

Chapter 2

INTRODUCING PARAMETERS FOR THE ASSESSMENT OF DRINKING WATER QUALITY

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Note: Inspiration and some text from World Health Organization (WHO) Guidelines (WHO, 1996; 1997) have been used for the preparation of this chapter.

2.1 Introduction

Chapter 1 introduced the index and indicator concept and outlined a number of microorganisms (and groups of microorganisms) that have been adopted in the quest to determine whether or not drinking water is microbiologically safe to drink. This chapter examines the range of both microbial and non-microbial parameters and briefly outlines their uses and applications. It is intended to act as an introduction to the parameters that can be used to assess drinking water quality and further details on their use in specific areas can be found in subsequent chapters.

The early impetus behind the bacteriological examination of drinking water was to determine whether water as consumed was contaminated. Much water consumed received no treatment and such treatment as was applied was mainly intended to improve aesthetic quality. At that time what was required was what is now referred to as an Index organism, although the term Indicator was generally applied. It has since been recognised that microbial parameters can provide useful information throughout the drinking water production process, including catchment survey, source water characterisation, treatment efficiency and examination of the distribution system. Adopting the index and indicator terminology as advocated by Waite (1991) and briefly outlined in Chapter 1, index organisms can give a measure of the amount of faecal pollution in a water source, whereas indicator parameters may be used to give

information on the effectiveness with which specific groups of microorganisms have been removed or inactivated by treatment processes, with their presence after treatment indicating that pathogens may still be present. For example, the presence of spores of sulphite-reducing clostridia or bacteriophages in treated drinking water suggests that highly persistent microorganisms may have survived, while colony counts of aerobic heterotrophic bacteria or direct microscopic counts can provide information on the availability of nutrients in the water, which may result in aesthetic problems or in the presence of opportunistic pathogens.

Although many waterborne pathogens can now be detected (and, indeed, a number are outlined in this chapter) the methods for their detection are often difficult to implement, relatively expensive, and time-consuming. Furthermore, the original logic behind the indicator (now index) concept still holds true, in that a range of pathogens may be shed into water from the faecal matter of infected people and animals, and there are enteric pathogens as yet unrecognised. As such, it is neither practicable nor recommended to examine water for every known pathogen that might be present. Examination of finished waters for pathogens will only permit confirmation that consumers have been exposed to the pathogens whereas examination for non-pathogenic organisms as an index of faecal pollution or an indicator of adequacy of treatment permits recognition of the potential for pathogens to be present without the need for their actual presence. This chapter describes the index/indicator parameters and highlights those that are best suited to a range of purposes (which are explored further in subsequent chapters), with the main thrust being towards minimising faecal-oral disease transmission.

2.2 Microbial parameters

This section outlines microbial parameters used to assess drinking water quality, examining the most appropriate uses, ease of analysis and some of the implications and responses relating to finding a positive sample. Characteristics such as speed of measurement, technical difficulty of the assay, microbial environmental survival and resistance to treatment are summarised at the end of the Section in Table 2.1, while Table 2.2 summarises the applicability and suitability of each parameter for assessing source water, treatment efficiency and so on.

A number of documents contain detailed information on taking samples for analysis of microbial parameters and their storage and transportation (WHO, 1997; Anon, 1994; APHA, AWWA, WEF, 1998), however, there are several key points that are summarised below:

- Care should be taken that the samples are representative of the water examined. This has implications in terms of the location and construction of the sampling points, the frequency of sampling and also the aseptic technique employed by the sampler.
- If the sample contains disinfectant (such as chlorine, chloramine, chlorine dioxide or ozone) sterile sodium thiosulphate should be included in the sample container in order to neutralise any residual. The concentration of the residual disinfectant and the pH at the sampling point should be determined at the time of collection.
- In order to minimise changes in the microbial content, samples should not be exposed to light and should be rapidly cooled to between 4-10°C. WHO and UNEP recommend that if samples can not be cooled they should be examined within two hours of sampling (Bartram and Ballance, 1996). Examination of cooled samples should begin as soon as possible after collection, ideally within six hours, with 24 hours being considered the absolute maximum (WHO, 1997; Bartram and Ballance, 1996).

Further details on sampling can be found in Chapter 6.

Internationally accepted methods of analysis for the microbial parameters discussed in this chapter can be found in a number of sources, including Anon (1994) and APHA, AWWA, WEF (1998). The International Organization for Standardization (ISO) also prepares and publishes methods (see Chapter 8).

Most of the microbial parameters discussed below are common in the environment and can easily be introduced in the course of sampling or analysis. It is therefore advisable to be cautious in the response to their detection in a single sample of treated water in the absence of supporting factors such as treatment problems, risks pointing to recontamination in distribution or lack of residual chlorine. Their detection in the presence of supporting factors, in associated samples, or on re-sampling, however should be taken as strong evidence that the quality of the water in supply has been compromised.

2.2.1 The coliform group

The coliform group is made up of bacteria with defined biochemical and growth characteristics that are used to identify bacteria that are more or less related to faecal contaminants. The total coliforms represent the whole group, and are bacteria that multiply at 37°C. The thermotolerant coliforms are bacteria that can grow at a higher temperature (44.2°C) and *Escherichia coli* is a thermotolerant species that is specifically of faecal origin.

A finding of any coliform bacteria, whether thermotolerant or not, in water leaving the treatment works requires immediate investigation and corrective action. There is no difference in the significance of total coliforms, thermotolerant coliforms and *E. coli* in water leaving a treatment works, as they all indicate inadequate treatment, and action should not be delayed pending the determination of which type of coliform has been detected. Upon detection in a distribution system, investigations must be initiated immediately to discover the source of the contamination.

Total coliforms: Coliform organisms, better referred to as total coliforms to avoid confusion with others in the group, are not an index of faecal pollution or of health risk, but can provide basic information on source water quality. Total coliforms have long been utilised as a microbial measure of drinking water quality, largely because they are easy to detect and enumerate in water.

They have traditionally been defined by reference to the method used for the group's enumeration and hence there have been many variations dependent on the method of culture. In general, definitions have been based around the following characteristics: Gram-negative, non-spore-forming rod-shaped bacteria capable of growth in the presence of bile salts or other surface-active agents with similar growth-inhibiting properties, oxidase-negative, fermenting lactose at 35-37°C with the production of acid, gas, and aldehyde within 24-48 hours. These definitions presume the use of cultural methods for identification and enumeration. There has recently been a move towards a genotypic definition based on the recognition that in order to ferment lactose, organisms must possess β -galactosidase activity. Using this approach total coliforms are defined as members of a genus or species within the family *Enterobacteriaceae* capable of growth at 37°C and possessing β -galactosidase.

Traditionally, total coliforms were regarded as belonging to the genera *Escherichia*, *Citrobacter*, *Enterobacter*, and *Klebsiella*. However, regardless of the definition adopted, the group is heterogeneous. It includes many lactose-fermenting bacteria, such as *Enterobacter cloacae* and *Citrobacter freundii*, which can be found in both faeces and the environment (nutrient-rich waters, soil, decaying plant material) as well as in drinking water containing relatively high concentrations of nutrients. It also includes members of genera such as *Budvicia* and *Rahnella*, which are never found in mammalian faeces.

Because total coliforms of non-faecal origin can exist in natural waters, their presence can occasionally be tolerated in unpiped or untreated water, in the absence of more specific index parameters. Where it can be demonstrated that coliforms in water are not faecally derived and are, thus, of no sanitary significance, expenditure to achieve their eradication may be considered

unnecessary and many standards require only absence of total coliforms from 95% of samples from within distribution systems. However, if used as an indicator of treatment efficiency, total coliform bacteria should not be detectable in water leaving a treatment works and in such cases their detection should provoke immediate investigation and corrective action.

They are detectable by simple, inexpensive cultural methods that require basic routine bacteriology laboratory facilities, but well-trained and competent laboratory workers. They pose very little risk to the health of laboratory workers given good standards of laboratory hygiene.

Thermotolerant ('faecal') coliforms: The term 'faecal coliforms', although frequently employed, is not correct: the correct terminology for these organisms is 'thermotolerant coliforms'. Thermotolerant coliforms are defined as the group of total coliforms that are able to ferment lactose at 44-45°C. They comprise the genus *Escherichia* and, to a lesser extent, species of *Klebsiella*, *Enterobacter*, and *Citrobacter*. Of these organisms, only *E. coli* (covered in the next section) is considered to be specifically of faecal origin, being always present in the faeces of humans, other mammals, and birds in large numbers and rarely, if ever, found in water or soil in temperate climates that has not been subject to faecal pollution (although there is the possibility of regrowth in hot environments, Fujioka *et al.*, 1999).

Thermotolerant coliforms other than *E. coli* may originate from organically enriched water such as industrial effluents or from decaying plant materials and soils. In tropical and subtropical waters, thermotolerant coliform bacteria may occur without any obvious relation to human pollution and have been found on vegetation in the tropical rainforest. This means that the occurrence of the thermotolerant coliform group in subtropical or tropical waters or those enriched with organic wastes does not necessarily suggest faecal contamination by humans. However, their presence in treated waters should not be ignored, as the basic assumptions that pathogens may be present and that treatment has been inadequate still hold good.

Thermotolerant coliforms are a less reliable index of faecal contamination than *E. coli* although, under most circumstances and especially in temperate areas, in surface water their concentrations are directly related to *E. coli* concentrations. Their use for water-quality examination is therefore considered acceptable when no other method is available. However, as methods for the simultaneous detection of thermotolerant coliforms and of *E. coli* are available, these methods should be preferred.

Thermotolerant coliforms are easily detectable and a variety of internationally standardised methods and media for their detection are available (ISO 9308-1; ISO 9308-2). These methods require basic routine bacteriology laboratory facilities and well-trained and competent laboratory workers. They should pose very little risk to the health of laboratory workers given good standards of laboratory hygiene.

Escherichia coli: *Escherichia coli* is a taxonomically well defined member of the family *Enterobacteriaceae*, and is characterised by possession of the enzymes β -galactosidase and β -glucuronidase. It grows at 44-45°C on complex media, ferments lactose and mannitol with the production of acid and gas, and produces indole from tryptophan. However, some strains can grow at 37°C but not at 44-45°C, and some do not produce gas. *E. coli* does not produce oxidase or hydrolyse urea. Complete identification of the organism is too complicated for routine use, but a number of tests have been developed for rapid and reliable identification with an acceptable degree of accuracy. Some of these methods have been standardised at international and national levels (*e.g.* ISO 9308-1; ISO 9308-2) and accepted for routine use, others are still being developed or evaluated.

E. coli is abundant in human and animal faeces, and in fresh faeces it may attain concentrations of 10^9 per gram. It is found in sewage, treated effluents, and all natural waters and soils subject to recent faecal contamination, whether from humans, wild animals, or agricultural activity. It has been suggested that *E. coli* may be present or even multiply in tropical waters not subject to human faecal pollution (Fujioka *et al.*, 1999). However, even in the remotest regions, faecal contamination by wild animals, including birds, can never be excluded and this suggestion requires further investigation. Because animals can transmit pathogens that are infective in humans, the presence of *E. coli* must not be ignored, because, as with the presence of thermotolerant coliforms, the presumption remains that the water has been faecally contaminated and that treatment has been ineffective.

E. coli is widely preferred as an index of faecal contamination. It is also widely used as an indicator of treatment effectiveness although, as with the other coliform indicators, it is more sensitive to disinfection than many pathogens (in particular viruses and protozoa). The detection of *E. coli* in water leaving a treatment works is of the same significance as any other coliform organism, but its absence does not necessarily indicate that pathogens have been eliminated.

Because *E. coli* is indicative of recent faecal contamination, with any positive finding consideration should be given to whether steps need to be taken to protect consumers. In the event of more than one related sample containing *E. coli*, or the recognition of other significant features such as treatment aberrations, the issue of advice to boil water intended for drinking may be considered appropriate (see Chapter 7). However, in many instances it may be acceptable to restrict the response to the taking of additional samples and sanitary inspection in order to assist interpretation of the initial results. If the water is a treated piped supply, a positive sample suggests that a failure or ingress has occurred, such as a breakdown in disinfection, treatment before disinfection has failed, or contaminated water has entered the system. Immediate action must, therefore, be taken to discover the source of contamination and to take appropriate steps (which will depend on the level of contamination) to protect consumers until the problem is resolved.

E. coli is detectable by simple, inexpensive cultural methods that require basic routine bacteriology laboratory facilities, but require well-trained and competent laboratory workers. It can pose a health risk for laboratory workers as some strains of this organism are pathogenic.

2.2.2 *Enterococci and faecal streptococci*

Chain forming gram-positive cocci used to be placed in the genus *Streptococcus* and faecal streptococci were those streptococci generally present in the faeces of humans and animals. All possess the Lancefield group D antigen. A sub-group of the faecal streptococci, which is relatively tolerant of sodium chloride and alkaline pH, have been grouped under the genus *Enterococcus*. Most of the *Enterococcus* species are of faecal origin and can generally be regarded as specific indices of human faecal pollution for most practical purposes.

Faecal streptococci are more resistant to stress and chlorination than *E. coli* and the other coliform bacteria. Although both faecal streptococci and enterococci remain in use as monitoring parameters in drinking water, enterococci appear likely to supplant faecal streptococci as the parameter of choice as they are clearly of faecal origin from warm blooded animals. Enterococci, as an index of faecal pollution, can also be used to complement *E. coli* in catchment assessment, in tropical climates (where *E. coli* is less appropriate because of the suspicion of multiplication) and in ground water source evaluation. Enterococci can also serve as an additional indicator of treatment efficiency. They are highly resistant to drying and thus may be valuable for routine control after new mains are laid or distribution systems are

repaired, or for detecting pollution of groundwater or surface waters by surface run-off. In the UK they have been used to assess the significance of doubtful results from other organisms (Gleeson and Gray, 1997).

Enterococci are detectable by simple, inexpensive cultural methods that require basic routine bacteriology laboratory facilities, but require well-trained and competent laboratory workers. They could pose a health risk for laboratory workers as some strains of these bacteria are pathogenic.

2.2.3 Ratios of counts

The ratio of counts of thermotolerant coliforms and faecal streptococci has been proposed as a means of differentiating between contamination from human and animal sources. Ratios of thermotolerant coliforms to faecal streptococci greater than four have been suggested to indicate a human source whereas ratios less than 0.7 indicate an animal source. These ratios are highly variable. They may vary according to the number of sources, are often site specific, differ with the effects of wastewater disinfection and the age of the contamination (due to the different survival rates of different *Enterococcus* species). All of these factors have a marked effect on the ratios. This ratio is therefore no longer recommended as a means of differentiating sources of pollution. The same applies to most ratios obtained for index, indicator and pathogenic microorganisms.

2.2.4 Direct total counts and activity tests (total and viable bacteria)

Quantification of the total numbers, viability or activity of microorganisms can be useful in assessing the general microbial content of water, its general cleanliness, the integrity of distribution systems and so on. However, these methods generally have little direct sanitary significance. Most direct tests are targeted to general microbial populations rather than faecal microorganisms.

Direct counts of bacteria can provide basic information on the numbers of bacteria in water during abstraction and treatment. Using vital stains, the viability of individual organisms can be assessed. More complex techniques can be used to provide information on serotype and genetic content. Very large numbers of aerobic and anaerobic bacteria are present in water and only a very small proportion can be grown on artificial media such that direct assays can be considered more representative.

Microscopic tests are performed by filtration on membrane filters and bacteria are stained with vital or non-vital stains. The tests require a very good microscope, but are not difficult to perform and can be done at relatively low cost. However, the limited sanitary significance of the results mean that these tests are generally only employed as part of research studies. Automated scanning instruments and flow cytometers can be used to determine total and viable counts more rapidly than by manual microscopy (see Chapter 8). These methods, however, are more expensive and complex than simple microscopic methods.

Assays for microbial metabolism can also be employed to assess general microbial levels. These can use sensitive chemical measures such as the determination of adenosine triphosphate (ATP – a high-energy phosphate carrier found in all living organisms) and are used for assessing microbial levels in food and pharmaceuticals. Being simple and rapid they could potentially be used in the testing of water. However, as they assess general microbial level and not faecal contamination they are of limited sanitary significance and, as such, are not used in routine monitoring.

2.2.5 Heterotrophic aerobic and aerobic spore-former bacterial counts

Colony counts of heterotrophic aerobic bacteria (often referred to as heterotrophic plate counts – HPC) and aerobic spore-former (mainly *Bacillus spp.*) bacteria can be used to assess the general bacterial content of water. They do not represent all the bacteria present in the water, only those able to grow and produce visible colonies on the media used and under the prescribed conditions of temperature and time of incubation. Colony counts are generally determined following incubation at 22°C and 37°C to assess bacteria that may be unrelated to faecal pollution. They are of little sanitary significance, but may be useful in the long-term assessment of the efficiency of water treatment, specifically the processes of coagulation, filtration, and disinfection, where the objective is to keep counts as low as possible. While actual counts are of limited value, changes from counts normally found at particular locations may warn of significant developments. They may also be used to assess the cleanliness and integrity of the distribution system and the suitability of the water for use in the manufacture of food and drink products, where high counts may lead to spoilage.

Cultural methods used for counting heterotrophic aerobic bacteria can be adapted to count only spores by exposing samples to temperatures of 70–80 °C for ten minutes before culturing. Counts of aerobic spore-forming bacteria before and after a treatment are useful in evaluating treatment effectiveness,

whether removal or disinfection. They have been proposed as surrogates for the removal of cysts of parasitic protozoa but their value in this respect is as yet unproven.

Heterotrophic bacterial counts are provided by simple, inexpensive cultural methods that require basic routine bacteriology laboratory facilities and can be performed by relatively unskilled persons. They are not an index of faecal pollution but provide basic information on culturable bacteria and their viability. They are not generally considered to be a health risk for laboratory workers, although certain HPC organisms are thought to be opportunistic pathogens.

2.2.6 Bacteriophages

Bacteriophages (also known simply as phages) are viruses that only infect bacteria. Some bacteriophages are comparable in size and behaviour to human enteric viruses and they are relatively easy to detect and enumerate (see Chapter 8). Various groups and types of bacteriophage, particularly those of coliform bacteria (coliphages) and those of *Bacteroides* spp., have been proposed as indices of faecal pollution (and possible enteric virus presence) and as indicators of treatment efficiency for both water and wastewater-treatment processes. Leclerc (2000) has reviewed the literature on the use of bacteriophages and concludes that they have significant limitations as indices of faecal pollution and enteric viruses. However, other published evidence indicates that bacteriophages have potential value as indices of faecal contamination and indicators of treatment effectiveness (Sobsey *et al.*, 1995; Grabow, 2001).

Coliphages: Coliphages are divided here into two groups, both of which occur in sewage and faecally polluted water, where they generally outnumber human viruses. However, the frequency of occurrence of coliphages in human and animal faeces varies, and sometimes they are detected in faeces at only low frequencies. In this respect, coliphages differ from bacterial indices of faecal contamination.

- Somatic coliphages. These infect host strains via cell wall (somatic) receptors and are frequently detected in human and animal faeces. The host normally used is *E. coli*. The bacteriophages (coliphages) detected by currently used *E. coli* hosts are relatively host-specific and most coliphage isolates do not infect other bacterial species, including species that may occur naturally in the aqueous environment. It is possible, but unlikely, that somatic coliphages occur unrelated to faecal pollution. However, their

usefulness as an index of faecal pollution and enteric viruses is limited by inadequate knowledge of their natural history. They may, when present in raw waters, be a suitable index of faecal contamination and an indicator of virus inactivation and removal during treatment.

- F-specific RNA bacteriophages (male-specific coliphages). These infect bacteria through the F- or sex-pili. Although they are only present in the faeces of a small proportion of people, they are commonly found in high numbers in sewage. They have been used primarily as an index of sewage contamination and, because of their relatively high persistence and similarity to viruses, as an additional indicator of treatment efficiency or for groundwater protection. There are two groups of F-specific coliphages, those containing RNA and those containing DNA and both groups are found in human and animal faecal wastes. The F-specific RNA coliphages are similar in size, shape and basic composition to many human enteric viruses (single-stranded RNA surrounded by a protein coat) such as astroviruses, caliciviruses and hepatitis A and E viruses. There are four major subgroups of F-specific RNA coliphages. Because there is some evidence that the occurrence of these groups differs between humans and other animals, it may be possible to distinguish human from animal contamination by grouping the F-specific RNA coliphages isolated from faecally contaminated waters (Hsu et al., 1995).

Bacteroides phages: *Bacteroides* spp. outnumber the coliform group in human faeces (Gleeson and Gray, 1997), with *Bacteroides fragilis* being the most commonly found species. They are strict anaerobes and they have not been shown to multiply in the environment. Bacteriophages of *Bacteroides* have been proposed as an index of faecal pollution as they are considered to be more resistant to natural inactivation and water treatment processes than bacterial indicators and have a decay rate similar to that of human enteric viruses. The draw-backs, however, are that their densities in raw waters may be low (requiring concentration from large volumes) and the methods of detecting them in water are currently not very reliable.

Coliphages are detectable by simple, inexpensive and rapid methods that can be applied in a basic routine bacteriology laboratory. *Bacteroides* bacteriophages, however, require facilities for anaerobic culture and require a greater degree of expertise and laboratory resources. Some internationally standardised methods exist (e.g. ISO 10705-1; 10705-2; 10705-4). They are generally not considered to be a health risk for laboratory workers, although some of the host bacterial strains may be opportunistic pathogens.

2.2.7 *Sulphite-reducing clostridia and Clostridium perfringens*

Sulphite-reducing clostridia are obligately anaerobic, spore-forming organisms, of which the most characteristic, *Clostridium perfringens*, is normally present in faeces (although in much smaller numbers than *E. coli*). Except for *Clostridium perfringens* they are not exclusively of faecal origin and can be derived from other environmental sources. The spores can survive in water for very long periods and are quite resistant to disinfection. As *C. perfringens* is faecally specific, unlike the other sulphite-reducing clostridia, it is the preferred parameter. Clostridia are not, however, recommended for the routine monitoring of distribution systems because of their length of survival they may be detected long after (and far from) the pollution event, leading to possible false alarms.

The presence of *C. perfringens* in groundwaters in the absence of *E. coli* and enterococci points to pollution at some time in the past and suggests the source may be liable to intermittent contamination. Being relatively resistant to disinfection, *C. perfringens* spores must be removed by some form of filtration as terminal disinfection is unlikely to inactivate them. Their presence in finished waters, therefore, suggests deficiencies in treatment filtration processes. It has been proposed that the detection of *C. perfringens* spores in finished water may indicate the potential for protozoan cysts to have passed through the treatment process.

International standardised methods are available (ISO 6461-1; 6461-2) and methods for detection of clostridia are relatively easy to perform, even though a simple pasteurisation step is required for the enumeration of spores and strict anaerobic conditions are needed for *Clostridium perfringens*. Clostridia detection only requires a basic routine bacteriology laboratory. They are not normally a health risk for laboratory workers but they are pathogenic and if carelessly handled can give rise to food poisoning and wound infections.

2.2.8 *Pseudomonas aeruginosa and Aeromonas spp.*

Aeromonas and *Pseudomonas* spp. are Gram-negative, rod-shaped, oxidase positive, non-spore-forming bacteria that are environmentally widespread, with some being opportunistic pathogens.

Ps. aeruginosa is commonly found in faeces, soil, water, and sewage but cannot be used as an index of faecal contamination, since it is not invariably present in faeces and sewage, and may also multiply in the enriched aquatic environment and on the surface of organic materials in contact with water.

However, its presence may be one of the factors taken into account in assessing the general cleanliness of water distribution systems. Its presence may lead to deterioration in bacteriological quality, and is often associated with a rise in water temperature or low rates of flow in the distribution system, and consequent complaints about taste, odour, and turbidity.

Aeromonas shows no particular association with faecal pollution. Most drinking water treatment processes reduce the numbers of *Aeromonas* to below detectable levels, but treated distributed water can contain larger numbers as a result of regrowth in mains and storage reservoirs. Regrowth of *Aeromonas* depends on the organic content of the water, temperature, the residence time in the distribution network and the presence of residual chlorine (WHO, 2001).

Neither *Pseudomonas* nor *Aeromonas* are indices of faecal pollution, but they may be useful in assessing regrowth in distribution systems. They are both detectable by simple, and inexpensive cultural methods that can be applied in a basic routine bacteriology laboratory. They may, however, pose a health risk for laboratory workers as some strains of these bacteria are pathogenic. *Ps. aeruginosa* is an opportunistic pathogen that mainly gives rise to superficial infections following contact with heavily contaminated water (but does not cause enteric infections by ingestion). Strains of *Aeromonas* have been implicated in enteric infection but there is no strong evidence that the strains found in water distribution systems are of these types and lead to enteric infection (WHO, 2001). *Aeromonas* strains may also cause wound infections.

2.2.9 Presence-absence test

Recognising that for good quality drinking waters the majority of samples should not contain any index/indicator organisms, and the detection of any such organism requires action, Clark (1968) developed simple presence-absence tests. Although not strictly speaking a parameter, the presence-absence technique (P-A) can be an economical alternative to coliform analysis. The need to determine the actual number of coliforms within all samples has been questioned, especially in light of the fact that studies have shown that these organisms tend to be irregularly distributed (Pipes and Christian, 1984). The P-A test, which is in essence the most probable number method reduced to a single tube, simply gives an indication of whether coliform bacteria are present or not (Clark, 1980). The test eliminates the types of errors associated with more complex enumeration techniques and record keeping. P-A testing is an effective screening device when assurance of zero coliform organisms is required on a large number of samples. However, it is not an appropriate test where contamination is common and, thus, it is not recommended for use in the

analysis of surface water, untreated small-community supplies or larger water supplies that may experience occasional operational and maintenance difficulties. Only a minimal amount of analytical experience is required for the person performing P-A testing because of the simplicity of the methods that are available. Tests have been developed that permit the simultaneous detection of total coliforms and *E. coli*. The P-A test is given as a standard procedure in APHA, AWWA, WEF (1998) and with appropriate confirmatory procedures a single test can detect total coliforms, *Aeromonas*, *Clostridium*, *E. coli*, faecal streptococci, *Pseudomonas* and *Staphylococcus*.

2.2.10 Hydrogen sulphide test

Manja *et al.* (1982) developed a very simple screening test for faecal pollution of water sources based on the detection of H₂S production by bacteria. Hydrogen sulphide (H₂S) is produced by some bacteria that are associated with faecal contamination, such as some members of *Enterobacteriaceae* (e.g. *Citrobacters*) and some other bacteria (sulphite-reducing clostridia, such as *Clostridium perfringens*). However, a variety of other bacteria not associated with faecal contamination are also capable of producing H₂S under certain conditions. Some bacteria produce H₂S by reducing sulphate and other oxidised forms of sulphur, while other bacteria produce H₂S by degradation of organic sulphur in amino acids and other organic constituents of biomass. The current status, advantages and limitations of H₂S testing for faecal contamination of water was recently reviewed (Sobsey and Pfaender, 2002).

Using a culture medium with thiosulphate as a sulphur source and ferric ammonium citrate as an 'indicator', certain bacteria will produce H₂S. The presence of a heavy metal, such as iron salts, in the medium inhibits some bacteria, although *Salmonella*, *Citrobacter* and *Proteus* are all able to produce H₂S in such a medium. The H₂S test uses a treated paper strip that is incubated with the water sample. If bacteria capable of producing H₂S under the test conditions are present in the sample, the production of H₂S turns the paper black. The test can also indicate the severity of contamination if it is used in a semi-quantitative manner by testing dilutions of the sample. Since its initial development, many modifications of the original H₂S test have been reported in the literature and now a number of different H₂S tests are available. Because of the lack of standardisation of these different H₂S tests, there is not a consensus H₂S test method that can be recommended for use. Furthermore, it has not been established that H₂S tests always detect H₂S-producing bacteria exclusively associated with faecal contamination. Therefore, it is possible that the test may detect other, non-faecal H₂S-producing bacteria from natural sources, leading to a 'false positive' result in terms of faecal contamination.

Despite its limitations, the H₂S strip test is a potentially useful tool for screening water sources and drinking water for faecal pollution, especially for small communities without access to water testing laboratories, or as a simple, initial, warning system. Correlations between the H₂S method and standard faecal pollution microbial indices have been reported even if the test is carried out at room temperature (*i.e.* without incubation). However, H₂S tests are not recommended as substitutes for more specific and better established microbiological parameters for faecal contamination, such as *E.coli*.

2.2.11 Other microorganisms

Other microorganisms (*e.g.* bifidobacteria, candida/yeasts, acid-fast bacteria etc.) have been considered in the past as potential parameters of drinking water quality. None of these has been widely accepted and they are not recommended as parameters for routine drinking water evaluation.

2.2.12 Pathogens

Various pathogenic microorganisms have been suggested as indices of faecal pollution or indicators of treatment efficiency. However, this approach does not provide the degree of public health protection afforded by the traditional non-pathogenic index or indicator organisms as it depends upon detecting an *actual* risk of infection rather than the *potential* of one. It is also impossible to monitor for all known pathogens and there are also pathogenic agents as yet unrecognised. Nevertheless, pathogen monitoring can provide relevant additional information to that provided by the traditional microbial parameters, particularly in a research context (*e.g.* in validating the significance of indicators of treatment efficiency). Information relating to the presence of pathogens in drinking water is also valuable in the investigation of possible waterborne disease outbreaks (see Chapter 7). Although if monitoring is only instituted when the outbreak has been recognised its value may be much reduced due to the time lag between exposure and development of disease. Transient contamination events or treatment aberrations may have resolved by the time disease occurs and is recognised (Allen *et al.*, 2000).

At present, pathogen monitoring should generally be considered for specific purposes such as research studies, watershed evaluations to target point sources of faecal contamination, outbreak investigations, research into treatment efficiency, and so on. Routine pathogen monitoring based on spot samples has not provided reliable data on their occurrence in source water or treated water. The finding of low numbers of specific pathogens in treated water has, on

occasion, resulted in major responses, without any indication of a public health problem. Pathogen detection in treated water should, however, always result in further investigation/evaluation and consideration/assessment of the need for urgent response.

The detection and enumeration of pathogens by culture methods should only be carried out by qualified staff, in specialised laboratories with the proper biosafety equipment and procedures. While most pathogens are present in low numbers in the environment, culturing results in a potential exposure to very high numbers of microorganisms. Molecular, chemical or immunological methods may present less risk, but concentration of large volumes of water still exposes the laboratory worker to a level of risk that requires evaluation and control.

Enteric viruses: Discharges of sewage and human excreta constitute the main source of human enteric viruses in the aquatic environment and enteric viruses are always associated with human or animal faecal pollution. However, failure to detect them does not indicate the absence of faecal pollution because their occurrence in faeces is highly variable. They can survive for long periods in the environment and are quite resistant to treatment.

Their enumeration can be expensive and results can take several weeks to obtain if molecular methods are not used (see Chapter 8). Furthermore, many cannot be grown under laboratory conditions. Their detection requires a very well-equipped laboratory and highly trained personnel. In addition, most enteric viruses are pathogenic (to human or animals), albeit at different levels of severity, and virus culture must only be carried out by suitably qualified staff in specialised laboratories with the proper biosafety equipment and procedures.

Protozoan parasites: *Cryptosporidium* oocysts and *Giardia* cysts are associated with human and animal faecal sources including amphibians, birds, and mammals, although the species capable of infecting man are restricted to warm-blooded hosts. However, the failure to detect cysts or oocysts does not constitute an indication of the absence of faecal pollution, as their numbers in faeces are highly variable. They can survive for very long periods in the environment and are quite resistant to treatment. They are sometimes found in treated water, usually in low numbers, and when found in filtered supplies suggest deficient coagulation-filtration processes. Viability is difficult to assess but even if non-viable their presence is an indicator of deficient physical treatment and the potential for viable (oo)cysts to be present at some time. Continuous sampling has some value in detecting short-term perturbations in treatment. As with enteric viruses, many species are pathogenic and their isolation and enumeration is expensive and requires a very well equipped

laboratory with the proper biosafety equipment and procedures, and highly trained personnel (see also Chapter 2.3.7).

Table 2.1. Microbial parameter and assay characteristics

Parameter	Association with faecal material (i.e. pathogens)	Risk to analyst (i.e. pathogenicity)	Speed of measurement	Cost	Technical difficulty	Survival in the environment	Resistance to treatment
Total coliforms		L	M	M	M	M	L
Thermotolerant coliforms	M	M	M	M	M	M	L
<i>Escherichia coli</i>	H	M	M	M	M	M	L
Faecal streptococci (enterococci)	M	M	M	M	M	M	ISD
Ratio between counts (any parameter)							
Total bacteria (microscopic)			H	M	M	H	H
Viable bacteria (microscopic)			M	M	M	H	M
Total bacteria (automated)			H	H	M	H	H
Viable bacteria (automated)			H	H	M	H	M
Heterotrophic bacteria		L	M	M	M	H	H
Aerobic spore-forming bacteria		L	M	M	M	H	H
Somatic coliphages	ISD	M	H	M	M	H	M
F specific RNA phages	ISD	M	H	M	M	H	H
Bacteroides phages	ISD	M	H	M	M	ISD	H
Sulphite-reducing clostridia		L	M	M	M	VH	VH
Clostridium perfringens	H	L	M	M	M	VH	VH
Pseudomonas, Aeromonas		M	M	M	M	VH	L
Enteric viruses		H	L	H	H	H	H
<i>Giardia</i> cysts		H	L	H	H	H	H
<i>Cryptosporidium</i> oocysts		H	L	H	H	VH	VH

Key:

L: low. M: medium. H: high. VH: very high. ISD: insufficient data. ■: Not applicable.

Table 2.2. Microbial parameter applicability and suitability

Parameter	Sanitary survey (catchment)	Source water characterisation	Groundwater characterisation	Treatment efficiency (removal)	Treatment efficiency (disinfection)	Treated water	Distribution system (ingress)	Distribution system (regrowth)	Outbreak investigation
Total coliforms	NR	NR	NR	NR	SA	S	SA*	S	S
Thermotolerant coliforms	SA	SA	SA	NR	SA	SA	SA*	S	S
<i>Escherichia coli</i>	S	S	S	S	S	SA	S*		S
Faecal streptococci (enterococci)	SA	SA							S
Ratio between counts (any parameter)	NR	NR	NR						
Total bacteria (microscopic)				SA	SA		SA	S	S
Viable bacteria (microscopic)				SA	SA		SA	S	S
Heterotrophic bacteria				S	S	NR	S	S	S
Aerobic spore-forming bacteria				S	S	NR			S
Somatic coliphages	SA	SA	SA		SA				S
F specific RNA phages	SA	SA	SA		SA				S
Bacteroides phages	SA	SA	SA		SA				S
Sulphite-reducing clostridia	NR	NR	NR						S
Clostridium perfringens	SA	SA	SA	SA					S
Pseudomonas, Aeromonas								S	
Enteric viruses	S	S	S	NR	NR				S
<i>Giardia</i> cysts, <i>Cryptosporidium</i> oocysts	S	S	SA	S	NR				S

Key:

S: suitable. *In distribution systems without residual disinfection. SA: suitable alternative.

NR: not recommended. ISD: insufficient data. ■: not applicable.

2.3 Non-microbial parameters

In addition to microbial measurements there are also various physicochemical assays of water quality that can provide useful information about the quality of, and changes in the quality of, raw water and the effectiveness of applied treatment processes. Many of the parameters can be

analysed relatively quickly and at less cost than the microbial parameters and a number can be measured on-line and can be automated providing real-time data that can be linked to alarms or process control equipment. Non-microbial parameters are outlined below and summarised, at the end of the section, in Tables 2.3 and 2.4.

For most non-microbial assays, the benefit of their use comes from the speed and simplicity of measurement rather than the specificity of the assay itself. The value of the tests comes from their application as triggers, to give early warning through the detection of changes or unusual events, which can then be followed up more rigorously.

2.3.1 *Rainfall events*

Rainfall events are one of the most important causes of degradation in source water quality affecting surface waters and ground waters (see Chapter 4). Rainfall drives the movement of pathogens into and through water bodies and can move soil, resuspend sediments, cause overflow of combined and poorly maintained sewers, degrade groundwater through infiltration and so on. Forecasting and rainfall detection systems such as radar, hydrographic monitoring equipment and remote sensing can now be used to provide authorities with advanced warnings of upcoming rainfall events that might influence water quality and treatment. Stream flows and heights can be measured on-line or manually to warn of major hydrological events. Although not a measure of faecal loading, rainfall events are useful in predicting deterioration in source water quality and permit appropriate precautionary measures to be taken to safeguard treated water quality.

2.3.2 *Flow*

Measurement of flow of surface waters as well as flow during drinking water treatment provides important information regarding the availability and production of quality water. Low flow in surface waters may lead to biological degradation and higher concentrations of pollutants due to reduced dilution of discharges. During treatment, changes in flow can adversely affect coagulation and sedimentation processes, while filtration rate and contact time with disinfectant are key factors in the production of safe drinking water. Flow is easily measured using continuous on-line measurements. Changes in flow rates within distribution systems can result in suspension of sediments and deterioration of supplies.

2.3.3 *Colour*

Colour in drinking water may be due to the presence of coloured organic matter, *e.g.* humic substances, metals such as iron or manganese, or highly coloured industrial wastes. The appearance of colour in water is caused by the absorption of certain wavelengths of light by coloured substances ('true' colour) and by the scattering of light by suspended particles, together these are termed 'apparent' colour. Treatment removes much of the suspended matter and, generally speaking, drinking water should be colourless. Source waters high in true colour can be treated to remove colour by oxidation with ozone and adsorption onto activated carbon.

Changes in colour from that normally seen can provide warning of possible quality changes or maintenance issues and should be investigated. They may, for example, reflect degradation of the source water, corrosion problems in distribution systems, changes in performance of adsorptive treatment processes (such as activated carbon filtration) and so on. It is simply and cheaply measured using a spectrophotometer or simple colorimeter or using visual comparison with known standards.

2.3.4 *pH*

The pH of water affects treatment processes, especially coagulation and disinfection with chlorine-based chemicals. Changes in the pH of source water should be investigated as it is a relatively stable parameter over the short term and any unusual change may reflect a major event. pH is commonly adjusted as part of the treatment process and is continuously monitored.

Equipment for continuous monitoring and data logging is available at reasonable cost. Simple paper strip or colorimetric tests are also available, while these are less precise they can provide valuable information. Test methods are inexpensive, require average skill, and are performed routinely by many laboratories and may easily be conducted on site.

2.3.5 *Solids*

Water always contains a certain amount of particulate matter ranging from colloidal organic or inorganic matter that never settles to silts, algae, plankton or debris of all kinds that can settle quite rapidly. Various methods have been devised to identify or measure these solids. In raw water storage reservoirs and other large bodies of water, discs can be used to measure the depth of water

through which the disc remains visible (*i.e.* transparency). Suspended solids can be measured indirectly as turbidity, which depends on the scattering of light by particles in water (see 2.3.6) or by particle size-counters (see 2.3.7). Nephelometers, particle size analysers and physico-chemical methods provide more precise measurements of the solids in water.

Solids can be dissolved solids or suspended solids in water: together they are referred to as total solids. They can be measured directly, separately or together by physico-chemical methods using combinations of filtration and evaporation. What is left after evaporation of the water before and after filtration through a 2.0 µm filter are referred to respectively as 'total solids' and 'total dissolved solids'. Material retained on the filter is referred to as 'total suspended solids'. Methods for the measurement of solids are well described (APHA, AWWA, WEF, 1998) and involve simple procedures such as filtration, evaporation and/or drying at specified temperatures, and weighing. Results are reported in mg/l.

The amount of solids in water affects both removal and disinfection processes. The solids content of waters can vary significantly with seasons and rainfall events. Abnormal changes in the amount or type of solids in source or treated water should be investigated. Solids, whether total or dissolved, can provide information on the pollution level of the water. Solids can affect taste and appearance of drinking water. Furthermore, a significant increase in the levels of solids could be related to contamination from a range of sources such as freshly derived surface run-off, ingress or wastewater.

Conductivity assays can be used to reflect total dissolved solids concentrations and can be applied rapidly on-line, although conductivity mainly reflects the mineral content. In relatively low salinity waters a marked change in conductivity can provide an indication of contamination with more saline waters, such as most types of wastewater (as wastewaters are typically more than an order of magnitude more saline than surface freshwater).

Many of the tests methods for solids are inexpensive, some can be undertaken in-field or on-line, most require average skill, and others can be performed routinely by many laboratories providing data within hours.

2.3.6 Turbidity

Turbidity is a measure of suspended solids. It has been singled out here because it is probably the most generally applicable and widely used non-microbial parameter that can provide the most significant data throughout the

water abstraction and treatment process. It is not associated specifically with faecal material, but increases in turbidity are often accompanied with increases in pathogen numbers, including cysts or oocysts. Turbidity is often determined by measuring the amount of light scattered by the particulate matter in the water using a nephelometer. Instruments for measuring turbidity are calibrated using commercially available certified standardised suspensions of formazin defined in Nephelometric Turbidity Units (NTU). The lowest level measurable by modern nephelometers is about 0.02 NTU. Nephelometers are available as on-line continuous turbidity meters and they can provide precise data on variations in water treatment efficiency. Data can be collected electronically and stored in a digital format for reporting, analysis or as part of a process-control scheme.

Waterworks using filtration should be able to achieve values of 0.5 NTU or less. Regulations in various countries specify values from 0.1 to 5 NTU in final treated water. Where financial resources are not available for continuous monitoring, manual measurements at regular and frequent intervals can be obtained using simple portable low cost instruments. Some of these are simple comparator devices. A very cheap turbidity measurement method is based on transparency, which can be used to measure down to 5 NTU, this is useful in terms of small community supplies where a high level of sensitivity is not necessary (WHO, 1997).

The turbidity of water affects treatment processes and especially disinfection with chlorine-based chemicals. It is important to know the turbidity characteristics of water sources and to respond to unexplained changes in turbidity. Turbidity of surface water sources may be heavily influenced by rainfall events or algal growth and treatment processes should be tailored to respond to such changes. Most groundwaters have a relatively stable turbidity and any change reflects a major event that needs to be investigated and corrected by tailoring the treatment to the incoming water quality. Even relatively small changes may be important and outbreaks of cryptosporidiosis have been associated with small changes in turbidity of relatively short duration (Waite, 1997). Turbidity is also a good measure of the extent to which treatment processes remove suspended matter. Turbidity of filtered water should be monitored at each filter and data above the expected values should be investigated. Monitoring of the combined filtrate alone from a number of filters may not detect significant loss of performance of an individual filter. This is particularly important in relation to the removal of cryptosporidial oocysts as they are not inactivated by conventional disinfection, and effective filtration is the only treatment means for their control.

Equipment for continuous monitoring and data logging is available at relatively low cost. Test methods are inexpensive, require average skill, and are performed routinely by most laboratories.

2.3.7 Particle size analysis

Particles in water are distributed over a wide range of size. Enumeration and identification of the nature of the larger particles is best achieved by microscopy (see section 2.3.8). Various other instruments have been developed to enumerate and size particles in water. These instruments measure the passage of particles in a sensing zone where each is counted and sized according to the electronic pulse generated. This pulse is proportional to the characteristics of the size and shape of the particle. The apparatus generates a report on the number of particles in each size-class selected. There are different types of instruments available, but they are all computerised, often complex and expensive. They also require careful calibration in order to generate data that is comparable between different instruments. They are especially useful in determining filtration efficiency during drinking water treatments. The surveillance of the removal of particles in the 2-5 micrometer size range (*i.e.* the size of cysts *Giardia* or oocysts of *Cryptosporidium*) is currently being evaluated as a potential surrogate for their removal.

Particle counting can provide a general index of removal effectiveness and as such is a good quality control parameter for filtration. However, factors other than size (such as electric charge on the particles) may affect removal processes. Particle size monitors are available as on-line instruments, however as mentioned earlier, the equipment is expensive and it requires a greater level of skill than turbidity analysis.

2.3.8 Microscopic particulate analysis

Microscopic particulate analysis provides detailed microscopic information on the nature of particulates in water. Biological particles (cysts, diatoms, fungi, zoo-plankton and phyto-plankton) and inorganic particles are described and enumerated. It is useful to identify contaminants in groundwater, providing information on the nature and likely origins of its contamination. Groundwater influenced by surface water will contain a significant amount of algae and other particles not normally found in protected groundwater. It is mainly of value as a research and investigational tool (see Chapter 7) rather than for routine monitoring. The analysis requires well-trained skilled personnel, is time-consuming and is performed by few laboratories.

2.3.9 Disinfectant residual concentration

Chlorine is the most widely used disinfectant in water treatment. For the majority of bacterial pathogens, and some viruses, terminal disinfection is the critical control point of treatment and proper measurement and control of disinfectant dose and contact time (alongside pH and turbidity) is imperative. The measurements of disinfectant dose, residual obtained and the time of contact are primary data that provide a minimal level of quality control of treated water and disinfectant residual concentration during and after disinfection is a required measurement at most water treatment works. Wherever possible residual concentration after contact should be continuously monitored, with suitable alarms to signal departures from the pre-set target range and, in some cases, provision for automatic shutdown of the treatment process may be appropriate. Instruments for continuous monitoring and data logging are also available at reasonable cost. Simple and inexpensive colorimetric tests using titration methods or kits are available for manual determination by relatively low skilled personnel.

2.3.10 Organic matter

Data on the level of organic matter in treated water provide an indication of the potential for the regrowth of heterotrophic bacteria (including pseudomonads and aeromonads) in reservoirs and distribution systems. Organic matter can be measured as Total Organic Carbon (TOC), Biochemical Oxygen Demand (BOD) or Chemical Oxygen Demand (COD). BOD is primarily used with wastewaters and polluted surface waters, and TOC is the only parameter applicable to drinking water. Measurement of these three parameters requires basic laboratory facilities and adequately trained personnel. TOC measurement can now be obtained using on-line instrumentation. The data provide information on the amount of matter present in the water. Not all organic matter is biologically available and it may be useful to measure the amount of organic material available to support bacteriological growth. Although BOD does this to a degree, a number of other measurements such as assimilable organic carbon (AOC) have been proposed. These latter methods require skilled personnel and a well-equipped laboratory.

2.3.11 Specific chemical parameters

Ammonia is rapidly oxidised in the environment and is typically found in natural waters at concentrations less than 0.1 mg/l. Concentrations significantly above this indicate gross contamination by fresh sanitary waste, where ammonia

levels are typically very high (tens to hundreds of mg/l). Relatively simple and rapid in-fields tests are available for ammonia that could be used as an initial screen. Ammonia combines readily with chlorine to produce chloramines, which are much less effective disinfectants but are more stable.

Boron measurement has been proposed as an index of faecal pollution. Salts of boron have been used as a water softener, and calcofluor as a whitener in detergents, resulting in their presence in wastewater. Their use, however, is widely being discontinued, which markedly reduces the value of these parameters as indices of sewage/wastewater pollution.

Excreted materials, such as faecal sterols, secretory immunoglobulin type A, caffeine, urobilin and a number of other parameters have been suggested as indices of faecal pollution. Their detection and measurement usually require well-equipped laboratories with trained personnel. Research on the use of these parameters is ongoing and, as yet, they are not recommended for routine monitoring.

Table 2.3. Non-microbial parameter assay characteristics

Parameter	Speed of measurement	Possibility of online monitoring or automation	Cost	Technical difficulty
Rainfall events	H	H	L	L
Flow	H	H	L	L
Colour	H	H	L	L
pH	H	H	L	L
Solids (Total and dissolved)	M	L	M	M
Conductivity	H	H	L	L
Turbidity	H	H	L	L
Particle size analysis	H	H	H	H
Microscopic particulate analysis	H	L	H	H
Disinfectant residual	H	H	L	L
Organic matter (TOC, BOD, COD)	M	H	M	M
Ammonia	H	M	M	M
Detergents (Boron, calcofluor)				
Faecal sterols, IgA (secretory), caffeine, urobilin				

Key: L: low. M: medium. H: high. ■: not applicable.

Table 2.4. Non-microbial parameter applicability and suitability

Parameter	Sanitary survey (catchment)	Source water characterisation	Groundwater characterisation	Treatment efficiency (removal)	Treatment efficiency (disinfection)	Treated water	Distribution system (ingress)	Distribution system (regrowth)	Outbreak investigation
Rainfall events	S								S
Flow	S	S			S	S		S	S
Colour						S			S
pH					S				S
Solids (Total and dissolved)	S	S	S						S
Conductivity	S	S	S						S
Turbidity	S	S	S	S					S
Particle size analysis				S					S
Microscopic particulate analysis			S						S
Disinfectant residual					S	S	SA		S
Organic matter (TOC, BOD, COD)	S	S	S					S	S
Ammonia	S	S	S				ISD		S
Detergents (Boron, calcofluor)	NR	NR	NR						
<i>Faecal sterols, IgA (secretory), caffeine, urobilin</i>									

Key:
 S: suitable. SA: suitable alternative. ISD: insufficient data. NR: not recommended.
 ■: not applicable.

2.4 Summary

For drinking water to be wholesome it should not present a risk of infection, or contain unacceptable concentrations of chemicals hazardous to health and should be aesthetically acceptable to the consumer. The infectious risks associated with drinking water are primarily those posed by faecal pollution, and their control depends on being able to assess the risks from any water source and to apply suitable treatment to eliminate the identified risks. Rather than trying to detect the presence of pathogens, at which time the

consumer is being exposed to possible infection, it is practice to look for organisms, while not pathogens themselves, that show the presence of faecal pollution and therefore the potential for the presence of pathogens. A number of microbial parameters have been used as 'index' organisms to give an indication of the amount of faecal pollution of source waters, the pre-eminent being *E. coli*. It is also important to be able to check on the effectiveness of treatment processes at eliminating any pathogens that might have been present in the untreated source, and 'indicator' organisms fulfil that role. While the perfect indicator needs to be as resistant to treatment processes as the most resistant potential pathogen, no single parameter is ideal. In principle, treatment should be able to eliminate all non-spore forming bacteria and enteric viruses and the less restricted the parameter chosen the more suitable it should be. There are a number of microbial parameters that are of some value as indices or indicators and these are discussed. Water quality can deteriorate in distribution due to ingress or regrowth and measures of regrowth potential are described.

A number of non-microbial parameters are described, which can provide useful information about quality, and changes in quality, of source waters and the effectiveness of treatment processes.

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