# Chapter 6: Bacteriological compliance

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# 6.1 Introduction

The most common and widespread risk associated with drinking-water is microbial contamination, the consequences of which mean that control of microbiological quality must always be of paramount importance, see Chapter 5 for general discussion. Microbiology compliance includes, or is related to:

- bacteria – this chapter
- viruses – Chapter 7
- protozoa – Chapter 8
- cyanobacteria – Chapter 9.

Obviously the entire drinking-water supply cannot be tested for compliance, so monitoring programmes must be designed to yield statistically reliable and practical information, see the Appendix in Chapter 1, section 2.4 of Chapter 2, and section 6.2.2. Testing a water supply for verification of microbiological quality must be designed to ensure the best possible chance of detecting contamination. Sampling should therefore take account of potential variations of water quality and increased likelihood of contamination, both at source and during distribution. Faecal contamination usually will not be distributed evenly throughout a piped distribution system. In systems where water quality is consistently good, the probability of missing the detection of faecal indicator bacteria is reduced.

The chances of detecting contamination in systems reporting predominantly negative results for faecal indicator bacteria can be increased by the use of more frequent presence/absence (P/A) testing. P/A testing can be simpler, faster and less expensive than quantitative methods and can maximise the detection of faecal indicator bacteria. However P/A testing is only appropriate for systems where the majority of tests for indicators are negative. Membrane filtration and multiple tube techniques give a numerical result and are preferred.

The more frequently a water supply is tested for faecal indicators, the more likely it is that faecal contamination will be detected. Frequent examination by a simple but reliable method is more valuable than less frequent testing by a complex test or series of tests. The indicator organism of choice for detecting probable faecal contamination is *Escherichia coli* abbreviated to *E. coli*.

*E. coli* monitoring requirements can be replaced or reduced by online measurement of the disinfection process, confirming that it is continuously operating satisfactorily, see section 6.3.7. These operational requirements also need to be monitored, implementing remedial actions when there is a transgression.

By necessity, *E. coli* monitoring is spasmodic. Also it yields results typically 24 hours after sample collection, so produces a historical; record; multiple results give a statistical record. The main reason for *E. coli* monitoring (ie compliance testing) is to determine whether the water supply meets the DWSNZ, implying that the water is safe for consumers to drink. Water safety plans (and these Guidelines) specify the required good management practices.

Section 5.3 in Chapter 5: Microbiological Quality discusses the bacteriological indicators that can be used for demonstrating drinking-water compliance and treatment plant efficacy and the reasons for the choice of *E. coli* as the sole bacterial indicator in the *Drinking-water Standards for New Zealand* (DWSNZ). This chapter addresses questions of compliance with limits set on this indicator. This includes an explanation of how some statistical issues have been addressed in determining the compliance rules, especially rare false positive results.

An important feature of the DWSNZ is the distinction between transgressions and non-compliance. For reasons explained in section 6.2.2, a very small proportion of exceedances of the Maximum Acceptable Value (MAV), ie, transgressions, can be tolerated with the water supply remaining in compliance with the DWSNZ. Nevertheless, preventive and remedial actions are required whenever a transgression occurs. Figures 4.1 and 4.2 in the DWSNZ summarise some of these actions.

The MAV for *E. coli* is less than 1 per 100 mL (Table 2.1 of the DWSNZ). The multiple tube technique used to enumerate *E. coli* reports the most probable number of organisms (or MPN) per 100 mL. For compliance purposes, an *E. coli* result of less than 1 MPN per 100 mL is considered equivalent to less than 1 per 100 mL, or more correctly 1 CFU per 100 mL, where CFU means colony forming unit.

WHO (2004a) discusses treatment processes suitable for pathogen control.

# 6.2 Monitoring for *E. coli*

## 6.2.1 General principles

A microbiologically contaminated drinking-water supply can be a major threat to the health of a community. The main source of this contamination is human and animal faeces. Not only does contaminated drinking-water have the potential to cause significant illness in consumers (as outbreaks, or more commonly, ongoing sporadic cases), it may also be the source of epidemics of disease that spread within the community and have an effect beyond the immediate area supplied with the contaminated water. The provision of safe drinking-water requires that a number of

barriers, including treatment processes, be put in place to minimise faecal contamination of water supplies and any ensuring health effects.

Testing a water supply on a regular basis for *E. coli*, and monitoring the disinfection process, are important steps for detecting whether the barriers being used to provide safe drinking-water and to prevent contamination are likely to have been breached. Note that *E. coli* monitoring should not be used to decide when further water treatment should commence, or processes adjusted, because by the time the alert has been raised by a positive test, a large volume of contaminated water will have entered the distribution system and may have reached some or many consumers. Largely for this reason, the DWSNZ have over recent editions, shifted the emphasis from reliance on compliance monitoring testing more to the implementation of risk management procedures.

To allow reliable detection of barrier failure it is essential that supplies be monitored sufficiently often that any breakdown is detected promptly and remedied as soon as possible. Ideally, water suppliers will have process control monitoring procedures in place that can warn of an impending breakdown; this should be addressed in the WSP.

*E. coli* compliance monitoring will require regular sampling and testing at a frequency and number based on population size. The larger the population served by a water supply, the greater the economic consequence to a community of a contaminated supply. The DWSNZ explicitly cater for population size (for example, see Tables 4.1, 4.2, 4.3, 4.4 and 4.5).

Sampling should be planned to be as effective as possible. Since only continuous monitoring for *E. coli* would give total confidence in the safety of the water (and this is not feasible), sampling must be targeted to give the maximum information. This will be achieved by focusing sampling on the water leaving the treatment plant, and in the case of protozoa, relating sample numbers to the nature of the source water and the number and types of treatment barriers present. The larger the population served by a supply the greater the impact of treatment failure (in terms of the community affected, rather than the individuals affected), and the larger and more extensive the distribution system, the more opportunity there is for a breach in its integrity to occur.

Section 4.4.4 of the DWSNZ refers to the need to collect samples for *E. coli* analysis on different days of the week. This may be difficult for some water suppliers due to isolation, availability of courier services, or the hours the laboratory are open for business. An exemption is permissible, provided the water supplier has conducted a risk analysis that shows that sampling on selective dates does not bias the results. Drinking-water is delivered seven days a week so suppliers need to know that the water quality is equally satisfactory on all seven. This is discussed further in Chapter 17: Monitoring, section 17.2.

If monitoring a water supply for *E. coli* is to have any significant role in preventing people becoming ill from drinking contaminated water, it is essential that there is an immediate response whenever a transgression occurs. As explained in section 6.2.2, a supply can transgress the MAV, yet the supply can still comply with the DWSNZ; this only happens if there are many samples tested and very few transgressions found, and the number of *E. coli* found in a sample is not high. If the only response is to retest, a delay of several days may occur before remedial action is taken and the breach of the

water treatment barriers identified. During that time the community may have been exposed to a significant health hazard from the contaminated water. False positive laboratory results are relatively uncommon, thus a transgression is more likely to suggest a breach to a treatment barrier. For a water supply to be well-managed it is essential that all transgressions be acted upon promptly. Any faecal material that is indicated to be in the water leaving a treatment plant must be of considerable concern to the supply operator because its presence is a clear warning of a system's failure. Small numbers of *E. coli* in a distribution system may pose less of a threat, especially if there is a chlorine residual, and accordingly the response may be less intensive, but high counts (eg, >10 per 100 mL) should be a signal for immediate action.

In all cases where faecal contamination is detected it is very important that a competent person inspect the source water for possible changes, and the treatment plant and/or the distribution system for unexpected breaches. Someone who thoroughly knows the system under investigation should be able to identify problems quickly. Trouble-shooting for anyone, familiar or not with the supply, will always be made easier by the system being clearly documented together with all contingency plans (which should be documented in the WSPs). Abnormalities in the system are much more readily noticed when it is known what should be there and how the system is designed to perform.

Every follow-up of a positive *E. coli* test should be recorded: everything that was observed and done needs to be recorded. This greatly assists later review(s) of the event and assists in the implementation of preventive measures. Repeated systems failure will become apparent sooner, and problems arising from different people, treatment rates, or weather conditions etc being involved at different times are overcome. If the remedial action taken to correct a problem is not written down, no-one can be sure that something was actually done.

### 6.2.2 Statistical considerations

The aim of a monitoring programme must be to give a high degree of confidence that the drinking-water supply is free of contamination. The only way to be 100 percent confident that 100 percent of the water is free of *E. coli* is to submit the entire supply for testing, and this is not feasible, there would be none left for drinking! Furthermore, if a small proportion of the water actually sampled is found to be positive, it may be the result of a false positive phenomenon (eg, contamination during sampling or processing, or detection of a non-faecal particle, or even misreporting), rather than a genuine event. Accordingly, practical compliance rules cannot be derived for 100 percent confidence (ie, certainty) that the supply never transgresses the MAV. This means that statistical methods must be used to develop the rule, accounting for the uncertainties. Two main items must be agreed on before those methods can be employed:

1 what percent of the time should the water have no transgressions, even if false positives occur?

2 what level of confidence should be attached to that claim? In other words, what is the appropriate burden-of-proof?

The Ministry of Health has a clear mandate in respect of public health to adopt a precautionary approach. Accordingly, in addressing the second issue, the level of confidence should be high; 95 percent has been adopted (as is common for precautionary approaches in the public health field).

For the first issue, the position adopted is that *E. coli*, turbidity, chemicals, disinfection C.t values and UV fluence should not transgress for more than 5 percent of the time. In bacterial compliance criterion 2A, the free available chlorine (FAC) content should not transgress for more than 2 percent of the time. The latter is the more stringent because this compliance criterion can be achieved without any *E. coli* monitoring, and is technologically straight-forward.

It is important to take a sufficient number of samples to be able to be confident in the results. It is also important to recognise the possibility of false positive results and occasional small exceedances of the MAV (ie, transgressions). The DWSNZ accommodate these contrasting requirements by using percentile standards, mostly 95 percentiles.

For important variables that cannot be (or are not) monitored continuously, there is always a risk of failing of making one of two errors:

- failing to detect the proportion of transgressions that actually occur
- detecting a higher proportion of transgressions than actually occur.

Compliance rules for these percentile standards (Table A1.4 in the DWSNZ, and discussed in more detail in the Appendix in Chapter 1) are based on a precautionary approach. To do that, the DWSNZ guard against the first kind of error (often called the consumer's risk). It does this by minimising that risk. This means that the second risk (the producer's risk) will not be minimised, particularly if the supply is truly borderline for compliance (ie, transgressions actually occurred for 5 percent of the time). So the DWSNZ are based on the notion of attaining at least 95 percent confidence of compliance.

This means that if only monthly bacteriological samples are collected in one year and none transgresses the MAV (which is less than 1 *E. coli* per 100 mL of sample), it is only possible to be 70 percent confident that the water is microbiologically safe.[1] Therefore the desired confidence cannot be attained. It is only attained for a 95 percentile when one has tested at least 38 samples, of which none transgressed the MAV. For a 98 percentile one would need at least 95 samples (with no transgressions), before attaining the desired confidence.

Figures 6.1 and 6.2 summarise all these results. It should be noted that these sampling requirements (and those in the DWSNZ editions from 2000) represent a relaxation from those discussed in the 1995 DWSNZ and Guidelines. For example, one needed a minimum of 58 samples (with no transgressions) to achieve 95 percent confidence of compliance with a 95 percentile standard in the 1995 discussion, but only 38 (with no transgressions) in the 2000 DWSNZ. This reduction is because the 1995 set was derived using classical statistical methods, whereas the present standards use Bayesian

[1] The situation is worse still if one of those samples is a transgression; the Confidence of Compliance falls to 20 percent (McBride and Ellis 2001, McBride 2005).

methods. It can be shown (McBride and Ellis 2001) that the classical methods are the most pessimistic of all possible compliance rules, which makes them somewhat inappropriate.

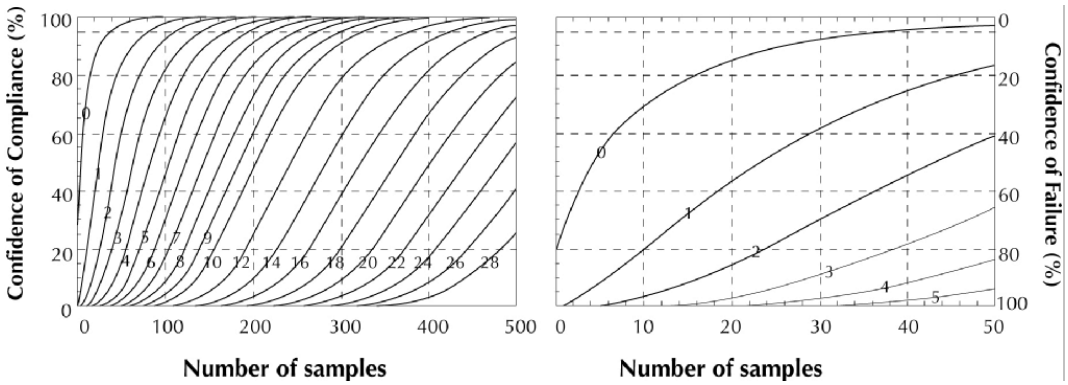
Figures 6.1 and 6.2 show the results of the calculations, from which Table A1.4 in the DWSNZ was derived, see McBride and Ellis 2001 or McBride 2005 for the full details, as summarised in the Appendix in Chapter 1 of the Guidelines).

As an example, reference to Table A1.4 shows that the desired 95 percent level of confidence is obtained when there are 38–76 samples, none of which transgresses the MAV. One transgression is allowed if there are between 77–108 samples. Similarly, if four transgressions occur, a minimum of 194 complying samples is required. These results can be obtained from Figure 6.1, by reading the point at which the curved lines cross the horizontal dashed line, which is at 95 percent confidence of compliance.

Note that in all cases the allowable proportion of transgressions in the samples is less than the DWSNZ requires. For example, allowing one transgression in 100 samples is 1 percent, yet the DWSNZ for Table A1.4 contemplates transgressions for up to 5 percent of the time. This is precisely because a precautionary stance has been taken to the burden-of-proof; it guards against the possibility of finding few transgressions when in fact the supply was in breach of the DWSNZ. So there is a high (~95 percent) probability that the MAV was not exceeded for more than 5 percent of the time if there is only one transgression in 100 samples, and very close to 100 percent confidence if there are none. In other words, the benefit-of-doubt is in favour of the consumer, not the supplier. This is as it should be.

Note too that as the number of samples increases, the proportion of allowable transgressions gets ever closer to 5 percent, eg, for 330 samples, one can have 10 transgressions (over 3 percent). Had a permissive stand been taken the allowable proportion of transgressions among the samples would always be greater than 5 percent.

**Figure 6.1: Confidence of compliance for a 95 percentile, over smaller and larger datasets**

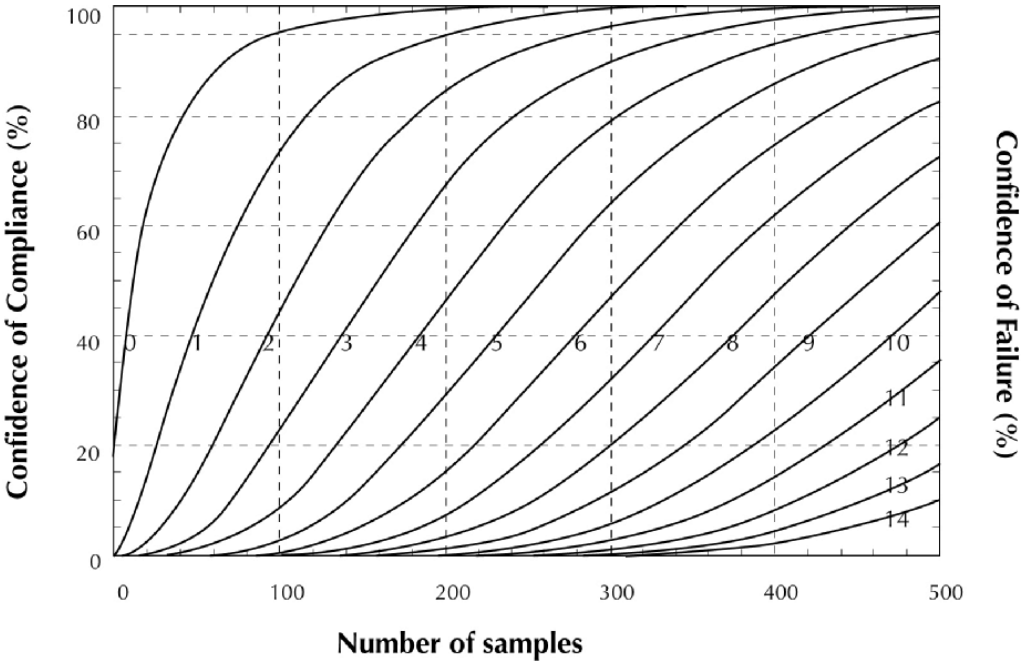



Source: McBride and Ellis 2001 and McBride 2005.

Numbers on the graphs are the observed number of transgressions.

Figure 6.2 has been included for historical reasons, and for interest. The 2008 DWSNZ do not have any instances where 98 percent confidence is required.

**Figure 6.2: Confidence of compliance for a 98 percentile**




Source: McBride and Ellis 2001 and McBride 2005.[2]

Numbers on the graphs are the observed number of transgressions.

# 6.3 Microbiological compliance

## 6.3.1 Introduction

The DWSNZ require that all water supplies be subjected to microbiological monitoring because microbiological determinands are considered to be Priority 1, ie, determinands of health significance for all drinking-water supplies in New Zealand.

The micro-organisms of most concern are those that are of faecal origin. However, as it would be impracticable to test for the presence of all faecal organisms, or even a selection of pathogens that could be in a contaminated water supply, it has been customary to test for microbiological compliance using indicator bacteria, as discussed in Chapter 5: Microbiological Quality, section 5.3.

However, in recent years it has become apparent that the traditional bacterial indicators of faecal contamination, ie, the faecal coliform or more recently the *E. coli* bacterium, are not good indicators for some viruses or for the pathogenic protozoa, in particular *Giardia* and *Cryptosporidium,* which have been found in some New Zealand surface waters and non-secure bore waters. The protozoa compliance criteria are covered in section 5 of the DWSNZ, and are discussed in Chapter 8: Protozoa Compliance of the Guidelines.

[2] These graphs update the version in the 1995 Guidelines, using Bayesian methods. The 1995 graphs were not Bayesian and so were unduly pessimistic. Furthermore, they contained an error (see McBride and Ellis 2001).

For bacterial compliance in New Zealand, we rely on monitoring *E. coli* as per the DWSNZ, and the implementation of WSPs. In the US, the Surface Water Treatment Rule (SWTR) requires that filtration and disinfection must be provided to ensure that the total treatment of the system achieves at least a 3-log removal or inactivation of *Giardia* cysts and a 4-log removal/ inactivation of viruses. In addition, the disinfection process must demonstrate by continuous monitoring and recording that the disinfectant residual in the water entering the distribution system is never less than 0.2 mg/L for more than four hours. Rather than using a log removal approach for bacteria, or a C.t value approach, the USEPA Total Coliform Rule requires that coliforms be absent.

### 6.3.2 Methods for detecting and enumerating *E. coli*

As discussed in Chapter 5, section 5.3, *E. coli* is now the sole bacterial indicator used in the DWSNZ. A number of the newer methods for testing for coliforms in water test for total coliforms and/or *E. coli*. When these tests are used it is only the *E. coli* result that is sought. Total coliforms have limited interest in their own right, but with one important exception: when total coliforms are detected in the absence of *E. coli,* it is important that the source be investigated as their presence may be indicative of a barrier failure or biofilm development.

The referee methods for testing bacterial compliance are shown in section A2 of the DWSNZ. Presence/absence tests that have been accepted by the MoH for compliance testing are listed in WINZ. IANZ accredited laboratories, and the laboratories that are recognised by the MoH for conducting bacterial compliance testing, can be found on **http://www.drinkingwater.org.nz**, or **http://www.ianz.govt.nz/**.

If a total (or presumptive) coliform method, or a faecal coliform method, is used that does not explicitly enumerate or detect *E. coli*, the results must be considered as equivalent to *E. coli*. Thus if these test results are positive, the action must be as if the test were for *E. coli*. Refer also to Chapter 5: Microbiological Quality, section 5.4.1.

### 6.3.3 Effective monitoring programmes

Maintaining a safe drinking-water supply is dependent on the presence of multiple barriers to reduce contamination and the transmission of pathogens. A monitoring programme is designed to provide an assurance that these barriers are continuing to function and have not been breached. The need for a large number of samples to be tested if a high level of confidence in the integrity of a supply is to be maintained is discussed in section 6.2.2. In addition to the minimum number of samples that are needed for confidence, it will also be important that sampling is carried out at a specified frequency, so that the minimum interval exists between successive samples. This will ensure that breaches to the system are identified soon after they occur. Thus a sampling routine is adopted, eg, once a week, as in the Table 4.2a of the DWSNZ.

It should be noted that not all contamination events are random. Occasionally they may be the result of a cyclic event, eg, management practices at a treatment plant, or an intermittent discharge upstream of the intake. Thus it is important that a sampling routine is randomised. This is most readily done by varying the time of day and the day of the week when regular sampling is performed. Sampling plans must be documented and adhered to; variations may be approved by the DWA. See Chapter 17: Monitoring, section 17.2 for further discussion.

## How to estimate the sampling frequency for water supplies with varying population

All water treatment plants and distribution zones are registered to supply a normal or usual population, which is the population most often found. Some water supply areas experience large fluctuations in population, such as beach resorts, ski fields and camping grounds. The peak population must be estimated and submitted to the DWA with the sampling plan. The sampling frequency should be that required for the higher population for the duration of the higher population, plus at least two weeks before the population is expected to increase. For water supplies that are shut down or operate at a very small fraction of the peak rate, this period may need to be extended to a month. Monitoring before the population increases ensures that there will be time for any treatment process to settle in, and time to remedy any problems that come to light.

## Monitoring stand-by, out-of-service or intermittent supplies

Scheduled samples do not need to be collected while a normally continuous supply is interrupted. However, accurate records need to be maintained so the absence of results from scheduled samples does not result in non-compliance.

Many water suppliers have a water source that is only used occasionally, eg, in the summer, during a drought, or when there is a problem with the regular source. These supplies do not need to be included in the routine monitoring schedules. No monitoring is required while a source or treatment plant is out of service for a period of time, however, the water supplier must ensure by appropriate monitoring that the source is free of *E. coli* or that the plant is operating to its full treatment capability before being placed back on line. Once the source is online, monitoring should proceed, as a minimum at the rate required by the DWSNZ. Compliance is based on statistical considerations and intermittent supplies will not be tested as often. Therefore additional monitoring is recommended while these sources or supplies are operating.

## Monitoring occasional low-level contamination

On some occasions a membrane filtration technique can prove useful because it can increase the detection limit of the *E. coli* test. This can prove helpful in understanding what is going on at some locations such as water treatment plants, service reservoirs or after a mains repair. For example, Rotorua District Council (Charleson, personal communication) found one bulk water supply point occasionally returning faecal

coliforms at 1 cfu/100 mL when using a 100 mL sample, giving rise to the sampler or laboratory being thought of as "having problems". After analysing 10 litre samples, counts of about 80 cfu per 10 L (0.8 per 100 mL) were obtained at the site of concern, as well as lower levels (20–40 per 10 L) at other supply points, demonstrating that there really was underlying contamination in the source water. Such an approach would not mean that transgressions would occur, because the DWSNZ requires "Less than 1 cfu in 100 mL of sample" for *E. coli* (Table 2.1 of MAVs, DWSNZ). However, in such circumstances, it is certainly advisable to investigate the cause and introduce an appropriate preventive action.

A benefit of this approach is that it dispels the often held belief amongst some water supply staff that zero *E. coli* means the drinking water is sterile! An *E. coli* result as low as 0.1 per 100 mL may still indicate a large number of *E. coli* entering the distribution system; for example one million *E. coli* per 1000 $m^3$!

### 6.3.4 Monitoring drinking-water leaving a treatment plant

The DWSNZ consider that there would usually be a greater potential risk to the community if the water entering the distribution system were contaminated than there would be from contamination during distribution. Monitoring the water as it enters the distribution system after the completion of all treatment steps is thus the most critical phase of the monitoring programme. Not only must it be frequent but also the frequency should reflect the nature of the source water and treatment processes and the size of the population drinking the supply (see Table 4.2a in the DWSNZ for presentation of minimum sampling frequencies). Thus the more vulnerable the source water to contamination, the more monitoring of the efficiency of the treatment process and the barriers to contamination there needs to be.

The frequency of *E. coli* monitoring is risk based. A secure bore water requiring no treatment needs only occasional (monthly or quarterly) testing, whereas surface water leaving the treatment plant supplied to populations over 10,000 and using bacterial compliance criterion 1 must be tested daily, Table 4.2a of the DWSNZ. Always bear in mind that the DWSNZ states the *minimum* sampling frequencies required in order to demonstrate compliance.

Water supply operators must always be alert to events that could have a major impact on source water quality or the efficiency of barriers against pathogens. Risk management plans should include an automatic increase in sampling when events occur that could impact significantly on source water quality or the treatment process, eg, high rainfall. For example, see the discussion in Chapter 3: Source Waters, section 3.5.1, that shows how *E. coli* (and presumably many other microbes) are stored in stream sediments during low flows, and occasionally flushed out in much higher concentrations during flood events.

Although there is just the one MAV of less than 1 *E. coli* per 100 mL, section 4.3 of the DWSNZ has established five sets of compliance criteria for water leaving the treatment plant. These are based on the type of disinfection employed, and the more effective the disinfection process, the fewer samples required for testing. The reduced sampling frequency is an attempt to balance risk with the costs of compliance.

Compliance criterion 1 (section 4.3.1 of DWSNZ) applies where there is no disinfection or inadequate disinfection. Also, a water supplier may choose to use solely *E. coli* testing for bacterial compliance, provided they have nominated this in their annual monitoring plan. Sampling frequency is population based and varies from weekly to daily.

Compliance criterion 2 (section 4.3.2 of DWSNZ) applies when chlorine is dosed continuously. Criterion 2A applies when the free available chlorine (FAC) is monitored continuously. Because the efficacy of FAC is pH dependent, pH must be monitored online too, so FACE can be calculated. *E. coli* testing is not required if the criterion 2A conditions are met. Criterion 2B applies when the water is considered to be non-continuously monitored. Sampling frequency is population based and varies from fortnightly to twice weekly.

Compliance criterion 3 (section 4.3.3 of DWSNZ) is the chlorine dioxide equivalent to criterion 2A, where a residual of 0.2 mg/L (as $ClO_2$) is considered equivalent to 0.2 mg/L FAC. If there is a chlorine dioxide residual as well as FAC, their concentrations may be added. Compliance criterion 3 also applies, with no additional requirements, if chlorine dioxide disinfection satisfies at least 0.25 protozoal log credits (section 5.14 in DWSNZ).

Compliance criterion 4 (section 4.3.4 of DWSNZ) applies when the water is continuously dosed with ozone, and the continuously monitored C.t value is at least 0.5, eg, a residual of 0.05 mg/L persists for at least 10 minutes. A reduced *E. coli* sampling frequency is allowed in acknowledgement of the disinfecting efficacy of ozone, but because there is no residual, fortnightly sampling for *E. coli* testing is required, regardless of population. Satisfying the protozoal compliance requirements by using ozone (section 5.15, 0.25 log credits or more) automatically achieves bacterial compliance, and no *E. coli* monitoring is required, ie, not compulsory.

Compliance criterion 5 (section 4.3.5 of DWSNZ) applies when UV disinfection is used. If all the protozoal compliance requirements are met when disinfecting with UV light using a dose equivalent to 40 $mJ/cm^2$ (section 5.16, DWSNZ), bacterial compliance is automatically achieved, and no *E. coli* monitoring is required. For bacterial compliance purposes, UV appliances must have been validated with MS2 organisms or acceptable equivalent, not for example with T1 (see section 5.3 of USEPA 2006). If the UV disinfection appliance is not validated, or any other requirements of section 5.16 are not met, bacterial compliance must be met by using bacterial compliance criteria 1, 2, 3 or 4.

If a water supplier has difficulty meeting compliance criteria 2, 3, 4 or 5, they cannot switch to compliance criterion 1. If routine monitoring finds *E. coli*, or that disinfection is inadequate, Figure 4.1 (in the DWSNZ) applies. This is likely to require additional samples to be collected for *E. coli* testing, which is the response action, not compliance criterion 1. See section 6.5.1 for further discussion.

## 6.3.5 Monitoring drinking-water from groundwater

### a) Demonstrating bore water security

Section 4.5.2 of the DWSNZ specifies the compliance criteria for demonstrating whether bore water is secure. These are discussed in more detail in Chapter 3: Source Water, section 3.2 Groundwater.

1 Bore water security criterion 1, section 4.5.2.1, covers demonstrating whether groundwater is affected by surface or climatic influences.

2 Bore water security criterion 2, section 4.5.2.2, covers bore head protection.

3 Bore water security criterion 3, section 4.5.2.3, covers demonstrating the absence of *E. coli*.

The *E. coli* monitoring requirements depend on the nature of the bore.

If the bore water is from a spring or a groundwater source drawing from an unconfined aquifer that is less than 10 m below the surface, the water is to be considered equivalent to surface water. That means one of the bacterial compliance criteria in section 4.3 of the DWSNZ applies, and one of the protozoal compliance criteria in section 5 applies.

If the bore has satisfied bore water security criterion 1, or is drawing from an unconfined aquifer at least 30 m deep and there is hydrogeological evidence that the bore water is likely to be secure, the bore is given 'interim secure status'. Table 4.5 in the DWSNZ specifies the *E. coli* monitoring requirements for interim secure bore water. Bore water security criterion 3 is satisfied if *E. coli* are absent for 12 months, thereafter sampling can be reduced to the secure bore water rate.

If the bore is drawing water from an unconfined groundwater source that is between 10 and 30 m below the surface, *E. coli* need to be absent during the 5 year monitoring period before bore water security criterion 3 is satisfied, see Table 4.5 in the DWSNZ. During the five- year proving period, one of the bacterial compliance criteria in section 4.3 of the DWSNZ, and one of the protozoal compliance criteria in section 5, must be satisfied. Generally, this is most likely to be achieved by using UV disinfection, or preferably by chlorination plus UV.

Section 4.5.5 of the DWSNZ explains the actions to be followed in the event that *E. coli* are found during the 'proving period'.

### b) Ongoing monitoring of secure bore water

Once security has been demonstrated, the initial sampling frequency for *E. coli* testing for all populations is monthly; this can be reduced to quarterly once a further 12-month period has passed with all samples containing less than 1 *E. coli* per 100 mL, see section 4.5.4 and Table 4.5 of the DWSNZ.

Section 4.5.3 offers reduced *E. coli* monitoring of bores drawing from a common bore field.

Sections 4.3.9 and 4.5.5 of the DWSNZ specify the actions to be followed in the event of *E. coli* been found. Any detection of *E. coli* requires an immediate reassessment of the supply's security status. As well as a sanitary survey and inspection of the bore head, increased *E. coli* sampling is required.

Section 3.2.3.1 in Chapter 3: Source Waters discusses procedures to be followed after events such as major floods and earthquakes. These should be covered in the WSP. Ideally, weekly samples for *E. coli* testing for at least four weeks should be collected whenever the bore water may been have affected due to damage to the confining layer, bore head or adjacent bores.

If the secure bore water receives treatment that could allow microbiological contamination, or is stored uncovered, the water leaving the treatment plant (ie, the water entering the distribution system) must satisfy one of the bacterial criteria in section 4.3. In this situation, proving bore water security offers little advantage.

If a bore water maintains its secure status, it satisfies the bacterial compliance criteria. If it is chlorinated so that FAC can be maintained in the distribution system, there are no additional monitoring requirements for the water leaving the treatment plant such as monitoring FAC concentration, pH or turbidity.

Once bore water (secure or not) enters the distribution system, the bacterial compliance criteria in section 4.4 of the DWSNZ apply.

### 6.3.6 Monitoring drinking-water in the distribution system

The frequency of monitoring of the water in the distribution system will, as for the water leaving the treatment plant, be related to the population size, so that the larger the population receiving the water, the more testing is needed; see Table 4.3a in the DWSNZ. There are two reasons for population-based sampling. One is the number of people at risk from a contaminated supply, and the other relates to the fact that a distribution system serving a large population will usually be more extensive than that for a smaller population, thus there is more opportunity for breaches of the integrity of the system to occur.

It is very important that, when determining the number of samples to be taken for a compliance monitoring programme, managers look closely at the nature and quality of the distribution systems, the population base and fluctuations that do or could occur, and events that could impact on the integrity of the system, eg, very low or very high temperatures (these extremes tend to occur when the main is shallow or is not even buried), pipework maintenance and replacement programmes, land use and development, and retention time or distance.

A sampling programme should not be based simply on the minimum number of samples required for compliance but reflect good management practice (see Chapter 2: Management of Community Supplies) and be specifically designed for each system. It must be reviewed regularly to ensure it still meets its objectives and should be responsive to all types of change.

Section 4.4.3 of the DWSNZ refers to a sampling plan. Table 4.3a shows the minimum number of samples to be collected quarterly. To meet compliance criterion 6A in a zone of 5001 to 10,000 people, at least 16 samples per quarter must be collected which equates to a minimum of 64 samples pa. The compliance monitoring period (CMP) is a year. A water supplier this size that elects to collect the minimum number of samples accepts the risk that a single transgressing sample will result in non-compliance. Had the water supplier decided to collect 20 samples a quarter, they would be allowed one transgression per annum.

In selecting sampling points for the monitoring of a distribution system it is important that the points chosen represent the water being supplied to the consumer and give a comprehensive cover of the network. Points of high draw off should be featured, as should extremities of the system, where deadends occur, and areas where breaches are more likely, eg, service reservoirs, low usage areas where the FAC may have dissipated, old pipework, areas of low pressure, or areas at risk of being excavated.

It is recommended that there be 2–4 times as many sites as the minimum number required, and that these are rotated on a regular basis. At least one site should be sampled every sample round in order to indicate trends, especially if FAC is measured at that site as well. The extra sites will allow good coverage of the distribution system.

Service reservoirs tend to be contaminated more often than water mains, due to both breaches in structural integrity and to dissipation of chlorine residual in low turnover reservoirs. Therefore all service reservoirs should be inspected and sampled at least once during the course of a year, provided they are connected to the supply at the time. If any are only used seasonally, ie, just satisfying peak summer demand, they should be tested before going back on line.

Water suppliers should consider installing special sample taps off a short link from a watermain, rather than using consumers' taps. This will overcome problems such as accidents while flaming, or obtaining a positive result because the (perhaps dirty) tap was not flamed.

The monitoring plan must be documented, ideally as part of or appended to the WSP. The sampling scheduler facility in WINZ may be helpful in designing the monitoring plan.

The bacterial compliance criteria for water in the distribution system are discussed in section 4.4 of the DWSNZ. Criterion 6A applies to the situation when only *E. coli* testing is used. Criterion 6B is for zones supplying a population of over 500 and the water supplier has chosen to substitute FAC monitoring for some of the *E. coli* monitoring; this is discussed further in section 6.3.7.

The DWSNZ also cover bulk distribution zones. These are the parts of the distribution network that deliver water from the treatment plant(s) to one or more distribution zones. Usually, but not necessarily, they are owned and operated by a different water supplier, may or may not include service storage, and services only a nominal number of consumers directly. A bulk distribution zone may be identified due to its operational characteristics, or the characteristics of the water it supplies, by agreement between the water supplier(s) and the DWA. See section 4.4.7 of the DWSNZ for details.

Section 6.4 and section 17.2 of Chapter 17: Monitoring, Water Treatment and Drinking-water, cover sampling.

### 6.3.7 Chlorine testing as a substitute for *E. coli*

Chlorine inactivation of pathogenic bacteria and viruses requires a combination of sufficient contact time and the chlorine concentration at the end of the contact time. Drinking-water with a low chlorine demand will maintain the residual for longer.

The hypochlorous acid molecule (HOCl) is a very effective bactericide and virucide. At alkaline pHs, this dissociates to the hypochlorite ion ($OCl^-$) which is not a very effective bactericide. Chlorine becomes increasingly less effective as the pH rises above 8, see Chapter 15: Treatment Processes, Disinfection. The disinfecting power of chlorine in water can be measured by FACE (the FAC equivalent), which is the FAC concentration that would have the same disinfecting power as the chlorine solution would have when adjusted to pH 8.

If chlorine is being used correctly and there is evidence that there is adequate chlorine remaining at the completion of the inactivation step, chlorine monitoring can be used to reduce the *E. coli* monitoring frequency required to satisfy bacterial compliance.

For water leaving the treatment plant, FACE concentrations are measured after a contact of at least 30 minutes, see DWSNZ section 4.3.2. Because water in the distribution system has had a much longer contact time, much of it at a pH less than 8.0, FAC measurements are appropriate.

Experience in New Zealand is that water leaving the treatment plant with a FACE of at least 0.2 mg/L is most unlikely to contain *E. coli*. Likewise, water in the distribution system only very rarely contains *E. coli* if the FAC is over 0.2 mg/L; 0.2 mg/L FAC after 30 minutes retention is equivalent to a C.t value of 6 mg/L.min. A further advantage in allowing substitution is that chlorine test results are available immediately, whereas *E. coli* results take at least 24 hours.

Compliant online chlorine monitoring of water leaving the treatment plant gives a very high level of confidence in the disinfection process. Therefore bacterial compliance criterion 2A allows FACE monitoring in lieu of *E. coli* monitoring, DWSNZ section 4.3.2.1. But because *E. coli* monitoring may be completely substituted, the FACE must be at least 0.2 mg/L for 98 percent of the time.

Bacterial compliance criterion 2B specifies the conditions that will allow a reduced level of *E. coli* monitoring, DWSNZ section 4.3.2.2. Likewise, bacterial compliance criteria 4 and 5 allow reduced *E. coli* monitoring, provided the ozone and UV disinfection processes are compliant, see sections 4.3.4 and 4.3.5. This option was introduced in 2005 because some smaller water suppliers claimed they could not afford to meet all the requirements of continuous monitoring in the time allowed. This option was never considered to be permanent.

Figure A1.1 in DWSNZ shows how much FAC is required to produce 0.2 mg/L FACE at a pH from 8.0 to 9.0. Figure 17.6 in Chapter 17: Monitoring (in the *Guidelines*), shows the percent of undissociated HOCl at a wide range of pHs. These figures are diagrammatic, so it is not possible to use them to convert mg/L FAC to mg/L FACE accurately.

This can be done more accurately using a spreadsheet, eg, Excel, see Table 6.1 for an example. Enter the FAC readings in column A and pH in column B. Copy the following formula and paste into cell C2 to obtain FACE concentrations. The formula is:

```
=IF(B2<8,A2,((A2*(1+((10^(-1*(3000/283-10.0686+(0.0253*283))))/10^-
8)))/(1+((10^(-1*(3000/283-10.0686+(0.0253*283))))/(10^-B2)))))
```

Substitution of chlorine tests for *E. coli* tests cannot be allowed so readily for water in the distribution system. This is because there is less control over the FAC once the water enters the distribution system. If a breach in the distribution system occurs, there will be no way of knowing whether there has been adequate contact time for microbial inactivation to have occurred.

**Table 6.1: Example spreadsheet for converting FAC to FACE**

| Row 1 | Column A<br>FAC | Column B<br>pH | Column C<br>FACE |
|---|---|---|---|
| 2 | 1.40 | 9.0 | 0.20 |
| 3 | 1.15 | 8.9 | 0.20 |
| 4 | 0.92 | 8.8 | 0.20 |
| 5 | 0.74 | 8.7 | 0.20 |
| 6 | 0.59 | 8.6 | 0.20 |
| 7 | 0.46 | 8.5 | 0.19 |
| 8 | 0.40 | 8.4 | 0.20 |
| 9 | 0.34 | 8.3 | 0.20 |
| 10 | 0.28 | 8.2 | 0.20 |
| 11 | 0.24 | 8.1 | 0.20 |
| 12 | 0.20 | 8.0 | 0.20 |
| 13 | 0.20 | 7.0 | 0.20 |
| 14 | 0.35 | 6.8 | 0.35 |
| 15 | 0.50 | 8.3 | 0.30 |
| 16 | 0.45 | 9.1 | 0.05 |

For water supplies serving more than 500 people, DWSNZ section 4.4.2 (compliance criterion 6B) allows some substitution of *E. coli* testing of water in the distribution system with chlorine tests, subject to turbidity constraints, and the FAC being generally >0.2 mg/L. Earlier (since 1995) the DWSNZ allowed partial substitution for water supplies serving more than 30,000. The success of this substitution has allowed this approach to be extended. The third addendum to the WHO Guidelines (2008) states in Table 8.27: "a chlorine residual should be maintained throughout the distribution system. At the point of delivery, the minimum FAC should be 0.2 mg/L".

The DWSNZ state in section 3.1.1: "the DWA must assess the competence of the analyst for commonly-performed plant or distribution system analyses (field tests), refer HDWAA 69ZL e and f, and 69ZP h; analysts must be certified as competent if carrying out compliance testing".

If free chlorine is the active disinfectant, free chlorine analysers must be used to monitor the disinfection process. Oxidation reduction potential (ORP) meters cannot be used to measure disinfection effectiveness for chlorination. Studies have demonstrated that chlorination effectiveness is not well predicted with ORP measurements and that ORP does not vary in direct proportion to chlorine residual. Furthermore, calculation of residual concentration from measured millivolts can result in large errors of ±30 percent (State of Victoria 2013).

Once again, these sampling frequencies are the minimum required to demonstrate compliance; additional process control testing is recommended. Also, a lot can be learned about the distribution system if chlorine is monitored continuously at at least one site.

Bacterial compliance criterion 7B, section 4.4.2 in the DWSNZ, specifies the conditions that allow full substitution of *E. coli* monitoring in bulk distribution zones with online FAC (or chlorine dioxide) monitoring.

The ability of chlorine dioxide to inactivate bacteria is at least as effective as chlorine, and it is not pH dependent. Bacterial compliance criterion 3 allows water leaving the treatment plant to be monitored by online chlorine dioxide measurement in lieu of *E. coli* monitoring, see section 4.3.3 in the DWSNZ. Bacterial compliance criterion 6B allows some *E. coli* tests to be substituted by monitoring the chlorine dioxide residual in the distribution system, see section 4.4.2 in the DWSNZ.

Experience with chloramine disinfection in New Zealand is limited, so the DWSNZ do not allow substitution of *E. coli* monitoring by monitoring chloramine residuals.

Disinfection at the treatment plant with ozone or UV light does not generate a residual that can be carried into the distribution system, so *E. coli* substitution is not allowed there.

# 6.4 Sampling and testing

## 6.4.1 Sample handling

The consequences arising from obtaining faulty samples are serious (eg, declaring that a secure bore water is no longer secure), so the sample collection technique must be thorough. Calling a positive test result a 'false positive' or blaming it on a contaminated sample (ie, the sampler), a frequently used excuse, is not acceptable; the minimum corrective action for this is retraining the staff concerned.

It is possible to include some quality assurance steps in the sampling process. Some water suppliers take a bottle of sterile water on the sample collection run and include it as a control sample with the samples collected. Another technique is to take an empty sterile bottle on the sample run and fill it back in the laboratory with sterile water for testing with samples collected. Another approach is to collect one sample in duplicate on every sample run in order to develop a history of repeatability. Water samplers should always take with them more sample bottles than required so that if there is any suspicion about the integrity of the bottle-filling step, another sample can be collected. Results of QA procedures should be recorded.

Ideally, sample sites should be shown on a sample map, with instructions about how to find them, and must be able to be recognised unambiguously. If the sample is collected from a house or other situation where there is more than one tap, the tap to be used must be indicated clearly.

It is important that the samples of water collected for testing are collected and transported properly. Water samplers must be trained in aseptic technique. If the samples are invalid the subsequent analysis could be a waste of time, and any reporting is likely to be misleading or not accepted. All sample collectors should be trained in the correct procedures (which should have been documented) and should be able to demonstrate their competence. Sample collection is part of field testing, so the DWA will assess the competence of the sampler. Participating laboratories should provide detailed sampling procedure instructions.

All water samples must be identified and labelled clearly. Samples to be included in a monitoring programme should be labelled with a unique number that clearly identifies the sampling site and can be interpreted by anyone familiar with the system for identification of New Zealand water supplies. Sample containers must be labelled on the body of the container not just on a lid, as these may become separated from the water sample during the laboratory analysis. Water suppliers and/or laboratories should specify the sample sites and sampling procedures in a sampling manual. Water suppliers must ensure that all samplers are appropriately trained for compliance monitoring. DWAs assess the competency of individuals performing field tests; sampling procedures are considered to be a field test (or part thereof).

Containers used for collecting microbiological samples must either be sterilised by the laboratory before use or single-use pre-sterilised containers may be used. Laboratory sterilisation requires either one hour at 170°C in a hot air oven for glass containers or 15 minutes in an autoclave at 121°C. A pressure cooker can be used if there is no alternative, but the sterilisation time may then need to be extended and an autoclave indicator used.

The sample containers must have securely fitting stoppers or a leak-free sealing system. Sealing the container must be a straightforward procedure that does not carry a risk of the sample becoming contaminated. Sample containers should be filled leaving sufficient air space for the sample to be thoroughly mixed by shaking before it is tested in the laboratory.

Where chlorine, chlorine dioxide, chloramine or ozone is used as a disinfectant for a water supply, it is important that the residual is neutralised by the addition of sodium thiosulphate to the sample so it does not continue to act. The thiosulphate must be added to the container before it is sterilised. It is not acceptable to add the thiosulphate afterwards, as this may lead to contamination of the water sample. For drinking-waters, 0.1 mL of a 3 percent solution of sodium thiosulphate will neutralise up to 5 mg/L of FAC in a 120 mL sample.

Specially dedicated taps off a short link to a water main can overcome problems of access and flaming. Service reservoirs should also have dedicated taps; if samples have to be collected by dipping, special sampling equipment that can be sterilised must be used. In choosing taps to sample from, avoid those that are leaking or have attachments or hose, unless these are a feature of the drinking-water system.

There is some debate about flaming taps. Taps in pits, valve chambers, etc (if they have to be used) should be flamed because they are likely to be contaminated by road dirt, dogs, etc. If flaming in a pit or valve chamber, check that there are no natural gas mains in the vicinity. Entering valve chambers requires health and safety training. People drink directly from taps in dwellings so, in theory, collecting a sample without flaming represents the drinking-water supply. However, if a fixture contains *E. coli* (eg, splash from dirty napkins on the tap in the washhouse) there is a possibility that the result does not reflect the true condition of the water supply. If taps are unsuitable for flaming then an alternative surface sterilisation is required, such as spraying with 70 percent alcohol or sodium hypochlorite solution, but ensure any residue is well and truly flushed off. A study by DWI (2004) found results for samples taken without prior preparation of the tap showed a number of failures, mostly for total coliforms. In contrast, the results obtained after disinfection of the tap – the normal sampling procedure – resulted in only a single failure (for enterococci).

Open the tap and let the water run to waste for several minutes before taking the sample to represent the water in the system, unless investigating the quality of the first flush or stagnant water in the pipe. When collecting samples for microbiological testing, fill the container without prior rinsing. Sample bottles must be kept closed until they are about to be filled. Take care when opening the container not to contaminate the neck of the container or the inside of the lid or cap with fingers or to make contact with tap or surrounds. Seal the containers carefully, again taking care not to contaminate the sample.

Both empty and filled sample containers must be stored in a clean environment. Empty containers that have not been used should be returned to the laboratory to be resterilised if they become dirty or there is any concern that the seal may have been broken. Devices such as strips of autoclave tape on the necks of bottles may be used as indicators of seal integrity.

Samples must be transported to the laboratory as quickly as possible after collection and should be kept cool and in the dark during transport. Water is not a natural environment for *E. coli*, so they are not expected to increase in numbers in New Zealand unless the water contains the required nutrients and is very warm. Water is such an unattractive environment that *E. coli* are more likely to die than grow. Their metabolic rate is slower in cold water allowing them to remain alive longer.

If transport times exceed one hour the samples should be maintained below 10°C but not frozen. Samples that arrive in the laboratory warmer than 10°C shall not be used for compliance testing unless the temperature of the water has not increased during transit. This can be demonstrated by:

1 measuring (and recording) the water temperature at the time of sampling and upon receipt into the laboratory, or

2 observing that the ice or coolant used in the container (eg, chillibin) to transport the samples is still frozen and that the sample bottles are packed in a manner that would allow the water sample to cool.

If the water sample has been collected for other tests as well (but obviously not containing sodium thiosulphate), do the microbiological tests first. If samples cannot be processed immediately on their arrival in the laboratory, they must be stored in a refrigerator, at a temperature not exceeding 5°C. The time the samples are processed should be recorded on the laboratory work sheet.

If the above temperature requirements are not satisfied, it may be valid still to process the samples, depending on the bacterial history of the supply and the exact details of sample temperature and transit time. However, the information must be used to modify the sample transport technique.

Normally, the temperature of water samples from a town supply will be very similar on any particular day, simply reflecting seasonal variation. The temperature of many bore water supplies are consistent throughout the year. However, there have been instances where samples have shown atypical temperatures. For example, long service pipes (perhaps feeding back sections) that are shallow or on the surface can produce water that is very warm (even over 40°C) in summer, or approach freezing in winter, and some houses or buildings have small header tanks where the water temperature can be affected by ambient conditions. Water in above ground service reservoirs with very low turnover has reached 32°C. Regrowth is probable at these elevated temperatures. If people are drinking water at atypical temperatures, it must be valid to test these samples. Preferably, the water supplier or property owner will rectify the situation leading to atypical water temperatures.

The laboratory results are probably the most reliable if the test is performed within six hours of the sample being collected. Samples more than 24 hours old should be discarded.[3] Tests performed on such samples cannot be interpreted with any confidence as bacterial counts may increase, decrease, or remain the same, over time. See section 4.3.6 of the DWSNZ. Sometimes it may be impossible to satisfy all the temperature and time requirements so there is an advantage in collecting more than the minimum number specified in the DWSNZ.

## 6.4.2 Test methods and sources

Bacterial compliance monitoring must be conducted by a laboratory recognised by the MoH for that work, see IANZ (2007).

The DWSNZ (Appendix A2.1) have specified the referee methods for testing for *E. coli*, faecal coliforms and total coliforms. These methods are described in *Standard Methods for the Examination of Water and Wastewater*, APHA, 21st edition, 2005 and are already in wide use in New Zealand laboratories.

Non-referee methods are acceptable for water testing provided the performance of the test compared with the referee test is known and there is provision for checking that the test continues to perform satisfactorily and the method has been approved for compliance testing by the Ministry of Health. This can be done either in-house or by regular parallel testing of samples by laboratories using a referee method. See: *The Ministry of Health procedure for approval of new test methods for bacteriological compliance testing of drinking-water samples using presence/absence methods*; **http://www.health.govt.nz/publication/ministry-health-procedure-approval-new-test-methods-bacteriological-compliance-testing-drinking**.

A report was prepared by NIWA (2005) for the Ministry of Health: *A Proposal for Strength of Agreement Criteria for Lin's Concordance Correlation Coefficient*. A simple test is proposed for establishing the equivalence of an analytical method with the referee method for *E. coli* prescribed in the DWSNZ. A concordance calculator enables the strength-of-agreement to be calculated.

Presence/absence tests and tests such as the Colilert and Colisure tests now have international recognition and are approved by the MoH as methods for testing water supplies, have been available for some years and now have been developed to the stage where they are an extremely useful and simple approach for testing water supplies where ready access to a routine laboratory is not available.

[3] There may be some exceptional circumstances where this is not possible, such as sampling remote water supplies where the courier service cannot satisfy the 24-hour requirement. In these circumstances section 4.3.6.1 of the DWSNZ refer readers to section 3.1.1 which states "Special procedures may be authorised in writing by the Ministry for small or remote drinking-water supplies".

Laboratories using presence/absence tests will also need to be able to perform, or get another laboratory to do for them, enumerations when a positive test result occurs. It is essential when problem solving a positive result that there are bacterial counts to allow an estimation of the severity of the problem and to monitor subsequent remedial action, DWSNZ sections 3.1.2 and 4.4.6.

Presence/absence (P/A) tests are unsuitable for testing water supplies known to have *E. coli* problems, as delays in obtaining quantitative results would make problem-solving unacceptably slow.

Whichever method is chosen for detection of *E. coli* or faecal coliforms, the importance of resuscitating or recovering strains that have been sub-lethally damaged by environmental stresses or during drinking-water treatment must be considered.

It is not acceptable to call a positive test result a false positive. False positives can occur, but are rare when using acceptable test methods. If it is believed that some positive P/A test results are false positives (ie, caused by bacteria other than *E. coli*), follow this procedure:

Culture the bacteria growing in the P/A broth on to a selective medium that *E. coli* can be recognised on (eg, EMB agar), isolate and purify each colony type, identify taxonomically each of the isolates and inoculate each pure culture into the P/A test medium. The result is to remain as a transgression unless all of the following conditions are satisfied:

1 none of the cultures tested are *E. coli*

2 all of the isolates are identified as something other than *E. coli*

3 at least one of the isolates gives a positive P/A reaction upon retesting.

*E. coli* can be enumerated by incubation on selective solid media and by incubating a series of inoculated tubes containing selective broths. The former method involves counting positive colonies and reporting the results as the number per 100 mL. The latter technique, the multiple tube technique, reports results as the most probable number (MPN) per 100 mL, and this is obtained by looking up MPN tables. Standard Methods (APHA 2005) offers a fairly restricted arrangement of tubes (numbers thereof and volumes), and therefore a correspondingly small number of MPN tables. The detection limit in their tables is 1.1 MPN per 100 mL, which is greater than the DWSNZ MAV of <1 per 100 mL.

Standard Methods includes an equation (called Thomas' simple formula) for calculating the MPN for when using different volumes or numbers of tubes. Provided more than 100 mL of aliquot is used in the multiple tube technique, the detection limit becomes suitable for bacterial compliance purposes. However, Thomas' simple formula produces approximate results. NIWA has developed a more exact approach using a program called XactMPN (McBride 2003).

Compliance with bacterial compliance criteria 2A and 7B can be achieved by FAC monitoring alone. See Chapter 15: Disinfection, section 15.5.1.3 for a discussion on chlorine measurement.

### 6.4.3 Laboratory competency

The DWSNZ (section 3.1.1) require that water testing laboratories that test water samples for compliance are on the Ministry of Health's Register of Laboratories that have been recognised by the Ministry as competent for the purpose. See Chapter 1: Introduction, section 1.3.10 for a summary of some requirements of recognised laboratories.

The Ministry will require laboratories to identify water samples with the unique drinking-water supply code published in the *Register of Community Drinking-water Supplies in New Zealand*, to be using acceptable methods (Appendix 2 of the DWSNZ), to have adequate documented quality assurance procedures, and to demonstrate that they are competent by satisfactory performance in an inter-laboratory comparison programme.

It is essential that laboratories have documented quality assurance procedures. This does not need to be in the form of very detailed manuals but the basic procedures of the laboratory must be written down. It needs to be quite clear what procedure is being used and exactly how the tests are carried out. All key activities must be documented and everyone involved in testing, from sample collector to the person reporting the results, must have a thorough understanding of their responsibilities and duties, any problems that could arise and how they should be dealt with. All activities undertaken must be recorded so that it is quite clear, from the time of collection of the sample to the reporting of the results, who did what and when.

All laboratories, regardless of size, must be able to demonstrate competence. This means they should be audited independently and ideally, participation in an inter-laboratory proficiency programme. In addition there are a number of other mechanisms for showing competence, eg, spiked samples, split samples, duplicates, positive and negative controls, both within the laboratory and in collaborative tests with other laboratories.

The positive control sample is particularly important. If all the water supply samples give a negative result, this could be explained by all the samples being free of *E. coli*, but equally it could be explained by the test not working. Maybe the incubation temperature was too hot or cold, or maybe there was an inhibitor in the water samples that caused the test not to work. With a positive control sample included in the same batch of samples, this problem is resolved:

a) if the control sample gives a positive result then the negative tests demonstrate the absence of *E. coli* in the samples that test negative

b) if the control sample gives a negative sample then the samples giving negative results may also contain *E. coli* that did not grow under the conditions of the test so invalidating the results for that batch of samples.

A negative control sample testing positive suggests contamination of the control sample, of the media or equipment, or handling, or sample identification. If water supply samples in this batch also tested positive, interpretation of results will be difficult.

See Chapter 17 for further discussion.

# 6.5 Transgressions

## 6.5.1 Response

An important aspect of a drinking-water monitoring programme is the response that is made to a transgression. When a sample of drinking-water is found to contain *E. coli* it is essential that there be an immediate response to identify the possible source of the contamination and to implement corrective actions. The minimum response recommended is shown by flow diagrams in section 4 of the DWSNZ, Figures 4.1 and 4.2.

Scheduled compliance sampling and testing must continue through this response phase. Sufficient additional monitoring is required in order to discover the cause of the problem. This means that sampling should be on at least a daily basis. It is not satisfactory to take a sample and then wait for the result of the test before further samples are collected. There must be a series of samples being evaluated over a period of time to give a comprehensive picture of the extent of the problem. The DWSNZ require that at least three consecutive days must be free of positive *E. coli* results before corrective action may be considered to have been successful. This means three days of tests, not tests three days apart!

Water suppliers' WSPs must also document planned responses to events other than failing to satisfy the criteria in the DWSNZ that will obviously lead to a bacterial transgression or non-compliance. These will tend to be supply-specific but will include matters such as dealing with power cuts, running out of disinfectant or failure of the disinfection system or disinfection demand exceeding the maximum dose rate, treatment problems, labour problems, work on the distribution system, commissioning new plant and equipment, breach of security, spills of wastewater or other contamination.

Undisinfected water supplies must include provision for disinfection for times when *E. coli* are found. It is inappropriate to not use chlorine on the grounds of perceived taste/odour problems, or colour/turbidity arising due to oxidation of iron and manganese in groundwater supplies.

The USEPA (2010) published a draft Assessments and Corrective Actions Guidance Manual which includes much discussion and several check lists.

### a) Response to finding *E. coli* in secure groundwater

This topic has already been discussed in section 6.3.5, which refers to sections 4.3.9 and 4.5.5 of the DWSNZ. Also, read section 3.2 (Groundwater) of Chapter 3: Source Waters for aspects concerning secure groundwater, water quality and bore head protection.

## b) Response to finding *E. coli* in the water leaving a treatment plant

Water suppliers using bacterial compliance criteria 1 and 2B must monitor *E. coli*. Water suppliers using bacterial compliance criteria 4 and 5 in such a manner that protozoal compliance is not achieved also must monitor *E. coli*. Remedial actions for when *E. coli* are found are covered in section 4.3.9 of the DWSNZ.

The detection of *E. coli* in samples taken from water leaving the treatment plant is a major concern to the plant operator as it indicates failure of one or more of the barriers and a major risk to the community of illness from drinking the contaminated water. For the susceptible sections of the population such as babies, the elderly, and those with a number of medical conditions, contaminated drinking-water may, in the absence of major pathogens, still be the cause of significant illness. Thus the supply authority must respond immediately and effectively to the detection of *E. coli* in repeat samples, eg, by additional disinfection and/or issuing a boil water notice (see Appendix, this chapter).

Other conditions may give rise to the need for a boil water notice, such as an increase in the turbidity of the final water after heavy rain, indicating a breakdown in the treatment process, or when the water entering the distribution system is turbid and unchlorinated. Issuing a boil water notice must be considered at an early stage in the investigation and not seen as a last resort when all else has failed. The community's health is paramount and there is a moral obligation for the water supply authority to alert the community to potential hazards. Boil water notices should remain in force until the water supply has returned to a satisfactory quality; however, they are not meant to be a permanent solution to a substandard supply.

The response to possible scenarios should be documented in the WSP. Firstly, see Figure 4.1 and section 4.3.9 of the DWSNZ.

In attempting to discover the cause, records of the previous day's turbidity, pH, and FAC levels in the final water should be examined, as well as the turbidity in the raw water and throughout the treatment process. Check all records of the operation, inspection of disinfectant dosage, and check all relevant calibrations.

If *E. coli* were found in a sample of water leaving the treatment plant the previous day, then that water may still be in the distribution today. This needs to be checked because contamination events that exceed 24 hours can be serious. Knowledge of the distribution system will indicate where the extra sample(s) should collected. The number of additional distribution system samples that are collected will depend on the results of the inspection of plant records, the size of the distribution system, and the number of *E. coli* present in the sample.

## c) Response to a transgression of an operational requirement

Water suppliers using bacterial compliance criteria 2A, 2B, 3, 4 and 5 for water leaving the treatment plant must monitor parameters related to the performance of the disinfection process being used. These operational requirement tests can include FAC, chlorine dioxide, and ozone concentrations, UV intensity, pH, turbidity, temperature and flow. Remedial actions are covered in section 4.3.9 of the DWSNZ. The DWSNZ allow some leeway with these operational requirements. For example, bacterial compliance criterion 2B requires turbidity to be less than 1.0 NTU for at least 95 percent of the compliance monitoring period; ie, 108 h in 90 days – that is 4.5 days – plenty of time to address a problem before it becomes a non-compliance. However, if this is a recurring problem it may be a design fault which needs to be resolved by improving the treatment process. Or it could be a staff training issue.

Satisfying bacterial compliance criteria 2A and 3, and bacterial plus protozoal compliance with compliance criteria 4 and 5, does not require any routine *E. coli* monitoring, so transgressions must be attended to immediately.

Figure 4.1 in the DWSNZ covers the response to a transgression in drinking-water leaving the treatment plant. Transgressions can result from finding *E. coli*, or finding evidence that the disinfection process is inadequate. Both need immediate action. It is not simply a matter of switching to bacterial compliance criterion 1. Criteria 1 and 2A (etc) are for routine monitoring in normal conditions. But this is not a normal condition – it is a situation with potentially increased risk. The "best" action will depend on the cause of the transgression, the quality of the raw water, etc, i.e. the perceived level of risk. There may well be water supplies where a switch to criterion 1 is appropriate while the problem is being attended to – but at the other extreme, a boil water notice may be advisable! Finding *E. coli* in water leaving the treatment plant is addressed in (b).

The DWSNZ recognise two types of transgression of the disinfection process:

1. when the transgression is a result of the monitoring process. If this happens the DWSNZ require a minimum of twice-daily manual measurement of the disinfectant, pH, turbidity (and flow if required) until the instrumentation is performing satisfactorily. There may be situations where this is not practical. An alternative could be to report the daily plant flow and weight of disinfectant used (or kWhs for ozone or UV) and calculating the daily dose rate and showing that this has continued to meet the disinfection target
2. when the transgression is a result of a disinfection malfunction. This problem needs to be covered in the WSP. Sensibly, and most simply, a WTP would have standby disinfection equipment, or spare containers of chlorine, or supplies of other chemicals, and spare parts for the equipment. Adequate storage, say 24 hours, of treated water is often overlooked too. When a transgression is due to elevated pH causing the FACE to fall below 0.20 mg/L, all that would be required is to increase the chlorine dosage until the FACE is over 0.20 mg/L. If chlorination is impaired by a turbidity transgression, additional E. coli sampling may be the most sensible option until the turbidity has returned to normal. These situations are supply-specific; the actions required at a clean mountain stream source will be different from a lowland river source.

A well-managed water treatment plant will have introduced control limits that trigger corrective actions before reaching the transgression level. Potentially useful actions will appear in the WSP. Water suppliers should be encouraged to think about what they have to do to demonstrate that the water is safe to drink, rather than non-compliance.

## d) Response to finding *E. coli* in the water in the distribution system or zone

Finding *E. coli* in one part of a distribution zone should trigger an immediate search for the source of that contamination. If the level of contamination is high (≥10 *E. coli* per 100 mL) the need to warn consumers in the affected areas should be considered. Where the source of the contamination is found quickly and corrected, there may be no need to alert the community because the hazard no longer exists. However, the drinking-water assessor should still be informed because there has possibly been an opportunity for transmission of waterborne disease. If the source of the contamination is not readily apparent, or is not able to be corrected immediately, the community must be informed.

As with all systems failures, it is important that the failure and the corrective actions are well documented and that sampling regimes remain enhanced until there is complete confidence that the corrective actions have been effective and no recurrence of the failure is likely. This will require consideration of various possibilities.

Firstly, see Figure 4.2 and section 4.4.6 of the DWSNZ. The distribution system can comprise three clearly different components; these are discussed separately below.

### The water suppliers' local pipework

Say the laboratory reports that *E. coli* has been found in a sample or samples collected the previous day. One of the responses the DWSNZ requires is to resample immediately. This requires some deliberation:

- if the water leaving the treatment plant also contained *E. coli*, and all samples collected that day from the distribution contained *E. coli*, then it is highly likely that there is a large scale public health problem, due to contaminated water or inadequately disinfected water passing through the system
- if the water leaving the treatment plant also contained *E. coli*, but only one sample (of many) from the distribution system contained *E. coli*, then the problem may have existed for only a relatively short period, or that the sampling had just detected the beginning of a large scale problem
- if the water leaving the treatment plant did not contain *E. coli*, and there had been only one sample collected from the distribution system, then it is possible that the cause was due to inadequately disinfected water passing through the system but that the cause (at the treatment plant) was largely diminished by the time the samples were collected; or it could a spasmodic contamination event in the distribution system

- if the water leaving the treatment plant did not contain *E. coli*, and the one sample with *E. coli* was one of many collected from the distribution system that day, then the problem may be either spasmodic, or the sampling detected the end of a larger scale problem.

Each of these scenarios suggests a different response. The two most practical responses are:

- the minimum resampling should include the sample site that produced the *E. coli*. If the contamination was local, this will show whether the problem still persists
- the previous day's water will now be further through the distribution system and it may still be contaminated. An understanding of the network will indicate the most likely sample sites to check this.

There may be other features or knowledge that suggest a different approach. For example:

- if the FAC level in the positive sample was lower than expected, it may indicate that some dirty water entered the distribution system while it was being repaired, or
- it may indicate that a service reservoir had been releasing water, or
- it may indicate that there had been some water leaving the treatment plant with less FAC than normal, or no FAC, for a while
- if the total plate count of heterotrophic bacteria at the site where *E. coli* were found was higher than usual, it may indicate that contaminated water entered the system; check where the mains repair gang has been operating, or if the Fire Service has been using or testing fire hydrants
- if the FAC level in the positive sample was within the normal range, it is possible that the contamination was very recent and/or very near the sample site.

For discussion on heterotrophic bacteria, see WHO (2003).

Throughout the above discussion, it is assumed that appropriate backflow prevention is in place.

The numbers of *E. coli* found will also suggest different actions. For example, finding several samples with more than say 10 *E. coli* per 100 mL should prompt a much more intensive and urgent response than finding just one sample with 1 *E. coli* per 100 mL.

Each water supply is unique, so the response when finding distribution system samples with *E. coli* should be based on the characteristics of the supply, with due acknowledgement of previous episodes. The various scenarios should be addressed in the WSP so the procedure is documented before the event, and valuable time is not lost.

### Service reservoirs

The response will depend on how the reservoir or tank is operated. Some are in constant use with such a short retention time that the FAC concentration in the water leaving the reservoir is not much lower than that going in.

Some have a very long retention time so that FAC is rarely found in the water leaving the reservoir. Others are only used to maintain pressure in hilly areas during periods of peak consumption. Some have a common inlet/outlet, so some water will be fresh and some old.

Advice on service reservoir design and operations appears in Chapter 16: The Distribution System.

Collecting samples from service reservoirs can be a challenge and may require special techniques and equipment. It is recommended that sample taps be included at the design stage of new reservoirs, and if possible, installed during a shutdown of existing reservoirs.

Finding *E. coli* in a service reservoir is usually a sign that it is not as secure as it should be. Apart from problems arising from poor design, problems can result from contaminated water entering through cracks in the concrete roof, or walls if partly submerged (Kettell and Bennett 1993). Problems can also result from hatches being left open, or being prised open by vandals, or if gaps are big enough to allow birds or other animals (or their wastes) egress. As well as collecting the samples, the water sampler should also inspect the reservoir.

The WSP should include a service reservoir inspection and maintenance programme.

### Bulk distribution zones

The response when finding *E. coli* (compliance criterion 7A) should be as for the water suppliers' local pipework above, except that the previous day's water will now be further through the distribution system and this probably means in another authority's system. The responses that should follow discovery of *E. coli* in a bulk distribution zone should be documented in agreement with the client(s), before *E. coli* are found. A minimum requirement must be to advise the client of the discovery.

If the FAC concentration falls to transgression level (compliance criterion 7B), investigate the cause immediately, see DWSNZ section 4.4.7.5. Possible remedial actions should be anticipated in the PHRPM, and may include: checking records of the FAC leaving the treatment plant, checking chlorine consumption vs flow, recalibrating monitoring equipment.

## 6.5.2 Record keeping

For each water supply there should be a fully documented description of the microbiological monitoring programme. The documentation should include details of the treatment plant and the barriers, the sampling regime and the results of the testing, both routine and non-routine.

The first step in the record keeping process will be to determine how many samples are to be taken, and when. This is decided after evaluation of the nature of the source water, the type of treatment process and the extent and age of the distribution system. This must include separate calculations for the water leaving the treatment plant from that in the distribution system. These calculations should be based on a hazard analysis of the system and identification of any critical points in the process and system where enhanced sampling would provide good assurance of the efficiency of the process, monitoring any weak points in the distribution system, being responsive to external factors that could affect efficiency, etc. Sampling points must be identified clearly and evaluated to give comprehensive coverage of the system.

The results of the routine sampling must be kept in an easily accessible form and must include an automatic alert when transgressions occur. This could be a function of the laboratory undertaking the tests. The laboratories must be provided with clear instructions regarding to whom transgressions are to be reported, and how. Once a transgression is notified the water supplier should follow the procedures documented in the WSP and all outcomes of this response recorded. Water supply managers may wish to include a format for recording the follow-up procedure in the WSP. At the end of a period of non-conformance, the episode should be analysed and the introduction of procedures to prevent a recurrence considered. Action plans must allow for contingencies such as the absence of any staff.

Where a number of transgressions occur, it is essential that a complete evaluation of the water supply occurs to look at how the situation can be improved. In extreme cases this may lead to a recommendation that a source no longer be used or that major improvements to the process and system be implemented to assure compliance with the DWSNZ. The information for making such decisions can only come from well-kept records that give a comprehensive overview of all test results, problems and attempted solutions.

Reporting requirements are covered in section 13 of the DWSNZ.

# Appendix: Boil water notices

Water suppliers need to accept that boil water notices may be needed at some stage to address short-term problems. These need to be considered in advance, ideally as a part of the Water Safety Plan (WSP – formerly known as Public Health Risk Management Plans, PHRMPs). The plan should address:

- the purpose of boil water notices
- which situations should prompt a boil water notice to be issued
- how to handle situations that boil water notices cannot address
- who should initiate, approve, authorise, and release a boil water notice
- who (in the water supply authority) should be informed
- who else needs to be told, including those with special needs
- maintaining a current contact list of all involved, including emergency contacts

- each person's responsibilities, including those outside the water supply authority
- what the boil water notice should say
- how all those affected shall be informed of the boil water notice
- how to inform those concerned with progress in dealing with the situation
- when an alternative water supply should be provided, and how to do this
- how and whom to advise that the boil water notice has been withdrawn
- procedures for reminding the public if the boil water notice is more than several days
- follow-up procedures to assess performance and improvements.

Health Canada (2015) summarises the factors that should be considered before boil water advisories are issued or rescinded. It provides specific guidance for use during a boil water advisory, including how to properly boil or disinfect water. Health Canada (2009) covers emergencies other than when a boil water advisory is appropriate ie, for when the water supply is contaminated, usually due to chemicals.

See DWI (2012) for a discussion on the effectiveness of different methods of informing the public of the need to boil water.

WHO (2015) states that bacteria are particularly sensitive to heat, and rapid kills – less than 1 minute per log (90%) reduction – are achieved at temperatures above 65°C. Based on these results, it is considered that the process of heating water to a rolling boil, as recommended in the *WHO Guidelines for Drinking-water Quality* (WHO 2011), is sufficient to inactivate pathogenic bacteria, viruses and protozoa. After the water has reached a rolling boil, it should be removed from the heat, allowed to cool naturally, without the addition of ice, and protected from post-treatment recontamination during storage. If turbid water needs to be clarified for aesthetic reasons, this should be done before boiling.

NHMRC, NRMMC (2016) added a six-page Information Sheet to their Australian Drinking Water Guidelines, titled "Guidance for issuing and lifting boil water advisories".

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