Manual on Treatment for Small Water Supply Systems

Final Report to the Department of the Environment, Transport and the Regions

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PREFACE

This manual is intended to assist local authorities in the UK in discharging their responsibilities for private water supplies. It may also be of use to anyone, in any country, who may be responsible for, or called on to give advice upon, assessment and treatment of small public or private water supplies in the context of their own national regulations.

Some 50 000 private water supplies serve approximately one percent of the population of England and Wales. In Scotland there are about 20 000 private supplies and there are also significant numbers in Northern Ireland. Wholesomeness standards are prescribed in the 1998 EC drinking water Directive. In the UK, regulations incorporate those wholesomeness standards and specify the duties of local authorities in respect of sampling and analysis of private supplies.

Those with responsibilities for assessing, monitoring or improving small water supply systems need to have access to technical advice on a range of issues. These issues include selection and protection of water sources as well as the specification of treatment necessary to improve the quality of water supplies.

This manual provides advice on source selection and protection and on the properties and likely sources of contamination of water. Methodology for assessing the risk of pollution of water sources is provided. The application of water treatment processes is described and small-scale devices that may find application in the treatment of private supplies are reviewed. Test protocols for assessing small scale treatment devices are summarised – these provide a comparable basis against which manufacturers' claims may be assessed and set out test procedures for establishing whether a device might cause any deterioration in the microbiological quality of water during treatment.

The manual includes the addresses of key organisations, provides a list of relevant reference documents, a glossary of technical terms and checklists for risk assessments of small water supplies.

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1. INTRODUCTION

1.1 Background

Water is essential to sustain life and an adequate supply of good-quality drinking water should be available to consumers. International guidelines on drinking water quality are published by the World Health Organization[1]. Within the European Union drinking water is subject to specific quality standards set out in the EC Directive on the Quality of Water Intended for Human Consumption (98/83/EC[2], the ‘drinking water Directive’) which takes into account the WHO guidelines.

The water quality standards laid down in the drinking water Directive apply to all public and private water supplies intended for drinking, cooking, food preparation and other domestic purposes. Member States had to introduce legislation implementing the requirements of the Directive by the end of 2000 and have to comply with most of the standards in the Directive by the end of 2003.

1.2 Private supplies

A private water supply is any water supply that is not provided by a statutory water undertaker. The responsibility for its maintenance and repair lies with the owner or person who uses it. Approximately one percent of the population of England and Wales are served by private water supplies. There are also significant numbers in Scotland and Northern Ireland.

A private water supply can serve a single household and provide less than one cubic metre of water per day or it can serve many properties or commercial or industrial premises and provide 1000 m^3/d or more. The water source could be a borehole, well, spring, lake, stream or river.

In England, Wales and Scotland local authorities are required to keep themselves informed about the quality of all water supplies in their areas. They are responsible for monitoring private supplies used for drinking, washing, cooking or food production purposes and can require improvements to be carried out where necessary. In Northern Ireland these responsibilities rest with the Drinking Water Inspectorate. District Councils and the Department of Agriculture and Rural Development also have interests in private water supplies in Northern Ireland. Local authorities carry out only limited testing of

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[1] WHO (1993). *Guidelines for drinking water quality*. Second Edition, Volume 1, Recommendations. World Health Organization, Geneva.

[2] EC (1998). Council Directive of 3 November 1998 on the quality of water intended for human consumption. *Official Journal of the European Communities*, No L330, 5th December 1998, pp 32-52 (98/83/EC).

public water supplies since these are regularly checked by water undertakers and the results must be made available to local authorities.

The monitoring requirements of the drinking water Directive vary according to the size of the supply; this is discussed further in Chapter 3. In addition to the volume of water produced (or population served), private water supplies should also be classified according to the nature of the supply:

- Single dwelling domestic use.
- Domestic use for persons normally residing on the premises.
- Premises used for commercial food production or with changing populations.

1.3 Construction products and chemicals in contact with drinking water

Chemicals used in water treatment and construction products used in water supply systems can adversely affect water quality. Potential effects include the addition of potentially toxic contaminants as well as aesthetic aspects such as taste and appearance. This source of potential contamination is best addressed through controls on the quality of chemicals and construction products used in water supply systems, from the point of collection to the point-of-use.

Currently there is no internationally recognised scheme for the regulation or approval of construction products and chemicals although some countries have guidelines, standards, regulations or approval systems. The drinking water Directive requires Member States to ensure that substances and materials (including associated impurities) used in water treatment and distribution do not cause a risk to public health. However, the implementation of schemes to control product quality is currently left to Member States.

A wide range of European standards for drinking water treatment chemicals has been published. There is also a European Union initiative to develop a European Acceptance Scheme for construction products in contact with drinking water. Operators of private water supplies are advised to use chemicals that conform to a European standard and to observe the dosing recommendations contained in the standard. Construction products should be approved under an appropriate national approval scheme.

Outside Europe, particularly in North America, relevant standards for treatment chemicals and construction materials are NSF Standards 60 and 61 respectively[3].

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[3] ANSI/NSF 60 Drinking water treatment chemicals – Health effects.

ANSI/NSF 61 Drinking water system components – Health effects.

2. PROPERTIES AND CONTAMINANTS OF WATER

2.1 Introduction

Methods used for the treatment of a raw water will depend on the properties of the water and the presence and concentrations of any contaminants. Groundwaters usually have low levels of colour and turbidity and consistent microbiological quality, although water from shallow wells and some springs may be more variable. Particular problems may include high or low pH value and alkalinity and high concentrations of iron, manganese, nitrate, chlorinated solvents or pesticides. Surface waters may have high levels of colour and turbidity and exhibit poor microbiological quality. Quality may be variable and deteriorate following periods of heavy rainfall. Other problems may include low pH value and alkalinity and high concentrations of aluminium, iron, manganese, nitrate or pesticides.

2.2 Microbiological parameters – general

Water used as a source for a small supply of drinking water may be of unknown origin and come from a catchment prone to consistent or intermittent contamination by faecal material from domestic and farm animals, wildlife or sanitation systems such as septic tanks. As a consequence, there is a high probability of pathogenic micro-organisms being present in the source water, and adequate treatment must be applied before the water is used for domestic purposes. Because no single treatment can be expected to remove all types of pathogenic agents, a multiple barrier approach in the form of two or more sequential treatment processes is recommended.

The microbiological quality of drinking water has traditionally been assessed by monitoring for bacteria called faecal indicator organisms (coliforms, *E. coli*, and enterococci). The presence of these organisms is indicative of past faecal contamination and hence the possible presence of enteric pathogens. Although indicator organisms are generally adequate for monitoring purposes they cannot completely be relied on to indicate the absence of pathogens. This is especially true where a pathogen is environmentally more robust, or can survive treatment better than the indicators. In these circumstances the indicator may be absent even though low numbers of pathogens still remain.

An example of a pathogen with which such a discrepancy can occur is the protozoan parasite *Cryptosporidium*. This micro-organism is very much more tolerant of the action of disinfectants than faecal indicators such as *E. coli* because it forms resistant spore-like bodies called oocysts. If disinfection is the sole treatment process used, the numbers of *Cryptosporidium* oocysts will remain unchanged whereas the numbers of *E. coli* may be reduced to undetectable levels.

The use of filtration before disinfection is more effective in that an appropriate physical treatment process will remove oocysts. In addition filtration will remove much of the particulate material present which could otherwise reduce the effectiveness of disinfection by creating an oxidant demand and/or shielding microbes from the effects of the disinfectant. This is a good example of why a multiple rather than a single barrier approach is preferred. In addition the use of multiple barriers will allow some protection to remain even if one process fails.

Despite the possible shortcomings in the use of faecal indicators as a measure of the microbiological safety of a water supply, monitoring for coliforms and *E. coli* is still recommended and standards of quality are expressed in terms of these organisms. The reason for this is that monitoring for the pathogens themselves remains rather uncertain because methods of analysis are relatively insensitive and costly compared to those for faecal indicators. Additionally the absence of one pathogen will not guarantee the absence of others. Therefore *E. coli* and coliforms remain the best and most sensitive general measure of water quality.

Monitoring needs and treatment requirements should however be the subject of regular review and if a need is identified, through say an outbreak due to a specific pathogen, treatment strategies and monitoring requirements may need to be changed.

Growth of algae can be a problem in some surface water sources and in uncovered water storage reservoirs. Algae are naturally present in all inland waters and concentrations can increase and decrease rapidly depending on climatic factors and the availability of essential nutrients. Algae can cause taste and odour in water. Some blue-green algae release toxins that may prejudice the recreational use of water. Although algal toxins have not been identified in drinking water supplies at concentrations that would affect health, it would be prudent to avoid the use of water sources that exhibit high concentrations of algae.

With the consent of the relevant environmental authorities, it may be possible in some circumstances to adopt measures to minimise the development of excessive algal blooms. The addition of iron salts to precipitate the nutrient phosphate is one measure, although it may not represent a long-term answer to the problem. In the past, dosing of copper sulphate has been used to reduce growth of algae in reservoirs but its efficacy is questionable. The forced circulation of reservoirs to keep water mixed is another measure. Blooms of algae occur mainly at the surface of reservoirs whereas water is abstracted at depth. Some forms of water treatment, including ozonation, activated carbon adsorption and addition of potassium permanganate can be effective in removing algal toxins. Algae are normally removed as particulate matter during water treatment but some algae can pass through filters or reduce the efficiency of filtration or sedimentation systems.

2.3 Micro-organisms associated with outbreaks and private supplies

2.3.1 Review of outbreaks

Fewtrell *et al.*[4] tested samples from 91 private supplies in the UK, and found the microbiological quality of the water in small supplies to be generally poor, with almost 50% of the supplies failing to meet the required quality standards on at least one occasion. They concluded that, given the high level of sanitary failures, there was the possibility that harmful micro-organisms could be present, and that a significant risk to health could not be discounted.

Poor microbiological quality of groundwater systems has caused many disease outbreaks in the USA. Between 1971 and 1994, 58% of U.S. waterborne disease outbreaks (356 in number) were caused by contaminated groundwater systems – 70% of these outbreaks were considered to be due to contamination of the groundwater source as opposed to the distribution system[5]. Being generally smaller and less well-equipped than public supplies, and being subject to less stringent surveillance and regulatory requirements, private supplies by their very nature are more likely to suffer water quality failures. In the UK 18 outbreaks of waterborne disease were associated with private water supplies between 1970-94 in which over 1388 people were affected in England and Wales[6]. The figure is almost certainly an underestimate as no data from 1987-93 were available and because of inherent under-reporting problems. In Scotland, private supplies caused 21 out of 57 waterborne disease outbreaks between 1945 and 1987 (37%)[7]. These 21 outbreaks gave rise to at least 9 362 cases[8].

Furtado *et al.*[9] have reviewed outbreaks of disease associated with both public and private water supplies in England and Wales between 1992 and 1995. In this period ten outbreaks were associated with public supplies, and nine with private supplies. The

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[4] Fewtrell, L., Kay, D. and Godfree, A. (1998). The microbiological quality of private water supplies. *Journal of the Chartered Institution of Water and Environmental Management* **12** (1), 45-47.

[5] Craun, G.F. and Calderon, R.L. (1997). Microbial risks in groundwater systems: epidemiology of waterborne outbreaks. In: *Under the microscope. Examining microbes in groundwater.* American Water Works Association Research Foundation, Denver Colorado.

[6] Fewtrell, L. and Kay, D. (1996). *Health risks from private water supplies.* CREH report EPG 1/9/79, University of Leeds, Leeds.

[7] Benton, C., Forbes, G.I., Paterson, G.M., Sharp, J.C.M. and Wilson, T.S. (1989). The incidence of waterborne and water-associated disease in Scotland from 1945-1987. *Water Science and Technology* **21**, 125-129.

[8] Lamb, A.J., Reid, D.C., Lilly, A., Gauld, J.H., McGaw, B.A. and Curnow, J. (1998). *Improved source protection for private water supplies: report on the development of a microbiological risk assessment approach.* School of Applied Sciences, Robert Gordon University, Aberdeen, 86pp.

[9] Furtado, C., Adak, G.K., Stuart, J.M., Wall, P.G., Evans, H.S. and Casemore, D.P. (1998). Outbreaks of waterborne infectious intestinal disease in England and Wales, 1992-5. *Epidemiology and Infection* **121**, 109-119.

pathogen responsible for all ten outbreaks from public supplies was *Cryptosporidium*. In contrast, the most common pathogen associated with private supplies was *Campylobacter*, along with *Cryptosporidium* and *Giardia*. In one outbreak the causal agent was not identified.

This difference is striking, and is most likely to reflect the differences in treatment strategies between public and private supplies. Public supplies usually employ a multiple barrier treatment strategy, normally with chlorination or possibly some other form of disinfection as a final stage. Any disease-causing organism which may have survived or broken through the conventional water treatment processes is therefore exposed to disinfection as a final barrier to prevent its entry into the distribution system. Provided that it is susceptible to the disinfectant, it will cause no problems. However, *Cryptosporidium* oocysts are highly resistant to chlorination at the levels applied in water treatment, and consequently this organism appears to be the most troublesome in public water supplies.

With private supplies a variety of treatment strategies are used, but often there is no treatment at all, and disinfection is both much less prevalent and can suffer from problems of unreliability. This allows the possibility for outbreaks to be caused by organisms that could easily be inactivated if some form of disinfection was employed. *Campylobacter* is such an organism. It is more susceptible to chlorine, ozone and ultraviolet (UV) irradiation than indicator organisms such as coliforms and *Escherichia coli*, but if there is no disinfection it can still cause outbreaks of disease, as has been observed with private supplies.

Table 2.1 summarises the outbreaks associated with private water supplies in the UK over the 25-year period from 1970 to 1995. This is not to say that these were the only outbreaks, but they are the ones that have been documented and have been subject to epidemiological investigation.

The following sections give a more detailed description of the micro-organisms that have been responsible for the outbreaks shown in Table 2.1.

2.3.2 *Campylobacter* species

The genus *Campylobacter* includes fourteen species with the most important human pathogens being the thermophilic species: *C. jejuni, C. coli and C. upsaliensis. Campylobacter jejuni* is a major cause of gastrointestinal illness and is common in the faeces of a wide variety of wild and domesticated animals. In England, Campylobacters are the main causes of food-related gastroenteritis. *C. jejuni* may adopt a dormant state with modified metabolism known as ‘viable but non-culturable’. The stimulus for the adoption of this state is stress, which includes the starvation conditions found in water.

The natural habitat of *Campylobacter* species is the intestinal tract of warm-blooded animals, particularly pigs and poultry. Faeces from infected animals will contain extremely high numbers of *Campylobacter* (several million per gram). Contamination of water sources should therefore be regarded with concern since the infective dose is relatively low, and 500 organisms have been shown to initiate infection. Most infections are relatively mild and resolve within a few days without medical intervention. However, serious complications can occur, particularly in the old or very young.

Table 2.1 Summary of outbreaks of disease associated with consumption of water from private supplies over the period 1970 to 1995

Pathogen	Number of outbreaks	Total cases
Campylobacter species	8	>647
Cryptosporidium	2	15
Cryptosporidium and *Campylobacter*	1	43
Escherichia coli serotype O157	1	4
Giardia	1	31
Paratyphoid fever	1	6
Streptobacillary fever	1	304
Viral gastroenteritis	3	>998
Unknown	1	51
Total:	**19**	**>2099**

Compiled from:

Fewtrell, L. and Kay, D. (1996). *Health risks from private water supplies*. Report No. EPG 1/9/79. Centre for Research into Environment and Health, University of Leeds.

Furtado, C., Adak, G.K., Stuart, J.M., Wall, P.G., Evans, H.S. and Casemore, D.P. (1998). Outbreaks of waterborne infectious intestinal disease in England and Wales, 1992-5. *Epidemiology and Infection* **121**, 109-119.

Galbraith, N.S., Barrett, N.J. and Stanwell-Smith, R. (1987). Water and disease after Croydon: A review of water-borne and water-associated disease in the UK 1937-86. *Journal Institution of Water and Environmental Management* **1**, 7-21.

Although *Campylobacter* does not multiply readily outside its natural habitat, survival in water can be protracted. They are more sensitive than *E. coli* to chlorine, ozone and UV at the levels normally applied as part of water treatment, so any viable organisms passing through the earlier stages of water treatment should not enter the supply. However, the action of disinfectants can be hindered if the water has not been conditioned adequately by the removal of dissolved organic material and particulates. The latter can have a shielding effect particularly where UV disinfection is being used.

Compliance with the normal standard of 0 *E. coli* in 100 ml should provide adequate protection. However between 1981 and 1994 there were nine recorded outbreaks involving nearly 700 cases associated with private water supplies.

2.3.3 *Cryptosporidium*

Cryptosporidia are unicellular protozoan parasites. Although many species are currently recognised, infecting a wide range of animals, *C. parvum* is thought to be the only species to cause the diarrhoeal disease cryptosporidiosis in humans. The incubation period (from infection to onset of symptoms) is 7 to 10 days. Person to person spread does occur. Infection is initiated by ingestion of the transmission stage which is a small (5 µm), round, resistant structure called an oocyst. Infected humans can excrete 10^9 oocysts per day and calves and lambs can excrete 10^{10} oocysts per day. The broad range of hosts, high outputs from infected individuals and environmental resistance ensure a high level of contamination in the environment. Cattle, sheep and human sewage are the main sources of contamination of private water supplies.

Cryptosporidium oocysts have been detected in river, canal, lake and reservoir waters, filter back wash waters, sewage effluents and in some groundwaters. The concentrations fluctuate considerably. 'Spikes' may occur in river waters after periods of heavy rainfall. Oocyst concentrations between 7 and 48 400 per 100 litres have been reported in raw surface water sources in the USA. Higher loadings have been reported in water receiving agricultural drainage

In sporadic cases (as distinct from outbreaks) the number of *C. parvum* infections is highest in children under five years of age. Most infections are reported during the spring and early autumn, the former probably coincidental with the lambing and calving season, and the latter with increased rainfall.

Physical treatment processes (coagulation, sedimentation and filtration) can provide an effective barrier to the parasite. Removal efficiencies of 99.8% for *C. parvum* oocysts by coagulation, clarification and sand filtration have been reported for efficiently operated systems. Membrane filters with sufficiently small pore sizes will effectively remove oocysts. Chlorination at the concentrations used in water supply does not inactivate oocysts. Disinfectants used in combination or sequentially may enhance disinfection activity against *C. parvum* and certain forms of UV treatment may be successful. However, very few published disinfection studies have been performed under conditions that are representative of actual high-risk conditions. A combination of catchment control, physical barriers and disinfection is required to provide protection from the organism.

Private supplies derived from surface waters and from some springs will be vulnerable to contamination with oocysts particularly in agricultural catchments. Here the use of a filtration stage in treatment is advisable to physically remove oocysts of *Cryptosporidium*, with disinfection aimed at inactivating any remaining viruses and bacteria.

Clapham reported that *Cryptosporidium* oocysts were found at one time or another in 60% of 15 private water supplies in the Bradford area, which had been monitored over roughly a 3-month period[10]. Oocysts were detected in 21 of a total of 150 samples taken (14%). These supplies were monitored after rainfall events (when the likelihood of oocysts entering supplies is thought to be increased) during the winter season (December to February – not usually a peak time for *Cryptosporidium* infections). This study clearly demonstrated that *Cryptosporidium* oocysts (and also *Giardia* cysts) can enter high-risk private supplies when conditions permit.

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[10] Clapham, D. (1997). *Cryptosporidium incidence in private water supplies and correlatory indicators*. Directorate of Housing and Environmental Protection, Bradford Metropolitan District Council.

A more recent study[11] monitored seven private water supplies in the UK for a range of micro-organisms including *Cryptosporidium* and *Giardia*. A monitoring cabinet was installed at each site and daily samples of 1000 litres were taken. Each site was monitored daily for six weeks in two phases, May to June 2000 and October and November 2000. The results are summarised in Table 2.2. Microbiological water quality deteriorated following heavy rainfall. At Site 7, filtration and electrochlorination were installed between Phases 1 and 2 but cysts were still found during extreme weather conditions.

Table 2.2 *Cryptosporidium* and *Giardia* in seven private supplies in the UK

Site		Samples found to contain cysts (%)			
		Cryptosporidium		*Giardia*	
		Phase 1	Phase 2	Phase 1	Phase 2
1	SW England	2.4	0.0	2.4	0.0
2	Scotland	75.0	60.0	50.0	42.5
3	S Wales	2.4	2.4	56.6	50.0
4	N Ireland	0.0	0.0	2.4	12.1
5	Scotland	33.3	15.4	56.0	65.9
6	S Wales	0.0	0.0	10.0	29.0
7	Yorkshire	52.2	57.7	91.0	84.4

Contamination of groundwater by *Cryptosporidium* and *Giardia* was reported in 12% of 199 groundwater sites in the USA, with the majority of positive detections in springs, infiltration galleries and horizontal (collector) wells[12]. Reports of *Cryptosporidium* and *Giardia* in groundwater in the UK are sparse, in part because high cost and difficult analytical procedures have made sampling very sporadic in public and private supplies alike.

The drinking water Directive does not stipulate a numerical standard for *Cryptosporidium*, but the UK Water Supply (Water Quality) Regulations 2000 include a treatment standard for all public supplies deemed to be at significant risk. The Regulations now require all supplies which are considered at significant risk to be continuously monitored for *Cryptosporidium* based on the collection of 1000 litres of water on average in every 24-hour period for analysis. Water is required to be treated to contain less than one *Cryptosporidium* oocyst per 10 litres.

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[11] CREH (2001). Report on the incidence of *Cryptosporidium* in water, Research Contract DWI 70/2/129.

[12] Hancock, C., Rose, J.B. and Callahan, M. (1997). The prevalence of *Cryptosporidium* and *Giardia* in US groundwaters. *Proceedings International Symposium on Waterborne Cryptosporidium*, Ed Fricker, C.R., Clancy J.L. and Rochelle P.A. American Water Works Association, Denver, CO, 147-152.

2.3.4 *Giardia*

Giardia are a group of flagellate protozoans which grow in the intestinal tracts of both vertebrates and invertebrates. *G. duodenalis* infects more than 40 species of vertebrates, including humans. It causes a diarrhoeal disease in humans and between 4 000 and 7 000 cases are reported in England and Wales each year. The disease can be transmitted by direct contact with infected animals and humans, or by consumption of water, food or beverages contaminated by the faeces of infected humans or animals. *Giardia* forms cysts that are infectious and these survive well in aqueous environments. The cysts are oval in shape and 9 to 12 µm in length. A large number of animals (including humans) are potential carriers of *Giardia* infectious to humans. In the UK, the organism is endemic in sheep, cattle, rodents, cats and dogs. Birds have also been suggested to be a potential reservoir of *Giardia* infectious to humans.

The cysts survive well in aqueous environments and show greater resistance to UV, chlorine, and ozone than bacteria and viruses, but they are less resistant than *Cryptosporidium* oocysts. Giardia cysts are inactivated by boiling or pasteurisation. Normal coagulation, sedimentation and filtration processes, if operated correctly, should achieve at least a 3-log (99.9%) removal of cysts.

Outbreaks associated with drinking water can occur where human or animal faeces contaminate the supply and there is inadequate treatment, filtration or chlorination. In the UK the threat to public supplies is regarded as being minimal due to the use of multiple treatment barriers. Post treatment contamination, such as could occur after repairs to mains that are not adequately cleaned and disinfected before recommissioning, could still be a particular risk.

Private supplies should be regarded as being at greater risk if the catchment is prone to contamination by the faeces of animals, if there is a rapid route for recharge to reach the raw water intake and if there are inadequate treatment barriers. Table 2.2 in Section 2.3.3 shows the results of sampling seven private water supplies in the UK for *Giardia*.

2.3.5 *Escherichia coli* serotype O157

The bacterium *E. coli* O157 is an increasing cause of severe disease in Britain. Although most outbreaks and individual illnesses have been due to contaminated food, the organism has been implicated in water-associated outbreaks. In the UK this has been confined to private supplies and there has been a strong association with possible contamination from animal faeces. In May 2000 an outbreak in Walkerton (Canada) associated with a large public water supply killed seven people and caused illness in hundreds more.

The main reservoirs of *E. coli* O157 are healthy cattle and sheep; and so foods of animal origin are amongst the most common vehicles of infection. Large numbers are excreted in the faeces of infected animals even though the animal may be showing no symptoms of disease. Because of the animal reservoirs *E. coli* O157 can be found in a wide range of environmental sources. Contamination of carcasses at abattoirs can create a chain of contamination through food processing plants to the consumer or when water becomes contaminated with animal faeces. E coli O157 can survive for long periods in water. During an outbreak in Missouri (USA) studies indicated that this organism survived in water for at least 35 days at 5 °C. After 7 days storage less than one log order reduction was observed. After 35 days 2 log orders reduction was observed at 5 °C and 5 log orders at 20 °C.

In the absence of evidence to the contrary it seems justified to assume that *E. coli* O157 will react to water treatment as do other strains of *E. coli*. Coagulation and sedimentation followed by sand filtration will give 2 to 4 orders of magnitude reduction. *E. coli* O157 is also susceptible to disinfection and chlorination with a Ct (concentration × time) value of 15 mg/l.min should provide up to 4 orders of magnitude reduction (the Ct concept is discussed in Section 5.9.1). A well maintained multiple barrier treatment strategy would therefore provide good protection.

Where such a treatment strategy is not used, such as in private supplies, the supply should be regarded as being at risk particularly if the catchment could be prone to faecal contamination from farm animals.

Because the infectious dose of *E. coli* O157 is thought to be relatively low (100 organisms), the detection of any *E. coli* in the supply should be regarded with concern.

Regular monitoring to ensure that the disinfection treatments are operating satisfactorily is essential and any failures of microbiological quality should be investigated immediately.

There are no specific standards for *E. coli* O157 in drinking water but, as mentioned above, the detection of any *E. coli* in water should be regarded as evidence that *E. coli* O157 could be present or that the supply is susceptible to breakthrough by this organism, or indeed other pathogens.

2.3.6 *Streptobacillus*

One outbreak of Streptobacillary fever has been associated with a private water supply. Over 300 people were affected and the illness was thought to be due to contamination of a spring source by rats.

Streptobacillary fever is a rare infection in the UK, and is caused by a bacterium called *Streptobacillus moniliformis.* This organism is normally associated with rat bites causing an illness termed rat-bite fever. However the bites of infected mice, squirrels, weasels, dogs and cats have also been recorded as causes of the illness. *Streptobacillus moniliformis* occurs in animals as a commensal inhabitant of the nasopharynx, but can occasionally be excreted in urine.

Haverhill fever is a form of Streptobacillary fever that is normally connected with direct contact with animals. It was named after the first recorded epidemic of the disease in Haverhill (Massachusetts, USA) caused by consumption of raw milk and milk products. An outbreak in the UK occurred at a boarding school in Essex in 1983. Although this was at first thought to be caused by the school's supply of unpasteurised milk, further case-controlled studies gave a strong association with the school's private water supply. This was a spring source where there was evidence of rat infestation. This source was used for the hot water supply in the school, but engineering investigations showed the possibility of cross-connection with the potable supply.

Streptobacillus moniliformis is a Gram negative bacterium, which generally occurs as short coccobacillary forms or rods (0.5 µm in length). Its small size may allow passage through water treatment filters particularly if there has not been a coagulation stage. The organism is pleomorphic and so should be susceptible to disinfectants. It can however occur in chains of filaments, which may increase its tolerance of disinfection.

2.3.7 Enteric viruses

There are several types of viruses, which can be present in faeces that can cause viral enteritis, notably, the rotaviruses, the Norwalk-Like Viruses (NLV), and members of the enterovirus group. There have been several relatively large outbreaks (each of more than 100 cases) of viral enteritis associated with private water supplies derived from surface water. In each of these there was evidence of faecal contamination of the supply which had either been inadequately chlorinated, or not disinfected at all. Birds also carry viruses and can contaminate reservoirs and open cisterns.

Although filtration will remove viruses to some degree the primary treatment barrier is disinfection, either by chlorine or UV irradiation. As stated earlier, for these to be most effective waters must be conditioned by filtration (to remove particulates and aggregates of viruses) before disinfection. Where disinfection is the only treatment being employed, it must be maintained and its performance monitored regularly to optimise disinfectant activity for the prevailing water conditions.

2.3.8 Paratyphoid fever

Notifications of paratyphoid fever in the UK decreased about four-fold from the late 1930s to the 1980s[13]. Information collected since the early 1970s has shown that roughly half the cases of paratyphoid fever in the UK were caused by *Salmonella paratyphi A*, 95% of these being contracted abroad, and half were caused by *S. paratyphi B*, with over 70% of these being infected abroad. There have been no reported cases or outbreaks of water-borne disease due to *S. paratyphi A*.

Paratyphoid B fever is usually food-borne, but two water-borne outbreaks have been recorded since 1970, consisting of 96 cases, with no deaths. One of these outbreaks involved a private water supply. This was an unpublished PHLS report of six cases in Herefordshire in 1975. These resulted from consumption of well water that was contaminated by leakage of sewage from a domestic drain close to the well.

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[13] Galbraith, N.S., Barrett, N.J. and Stanwell-Smith, R. (1987). Water and disease after Croydon: A review of water-borne and water-associated disease in the UK 1937-86. *Journal Institution of Water and Environmental Management* **1**, 7-21.

Salmonellae would be expected to respond to water treatment processes in a similar way to coliform organisms and *E. coli*, and would have a similar susceptibility to chlorination or other disinfection processes. A well-maintained multiple barrier system would therefore give good protection. As salmonellae, if present in raw water at all, would be less numerous than coliforms and *E. coli*, the absence of these indicator organisms should give a good assurance of the absence of this particular pathogen.

2.4 Chemical contaminants

2.4.1 Metals

Aluminium

Aluminium is a natural constituent of many raw waters, particularly acidic surface waters derived from upland catchments. Aluminium compounds may also be introduced into treated water as the result of its use as a coagulant to remove colour and turbidity. Aluminium can deposit within the distribution system and give rise to aesthetic problems. The UK drinking water quality regulations include a national standard for aluminium of 200 µg/l. The standard for aluminium is based on avoiding problems of cloudiness and discoloration rather than being health-based. Aluminium in raw water can be removed by coagulation and filtration. The use of aluminium sulphate as a coagulant in water treatment should normally result in a residual concentration of no more than 50 to 100 µg/l Al. Aluminium in small water supplies can be removed by use of filtration or membrane techniques.

Iron and manganese

Iron and manganese derived from minerals and sediments can be present in particulate or dissolved form in groundwaters and surface waters. Iron and manganese concentrations in surface waters are usually less than 1 mg/l but much higher concentrations (up to 50 mg/l Fe and 30 mg/l Mn) can be encountered in groundwaters.

Iron and manganese deposit in treatment and distribution systems and can also interfere with the efficiency of UV disinfection by coating treatment units. Iron and manganese suspensions cause aesthetic problems including metallic taste and discoloration of water fittings and laundry. High dissolved iron and manganese concentrations can also increase chlorine demand and thus reduce the efficiency of chlorine disinfection. The UK drinking water quality regulations include national standards for iron and manganese of 200 µg/l and 50 µg/l, respectively. Iron and manganese can be removed by filtration although oxidation, coagulation and sedimentation may be required for high concentrations particularly if the metals are in dissolved form. An oxidation (aeration) process is invariably required when groundwaters contain more than 1 mg/l of dissolved iron or manganese.

Lead

The concentration of lead in raw waters rarely exceeds 20 µg/l but higher concentrations do occur in water drawn from strata containing galena or other lead ores. High levels of lead in drinking waters are usually caused by the dissolution of lead (plumbosolvency) from lead pipework, tank linings or use of leaded alloys in water fittings. Traces of lead may also be derived from lead solder and from PVC pipes containing lead-based stabilisers. The UK drinking water quality regulations specify a standard for lead of 10 µg/l to be met by 2013, with an intermediate standard of 25 µg/l to be met by 2003. For small water supply systems the best approach is the replacement of lead-containing materials with non-leaded alternatives. Treatment methods are available to reduce plumbosolvency – see Section 5.10. Water that has been standing in lead pipes for long periods, for example overnight, should not be drunk. In these circumstances, the tap should be run for 30 to 60 seconds to clear the pipes before taking water for drinking or cooking.

Arsenic

Arsenic is introduced into water through the dissolution of minerals and ores, from industrial effluents, and from atmospheric deposition; concentrations in groundwater in some areas are sometimes elevated as a result of water-rock interaction in the aquifer. The most prevalent species of arsenic in water are inorganic. The predominant form is either arsenic (V) (arsenate), which predominates in oxidising conditions, or arsenic (III) (arsenite), which is present in reducing conditions.

Inorganic arsenic is a documented human carcinogen. A relatively high incidence of skin cancer and possibly other cancers that increase with dose and age has been observed in populations ingesting water containing high concentrations of arsenic. The standard for arsenic is 10 µg/l.

Arsenic (V) can be removed effectively by iron or aluminium coagulation. If present as Arsenic (III) then pre-oxidation (e.g. using chlorine) is required. Other potential removal techniques include ferric oxide, activated alumina, ion-exchange and reverse osmosis.

2.4.2 Nitrate

Nitrate (NO_3^-) occurs naturally in water as a result of the oxidation of ammonia, which is released during mineralisation of organic nitrogen. In some areas agriculture is the major source of nitrate in surface waters and groundwaters. The discharge of nitrate-containing effluents from sewage treatment works contributes to the concentration of nitrate in some surface waters. The UK drinking water quality regulations specify a standard for nitrate of 50 mg/l as NO_3. In addition the water must satisfy the following formula, where the square brackets signify the concentrations in mg/l of nitrate and nitrite:

$$\frac{[nitrate]}{50} + \frac{[nitrite]}{3} \leq 1$$

Ion-exchange, biological de-nitrification and certain membrane processes can reduce nitrate concentrations. Of these, only ion-exchange and membrane processes are likely to be practicable for small water supplies. It may be appropriate to consider controls over agricultural activities within catchment areas as a long term means of reducing the leaching of nitrate into water supplies, if these are the source.

2.4.3 Ammonia

Most natural waters contain traces of ammonia or ammonium compounds. The ammonia found in water may occur naturally or it may indicate that recent pollution has taken place. Certain anoxic groundwaters may contain elevated concentrations of ammonia (greater than 1 mg/l as NH_4) resulting from natural ammonification and denitrification processes. Ammonia may also be derived from the decay of organic material in the soil resulting in small concentrations in water; unpolluted river waters rarely contain more than 0.05 mg/l NH_4. On the other hand, the presence of ammonia could indicate contamination from human or animal sources. Elevated concentrations in water should be investigated to ascertain the cause.

The UK drinking water quality regulations set an indicator parameter value for ammonia of 0.5 mg/l NH_4. However, the appearance of even small amounts of ammonia (e.g. above 0.05 mg/l NH_4) in a groundwater which is normally free from ammonia warrants further investigations.

Ammonia can be removed from water by aeration (after increasing pH to 11), ion-exchange, biological denitrification and breakpoint chlorination. Of these, only chlorination is likely to be applicable to small supplies. Chlorination converts ammonia to chloramines (see Section 5.9.3) which are less potent disinfectants than chlorine itself and can give rise to taste and odour complaints. Therefore, when designing chlorination systems for ammonia-containing waters, the chlorine capacity must be sufficient to produce a free chlorine residual.

2.4.4 Pesticides

The use of pesticides for agricultural and non-agricultural purposes is widespread and there are approximately 450 different active ingredients in pesticides licensed for use in the UK. In surveys of UK surface and groundwater sources, the most commonly reported pesticides are atrazine, simazine and dieldrin. In the past, atrazine was used almost entirely for non-agricultural control of weeds on roadside verges and railways and much of the use of simazine was attributable to non-agricultural uses. Controls on agricultural uses and withdrawal of approvals for non-agricultural uses of these pesticides were introduced in the UK in 1992. Other pesticides commonly reported in water sources used for public supplies include isoproturon, mecoprop and chlorotoluron. The UK drinking water quality regulations specify standards of 0.1 µg/l for individual pesticides and 0.5 µg/l for total pesticides. These standards do not have any toxicological basis. Advice on what constitutes a significant breach of the pesticide standard is given in Guidance on Safeguarding the Quality of Public Water Supplies (Appendix C). Some pesticides, e.g. atrazine and simazine, have been found in water sources used for drinking water supplies at levels exceeding 0.1 µg/l. Peaks in pesticide concentrations have been observed in surface waters following heavy rainfall.

Careless or improper use or storage of pesticides can contaminate water sources. Pesticides must not be used near wells. Sheep dip chemicals (organophosphates and synthetic pyrethroids) present a particular risk to water sources. Sheep dip chemicals should be handled carefully, used sheep dip should be disposed of properly (i.e. not to a soakaway), and freshly dipped sheep should be kept away from water supplies.

Several ‘advanced’ water treatment processes have been investigated for the removal of pesticides including ozonation, activated carbon adsorption and oxidation processes using combinations of oxidants. Concentrations of individual pesticides found in typical surface waters can be reduced to less than 0.1 µg/l by adsorption on granular activated carbon (GAC) with an empty bed contact time of typically 15 to 30 minutes, depending on the pesticide, its concentration, GAC type and system design. Ozonation will also reduce pesticide concentrations to varying degrees. It is unlikely that treatment to remove pesticides from small supplies will be practicable and where significant concentrations are detected it will be necessary to consider provision of an alternative supply.

2.4.5 Chlorinated solvents

Contamination of groundwaters by chlorinated solvents can result from accidental spillage of chemicals, leakage from underground storage tanks, leakage from disposal sites and deliberate discharges to soakaways. The rate of transport of the solvents through the aquifer is dependent on the properties of the aquifer; rapid transport can occur if the overlying material is highly porous or fissured. Contaminated water can travel large distances, making it difficult to pinpoint the source of pollution.

The UK drinking water quality regulations specify standards of 3 µg/l for 1,2-dichloroethane and 10 µg/l for the sum of the detected concentrations of tetrachloroethene and trichloroethene. Solvent concentrations can be reduced by aeration or activated carbon adsorption. Activated carbon adsorption is likely to be the method of choice for small water supplies although provision of an alternative supply may be an economic consideration.

2.4.6 Disinfection by-products

Trihalomethanes

Trihalomethanes (THMs) are formed as a result of reactions between chlorine and some organic substances present in raw waters. Highly coloured surface waters which contain humic and fulvic acids are particularly prone to THM formation. The UK drinking water quality regulations specify a standard for Total THMs of 100 µg/l for the sum of the detected concentrations of four specified THMs (trichloromethane, dichlorobromomethane, dibromochloromethane and tribromomethane) to be met by 2003.

THM formation can be controlled by reduction of the organic content of the water before disinfection, modification of the disinfection practice or the use of disinfectants other than chlorine, such as ultraviolet radiation or ozone but ozone may cause other problems by reacting with organic matter. THMs precursors can be removed to some extent by adsorption on activated carbon.

Bromate

Bromate is not present in source waters but is formed by oxidation of bromide if ozonation is used for water treatment. Elevated bromide concentrations occur where saline intrusion occurs into fresh aquifers in coastal areas, increasing the potential for bromate formation during ozonation. Bromate is also a potential impurity in sodium hypochlorite, a commonly-used disinfectant. The UK drinking water quality regulations specify a standard for bromate of 10 μg/l to be met by 2003.

The formation of bromate during ozonation depends on several factors including concentrations of bromide and ozone and the pH. It is not practicable to remove bromide from the raw water and it is difficult to remove bromate once formed, although granular activated carbon filtration has been reported to be effective under certain circumstances. Bromate formation can be minimised by using lower ozone dose, shorter contact time and a lower residual ozone concentration.

2.5 Physical and chemical properties

2.5.1 pH value

The pH value of water is a measure of acidity or alkalinity. Pure water is very slightly ionised into positively charged hydrogen ions (H^+) and negatively charged hydroxide ions (OH^-). Water is neutral when the numbers of hydrogen ions and hydroxide ions are equal. When the concentration of hydrogen ions exceeds that of hydroxide ions, the water is acidic and has a pH value less than 7. Conversely, when the concentration of hydroxide ions exceeds that of hydrogen ions, the water is alkaline and has a pH value greater than 7. The pH scale is logarithmic, therefore a change in pH value of one unit represents a tenfold change in the concentrations of hydrogen and hydroxide ions.

Acidity in raw waters can result from the dissolution of carbon dioxide to produce weak carbonic acid. Groundwaters and surface waters may also contain organic acids produced during the decomposition of vegetation. A surface water derived from a peaty moorland catchment may have a pH value as low as 4. Alkaline waters result almost entirely from the dissolution of the bicarbonate, carbonate and hydroxide salts of calcium, magnesium, sodium and potassium. Soft acidic waters can cause corrosion of pipework and the dissolution of metals such as copper, zinc and lead. Hard, alkaline waters can cause problems associated with scale formation. Some hard waters may also be plumbosolvent.

The UK drinking water quality regulations include pH as an indicator parameter and specify a minimum pH of 6.5 and a maximum pH of 10.0. In water treatment, the pH value can be changed by aeration, alkali or acid dosing or contact with alkaline material in contact beds.

2.5.2 Hardness

Water hardness is caused by dissolved salts of calcium and magnesium. Total hardness consists of temporary and permanent hardness. Temporary hardness is caused almost entirely by the carbonates and bicarbonates of calcium and magnesium. Temporary hardness is precipitated by evaporation and boiling. Permanent hardness is caused almost entirely by the sulphates and chlorides of calcium and magnesium. Permanent hardness is not precipitated by boiling.

The hardness of waters, expressed in mg/l $CaCO_3$ (calcium carbonate), can be classified as shown below:

Water	Hardness (mg/l $CaCO_3$)
soft	up to 50
moderately soft	50 – 100
slightly hard	100 – 150
moderately hard	150 – 200
hard	200 – 300
very hard	over 300

The drinking water Directive and the UK drinking water quality regulations do not specify standards for hardness, calcium or magnesium. Water softening may be applied at water treatment works[14]. This can be achieved by lime-soda softening – the addition of lime ($Ca(OH)_2$) and sodium carbonate (Na_2CO_3) to the water which causes the hardness compounds to precipitate. An alternative method, common in domestic water softeners, is ion-exchange (base exchange), whereby the calcium and magnesium ions in the water are replaced by sodium ions. Where water is softened by base exchange softening it is important to provide an unsoftened outlet for potable purposes. Installation of a softener just before the hot water tank or boiler is a more economical method for preventing precipitation of hardness salts (limescale) than softening the whole supply.

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[14] The UK Department of Health has stated that “in view of the consistency of the [epidemiological] evidence [of a weak inverse association between natural water hardness and cardiovascular disease mortality], it remains prudent not to undertake softening of drinking water supplies ... it appears sensible to avoid regular consumption of softened water where there is an alternative”.

2.5.3 Colour

Water can be coloured by humic and fulvic materials leaching from peat or other decaying vegetation and by naturally occurring salts of iron or manganese. Surface waters derived from peaty moorland catchments may be strongly coloured. The characteristic brown colour of these waters is variable and often shows a strong seasonal effect, with concentrations being greatest in late autumn and winter. Waters derived from lowland rivers can similarly show a seasonal increase in colour following autumn leaf fall.

A water may appear coloured because of material in suspension and true colour can only be determined after filtration. Colour is expressed in mg/l on the platinum-cobalt (Pt-Co) scale, which is equivalent to measurements expressed in Hazen units (°H). The removal of colour from water is necessary not only for aesthetic reasons but also because chlorination of highly coloured waters can give rise to high concentrations of trihalomethanes (see Section 2.4.6). High colour also reduces the efficiency of disinfection by UV irradiation, chlorination and ozonation. Colour will also cause fouling of reverse osmosis membranes.

The drinking water Directive includes colour as an indicator parameter without a numeric standard but with the requirement “Acceptable to consumers and no abnormal change”. The UK water quality regulations specify a standard of 20 mg/l Pt-Co.

Colour removal at a water treatment works is usually achieved by coagulation followed by sedimentation or flotation and filtration. Filtration techniques may be applied to small supplies but the efficiency of colour removal is usually relatively poor.

2.5.4 Turbidity

Turbidity is caused principally by inorganic matter in suspension including mineral sediments and oxides of iron or manganese but organic matter including algae can also cause significant turbidity. Most surface waters show particularly high turbidity following periods of heavy rainfall. Groundwaters generally show low to very low turbidity and variations, following heavy rainfall for example, may indicate rapid recharge bringing in contaminants from the surface.

Turbidity measurement gives a quantitative indication of the clarity of a water and analysis is carried out using a nephelometer. Nephelometers measure the intensity of light scattered in one particular direction, usually perpendicular to the incident light and are relatively unaffected by dissolved colour. Nephelometers are calibrated against turbidity standards prepared from a suspension of formazin and the standard unit of turbidity is the nephelometric turbidity unit or NTU.

Turbidity is removed for aesthetic reasons and because high turbidity can impair the efficiency of disinfection. The drinking water Directive includes turbidity as an indicator parameter without a numeric standard but with the requirement “Acceptable to consumers and no abnormal change”. It also states that for treated surface waters the value should not exceed 1 NTU.

The UK water quality regulations specify a standard of 4 NTU at consumers' taps with an indicator parameter value of 1 NTU in water leaving treatment works.

Rapid sand filtration or microstraining can remove coarse turbidity and some species of algae. Fine turbidity and many species of algae that may penetrate rapid filters can be removed by slow sand filtration or by coagulation followed by sedimentation or flotation and filtration. A variety of filtration techniques can be successfully applied to small supplies.

2.5.5 Taste and odour

Sources of taste and odour in water include decaying vegetation, algae, moulds and actinomycetes. Taste and odour are usually associated with the presence of specific organic compounds released by the source agent which give rise to 'earthy' or 'musty' taste or odour. Chlorine and the by-products of chlorination can also cause complaints of taste or odour. Relatively high concentrations of iron, manganese and some other metals can impart an unpleasant metallic taste.

The drinking water Directive includes taste and odour as indicator parameters without numeric standards but with the requirement "Acceptable to consumers and no abnormal change". The intensity of odour and taste is expressed as Dilution Number – the dilution of the sample with odour or taste free water at which the odour or taste is undetectable. The UK water quality regulations specify standards for both odour and taste of 3 dilution number at 25 °C.

Taste and odour are removed principally for aesthetic reasons. Taste and odour can be reduced or removed by aeration, ozonation or adsorption on activated carbon or, where chlorination is the source of taste or odour, by control of the disinfection process.

2.6 Radioactivity

All waters contain traces of naturally occurring radionuclides, the concentrations depending on the origin of the water. The natural radionuclides of most relevance are radon (Rn) and uranium (U). Radon is volatile and as a result it can be released from water as a gas. This is of concern if the release occurs within a confined space with insufficient ventilation.

Radon and uranium are only found in significant concentrations in groundwater in certain parts of the UK, depending on the type of geology. Further advice is available from local authorities and the National Radiological Protection Board (NRPB, see Appendix B). These substances are not significant for any surface water sources in the UK.

The concentration of radioactive elements in water is expressed in terms of their activity, in Bequerels per litre (Bq/l). There is currently no official recommended level of radon in drinking water in the UK. There is a draft European Commission recommendation on radon in drinking water supplies of 100 Bq/l for public supplies and an action level of

1000 Bq/l for non-commercial private supplies. The EU level of 1000 Bq/l is consistent with recent advice from the NRPB. Uranium limits were proposed to be in the range 20 to 100 µg/l. The uranium guideline is currently 20 Bq/l (equivalent to a concentration of approximately 2 mg/l).

Treatment for radon removal cannot use point-of-use systems fitted to the tap because, being volatile, it is released into the atmosphere whenever water is used. Under-sink treatment using an activated carbon filter is also inadvisable because the filter would become radioactive. Radon removal treatment therefore has to be installed before entry of water into a building. Aeration is the preferred treatment technique but other methods are feasible. Treatment is discussed further in Section 7.

Uranium removal is best achieved by point-of-use systems, as discussed in Section 7.

3. SOURCE SELECTION, PROTECTION AND MONITORING

3.1 Introduction

Water in oceans, lakes or lochs, rivers and the ground, as well as snow and ice, constitutes the hydrosphere. Water in the hydrosphere is involved in the hydrological cycle, which covers movement of water between the hydrosphere and the atmosphere. Precipitation and evaporation are the principal agents of this movement.

Water which flows in streams and rivers or which is contained in lakes or lochs is called surface water whilst water which percolates into the ground and reaches the water table is called groundwater. The general features of geological formations associated with surface water and groundwater sources are shown in Figure 3.1.

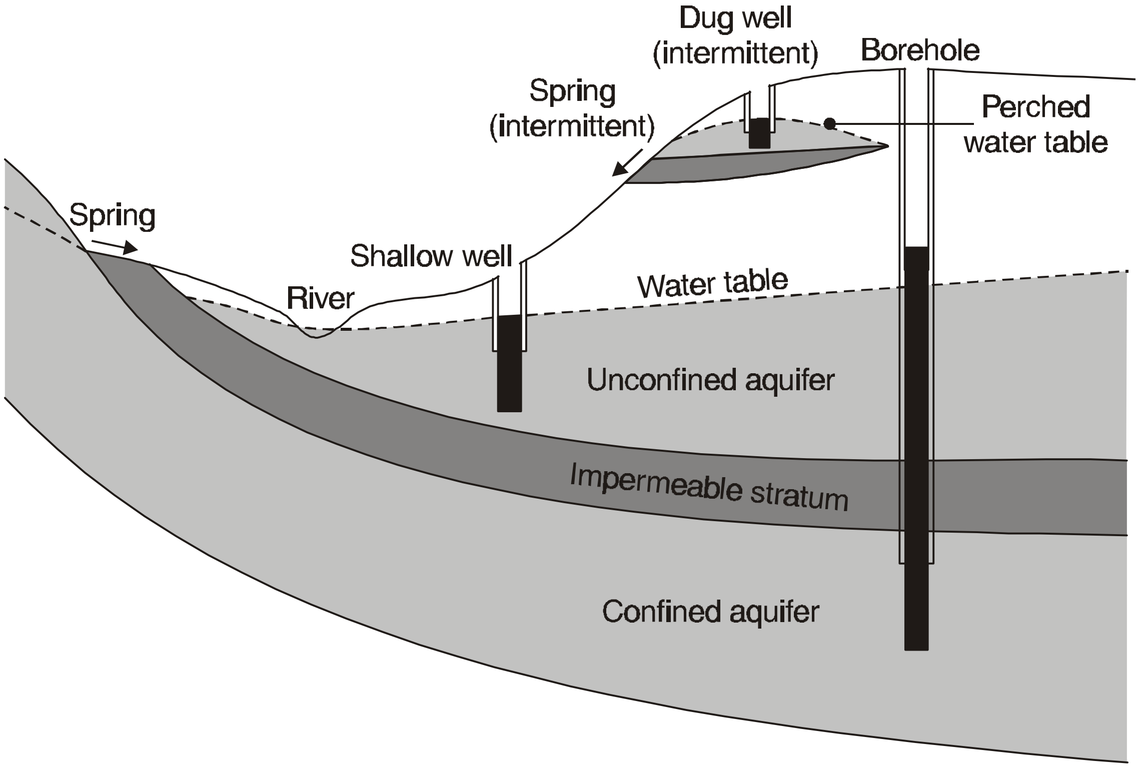

Figure 3.1 Groundwater and surface water sources

3.2 The hydrological cycle

Evaporation from the oceans produces water vapour, which rises and condenses to form clouds; these clouds move with atmospheric circulation until they lose thermal energy and the condensed water vapour is released as precipitation. The precipitation introduces water into the terrestrial environment where it may percolate into the ground, run-off as rivers and streams, or be returned to the atmosphere through evapotranspiration. Eventually such moisture returns to the oceans or the clouds and the cycle begins again (Figure 3.2).

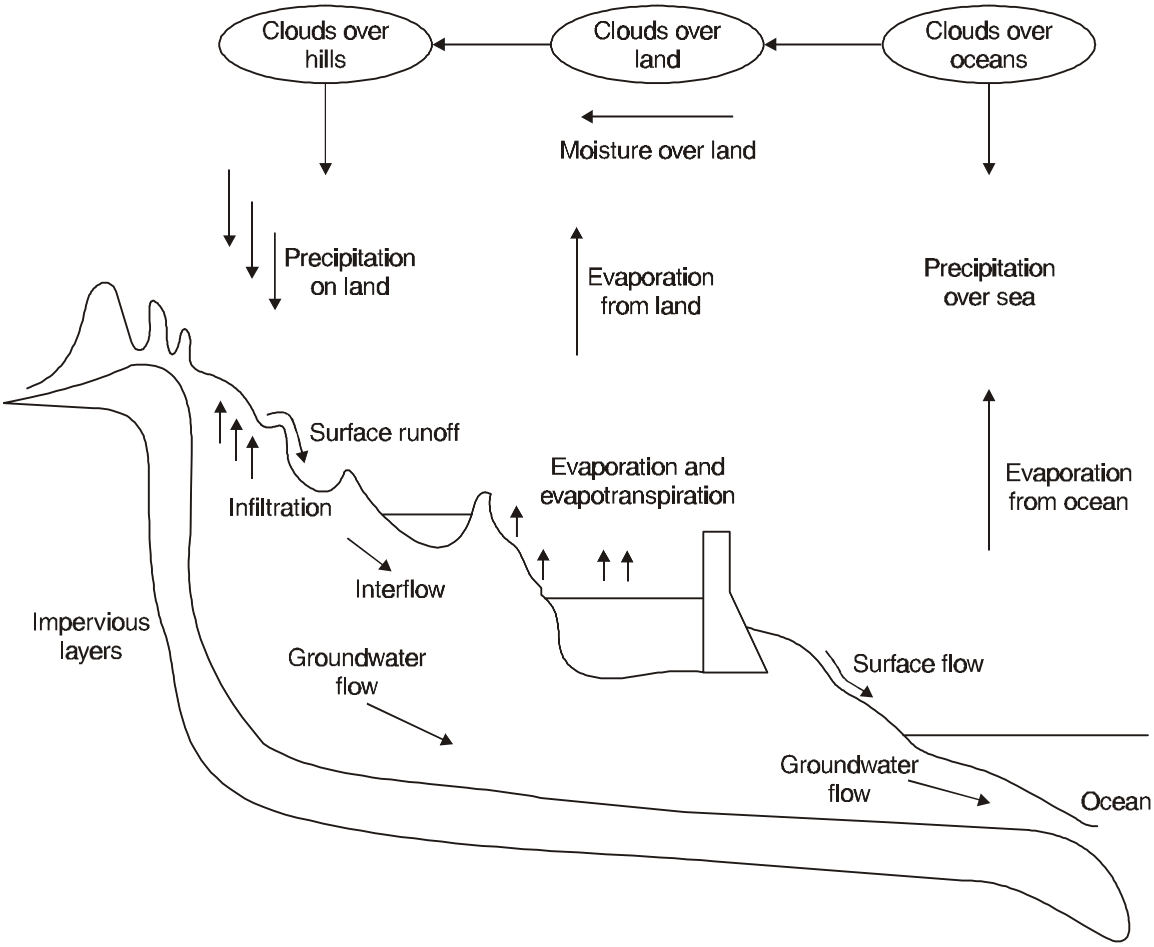

Figure 3.2 Hydrological cycle

Within this cycle raw water may be obtained from rivers or streams, from lakes and reservoirs, or from groundwater. Of these sources, groundwater is the most abundant. World-wide groundwater constitutes around 95% of the available freshwater reserves. Precipitation falling on to a soil will wet the soil surface and then infiltrate below ground level where it adheres to the soil particles by a combination of surface tension and molecular attraction to form pellicular water. Such pellicular water escapes the forces of gravity as the attractive forces of surface tension and molecular attraction are such that only evapotranspiration can remove this bound water. Thus precipitation will only penetrate deeper once the soil reaches its field capacity when the force of gravity exceeds the attractive forces binding water to soil particles and allows the water to drain downwards. In this region of the soil the voids present in the soil or rock are not completely filled with water and so this region of the subsurface is known as the unsaturated zone. As gravity pulls the water down to greater depths the voids become completely filled with liquid and this is termed the saturated zone. Water in this saturated zone is termed groundwater and the boundary between the unsaturated and saturated zone is termed the water table. This separation is not clear-cut and the transition phase between the unsaturated and saturated zone is called the capillary zone or capillary fringe.

If these zones are viewed in terms of pressure then it is found that the unsaturated and saturated zones have different characteristics. The pressure gradient in the unsaturated zone is less than atmospheric pressure, i.e. atmospheric minus capillary pressure, whereas in the saturated zone the voids are completely filled with water at a pressure above atmospheric pressure. Thus the water table may be defined in terms of pressure as the level in the subsurface where atmospheric pressure occurs. These pressure differentials mean that if a well or borehole is excavated into the saturated zone, water will flow from the ground into the well. Water will then rise to a level in the well where the pressures equilibrate. Groundwater can be broadly defined as that water located below the water table, i.e. in the geomatrix (soil, rock or other geological material) where the void area, the space between the constituents of the geomatrix, is approximately 100% occupied by water. These voids or pores can be used to classify groundwater-bearing rocks into two broadly exclusive groups

- reservoirs - geomatrix containing voids that allows liquid to penetrate into the main body of the material;

- non-reservoirs - geomatrix lacking any void space and therefore unable to harbour any liquid.

Reservoirs vary in the degree to which stored water will be released as some may not easily release their stored water e.g. clays are reservoirs but do not release their stored water. This feature of reservoirs requires a further division into permeable and impermeable reservoirs.

Another feature is that groundwater is dynamic, being constantly in motion through the geomatrix. The ease with which water can pass through particular rock strata depends on a combination of the size of the pores and the degree to which they are interconnected resulting from the degree to which the rock is permeable. An aquifer is any rock which contains interconnected pores or fissures which can hold and transfer water (Figure 3.3) and may be defined as a water-bearing rock formation that contains water in sufficient amount to be exploited and brought to the surface by wells.

Geomatrix materials that can serve as aquifers include gravel, sand and sandstone, alluvium, cavernous limestone, vesicular basalt and jointed slate. The different components that combine to produce an aquifer system are shown in Figure 3.3. It is apparent that there are two distinct types of aquifers: confined or unconfined. In an unconfined aquifer the water table is unrestricted and can thus move up or down through the geomatrix. By contrast a confined aquifer is restrained by an upper layer of impermeable rock, termed an aquiclude, which prevents water moving upwards. As discussed above, the pressure in a confined aquifer will be above atmospheric pressure and this pressure difference will cause water to rise in a well shaft that penetrates the aquiclude. Such wells are termed artesian wells. An imaginary line joining the water surface in many wells in a confined aquifer is called the potentiometric surface (Figure 3.3).

To complete the hydrological cycle within the groundwater area, all freshwater found underground must have a source of recharge such as rainfall or leakage from surface drainage such as rivers, lakes or canals. It should be borne in mind that groundwater systems are dynamic with water continuously moving from areas of recharge to areas of discharge with transit times of many years.

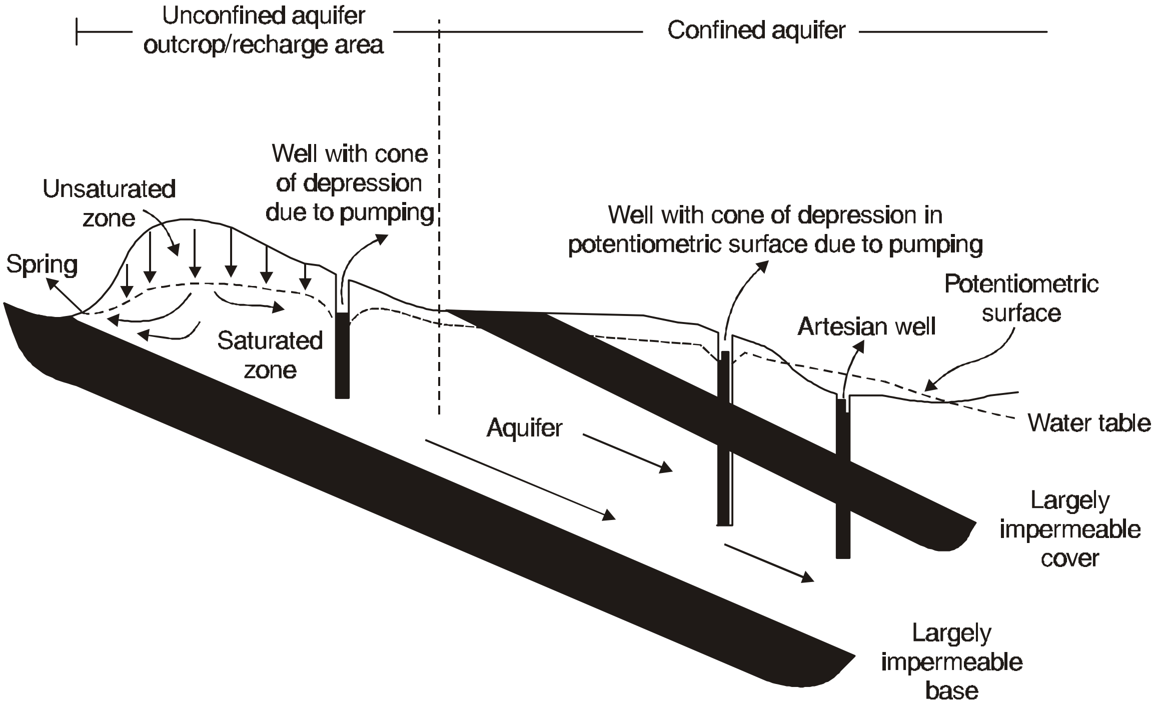

Figure 3.3 Confined and unconfined aquifers

3.3 Source selection

The principal sources of private supplies are springs, wells and boreholes. Streams and rivers are also used but to a lesser extent because of the more variable quality of surface waters compared to groundwaters. Whatever the source, it must consistently yield a quantity of water sufficient to satisfy the requirements of the user.

3.3.1 Streams and rivers

Streams and rivers offer more reliable yields but may be susceptible to pollution and may exhibit variable quality. The risk and extent of pollution depends on the catchment and the activities being undertaken on it. Waters derived from upland catchments that are not unduly peaty and not used for agricultural purposes are usually of good chemical quality. However, soft acidic upland waters derived from peaty moorland catchments may be corrosive and contain relatively high concentrations of dissolved metals. Small streams often exhibit variable quality because of the activities of man and animals within the catchment.

Lowland surface waters are likely to be of poorer quality. The quality of surface waters may show a strong seasonal variability. Colour may be highest in late autumn and winter. Turbidity may be highest following periods of heavy rainfall.

Because of these potential problems, a surface water source is normally only considered for use as a drinking water supply where a groundwater source is unavailable. Water treatment will require a minimum of filtration and disinfection and should be designed for the worst expected raw water quality. A small reservoir or tank installed at the source can provide a period of settlement and reduce the variability in water quality. This tank will require regular inspection and cleaning. Figure 3.4 shows the construction of brick or concrete reservoirs; pre-cast concrete reservoirs can also be used.

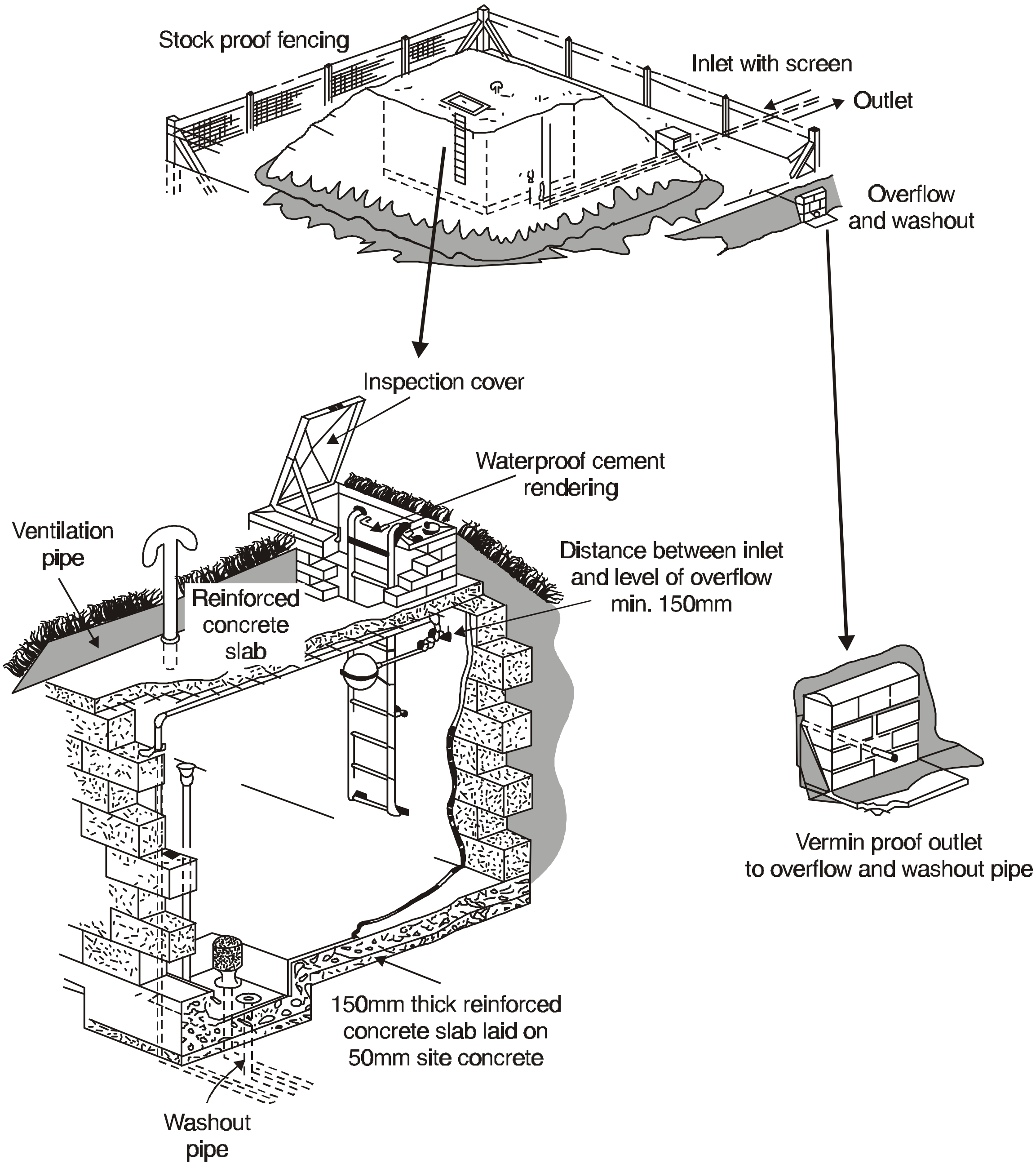

Figure 3.4 Brick or concrete reservoirs

3.3.2 Springs

The quantity of water available from a spring depends on its source. Most reliable are springs issuing from deep-seated aquifers whereas those from perched water tables or supported by flow from fissured limestone or granite aquifers may dry up after a short period without rain. Spring sources can be of good chemical and microbiological quality although springs from shallow or fractured strata may be of variable quality because of surface contamination. The treatment of spring waters is usually simpler than for surface waters because spring water is likely to contain less suspended matter.

Some ‘spring’ sources used for small water supplies are in fact artificial land drains. If the whole drainage system is properly maintained, the quantity and quality of water may be acceptable for a drinking water supply but for assessing treatment needs, a land drain should be regarded as effectively a surface water. If maintenance is poor, the water quality and flow may decrease. The probability of agricultural pollution must be considered carefully.

3.3.3 Wells and boreholes

Many small drinking water supplies are derived from wells and boreholes. Wells are usually of large diameter, not less than about one metre, and dug by hand or, more rarely, by a mechanical excavator. Boreholes are of smaller diameter, variable depth and are drilled by a specialist contractor using percussion or rotary drilling.

The quantity of water available will depend on the characteristics of the aquifer and can be determined by test pumping after construction. A well or borehole that penetrates an extensive aquifer will be the most reliable. A well or borehole sunk into a perched aquifer may dry up after a short period without rain. Normally a properly designed and constructed borehole will be able to supply water sufficient for at least a single household. Water is usually pumped from a well or borehole by a surface mounted or submersible pump.

Water abstracted from deep wells and boreholes may have originated from catchments several miles away. If the aquifer is a porous stratum, such as sand or gravel, the water will have undergone thorough filtration. Such water will usually be of very good quality. Some aquifers, such as limestone or granite strata, may be fissured and the filtration of the water will not have been so thorough. Groundwaters abstracted from shallow wells and boreholes may be prone to local pollution unless adequate precautions are taken. Groundwaters are usually of good quality and treatment may consist of disinfection only. However, some groundwaters contain high concentrations of iron and manganese, which are usually removed by oxidation and filtration. Others may be polluted by nitrate or pesticides derived from agricultural or other activities or by chlorinated solvents from industrial sites.

3.4 Source protection

3.4.1 Streams and rivers

Pollution and natural variations in water quality are the main problems associated with stream and river sources that need to be considered when siting and constructing an intake. Water may be pumped directly from the stream or river or it may be collected from the ground in the immediate vicinity of the stream or riverbank. The advantage of the latter is that where the strata have suitable transmissive properties, supplies taken in this way are naturally filtered and of better quality than the river water itself.

The intake should be located away from any features that might create turbulence during periods of heavy rainfall and increase the turbidity of the water. This means that intakes should not be situated on bends in the stream or river or at places where sudden changes in level occur. Most commonly, intake pipes are situated in the stream or river protected by a strainer to prevent the ingress of debris, fish and vermin. The inlet pipe feeds a settlement tank that allows particulate material to settle. The outlet of the tank, fitted with a strainer, should be situated above the floor of the tank to prevent contamination by sediment. The tank must be built of a material that will not impair water quality and designed to prevent entry of vermin and debris. An example of a slightly more sophisticated intake is shown in Figure 3.5. The inlet pipe is situated in a small gravel-filled tank buried upside down in the stream or riverbank (alternatively, the tank may be buried in the stream or river bed). The water enters the tank through a substantial thickness of riverbank material. This type of infiltration gallery will only be appropriate where the riverbank is sufficiently permeable to allow water to enter the tank at an adequate rate. The intake may suffer a gradual loss of capacity through siltation.

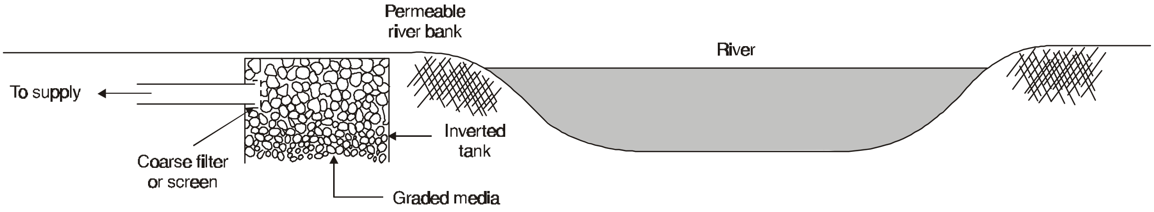

Figure 3.5 River source

3.4.2 Springs

Spring water can be of good quality but it must be protected from possible contamination once it has reached ground level. In particular, it is necessary to consider the possibility of pollution from septic tanks or from agricultural activities. A small chamber built over the spring, for example as shown in Figures 3.6 and 3.7, will protect it from pollution, provide storage for periods of high demand and serve as a header tank. The collection chamber should be built so that the water enters through the base or the side. The top of the chamber must be above ground level and it should be fitted with a lockable watertight access cover. An overflow must be provided appropriately sized to take the maximum flow of water from the spring. The outlet pipe should be fitted with a strainer and be situated above the floor of the chamber.

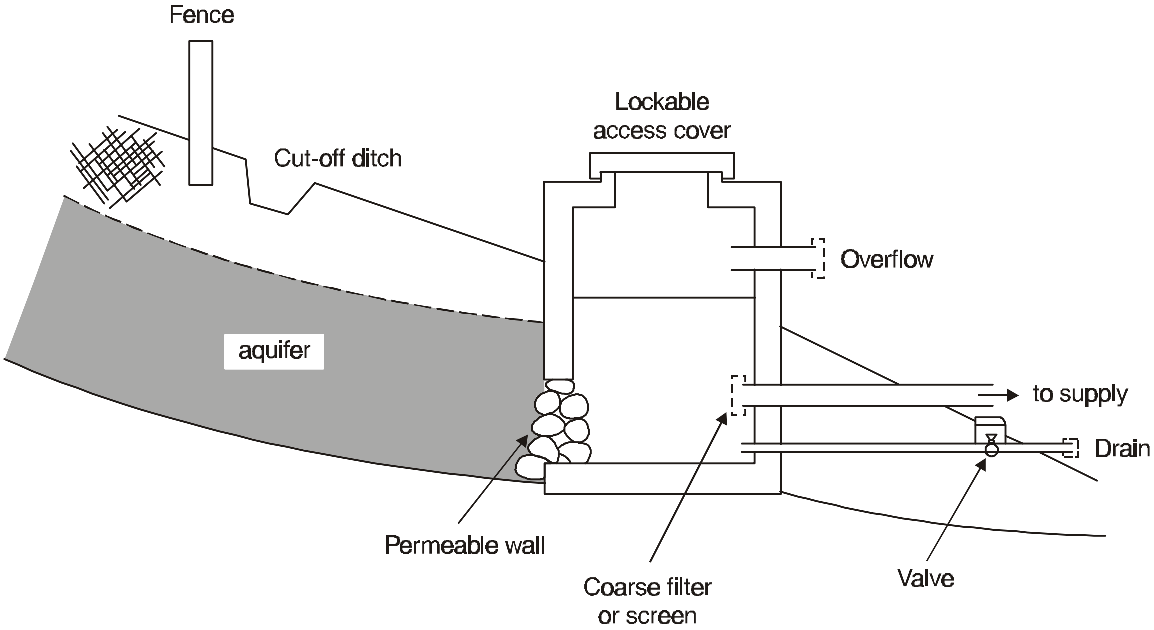

Figure 3.6 Spring source – schematic

The chamber should be built of a material that will not impair water quality and be designed to prevent the entry of vermin and debris. The area of land in the immediate vicinity of the chamber should be fenced off and a small ditch dug upslope of the chamber to intercept surface run-off.

3.4.3 Wells and boreholes

Shallow wells and boreholes are more at risk from contamination than deep wells and boreholes but if built and sited correctly, both may provide good quality water. Similar measures may be taken to protect both sources and an example is shown in Figure 3.8.

The upper section of the shaft must be lined and sealed against the surrounding material to exclude surface water ingress and, in the case of shallow wells and boreholes, water from the upper layer of the aquifer. Such sanitary seals range from 6 to 30 m in depth and must extend above ground level. Wells are often lined with masonry or concrete pipes and boreholes with steel, plastic or glass-reinforced plastic casings and sealed into the ground by a cement grout injected into the annular space between the casing and the surrounding ground. The shaft lining material should not affect water quality.

Where boreholes are drilled through a perched aquifer into lower water bearing strata, highly variable water quality may be obtained. Use of such boreholes as sources of potable water should be avoided unless the area through the perched aquifer is sealed.

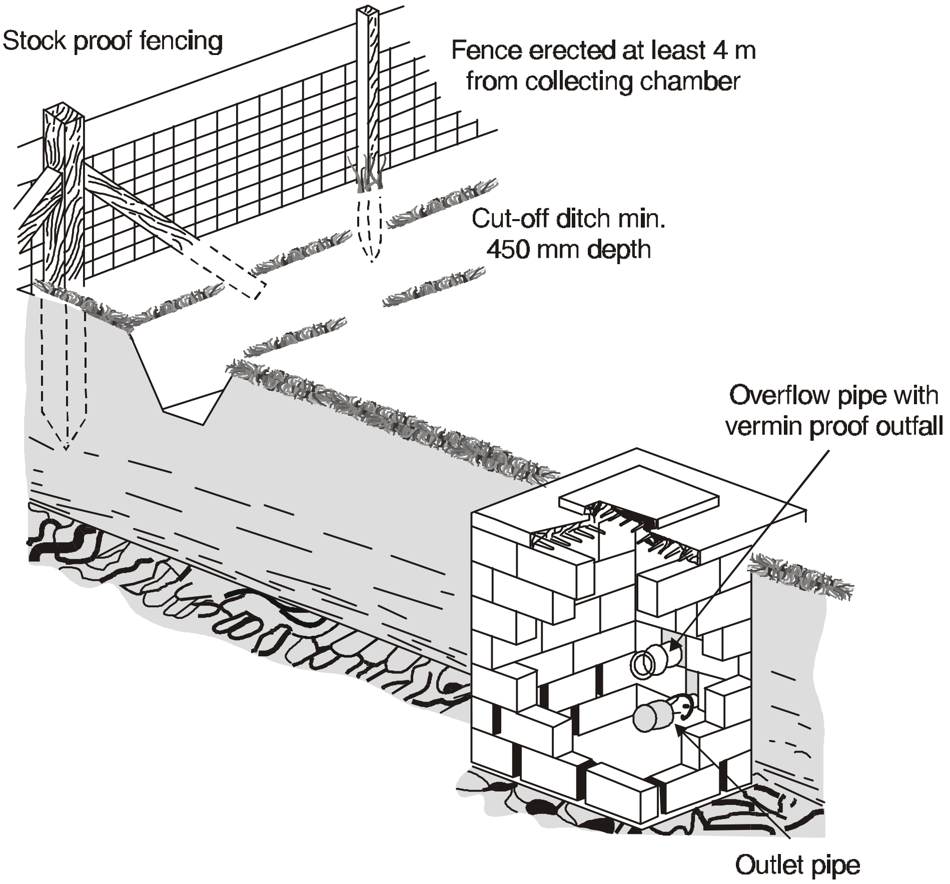

Figure 3.7 Spring collection chambers

The borehole lining may extend some depth into the aquifer if the bottom section requires support. Slotted or perforated linings are inserted which allow the ingress of groundwater. A gravel packing may be necessary if the borehole penetrates unconsolidated sand or sand and gravel to prevent fine material being drawn into the well during pumping.

At ground level, the well or borehole should be covered by a watertight chamber with a lockable cover. A concrete apron should slope away from the chamber to drain surface water. The well or borehole should be sited up-hill of, and at least 30 m away from, potential sources of pollution which include septic tanks, sewer pipes, cess pools and manure heaps. Typical arrangements for wells and boreholes are shown in Figures 3.9 to 3.11.

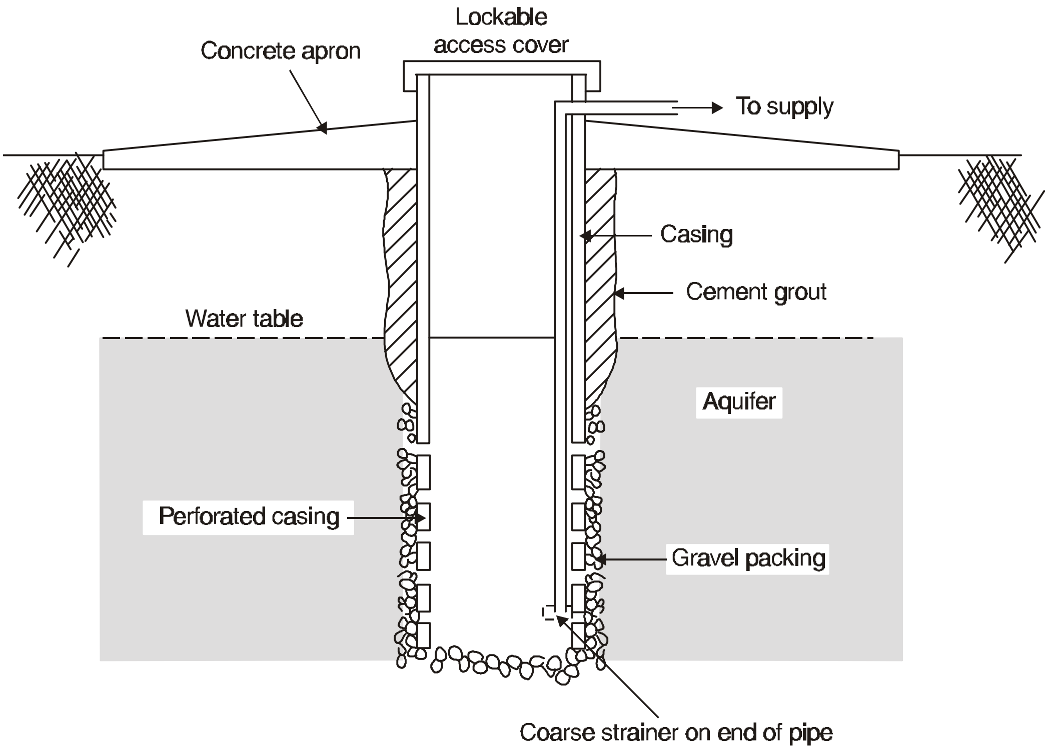

Figure 3.8 Well or borehole source – schematic

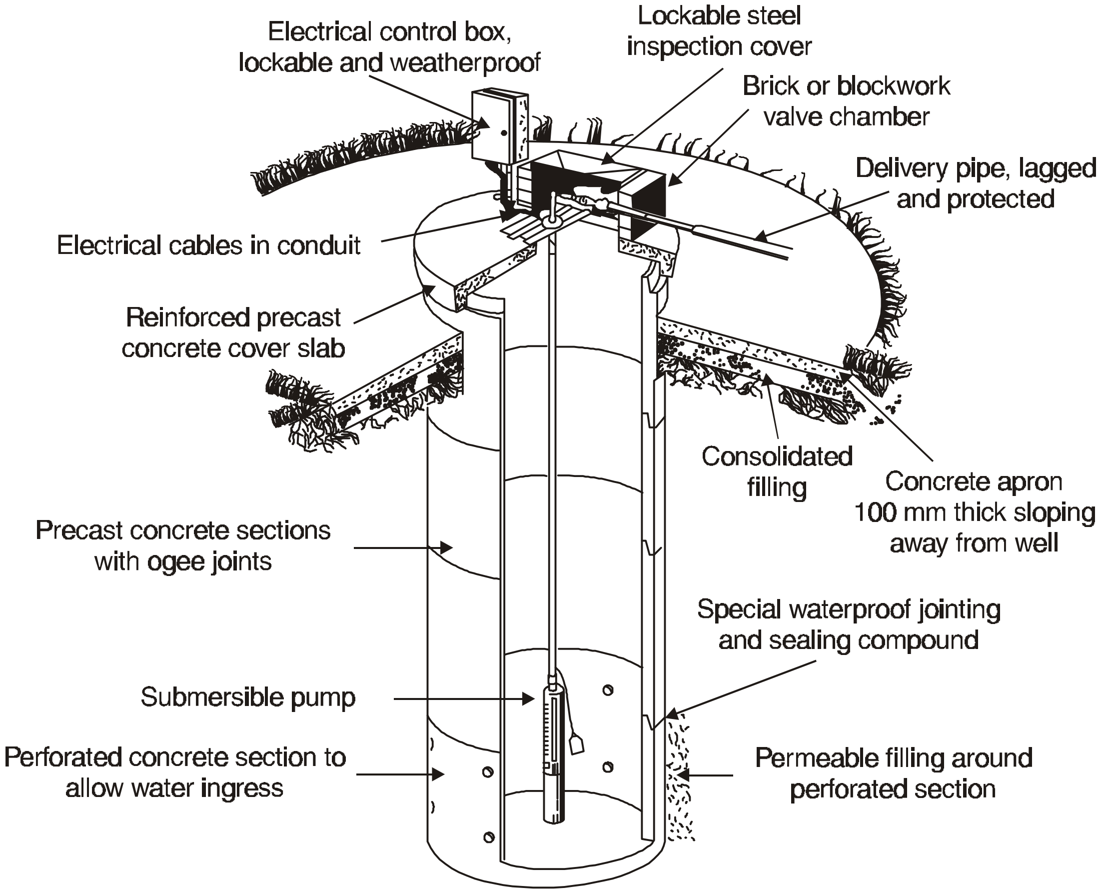

Figure 3.9 Well and submersible pump installation – typical arrangement

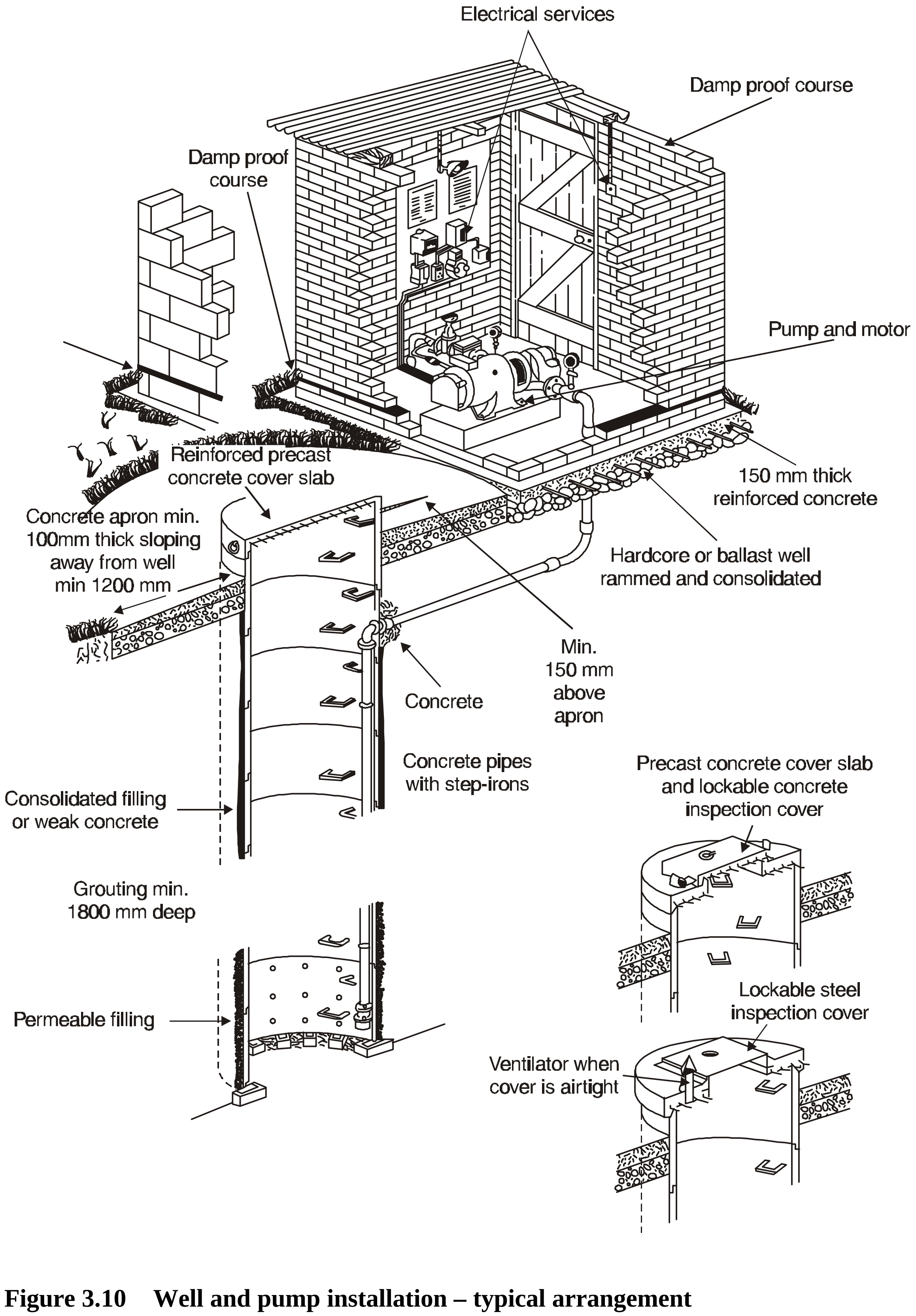

Figure 3.10 Well and pump installation – typical arrangement

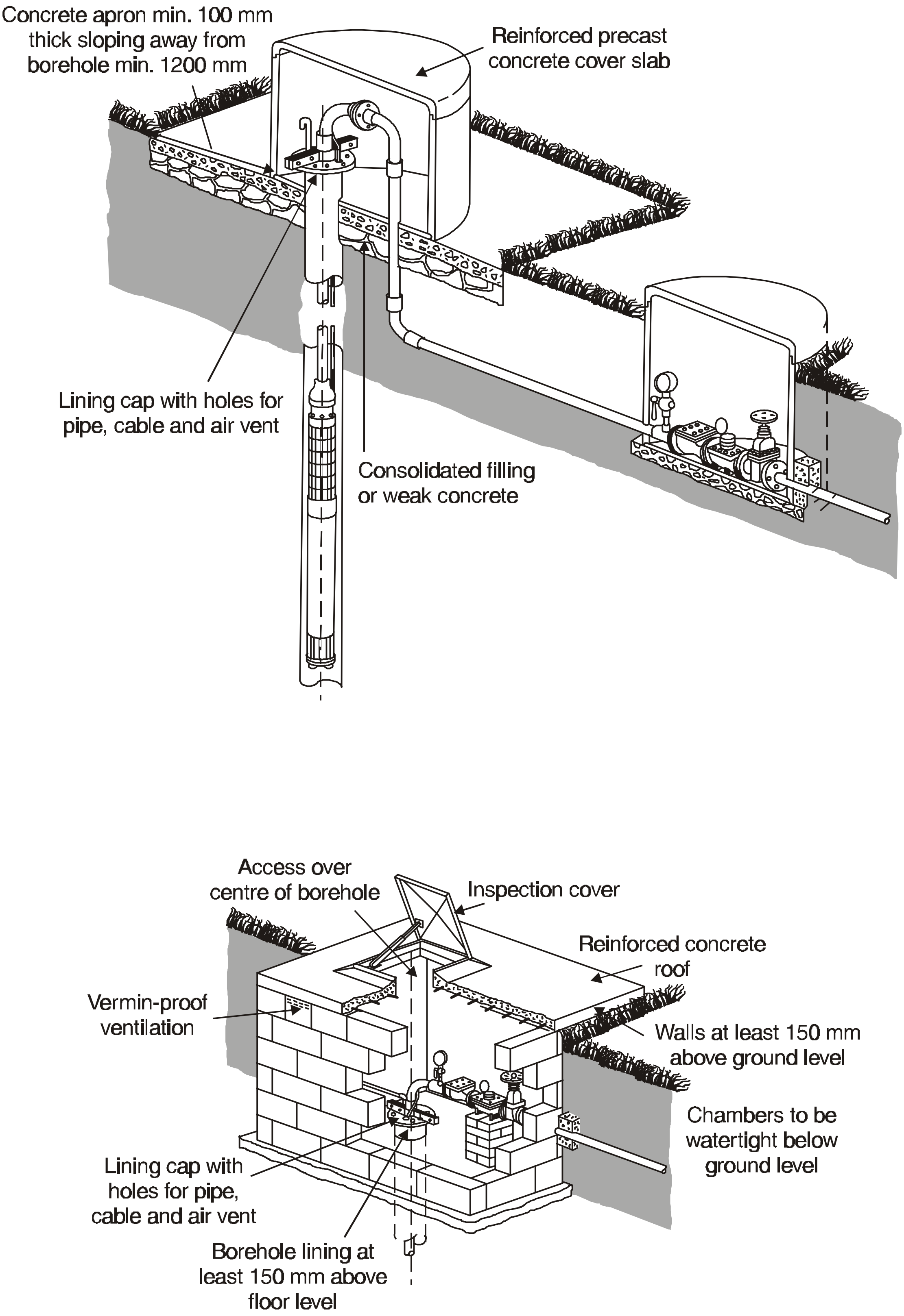

Figure 3.11 Borehole headworks

3.5 Monitoring

The monitoring requirements of the drinking water Directive are summarised in Table 3.1. The sampling frequency increases with the size of the supply; for supplies up to 100 m^3/d the monitoring frequency is left to the discretion of Member States. In the UK, private water supplies will need to be monitored in accordance with the requirements of the new Private Water Supplies Regulations when they are made.

Table 3.1 Frequency of monitoring

Volume of water distributed or produced m^3/day		Check monitoring number of samples per year	Audit monitoring number of samples per year
	≤ 100	To be decided by Member State	
> 100	≤ 1 000	4	1
> 1 000	≤ 10 000	4 + 3 for each 1 000 m^3/d and part thereof of the total volume	1 + 1 for each 3 300 m^3/d and part thereof of the total volume
>10 000	≤ 100 000		3 + 1 for each 10 000 m^3/d and part thereof of the total volume
> 100 000			10 + 1 for each 25 000 m^3/d and part thereof of the total volume

Larger supplies should be sampled for all parameters specified in the drinking water Directive. Smaller supplies could be sampled for a reduced list of parameters. Smaller supplies used in whole or in part for food production purposes should be sampled more frequently than the smaller supplies used solely for domestic purposes. Similar considerations apply to supplies serving premises with changing populations. It is not considered necessary for supplies serving single households for domestic purposes to be monitored routinely. However such supplies should be checked from time to time to ensure that the water does not pose a threat to public health.

Monitoring for the presence of specific pathogenic bacteria, viruses and other agents in water is impracticable and indeed unnecessary for routine control of most small supplies. Pathogens are only shed by infected humans and animals, so will not be present all the time, and it is infeasible to examine water for every possible pathogen, which might be present. Any pathogenic micro-organisms that are present will often be so only in small numbers, and the methods for their detection are usually difficult, comparatively expensive, and time-consuming. Reliance is therefore placed on simpler and more rapid bacteriological tests for the detection of certain commensal intestinal bacteria – especially enterococci, *Escherichia coli* and other coliform organisms – because they are easier to isolate and characterise, and because they are always present in the faeces of man and warm-blooded animals (and hence also in sewage) in large numbers. The presence of such faecal indicator organisms in a sample of drinking water denotes that intestinal pathogens could be present, and that the supply is therefore potentially dangerous to health.

As discussed earlier, *E. coli* and coliforms have been and still are the most commonly used indicator organisms. *E. coli* is particularly important because it is specifically of faecal origin. It is abundant in the faeces of humans, other mammals and birds, and is rarely found in water or soil that has not been subject to faecal contamination. However, other indicators are available which could be equally relevant, or even more so, in assessing the quality of small water supplies.

Enterococci (previously referred to as faecal streptococci) are bacteria that are found exclusively in the faeces of warm-blooded animals. They are more tolerant of the aquatic environment and water treatment processes (including disinfection) than *E. coli* and coliforms, but are present in smaller numbers in human faeces. However, they are found in higher numbers than *E. coli* in the faeces of many domestic and farm animals. There is some evidence that testing for enterococci (and especially their speciation) might be useful in identifying faecal pollution as being of human or animal origin, but this has not been widely tried or accepted.

Methods of analysis for enterococci are no more expensive than those for *E. coli* and coliforms (though a longer incubation period is usually necessary), and no special sampling equipment is required.

The sulphite-reducing bacteria belonging to the genus *Clostridium* can also be useful indicators of faecal contamination. Only *Clostridium perfringens* is specific to faecal material, with other species being found in soil and other environmental materials. Clostridia can form spores that are extremely resistant to the water environment and water treatment processes. As a consequence, their presence in the absence of *E. coli* and enterococci can be taken to indicate a historic pollution event. *Cl. perfringens* is present in lower numbers than *E. coli* or enterococci in the faeces of all animals, so its value as an indicator comes from the resistance of its spores to a wide range of environments.

The parameter included in the drinking water Directive 98/83/EC is "*Clostridium perfringens* (including spores)" but it is also possible to test for spores alone, if necessary. In either case the method of analysis is slightly more complex than the methods for the other indicator organisms, but should be within the scope of any competent microbiology laboratory.

Because of logistic difficulties the monitoring of private water supplies is commonly infrequent. As a consequence, the value of the monitoring as an aid to protection of public health is often questioned, since contamination of the source may be sporadic and dependent on factors such as rainfall. In these circumstances the use of indicators that survive for longer periods of time than *E. coli* would be advantageous, in that they should allow historic or intermittent pollution to be detected.

Risk assessment of the catchment is much more useful than monitoring for micro-organisms. To be of most value, monitoring for faecal indicators needs to be undertaken frequently, so that samples representative of the water quality are obtained. This is generally impractical for small water supplies and therefore a risk assessment of the catchment should be carried out, and protection measures aimed at excluding faecal contamination should be taken. If the risk assessment predicts a high risk of faecal contamination, alternative sources of supply will need to be considered.

Where total exclusion cannot be guaranteed, and no other supplies offer a viable alternative, treatment barriers must be strengthened and assessed against the microbial loading predicted to occur in the source water.

Following installation of the treatment processes a period of validation based on microbiological monitoring should be undertaken to ensure that the strategy adopted is adequate for the protection of public health. This would usually involve relatively intensive monitoring of the source and final water quality using faecal indicator organisms, but some sampling for specific pathogens should be considered where a particular risk has been identified (e.g. high probability of contamination from farm animals, where monitoring for *Campylobacter* and *Cryptosporidium* might be appropriate). Ideally this monitoring should include periods when the risk assessment has shown that the source water is highly likely to become contaminated (e.g. following heavy rainfall).

Regulatory monitoring frequency should only be introduced once satisfactory performance from the treatment has been obtained, and a maintenance procedure has been introduced which will ensure that any shortcomings in the performance of the treatment are detected at an early stage. This procedure will include very frequent (at least daily) checks that UV or other disinfection equipment is operating properly, and observation of the performance of any filtration processes being used. This procedure should also include a contingency plan for the use of alternative supplies or the instigation of a boil water regime, when necessary, for water used for drinking.

4. ASSESSMENT OF POLLUTION RISK TO SMALL WATER SUPPLIES

4.1 Raw water sources

4.1.1 Influence of micro-organisms on groundwater systems

The major influence of micro-organisms on groundwater quality is in terms of their persistence and mobility in the subsurface environment. Bacteria derived from man-made sources are usually eliminated in the subsurface environment through a combination of physico-chemical and biological processes. However previous studies have shown that elimination rates are specific for each particular microbial species. Figure 4.1 illustrates the elimination rates of various bacteria and viruses as the time required for 99.9% elimination and the Elimination Constant. The Elimination Constant is the fraction of the micro-organism population that is eliminated per day, e.g. if the Elimination Constant is 0.4 per day (1/day) then 40% of the remaining micro-organisms are eliminated each day. Virus survival and migration appear to be controlled by the climate, clay content and moisture-holding capacity of the geomatrix and the specific class of virus involved.

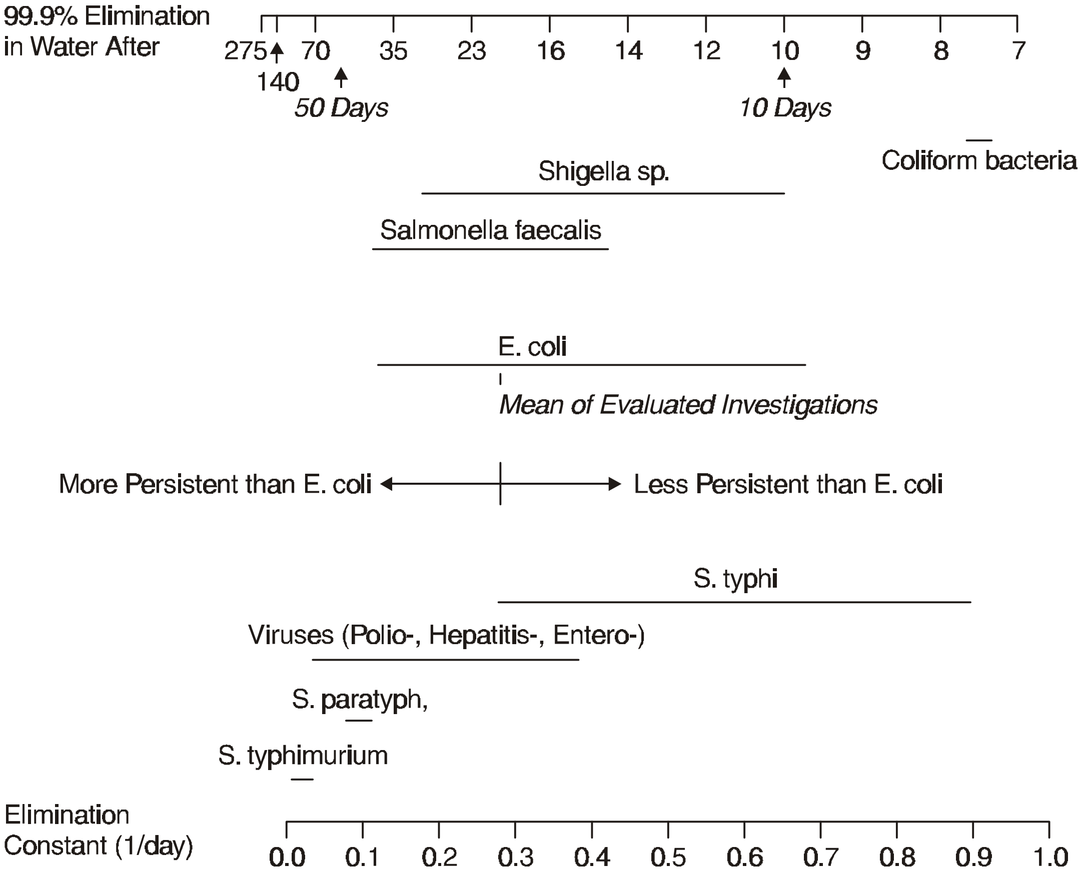

Figure 4.1 Elimination rates of bacteria and viruses

4.1.2 Raw water source catchment

The removal of water from a well or borehole has the effect of lowering the level of the water in an unconfined aquifer in the immediate vicinity of the abstraction point. This drawdown will be broadly circular in plan view, assuming that the aquifer is homogeneous and no impermeable strata are present. The area of this circle is related to the hydraulic characteristics of the aquifer and the rates of abstraction and recharge. The cross-sectional shape of the drawdown is like an inverted cone with the apex being at or near the base of the well or borehole. This phenomenon is known as the cone of depression (Figure 4.2). Around each groundwater discharge an area is created that will drain towards the source separated by a groundwater divide beyond which water will by-pass that particular source. This divide in the flow of groundwater delineates the capture zone for the source.

It is important to distinguish between the capture zone and the cone of depression around the source. The capture zone consists of the up-gradient and down-gradient areas that will drain into the source. In the unlikely event that the water table was perfectly flat, the capture zone would be circular and would correspond to the cone of depression (Figure 4.2). However, the more common case is for the water table to be sloping due to regional groundwater gradients. In these circumstances the cone of depression and the capture zone will not correspond. This situation arises due to the hydraulic gradient of the water table downstream being dramatically changed through the action of pumping. Water will only flow towards the well where the pumping-induced change in the gradient is sufficient to fully reverse the regional groundwater gradient experienced. As pumping continues, the area of the capture zone increases and this process will continue until the rate of abstraction is equalled by the recharge over the entire capture zone area, effectively when steady-state conditions are achieved. Thus the entire capture zone is known as the source catchment.

Groundwater-fed springs may dry up as the water table falls during periods of low precipitation, or they may flow continuously as perennial springs with only slight variations in discharge rate throughout the year. When considering source protection the degree of protection afforded to a spring must be derived from the total spring discharge as the movement of the water through an aquifer system and issuing as a spring at any particular time is unknown. For this reason, protection zones around springs that are used as sources of supply must be derived on the basis of the total flows issuing through the spring.

4.1.3 Protection zone delineation for groundwater sources

Once the source catchment has been identified, being the area of land needed to sustain the groundwater abstraction by natural recharge, the source protection zones can be delineated for highly permeable and moderately permeable aquifers (Figure 4.3). Such source protection zones are required to minimise microbial contamination of the groundwater being abstracted. These source protection zones utilise a tripartite zonation system where the source catchments are sub-divided into 3 generally concentric zones. Two of these zones are determined by time of travel of the pollutant and the third by the source catchment itself.

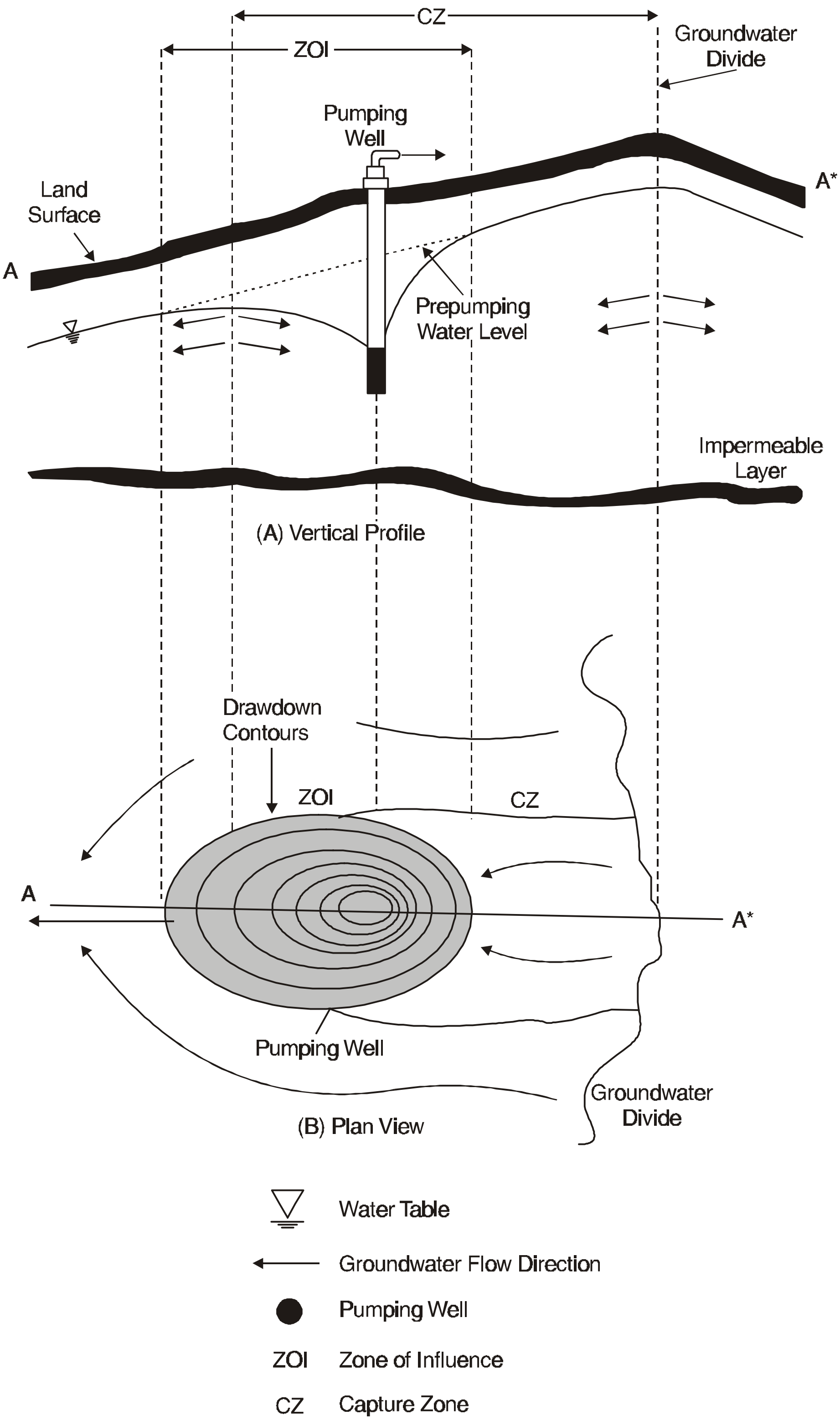

Figure 4.2 Zone of influence and capture zone[15]

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[15] Adapted from Keating, T. and Packman, M.J. (1995). *Guide to groundwater protection zones in England and Wales*. National Rivers Authority, HMSO, London.

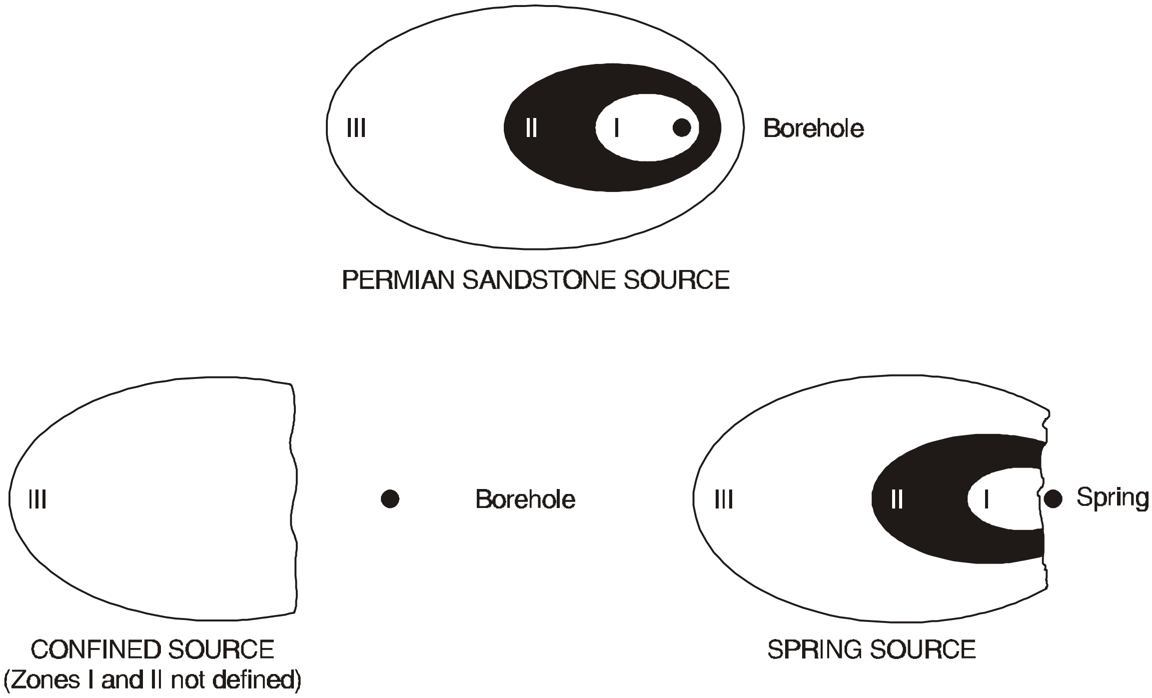

Figure 4.3 Schematic diagrams of the relationship between source protection zones[16]

The protection zones used in the UK by both the Environment Agency and SEPA are described below and arose out of work undertaken by the British Geological Survey (BGS) in 1990. The BGS reviewed all available information and produced the following tripartite zonation around a water source.

Zone 1: Inner source protection

This zone is located immediately adjacent to the groundwater source. It is designed to protect against the effects of human activity that might have immediate effect upon the source. The area is defined by a 50-day travel time from any point below the water table to the source and as a minimum of 50 metres radius from the source. This 50-day travel time zone is based on the time it takes for biological contaminants to decay (see Section 4.1.1). In most cases the land immediately adjacent to the source and controlled by the operator of the source is included within this zone.

Zone II: Outer source protection

This zone is larger than Zone I and is the area defined by a 400-day travel time from any point below the water table to the source. The travel time is based upon that required to provide delay and attenuation of slowly degrading pollutants. In high storage aquifers,

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[16] Adapted from SEPA (1997). Policy No 19. *Groundwater protection policy for Scotland*. Scottish Environment Protection Agency.

such as sandstone, Zone II is defined as the larger of either the 400-day travel period, or the recharge catchment area calculated using 25% of the long term abstraction rate for the source. This will ensure an adequate Zone II in all situations.

Zone III: Source catchment

This zone covers the complete catchment area of a groundwater source. All groundwater within it will eventually discharge to the source. It is defined as an area needed to support an abstraction from long term annual groundwater recharge effectively resulting from rainfall. In areas where the aquifer is confined beneath impermeable cover, the source catchment may be some distance from the actual abstraction point.

The application of this source protection methodology to small sources, being those abstracting less than 250 m^3/d, has been evaluated and it was concluded that a default 50 metre radius zone (Arbitrary Fixed Radius Circles ($AFRC_{50}$)) is probably the only option for protection of very small sources.

4.2 Assessment of groundwater vulnerability - soil and land use factors

4.2.1 Vulnerability and risk considerations

The susceptibility of groundwater to microbiological contamination from surface or near-surface derived pollutants is greater under certain conditions than others. At any specific site, groundwater contamination depends on the natural or man-made characteristics of the site. Thus the ease with which the potential pollutant can migrate to the underlying water table or spring source depends on the physical, chemical and biological properties of the local strata. The factors that determine the vulnerability of groundwater to given pollutants or activities are as follows:

- characteristics of the overlying soil;
- characteristics of the drift deposits;
- nature of the solid geological strata within the unsaturated zone;
- depth to groundwater; and
- nature of contaminant.

Land use is a critical factor and man-made structures or excavations can modify the impact of the factors listed above. Groundwater vulnerability classification is determined by the nature and quantity of material in the unsaturated zone, i.e. above the water table. In the absence of major fissures or cracks within that zone, water movement is essentially slow, being confined to interconnected soil pores within an aerobic environment.

However, the rate of this movement depends on the moisture content of the soil and will vary throughout the year. The overlying soil provides the potential for interception, adsorption and elimination of bacteria and viruses. Where vertical fissures occur or shattered rock comes close to the earth's surface, there is the potential for rapid flow of micro-organisms to groundwater. These features reduce the ability of the soil and substrate to act as a barrier or filter.

4.2.2 Use of groundwater vulnerability maps

Introduction

A methodology for classifying soils into three leaching potential classes has been developed by the Soil Survey and Land Research Centre for use in groundwater vulnerability maps. This classification also embraces all Soil Series that have been mapped to-date within the UK, with each soil series being assigned a value corresponding to the ease with which a representative pollutant could move through the soil. This representative pollutant is assumed to be soluble and able to adsorb or stick onto clay particles and organic matter. Not all pollutants have these characteristics; the classification provides a generalised picture and many of the central concepts are valid in the assessment of the risks of microbiological contamination.

Soil leaching potential categories

A classification has been published[17] that defines three main categories of leaching potential ranging from high to low. These classes were derived primarily for assessing the vulnerability of major aquifers to contamination from a wide range of pollutants and are as follows.

Class 1 High vulnerability or soil leaching potential

Soils in which water has the potential to move relatively rapidly from the surface to underlying strata or to shallow groundwater. This may be because there is fissured rock or gravel near to the soil surface. Alternatively the soil has a low volumetric water content or, at certain times of the year, there is either groundwater near to the soil surface or there is by-pass flow through the upper soil layers. In such soils there is a high risk that at certain times of the year, contaminants will move rapidly through the soil with little time for attenuation. The high category has been subdivided into four classes with soils in the H1 subclass having a greater soil leaching potential than H2, and so on.

H1 Soils with groundwater at shallow depth. Soils with rock, rock-rubble or gravel at shallow depth. Undrained lowland peat soils with permanently wet topsoil.

H2 Sandy soils with low topsoil organic matter content.

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[17] Palmer, R.C., Holman, I.P., Robins, N.S. and Lewis, M.A. (1995). *Guide to groundwater vulnerability mapping in England and Wales.* National Rivers Authority, HMSO, London.

H3 Sandy soils with a moderate topsoil organic matter content. Soils with rock, rock-rubble or gravel at relatively shallow depth within the soil profile.

HU Soils in urban areas and areas of restored mineral workings for sand/gravel.

Class 2 Intermediate vulnerability or soil leaching potential

Soils in which it is possible that significant amounts of water will penetrate to below 2 metres in depth. In such soils contaminants may move vertically through the soil, but are likely to be substantially attenuated by the processes of biological and chemical degradation, adsorption and dilution. The intermediate category has been divided into two subclasses; mineral soils are placed in I1 and peat soils in I2.

I1 Deep loamy and clayey soils unaffected by marked seasonal waterlogging, with topsoil of low or moderate organic matter content.

I2 Lowland peat soils which have been drained for agricultural use.

Class 3 Low vulnerability or soil leaching potential

Soils in which excess water movement is predominantly horizontal, with little likelihood of any contaminants penetrating below 2 metres in depth. Where such soils fringe those in classes 1 and 2 however, lateral drainage may contribute to groundwater recharge and hence potential pollution. There is no subdivision of the low category of soil leaching potential.

L Soils with a dense subsoil that restricts downward water movement. Upland soils with a permanently wet peaty topsoil.

Benefits of groundwater vulnerability maps

In England and Wales a series of 53 such maps has been published by the Environment Agency at the scale of 1: 100 000. Similar maps within Scotland and Northern Ireland have been produced by the British Geological Survey. In simple terms, the maps contain three layers of information which from the surface downward include:

- soil leaching potential classes and subclasses;
- presence, where applicable, of low permeability drift deposits at the surface above aquifers; and
- permeability of the geological deposits.

Together these layers of information produced 27 different vulnerability combinations, some of which must be interpreted with caution because of limitations within the following:

- Soil data – differences in map scale and variability within mapping units.

- Drift data – possible mismatches with soil information.

- Geological data – lack of data on the variability of mapped units, inadequate description of drift deposits and difficulties of portraying multi-aquifers as a single unit.

However these vulnerability combinations provide critical information for assessing the level of protection afforded to shallow groundwater by the soil and drift deposits, in particular the soil leaching potential. This information has been systematised allowing the rapid assessment of the protection afforded by the soil to private water supplies in terms of microbiological contamination. This information can be used to give assistance to site-specific assessments in the area immediately surrounding a water supply when used in conjunction with soil inspection pits. Alternatively, and where the exact location of the source is not known, or where there is a substantial catchment area associated with the supply, interpreted soil maps can be used. This approach has the benefit that the interpretation of the soil information is made by experts. Furthermore, it has a spatial component that takes account of the fact that the supply should be protected within a 50 metre radius. However, the scale of the available soil information may not always be suitable and there is an inherent variability in soils which can not always be shown on maps. Either soil interpretation or interpretative soil maps must be used in conjunction with information on land use. Even water supplies that are classified as having a soil which offers poor protection may not become contaminated if the land use in the surrounding area precludes the introduction of a contaminant.

Other factors that influence groundwater vulnerability

A series of site-specific factors can contribute towards possible groundwater contamination but, in most instances, it is not possible to quantify the degree of risk. Examples of these are listed below.

- Physical disturbance of aquifers and groundwater flow. These activities lead to the disturbance of the physical barrier offered by the soil and may provide preferential pathways of water (and contaminant) movement to shallow groundwaters. These include: most forms of groundwater extraction; landfill operations; nearby borehole construction; any activity which interconnects naturally separate aquifers; existing or modified field drainage schemes that intercept recharge water; quarrying and gravel extraction both above and below the water table.

- Waste disposal to land. Many waste disposal practices have the potential to cause groundwater contamination. In this respect, the Environment Agency has laid down certain regulations, many of them statutory, to ensure specific objectives. For example, there will normally be objections at the planning stage to waste disposal activities that extend to or below the water table within prescribed limits of a source. However, the disposal of slurries and other wastes on agricultural land in the vicinity of a private water supply is not subject to the same regulation. although codes of good agricultural practice do exist.

- Contaminated land, being land currently or previously used in connection with the following activities: sewage treatment works; landfill sites and other waste disposal and recycling activities; waste lagoons. Also the EA will seek to protect water supplies where any of the above activities are to be found in close proximity to a water source.

- The application of liquid effluents, sludge and slurries to land. Three categories of waste are recognised, being controlled wastes (industrial effluent and sludge, both organic and inorganic in nature), sewage sludge and agriculture waste. Where the EA considers that any of these will give rise to a significant risk of polluting groundwater or surface water, there will be a presumption against spreading or compliance with existing environmental legislation. Farmers should have a waste management plan, with information relevant to suitable land available for spreading liquid effluents, sludge and slurries.

- Discharges to underground strata. Three areas of concern have been identified:

  - sewage effluent discharges including septic tank and sewage treatment plant effluents from individual properties or small housing estates;

  - trade effluent discharges; and

  - surface water discharges that include contaminated run-off from roofs and impermeable areas such as roads, car parks, storage areas and so on.

- Diffuse pollution of groundwater. Diffuse pollution refers to pollution spread over time and space and caused by mechanisms other than local and specific discharges or events. Such pollutants are usually at much lower levels than other sources and are therefore at lower concentrations in the soil water. However, the build-up over a long period can generate potential problems. Diffuse pollution varies in character between urban and rural areas. Within the former, the two most notable examples of pollution arise from industrial sites and discharges from sewage systems. In contrast, within rural areas, the pollutant is not from an individual point discharge but arises from activities connected with intensive arable and livestock farming.

- Additional activities or developments which pose a threat to groundwater quality include miscellaneous activities such as: storage of farm wastes and intensive livestock housing; graveyards and animal burial sites; sewage works; storm overflows.

Conclusion

Soil can offer protection to the shallow groundwater associated with many private water supplies while a combination of soil and geological factors need to be considered when assessing deep groundwater. Groundwater vulnerability maps are available that can be used to assess the susceptibility of the aquifer to contamination that could pass rapidly to the borehole, well or spring. However, both the current and past land use practices have a bearing on the ability of the soil to function as a filter and buffer to potential contaminants. Therefore, land use remains a key component in any site appraisal.

4.2.3 Soil and land use factors underpinning the assessment of surface water vulnerability

Introduction

In some instances, small water supplies are fed by surface waters. The rôle of soils in offering protection to these sources is much more limited than that described above for groundwater but nonetheless, differences in soil type will have an influence on the risk of microbiological contamination of these waters. Clearly, the soil has no rôle where the contaminant is deposited directly into the water body, but where a potential contaminant is deposited near to a water body, then there are a number of factors which affect the risk of contamination. The main factors are surface run-off which washes the contaminant into the water body and stream extension (both laterally and upslope) which entrains the contaminant.

The degree of surface flow is dependent on the intensity and duration of rainfall, the soil type, slope and land use. In general terms, high intensity rainfall, like that associated with thunderstorms, is likely to initiate overland flow in most soils as the infiltration rate of the soil is exceeded by the rainfall intensity. More recently, it has been recognised that low intensity rainfall over a prolonged period of time can also lead to overland flow. In both cases the soil type can have a major influence on the amount of rainfall that can be absorbed before the initiation of run-off. Soils with open, porous structures and with no slowly permeable layer will be able to absorb more than shallow soils or those with slowly permeable layers near to the soil surface. The land use can act both as an interceptor for rainfall (for example, a forest), reducing the amount that reaches the soil surface as well as providing the opportunity for the presence of potential contaminants (for example, open moorland that is grazed by domestic and wild animals).

Stream extension is the process whereby the apparent stream network as seen under dry conditions extends during rainfall, with the development of ephemeral streams and rivulets that occupy topographic hollows and are interconnected with the normal stream network. In many catchments, these streams and rivulets become dry soon after the rain has stopped. However, during rainfall the water flowing along these pathways will often be sufficiently fast and deep to entrain contaminants such as animal faeces. The occurrence of these pathways is difficult to predict from soil maps but some soil types will be more likely to behave in this way than others. During periods of rainfall, the levels of streams and rivers generally rise and may extend out beyond their normal channel to occupy their floodplain. In many small catchments, these floodplains may be only a few metres wide, but any faecal material or other potential contaminants on the surface may be entrained in the stream.

Soil assessment

The risk assessment of the vulnerability of surface waters is not as well developed as that of groundwater, however, the concepts of surface and immediate sub-surface flow have been developed in other sub-disciplines within soil science and can be used to derive a provisional vulnerability classification. The general concepts are derived from the Hydrology of Soil Types (HOST) technical report[18]. This work derived a classification of UK soils which both describes the dominant pathways of water movement through the soil and assigns proportions of the rainfall likely to lead to a fast response in streams and rivers. These proportions are termed standard percentage run-off and can be used to indicate the soils likely to have a high incidence of overland flow as well as those likely to cause a rapid rise in river levels or to initiate stream extension. This work indicates that soils with peaty surface layers tend to initiate surface run-off quicker than soils with a mineral surface layer and that soils with a slowly permeable layer close to the soil surface will initiate surface run-off more quickly than deep, porous soils.

Although still an underdeveloped area of microbiological risk assessment, the results and concepts derived from soil hydrological research can be used to rank the rôle of soil in assessing the vulnerability of these waters to contamination. However, the very fact that there is no protection from the direct entry of contaminants into surface waters, means that these sources must remain at a high risk of contamination.

4.3 Microbiological risk assessment

4.3.1 Applicability of a risk assessment approach

Within the food industry Hazard Analysis and Critical Control Points (HACCP) and Hazard Operability (HAZOP) systems for appraisal of microbiological risks associated with foodstuff preparation have gained widespread acceptance and approval. A risk assessment approach is considered to be the mechanism with the greatest potential for improving source protection for small water supplies. Risk analysis provides a suitable framework for consistent, objective and reliable assessment of small water supplies to be made. In overall terms, information recorded from a systematic microbiological risk assessment (MRA) appraisal of small water supplies can be used for the mutual benefit of those with remits covering public safety, as well as the consumers utilising these supplies.

4.3.2 Definition of terminology

One aspect that has caused a considerable amount of confusion in risk analysis is the variation in definition of specific terms, particularly ‘hazard’, ‘risk’ and ‘risk assessment’. The Advisory Committee on Dangerous Pathogens (ACDP) was

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[18] Boorman, D.B., Hollis, J.M. and Lilly, A. (1995). *Hydrology of soil types: a hydrologically-based classification of the soils of the United Kingdom*. Institute of Hydrology Report No. 126. Institute of Hydrology, Wallingford.

commissioned to investigate and report on the current state of risk assessment as applied to the broad field of microbiology. One essential function performed by the ACDP was to provide concise definition of terminology relevant to MRA and these terms are used here. The specific terms and their definitions are as follows:

- Hazard – the disposition of a thing, a condition or a situation to produce injury; or a combination of circumstances that could potentially have adverse consequences.
- Risk – the probability that a specified hazard will be realised.
- Microbiological risk assessment – the formal structured procedure for identifying and characterising microbiological hazard and determining the risk associated with it.

4.3.3 Microbiological risk assessment system for small water supplies

The multi-factorial nature of hazards that may impact upon a given source rules out a fully quantitative system. A quantitative approach would suffer from the serious drawback that some hazards have a more significant impact than do other hazards and a weighting system would then be required. Any attempt to apply weighting would be inappropriate when considering the fundamental lack of scientific evidence for the relative importance of these hazards. Also by introducing a quantitative system the element of subjectivity assumes a significant rôle, where a human factor is involved. For these reasons, a qualitative system is presented that takes the form of ‘Low’, ‘Medium’ or ‘High’ risk categorisation.

The risk assessment forms are given in Appendix E, and the essential details are summarised below. The format contains three main sections, these being for general information, a source inspection and a general site survey. The first section is used to allow recording of basic information pertinent to the supply (Appendix E.1).

In application the MRA is required to identify all the specific factors and activities which are hazardous to the maintenance of good microbiological water quality at source. Hazards are placed into one of two main categories: hazards in the immediate locality of the source and those within a 50 to 250 metre radius of the source, as determined by Zone 1/Zone II for source protection (see Section 4.1.3). Consequently the MRA form allows assessment to be made of these two distinct hazard groups.

The factors located at the source are primarily concerned with the physical nature and construction of the source. These parameters are grouped into a category referred to as the source survey of the risk assessment process. A source type specific form is used due to the variable nature for each of these source types. An example of the source survey specific to a shallow well is shown in Appendix E.2.

At the end of the section a series of instructions are provided that assist in assigning the overall risk for the source survey (see Appendix E). By following the simple guidance provided, a risk categorisation may then be determined. In view of the importance of soil for groundwater protection, a limited evaluation of underlying soil structure, *via* preparation of an inspection pit, could be incorporated into the field assessment.

The second group of hazard factors constitutes any practice or activity in the near vicinity of the source having the potential to introduce microbiological contamination to the source water. This grouping of factors constitutes the ‘General Site Survey’ for the risk assessment (Appendix E).

It is necessary to set limits as to the zone of influence from the activities outlined in the General Site Survey. Two zones are identified into which these factors could be placed. The zones are set at 50 and 250 metres based upon previous evaluations by the NRA and MAFF. The 50 metre zone reflects the arbitrary fixed radius circle determined to be the minimum distance required to protect the water source from human activities that can cause contamination. The 250 metre radius follows the recommendation of MAFF regarding disposal of animal remains.

Upon completion of the MRA, each of the two sections is scored as being low, medium or high risk by following the guidelines at the end of each section (see Appendix E). The overall MRA for the source is determined by applying the highest level of risk from the individual sections. Once the MRA has been completed and the overall risk for the source assigned, this score is then recorded on the front of the form for ease of future reference. Surface water sources, and supplies whose source cannot be established, are automatically classified as “High Risk”.

5. WATER TREATMENT PROCESSES

5.1 Introduction

Larger water supplies, serving many properties or commercial or industrial premises, are usually treated by point-of-entry treatment methods, similar in principle to those used at municipal water treatment works. It is essential that the design of any treatment process is based on a full investigation of site conditions, including chemical and microbiological analysis of water and the results of laboratory or pilot-scale tests to determine the effectiveness of the process and the chemical dosing requirements. This chapter provides an overview of the basic principles of water treatment – anyone planning to install or upgrade a water treatment process should seek expert guidance.

For small supplies, for treatment to be truly precautionary it should include a preventive element. In practice this means that treatment of a groundwater supply should automatically include disinfection – a disinfection stage should only be dispensed with if the supply can be shown by risk assessment and frequent surveillance to be likely to be consistently pathogen-free.

It is important to choose equipment suppliers and consultants carefully. Recommendations from previous clients can be useful provided that they relate to similar types of project. Consultants should be members of an appropriate professional institution. Purchasers of water treatment plant and supplies should:

- ensure that potential suppliers are aware of the size and nature of the water supply;
- confirm that potential suppliers can furnish suitable equipment;
- check whether the supplier is certified to the ISO 9000 quality system;
- establish whether suppliers can provide references relating to similar projects;
- if practicable inspect other, similar, installations; and
- establish that the operating and maintenance manual, and training, will be adequate for the end user of the equipment.

A range of water treatment processes is covered here and in the following chapter, which deals with point-of-use systems for treatment of water at a single tap. Figure 4.1 indicates the capability of the various treatment techniques for removing common contaminants. For some contaminants, potentially several techniques could be appropriate and the choice between processes should be made on grounds of cost, taking into account local circumstances. For example, membrane processes can remove a broad spectrum of contaminants but cheaper and simpler alternatives may be just as effective in particular cases. It is likely that a combination of processes will be required to deal with particular waters, for example filtration followed by UV to remove particles and inactivate micro-organisms.

	Bacteria	Cysts	Viruses	Algae	Coarse particles	Turbidity	Colour	Aluminium	Ammonia	Arsenic	Iron & manganese	Nitrate	Pesticides	Solvents	Taste & odour
Coagulation/flocculation[1]	+	+	+	+	++	++	++	++		+	++				
Sedimentation					++	+		+			+				
Gravel filter/screen				+	++	+		+			+				
Rapid sand filtration	+	+	+	+	++	+		+			+				
Slow sand filtration	++	++	++	++	++	++		+			+				
Chlorination	++		++	+			+		++						
Ozonation	++	+	++	++			+						++		++
UV	++	+	++	+											
Activated carbon							+						+	+	++
Activated alumina										++					
Ceramic filter	++	++		++	++	++									
Ion exchange									+	+		++			
Membranes	++	++	++	++	++	++	++	++		+	++	++	++		++

+ Partly effective ++ Effective/preferred technique

[1] Pre-oxidation may be required for effective removal of aluminium, arsenic, iron and manganese

Figure 5.1 Overview of treatment methods

5.2 Multiple barriers

All water sources require treatment prior to consumption to ensure that they do not present a health risk to the user. Health risks from poor quality water can be due to microbiological or chemical contamination. Microbiological contamination is generally the most important to human health as this can lead to infectious diseases. Chemical contamination, with the exception of a few substances such as cyanide and nitrate, tends to represent a more long-term health risk. Substances in water which affect its appearance, odour or taste may make water objectionable to consumers. As micro-organisms can be associated with particles in water, physical contamination may also represent a health risk as it makes disinfection more difficult.

Most treatment systems are designed to remove microbiological contamination and those physical constituents, such as suspended solids (turbidity) that affect aesthetic acceptability or promote survival of micro-organisms. A final disinfection stage is nearly always included to inactivate any remaining micro-organisms. When a persistent disinfectant, such as chlorine, is applied this also provides a ‘residual’ that will act as a preservative during storage and/or distribution in larger systems.

Treatment processes are based on the physical removal of contaminants through filtration, settling (often aided by some form of chemical addition) or biological removal of micro-organisms. Usually, treatment consists of a number of stages, with initial pre-treatment by settling or pre-filtration through coarse media, sand filtration followed by chlorination. This is called the multiple barrier principle.

This is an important concept as it provides the basis for effective treatment of water and prevents complete failure of treatment due to a malfunction of a single process. For instance, with a system that comprises coagulation/flocculation, sedimentation and rapid sand filtration with terminal disinfection, failure of the rapid sand filter does not mean that untreated water will be supplied. The coagulation/flocculation and sedimentation processes will remove a great deal of the suspended particles, and therefore many of the micro-organisms in the water, and the terminal disinfection will kill many of the remainder. Provided that the rapid sand filter is repaired promptly, there should be little decrease in water quality.

The multiple barrier principle extends back from the treatment stage to the catchment, so a key element is to ensure that the source of water is protected and maintained at as high a quality as possible. Proper selection and protection of water sources are of prime importance in the provision of safe drinking water. The subsurface is often an effective medium for attenuating contaminants present on the catchment while the design and good maintenance of the well, borehole, spring or intake can help exclude localised pollution. It is always better to protect water from contamination than to treat it after it has been contaminated. Effective source protection, careful choice of aquifer or water intake and well-designed, well-maintained abstraction structures all constitute effective barriers in the multiple barrier principle.

5.3 Coagulation and flocculation

Coagulation and flocculation are used to remove colour, turbidity, algae and other micro-organisms from surface waters. The addition of a chemical coagulant to the water causes the formation of a precipitate, or floc, which entraps these impurities. Iron and aluminium can also be removed under suitable conditions. The floc is separated from the treated water by sedimentation and filtration, although flotation processes may be used in place of sedimentation.

The most commonly used coagulants are aluminium sulphate and ferric sulphate, although other coagulants are available. Coagulants are dosed in solution at a rate determined by raw water quality near the inlet of a mixing tank or flocculator. The coagulant is rapidly and thoroughly dispersed on dosing by adding it at a point of high turbulence. The water then passes into the sedimentation tank to allow aggregation of the flocs, which settle out to form sludge.

The advantages of coagulation are that it reduces the time required to settle out suspended solids and is very effective in removing fine particles that are otherwise very difficult to remove. Coagulation can also be effective in removing many protozoa, bacteria and viruses.

The principal disadvantages of using coagulants for treatment of small supplies are the cost and the need for accurate dosing and frequent monitoring. Coagulants need accurate dosing equipment to function efficiently and the dose required depends on raw water quality that can vary rapidly. The efficiency of the coagulation process depends on the raw water properties, the coagulant used and operational factors including mixing conditions, coagulant dose rate and pH value. The choice of coagulant and determination of optimum operating conditions for a specific raw water have to be determined by bench-scale coagulation tests (‘jar tests’).

Thus, while coagulation and flocculation are the most effective treatment for removal of colour and turbidity they may not be suitable for small water supplies because of the level of control required and the need to dispose of significant volumes of thin sludge.

5.4 Sedimentation

Simple sedimentation (i.e. unassisted by coagulation) may be used to reduce turbidity and solids in suspension. Sedimentation tanks are designed to reduce the velocity of flow of water so as to permit suspended solids to settle under gravity. There are many different designs of tanks and selection is based on simple settlement tests or by experience of existing tanks treating similar waters.

Sedimentation tanks are usually rectangular with length to width ratios between 2:1 and 5:1. The depth of the tank is usually between 1.5 and 2.0 m. The inlet and outlet must be at opposite ends of the tank. The inlet should be designed to distribute the incoming flow as evenly as possible across the tank width and to avoid streaming which would otherwise reduce sedimentation efficiency. Baffles may be installed to prevent short-circuiting. The outlet should be designed to collect the clarified water over the entire tank width. The tank should be covered to prevent contamination. Sedimentation tanks require cleaning when performance drops off. This will not normally be more frequent than once per year.

5.5 Filtration

5.5.1 General

Turbidity and algae are removed from raw waters by screens, gravel filters and slow sand or rapid gravity filters. The difference between slow and rapid sand filtration is not a simple matter of the speed of filtration, but in the underlying concept of the treatment process. Slow sand filtration is essentially a biological process whereas rapid sand filtration is a physical treatment process.

5.5.2 Screens

Screens are effective for the removal of particulate material and debris from raw waters and are used on many surface water intakes. Coarse screens will remove weeds and debris while band screens or microstrainers will remove smaller particles including fish and may be effective in removing large algae. Microstrainers are used as a pre-treatment to reduce solids loading before slow sand filters or chemical coagulation. A microstrainer consists of a rotating drum fitted with very fine mesh panels. Raw water flows through the mesh and suspended solids including algae are retained and removed by water wash, producing a wastewater, which may require treatment before disposal.

5.5.3 Gravel filters

Gravel filters may be used to remove turbidity and algae. A simple gravel filter for the protection of a stream or river inlet is described in Section 3.4.1. A larger gravel filter may consist of a rectangular channel or tank divided into several sections and filled with graded gravel (size range 4 to 30 mm). The raw water enters through an inlet distribution chamber and flows horizontally through the tank, encountering first the coarse and then the finer gravel. The filtered water is collected in an outlet chamber. Solids removed from the raw water accumulate on the floor of the filter. Gravel filters can operate for several years before cleaning becomes necessary. The size of a gravel filter will depend on water quality, flow rate and size of gravel. A filter can be up to 12 m long, 2 to 5 m wide and 1 to 1.5 m deep. The filter should normally be sized for a flow rate of between 0.5 to 1.0 cubic metres per square metre of filter surface area per hour ($m^3/m^2.h$).

5.5.4 Slow sand filters

Slow sand filters, sometimes preceded by microstraining or coarse filtration, are used to remove turbidity, algae and micro-organisms. Slow sand filtration is a simple and reliable process and is therefore often suitable for the treatment of small supplies provided that sufficient land is available.

Slow sand filters usually consist of tanks containing sand (size range 0.15-0.30 mm) to a depth of between 0.5 to 1.5 m. For small supplies, modular units of 1.25 m diameter are available – a tandem installation would occupy a concrete apron of about 8 to 10 m^2. The raw water flows downwards and turbidity and micro-organisms are removed by filtration in the top few centimetres of the sand. A biological layer of sludge, known as the ‘schmutzdecke’, develops on the surface of the filter that can be effective in removing micro-organisms. Treated water is collected in underdrains or pipework at the bottom of the filter. The top few centimetres of sand containing the accumulated solids are removed and replaced periodically. Filter runs of between 2 and 10 weeks are possible, depending on raw water quality and flow rate. Slow sand filters are often operated in tandem; one in service whilst the other is cleaned and time allowed for the schmutzdecke to re-establish.

A variant of the slow sand filter, the “Inverness filter”, has been widely used in Scotland. It uses the same grade of sand and operates at the same flow rate as the traditional slow sand filter but the water flows upwards. Filtration is achieved throughout the filter bed and a true ‘schmutzdecke’ does not develop. The sand is ‘washed’ by opening a valve at the bottom of the filter and allowing the filter bed to drain rapidly.

Slow sand filters should be sized for a water flow rate of between 0.1 and 0.3 $m^3/m^2.h$. The flow rate should be controlled and the filter designed with a treated water reservoir of sufficient capacity to accommodate fluctuations in demand, and thus permit operation of filters at a steady and continuous rate.

5.5.5 Rapid gravity filters

Rapid gravity filters are most commonly used to remove floc from coagulated waters. They may also be used to remove turbidity, algae and iron and manganese from raw waters. Granular activated carbon medium is used to remove organic compounds and filters incorporating an alkaline medium are used to increase the pH value of acidic water.

Rapid gravity sand filters usually consist of rectangular tanks containing silica sand (size range 0.5 to 1.0 mm) to a depth of between 0.6 and 1.0 m. The water flows downwards and solids become concentrated in the upper layers of the bed. Treated water is collected *via* nozzles in the floor of the filter. The accumulated solids are removed periodically by backwashing with treated water, usually preceded by scouring of the sand with air. Frequency of backwashing depends on loading rate and raw water quality and is typically every 24 hours. Backwashing can be initiated automatically after a pre-determined headloss has been reached or may be carried out manually. A dilute sludge that requires disposal is produced which may be discharged to sewer, soakaway or, after treatment, to a watercourse provided that any required discharge consent is obtained.

A number of proprietary filters contain media of different sizes and densities. In some filters, the raw water flows upwards and improved filtration efficiency is claimed. The size of a rapid gravity filter is determined by the filtration rate if backwashed automatically, or by the solids retention if backwashed manually. Filters should normally have sufficient area to enable them to be operated at no more than 6 m/h at peak flow or to retain 1 kg of solids per square metre of bed between washes at peak loading, whichever is greater.

5.5.6 Pressure filters

Pressure filters are sometimes used where it is necessary to maintain head in order to eliminate the need for pumping into supply. The filter bed is enclosed in a cylindrical shell. Small pressure filters, capable of treating up to about 15 m^3/h, can be manufactured in glass reinforced plastics. Larger pressure filters are manufactured in specially coated steel. Operation and performance are generally as described for the rapid gravity filter (see Section 5.5.5) and similar facilities are required for backwashing and disposal of the dilute sludge. A similar range of contaminants can be removed depending on the filter medium.

5.6 Aeration

Aeration processes are designed to achieve efficient mass transfer of oxygen into water and removal of gases and volatile compounds by air stripping. Oxygen transfer can usually be achieved using a simple cascade or diffusion of air into water, without the need for elaborate equipment. Stripping of gases or volatile compounds, however, may require specialised plant that provides a high degree of mass transfer.

For oxygen transfer, cascade or step aerators are designed so that water flows in a thin film to achieve efficient mass transfer. Cascade aeration may introduce a significant headloss; design requirements are between 1 and 3 metres to provide a loading of 10 to 30 $m^3/m^2.h$. If such headloss is unacceptable the alternative is to use compressed air diffused through a system of submerged perforated pipes. These types of aerator are used for oxidation and precipitation of iron and manganese.

To achieve air stripping various techniques can be used including counter-current cascade aeration in packed towers, diffused aeration in basins and spray aeration. Packed tower aerators are most commonly used because of their high energy efficiency and compact design. Air stripping is used for removal of volatile organics (e.g. solvents), some taste and odour causing compounds, and radon (Section 7.1).

5.7 Chemical treatment

5.7.1 Control of pH

The pH value of water may need to be adjusted during treatment and before distribution for several reasons, including:

- to ensure that the pH value meets the water quality standards;
- to control corrosion in the distribution system and consumers' installations or to reduce plumbosolvency;

- to improve the effectiveness and efficiency of disinfection;
- to facilitate the removal of iron and manganese; and
- to facilitate the removal of colour and turbidity by chemical coagulation.

Many raw surface waters are slightly acidic and coagulation processes further increase acidity. Increase of pH can be achieved by:

- dosing with sodium hydroxide, calcium hydroxide or sodium carbonate;
- passage of the water through a bed of alkaline medium; or
- removal of excess carbon dioxide by aeration.

Where necessary, reduction of pH can be achieved by dosing with a suitable acid such as sulphuric acid, hydrochloric acid, sodium hydrogen sulphate or carbon dioxide.

5.7.2 Iron and manganese removal

In groundwaters, iron is usually present as dissolved ferrous compounds. To remove iron in this form, it is necessary to oxidise ferrous iron, usually by aeration, to the insoluble ferric hydroxide and to remove the precipitated material in a subsequent filtration stage. It is important to ensure that oxidation does not give rise to colloidal species which may pass through the filters. If the iron is present as an organic complex, a strong oxidant such as chlorine or potassium permanganate must be used. Manganese is usually present as dissolved manganous compounds. Removal is achieved by oxidation to insoluble manganese dioxide using catalytic filters or potassium permanganate followed by filtration, or by coagulation at high pH followed by filtration.

In surface waters, iron and manganese are usually present in their oxidised forms and are associated with the suspended solids, which can be removed by filtration. Where coagulation is practised for the removal of colour and turbidity, iron removal may be achieved simultaneously. Iron and manganese may be combined with organic matter in very stable forms. The usual treatment in this case is coagulation followed by oxidation with chlorine or potassium permanganate and filtration.

5.7.3 Taste and odour removal

Taste and odour can be removed by several methods, including aeration, ozonation and adsorption on activated carbon. The method used will depend on the source of the taste and odour. Adsorption on activated carbon is generally the most effective method for the removal of ‘earthy’ or ‘mouldy’ taste and odour. Powdered activated carbon can be dosed directly to the water before coagulation and sedimentation. Granular activated carbon may be used as a filter medium replacing sand in existing filters or alternatively in a post-filtration adsorption stage.

5.7.4 Nitrate removal

Nitrate removal is usually achieved by ion-exchange. Water is passed through a column of synthetic resin beads that remove anions including nitrate and exchange them for equivalent amounts of chloride. When the capacity for exchange is exhausted, the resin is regenerated by backwashing with a concentrated solution of sodium chloride. This restores the resin to its initial chloride form. The bed is then rinsed with clean water and returned to service. The waste solution and rinse waters, containing high concentrations of sodium chloride, as well as nitrate, are collected for disposal.

Conventional anion exchange resins have a higher affinity for sulphate than for nitrate. This means that they preferentially remove sulphate and reduce the capacity for nitrate, leading in turn to higher running costs (for regenerant) and greater volumes of waste for disposal. As a result, nitrate-selective resins, which give better uptake of nitrate in the presence of sulphate and reduce process costs, are preferred.

Nitrate-selective resins also add less chloride to the treated water because of the lower sulphate removal; this is desirable since high chloride concentrations and chloride-to-bicarbonate ratios are associated with increased corrosion of certain metals. A sodium bicarbonate rinse can be used after regeneration with sodium chloride to convert the resin in the lower part of the bed to the bicarbonate form and reduce the chloride-to-bicarbonate ratio during the early part of the run.

An ion-exchange plant consists of two or more reactors operated in parallel. Run lengths of up to 24 hours can be achieved before regeneration is necessary. Regeneration consumes up to 2 percent of the volume of treated water and takes about two hours. Performance is affected by the choice of resin, the concentrations of nitrate and sulphate in the raw water, and the volume and concentration of sodium chloride solution used for regeneration. Operation of an ion-exchange plant is normally fully automatic.

Even when using nitrate-selective resins the concentrations of nitrate, sulphate, bicarbonate and chloride vary during a run. These variations can be balanced out by operating two or more beds out of phase and blending the products or by installing large mixing tanks prior to distribution.

Surface waters may require pre-treatment by coagulation to remove organic colour and suspended solids, which would foul the resin.

Nitrate can also be removed by some membrane processes and by biological denitrification. Membrane processes are described in Section 5.8. In biological denitrification, nitrate is converted to nitrogen by de-nitrifying bacteria which, in the absence of dissolved oxygen, use the nitrate as an oxygen source. Biological denitrification occurs naturally in some confined aquifers but is not appropriate for the treatment of small water supplies because of the complexity of the process and the relatively high capital cost.

5.8 Membrane processes

The membrane processes of most significance in water treatment are reverse osmosis, ultrafiltration, microfiltration and nanofiltration. These processes have traditionally been applied to the production of water for industrial or pharmaceutical applications but are now being applied to the treatment of drinking water. Their characteristics are illustrated in Figure 5.2.

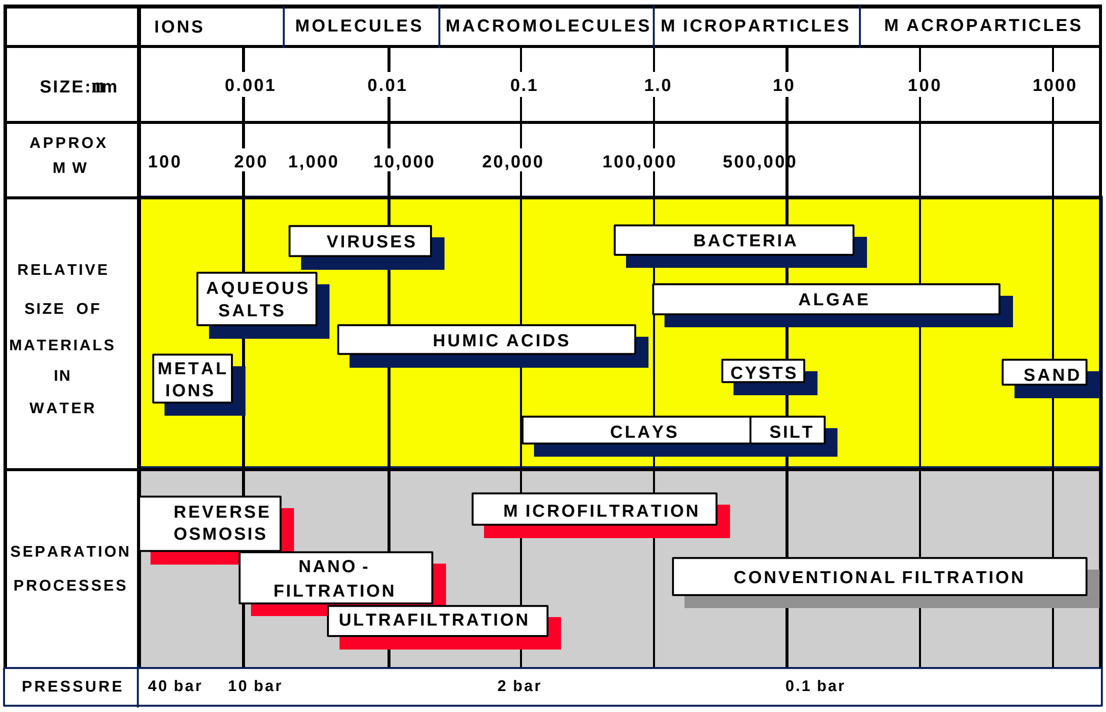

Figure 5.2 Characteristics of membrane processes

If two solutions are separated by a semi-permeable membrane, i.e. a membrane that allows the passage of solvent but not of the solute, the solvent will pass from the lower concentration solution to the higher concentration solution. This process is known as osmosis. It is possible, however, to force the flow of solvent in the opposite direction, from the higher to the lower concentration, by increasing the pressure on the higher concentration solution. The required pressure differential is known as the osmotic pressure and the process as reverse osmosis.

Reverse osmosis results in the production of a treated water stream and a relatively concentrated waste stream. Typical operating pressures are in the range 15 to 50 bar depending on the application. Membrane pore sizes are less than 0.002 µm. The most common application of reverse osmosis is desalination of sea water although the use of reverse osmosis for nitrate removal has also been proposed.

Ultrafiltration is similar in principle to reverse osmosis, but the membranes have much larger pore sizes (typically 0.002 to 0.03 µm) and operate at lower pressures. Ultrafiltration membranes reject organic molecules of molecular weight above 800 and usually operate at pressures less than 5 bar. Microfiltration membranes have pore sizes typically in the range 0.01 to 12 µm and do not separate molecules but reject colloidal and suspended material at operating pressures of 1 to 2 bar.

Nanofiltration uses a membrane with properties between those of reverse osmosis and ultrafiltration membranes; pore sizes are typically 0.001 to 0.01 µm. Nanofiltration membranes allow monovalent ions such as sodium or potassium to pass but reject a high proportion of divalent ions such as calcium and magnesium and organic molecules of molecular weight greater than 200. Operating pressures are typically about 5 bar. Nanofiltration may be effective for the removal of colour and organic compounds.

Microfiltration is a direct extension of conventional filtration into the sub-micron range. Microfiltration is capable of sieving out particles greater than 0.05 µm and will remove most bacteria and amoeboid cysts. It has been used for water treatment in combination with coagulation or powdered activated carbon (PAC) to remove viruses, bacteria, dissolved organic carbon and to improve permeate flux.

Membrane processes can provide adequate removals of pathogenic bacteria, *Cryptosporidium*, *Giardia* and, potentially, human viruses and bacteriophages. However, they should not be relied upon as the sole means of disinfection as there is no simple means to check membrane integrity to warn of potential break-through of micro-organisms.

5.9 Disinfection

5.9.1 General

Contamination by sewage or by human or animal faeces is the greatest danger associated with water for drinking. This is because sewage from human or animal sources may contain the causative organisms of many communicable diseases. The use of disinfection to kill or inactivate pathogenic micro-organisms is necessary if the raw water contains such organisms.

Surface waters may contain between a few tens of *E. coli* per 100 ml in a source derived from a protected upland catchment and many thousands of *E. coli* per 100 ml in a source derived from a lowland river containing treated sewage effluents. Groundwaters are less prone to contamination.

Several disinfection methods are used in water treatment. Disinfection with chlorine is the most widely used method for large water supplies but its application is less common in small supplies. Other methods that are increasingly used include ultraviolet irradiation and ozonation.

Different micro-organisms have different susceptibilities to disinfectants, and disinfectants vary in their potency. For a given micro-organism, disinfection efficiency is affected especially by disinfectant concentration and contact time, and also by disinfectant demand of the water, pH and temperature. The product of disinfectant concentration (C in mg/l, measured at the end of the contact period) and time (t in minutes) is called Ct (in mg/l.min) and is an expression of exposure to the disinfectant:

$$Ct = C \times t$$

The greater the Ct value, or exposure, the more effective disinfection is. Either concentration or contact time, or both, can be manipulated to obtain a desired Ct value. Values of Ct can be useful for comparing the efficiency of disinfectants – the lower the value of Ct to attain a given kill of micro-organisms, the more effective the disinfectant. The Ct value can also be used to rank the relative susceptibility of different micro-organisms – the higher the Ct value necessary to achieve a given level of kill the more resistant the micro-organism.

In the case of ultraviolet irradiation, Ct cannot be calculated in the same way and the exposure is expressed as UV radiation energy density, which is equivalent to (power × time) per unit area, expressed in milliwatt seconds per square centimetre (mW.s/cm^2).

5.9.2 Ultraviolet irradiation

Ultraviolet (UV) irradiation is the preferred method for disinfection of small supplies except for larger schemes in which it is necessary to maintain a residual disinfectant during storage and distribution. UV disinfection efficiency is particularly affected by water quality and flow rate. The water to be disinfected must be of good quality and particularly low in colour and turbidity. It is generally necessary for the turbidity of water to be less than 5 NTU, preferably much lower, for successful UV disinfection. Therefore pre-filtration is advisable, especially if *Cryptosporidium* is likely to be present, as discussed below.

Special lamps are used to generate UV radiation, and are enclosed in a reaction chamber made of stainless steel or, less commonly, plastics. Low pressure mercury lamps, which generate 85% of their energy at a wavelength of 254 nm, are most commonly used; their wavelength is in the optimum germicidal range of 250 to 265 nm. These lamps are similar in design, construction and operation to fluorescent tubes except that they are constructed of UV-transparent quartz instead of phosphor-coated glass. The optimum operating temperature of the lamp is around 40 °C so the lamp is normally separated from the water by a ‘sleeve’ to prevent cooling by the water. The intensity of UV radiation emitted decreases with lamp age; typical lamp life is about 10 to 12 months after which the output is about 70% of that of a new lamp, and lamp replacement is required.

The usual UV reactor configuration is a quartz-sleeved low pressure mercury lamp in direct contact with the water; water enters the unit and flows along the annular space between the quartz sleeve and the wall of the chamber. Other configurations include lamps separated from the water, for example lamps surrounded by ‘bundles’ of PTFE tubes through which the water flows.

Disinfection will only be effective provided that a sufficient dose of UV is applied. The ‘dose’ of UV radiation is expressed as an energy flux, in units of mW.s/cm^2 (milliwatt seconds per square centimetre), which is the product of the intensity given out by the lamp and the residence time of water in the reactor. The minimum dose required for disinfection depends on several factors, including the susceptibility of micro-organisms but is generally taken to be in the range 16 to 40 $mW.s/cm^2$.

It is important, to ensure effective disinfection, that both residence time and UV intensity are adequate. UV intensity will be diminished by ageing of the lamp, fouling of the lamp by deposits, and absorption of UV radiation by water contaminants such as natural colour. For these reasons, lamps need to be changed at the recommended intervals and the quartz sleeve may require periodic cleaning. Some units incorporate a manual ‘wiper’ for cleaning whilst others incorporate automatic mechanical cleaning.

Colour and turbidity will both affect radiation intensity in the reactor and turbidity may protect micro-organisms from the radiation. The water to be treated should be tested for transmissivity by the manufacturer or supplier in order to estimate worst-case transmission values and to adjust contact time accordingly. More advanced units incorporating UV monitors have the facility to automatically adjust the energy input to the UV lamp to achieve the required UV intensity.

The water flow rate affects the retention time in the reactor, which is designed for a maximum flow rate. The maximum water flow rate should not be exceeded.

There is evidence that UV is effective in inactivating *Cryptosporidium* provided that a sufficient UV dose is applied although there is a dearth of data on effectiveness under high-risk conditions of water quality. However, where *Cryptosporidium* is likely to be present and cyst removal is required then pre-filtration capable of removing particles of 1 μm diameter is recommended prior to UV disinfection. Pre-filtration provides an additional barrier to passage of oocysts into the treated water, removes particles that shield micro-organisms from the UV light and helps to reduce fouling of the UV lamp.

Several new treatment technologies have been developed for inactivation of *Cryptosporidium*. These include pulsed UV or white light systems and combined filtration-irradiation or adsorption-irradiation techniques that increase exposure to UV, for example by trapping the micro-organisms on a filter then subjecting them to UV irradiation. Pulsed UV and pulsed white light devices that generate high intensity, short duration, pulses of radiation are reported to give more effective inactivation of oocysts than conventional UV systems. At present, such systems are not applied to any extent for treatment of small water supplies.

UV irradiation equipment is compact and simple to operate. Maintenance requirements are modest, although specific systematic maintenance is essential. Other advantages include short contact time and the absence of any known by-products of significance to health. An ‘overdose’ of UV presents no danger and actually adds a safety factor. The principal disadvantage is the absence of any residual effect, necessitating careful attention to hygiene in the storage and distribution system.

The build-up of scale on the sleeves of the lamps will eventually reduce their transmittance and they must be cleaned or replaced regularly. Some units have UV intensity monitors and alarms which provide a continuous check on performance and these are strongly recommended. These devices may prevent the flow of water if the required intensity of UV radiation is not achieved, for example when the lamps are warming-up or because of scale formation. UV intensity monitors may not be available on smaller units and it is therefore essential that the manufacturer's instructions regarding lamp warm-up, cleaning and replacement are followed to ensure optimal performance.

Lamp replacement is usually a simple operation but may involve a significant downtime for reactors with many lamps. This difficulty may be overcome by use of multiple units or by having a treated water storage tank capable of maintaining supply whilst maintenance is carried out. The materials of construction and design of storage systems should not allow deterioration in water quality to occur.

5.9.3 Chlorine

Chemistry

Chlorine, whether in the form of pure chlorine gas from a cylinder, sodium hypochlorite or calcium hypochlorite, dissolves in water to form hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). For example, chlorine gas dissolves rapidly in water, initially forming hypochlorous and hydrochloric acids:

$$Cl_2 + H_2O \Leftrightarrow HOCl + HCl$$

Hypochlorous acid is a weak acid which undergoes partial dissociation to produce a hydrogen ion (H^+) and a hypochlorite ion (OCl^-):

$$HOCl \Leftrightarrow H^+ + OCl^-$$

The total concentration of chlorine, hypochlorous acid and hypochlorite ions is referred to as the 'free available chlorine'. If ammonia is present in the raw water, the hypochlorous acid can react to produce chloramines. The total concentration of the chloramines and any organic nitrogen chlorine-containing compounds is referred to as the 'combined available chlorine'. Combined available chlorine is a less powerful disinfectant than free available chlorine but gives a more persistent residual.

Formation of combined chlorine is due to a sequence of reactions. Hydrogen in ammonia is progressively replaced by chlorine as follows:

NH_3	$\Rightarrow$	NH_2Cl	$\Rightarrow$	$NHCl_2$	$\Rightarrow$	$NHCl_3$
Ammonia		Mono-chloramine		Dichloramine		Nitrogen trichloride

If a large chlorine dose is applied (relative to ammonia), as is practised in breakpoint chlorination, then nitrogen is formed.

$$2NH_2Cl + Cl_2 \Rightarrow N_2 + 4HCl$$

The effectiveness of chlorine for disinfection depends on the form of chlorine, its concentration and the contact time. Hypochlorous acid is a more powerful disinfectant than the hypochlorite ion and chlorination is usually practised at values of pH favourable to its formation. The World Health Organization recommends that for the effective disinfection of drinking water "the pH should preferably be less than 8.0 and the contact time greater than 30 minutes, resulting in a free chlorine residual of 0.2 to 0.5 mg/l".

Chlorination processes need to be carefully controlled in order to minimise problems with complaints of taste and odour. There may also be a need to control the formation of THMs (see Section 2.4.6). Therefore, for small supplies, consideration should be given to using alternatives to chlorination, such as UV.

Sources of chlorine

Chlorination can be achieved by using liquefied chlorine gas, sodium hypochlorite solution or calcium hypochlorite granules. Chlorine gas is very reactive and highly toxic and must be carefully stored and handled. It is used for treatment of large public supplies but the inherent danger of using chlorine gas has resulted in an increased use of sodium hypochlorite or the electrolysis of brine (electro-chlorination) as alternative sources of chlorine.

The use of chlorine gas for treatment of small water supplies is not recommended. Gas chlorination is generally not appropriate for supplies of less than 10 m^3/d or where the available head is less than about 4 m. Leaks of chlorine gas are very dangerous. A separate area is necessary for storage of chlorine gas and an alarm system to detect leakage of chlorine must be installed. It is common practice to install alarm systems to indicate failure of the chlorine injector system or carrier water flow.

Liquefied chlorine gas is supplied in pressurised containers. The gas is withdrawn from the cylinder and is dosed into water by a chlorinator, which both controls and measures the gas flow rate.

Sodium hypochlorite solution (14 to 15% by mass (*m*/*m)* available chlorine) can be delivered to site in drums. No more than one month's supply should be delivered at one time, as its decomposition (particularly on exposure to light) results in a loss of available chlorine and an increase in concentration of chlorate, relative to chlorine.

Alternatively, sodium hypochlorite solution (0.5 to 1.0% mass per volume (*m*/*V*) available chlorine) can be generated on site by the electrolysis of brine (sodium chloride solution). A typical electrochlorination system consists of a water softener, a salt saturator, a voltage rectifier, an electrolysis cell and a storage tank containing up to three days' supply of hypochlorite solution. Hydrogen, which is produced during electrolysis, must be vented safely. These systems are compact and eliminate the need to store and handle the toxic and corrosive chlorination chemicals.

There is a wide choice of equipment available for dosing sodium hypochlorite solution. Simple gravity-fed systems in which sodium hypochlorite solution is dripped at a constant rate into a tank of water have been used successfully and have proven reliable provided that the rate of flow into supply and the chlorine demand of the water are constant. Where the flow is more variable, water-powered hypochlorinators that adjust the flow of sodium hypochlorite proportionately to the flow of water may be suitable. Electric dosing pumps can operate under flow proportional or chlorine residual control and thus maintain a consistent chlorine residual under conditions of variable flow or chlorine demand.

Calcium hypochlorite can be supplied in powdered, granular or tablet form (65 to 70% *m*/*m* available chlorine). Calcium hypochlorite is stable when dry and several months' supply can be stored. It will however react with moisture in the air to form chlorine gas. Calcium hypochlorite dosers are relatively simple. Most allow calcium hypochlorite to dissolve in a known volume of make-up water, which is then mixed with the main supply. Tablets are most commonly used, as their rate of dissolution is predictable. Control of dosage (proportional to the rate of dissolution) is often limited to changing the depth of immersion of the tablets in the make-up water or to changing the proportion of the make-up water to total flow.

Methods of chlorination

Several regimes of chlorination can be used, including marginal (simple) chlorination, breakpoint chlorination, superchlorination/dechlorination and chloramination. On small supplies, it is probable that only marginal chlorination would be used in most cases. Marginal chlorination involves the dosing of chlorine to produce a suitable residual free available chlorine concentration.

Breakpoint chlorination could be used for removal of ammonia. Sufficient chlorine is added to exceed the demand for chloramine production and to ensure a free available chlorine residual. The chlorine dose must be carefully controlled to avoid forming dichloramine and nitrogen trichloride which can cause taste and odour problems. Breakpoint chlorination requires a dose of around 10 mg/l chlorine dosed per mg/l ammonia removed – the actual dose depends on water quality and has to be determined for each water.

The resultant free available chlorine residual should remain in the range 0.2 to 0.5 mg/l. It is recommended that the contact time should be at least 30 minutes. The design of the contact system is very important. Applied chlorine must be mixed rapidly with the water and the system must not permit short-circuiting or retention in dead zones.

Control of chlorination

Residual control is the most common method of control where chlorine is dosed continuously into the water. If the quality of the water and hence the chlorine demand varies appreciably, it is necessary to use a control system to maintain a constant chlorine residual. A sample of chlorinated water is withdrawn downstream of the chlorination system and the chlorine residual in the treated water is monitored continuously. The signal from the chlorine analyser system is used to adjust the chlorine dose thus maintaining the required residual chlorine concentration. Where water quality is invariably good, constant rate control or flow proportional control may be appropriate. In the former, a constant dose of chlorine is applied and in the latter a chlorine dose proportional to the flow of water is applied automatically under control of a signal from the flow sensor.

5.9.4 Ozone

Ozone is a powerful oxidant and disinfectant that effectively destroys bacteria and viruses. It is also more effective than chlorine in the destruction of *Cryptosporidium* oocysts. However it cannot be relied upon as the sole means of disinfection of waters that may contain *Cryptosporidium* under the conditions of dosing and water temperature normally used and found in the UK. Ozone may also reduce levels of colour, taste and odour in water. Ozonation tends to increase the concentration of Assimilable Organic Carbon (AOC), i.e. that fraction of the total organic carbon which can be utilised by bacteria. This can lead to multiplication of bacteria within the distribution system unless the AOC concentration is reduced by adsorption on granular activated carbon filters.

Ozone is a gas produced by the discharge of an alternating current through dry air. Small units can operate from a 240 Volt mains supply but larger installations require 3 phase 415 Volt supplies or higher. The ozone-containing air is mixed with the raw water in a contact column. For effective disinfection, the ozone contact system should give at least 4 minutes retention time and the ozone residual should be at least 0.4 mg/l throughout the contact period. Ozone decomposes rapidly and does not leave a persistent residual. Unless the water is used immediately, it is advisable to provide a disinfectant residual by applying a small dose of chlorine. Ozone gas is highly toxic and any excess in the vent gases from the contactor must be destroyed using a thermal or catalytic destructor.

Ozone reacts with many organic and inorganic constituents of water, thus there is an ozone demand (analogous to a chlorine demand) that must be satisfied and the ozone dose required should be determined by trials. Ozonation does not produce THMs but does form bromate if bromine compounds are present. The identity and toxicity of many of the organic oxidation products of ozone are unknown.

Small-scale package ozonation equipment is available that could be suitable for treatment of small water supplies. However, ozone is not widely used because of the high power requirements, complexity of the equipment and relatively high capital cost.

5.10 Corrosion control

5.10.1 General

Corrosion is the partial dissolution of the materials constituting the treatment and supply systems, tanks, pipes, valves, and pumps. It may lead to structural failure, leaks, loss of capacity, and deterioration of chemical and microbiological water quality. The internal corrosion of pipes and fittings can have a direct impact on the concentration of some water constituents, including lead, copper and nickel. Corrosion control is therefore an important aspect of the management of a water supply system.

Corrosion control involves many parameters, including the concentrations of calcium, bicarbonate, carbonate, and dissolved oxygen, as well as pH. The detailed requirements differ depending on water quality and for each distribution system material. The pH controls the solubility and rate of reaction of most of the metal species involved in corrosion reactions. It is particularly important in relation to the formation of a protective film at the metal surface. For particular metals, alkalinity (carbonate and bicarbonate) and calcium (hardness) also affect corrosion rates.

5.10.2 Lead

Lead corrosion (plumbosolvency) is of particular concern. Lead piping is still common in old houses, and lead solders have been used widely for jointing copper tube. The solubility of lead is governed by the formation of insoluble lead carbonates. The solubility of lead increases markedly as the pH is reduced below 8 because of the substantial decrease in the equilibrium carbonate concentration. Thus, plumbosolvency tends to be at a maximum in waters with a low pH and low alkalinity, and a useful interim control procedure pending pipe replacement is to maintain pH in the range 8.0 to 8.5 and possibly to dose orthophosphate.

5.10.3 Copper

Copper tubing may be subject to general corrosion, impingement attack and pitting corrosion. General corrosion is most often associated with soft, acid waters; waters with pH below 6.5 and hardness of less than 60 mg/l $CaCO_3$ are very aggressive to copper. Impingement attack is the result of excessive flow velocities and is aggravated in soft water at high temperature and low pH. The pitting of copper is commonly associated with hard groundwaters having a carbon dioxide concentration above 5 mg/l and high dissolved oxygen. Surface waters with organic colour may also be associated with pitting corrosion. A high proportion of general and pitting corrosion problems are associated with new pipe in which a protective oxide layer has not yet formed.

5.10.4 Nickel

Concentrations of nickel up to 1 mg/l may arise due to the leaching of nickel from new nickel-chromium plated taps and from stainless steel pipes and fittings. Nickel leaching falls off over time. Increase of pH to control corrosion of other materials should also help to reduce leaching of nickel.

5.10.5 Concrete and cement

Concrete is a composite material consisting of a cement binder in which an inert aggregate is embedded. Cement is primarily a mixture of calcium silicates and aluminates together with some free lime. Cement mortar, in which the aggregate is fine sand, is used as a protective lining in iron and steel water pipes. In asbestos–cement pipe, the aggregate is asbestos fibres. Cement is subject to deterioration on prolonged exposure to aggressive water – due either to the dissolution of lime and other soluble compounds or to chemical attack by aggressive ions such as chloride or sulphate – and this may result in structural failure. Aggressiveness to cement is related to the 'Aggressivity Index', which has been used specifically to assess the potential for the dissolution of concrete. A pH of 8.5 or higher may be necessary to control cement corrosion.

5.10.6 Characterising corrosivity

Most of the indices that have been developed to characterise the corrosion potential of waters are based on the assumption that water with a tendency to deposit a calcium carbonate scale on metal surfaces will be less corrosive. The Langelier Index (LI) is the difference between the actual pH of a water and its 'saturation pH', this being the pH at which a water of the same alkalinity and calcium hardness would be at equilibrium with solid calcium carbonate. Waters with positive LI are capable of depositing calcium carbonate scale from solution.

There is no corrosion index that applies to all materials, and corrosion indices, particularly those related to calcium carbonate saturation, have given mixed results. The parameters related to calcium carbonate saturation status are, strictly speaking, indicators of the tendency to deposit or dissolve calcium carbonate (calcite) scale, not indicators of the 'corrosivity' of water. For example there are many waters with negative Langelier Index that are non-corrosive, and many with positive LI that are corrosive. Nevertheless there are many documented instances of the use of saturation indices for corrosion control based on the concept of laying down a protective 'eggshell' scale of calcite in iron pipes. In general waters with high pH, calcium and alkalinity are less corrosive and this tends to be correlated with a positive LI.

The ratio of the chloride and sulphate concentrations to the bicarbonate concentration (Larson ratio) has been shown to be helpful in assessing the corrosiveness of water to cast iron and steel. A similar approach has been used in studying zinc dissolution from brass fittings - the Turner diagram.

5.10.7 Water treatment for corrosion control

To control corrosion in water distribution networks the methods most commonly applied are adjusting pH, increasing the alkalinity and/or hardness, or adding corrosion inhibitors such as sodium polyphosphates or silicates and orthophosphate. The quality and maximum dose to be used should be in line with appropriate national specifications for such water treatment chemicals. Although pH adjustment is an important approach its possible impact on other aspects of water supply technology, including disinfection, must always be taken into account.

Treatment to reduce plumbosolvency usually involves pH adjustment. When the water is very soft (less than 50 mg/l $CaCO_3$), the optimum pH is about 8.0 to 8.5. Alternatively, dosing with orthophosphoric acid or sodium orthophosphate might be more effective particularly when plumbosolvency occurs in non-acidic waters. Wherever practicable, lead pipework should be replaced. Grants for pipe replacement may be available from the local authority and some water companies offer a lead pipe replacement service.

5.11 Treated water storage

A water supply system needs to include some form of treated water storage to provide a reserve of drinking water in the event of planned maintenance or problems with the source or treatment and to cater for fluctuations in demand. Storage may take the form of a small covered reservoir, providing sufficient head to supply more than one property, or may be a suitably positioned storage tank (e.g. in the roof space of the property), from which water flows under gravity to the taps. The tank or reservoir should hold a volume sufficient to accommodate the peak demand and the maximum period of interruption of supply.

The storage tank, and other parts of the water supply system, may be contaminated during construction and should therefore be disinfected before use. This may be achieved by filling the system with a strong (20 mg/l) solution of chlorine and leaving to stand for several hours, preferably overnight. The chlorine solution should be drained off and the system rinsed thoroughly using treated water.

All storage tanks must be insulated to guard against freezing during the winter. Insulation will also prevent the water from warming up too much during the summer months. The tank must be fitted with a lockable, well-fitting (but not airtight) lid to exclude light and pollutants. It is especially important to guard against the ingress of insects and animals and all openings must be protected using a fine mesh screen.

The storage tank must be inspected regularly; at least annually and preferably every six months. If necessary, any accumulated silt can be flushed or siphoned out and the system disinfected as described above.

5.12 Maintenance and training requirements

One of the most neglected aspects of small water supply systems is maintenance. The usual practice is to deal with equipment failures as they arise, with the risk that contaminated water will be supplied until the problem is fixed. Proper maintenance involves a regular, preventive, maintenance programme. This enables early identification of problems. Equipment manufacturer’s maintenance instructions must be followed as a minimum requirement. Simple checks can be used to give forewarning of problems:

- daily (or more frequent) check on operation of disinfection equipment (e.g. check that UV lamp is on, measure chlorine residual);
- investigate causes of dirty or discoloured water;
- regular cleaning of filters, sedimentation tanks and so on;
- site inspection to check for signs of pollution of the water source; and
- structural inspection of the treatment plant, storage tanks and pipework.

Maintenance should always be performed by people familiar with the equipment. Some suppliers of treatment equipment may offer maintenance and servicing contracts. At the time a water treatment plant is installed and commissioned, the supplier should provide training on routine operation and maintenance tasks. The training should cover:

- checking that treatment is operating correctly;
- topping-up chemicals as required;
- routine maintenance of the equipment; and
- making simple repairs.

This on-site training should be supported by appropriate documentation, such as an operation and maintenance manual.

6. POINT-OF-USE TREATMENT

6.1 Introduction

A point-of-use device is any form of water treatment apparatus that may be installed or used by a householder within his premises and normally at the point of supply. A point-of-use device may be installed before the householder's tap (plumbed in-line or otherwise attached to the water pipe), connected to the tap by an adapter or separate from the plumbing system (such as a free-standing gravity filter). These devices handle relatively small volumes and it is usual for only water used for drinking and cooking to be treated. The treated water is supplied to a separate tap. It is important that the householder is made aware of the need to use the dedicated drinking water tap. Moreover, point-of-use treatment may not be appropriate if the untreated water would pose a risk to health if used for bathing or washing. In any case, it may be necessary to consider the possibility of providing an alternative supply, rather than attempting to improve a supply of inferior quality.

Some point-of-use devices have been designed and developed to provide additional treatment to mains water, although equipment designed for use with raw water sources is available. The manufacturers' recommendations regarding installation and maintenance are often based on arbitrary assumptions that take no account of the quality of individual water sources. In some cases quality typical of municipally treated water supplies is assumed. Recommendations concerning the replacement of filters are often vague and maintenance requirements may be underestimated. If the quality of water to be treated is poorer than mains water, maintenance requirements will be increased.

Contaminants in a raw water source may be present at higher concentrations than in a public supply and may affect the performance of some point-of-use devices. For example hardness compounds may precipitate on filters and membranes and iron and manganese compounds may deposit on UV tubes. Some manufacturers of point-of-use devices incorporating activated carbon specifically state that their devices should not be used on waters that are microbiologically unsafe or of unknown quality.

The foregoing observations do not rule out the application of point-of-use devices to small water supplies but appropriate pre-treatment may be required and careful attention must be paid to maintenance of the device. Where there is any doubt as to the effect of water quality on the performance of a point-of-use device, water quality data should be obtained and expert advice on the applicability of the device should be taken.

6.2 Particulate filters

There are several types of particulate filters using different media to remove suspended matter from water in the range 0.5 to 50 µm, or greater. Particulate filters may be used to reduce turbidity and micro-organisms, or to remove specific inorganic particulates such as iron, aluminium or manganese compounds. Many particulate filters are incorporated into proprietary point-of-use devices to protect subsequent processes such as activated carbon filtration, reverse osmosis or UV disinfection.

Filters are made in several forms, for example discs, woven or resin-bonded cartridges and ceramic candles. Filtration is effected by pleated paper and felt, woven cartridge filters manufactured from viscose, polypropylene, fibrillated polypropylene, nylon or fibreglass, non-woven cartridges manufactured from resin-bonded polyester, and Kieselguhr ceramic.

Water passes through the filter and particles and micro-organisms may be retained depending on the pore size of the filter. Particle removal may be achieved by surface filtration or by retention within the filter material. Some of the cartridge and ceramic filters have graded pore sizes so that larger particles are retained on the surface while smaller particles penetrate the filter where they are retained. As the filter blocks the flow rate of water decreases and this is often the first sign that a filter needs replacing or cleaning. Replacement of a filter is usually recommended after a specific time or after a specific volume of water has been filtered and filtration period will depend on the quality of water being treated. A ceramic candle may additionally require periodic cleaning of the surface. Growth of bacteria on these filters and the possible contamination of the treated water are of concern. Some filters are impregnated with silver to prevent or inhibit the growth of bacteria.

The treatment capacity of these filters depends on the water quality, water pressure and the pressure drop across the filter, which in turn is dependent on pore size and porosity. An 18 cm ceramic candle operating under gravity may have an output of 20 litres per day whereas a 13 cm ceramic candle operating at 3 bar may have an output of 150 litres per hour. In hard water areas (greater than about 200 mg/l $CaCO_3$), calcium carbonate may precipitate and block the device. The manufacturer's advice on suitability should, therefore, be sought.

6.3 Reverse osmosis units

Reverse osmosis (RO) has been used in recent years for the production of drinking water from low quality raw waters. Large-scale RO plants are used for the desalination of seawater to produce drinking water in countries where adequate supplies of fresh water are not available. Because of the high concentrations of dissolved salts in seawater, the osmotic pressure is high and operating pressures up to 70 bar are used. Domestic RO units operate at much lower pressures, as low as 1 bar, because of the typically lower concentration of dissolved salts in the water to be treated. RO systems will remove, to varying degrees, a range of physically and chemically diverse substances including dissolved inorganic species (e.g. sodium, calcium, nitrate and fluoride) and organic pollutants including pesticides and solvents. RO can also produce pathogen-free water.

The water to be treated by RO must be of good quality to prevent fouling or scaling of the membrane and a raw water supply will usually require pre-treatment.

Raw water enters the RO unit and treated water flows through the semi-permeable membrane, usually manufactured from polyamide. Some membranes such as cellulose acetate may support bacterial growth and are therefore unsuitable. The flow rate of treated water is very low at the pressures used in a domestic unit and the treated water is collected in a storage tank to buffer supply and demand. Usually a level sensor in the storage tank controls the operation of the RO unit.

The membrane does not become exhausted or saturated although it will require periodic chemical cleaning and replacement, usually after several years. The storage tank must be constructed of a material suitable for potable water and be protected from contamination. Periodic disinfection of the tank is recommended. There is evidence that inadequate cleaning of the storage system and pipework associated with RO units can result in proliferation of bacteria that are of health significance.

Water treated by reverse osmosis will generally be very soft. It is not known whether regular long-term consumption of water containing unusually low levels of dissolved inorganic constituents has any effect on health. Such water will contain insufficient fluoride to protect against dental caries. In addition, although there is no established explanation for the tendency for areas supplied with naturally soft water to have higher rates of cardiovascular disease than hard water areas, it appears sensible to avoid regular consumption of artificially softened water where there is an alternative. However, in the context of private supplies RO may offer the only practicable means of rendering potable a water source containing an excess of dissolved inorganic constituents. Some units have a ‘re-hardener’ system to increase the hardness and alkalinity of the treated water, thus rendering it less aggressive. It is not known whether this is a necessary or effective measure to protect health.

A further disadvantage of RO could be that a relatively high volume of water is wasted. Typically, for each volume of drinking water produced, three volumes must be wasted unless it can be used for non-potable purposes such as toilet flushing. RO should be considered if no alternative treatment could make a raw water safe to drink.

6.4 Nitrate removal units

Ion exchange, using nitrate-specific anion exchange resins, can be used to remove nitrate ions from water. Water is passed through a bed of anion exchange resin and the anions in the water, including nitrate, are replaced by chloride ions. The resins used are ‘nitrate selective’, i.e. nitrate is exchanged in preference to other ions such as sulphate and bicarbonate. The chloride concentration in the treated water will invariably be increased, possibly to above the indicator parameter value of 250 mg/l; this could have an adverse effect on the taste of the water but probably would not have implications for health. However, excessive chloride concentrations could lead to corrosion of pipework and fittings.

Ion exchange units are installed in-line and the resin is regenerated as required (manually or automatically) with sodium chloride solution (brine). Microbiological growth on the resin could result in the formation of nitrite from nitrate but, as the brine also acts as a disinfectant, this should not be a problem provided that regeneration is performed at intervals of five days or less. Units incorporating replaceable or disposable cartridges containing resin are also available.

Where anion exchange treatment is applied to a source that exhibits unsatisfactory bacteriological quality, it will be necessary to provide a disinfection stage after the resin.

6.5 Adsorption filters

6.5.1 Activated carbon

Activated carbon removes contaminants from water by physical adsorption. Adsorption will be affected by the amount and type of the carbon, the nature and concentration of the contaminant, retention time of water in the unit, and general water quality (temperature, pH, etc.). Granular activated carbon (GAC) is the most common medium employed although powdered activated carbon (PAC) and block carbon are also used. The filter medium is contained in replaceable cartridges; a particulate filter at the outlet of the cartridge removes carbon fines from the treated water. Other similar types of filter are pre-coated activated carbon filters and filters using different adsorbents, such as bone charcoal (an adsorbent made from charred animal bones, consisting principally of hydroxyapatite together with about 10% by weight of carbon).

Activated carbon filters will remove (to varying degrees) suspended solids, chlorine and organic contaminants including pesticides, trihalomethanes (THMs) and some of the humic substances responsible for the yellow to brown coloration in ‘peaty’ waters. The hydraulic retention time is a critical factor in determining the removal of contaminants. In point-of-use devices this is often short and can limit the removal of contaminants, particularly pesticides. Domestic devices for treatment of mains water are probably used primarily for aesthetic reasons – removal of compounds causing taste and odour; removal of residual chlorine; partial removal of colour; removal of suspended solids and turbidity.

Unfortunately, activated carbon is an ideal medium for the accumulation and growth of micro-organisms. There is concern that direct consumption of water from activated carbon devices may cause health problems due to bacteria released into the water; inhalation of bacteria-containing aerosols, for example during washing, could also be harmful. Activated carbon removes chlorine from the water, and bacterial growth can occur even on filters treating chlorinated water.

Some filters are impregnated with silver to inhibit the growth of bacteria. However, it has been demonstrated that high numbers of bacteria can be found in water treated by silver impregnated units; apparently silver serves as a selective agent, inactivating some bacteria but allowing others to grow. The problem of bacterial growth will be increased if the user fails to install or maintain the filter as recommended by the manufacturer. Some manufacturers specifically state that their devices should not be used on waters that are “microbiologically unsafe or of unknown quality”.

6.5.2 Activated alumina filters

Activated alumina is manufactured by calcining aluminium hydroxide. Filters containing granular activated alumina can be used for the removal of arsenic and other chemicals, including fluoride. In point-of-use applications, once the activated alumina bed reaches its capacity, the spent cartridge has to be replaced and disposed of or returned to the supplier for regeneration.

6.6 Water conditioners

6.6.1 Ion-exchange softeners

It is sometimes beneficial to remove calcium and magnesium in order to prevent scaling and encrustation with limescale from very hard waters. Softening is achieved by cation exchange. Water is passed through a bed of cationic resin and the calcium ions and magnesium ions in the water are replaced by sodium ions. Unlike the carbonates and bicarbonates of calcium and magnesium, sodium carbonates and bicarbonates do not cause scale formation or increased use of soap for washing. When the ion-exchange resin is exhausted, i.e. the sodium ions are depleted, it is regenerated using a solution of sodium chloride.

Water softening can reduce the total hardness below that recommended in the UK for artificially softened drinking water (60 mg/l as Ca)[19] and could possibly result in a breach of the UK national standard for sodium (200 mg/l)[20]. Softened water should not be used for drinking but may be used for washing – water softeners of this type are not intended for the production of drinking water. Blending softened and unsoftened water can produce partially softened water, suitable for drinking. In all cases where these devices are installed, a separate unsoftened drinking water supply must be maintained.

The process of ‘de-alkalisation’ can also soften water. Water is passed through a bed of weakly acidic resin and the calcium ions and magnesium ions are replaced by hydrogen ions. The hydrogen ions react with the carbonate and bicarbonate ions to produce carbon dioxide. The hardness of the water is thus reduced without any increase in sodium levels. De-alkalisation resins are available as disposable cartridges. They must be replaced after the interval recommended by the manufacturer, otherwise they become exhausted or colonised by bacteria during periods of non-use.

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[19] The UK Department of Health has stated that “in view of the consistency of the [epidemiological] evidence [of a weak inverse association between natural water hardness and cardiovascular disease mortality], it remains prudent not to undertake softening of drinking water supplies ... it appears sensible to avoid regular consumption of softened water where there is an alternative”.

[20] The UK Department of Health has advised that there should be a mandatory standard for sodium of 200 mg/l to help prevent infantile hypernatraemia (raised sodium levels in the plasma, commonly leading to permanent neurological damage) and to assist in reducing sodium intake in the general population.

6.6.2 Chemical water conditioners

Dosing the water with polyphosphate-based compounds can reduce scale formation. The hardness compounds are modified and the problems associated with temporary hardness are eliminated. It is also claimed that a thin protective film forms on the internal surfaces of the pipework, reducing corrosion.

Several devices are available which can be installed under mains pressure, treating the whole flow to a household or only part of the flow. Water contacts the slowly dissolving polyphosphate crystals, which are contained in a replaceable cartridge. The frequency of replacement depends on demand for water but is typically between several weeks and several months.

Chemical water conditioners do not usually affect micro-organisms and if such devices are used to treat water of unsatisfactory bacteriological quality it will be necessary to incorporate a disinfection stage.

6.6.3 Physical water conditioners

A variety of devices on the market generate magnetic or electrical fields for the water to pass through, or may be intended to release trace concentrations of zinc or other metals. Some of these devices must be plumbed into the pipework, whilst others are non-intrusive and can be simply clamped on or wrapped around the pipework. The effect of these devices can be to physically condition the water. The physical conditioning causes no change to the chemical composition of the water and only exerts a physical effect. Since the chemical composition is not changed, the calcium salts still precipitate when the water is heated or concentrated by evaporation. The effect of the physical conditioning, or presence of zinc, is to cause the calcium salts to precipitate differently such that they are less encrusting. Physical conditioning can produce some of the benefits of softening but without actually removing calcium.

Unfortunately there is an inadequate understanding of the design characteristics needed to secure reliable operation of physical water conditioners. There is ample evidence of the potential of magnetic fields to modify the crystalline structure of precipitated calcium carbonate. However, many other factors appear to determine the performance of specific products under defined conditions of water quality and design of the water supply system. These factors include: flowrate, magnetic field strength, temperature, time lag between conditioning and use of water and concentration of iron in the water supply. Until these devices are conclusively proven to work, it is recommended that physical conditioners should only be purchased from firms offering an extended-time money-back guarantee.

Physical water conditioners do not affect micro-organisms and if such devices are used to treat water of unsatisfactory bacteriological quality it will be necessary to incorporate a disinfection stage.

6.7 Disinfection units

6.7.1 Ultraviolet irradiation

UV disinfection is discussed fully in Section 5.9.2. Point-of-use UV disinfection units are available for domestic use. These units are installed in-line. No residual disinfecting capacity is imparted to the treated water so the unit should be located as close as possible to the drinking water tap. The need to consider the suitability of the untreated water for use in bathing and washing has been stated in Section 6.1. UV devices are most effective when the water is of low colour and turbidity. UV devices are often installed together with other upstream treatments, such as filtration, to prepare the water for effective disinfection.

Manufacturers' recommendations must be followed regarding installation, operation and maintenance. In particular, the maximum design flow rate should not be exceeded, lamps should be allowed to reach their operating temperatures before water is passed through the unit and lamps should be cleaned and replaced as recommended. A continuous UV monitor and an alarm or fail-safe device is strongly recommended and although not usually fitted as standard on point-of-use units, they are usually available as an extra.

6.7.2 Chlorination

Chlorination is discussed fully in Section 5.9.3. Chlorination is generally unsuitable for point-of-use treatment.

6.7.3 Ozonation

Ozonation is discussed fully in Section 5.9.4. Small package ozone units are available, suitable for the treatment of water for a single home or business.

6.8 Combination devices

Some point-of-use devices require a high quality water in order to operate effectively, for example reverse osmosis units and ultraviolet irradiation units require that the influent water is of very low turbidity. Where such devices are used on small supplies, pre-treatment of the water may be required. Combination devices are designed for this purpose and it is usual for point-of-use devices that require a high quality of water to include pre-treatment units. The Test Protocols described in Chapter 7 require that the device is tested in association with any pre-treatment unit that is specified by the manufacturer.

6.9 Maintenance requirements

Point-of-use water treatment equipment in general is not 'fit and forget' technology – regular maintenance is essential to ensure the continued supply of safe drinking water.

Equipment manufacturer's maintenance instructions must be followed as a minimum requirement. Ideally maintenance requirements should reflect the raw water quality and flow, but this is often not the case and instructions may be vague. Manufacturers' maintenance instructions may be based on the assumption that the equipment will be used to treat mains drinking water. Raw waters used for private supplies will always be of worse quality than public supplies and maintenance requirements quoted for treatment of feed water of potable standard will be inadequate.

Maintenance requirements must be clear and the consequences of failing to maintain adequately should be highlighted. The majority of devices that fail do so as a result of inadequate maintenance. Special points to observe include:

- Power supplies should be disconnected prior to servicing.

- Filter cartridges must be changed on a regular basis. The water supply must be turned off before the housing is unscrewed and the cartridge is removed. The housing should be rinsed out with clean water (only use cleaning materials if specified by the manufacturer) and the new cartridge installed. The old cartridge may be contaminated and must be disposed of safely; precautions should be taken to prevent contamination of the replacement filter. Manufacturers of point-of-use devices should provide, within their instructions for filter units, guidance on the safe handling and disposal of used filter elements.

- UV lamps should be disconnected from the electricity supply and withdrawn carefully. Replacement is simply the reverse operation but care must be taken not to handle the glass. Exposure to UV irradiation must be avoided.

- Intermittent operation may reduce the life of a UV lamp and frequent on/off operation should be avoided (this may invalidate any warranty). Low pressure lamps give out little heat and will not be damaged by operation under no flow conditions. However, scale formation may be greater under these conditions and more frequent cleaning of the quartz sleeve may be required. Again care must be taken when withdrawing and installing the sleeve.

7. TREATMENT FOR RADON AND URANIUM

7.1 Radon removal

7.1.1 Introduction

There are three main treatment methods for radon removal – decay storage, GAC and aeration. Due to the large size of the radon atom, it can also be removed by reverse osmosis and nanofiltration techniques. With all the removal systems, location is a key issue, both for hydraulic reasons and radiation exposure. Some systems may require an additional pump to be installed, or a bypass system. This increases the complexity of the system. Where a system results in the build-up of radioactive substances, it may not be appropriate to keep it under the sink. On the other hand, if the radiation risk means that there is a need to build an extra outbuilding to house a unit, the cost may be prohibitively expensive. For radon removal, point-of-use systems fitted to the drinking water tap (as opposed to point-of-entry systems, which treat the entire supply) are not acceptable as radon is released wherever water is used in the house and it can then be inhaled. Table 7.1 summarises the features of the principal methods for radon removal.

7.1.2 Decay storage

As radon (^{222}Rn) has a half-life of 3.82 days (i.e. its radioactivity halves every 3.82 days), it is possible (provided that mixing and short-circuiting are avoided) to store it to achieve an adequate reduction in radioactivity. The amount of time required will depend on the level of activity. An eight-fold reduction would take two weeks to achieve. For household consumption, this would typically require two 10 m^3 tanks, used alternately – impracticably large for most locations. With a lower activity level, requirements would be less and this option may be feasible.

7.1.3 Granular activated carbon

GAC was first used in the US in 1981 for radon removal. The method has been found to be very effective and is generally quoted as achieving about 95% radon removal. GAC is commonly used for removing taste, colour, odour and synthetic organic chemicals. It works by adsorption and the extremely high internal surface area within the porous structure is responsible for its effectiveness. GAC filters are described in Section 6.5.1.

The main drawback of GAC is that as the radon is trapped in the filter, the radioactivity of the filter increases. Although radon decays rapidly, there is a continuously increasing radioactivity due to other radionuclides being trapped and the build up of longer-lived radionuclides further down the radon decay chain (notably ^{210}Pb). As such, it is important to either shield the filters or place them in a separate shed outdoors or in an unused basement. There are also disposal problems with these levels – the filters have to be handled with care.

Table 7.1 Radon removal techniques

Treatment option	Efficiency	Availability	Disposal issues	Approximate cost per household	Other issues
Decay storage	Up to 100%	Storage tanks readily available.	Good ventilation system required (or very large tanks).	Variable, depending on size of tank and ventilation system.	Low maintenance. Would need to be designed for each site. Would require further testing and monitoring. Cannot handle higher levels easily.
GAC specifically designed for radon removal	Variable. Up to >99.9%	Common technology. Many carbon suppliers and suitable apparatus.	Carbon becomes radioactive and high radiation doses reported around filter as well – needs careful placement / shielding. Used filter may need specialist disposal.	£500 - £1,000, assuming no pre-treatment and no new building required. Possible annual filter replacement and high disposal costs.	Widely used in USA. Computer program available for home users (free download from EPA) to assess radiation risks and removal rates. Waste disposal and maintenance are key concerns. A number of available carbons have been specifically tested for radon removal. Not as effective or 'safe' as aeration.
GAC – standard water treatment package	Unknown. May be up to 99.9%	Yes – domestic water treatment companies.	As GAC above.	About £2,500.	Provides a complete water treatment system. From initial observations, size of GAC filter too small for effective radon removal. No specific units have quoted radon removal rates. Expensive, and complex waste / maintenance issues.
Aeration	Up to >99.9%	Widely used technology but not for this application at this scale – companies are able to design and test systems. A few ready-tested ones available.	Adequate ventilation required.	£1,000 upward. Running costs about £20 p/a.	Can operate without pre-treatment, unless water is very hard and needs softening. Some very good package systems available. Low maintenance – one annual clean recommended. With less disposal issues, no radiation build up and reasonable costs, aeration appears to be the best solution.

With local authority permission, substances up to a radioactivity of 15 Bq/g can be disposed of to landfill with other household waste. The time before the filter reaches this level will depend on activity levels of radon in the raw water and on the retention time in the GAC. Once a GAC filter is taken out of service its radioactivity will fall as the adsorbed radon and other radionuclides decay – it has been shown that after three to four weeks out of service the activity of a GAC unit can be close to background levels[21].

In order to avoid clogging of the filter and to extend its life, it may well be necessary to pre-treat the water. Typically, this would involve a sediment filter and possibly an ion-exchange unit to remove other radionuclides but the treatment required would depend on the levels of other contaminants in the water.

7.1.4 Aeration

Aeration is the preferred treatment for radon removal. In the natural environment this process ensures that most waters coming from springs in radon emitting rocks quickly lose their radon to the atmosphere. The main reason why problems occur with radon in many private supplies is because the water is either abstracted from the rock directly or very soon after. There are many different aeration methods (Section 5.6). With aeration, radon can be easily vented to the outside air. This prevents build up of radiation levels and means there are no disposal issues. As such, the system will, typically, require less maintenance. Depending on the system, there may be a need for a pressure tank or an additional pump.

7.2 Uranium removal

Unlike radon, uranium does not transfer from water to air once inside houses and thus treatment at point-of-use seems more appropriate than treatment at point-of-entry. Point-of-use treatment has the potential advantage that much smaller volumes require treatment. Many methods are available for removing heavy metals from water and as such there is no shortage of possible solutions to a problem with uranium but ion-exchange and reverse osmosis are the only suitable options for private water supplies, the former is normally the preferred method. For ion-exchange, by changing the resin in commercially available water softening equipment it will be possible to easily provide effective treatment systems. Reverse osmosis is also effective. It has the advantage that package point-of-use systems are available that can be used without any modifications. Uranium removal is rarely practised so advice should be sought from professional water treatment equipment suppliers or consultants. Table 7.2 summarises available systems.

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[21] Lowry, J.D. and Brandow, J.E. (1985). Removal of radon from water supplies. *Journal Environmental Engineering* **111**(4), 511-527.

Table 7.2 Uranium removal techniques

Treatment option	Efficiency	Availability	Disposal issues	Approximate cost per household	Other issues
Reverse Osmosis Point-of-use (under sink)	>95%	Package systems available from domestic water treatment suppliers.	Waste stream unlikely to be a problem. There will be a build up over time on the membrane and to some extent on any preceding GAC filter – this should be monitored.	About £500. Running costs about £40 a year.	Pre-treatment for radon removal required. Possibly a need for shielding of the system, due to build-up on the RO membrane. No direct process guarantees from manufacturers. Regular changing of the membranes and any pre-filters would be required.
Reverse osmosis Point-of-entry (whole supply)	>95%	Package systems available from domestic water treatment firms. Also available from medical sector.	As above.	About £2,500, with £200 a year running costs	Possible need for shielding / careful location. Again, no direct process guarantees. Regular filter changes required. Generally, treating far more water than is required.
Ion-exchange Point-of-use (under sink)	>95% (dependent on resin)	Many water softeners available. Suitable resins (to replace those in the softeners) are also available.	Resin can be effectively regenerated, meaning no long term build-up. Regenerant stream should be suitable for disposal (sufficient dilution possible).	From £500, plus resin cost. Low annual running cost (£20?) depending on water usage and type of system.	Well proven and effective system, although no tests done in UK. As such, a testing regime may be of benefit. The type of resin used is very important. Note: Not used as a softener.
Ion-exchange Point-of-entry	>95% (dependent on resin)	As above.	As above.	Similar to above; higher running cost.	As above. Treating far more water than required.

8. QUALITY ASSURANCE OF POINT-OF-USE DEVICES

8.1 General

8.1.1 Background

A series of test protocols has been produced as an aid for anyone with responsibility for the installation or operation of small drinking water systems. The purpose of the protocols is to provide a consistent basis for evaluating and reporting on the claims made for the performance of water treatment units. It is recommended that testing be carried out in laboratories accredited to ISO 9000 or equivalent for testing or calibration that is relevant to the protocols. Each protocol represents a standard of good practice. Compliance with a protocol does not confer immunity from relevant legal requirements.

The protocols were drafted by the Committee on Point of Use Device Test Protocols. This Committee was appointed by the Department of the Environment in 1991 to provide advice to local authorities on water treatment for private water supplies. Production and editing of the protocols was carried out by WRc under the terms of a DOE research contract.

The protocols incorporate existing standards produced by British Water and were developed on the basis of existing copyrighted standards (ANSI/NSF Standards 42, 44, 53, 55, 58 and 62) produced by NSF International. British Water and NSF International played an active rôle in developing the protocols and their contributions and permission to make use of copyright material are gratefully acknowledged.

8.1.2 NSF standards

NSF International is an independent, not-for-profit organisation that works with manufacturers, users and regulators to develop and maintain standards, then tests and evaluates products to their requirements. NSF's Drinking Water Treatment Unit (DWTU) programme has the following standards for point-of-use and point-of-entry treatment technologies:

ANSI/NSF 42: Drinking water treatment units - Aesthetic effects

ANSI/NSF 44: Cation exchange water softeners

ANSI/NSF 53: Drinking water treatment units - Health effects

ANSI/NSF 55: Ultraviolet microbiological water treatment systems

ANSI/NSF 58: Reverse osmosis drinking water treatment systems

ANSI/NSF 62: Drinking water distillation systems

All have basic requirements that products must satisfy in order to be certified to the standard:

- verification of contaminant reduction claims made by the manufacturer or assembler for which certification is requested;
- structural integrity testing of the product;
- toxicological assessment and acceptance of all materials used in the fabrication of the product;
- extraction testing and health effects assessments of all materials in contact with the water to assure the product is not adding any substance of toxicological significance; and
- review and acceptance of all labelling and sales literature used with the product.

All certified products bear the NSF Mark and appear in the listing book and on the internet at www.nsf.org.

8.1.3 The test protocols

The following Sections provide a summary of the principal requirements and testing specified in the protocols. All of the protocols include general requirements relating to the suitability of materials in contact with drinking water. The following summaries cover the performance requirements specified in the protocols. The actual protocols should be consulted regarding the detailed requirements and test methodology. The protocols are available in *Adobe Acrobat* format and can be downloaded from http://www.dwi.detr.gov.uk/regs/protocol/index.htm.

It is recommended that only products that conform to the requirements of the test protocols, or relevant standards of international standing (e.g. NSF standards), should be used for treatment of drinking water.

8.2 Ultraviolet (UV) disinfection units

8.2.1 Performance requirements

Performance indication. Systems shall be equipped with a UV sensor and alarm to monitor UV transmission or intensity through the water during operation.

Disinfection performance. Disinfection performance for a UV system shall provide a minimum UV dose equivalent to 38 000 µW.sec/cm^2 at the fail safe point.

UV alarm performance. The alarm shall operate for at least 100 on-off cycles.

8.2.2 Testing

Challenge water is specified as chlorine-free water spiked with *Bacillus subtilis* spores (5×10^4 to 1×10^5 spores/ml). Sufficient parahydroxybenzoic acid (PHBA) is added to reduce UV light transmission to the fail-safe set point in the device.

A calibration is performed to determine the actual UV sensitivity of the *Bacillus subtilis* challenge used in the performance test method. This is done by using a radiometer to determine the output of a UV lamp (not the unit under study). Then samples of challenge water in petri dishes are irradiated for various time periods to provide a graph of organism survival versus total UV dose which is interpolated to determine the inactivation for a UV dose of 38 000 µW.sec/cm^2.

Testing of flow-through systems is carried out in duplicate using an operating cycle of 50 percent on, 50 percent off with a 15 to 40 minute cycle, 8 hours per day over a 10 day period. Samples of influent and effluent water are collected at specified sampling points. A test method is also given for batch treatment systems. To pass the protocol, the geometric mean of all *B. subtilis* spore counts on influent samples minus the geometric mean of counts on all effluent samples have to demonstrate a reduction of *B. subtilis* equal to or greater than the reduction caused by a dose of 38 000 µW.sec/cm^2.

A UV alarm system performance test is performed to determine that the UV alarm sensor provided with the system will activate 100 consecutive times in response to decreased UV intensity. The dose of PHBA sufficient to activate the alarm system is determined. This dose is then injected into the feed to the unit in order to activate the alarm. This is repeated 100 consecutive times.

8.3 Activated carbon filter units

8.3.1 Performance requirements

Rated capacity. The manufacturer or supplier shall state the activated carbon filter rated capacity. This will be confirmed by conducting contaminant reduction tests. This rated capacity will allow for an over-run of at least 20% (e.g. to achieve a rating of 10 000 litres a unit would have to treat 12 000 litres).

Chemical contaminant reduction. The unit may be classified for chemical contaminant reduction in one of the categories below for each chemical contaminant tested.

Category	Reduction (%)
A	≥90
B	70 to 89
C	50 to 69
No category	<50

Silver leaching. The silver content in treated water samples shall not exceed 80 µg/l.

Microbiological growth potential. The geometric mean of the treated water Total Viable Counts (flowing samples) shall be no greater than five times the geometric mean of the influent TVC. The TVCs in stagnation samples shall be no greater than ten times the geometric mean of the TVCs of the influent samples. There shall be no demonstrable increase in *Pseudomonas aeruginosa* numbers. Samples taken immediately after start-up shall have total and faecal coliform counts not exceeding 0 per 100 ml.

Taste and odour. The flowing sample taken at 120% capacity shall comply with the standards for taste and odour.

8.3.2 Testing

The test conditions, test apparatus and test water quality are specified in detail. Duplicate units are tested and water samples are taken to correspond to treated water volumes of 25, 50, 75, 100 and 120% of the manufacturer's claimed capacity. Plumbed-in units are run with an operating cycle of 10 percent on, 90 percent off, with a 15 to 40 minute cycle (e.g. 3 min on, 27 min off), for not more than 16 hours per day, 7 days per week. Two stagnation periods are imposed: one period of 80 ± 8 hours after 50% capacity and one of 7 to 10 days after 100% of claimed capacity. Surrogate compounds may be used to test removal of PAHs, phenols, surfactants and THMs but for other species individual compounds have to be tested.

A microbiological growth potential test is conducted to determine whether a filter supports microbiological growth. Silver leaching and taste and odour testing are carried out at the same time. The suitability of the test rig has to be determined prior to the test. The basic test procedure is the same as for chemical reduction testing. For each sampling time (e.g. corresponding to 20% of capacity), samples of influent and effluent are taken and analysed .The odour and taste of the 7-day stagnation sample taken at 100% capacity and the flowing sample taken at 120% capacity are determined. Where an activated carbon filter has silver impregnated carbon and/or other silver treated components in contact with the filtered water the treated water is tested to determine the amount of silver being leached.

8.4 Ceramic and cartridge filters

8.4.1 Performance requirements

Mechanical filtration units. Claims for particulate reduction may be made for the classes below provided that at least 85% removal of the specified size rating is achieved.

Class	Rating (µm nominal)
I	0.5 to less than 1
II	1 to less than 5
III	5 to less than 15
IV	15 to less than 30
V	30 to less than 50
VI	50 and up

Bacteriological filtration. Claims for reduction of pathogenic bacteria may be made where filtration efficiency of greater than 99.9% is measured against a particle size of 0.5 to 1.0 µm. Claims for cyst reduction may be made where filtration efficiency of greater than 99.9% is measured against a maximum particle size of 1 to 1.5 µm.

Filter media. All media, which may be subject to blocking, shall be tested to withstand the maximum pressure drop stipulated by the manufacturer.

Bacteriostatic units. The geometric mean of the treated water Total Viable Counts (TVCs) (flowing samples) shall be no greater than five times the geometric mean of the influent TVC. The TVCs in stagnation samples shall be no greater than ten times the geometric mean of the TVCs of the influent samples; and there shall be no demonstrable increase in *Pseudomonas aeruginosa* numbers.

Silver leaching. The silver content in treated water samples shall not exceed 80 µg/l.

Microbiological contamination. Samples taken immediately after start-up shall have total and faecal coliform counts not exceeding 0 per 100 ml.

Pressure drop. The pressure drop across the clean filter cartridge and housing shall not exceed that specified by the manufacturer at the rated service flow.

8.4.2 Testing

The test conditions, test apparatus and test water quality are specified in detail. Duplicate units are tested. Particulate test water is prepared using standard test dusts. Challenge water is fed to the filters and two successive feed and effluent particle counts are determined for each of the two filters under test.

To test the integrity of the filter media, challenge water is pumped through the test filter until the manufacturer's stated maximum pressure drop is achieved. Influent and effluent samples are checked for turbidity and evidence of media in the effluent.

The pressure drop across the unit is determined by measuring the influent and effluent pressures of the unit under flow.

A test is conducted on filters claimed to be bacteriostatic. Silver leaching testing is carried out at the same time. The suitability of the test rig has to be determined prior to the test. Test water is run through the unit using a cycle of 50% on, 50% off with a minimum cycle time of two hours. Samples of influent and effluent are taken after 25, 50, 75, 100 and 120% of the manufacturer's claimed capacity. In addition, the filter units are allowed to stagnate for a period of 80 ± 8 hours at 50% capacity and for a period of 7 to 10 days at 100% capacity.

8.5 *In situ* regenerated ion-exchange nitrate removal units

8.5.1 Performance requirements

Accuracy of the brine system. The brine refill and draw system shall be accurate to within ±5% of the manufacturer's stated figures.

Rated nitrate capacity. The claimed capacity shall be based on the average volume of treated water per pressure vessel produced in three runs between successive regenerations. The treated water nitrite concentration shall be no more than 0.1 mg/l.

Regeneration water volume. The total volume of regeneration water for each pressure vessel shall not exceed 18 bed volumes (BV).

Rinse effectiveness. On completion of a normal regeneration cycle the conductivity of the treated water shall not be more than 20% higher than the conductivity of the mains or test water.

Overrun. When overrun by a factor of twice the rated capacity volume the treated water nitrate level shall not exceed 110% of the influent test water and that the nitrite concentration shall not exceed 0.1 mg/l.

Microbiological contamination. Samples taken immediately after start-up shall have total and faecal coliform counts not exceeding 0 per 100 ml.

Microbiological colonisation. Samples of treated water taken one day before and one day after regeneration shall have total viable counts (22 °C, 72 hour) no greater than 100 times the corresponding influent water counts.

8.5.2 Testing

The test conditions, test apparatus and test water quality are specified in detail. Test water has a nitrate concentration of 150 ±10 mg/l as NO_3, a sulphate concentration of 250 ±10 mg/l as SO_4, and a nitrite concentration <0.01 mg/l as NO_2. The suitability of the test apparatus for bacteriological testing has to be demonstrated prior to the test run. The unit is conditioned over five exhaustion/regeneration cycles prior to testing. At this stage the coliform counts are measured to check for microbiological contamination. The volume of the brine system is measured five times to determine its accuracy.

The rated nitrate capacity is determined by running the unit and determining nitrate concentrations at intervals. The regeneration water volume is measured during these runs. The overrun test is conducted in a similar manner, running the unit to twice the rated nitrate capacity.

Rinse effectiveness is determined by comparing the conductivity of the test water and treated water immediately following regeneration.

To test whether the resin bed becomes colonised by micro-organisms to an unacceptable extent, samples of influent and treated water are taken and Total Viable Count, (22 °C, 72 hours) are determined.

8.6 Reverse osmosis units

8.6.1 Performance requirements

Total Dissolved Solids reduction. Reverse osmosis systems shall reduce the TDS by at least 75%.

Chemical reduction. The system shall reduce the level of contaminant from an influent challenge level of twice the regulated value. The unit may be classified according to the removal achieved, as for activated carbon units (Section 7.3.1).

Product water contamination. Treated water shall be monitored for metals used in the product and the arithmetic mean of all samples and 95% of the individual product water samples shall comply with the regulated concentrations of these metals.

Microbiological growth potential. The geometric mean of the treated water Total Viable Counts shall be no greater than five times the geometric mean of the influent TVC. There shall be no demonstrable increase in *Pseudomonas aeruginosa* numbers.

Microbiological contamination. Samples taken immediately after start-up shall have total and faecal coliform counts not exceeding 0 per 100 ml.

8.6.2 Testing

The test conditions, test apparatus and test water quality are specified in detail. For testing TDS reduction by reverse osmosis membranes a 750 mg/l sodium chloride solution is used (conductivity 1500 µS/cm). For testing nanofiltration membranes a magnesium sulphate solution with a conductivity of 1000 µS/cm is used. The unit is operated continuously and conductivity is measured every five minutes for one hour.

To test chemical reduction, the unit is operated for 7 days against challenge water spiked with contaminants and run continuously. A minimum of 20 samples is taken from the outlet tap and the samples shall be taken at intervals of not less than 3 hours. The concentrations of metals are measured in the permeate during the chemical contaminant reduction tests to check for contamination from metals in contact with treated water.

The suitability of the test apparatus for bacteriological testing has to be demonstrated prior to the test run. The reverse osmosis unit is checked for microbiological contamination by starting the unit up and immediately sampling for total coliforms, faecal coliforms and total viable count (22 °C, 72 h). The test for microbiological contamination is made on at least 20 samples taken at intervals of not less than three hours.

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Chapter 4 is based upon the microbiological risk assessment approach suggested by Lamb *et al.* (1998)[8].

APPENDIX A STANDARDS, INDICATOR PARAMETERS AND MONITORING FOR DRINKING WATER QUALITY

A.1 PRESCRIBED CONCENTRATIONS AND VALUES

A.1.1 Microbiological parameters

A.1.1.1 Part I: Directive requirements

Item	Parameters	Concentration or Value (maximum)	Units of Measurement
1.	Enterococci	0	Number/100ml
2.	Escherichia coli (E. coli)	0	Number/100ml

A.1.1.2 Part II: Additional National requirements

Item	Parameters	Concentration or Value (maximum)	Units of Measurement
1.	Coliform bacteria	0	Number/100ml

A.1.2 Chemical parameters

A.1.2.1 Part I: Directive requirements

Item	Parameters	Concentration or Value (maximum)	Units of Measurement
1.	Acrylamide	0.10	µg/l
2.	Antimony	5.0	µgSb/l
3.	Arsenic	10	µgAs/l
4.	Benzene	1.0	µg/l
5.	Benzo(a)pyrene	0.010	µg/l
6.	Boron	1.0	mgB/l
7.	Bromate	10	µgBrO_3/l
8.	Cadmium	5.0	µgCd/l
9.	Chromium	50	µgCr/l
10.	Copper**(ii)**	2.0	mgCu/l
11.	Cyanide	50	µgCN/l
12.	1, 2 dichloroethane	3.0	µg/l
13.	Epichlorohydrin	0.10	µg/l
14.	Fluoride	1.5	mgF/l
15.	Lead **(ii)**	(a) 25, from 25th December 2003 until immediately before 25th December 2013	µgPb/l
		(b) 10, on and after 25th December 2013	µgPb/l
16.	Mercury	1.0	µgHg/l
17.	Nickel **(ii)**	20	µgNi/l
18.	Nitrate **(iii)**	50	mgNO_3/l
19.	Nitrite **(iii)**	0.50	mgNO_2/l
20.	Pesticides **(iv)(v) -** Aldrin} Dieldrin} Heptachlor} Heptachlor epoxide}	0.030	µg/l
	other pesticides	0.10	µg/l
21.	Pesticides: Total **(vi)**	0.50	µg/l
22.	Polycyclic aromatic hydrocarbons **(vii)**	0.10	µg/l
23.	Selenium	10	µgSe/l
24.	Tetrachloroethene and Trichloroethene **(viii)**	10	µg/l
25.	Trihalomethanes: Total **(ix)**	100	µg/l
26.	Vinyl chloride	0.50	µg/l

Notes:

(i) The parametric value refers to the residual monomer concentration in the water as calculated according to specifications of the maximum release from the corresponding polymer in contact with the water. This is controlled by product specification.

(ii) Method of monitoring determined by the Secretary of State.

(iii) The water must satisfy the formula [nitrate]/50 + [nitrite]/3 ≤ 1, where the square brackets signify the concentrations in mg/l for nitrate (NO_3) and nitrite (NO_2).

(iv) "pesticides and related products" means -

a) any organic insecticide;
b) any organic herbicide;
c) any organic fungicide;
d) any organic nematocide;
e) any organic acaricide;
f) any organic algicide;
g) any organic rodenticide;
h) any organic slimicide, and
i) any product related to any of (a) to (h) (including any growth regulator),

and includes their relevant metabolites, degradation and reaction products;

(v) The parametric value applies to each individual pesticide.

(vi) "Pesticides: Total" means the sum of the concentrations of the individual pesticides detected and quantified in the monitoring procedure.

(vii) The specified compounds are:

- benzo(b)fluoranthene
- benzo(k)fluoranthene
- benzo(ghi)perylene
- indeno(1,2,3-cd)pyrene.

The parametric value applies to the sum of the concentrations of the individual compounds detected and quantified in the monitoring process.

(viii) The parametric value applies to the sum of the concentrations of the individual compounds detected and quantified in the monitoring process.

(viii) The specified compounds are:

- chloroform
- bromoform
- dibromochloromethane
- bromodichloromethane.

The parametric value applies to the sum of the concentrations of the individual compounds detected and quantified in the monitoring process.

A.1.2.2 Part II: National requirements

Item	Parameters	Concentration or Value (maximum unless otherwise stated)	Units of Measurement
1.	Aluminium	200	µgAl/l
2.	Colour	20	mg/l Pt/Co
3.	Hydrogen ion	10.0	pH value
		6.5 (minimum)	pH value
4.	Iron	200	µgFe/l
5.	Manganese	50	µgMn/l
6.	Odour	3 at 25 °C	Dilution number
7.	Sodium	200	mgNa/l
8.	Taste	3 at 25 °C	Dilution number
9.	Tetrachloro-methane	3	µg/l
10.	Turbidity	4	NTU

A.2 INDICATOR PARAMETERS

Item	Parameters	Specification Concentration or Value (maximum) or State	Units of Measurement
1.	Ammonium	0.50	mgNH_4/l
2.	Chloride **(i)**	250	mgCl/l
3.	*Clostridium perfringens* (including spores)	0	Number/100 ml
4.	Coliform bacteria	0	Number/100ml
5.	Colony counts	No abnormal change	Number/1 ml at 22 °C Number/1 ml at 37 °C
6.	Conductivity **(i)**	2500	µS/cm at 20 °C
7.	Sulphate **(i)**	250	mgSO_4/l
8.	Total indicative dose (for radioactivity) **(ii)**	0.10	mSv/year
9.	Total organic carbon (TOC)	No abnormal change	mgC/l
10.	Tritium (for radioactivity)	100	Bq/l
11.	Turbidity	1	NTU

Notes:

(i) The water should not be aggressive.

(ii) Excluding tritium, potassium-40, radon and radon decay products.

A.3 MONITORING

A.3.1 PARAMETERS AND CIRCUMSTANCES FOR CHECK MONITORING

Item	Parameter	Circumstances
1.	Aluminium	When used as flocculant or where the water originates from, or is influenced by, surface waters
2.	Ammonium	
3.	*Clostridium perfringens* (including spores)	Where the water originates from, or is influenced by, surface waters
4.	Coliform bacteria	
5.	Colour	
6.	Conductivity	
7.	*Escherichia coli (E. coli)*	
8.	Hydrogen ion concentration	
9.	Iron	When used as flocculant or where the water originates from, or is influenced by, surface waters
10.	Manganese	Where the water originates from, or is influenced by, surface waters
11	Nitrate	When chloramination is practised
12.	Nitrite	When chloramination is practised
13.	Odour	
14.	Taste	
15.	Turbidity	

A.4 ANALYTICAL METHODOLOGY

A.4.1 Parameters for which methods of analysis are prescribed

Parameter	Method
Clostridium perfringens (including spores)	Membrane filtration followed by anaerobic incubation of the membrane on m-CP agar***** at 44 ± 1 °C for 21 ± 3 hours. Count opaque yellow colonies that turn pink or red after exposure to ammonium hydroxide vapours for 20 to 30 seconds.
Coliform bacteria	ISO 9308-1
Colony count 22 °C – enumeration of culturable microorganisms	PrEN ISO 6222
Colony count 37 °C – enumeration of culturable microorganisms	PrEN ISO 6222
Enterococci	ISO 7899-2
Escherichia coli (E. coli)	ISO 9308-1

*The composition of m-CP agar is:

Basal medium

Tryptose	30.0g
Yeast extract	20.0g
Sucrose	5.0g
L-cysteine hydrochloride	1.0g
$MgSO_4 \cdot 7H_2O$	0.1g
Bromocresol purple	40.0mg
Agar	15.0g
Water	1,000.0ml

Dissolve the ingredients of the basal medium, adjust pH to 7.6 and autoclave at 121° C for 15 minutes. Allow the medium to cool and add:

D-cycloserine	400.0mg
Polymyxine-B sulphate	25.0mg
Indoxyl-β-D-glucoside to be dissolved in 8ml sterile water before addition	60.0mg
Filter - sterilised 0.5% phenolphthalein diphosphate solution	20.0ml
Filter - sterilised 4.5% $FeCl_3 \cdot 6H_2O$	2.0ml

A.4.2 Parameters in relation to which methods of analysis must satisfy prescribed characteristics

Parameters	Trueness % of prescribed concentration or value or specification	Precision % of prescribed concentration or value or specification	Limit of detection % of prescribed concentration or value or specification
Aluminium	10	10	10
Ammonium	10	10	10
Antimony	25	25	25
Arsenic	10	10	10
Benzene	25	25	25
Benzo(a)pyrene	25	25	25
Boron	10	10	10
Bromate	25	25	25
Cadmium	10	10	10
Chloride	10	10	10
Chromium	10	10	10
Colour	10	10	10
Conductivity	10	10	10
Copper	10	10	10
Cyanide**(i)**	10	10	10
1,2-dichloroethane	25	25	10
Fluoride	10	10	10
Iron	10	10	10
Lead	10	10	10
Manganese	10	10	10
Mercury	20	10	20
Nickel	10	10	10
Nitrate	10	10	10
Nitrite	10	10	10
Pesticides and related products **(ii)**	25	25	25
Polycyclic aromatic hydrocarbons**(iii)**	25	25	25
Selenium	10	10	10
Sodium	10	10	10
Sulphate	10	10	10
Tetrachloroethene**(iv)**	25	25	10
Tetrachloromethane	20	20	20
Trichloroethene**(iv)**	25	25	10
Trihalomethanes: Total**(iii)**	25	25	10
Turbidity **(v)**	10	10	10
Turbidity **(vi)**	25	25	25

Notes:

(i) The method of analysis should determine total cyanide in all forms.

(ii) The performance characteristics apply to each individual pesticide and will depend on the pesticide concerned.

(iii) The performance characteristics apply to the individual substances specified at 25% of the parametric value.

(iv) The performance characteristics apply to the individual substances specified at 50% of the parametric value.

(v) The performance characteristics apply to the prescribed value of 4 NTU.

(vi) The performance characteristics apply to the specification of 1 NTU for water leaving treatment works.

APPENDIX B KEY ORGANISATIONS IN THE UK

Advice regarding private water supplies in England, Wales and Scotland should be addressed in the first instance to the appropriate local authority Environmental Health Department. In Northern Ireland advice should be sought from the Northern Ireland Environment and Heritage Service Drinking Water Inspectorate.

The following organisations may be able to provide more general information, advice and services. Enquiries about specific water treatment technology should be made to British Water or the Society of British Water Industries. Analysis of water samples should be undertaken by suitably accredited laboratories (e.g. ISO 9000) – local authorities or water undertakers can provide further advice.

ADAS Gleadthorpe
The Grange
Meden Vale
Mansfield
Nottinghamshire
NG20 9PD
Tel: 01623 846742
http://www.adas.co.uk

British Geoglogical Survey
Hydrogeological Enquiries Service
Maclean Building
Crowmarsh Gifford
Wallingford
Oxfordshire
OX10 8BB
Tel: 01491 838800
http://www.bgs.ac.uk/enquiries/hydro.html

British Water
1 Queen Anne's Gate
London
SW1H 9BT
Tel: 020 7957 4554
http://www.britishwater.org

Chartered Institute of Environmental Health
Chadwick Court
15 Hatfields
London
SE1 8DJ
Tel: 020 7928 6006
http://www.cieh.org.uk

Drinking Water Inspectorate
Floor 2/A1
Ashdown House
Victoria Street
London
SW1E 6DE
Tel: 020 7944 5956
http://www.dwi.detr.gov.uk/index.htm

Environment Agency
National Library and Information Service
Block 1, Government Buildings
Burghill Road
Westbury on Trym
Bristol
BS10 6BF

Tel: 0117 914 2768

http://www.environment-agency.gov.uk

National Radiological Protection Board
Chilton
Didcot
Oxfordshire
OX11 0RQ

Tel: 01235 831600

http://www.nrpb.org.uk

National Assembly for Wales
Cardiff Bay
Cardiff
CF99 1NA

Tel: 029 20 825111

http://www.wales.gov.uk

Northern Ireland Environment and Heritage Service
Drinking Water Inspectorate
Calvert House
23 Castle Place
Belfast
BT1 1FY

Tel: 028 9025 4750

http://www.ehsni.gov.uk

Royal Environmental Health Institute of Scotland
3 Manor Place
Edinburgh
EH3 7DH

Tel: 0131 225 6999

http://www.royal-environmental-health.org.uk

Scottish Environment Protection Agency
Erskine Court
Castle Business Park
Stirling
FK9 4TR

Tel: 01786 457700

http://www.sepa.org.uk

Scottish Executive
Victoria Quay
Edinburgh
EH6 6QQ

Tel: 0131 244 0763

http://www.scotland.gov.uk

Society of British Water Industries
38 Holly Walk
Leamington Spa
CV32 4LY

Tel: 01926 831530

http://www.sbwi.co.uk

Water Regulations Advisory Scheme
Fern Close
Pen-y-Fan Industrial Estate
Oakdale
Gwent
NP1 4EH

Tel: 01495 248454

http://www.wras.co.uk

WRc-NSF Ltd
Henley Road
Medmenham
Marlow
Buckinghamshire
SL7 2HD

Tel: 01491 636500

http://www.wrcnsf.com

APPENDIX C FURTHER READING

Brassington, R. (1995). *Finding water – A guide to the construction and maintenance of private water supplies*, 2nd Edition. John Wiley and Sons Ltd., ISBN 047 1957 119.

Cryptosporidium in water supplies. Available from Drinking Water Inspectorate (see Appendix B) or http://www.dwi.detr.gov.uk/pubs/bouchier/index.htm.

Hall, T. and Hyde, R.A. (Eds.) (1997). Water Treatment Processes and Practices, 2nd Edition, WRc, ISBN 1 898920 32 X.

HMSO (1989). *Guidance on safeguarding the quality of public water supplies*, Department of the Environment and Welsh Office.

HMSO (1994). *The microbiology of water 1994 Part 1 - drinking water*. Report on Public Health and Medical Subjects No. 71, Methods for the Examination of Waters and Associated Materials.

List of products and processes approved under Regulations 25 and 26 for use in connection with the supply of water for drinking, washing, cooking and food production purposes. Available from the Drinking Water Inspectorate (see Appendix B) or http://www.dwi.detr.gov.uk/regs/soslist/index.htm.

Mays, G. and Young, L. (2001). *Water regulations guide*. Published by WRAS (see Appendix B).

Private Water Supplies, Joint circular from Department of the Environment (Circular 24/91) and Welsh Office (Circular 68/91). For Scotland, the Private Water Supplies Guidance Circular 20/1992.

Scottish Office (1990). *Guidance on safeguarding the quality of public water supplies in Scotland*.

Twort, A.C., Ratnayaka, D.D. and Brandt, M.J. (2000). *Water supply*, 5th Edition. John Butterworth-Heinemann, ISBN 034 072 0182.

Warden, J.H. (Ed.) (1989). *Disinfection of rural and small-community water supplies. A manual for design and operation*, World Health Organization, published by WRc.

Water Quality Association[22] – a range of publications on water treatment.

WRAS *Water fittings and materials directory*. Published twice yearly (see Appendix B).

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[22] WQA, 4151 Naperville Road, Lisle, Illinois 60532-1088, USA. http://www.wqa.org.

B). ISSN 0954-3643.

APPENDIX D GLOSSARY OF TECHNICAL TERMS

The following is a list of working definitions of technical terms used in this manual. To aid comprehension, the definitions have been expressed in relatively simple terms, and as such are not necessarily scientifically exact.

Absorption	The process by which one substance is taken into the body of another substance, called the absorbent. An example is the absorption of water into soil.
Acid	A substance which in solution produces hydrogen ions (H^+), the concentration of which is expressed in terms of pH units.
Acidic	Having a pH value less than 7.
Acidity	A measure of the capacity of a solution to neutralise alkali.
Activated carbon	A family of carbonaceous substances manufactured by processes that develop adsorptive properties. Sometimes called ‘activated charcoal’.
Adsorption	The process by which one substance is taken onto the surface of another substance by physical and/or chemical forces.
Aeration	The vigorous exposure of water to a stream of air bubbles. This process may increase pH by stripping carbon dioxide, remove odour-producing compounds and will increase the dissolved oxygen concentration to facilitate oxidation reactions (e.g. oxidation of iron).
Algae	Microscopic planktonic plant forms which occur in unicellular, colonial or filamentous forms. Substantial growths (‘blooms’) may be observed in nutrient-rich waters during the summer.
Alkali	Any highly basic substance, for example, hydroxides and carbonates of alkali metals such as sodium and potassium. See base.
Alkaline	Having a pH value greater than 7.
Alkalinity	A measure of the capacity of a solution to neutralise acid. Note that there is a distinction between ‘alkaline’ and ‘alkalinity’ – e.g. a water of acid pH (i.e. not alkaline) may contain amounts of carbonate/bicarbonate which result in a degree of alkalinity.
Anoxic	Water depleted of dissolved oxygen.
Aquifer	A porous rock which holds and transmits water.

Bacteria	Unicellular micro-organisms that typically reproduce by cell division. Many bacteria are disease-producing.
Baffle	A slat, plate or plank used in a tank to alter the flow of water in order to avoid short-circuiting, e.g. in a chlorine contact tank. NB. in other contexts, baffles can be used to promote mixing.
Base	Any chemical species capable of reacting with hydrogen ions. See alkali.
Base exchange	A softening process using cation exchange resin to replace calcium and magnesium ions in the water with sodium ions.
Breakpoint chlorination	A method of chlorination in which a sufficient dose of chlorine is added to rapidly oxidise all of the ammonia in the water and leave a free chlorine residual.
Buffering capacity	The capacity of a water to resist pH change. This is closely related to alkalinity.
Chloramines	Compounds formed from the reaction of chlorine with ammonia, successively replacing hydrogen atoms with chlorine atoms to produce monochloramine and dichloramine (and nitrogen trichloride if the pH is low and the chlorine:ammonia ratio is very high). Chloramines are less efficient disinfectants than chlorine itself but are more persistent.
Chlorination	A process for disinfection of water using chlorine, sodium hypochlorite or calcium hypochlorite.
Chlorine	A gas (Cl_2) widely used in disinfection and oxidation processes.
Coagulation	A process for turbidity and colour removal in which a coagulant (typically aluminium sulphate or ferric sulphate) is added to the water, causing colloidal turbidity-causing material and dissolved coloured substances to agglomerate into a precipitate (‘floc’) which is subsequently removed e.g. by sedimentation and/or filtration.
Coliform bacteria	A group of bacteria found in vast numbers in human excreta. Their presence in water is an indication of potential faecal contamination; consequently they are used as indicator organisms. See Escherichia coli.
Colloid	A state of matter consisting of very finely divided (less than 1 micrometer) particles suspended in a fluid, e.g. water. Although the particles are not dissolved they are too small to settle at any meaningful rate.

Colour	The shade or tint imparted to water, typically by organic substances in solution.
Combined available chlorine	The total concentration of chloramines and any organic nitrogen chlorine containing compounds. Combined chlorine is a less effective disinfectant than free chlorine.
Contaminant	Any undesirable physical, chemical, or microbiological substance in water.
Cryptosporidium	A protozoan parasite which causes acute diarrhoeal disease in humans. The organism can be transmitted by contaminated water; both surface and groundwaters may be contaminated by the cyst stage of *Cryptosporidium*, known as oocysts.
Cyst	A capsule associated with a dormant stage of reproduction in micro-organisms. See oocyst.
Denitrification	The reduction of nitrate to nitrogen gas. Biological denitrification is a process in which reduction is brought about by naturally occurring bacteria.
Desalination	The removal of dissolved salts (mainly sodium chloride) from sea water or brackish water to render it potable.
Disinfection	The removal, destruction or inactivation of pathogenic organisms in water.
Escherichia coli	The most abundant coliform organism present in the human and animal gut. The presence of *E. coli* in a water sample indicates potentially dangerous contamination of human or animal origin – see also coliform bacteria and indicator organism.
Filter	A unit for carrying out the process of filtration which consists of a combination of filter medium and a suitable holder for constraining and supporting the medium in the path of the water.
Filtration	The passage of water containing particles through a filter to effect a separation of particles from the water.
Flocculation	A term often used interchangeably with coagulation, it refers to the process by which particles are agglomerated to form flocs (see coagulation).
Flotation	A process for separating flocs from water. A recycled side-stream of water saturated with air under pressure is injected into the water. Microscopic air bubbles form at the point of injection, attach to the flocs and cause them to float to the surface where the accumulated solids can be removed e.g. by scrapers.

Free available chlorine	The total concentration of free chlorine, hypochlorous acid and hypochlorite ion in water.
Gravel filter	A coarse filter for rapid filtration, consisting of a bed of gravel graded from coarse at the inlet to fine at the outlet.
Hardness	Water hardness is caused by dissolved salts such as those of calcium and magnesium. Hard waters are associated with scale formation and increased use of soap; conversely soft waters are often acidic and corrosive. See total, permanent and temporary hardness.
Hazen units (°H)	An arbitrary unit for expressing the colour of water; it can be represented as the platinum-cobalt (Pt-Co) scale in which colour is expressed in mg/l Pt.
Hypochlorite	The hypochlorite ion (OCl^-) is one of the ionic species formed when chlorine is added to water. The term ‘hypochlorite’ is also used to refer to sodium hypochlorite, another chemical used for chlorination.
Hypochlorous acid	Hypochlorous acid ($HOCl$) is one of the species formed when chlorine is added to water.
Indicator organism	It would be futile and impractical to screen water samples for all possible pathogenic organisms. *Escherichia coli* and other coliform bacteria are therefore monitored as indicator organisms; their presence in a water sample would be indicative of faecal contamination and the potential presence of pathogenic organisms in water.
Ion	An atom or group of combined atoms which has lost (or gained) one or more electrons to become a positively charged cation (or negatively charged anion).
Ion-exchange	A process in which ions of like charge are exchanged between the water phase and the solid resin phase.
Ion-exchange resin	A synthetic organic ion-exchange material, used for example in ion-exchange softeners and nitrate removal units. Typical resins are in the form of small beads.
Marginal (simple) chlorination	The usual chlorination technique employed for small supplies of high quality. It is simply the dosing of sufficient chlorine to produce a suitable free chlorine residual.
Membrane	A semi-permeable barrier that allows passage of water but not dissolved substances. Commonly used membranes are made of cellulose acetate and polyamides.

Microfiltration	A pressure-driven membrane process using a membrane with pore size in the range 0.05 to 2 µm to separate suspended and colloidal material.
Microgram per litre (µg/l)	A unit of concentration used in reporting analytical results at trace levels. For practical purposes it is the same as ppb (parts per billion). Note: 1000 µg/l = 1 mg/l.
Micrometre (µm)	A linear measure equal to one millionth of a metre; also called a micron (µ).
Microstrainer	A type of filter for removing mineral and biological solids, consisting of a rotating drum fitted with fine mesh panels. Water washing is used to remove accumulated debris.
Milligram per litre (mg/l)	A unit of concentration used in reporting analytical results. For practical purposes it is the same as ppm (parts per million).
Molecule	The smallest particle into which a compound may be divided and still retain the essential composition and properties of that compound. Molecules are composed of the atoms of individual elements.
Nanofiltration	A pressure-driven process using a membrane with properties intermediate between reverse osmosis and ultra-filtration membranes. Nanofiltration membranes allow monovalent ions (e.g. sodium) to pass but selectively remove divalent ions (e.g. calcium).
Nephelometer	An instrument used to measure turbidity of water. A nephelometer measures the amount of light scattered by suspended particles.
Nitrification	The oxidation of ammonia to nitrite and nitrate. Biological nitrification is a process in which the oxidation is brought about by naturally occurring bacteria.
NTU	Nephelometric Turbidity Unit. An arbitrary unit for expressing turbidity measured using a nephelometer. Also commonly used, closely related and practically numerically equivalent are Formazin Turbidity Unit (FTU) and Jackson Turbidity Unit (JTU).
Oocyst	The dormant encysted form of a protozoan parasite such as *Cryptosporidium*. The oocyst is the environmentally stable, infective, form of the parasite.
Oxidation	A chemical reaction in which the oxygen content of a compound is increased or in which a compound or ion loses electrons, thereby increasing its positive valency state (e.g. oxidation of ferrous to ferric iron).

Ozonation	A process used for oxidation and disinfection using ozone.
Ozone	A gas (O_3) used as an oxidant and disinfectant in water treatment. Ozone is generated at the point-of-use using an ozoniser that employs high voltage electrical discharge through air or oxygen to produce ozone at a concentration of a few percent in the feed gas.
Pathogen	A disease causing organism.
Peak demand	The maximum momentary load (maximum water flowrate) placed on a water supply system. Domestic peak demand can be as great as 3 times the average daily demand.
Permanent hardness	Hardness which is not precipitated by boiling. It is due to the presence of the chlorides and sulphates of calcium and magnesium.
pH value	A logarithmic measure of acid or alkaline nature. pH 7 is neutral, acid solutions have a pH less than 7, alkaline more than 7. Each successive pH unit represents a tenfold change in acid or alkaline nature.
Plumbosolvency	The contamination of water by lead resulting from dissolution of corrosion products from lead pipes and lead-containing solders or fittings.
Point-of-entry	A term referring to the treatment of the entire supply of water delivered to or entering buildings or properties.
Point-of-use	A term referring to treatment of water for drinking at the point-of-use or immediately prior to the point of delivery, i.e. typically at the kitchen tap, using for example a plumbed-in unit or system.
Pressure filter	A type of filter consisting of graded sand layers contained within a closed steel vessel, through which water is passed under pressure.
Private water supply	Any water supply which is not provided by a statutory water undertaker.
Protozoa	Animal or vegetable organisms that consist of a single cell and which reproduce by fission. Most are microscopic, aquatic, and some are parasites.
Rapid sand filter	Otherwise known as a rapid gravity filter, this consists of a bed of sand or other filtration medium contained in a concrete or steel vessel, through which water passes downwards by gravity.
Reverse osmosis	A pressure-driven membrane process using a membrane with pore size below 0.002 µm to remove dissolved salts and organic compounds.

Sedimentation	A process for removing suspended solids by passing water slowly and evenly through a lagoon, channel or tank to allow sediment to settle. Many different types of sedimentation system exist. Accumulated solids are removed periodically by appropriate mechanical or manual means.
Slow sand filter	This consists of a layer of fine sand supported by a layer of gravel with a system of underdrains. Water is passed downwards at a low flowrate and solids accumulate at the sand surface, forming a biologically-active layer. Impurities are removed both by physical straining and biological action.
Softening	Reduction of hardness (calcium and magnesium) by precipitation (lime or lime-soda softening) or ion-exchange (base exchange softening). Water conditioners which dose polyphosphates modify the hardness compounds, preventing them from precipitating and forming scale, but do not actually soften the water in the sense of removing calcium and magnesium.
Superchlorination/ dechlorination	A chlorination process involving the addition of a large dose of chlorine to effect rapid disinfection and chemical reaction. This is followed by a dechlorination stage using e.g. sulphur dioxide or sodium bisulphite to reduce the excess free chlorine residual.
Temporary hardness	Hardness which is precipitated by boiling. It is due to the presence of calcium and magnesium bicarbonate.
Total hardness	A measure of the total amount of calcium and magnesium in solution. Total hardness is equal to the sum of permanent and temporary hardness.
Trihalomethanes	A group of organic chemicals, including chloroform, which are formed in low concentrations during chlorination of waters containing natural organic compounds, such as the coloured humic and fulvic acids.
Turbidity	An optical property of water resulting from the scattering of light by suspended and colloidal particles. Turbidity is determined using a nephelometer and the results give a measure of the amount of particulate matter present.
Ultraviolet (UV) irradiation	A disinfection process using a mercury discharge lamp to irradiate the water, contained in a suitable chamber, with UV-C radiation in order to inactivate micro-organisms.
Virus	A sub-microscopic infective agent which may be a living organism or a complex protein capable of living in cells. Viruses cause a number of diseases in animals and plants.

APPENDIX E RISK ASSESSMENT FORMS

INSTRUCTIONS

The sections below relate to the supply under investigation. Complete the appropriate questions as fully as possible to estimate the risk for the supply. Most of the questions will require information from the person responsible for the supply, who should, if possible, be present during the evaluation. Once the appropriate section is completed, identify the overall risk assessment for the supply at the bottom of this page.

E.1 SUPPLY DETAILS

1. Supply category
2. Address of supply (include telephone number if available)

   Telephone number:

3. Name of person responsible for supply
4. Address of responsible person (if different from above)

5. Map grid reference for supply location (OS 6-figure)
6. Sketch or plan of supply

Overall Risk Score for Water Supply: Low / Medium / High

E.2 WELLS

Source survey

Are any of the following known to be present at the source?		**Yes**	**No**	**Not known**
7	Stock-proof fence at a minimum of 4 metres around the source			
8	Concrete apron, a minimum of 1200 mm, sloping away from the well and in good repair			
9	Reinforced pre-cast concrete cover slab in satisfactory condition			
10	Are any junctions present in the supply network, particularly to supply animal watering systems			
11	Is the top of the well 150 mm above the apron described in [8]			
12	A watertight, vermin-proof inspection cover present with or without ventilation			
13	Is the well construction in a satisfactory state of repair			
14	Is the supply network constructed from material liable to fracture, e.g. asbestos-concrete, clay etc.			
15	Is the well cleaned as part of a routine maintenance programme			
16	Is the well flushed with disinfectant as part of a routine maintenance programme			
17	Is there a header tank with vermin-proof cover within the property or properties supplied by the source			

If any answers 7–10 are No or Not Known then assign High Risk

If any answers 11–14 are No or Not Known then assign Medium Risk

If any answers 15–17 are No or Not Known then assign Low Risk

If all answers 7–17 are Yes then assign Low Risk

General site survey

Are any of the following known to be present within 50 metres of the source?		**Yes**	**No**	**Not known**
15	Unsewered human sanitation including septic tanks, pit latrines, soakaways			
16	Sewage pipes, mains or domestic (e.g. leading to or from septic tank)			
17	Sewage effluent lagoons			
18	Sewage effluent discharge to adjacent watercourse (where present)			
19	Landfill site or rubbish tip			
20	Soil cultivation with wastewater irrigation or sludge or slurry application			
21	Remediation of land using sludge or slurry			
22	Evidence or history of poor drainage causing stagnant or standing water (within 2 metres of well)			
23	History of livestock (including poultry) production (rearing, housing, grazing)			

Are any of the following known to be present within 250 metres of the source?		**Yes**	**No**	**Not known**
24	Supplies or wells not in current use			
25	Disposal sites for animal remains			
26	Disposal of slaughter waste to land			

If any answers 15–26 are Yes or Not Known then assign High Risk

If all answers 15–26 are No then assign Low Risk

Risk assessment

Mark the appropriate box for each section of the survey. Assign the overall risk as the highest level of risk found and apply to the whole supply – e.g. if Source Survey is Medium Risk and General Site Survey is High Risk, the overall assessment is High Risk.

	High	Medium	Low
Source survey			
General site survey			
Overall risk			

E.3 BOREHOLES WITH HEADWORKS LOCATED BELOW GROUND

Source survey

Are any of the following known to be present at the headworks site?		**Yes**	**No**	**Not known**
27	Chamber watertight below ground level			
28	Borehole lining at least 150 mm above floor level			
29	Watertight lining cap			
30	Watertight, vermin-proof inspection cover with or without ventilation			
31	Walls of chamber at least 150 mm above ground level			

If any answers 27–29 are No or Not Known then assign High Risk

If any answers 30–31 are No or Not Known then assign Medium Risk

If all answers 27–31 are Yes then assign Low Risk

General site survey

Are any of the following known to be present within 50 metres of the source?		**Yes**	**No**	**Not known**
32	Unsewered human sanitation including septic tanks, pit latrines, soakaways			
33	Sewage pipes, mains or domestic (e.g. leading to or from septic tank)			
34	Sewage effluent lagoons			
35	Sewage effluent discharge to adjacent watercourse (where present)			
36	Landfill site or rubbish tip			
37	Soil cultivation with wastewater irrigation or sludge or slurry application			
38	Remediation of land using sludge or slurry			
39	History of livestock (including poultry) production (rearing, housing, grazing)			

Are any of the following known to be present within 250 metres of the source?		**Yes**	**No**	**Not known**
40	Supplies or wells not in current use			
41	Disposal sites for animal remains			
42	Disposal of slaughter waste to land			

If any answers 32–42 are Yes or Not Known then assign High Risk

If all answers 32–42 are No then assign Low Risk

Risk assessment

Mark the appropriate box for each section of the survey. Assign the overall risk as the highest level of risk found and apply to the whole supply – e.g. if Source Survey is Medium Risk and General Site Survey is High Risk, the overall assessment is High Risk.

	High	Medium	Low
Source survey			
General site survey			
Overall risk			

E.4 BOREHOLES WITH HEADWORKS LOCATED ABOVE GROUND

Source survey

Are any of the following known to be present at the headworks site?		**Yes**	**No**	**Not known**
43	Watertight, vermin-proof, secure housing covering headworks installation			
44	Borehole lining at least 150 mm above floor level			
45	Concrete apron sloping away from borehole lining for a minimum distance of 1200 mm			
46	Lining cap with appropriately sized holes for pipe, cable and air vent			

If any answers 43–44 are No or Not Known then assign High Risk

If any answers 45–46 are No or Not Known then assign Medium Risk

If all answers 43–46 are Yes then assign Low Risk

General site survey

Are any of the following known to be present within 50 metres of the source?		**Yes**	**No**	**Not known**
47	Unsewered human sanitation including septic tanks, pit latrines, soakaways			
48	Sewage pipes, mains or domestic (e.g. leading to or from septic tank)			
49	Sewage effluent lagoons			
50	Sewage effluent discharge to adjacent watercourse (where present)			
51	Landfill site or rubbish tip			
52	Soil cultivation with wastewater irrigation or sludge or slurry application			
53	Remediation of land using sludge or slurry			
54	History of livestock (including poultry) production (rearing, housing, grazing)			

Are any of the following known to be present within 250 metres of the source?		**Yes**	**No**	**Not known**
55	Supplies or wells not in current use			
56	Disposal sites for animal remains			
57	Disposal of slaughter waste to land			

If any answers 47–57 are Yes or Not Known then assign High Risk

If all answers 47–57 are No then assign Low Risk

Risk assessment

Mark the appropriate box for each section of the survey. Assign the overall risk as the highest level of risk found and apply to the whole supply – e.g. if Source Survey is Medium Risk and General Site Survey is High Risk, the overall assessment is High Risk.

	High	Medium	Low
Source survey			
General site survey			
Overall risk			

E.5 SPRINGS

Source survey

Are any of the following known to be present at the source?		**Yes**	**No**	**Not known**
58	Stock-proof fence at a minimum of 4 metres around the source			
59	Cut-off ditch adjacent to fence and complete around site			
60	Vermin-proof overflow pipe			
61	Watertight, vermin-proof inspection cover with or without ventilation			

If any answers 58–60 are No or Not Known then assign High Risk

If answer 61 is No or Not Known then assign Medium Risk

If all answers 58–61 are Yes then assign Low Risk

General site survey

Are any of the following known to be present within 50 metres of the source?		**Yes**	**No**	**Not known**
62	Unsewered human sanitation including septic tanks, pit latrines, soakaways			
63	Sewage pipes, mains or domestic (e.g. leading to or from septic tank)			
64	Sewage effluent lagoons			
65	Sewage effluent discharge to adjacent watercourse (where present)			
66	Landfill site or rubbish tip			
67	Soil cultivation with wastewater irrigation or sludge or slurry application			
68	Remediation of land using sludge or slurry			
69	History of livestock (including poultry) production (rearing, housing, grazing)			

Are any of the following known to be present within 250 metres of the source?		**Yes**	**No**	**Not known**
70	Supplies or wells not in current use			
71	Disposal sites for animal remains			
72	Disposal of slaughter waste to land			

If any answers 62–72 are Yes or Not Known then assign High Risk

If all answers 62–72 are No then assign Low Risk

Risk assessment

Mark the appropriate box for each section of the survey. Assign the overall risk as the highest level of risk found and apply to the whole supply – e.g. if Source Survey is Medium Risk and General Site Survey is High Risk, the overall assessment is High Risk.

	High	Medium	Low
Source survey			
General site survey			
Overall risk			

E.6 SURFACE-DERIVED SOURCES

Surface-derived sources are automatically classified as High Risk.

If a source survey is conducted, the following should be included:

Are any of the following known to be present at the source?		**Yes**	**No**	**Not known**
73	Stock-proof fence at a minimum of 4 metres around the source			
74	Overflow or washout pipe fitted with vermin proof cap			
75	Coarse filter or screen on inlet pipe			
76	Watertight, vermin-proof inspection cover with or without ventilation			

E.7 UNCLASSIFIED SOURCES

If the type of supply cannot be established, the overall assessment is High Risk.