4 Water quality and quantity

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4.1 Introduction

The availability of a clean and safe water supply is essential for public health. Water is used for a number of needs but in subsistence economies the most important use is for domestic purposes and for small productive uses such as garden irrigation. Water for domestic use needs to be safe and free from pathogens and other harmful substances. In this chapter we will attempt to provide guidelines for the quality and quantity of water required for different levels of service.

The report Global Water Supply and Sanitation Assessment 2000, prepared jointly by the World Health Organization and UNICEF, indicates that in the year 2000 nearly 1100 million people still remained without access to improved sources of water and that about 2400 million had no access to any form of improved sanitation facilities.

4.2 Water quantity

The amount of water a person needs each day is determined by a number of factors. Depending on climate and workload, the human body needs from 3-10 litres of water per day for normal functioning. Part of this water may be derived from food.

Factors influencing the amount of water used are

- cultural habits
- socio-economic status and standard of living
- hygiene awareness
- productive uses
- the charges for water
- the quality of the water as experienced by the users[1]

The water demand of the community depends on climate, standard of living, availability and method of distribution.

Table 4.1 shows the per capita usage of water for domestic purposes (via a house connection) for countries in Southern Asia.
Table 4.2 sets out typical domestic water usage data for different types of water supply systems.

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1 The criteria of users and engineers are not always the same. Understanding the perspectives of the users so as to adjust designs where possible and tailor any advocacy to their concepts is more effective than simply requiring that users 'be educated' to adopt outsiders' criteria.

Table 4.1 Water usage for domestic purposes in Southern Asia

Purpose	**Quantity (lcd)***
Drinking	5
Cooking	3
Sanitary purposes	18
Bathing	20
Washing utilities	15
Clothes washing	20
Total (excluding water loss and wastage)	81

**lcd: litres per capita per day*
Source: Design Manual for Water Supply and Treatment, India, 1991

Table 4.2 Typical domestic water usage data for different types of water supply systems

Type of water supply Typical water consumption	(litres/capita/day)	Range (litres/capita/day)
Communal water point (e.g. village well, public standpipe)		
At considerable distance (> 1000 m)	7	5 – 10
At medium distance (500 – 1000 m)	12	10 – 15
Village well Walking distance < 250 m	20	15 – 25
Communal standpipe Walking distance < 250 m	30	20 – 50
Yard connection Tap placed in house-yard	40	20 – 80
House connection		
Single tap	50	30 – 60
Multiple tap	150	70 – 250

Individual house connections provide a higher level of service than a tap placed in the house yard while the yard connection generally is preferred over a communal village point such as a well or a standpipe. In the selection of the type of service, finance is usually an important factor and the choice also depends on the location and size of the community, the geographical conditions and the available water source.

To obtain a first estimate of the water demand of a community it is often easier to establish the number of households from an aerial survey rather than a door-to-door census. Domestic water use can then be computed using an average size of family. Studies of existing small community water supply systems in the same area can provide useful water usage data. If possible field measurements should be taken. An alternative approach is to use a social map that community women and men prepare, in which they draw the compounds and may indicate what service level the women and men household heads have agreed upon. When sizing the water supply system (including the water treatment plant) and the type of supply, account has to be taken of other uses too. The presence in the area of a school, hospital, hostel, etc. needs to be taken into account and an adequate supply provided for these purposes as well. Table 4.3 includes figures for some typical uses in developing countries. These estimates should be used for preliminary planning and design only and should be considered as a rough guide. There is no substitute for local knowledge and this will be needed for the final design criteria for any given region or smaller administrative area.

Table 4.3 Various water requirements in developing countries

Category	Typical water use
Schools	
Day schools	15-30 l/day per pupil
Boarding schools	90-140 l/day per pupil
Hospitals (with laundry facilities)	220-300 l/day per bed
Hostels	80-120 l/day per resident
Restaurants	65-90 l/day per seat
Cinema houses, concert halls	10-15 l/day per seat
Offices	25-40 l/day per person
Railway and bus stations	15-20 l/day per user
Livestock	
Cattle	25-45 l/day per head
Horses and mules	20-35 l/day per head
Sheep	15-25 l/day per head
Pigs	10-15 l/day per head
Poultry	
Chicken	15-25 l/day per 100

(Adapted from IRC, 1981)

Table 4.4 shows water consumption patterns in South Africa in 1980 and indicates the relative amounts of water used in various sectors of the economy. This provides a guideline as to the general level of domestic consumption, relative to the total, in a partially industrialised economy. In a predominantly agricultural country, irrigation consumes a substantial proportion of the available water supply. Obviously trade-offs have to be made, where the needs of a community have to be set against the needs from organised agriculture. This could be a major consideration in many countries where agricultural use of water is a significant portion of the total. In general priority is given to domestic water supply, but productive use is important as it creates the economic basis for payment for water. In areas with a scarcity of good quality water, alternative sources of water could be used for different water uses. In some countries rainwater is preferred as drinking water. Lower quality water can be used for non-drinking purposes or productive use if no negative effects are expected.

Table 4.4 Water consumption patterns in South Africa

Demand sector	**(million m^3/a)**	**(%)**
Direct use		
Municipal and domestic	1 516	9.3
Industrial	1 031	6.3
Mining	446	2.9
Power generation	282	1.7
Irrigation	8 504	52.2
Stock-water	262	1.6
Nature conservation	178	1.1
Indirect use		
Forestry runoff reduction	1 284	7.9
Ecological use, estuaries and lakes	2 768	17.0
Total	16 291	100.0

Based on 1980 data

It is often very difficult to estimate the future water demand of a community accurately and the engineer has to apply considerable design judgement in making the analysis. In countries with positive economic development there is a progressive increase in water consumption for economic and domestic purposes. Economic activities demand more water, and people with an increasing living standard seek a higher level of water service and more water per capita. Design criteria have to take these trends into account so as not to find the water system capacity inadequate a few years after construction. Expansion of water supply systems will generally be far less economic than construction of larger systems from the beginning. On the other hand, over-sizing due to overestimation of population and consumption makes schemes uneconomical and leads to high unit costs for those people already connected to the supply. The right decision requires careful analysis.

If present water sources are inadequate to meet the estimated demand then new sources have to be considered that may imply a much higher water production cost. Water demand management is an important way to forestall the use of expensive new sources. It needs to be applied to all the different forms of consumption. Awareness raising and price elasticity are key elements for effective water demand management, and, as with all pricing issues, the poor need to be protected against measures which might reduce their consumption to dangerously low levels.

It is worth reiterating that local knowledge of population growth rates, affordability criteria and the type of schemes envisaged will lead to better estimates of water quantity. This is essential if errors of underestimation or overestimation are to be avoided. Also consultation with the local communities on the demands of the different user groups and arriving at a mutually agreed decision are vital for the success of a scheme. Building on experiences from neighbouring or similar areas is helpful. If water conservation is needed because of limited capacities of available sources, good communication with the consumers on demand management is crucial.

The water usage figures, given in table 4.3, include about 20% allowance for water losses and wastage. In many developing regions there are considerable losses from leaks and, sometimes, unauthorised withdrawal of water from the distribution system. Losses in these cases can be higher than 30% and sometimes even approaching 50-60% of the normal production.

As a tentative estimate, the water supply for a more or less centralised community settlement would need to have a capacity of 0.3 litres per second per thousand people when the water is mainly distributed by means of public standpipes (about 25 litres per capita per day) and about 1.5 litres per second or more per thousand people when yard and house connections predominate (approximately 130 litres per capita per day). Schemes should provide for future connections, population growth and a rise in the standard of living, which is not uncommon when the infrastructure is improved. The design would typically be based on the daily water demand estimated for the end of the specified design period (typically 10 years for water intake works and treatment plant, and 25 years for the distribution network system). The estimation would use a design population (present population multiplied by growth factor such as in table 4.5) multiplied by an estimate of initial and final per capita consumption.

Table 4.5 shows population growth factors for various yearly growth rates for periods of 10, 15, 20 and 25 years.

Table 4.5 Population growth factors

Design period (years)	Yearly growth rate 2%	3%	4%	5%
10	1.22	1.34	1.48	1.63
15	1.35	1.56	1.80	2.08
20	1.49	1.81	2.19	2.65
25	1.64	2.09	2.67	3.39

A community water supply system should also be able to cater for maximum hourly or peak water demands during the day. It would be normal to provide a storage reservoir of 24 or even 48 hours capacity based on average demand and to feed this at constant rate from the treatment system either by gravity or by pumps. Peak demands can then be catered for by drawing down the reservoir.

4.3 Water quality

Water for domestic use is required to be both wholesome and safe. For aesthetic reasons it is desirable that the water be clear (low turbidity) and that it be free from taste, odour and colour. For health reasons a number of chemical characteristics need to be considered. Water should have calcium and magnesium contents within an optimum range; it should not have excessive sodium; the sulphate and nitrate content needs to be limited; and various toxic metals should not be present in quantities greater than very low limits which are set in the many standards which apply to water treatment.

Of prime importance, however, is the bacteriological quality of water. Water for domestic use should be free from pathogenic organisms viz. bacteria and viruses which may cause disease. The importance of water as vehicle for the potential spread of diseases is the main concern in water quality control. It has often been stated by world health authorities that disinfection of water alone has saved more lives than the whole of the medical industry.

Many studies have been conducted on the effects of water quality on human and animal health, the acceptable limits for physical characteristics and the useful life of water distribution systems. Based on these studies, the World Health Organization (WHO) has published guidelines to help countries to set quality standards with which domestic water supplies should comply. These will often be considered as long-term goals rather than rigid standards, as the importance of providing a suitable quantity of water of a reasonable standard for drinking and hygiene is a top priority.

The basic requirements for drinking water are that it should be free from pathogenic (disease causing) organisms; clear (low turbidity, little colour), not saline (salty); free from offensive taste or smell; free from compounds that may have had adverse effects on human health (harmful in the short or long term); free from chemicals that may cause corrosion or encrustation.

The most practical way to express quality requirements for drinking water is in tables which give the "highest desirable" and "maximum permissible" levels for each parameter. To repeat, they are guideline figures and may take time to achieve. Interim improvements that would give people enough water for their basic hygiene needs should not be inhibited by rigid adherence to “ideal" standards.

Guidelines for water quality are divided into four main aspects: bacteriological, physical, chemical, and radiological. Regular sampling and monitoring verifies that sources and delivered water meet specified criteria, but "sanitary surveys" are a vital part of ensuring that all the potential contamination risks have been taken into account. Annex 1 describes the key features of sanitary surveys and laboratory analysis in safeguarding public supplies.

Bacteriological parameters

As far as public health is concerned the most important aspect of drinking water quality is the bacteriological quality, i.e. the presence of bacteria and viruses. It is not practical to test water for all organisms that it might possibly contain. Instead the water is examined for a specific type of bacteria that originates in large numbers in human and animal excreta, and its presence is indicative of faecal contamination. Faecal or thermotolerant coliform bacteria including the Escherichia *Coli* (E.coli) are members of a wider group of bacteria known as coliforms, of which many types are present in soil. Thermotolerant coliforms multiply in the human gut and can be detected relatively easily by culturing. Consequently, they are the most widely used bacteriological indicator. Another, somewhat less commonly used, indicator organism is faecal streptococci. When these bacteria are found in water it indicates fairly fresh faecal contamination and the need for disinfection. Faecal bacteria are likely to be found in almost all small community water supply systems. It would be excessive to condemn all supplies that contain some contamination, especially when alternatives may be even more polluted. Rather, bacteriological testing of the water determines the level of pollution in each available source and the optimum source can then be chosen. In designing a water treatment plant one would include chlorination or other means of disinfection to remove the danger of waterborne disease.

Brief descriptions of water sampling for bacteriological analysis and the different methods for testing (membrane filtration and "most probable" number using the multiple-tube method) are given in annex 1.

According to the WHO Drinking Water Quality Guidelines, water intended for drinking should not contain any detectable E-coli or thermotolerant coliform bacteria in any 100 ml sample. However, it is recognised that faecal contamination is widespread in the majority of rural water supplies in developing countries. The sensible way forward is for the responsible national agency to set medium-term targets for the progressive improvement of water supplies.

Table 4.6 is an example of a risk classification based on thermotolerant coliforms for rural water supplies that gives the motivation and urgency to improve the quality of water meant for drinking.

Table 4.6 Example of risk classification for thermotolerant (or faecal) coliforms or E. coli for rural water supplies

Count per 100 ml	Risk category
0	In conformity with WHO guidelines
1-10	Low risk
11-100	Intermediate risk
101-1000	High risk
>1000	Very high risk

Table 4.7 shows the South African Bureau of Standards limits for these microbiological constituents. In addition to this, limits exist in some guidelines for faecal streptococci, Salmonella, Staphylococcus aureus and Clostridium perfringens. Many guidelines only limit the first three organisms in Table 4.7, however, and these are usually adequate for assessment purposes.

Table 4.7 Microbiological requirements

1	2	3	4	5
Determinants	Units	Allowable compliance contributions*		
		95% min.	4% max.	1% max.
		Upper limits		
Heterotrophic plate count	count/ml	100	1 000	10 000
Total coliform	count/100 ml	Not detected	10	100
Faecal coliform	count/100 ml	Not detected	1	10
Somatic coliphages	count/10 ml	Not detected	1	10
Enteric viruses	count/100 l	Not detected	1	10
Protozoan parasites (Giardia/Cryptos poridium)	count/100 l	Not detected	1	10

* The allowable compliance contribution shall be at least 95% to the limits indicated in column 3, with a maximum of 4% and 1% respectively, to the limits indicated in columns 4 and 5. The objective of disinfection should, nevertheless, be to attain 100% compliance to the limits indicated in column 3.

Physical and organoleptic parameters

The physical and organoleptic (aesthetic) parameters most commonly regarded as significant are turbidity, colour, odour, pH and taste.

High turbidity and/or colour impart an aesthetically displeasing appearance to water. The turbidity in surface waters results from the presence of colloidal material such as clay and silt, plankton and micro-organisms. Apart from a displeasing appearance, the particles which create turbidity also provide adsorption sites for chemicals that may be harmful or cause undesirable taste and odour. They also allow adsorption of biological organisms, which shields the organisms and interferes with disinfection.

Colour in drinking water is due to natural organics such as humid substances or dissolved inorganic compounds of iron or manganese. Highly coloured industrial waste can also impart colours in water. Apart from the aesthetic appearance, organic colour when disinfected with chlorine will produce chlorinated organics, some of which are carcinogenic. The presence of iron in the water can lead to staining of clothes when washed in such waters. Odour and taste problems in water are due mainly to the presence of organic substances. Objectionable taste or odour will cause consumers to reject a bacteriologically safe supply in favour of a less satisfactory source. It follows that water needs to be free of offensive taste and odour, usually determined by testing panels and judged according to the dilution needed to reach undetectable levels.

The pH of a particular water is a measure of its acidity/alkalinity, which in turn means its aggressivity as far as metals and concrete in pipes and treatment works are concerned. Low pH can increase corrosion, while too high a value can lead to calcium carbonate deposition and encrustation of pipe networks. Because the pH level can have an impact on the efficiency of water treatment processes such as coagulation, pH adjustment is a common practice in water treatment works.

Table 4.8 shows a comparison of recommended standards for physical parameters.

Table 4.8 Standards for physical quality

Characteristic	U.S.	Canadian	EEC	WHO	Australian guideline
Turbidity (NTU)	1-5	5*	0-4	<5	5
Colour (TCU)	15	15	20 mg Pt-Co/L	15	15
Odour (TON)	3	-	0-2 dilution numbers at 12°C	-	No objectionable odour
pH	6.5-8.5	6.5-8.5	6.5-8.5**	<8.0	6.5-8.5
Taste	-	-	2 dilution numbers at 12°C	-	-

(Adapted from Sayre, 1988; NHMRC-AWRC, 1987; and WHO, 1993)

Note: - = Data not available

* Decker and Long (1992) give the Canadian standard for turbidity as 5 NTU aesthetic objective and 1 NTU as the maximum acceptable value.

** pH value 6.2-8.5 according to EC directive 80/778 (AQUA, 1992).

Chemical

The chemical requirements of a water supply are conveniently divided into macro-determinants and micro determinants. Macro-determinants such as ammonia, calcium, chloride, fluoride, magnesium, nitrates, potassium, sodium, sulphate and zinc can be present in comparatively larger quantities. Excessive levels have a harmful effect on health, but in many cases limited quantities are necessary for the maintenance of living organisms and low concentrations are therefore desirable in the water supply. The micro determinants consist mainly of the toxic or heavy metals and are limited to very low concentrations.

In the WHO Guidelines for Drinking Water Quality, the organic constituents are divided in two categories: (i) chemicals of health significance in drinking water; and (ii) substances in drinking water that may give rise to complaints from users.

Table 4.9 lists the physical and chemical parameters set out in the South African Bureau of Standard Guidelines. Class 0 water is regarded as ideal; class 1 is acceptable and class 2 permitted when no other supply is available (but this should only be used for limited periods).

Table 4.9 Physical, organoleptic and chemical requirements

1	2	3	4	5	
Determinants	**Units**	**Upper limit and ranges**			
		Class 0 (Ideal)	**Class I (Acceptable)**	**Class II (Max. allowable)**	**WHO Guideline values**
Physical and organoleptic requirements					
Colour	mg/l Pt	15	20	50	15
Conductivity at 25°	mS/m	70	150	370	-
Dissolved solids	mg/l	450	1 000	2 400	1 000
Odour	TON	1	5	10	-
pH value at 25°C	pH units	6.0-9.0	5.0-9.5	4.0-10.0	<8.0
Taste	FTN	1	5	10	-
Turbidity	NTU	0.1	1	10	≤ 5
Chemical requirements: Macro-determinants					
Ammonia as N	mg/l	0.2	1.0	2.0	1.5
Calcium as Ca	mg/l	80	150	300	-
Chloride as Cl	mg/l	100	200	600	250
Fluoride as F	mg/l	0.7	1.0	1.5	1.5
Magnesium as Mg	mg/l	30	70	100	-
Nitrite and nitrate as N	mg/l	6.0	10.0	20.0	≤ 1
Potassium as K	mg/l	25	50	100	-
Sodium as Na	mg/l	100	200	400	200
Sulphate as SO4	mg/l	200	400	600	250
Zinc as Zn	mg/l	3.0	5.0	10.0	3
Chemical requirements: Micro-determinants					
Aluminium as Al	µg/l	150	300	500	200
Antimony as Sb	µg/l	5	10	50	5
Arsenic as As	µg/l	10	50	200	10
Cadmium as Cd	µg/l	3	5	20	3
Chromium as Cr	µg/l	50	100	500	50

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1	2	3	4	5	
Determinants	**Units**	**Upper limit and ranges**			
		Class 0 (Ideal)	**Class I (Acceptable)**	**Class II (Max. allowable)**	**WHO Guideline values**
Cobalt as Co	µg/l	250	500	1 000	-
Copper as Cu	µg/l	500	1 000	2 000	2 000
Cyanide (free) as CN	µg/l	70	70	70	70
Cyanide (recoverable) as CN	µg/l	70	200	300	-
Iron as Fe	µg/l	10	200	2 000	-
Lead as Pb	µg/l	10	50	100	10
Manganese as Mn	µg/l	50	100	1 000	100
Mercury as Hg	µg/l	1	2	5	1
Nickel as Ni	µg/l	50	150	350	20
Selenium as Se	µg/l	10	20	50	10
Vanadium as V	µg/l	100	200	500	-

Note: The limits for iron are based on aesthetic aspects.

Organic constituents

Tables 4.10 and 4.11 give limits for various organic substances that are undesirable in the water. Some are classified as known carcinogens, others are not classifiable on the basis of inadequate evidence.

Table 4.10 Classified categories of carcinogens

Category	A	B1	B2	C	D
Volatile organic compounds	Benzene vinyl chloride		• Trichloroethylene • Pentachlorophenol • Chloroform • Bromodichloro-methane bromoform • Carbon tetrachloride • 2,4,6-Trichlorophenol • Acrylamide • 1,2-Dichloroethane	• 1-Dichloroethane • 1,11,2-Tetrachloro-ethylene • 1,1-Dichloro-ethylene • Dibromochloro-methane • P-Dichlorobenzene	• Toluene • Xylene • Mono-chlorobenzene • Ethylbenzene • Hexachloro-cyclopentadiene • 1,1,1-Trichloroethane • 1,2-Dichlorobenzene

Category	A	B1	B2	C	D
Pesticides			• Heptachlor epoxide • Hexachloroenzene • Toxaphene • Aldrin • Malathion	• Endrin • Methoxychlor • Ethoxychlor	

Source: Chung, 1993

Note: A. Human carcinogen, based on sufficient evidence from epidemiological studies.

B. Probable human carcinogen, based on at least limited evidence or carcinogenicity to humans (B1), or usually a combination of sufficient evidence in animals and inadequate data in humans (B2).

C. Possible human carcinogen, based on limited or equivocal evidence of carcinogenicity in animals in the absence of human data.

D. Not classifiable, based on inadequate evidence of carcinogenicity from animal data.

Table 4.11 Groups of organic compounds of potential health significance that could be present in water sources, and treatment and distribution systems

Chlorinated alkanes	Chloramines
Chlorinated ethenes	Chlorophenols
Aromatic hydrocarbons	Trihalomethanes
Polynuclear aromatic hydrocarbons (PAH)	Chlorinated acetic acids
Chlorinated benzenes	Halogenated acetonitriles
Pesticides	

(Adapted from WHO, 1993)

Most of the organic compounds are from industrial sources and quite often from the petroleum industry. In rural areas such compounds are unlikely to be present but in cases where there are chemical or petrochemical industries in the vicinity it would be safe to err on the side of caution and perhaps to analyse for volatile organics.

Radiological constituents

It is uncommon for radioactivity to be a cause for concern but this aspect is considered in a number of standards. The World Health Organization (WHO) limit the following:

Gross alpha activity	0.1	Bq/l
Gross beta activity	1.0	Bq/l

If radioactivity is suspected the water should be tested.

Sampling

In assessing an existing or potential water supply, every effort should be made to take suitable samples of the water and to have them analysed as fully as possible. Distance and lack of facilities can make bacteriological analyses difficult to carry out, but modern technology test kits are now available which can determine many of the common microbiological indicators in the field. With portable refrigeration and incubation available reasonably reliable counts can usually be obtained.

Analytical methods are available from Standard Methods for the Examination of Water and Wastewater published by APHA, AWWA and the WEF, but many of the field test kits come with their own methods. See also annex 1.

For chemical analyses it is not as important that the sample be fresh, although care should be taken to preserve samples as far as possible and these can then be analysed in a suitable laboratory for macro- and micro-determinants. At least one full analysis should be carried out if at all possible prior to the drinking water source selection. Furthermore, during the course of the project additional analyses of certain key determinants should be undertaken. Obviously the more knowledge that is available regarding the supply, the better.

Annex 1 discusses the role of sanitary surveys and laboratory analysis in maintaining quality standards.

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Web sites

Water quality: http://www.who.int/water_sanitation_health/index.html

Discussion groups

GARNET (Global Applied Research Network) Water Quality Monitoring, see http://info.lut.ac.uk/departments/cv/wedc/garnet/tncwq.html