CHAPTER 6

BACTERIAL 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. 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 in distribution. Faecal contamination usually will not be distributed evenly throughout a piped distribution system. In systems where water quality is good, this reduces the probability of detecting faecal indicator bacteria in the relatively few samples analysed.

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 techniques give a numerical result.

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 faecal contamination is *E. coli.*

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 2005* (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), i.e. transgressions, can be tolerated with the water supply remaining in compliance with the DWSNZ. Nevertheless, action is required whenever a transgression occurs, see Figures 4.1 and 4.2 in the DWSNZ.

6.2 MONITORING FOR *E. COLI*

6.2.1 GENERAL PRINCIPLES

A 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* is an important method for detecting if the barriers being used to provide safe drinking-water and to prevent contamination have been breached. Note that this monitoring should not be used to decide when further water treatment should commence, because by the time the alert has been raised by a positive test, a large volume of contaminated water may have reached consumers. Largely for this reason, the DWSNZ have over recent editions, shifted the emphasis from reliance on compliance monitoring 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. This 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 caters for population size (see its Tables 4.1, 4.2, 4.3 and 4.4).

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. It is for these reasons that sampling effort under the DWSNZ is related to population size.

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. 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 suggests 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 systems 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 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 system and look for unexpected breaches. Someone who thoroughly knows the system under investigation will 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 PHRMPs). 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 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, (e.g. contamination during sampling or processing, or detection of a non-faecal particle), rather than a genuine event. Accordingly, practical compliance rules cannot be derived for 100% confidence, (i.e. 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% has been adopted (as is common for precautionary approaches).

For the first issue, the position adopted is that *E. coli*, turbidity and chemicals should not transgress for more than 5% of the time, and that where applicable, disinfection C.t values and UV fluence should not transgress for more than 2% of the time. The latter is the more stringent, because it measures the effect of an important barrier: disinfection.

Figures 6.1 and 6.2 show the results of the calculations, from which Tables A1.3 and A1.4 in the DWSNZ were derived, see McBride & Ellis 2001 or McBride 2005 for the full details, as summarised in Appendix 2 (in Volume 2 of the Guidelines).

Figure 6.1: Confidence of compliance for a 95%ile, over smaller and larger datasets. Numbers on the graphs are the observed number of transgressions. *Source*: McBride & Ellis (2001) and McBride (2005)

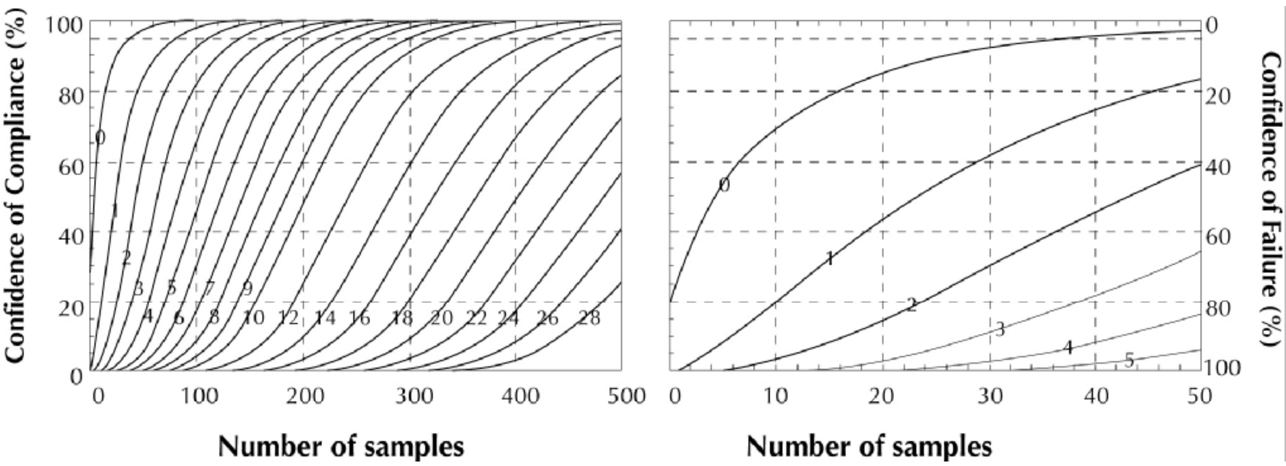
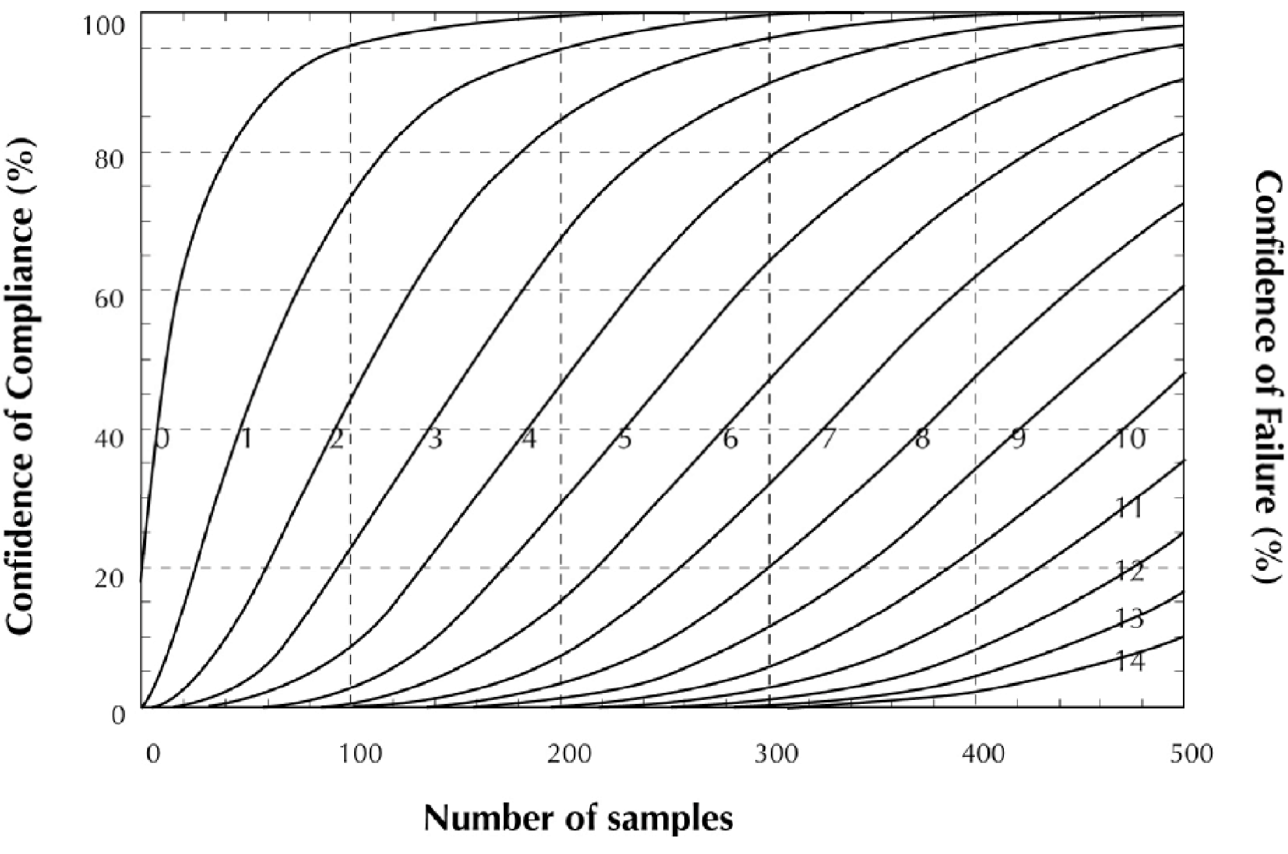


Figure 6.2: Confidence of compliance for a 98%ile. Numbers on the graphs are the observed number of transgressions. *Source*: McBride & Ellis (2001) and McBride (2005)[1]



As an example, reference to Table A1.3 shows that the desired 95% 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. These results can be read from Figure 6.1, by reading the point at which the curved lines cross the horizontal dashed line, which is at 95%

[1] 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 & Ellis 2001).

confidence of compliance. Similarly, the entries for Table A1.4 can be read from Figure 6.2, for example, for twice-weekly sampling over a year.

Note that in all cases the allowable proportion of transgressions in the samples is less than the DWSNZ requires. For example, allowing 1 transgression in 100 samples is 1%, yet the DWSNZ for Table A1.3 contemplates transgressions for up to 5% 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%) probability that the MAV was not exceeded for more than 5% of the time if there is only one transgression in 100 samples, and very close to 100% 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%, e.g. for 330 samples, one can have 10 transgressions (over 3%). Had a permissive stand been taken the allowable proportion of transgressions among the samples would always be greater than 5%.

6.3 MICROBIOLOGICAL COMPLIANCE

6.3.1 INTRODUCTION

The DWSNZ requires that all water supplies be subjected to microbiological monitoring because microbiological determinands are considered to be Priority 1, i.e. 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 bacteria, or even a selection of pathogens that could be in a contaminated supply, it is usual to test for indicator bacteria, as discussed in Chapter 5: Microbiological Quality, Section 5.3. These indicator bacteria must also be of faecal origin and their survival in water and response to treatment processes must parallel that of the pathogenic species they are acting as indicators for.

However, in recent years it has become apparent that the traditional bacterial indicators of faecal contamination, i.e. the faecal coliform or more recently the *E. coli* bacteria, are not good indicators for the pathogenic protozoa, in particular *Giardia* and *Cryptosporidium,* which have been found in some New Zealand surface waters and non-secure groundwaters. The pathogenic protozoa are discussed in Chapter 8: Protozoa Compliance.

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.

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 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 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, e.g. once a week, is adopted, as required in the DWSNZ (Table 4.3a). It should be noted that not all contamination events are random. Occasionally they may be the result of a cyclic event, e.g. management practices at a treatment plant, or an irregular 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 approved by the drinking-water assessor (DWA).

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

Occasional low-level contamination, using membrane filtration
On some occasions a membrane filtration technique can prove useful because it can increase the detection limit of the test. This can prove helpful in understanding what is going on at some locations. For example, Rotorua District Council (Charleson, pers. comm.) had one bulk water supply point occasionally returning faecal coliforms at 1 cfu/100 mL when using a 100 mL sample. After analysing 10 litre samples, counts of about 800 cfu per 10 L were obtained at the site of concern, as well as lower levels (200 - 400 per 10 L) at other supply points, demonstrating that there really was underlying contamination. 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, it is certainly advisable to investigate the cause and introduce an appropriate remedial action.

6.3.4 MONITORING DRINKING-WATER LEAVING A TREATMENT PLANT

The DWSNZ considers 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.

Sometimes sampling needs to be more frequent that the minimum given in the DWSNZ. A secure groundwater requiring no treatment needs only occasional (monthly or quarterly) testing, while surface water with inadequate disinfection (or none at all) supplied to populations greater than 10,000 people must be tested daily for *E. coli*, or be monitored continuously for free available chlorine (FAC, or more correctly, FACE) subject to conditions described in Table 4.2b of the DWSNZ. For smaller populations, less frequent sampling may be considered sufficient, see Section 4.3.8 of the DWSNZ, but more frequent testing would give a higher level of confidence in the supply being safe. Always bear in mind that the DWSNZ states *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 certain hazardous events occur that could impact significantly on source water quality or the treatment process, e.g. 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 six 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 where a water supplier chooses to use solely *E. coli* testing for bacterial compliance. Sampling frequency is population based and varies from weekly to daily.

Compliance criterion 2 (section 4.3.2 of DWSNZ) applies when chlorine is used. Criterion 2A applies when the free available chlorine (FAC) and pH are monitored continuously to allow calculation of FACE. *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 1.

Compliance criterion 4 (section 4.3.4 of DWSNZ) applies when the water is dosed with ozone but no chlorine. A reduced sampling frequency is allowed in acknowledgement of the disinfecting efficacy of ozone, but because there is no residual, fortnightly sampling is required, regardless of population.

Compliance criterion 5 (section 4.3.5 of DWSNZ) is the UV equivalent of criterion 4.

The sixth situation is discussed in the next section.

6.3.5 MONITORING DRINKING-WATER FROM GROUNDWATER

Section 4.3.10 of DWSNZ explains the monitoring procedures to be used for groundwater entering the distribution system. Once security has been demonstrated, the initial sampling frequency for all populations is monthly; this can be reduced to quarterly once a 12-month period has passed with all samples containing less than 1 *E. coli* per 100 mL.

Section 4.5 of the DWSNZ specifies the requirements for demonstrating that a groundwater is secure. This is covered in detail in Chapter 3: Source Waters, Section 3.2, Groundwater.

Weekly sampling for at least 4 weeks is required when the source water may have changed, e.g. after an earthquake because it may have affected the confining layer, or after flooding around or damage to the bore head or adjacent bores, see DWSNZ, section 4.3.10 and Chapter 3 of the Guidelines.

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. The sampling frequency for the first 3 months after finding *E. coli* is:

- weekly for populations up to 500
- twice weekly for 501 – 10,000
- daily for populations >10,000.

If no further *E. coli* are found in this 3-month period, sampling can be reduced to monthly for the next 9 months, for all populations. Full secure groundwater status is restored if no further *E. coli* are found during this 9-month period.

If only one sample contains *E. coli*, the groundwater source is called provisionally secure (section 4.5.3 of DWSNZ), and with the increased testing, sufficient samples will be collected for bacterial compliance to be restored.

If more than one sample contains *E. coli*, the source is immediately reclassified as non-secure, in which case, for the water supply to satisfy the bacterial compliance criteria, disinfection will be required. If the secure status is no longer desired, sampling can revert to the appropriate non-secure frequency in Table 4.2a of the DWSNZ. If the secure status is still desired, the increased sampling rate for 3-months, as above, must recommence.

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 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, e.g. very low temperatures, pipework maintenance and replacement programmes, land use and development.

A sampling programme should not be based simply on the minimum 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.

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, e.g. 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 tap samples. Therefore all service reservoirs should be 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, i.e. 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 tap was not flamed.

The monitoring plan must be documented and approved by the drinking-water assessor.

The 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 30,000 and choose 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 – 4.4.12 of the DWSNZ for details.

See Chapter 17:Monitoring, Water Treatment and Drinking-water, Section 17.2 for some general information on sampling.

6.3.7 CHLORINE TESTING AS A SUBSTITUTE FOR *E. COLI*

Section 4.4.2 of the DWSNZ (compliance criterion 6B) allows some substitution of *E. coli* testing with chlorine tests, subject to turbidity constraints. This is because chlorine is amenable to monitoring at high frequencies and is also based on the assumption that *E. coli*, and therefore the pathogens for which they serve as indicators, are inactivated if exposed for sufficient time to an adequate level of free available chlorine. To add a precautionary feature to this assumption, the compliance rule is based on a 98%ile, allowing transgressions for no more than 2 percent of the time, see Table A1.4 in the DWSNZ.

Chlorine inactivation of pathogens requires sufficient contact time. Chlorine is less efficient at inactivation in high pH water (pH>8), and also progressively loses killing power as the turbidity of the water increases, see Chapter 15: Treatment Processes, Disinfection. However, if chlorine is being used correctly and there is evidence that there is adequate chlorine remaining at the completion of the inactivation step (i.e. there is still some free available chlorine present), chlorine tests may be substituted for *E. coli* tests for water leaving the treatment plant, see Table 4.3a in the DWSNZ. Compliant continuous chlorine monitoring gives a very high level of confidence in the safety of a water supply.

For water leaving the treatment plant, FACE levels are measured after a contact of at least 30 minutes (see sections 4.3, 4.3.2.1 and Figure A1.1 of DWSNZ). 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 satisfactory.

For water in the distribution system, the substitution of chlorine tests for *E. coli* tests cannot be made so easily. 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.

Thus the DWSNZ allows substitution of chlorine testing for some but not all *E. coli* tests, see DWSNZ section 4.4.2 for the minimum sampling frequencies and other conditions. Note that this option is only available in distribution zones supplying more than 30,000 people.

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

6.4 SAMPLING AND TESTING

6.4.1 SAMPLE HANDLING

The consequences (i.e. declaring that a secure groundwater is no longer secure) from obtaining a faulty sample are serious, so the sample collection technique must be thorough. 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 test sample with the samples collected. Another technique is to take an empty sterile bottle on the sample run and fill it in the laboratory with sterile water for testing with samples collected. Another approach is to collect one sample in duplicate on every sample run. Water samplers should always take 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.

It is important that the samples of water collected for testing are collected and transported properly. If the samples are invalid the subsequent analysis could be a waste of time. All sample collectors should be trained in the correct procedures (which should have been documented) and should be able to demonstrate their competence. Participating laboratories should provide detailed sampling procedure instructions.

All water samples must be clearly identified and labelled. 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.

The sample containers must have securely fitting stoppers or a leak-free sealing system. Sealing the container must be an easy procedure that does not carry a risk of the sample becoming contaminated. The sample containers 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.

Where chlorine is used as a disinfectant for a water supply, it is important that the chlorine residual is neutralised by the addition of sodium thiosulphate to the sample and so 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.

Sample containers should be filled leaving sufficient air space for the sample to be thoroughly mixed by shaking before it is tested. In choosing taps to sample from, avoid those that are leaking or have attachments, unless these are a feature of the system. There is some debate about flaming taps. Taps in pits, valve chambers, etc should be flamed because they are likely to be contaminated by road dirt, dogs, etc. People drink directly from taps in dwellings so, in theory, collecting a sample without flaming represents the drinking-water. However, if the sample grows *E. coli* 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% alcohol or sodium hypochlorite solution.

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. 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. If transport times exceed one hour the samples should be maintained below 10°C but not frozen. The laboratory results are probably the most reliable if the test is performed within six hours of the sample being collected. Samples more that 24 hours old should be discarded. Tests performed on such samples cannot be interpreted with any confidence as bacterial counts may increase, decrease, or remain the same, over time.

6.4.2 TEST METHODS AND SOURCES

The DWSNZ has 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, 20th edition, 1998 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.

Presence/absence tests and tests such as the Colilert and Colisure tests 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.

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 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.

Presence/absence 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.

Whatever 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.

See Chapter 15: Disinfection, Section 15.5.1.3 for a discussion on chlorine measurement.

6.4.3 LABORATORY COMPETENCY

The DWSNZ requires 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 3 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, e.g. spiked samples, split samples, duplicates, positive and negative controls, both within the laboratory and in collaborative tests with other laboratories.

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.

Sampling and testing must continue through this response phase at an elevated level. 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 requires 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' PHRMPs 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, labour problems, breach of security, spills of wastewater or other contamination.

(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 4.5.3 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

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, e.g. by additional disinfection and/or issuing a boil water notice.

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.

The response to possible scenarios should be documented in the PHRMP. 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 and inspection of disinfectant dosage.

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 quite 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 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.

<u>The water suppliers' local pipework</u>

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 event

- 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, 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.

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 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 to 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 PHRMP so the procedure is documented before the event, and valuable time is not lost.

<u>Bulk distribution zones</u>

The response 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.

<u>Service reservoirs</u>

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 & 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 egress. As well as collecting the samples, the water sampler should also inspect the reservoir.

6.5.2 KEEPING RECORDS

For each water supply there should be a fully documented description of the microbiological monitoring programme, previously approved by the Drinking-Water Assessor. 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 effect efficiency, etc. For further discussion see section 12 of the DWSNZ. 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 PHRMP and all outcomes of this response recorded. Water supply managers may wish to include a format for recording the follow-up procedure in the PHRMP. 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.

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