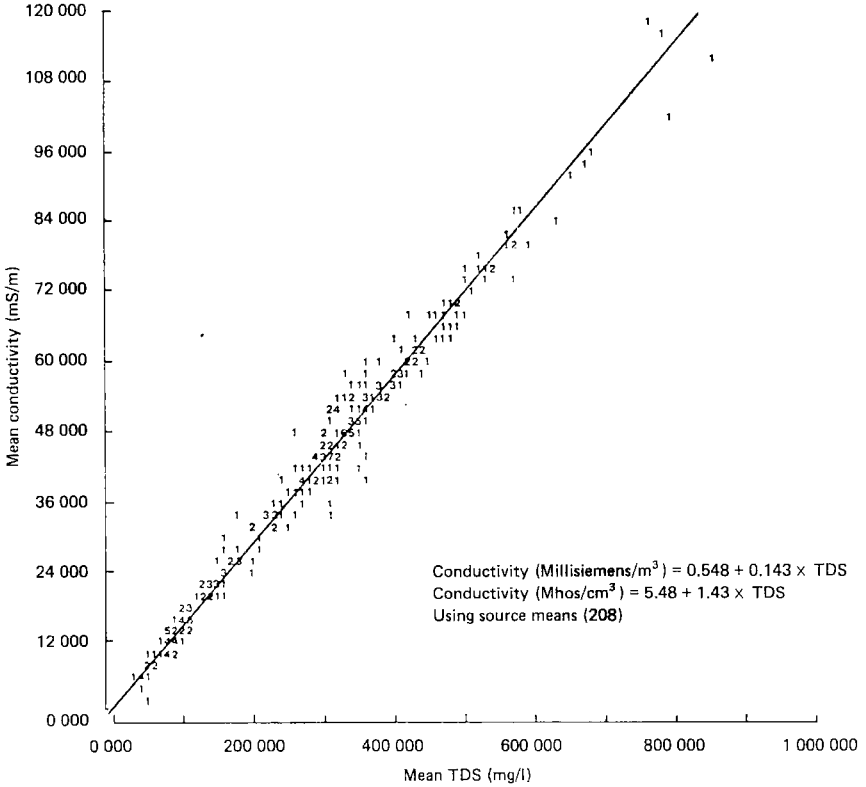
Levels of Conductivity in Drinking-Water

Information on the electrical conductivity in water sources supplying large towns in the United Kingdom is shown in Fig. 2. The levels shown are five-year means for the period 1969−73.

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Fig. 2. Electrical conductivity in water sources; United Kingdom

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                              *
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                      *       *   *
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                      *       *   *
          *                   *   *   *
          *   *               *   *   *
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          *   *               *   *   *
          *   *               *   *   *
          *   *               *   *   *
          *   *               *   *   *       *
          *   *               *   *   *   *   *
          *   *   *           *   *   *   *   *
          *   *   *       *   *   *   *   *   *
          *   *   *   *       *   *   *   *   *   *
          *   *   *   *       *   *   *   *   *   *
          *   *   *   *   *   *   *   *   *   *   *
          *   *   *   *   *   *   *   *   *   *   *   *                   *
      *   *   *   *   *   *   *   *   *   *   *   *   *   *               0
      *   *   *   *   *   *   *   *   *   *   *   *   *   *               0
      *   *   *   *   *   *   *   *   *   *   *   *   *   *           *   0
      *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   0
      *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   0
 I-----------I-----------I-----------I-----------I-----------I-----------I
 0.0         20.0        40.0        60.0        80.0        100.0
         Conductivity              mS/m                 Mean
         448 sources      (each  * =  2 sources)
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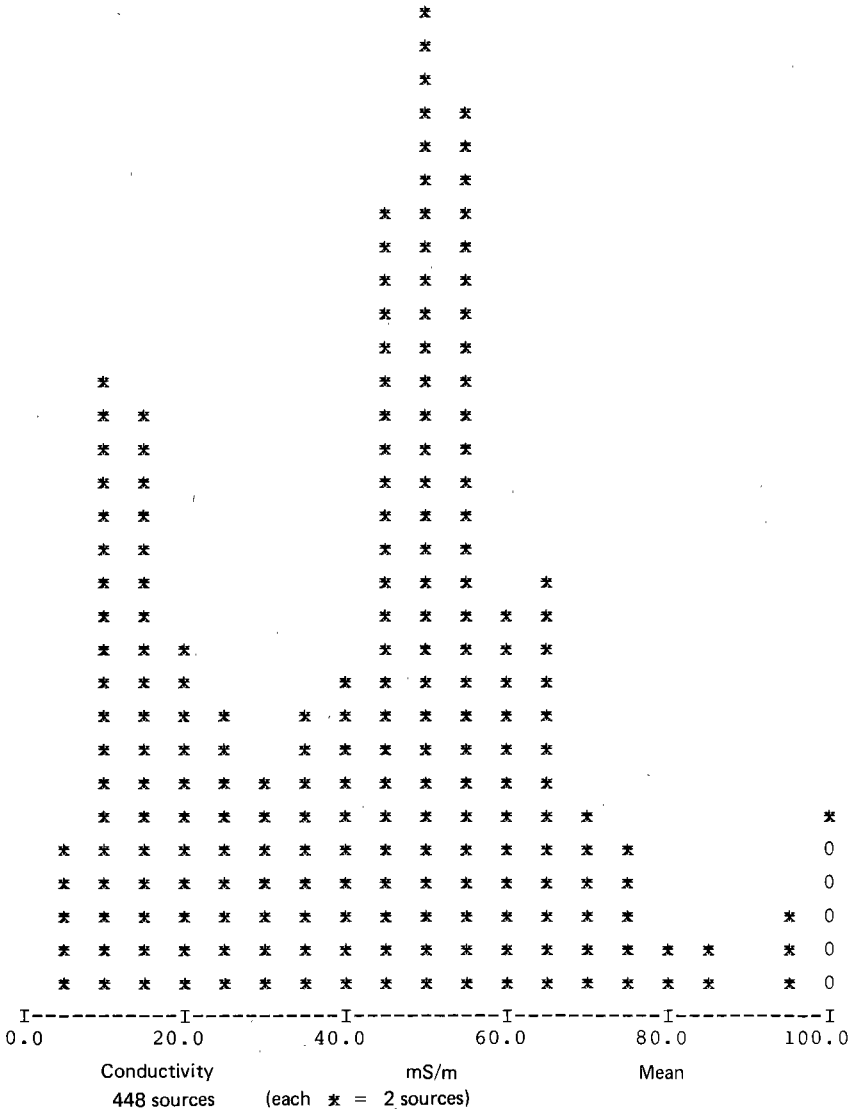
This histogram may also be typical for other countries, e.g. Federal Republic of Germany. Drinking-water from the Weser, however, has a conductivity up to 200 mS/m.

The conductivity of most Canadian drinking-water shows a wide range from 3 to 200 mS/m, about 80% of the values being below 80 mS/m. In some places, e.g. Northwest Territories, 90% of the values are below 30 mS/m.

In Denmark not all waterworks measure conductivity. Instead of real values the figures below have been calculated from values of residence – TDS (Conductivity in mS/m = TDS/7). Copenhagen (1.6 million inhabitants): minimum 47 mS/m, maximum 120. Rest of the country (3.0 million inhabitants): minimum 3.8, maximum 250 mS/m. The mean value is suggested to be 60 mS/m.

In the Netherlands the ground waters supplied in the east of the country have a conductivity between 9.6 and 60.0 mS/m. In the west of the country, predominantly supplied by surface water plants, the conductivity of drinking-water approaches 120 mS/m in several cases where it originates from large plants. Some ground water supplies in that area, using water from layers of marine origin, also produce drinking-water with a conductivity up to 110 mS/m. As an example the possible (salt) compositions of water at the value 40 mS/m are reproduced in Table 2. These values can be calculated using conductivity factors (1).

Table 2. Calculation of conductivity for some examples of water analysis

Remarks	Examples	Conductivity K as mS/m at 20°C	Ion concentration as mol/m³			
			Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-
Examples for the	a)	40	0.5	0.25	0.5	1.5
guide value (40 mS/m)	b)	40	1	0.25	2	
of CEC	c)	40	2	0.5	3	

Conductivity as a Means of Water Quality Control

Modern instruments for measuring conductivity with a high solution rate and good automatic temperature compensation can be effectively applied in the field of water purification.

By automatic continuous recording of the conductivity measured, changes in water quality can be detected and the performance of the equipment monitored.

Conductivity — a tool for detecting changes in water quality

Concern has been expressed among water suppliers and public health officials about the problems of preventing widespread harm to public health which may occur through accidental or deliberate introduction of toxic chemicals into water supply systems. While introduction into reservoirs presents relatively little risk owing to their large volume, the situation is much more dangerous in distribution networks.

The major source of such incidents to date is cross-connexions and the literature abounds with documented cases. Fortunately the number of deaths from such contamination is not large but the number of cases of disease and chemical poisoning is significant. Measures to prevent cross-connexions have largely involved installation of back-flow preventers and vacuum-breakers but they are far from universal. Moreover, such measures depend for their effectiveness upon constant surveillance, which few water suppliers are willing to finance. Back-flow preventers and vacuum-breakers must be continually checked, and larger devices such as reduced pressure zone back-flow preventers should be tested at regular intervals. Neither of these precautions are widely observed.

The threat of deliberate contamination is more serious. Certain documents have indicated that terrorists are aware of the vulnerability of the water distribution system. In the USA the authorities had to take action on several occasions following threats to water reservoirs but with one exception all proved to be hoaxes. However, with the deteriorating world societal structure, it is only a matter of time before real incidents will occur.

There appear to be two methods of detecting or preventing contamination of water supplies. One is structural piping arrangements where in every communication pipe a check valve has been incorporated to prevent any back-flow from the premises it serves. As single check valves are known to fail frequently this measure is not fail-safe. The second method is to install sensing elements at key points in the distribution system which will detect changes in the usual physico-chemical properties of the water. Such devices should be inexpensive, sturdy and suitable for transmitting signals to a central control point. Two parameters are suggested for such measurements, namely pH and conductivity. pH has the disadvantage of local fluctuations which may be in no way associated with a contamination incident. An example is the passage of water through an open reservoir with resultant pH changes. Conductivity on the other hand tends to remain more constant as it is a measure of the total dissolved salts content. The use of conductivity meters placed at strategic points in a water system should be explored as a tool for detecting major changes in water quality.

Control of treatment processes

Mixing water from different origins

Where different types of water have to be blended the mixing rate can be controlled by measuring the conductivity of the original and blended water. Continuous recording is advised for each type of water.

Softening

Lime-treatment has a marked effect on the conductivity of water. This process can be controlled by measuring the conductivity of the water.

Calcium and magnesium ion exchange does not affect the overall ion concentration and has as such a minor effect on conductivity, through differences in mobility of the ions concerned.

Desalination by reverse osmosis or multiple flash evaporation will significantly reduce the ion concentration of water. The process can be controlled very effectively by measuring the electrical conductivity.

Flocculation

Many types of water are flocculated using aluminium or iron salts. The hydrogen carbonate concentration is reduced and the chloride or sulfate concentration increased. The effect on conductivity is too small to be used for control purposes.

Considerations in Relation to Standards or Recommended Limits

Owing to the difficulty or impossibility of setting up an obligatory standard value for electrical conductivity, it is preferred to recommend a guide value that can be used as an indicative reference for example to control the quality of specific water from a known source.

Electrical conductivity depends in particular on the nature of the ions present in drinking-water. For these reasons, the European Community has only proposed guide values for conductivity in its directive on surface waters and in its draft directive on drinking-water.

Electrical conductivity is highly correlated with the level of total dissolved solids (TDS), of which it provides a convenient measure. When limits for TDS are set they should also be expressed in terms of conductivity.

Other Effects

Distributed water is used in the home for other purposes in addition to human consumption. Irrigation of indoor plants requires water with low osmotic pressure. If the osmotic pressure of the soil solution is increased, the availability of the water for the plant is reduced, causing severe retardation in growth (5).

A high salt content, or high conductivity, makes water less suitable for washing glassware, windows, cars, etc.

In some cases process water for industry must have a low salt content and low conductivity, for instance, in the paper and electrical industries. For these purposes drinking-water with a high conductivity has to be treated. The regeneration of the exchangers indirectly results in an increased sodium concentration in surface or ground water.

Measuring Methods and Frequency

It is customary to measure electrical conductivity by means of a bridge circuit. To avoid polarization at the electrodes, alternating current is used (e.g. 80 or 400 Hz); as this causes disturbances (capacitance) in the leads, short leads are required between the measuring cell and the amplifier. To avoid this problem modern equipment uses operation amplifiers, which are particularly suitable for measuring differential conductivities. Non-contact, high-frequency circuits, which are suitable for water with a higher conductivity, are a special case. The fact that conductivity varies considerably with temperature requires careful compensation if correct results are to be obtained. This can be achieved through thermoresistors in a suitable electrical circuit. Correct compensation is possible only if a measuring cell with water is used as a comparison electrode, containing substances in a given concentration or in the same combination as in the water to be tested. The fact that the geometry of the cell (cell factor in cm) is constantly changing makes it necessary to perform regular calibrations with standard conductivity solutions of varying concentration (6).

This method of determination is very suitable for continuous measuring with good reproducibility and requires only small investments.

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CONCLUSIONS AND RECOMMENDATIONS

Sodium

1. Sodium in drinking-water can arise naturally or as the result of human activities. A general tendency for sodium levels in drinking-water to increase has been reported in many countries. This may be caused by increased pollution of sources or by water treatment processes.

2. Until recently, serious attention was not given to the possibility of health effects being associated with sodium in drinking-water; the main limitation was related to taste. In the WHO European and International Standards, dated respectively 1970 and 1971, sodium is not listed. Interest in sodium has since increased because of its apparent relation to hypertension, which has led to recommendations that dietary sodium intake should be reduced. The Working Group recognized that there is strong evidence of a relationship between sodium and hypertension.

3. Since drinking-water is a fundamental dietary ingredient, it is important that sodium concentrations should be maintained at the lowest practicable level and that trends towards increasing sodium levels in water supplies should be discouraged.

4. For the adult general population, it was agreed that it would now be reasonable to aim at a progressive reduction of total sodium chloride intake from present levels to 6 g per day. A long-term goal of 3 g per day may well be desirable, but further research is necessary. If one makes the arbitrary assumption that the contribution from drinking-water to the total dietary intake of salt is 10%, then the concentration of sodium, assuming a consumption of 2 litres per day, would be 120 mg/l and 60 mg/l for total intakes of 6 g and 3 g NaCl respectively.

5. For patients with hypertension or congestive heart failure there is a need for further restriction in the total dietary intake to a maximum of 500 mg Na per day, i.e., 1.3 g NaCl. As it is not practicable to provide food with less than 460 mg Na per day, i.e., 1.2 g NaCl, the contribution from drinking-water should be limited to 40 mg Na per day. Thus, again assuming a consumption of 2 litres per day, the concentration of sodium should not exceed 20 mg/l. In the case of water supplies where this figure is exceeded, the appropriate public health authorities should be notified.

6. If it becomes necessary to take special steps to reduce the level of sodium in water supplies, additional treatment processes (desalination) may need to be introduced, which may substantially increase the cost of treatment.

7. A number of other measures for the reduction of sodium levels could be considered, including the protection of water supply sources from becoming contaminated by wastes containing sodium, and minimizing the use of salt for de-icing roads.

Chlorides

1. In the 1971 WHO International Standards for Drinking-Water, the highest desirable limit for chloride is given as 200 mg/l and the maximum permissible limit as 600 mg/l. These limits were based on factors relating to corrosion and taste. Due to the health significance of sodium, the concentration of chloride as a "counter-ion" now has added importance. Levels of chloride are reported as increasing in many water supply sources due to a wide variety of causes.

2. It is recommended that the chloride concentration in drinking-water should not exceed 200 mg/l and use of the previously accepted higher figure of 600 mg/l should be discouraged.

Conductivity

1. The measurement of electrical conductivity provides a valuable control technique in many water supply operations for continuously detecting changes in water quality, for example the control of softening and desalination processes and the control of pumping from aquifers affected by sea-water intrusion.

2. The electrical conductivity of water reflects the total concentration of dissolved electrolytes. It has no health significance and therefore no upper limit has been recommended.

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