

# Chapter 8: Protozoal compliance

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# 8.1 Introduction

The Maximum Acceptable Value (MAV) for total pathogenic protozoa in drinking-water is less than 1 infectious (oo)cyst (cysts and oocysts) per 100 litres; see Table 2.1 of the *Drinking-water Standards for New Zealand 2005, revised 2008* (DWSNZ). Note that until the methodology for determining the viability or infectivity of detected (oo)cysts improves, results are to be reported as verified (oo)cysts.

*Cryptosporidium* and *Giardia* testing of drinking-waters:

- requires very large volumes to be filtered in order to achieve the sensitivity required
- requires two or more days to achieve a result
- requires very skilled laboratory personnel
- requires very expensive laboratory equipment
- does not allow large numbers of samples to be processed per day
- very few laboratories in New Zealand are accredited for this work.

Because it is impractical to demonstrate compliance with the protozoal MAV in the DWSNZ with statistical rigour, operational requirements for treatment processes known to remove or inactivate (oo)cysts are used instead. In many situations, when a monitoring test result fails to satisfy an operational requirement, the point of failure is readily identified; this would not be the case if testing directly for protozoa.

The operational requirements include:

- turbidity monitoring (or particle counting) for filtration processes
- direct integrity testing (for membrane filtration plants)
- indirect integrity testing, normally turbidity (for membranes, bags and cartridges)
- pressure differential for bag and cartridge filtration
- monitoring with UV intensity sensors
- C.t values for ozone and chlorine dioxide disinfection
- and in several cases the use of certificated or validated water treatment appliances is required.

This chapter discusses the compliance issues relating to the removal or inactivation of protozoa at the water treatment plant. Chapters 12–15 discuss the management and operational aspects of pre-treatment, coagulation, filtration, and disinfection processes respectively.

If the compliance criteria for *Cryptosporidium* are met, it is assumed that other protozoa should not present health issues in that drinking water.

If water leaving the treatment plant satisfies the appropriate protozoa compliance criteria, and if the bacterial compliance criteria for water in the distribution system are satisfied, then it is considered that it is unlikely that protozoa will present a health risk in the distribution system.

Some more general aspects of microbiology and related illnesses are discussed in Chapter 5: General Microbiological Quality.

Water sources and their selection are covered in Chapters 3 and 4, although section 8.2 of this chapter deals with source water protozoal risk categorisation based on *Cryptosporidium* occurrence or catchment characteristics.

Much of the early work was carried out in the UK after various outbreaks of cryptosporidiosis. Badenoch produced the first major reports in 1990 and 1995, with recommendations, and Bouchier (1998) updated these.

WHO (2004a) discusses treatment processes suitable for pathogen control. The WHO (in 2006) produced WHO Guidelines for Drinking Water Quality: *Cryptosporidium* which discusses many issues related to this protozoan, and includes an extensive bibliography.

Health Canada (2012) released enteric protozoa guidelines, also based on the USEPA LT2ESWTR.

Details of specific protozoa (not just *Cryptosporidium* and *Giardia*) are covered in the datasheets.

## 8.2 Source water

### 8.2.1 Introduction

The requirements for protozoal compliance with the DWSNZ are based on a cumulative log credit approach explained in section 5.2 of the DWSNZ and section 8.3 of the Guidelines. To define the level of treatment required for a water supplier to demonstrate protozoal compliance with the DWSNZ, the raw water must be categorised with respect to the risk presented by the concentrations of protozoa in the water. This can be done by either assessing protozoal risk, or by measuring *Cryptosporidium* oocyst numbers. The categorisation determines the minimum number of protozoal log credits the supply's treatment processes must achieve. Section 5.2.1 of the DWSNZ specifies how the categories are defined, and the way in which the source

water quality is to be evaluated. The oocyst concentrations that define the risk categories are based on the boundaries used by the USEPA to define the 'bin classifications' contained in their proposed *Long Term 2 Enhanced Surface Water Treatment Rule* (USEPA 2003a), and confirmed in their final rule (USEPA 2006a).

*Cryptosporidium* and *Giardia* sampling and testing is discussed in section 8.6.1. The analytical procedure to be used is based on Method 1623 (USEPA 2005b). See also *Source Water Monitoring Guidance Manual for Public Water Systems for the Long Term 2 Enhanced Surface Water Treatment Rule* (USEPA 2006b). Laboratories conducting protozoa testing for compliance purposes are to have IANZ accreditation for this work.

Ideally, protozoal categorisation would only be based on the results of monitoring oocysts. Water suppliers made it abundantly clear during the DWSNZ consultation process that they felt this would be too expensive; hence the introduction of the catchment risk category approach for supplies <10,000 population.

In recognition of the relatively high cost of analysing samples for *Cryptosporidium*, the USEPA (2003a) explored the use of indicator criteria to identify raw waters that may have high levels of *Cryptosporidium* occurrence. Data were evaluated for possible indicator parameters, including faecal coliforms, total coliforms, *E. coli*, viruses, and turbidity. *E. coli* was found to provide the best performance as a *Cryptosporidium* indicator in source waters, and the inclusion of other parameters like turbidity was not found to improve accuracy. As a consequence, the DWSNZ 2005 had also adopted some *E. coli* monitoring of source water. The basis for this was not strong, so the requirement for *E. coli* monitoring of source waters was dropped from the 2008 revision.

Because bore waters are often free from microbiological contamination, their protozoal log credit requirement is assessed in a different manner than used for surface water. Protozoal risk categories for bore waters will be one of 0, 2, 3, 4 or 5 log credits; see section 8.2.2. Source water protozoal risk categories for surface supplies will be one of 3, 4 or 5 log credits. Secure bore waters are considered to be free from protozoa. Bore water security is discussed in Chapter 3.

In effect, there is a default for surface waters of 4 logs. If no towns are in the catchment or the effects of agricultural wastes are minimal, this drops to 3 logs; with excessive farm or human wastes 5 log removals could be required. Note however that no New Zealand source water is expected to need 5 log removals. If a source water is so bad that 5 logs are really needed, there is a huge incentive to change the source or clean up the land use practices.

One DWSNZ draft attempted to reduce the log credit requirement for lakes/reservoirs, but that became bogged down in discussions about (oo)cyst settling rates, the effect of sunlight and predators, water temperature, retention time, stratification, mixing, and depth of abstraction valve, etc.

It was assumed that the quality of springs and very shallow bores may be no better than that of a surface water passing through <10 m of gravel, hence the 3–5 log removal requirement was retained. The 10–30 m deep group of bores was allowed 1 log credit requirement less than the 'default' on the grounds that the quality would improve as the water percolated through the extra depth of soil. The DWSNZ Expert

Committee couldn't reduce the log credit requirement any further for non-secure bore waters because it is well known that die-off of micro-organisms is less prominent in gravel, limestone and basalt structures due to their relatively rapid transport rates. It was accepted that any large groundwater user that felt they were being asked to meet too many log credits would choose to prove their point by monitoring for oocysts – that would be cheaper than installing extra water treatment plant. The intention was that use of unconfined shallow bores/springs was to be discouraged; any > 10 m should only need UV disinfection at most.

Massey University, for the MoH, has collected 720 samples from 20 sites across New Zealand, ie, 36 quarterly samples per site over a nine-year period (September 2009–January 2019). Results (rounded) can be summarised as follows:

<b><i>Cryptosporidium</i></b>		
<b>Sample group</b>	<b>% samples containing <i>Cryptosporidium</i></b>	
Groundwater/springs	0	
Bush catchments	1	
Intermediate rivers	1	
Lowland rivers	42	
<b><i>Giardia</i></b>		
<b>Sample group</b>	<b>% samples containing <i>Giardia</i></b>	
Groundwater/springs	0	
Bush catchments	3	
Intermediate rivers	6	
Lowland rivers	58	
<b><i>E. coli</i></b>		
<b>Sample group</b>	<b>% samples containing <i>E. coli</i></b>	
Groundwater/springs	7	
Bush catchments	84	
Intermediate rivers	88	
Lowland rivers	100	
<b>Sample group</b>	<b>arithmetic mean</b>	<b>median</b>
Groundwater/springs	0.2	0
Bush catchments	23	3.5
Intermediate rivers	71	17
Lowland rivers	277	96
<b><i>Campylobacter</i></b>		
<b>Sample group</b>	<b>% samples containing <i>Campylobacter</i></b>	
Groundwater/springs	2	
Bush catchments	10	
Intermediate rivers	21	
Lowland rivers	58	

Some observations to date:

- Most *Cryptosporidium* oocysts in the 154 lowland river samples were found in autumn and spring. None were found in February and one was found in January; seven were found in June/July and none in August.
- The Waikato River at Tuakau and at Hamilton, the Oroua River at Feilding and the Waiorohi Stream (Oropi Road, Tauranga) contained protozoa in about half the samples. The numbers found indicate that these sites would not be required to achieve more than 3-log removal of *Cryptosporidium* oocysts.
- None of the 184 groundwater/spring sites contained protozoa, despite being selected because they were shallow or not secure, and had a previous history of containing *E. coli*.
- Only about 1–2% of bush catchment and intermediate rivers samples contained *Cryptosporidium*.

## 8.2.2 Approach to categorisation

### 8.2.2.1 Bore waters

#### a) Bores drawn from confined aquifers

A bore of any depth drawing from a confined aquifer can be given interim security if it satisfies bore water criterion 1 and bore water criterion 2 (see section 4.5 of DWSNZ). Secure and interim secure bores are deemed to satisfy the protozoal compliance criteria, ie, no protozoal log credits required. The secure status is gained/maintained so long as bore water criterion 3 (absence of *E. coli*) is satisfied. Note that it may be difficult to show that bores up to 10 m deep are drawing from confined aquifers, and it may be difficult for them to satisfy bore water criterion 1 and bore water criterion 3; however, they are included for completeness.

Water drawn from an aquifer that is considered to be confined but does not satisfy (or has not been assessed against) bore water criterion 1 and/or bore water criterion 2, is deemed to be equivalent to water drawn from an unconfined aquifer.

#### b) Bores drawn from unconfined aquifers (or if status of aquifer unknown)

A bore drawing from an unconfined aquifer more than 10 m below the ground surface can be given interim security if it satisfies bore water criterion 1 and bore water criterion 2, and some other conditions: see section 4.5.1 of the DWSNZ. Secure and interim secure bores are deemed to satisfy the protozoal compliance criteria. Note that bores drawing from unconfined aquifers are a lot less likely to satisfy bore water criterion 1, and consequently may fail to satisfy bore water criterion 3.

Chapter 3: Source Waters, section 3.2.4 has further discussion on establishing the security of bore water supplies.

Tables 5.1a and 5.1b in the DWSNZ have confused some readers. The following applies for the situations where bore water criterion 1 cannot be or is not satisfied.

Depth (m)	Protozoal log credit requirement
<10	Equivalent to surface water, so 3–5 log removals needed, see section 8.2.2.2
10–30	3 log credits required during the five-year <i>E. coli</i> proving period
30+	If hydrogeological evidence suggests that the bore water is likely to be secure, then interim secure status may be granted, see (a), otherwise 2 log credits required, provided bore water criterion 2 is satisfied

### 8.2.2.2 Surface waters

There are two approaches for determining the protozoal risk categorisation of surface waters, see DWSNZ sections 5.2.1.1 and 5.2.1.2, and both require a five-yearly review, see section 8.2.6.

#### a) Catchment risk category approach (Guidelines section 8.2.3)

This is the default option for supplies serving a population up to 10,000, and is based on assessing the perceived risk related to the surface water catchment categories as defined in DWSNZ Table 5.1a. Should a water supplier consider the assignment of the log credit requirement to be inappropriate, any appeal must be supported by data obtained by monitoring *Cryptosporidium* (see b).

#### b) Measurement of *Cryptosporidium* oocysts approach (Guidelines section 8.2.4)

This is the default option for supplies serving a population over 10,000, and is based on matching the mean oocyst concentration with the log credit categories in Table 5.1b of the DWSNZ. Should the water supplier consider this approach to have led to an inappropriate log credit requirement, the log requirement based on the perceived risk related to the surface water catchment categories as defined in section 5.2.1.1 and Table 5.1a may be adopted.

Note that all water suppliers conduct catchment assessments as part of their PHRMP (now Water Safety Plan or WSP) process, and this is an ongoing process. Catchment assessments are intended to consider all aspects that may impact on the quality of the raw water and the security of the supply. Information from the initial catchment assessment will have been used in the selection of the water treatment plant site and design. Protozoal risk categorisation only considers those activities that may affect the number of *Cryptosporidium* oocysts.

## 8.2.3 Catchment risk category approach

The catchment risk categorisation procedure involves a survey of the catchment. The form for recording the survey results appears in Appendix 3 of the DWSNZ. The DWA will assign the log credit requirement once the catchment assessment has been completed. Where appropriate the assignment process will make use of the *Cryptosporidium* monitoring results provided by the > 10,000 supplies.

When water is drawn from more than one catchment, the catchment with the greatest protozoal risk will determine the log credit requirement for the treatment plant.

This risk categorisation approach should provide an evaluation of the catchment that identifies all likely sources of *Cryptosporidium* oocysts in the raw water, even if the frequency at which these events occur is low. Risk assessment is a difficult tool to use meaningfully when the relationships between activities in the catchment and raw water quality are not understood. The water supply needs to be safe to drink at all times, therefore the catchment survey must take into account the conditions most likely to challenge the treatment process.

Scottish Water (2003) devised a scoring system for assessing water supply catchments in response to *Cryptosporidium* problems. This publication indicates their weighted assessment of the various impacts due to *Cryptosporidium*, and has some relevance to New Zealand conditions so should provide some useful background reading. Also, drinking water assessors have produced Guidance Notes which is more detailed than Appendix 3 of the DWSNZ. These Guidance Notes are appended to this chapter.

## 8.2.4 Measurement of *Cryptosporidium* oocysts approach

Although this approach seems to have the advantage of providing quantitative information for the categorisation, the mean oocyst concentration will depend on the frequency of sampling and whether the collection times coincide with episodes of poor or good water quality. Samples taken too infrequently may miss poor water quality episodes when oocyst counts are high. This could result in an inadequate level of treatment being provided. Conversely, excess treatment may be indicated.

To achieve a balance between accuracy and costs, the monitoring programme must comprise at least 26 samples collected over a 12-month period at approximately equal time intervals to attempt to ensure representative samples and minimise seasonal bias. The samples must be tested quantitatively for *Giardia* cysts and *Cryptosporidium* oocysts. Subject to laboratory and delivery services, samples should be taken to cover every day of the week and must cover at least Monday to Friday three times during the sampling programme; this has been discussed further in Chapter 17: Monitoring, section 17.2. The results from the monitoring programme must be reported to the DWA who will assign the log credit requirement.

The DWA must be informed of the year's monitoring plan before it starts, and any changes to it must be agreed with the DWA before the changes are made. This is to avoid samples being taken intentionally at times when the concentrations of oocysts in the raw water are expected to be low.

The sampling location must meet a number of criteria (see DWSNZ section 5.2.2). These are designed to ensure that the samples are representative of the water quality entering the first treatment process for which log credits will be claimed. If water taken from the source at the point of abstraction does not undergo any changes in quality before treatment, then the untreated water may be obtained from this location. Where water is drawn from multiple sources, samples must be taken from the combined flow.

DWSNZ section 5.2.1.3 specifies the requirements for when waste water is recycled to the head of a treatment plant. Poor quality recycle water, and large or sudden discharges of recycle water will challenge the treatment process. That is why the DWSNZ require the instantaneous return rate not to exceed 10 percent of the plant inflow, and the recycle water turbidity is to be measured to show that the solids/liquid separation process is operating effectively. The DWSNZ did not specify turbidity limits/durations because that would be too prescriptive, instead turbidity monitoring was adopted that would show a water supplier when a suitable response is required, eg, to divert to waste. AWWA (2001) recommends that the return rate target be <5%, that it be continuous and well mixed, and shut off when its turbidity exceeds 20 NTU. Interestingly, the Southern Milwaukee Water Treatment Plant was recycling filter backwash water at the time of their massive *Cryptosporidium* outbreak; they ceased that practice (McKenzie et al 1994).

If any water supplier measures oocysts with a recovery of around 40 percent in the raw water, but <10 percent for recycle water, they should attend to their solids/liquid separation process before wasting too much time collecting dubious data. A water supplier that recycles their wastes in accordance with the requirements of section 5.2.1.3 of the DWSNZ would be unlikely to require any more log credits than the raw water requires.

DWSNZ Table 5.1b refers to the mean value; this is the arithmetic mean. Laboratories must achieve a detection limit of better than 0.75 oocysts/10 litres. This is to ensure that there is no misclassification of source waters because the sensitivity of the technique was inadequate. When calculating the mean oocyst concentration, results that have been reported as less than the detection limit, should be assigned an arbitrary value of zero.

USEPA (2003a, 2006a) stated "Spike data indicate that average recovery of *Cryptosporidium* oocysts with Methods 1622 or 1623 in a national monitoring program will be approximately 40 percent. Studies on natural waters for *Cryptosporidium* using both Method 1623 and a method (cell culture-PCR) to test for infectivity suggested that 37 percent of the *Cryptosporidium* oocysts detected by Method 1623 were infectious". Consequently, USEPA accepted the "recommendation that monitoring results should not be adjusted to account for either recovery or the fraction that is infectious".

However, for the purpose of protozoal risk categorisation in the DWSNZ, oocysts numbers should be reported after normalising to a 40 percent recovery rate. Because individual recoveries can commonly vary from 15–55 percent, the normalising approach was considered to be fairer and more consistent. Therefore, if a test result of 0.48 oocysts per 10 L was obtained in a batch that achieved 30 percent recovery, the result to be reported =  $0.48 \times 40/30 = 0.64$ . Conversely, had the recovery been 56 percent, the reported result should =  $0.48 \times 40/56 = 0.34$ .

To assist in understanding the relationships between catchment activities and *Cryptosporidium* oocysts levels, it would be helpful to collate the following additional information when samples are collected:

- 1) weather conditions, or the operation of irrigation systems, in the catchment or recharge zone on the day the sample was collected and on each of the two previous days
- 2) for surface waters, the turbidity, a description of the source water quality (visual appearance) and how this compared with the water quality during fine weather, and river flow/river height
- 3) for all sources, the date and time of sampling
- 4) which sources are in use at the time of sampling if the treatment plant is fed from multiple sources
- 5) other factors that might influence the level of raw water contamination, such as irregular or seasonal land-use activities, and precedent weather.

## 8.2.5 Comparison of protozoal risk assessment and oocyst monitoring data

Water suppliers that consider the original protozoal risk categorisation to be inappropriate are permitted to use the other approach. It is possible that in doing so, the conclusion from each approach may be different. Similarly, it may be possible that the five-yearly review produces a different outcome. Before rejecting one or other of the conclusions, the reasons for such discrepancies should be identified. The most likely reasons for a discrepancy are:

- a) monitoring oocysts has missed high risk but low frequency events
- b) the catchment risk assessment has omitted, or underestimated the importance of, a contaminating activity in the catchment, or land use changes have occurred
- c) monitoring oocysts has coincided with atypical events
- d) the risk assessment has placed too high an importance on a contaminating activity in the catchment.

When considering protection of public health, reasons a) and b) are a primary concern. Moreover, if b) is the reason for the discrepancy, remedial actions to reduce the risk to supply may be misdirected because important sources of contamination may have been overlooked.

A review of the weather conditions and the appearance of the source water, when samples for *Cryptosporidium* testing were taken is a helpful place to start in investigating the cause of discrepancies. The five additional pieces of information discussed in the previous section that should be collected when samples are taken will assist in this investigation.

Comparison of this information with what is known about potential sources of contamination in the catchment may explain the reason for measured oocyst concentrations being lower or higher than expected on the basis of the risk assessment. For example, high oocyst concentrations in the absence of rain points to the source of contamination not being reliant on rain to transport contaminants to the receiving water, eg, stock had direct access to the water source, or human wastes are entering the source water. Sampling dates/times may help to ascertain whether an unexpected event, such as an upstream wastewater treatment malfunction, may have contributed to the poor quality of the raw water.

A review of the protozoal risk categorisation questionnaire to determine which activities contributed most to the overall risk score may help to answer questions such as:

- to what degree are these likely to have been influenced by rain, and was it raining about the time of sampling?
- are these activities likely to contribute intermittently to poor water quality, and therefore were they likely to have been significant at the times when samples were taken?

Land use can have a large impact on water quality. Check matters such as whether:

- dairy conversions have been occurring
- stock numbers have been as expected
- calving has taken place
- stock has been moved
- animal wastes have been irrigated
- animal waste treatment systems have performed poorly
- riparian strips and fences installed or damaged
- any stock have direct access the natural water in the catchment
- pasture was overgrazed before heavy rain fell.

Information acquired during the investigation, or simply from undertaking the risk assessment, may highlight actions that could be taken to reduce the level of risk to the supply. For example, high contaminant levels in the raw water may occur on an infrequent basis and consequently may not become evident from monitoring. These low-frequency events may challenge the treatment plant's ability to reduce oocyst concentrations to an acceptable level, even if the treatment plant is compliant with the DWSNZ. Knowing the cause of these events could provide a guide to remedial actions needed in the catchment. Water suppliers would be expected to address such matters in their PHRMPs.

## 8.2.6 Catchment categorisation review

In the DWSNZ, section 5.2.1.1 Catchment risk category approach includes: “Reassessments must be made at least five-yearly intervals”. Section 5.2.1.2 *Cryptosporidium* monitoring includes: “The protozoa monitoring programme must be repeated at least five-yearly intervals”. Taken literally, this could involve an unnecessarily expensive process. The real intent is explained below in a) or b).

Also, a source water that receives a higher level of treatment than the minimum requirement only needs to be reviewed if the source water quality is likely to deteriorate markedly. For example, some water suppliers have chosen to process a 3-log source water in a 4-log removal water treatment plant. Even if the source water quality deteriorated, it is highly improbable that it could become a 5-log source water.

If the review suggests the log credit requirement has increased resulting in the need to upgrade the water treatment process, the water supplier shall address how and when they will do this in their PHRMP (WSP).

### a) Catchment risk category approach

Water suppliers whose source water has a risk of requiring an increase in the number of protozoal log removals should be looking at their catchment on a regular basis, including attempting to control catchment land use through the regional council consent process, using NES where appropriate. These activities should be described in their PHRMP. If such a water supplier believes the risk has increased, they should check whether there is something they can do about it, such as modifying their intakes or improving their water treatment process – they should want to do that to ensure that their drinking water remains safe to drink – they should not wait until the five-yearly review is due.

Note: paragraph 2 in section 5.2.1.1 of the DWSNZ states “Should the assignment of the log credit made by the Ministry be considered inappropriate, any appeal (section 1.9) must be supported by data obtained by monitoring *Cryptosporidium* (section 5.2.1.2)”. It is reasonable to assume that this approach may also apply to the five-yearly reviews.

### b) *Cryptosporidium* monitoring

The words “The protozoa monitoring programme must be repeated at least five-yearly intervals” can be interpreted more reasonably as:

The protozoa monitoring programme must be repeated in response to:

- a change in catchment activities that indicates a likely increase in oocyst numbers; or
- an intention by the water supplier to employ a protozoal treatment with a reduced protozoal log removal rating; or
- an outbreak of waterborne protozoal infection linked to the water supply that is not explained by a lapse in protozoal treatment.

In the extreme (but fairly common situation) of a bush catchment, a water supplier may need to do no more than state that “the raw water is still being drawn from a bush catchment with no agricultural activity or human wastes”. It could be helpful if they operate an ongoing predator control programme.

If the original log removal requirement had been based on protozoa numbers and the review (also using protozoa numbers) suggests more log credits are required, then that means the protozoa risk has increased, OR it was simply ‘bad luck’ when the latest samples were collected (or good luck with the first). How this is handled will depend on the results. For example:

- if the original results produced mean oocysts of say 0.70 per 10 L and the review mean is 0.80, it could be suggested sampling continue until a clearer pattern has emerged
- but if the results went from say 0.20 per 10 L to 1.25 per 10 L, there can be little to argue about, the source water has certainly changed from 3-log to 4-log
- if most samples were ‘less thans’ and one was ‘large’ for no obvious reason, perhaps it should be suggested that sampling continues until there is more confidence that the ‘large’ result was really an outlier.

Note: section 5.2.1.2 says in the second paragraph: If the water supplier considers the *Cryptosporidium* monitoring option results in an inappropriate log credit requirement, the catchment risk categorisation approach as defined in section 5.2.1.1 and Table 5.1a may be adopted. It is reasonable to assume that this approach may also apply to the five-yearly reviews.

## 8.3 The cumulative log credit approach

Section 5.2 of the DWSNZ explains the cumulative log credit approach for the removal or inactivation of protozoa. Editions prior to 2005 did not take account of the additive effect of a series of treatment processes on protozoa removal.

The cumulative effect of successive treatment processes can be calculated by adding the log credits of the qualifying processes that are in continuous use. Using the log credit approach allows the cumulative effects to be added, because, arithmetically, it is not possible to add percentages. See Table A1.2 in DWSNZ for the conversion table from percentage removal to logarithms. Some examples of the calculations follow.

## 8.3.1 Calculation of log credits

Example 1: say the influent contained 1000 'things' per litre and the effluent contained 100:

$$\frac{1000 - 100}{1000} = \frac{900}{1000} = 0.90 = 90\% \text{ removal}$$

$$\log 1000 - \log 100 = 3.0 - 2.0 = 1 \text{ log removal}$$

Example 2: say the influent contained 100,000 'things' per litre and the effluent contained 10:

$$\frac{100,000 - 10}{100,000} = \frac{99,990}{100,000} = 0.9999 = 99.99\% \text{ removal}$$

$$\log 100,000 - \log 10 = 5 - 1 = 4 \text{ log removal}$$

Example 3: say the influent contained 1000 'things' per litre and the effluent contained 30:

$$\frac{1000 - 30}{1000} = \frac{970}{1000} = 0.97 = 97\% \text{ removal}$$

$$\log 1000 - \log 30 = 3.00 - 1.48 = 1.52 \text{ log removal (round to 1.5)}$$

Note: Using a spreadsheet, eg, key in =log10(30) to get the log of 30 (ie, = 1.4771).

Example 4: raw water turbidity = 0.96 NTU and settled water = 0.51 NTU:

$$\frac{0.96 - 0.51}{0.96} = \frac{0.45}{0.96} = 0.469 = 46.9\% \text{ removal}$$

$$\begin{aligned} \log 0.96 - \log 0.51 &= 0.0177 - (-0.2924) &&= -0.0177 + 0.2924 \\ &&&= 0.2747 \text{ (round to 0.27) log removal} \end{aligned}$$

The negative signs make the arithmetic a little more complex, so percentages have been adopted in the DWSNZ section 5.4.1 for the coagulation/sedimentation process not using rapid gravity (or pressure) granular particle filtration.

Section 5.2.1 of the DWSNZ and section 8.2 of the Guidelines explain how the source water protozoal risk categories are determined. The concept of source water categorisation is quite simple: the dirtier the water, the greater the amount of treatment needed. This is called risk-based. The result is that once a water source has been tested and categorised, water suppliers will know how many log credits are required in order to comply with the protozoa criteria in the DWSNZ. They can then choose a process or combination of processes that suits their particular requirements. See Chapter 4: Selection of Water Source and Treatment, section 4.5 for discussion relating to treatment processes other than for protozoa.

## 8.3.2 Which treatment processes are additive for protozoal compliance?

Section 5.2.3 of the DWSNZ explains which treatment processes can be combined for the purposes of being awarded log credits. The processes discussed below may be preceded by qualifying bank filtration (0.5 or 1.0 log credit).

## 1a) Coagulation-based processes (using traditional rapid granular media filtration)

- Coagulation/sedimentation/filtration (3.0 log credit), or
- Coagulation/direct sand filtration (2.5 log credit).

These processes may be followed by:

- enhanced combined filtration (0.5 log credit), or
- enhanced individual filtration (1.0 log credit), or
- secondary granular filtration (eg, sand or carbon) (0.5 log credit).

## 1b) Coagulation based processes (using membrane filtration)

- Coagulation/sedimentation/rapid granular media filtration (3.0 log credit), or
- Coagulation/direct rapid granular media filtration (2.5 log credit), or
- Coagulation/sedimentation without rapid granular media filtration (0.5 log credit).

These processes (1a and 1b) may be followed by membrane filtration (for log credits, see DWSNZ section 5.11, almost entirely 4-log).

## 1c) Disinfection following a process that uses coagulation

Steps included in 1a) and 1b) can be followed by:

- chlorine dioxide disinfection (dose dependant log credit), or
- ozone disinfection (dose dependant log credit), or
- UV disinfection (dose dependant log credit).

Note that these disinfectants can be used singly, or in combination, up to 3 log credits.

## 2a) Filtration processes without coagulation (using a single filtration process)

- Diatomaceous earth (2.5 log credit), or
- Slow sand (2.5 log credit), or
- Membrane filtration (for log credit, see DWSNZ section 5.11, most likely 4-log), or
- Cartridge filtration (2.0 log credit), or
- Bag filtration (1.0 log credit).

## 2b) Any option in step 2a can be followed by

- Chlorine dioxide disinfection (dose dependant log credit), or
- Ozone disinfection (dose dependant log credit), or
- UV disinfection (dose dependant log credit).

Note that these disinfectants can be used singly, or in combination, up to 3 log credits.

## 3a) Filtration processes (using two filtration processes)

- Diatomaceous earth (2.5 log credit), or
- Slow sand (2.5 log credit).

These processes may be followed by:

- membrane filtration (for log credit: see DWSNZ section 5.11, most likely 4-log), or
- cartridge filtration (0.5 log credit), or
- bag filtration (0.5 log credit).

## 3b) Any option in step 3a can be followed by

- Chlorine dioxide disinfection (dose dependant log credit), or
- Ozone disinfection (dose dependant log credit), or
- UV disinfection (dose dependant log credit).

Note that these disinfectants can be used singly, or in combination, up to 3 log credits.

## 4) Disinfection only

- Chlorine dioxide disinfection (dose dependant log credit), or
- Ozone disinfection (dose dependant log credit), or
- UV disinfection (dose dependant log credit).

Note that these disinfectants can be used singly, or in combination, up to 3 log credits.

Log credits for combinations not shown above may be obtained by application to the Ministry of Health. See also DWSNZ section 5.17 and section 8.4.5 of the Guidelines.

When filters are not used in a primary role they do not qualify for the full number of log credits. For example, coagulation/sedimentation/sand filtration earns 3.0 log credits, and coagulation plus sedimentation without filtration earns 0.5 log credits, implying that a sand filter used in its primary role is worth 2.5 log credits. But used as a secondary filter in a process that includes coagulation, it earns only 0.5 log credits. The same approach has been adopted for when cartridge and bag filters are used in a secondary role.

Credits for filters used following the primary filter are only awarded if they are finer than the primary filter. Sand filters do not earn any log credits once all (or almost all) the coagulant has been removed, eg, after membrane filtration. Sand filters operate mainly by charged particles (associated with floc) adsorbing to the sand grains, which is how particles that are theoretically small enough to pass through the filter are removed. Without coagulation there is little adsorption; filtration in that situation is only by straining.

The USEPA (2003a, 2006a) states that since the available data are not sufficient to support the C.t calculation for an inactivation level greater than 3 log, total disinfection inactivation credits are limited to less than or equal to 3 log. If one disinfection system is operated such that 3 log inactivation of *Cryptosporidium* is being achieved, then it is not likely that a second disinfectant (also being dosed at sufficient to achieve 3 logs) would remove any (or many) more oocysts. So using two disinfectants would not realistically be additive, ie, it wouldn't deserve 6 log credits. The second disinfectant is certainly an additional barrier, but beyond 3 log, it is not an additive one. A second disinfectant doesn't necessarily improve the inactivation of *Cryptosporidium* oocysts in the water (unless of course one of the barriers fails, but while it's broken down it earns zero credits).

However, using filtration plus disinfection does constitute two barriers, two completely different treatment processes, so these are additive.

The following examples illustrate how to match treatment processes to the log credits required by the source water categorisation:

### To earn 2 log credits

Non-secure bore waters drawn from an unconfined aquifer more than 30 m below the surface need only 2 log credits to satisfy the protozoa compliance criteria. This can be achieved by filtering the water, eg, using diatomaceous earth or cartridge filtration. It can also be achieved by disinfecting at the appropriate dose of UV, ozone or chlorine dioxide. Note however, that if UV disinfection is being used for protozoal compliance without chlorine, the UV dose will need to be equivalent to 40 mJ/cm<sup>2</sup> in order to achieve bacterial compliance criterion 5, see section 4.3.5 of the DWSNZ.

### To earn 3 log credits

Most surface water supplies, non-secure bore waters less than 30 m deep, and springs should only need to achieve 3 protozoal log credits (refer section 8.2). Of course, water suppliers may want the security or back-up of achieving more than the minimum requirement.

- a) Source waters without colour and with fairly consistently low turbidity, such as non-secure bore waters and upland streams in catchments without much bush or peaty soil, probably do not need to use a chemical coagulation processes. Subject to meeting all the requirements of the DWSNZ, they may choose to:

- dose enough ozone and/or UV light to satisfy the C.t values in Tables 5.6 or 5.7 of the DWSNZ to earn 3 log credits
  - use bag filtration (1 log) plus enough ozone and/or UV to earn 2 more log credits
  - use cartridge filtration (2 log) plus enough ozone and/or UV to earn 1 log credit
  - use diatomaceous earth filtration (2.5 log) plus a low dose of UV to earn another 0.5 log credits
  - use bank filtration (0.5 or 1.0 log credits) plus cartridge filtration (2 log) plus a low UV dose.
- b) Source waters that need or choose to use coagulation to remove colour or where the turbidity is too high for filtration-only systems may:
- use alum/PAC coagulation with sedimentation/DAF plus rapid granular media filtration so that water leaving each filter is less than 0.30 NTU (3 log)
  - use direct filtration (2.5 log) plus enhanced filtration (0.5 log if the combined filtered water turbidity is less than 0.15 NTU)
  - use coagulation with direct rapid granular media filtration (2.5 log) plus a low dose of UV, ozone or chlorine dioxide to earn another 0.5 log
  - use diatomaceous earth filtration (2.5 log) plus enough ozone (which may remove some of the colour too) to earn another 0.5 log.

## To earn 4 log credits

Only a few New Zealand source waters will probably need to achieve 4 log removals. If the water is not highly coloured or turbid, this can be achieved simply by increasing the disinfectant dose in the last four examples in a) or the last two examples in b).

A number of options are available for source waters that are not so clean. Some are:

- use alum/PAC coagulation with sedimentation/DAF plus rapid gravity sand filtration (3 log) plus a fairly low dose of UV and/or ozone to earn another 1 log
- use coagulation with direct filtration (2.5 log) plus enough UV and/or ozone to earn another 1.5 log credits
- use bank filtration (0.5 or 1.0 log) with direct filtration (2.5 log) plus enough UV and/or ozone to earn another 0.5 or 1.0 log credits
- use coagulation, sedimentation plus filtration (3 log) plus enhanced filtration (0.5 log if the combined filtered water turbidity is less than 0.15 NTU), plus a low dose of UV, ozone or chlorine dioxide to earn another 0.5 log
- use membrane filtration, which will probably earn 4 log credits, along with whatever other treatment is necessary to achieve the desired filtered water quality.

These are just examples. As can be seen, many treatment processes can be combined in order to achieve the required number of log credits.

Note that although chlorine is not effective in the inactivation of *Cryptosporidium*, it is still a very effective disinfectant for other micro-organisms. Subject to C.t values, chlorine can inactivate *Giardia* cysts. It also allows a residual to pass into and persist through the distribution system. Its use is still very highly recommended.

## To earn 5 log credits

It is extremely unlikely that any source water in New Zealand would require 5-log treatment. If it did, it is strongly recommended that a new source water be found.

However, water is abstracted from some very dirty rivers overseas, such as the lower reaches of the Rhine. Treatment there could include bank filtration, coagulation, membrane filtration, disinfection with ozone, followed by biologically active filters, and then chlorinated to maintain a residual in the distribution system. This treatment train could earn 6–9 log credits!

## 8.4 Compliance

This section offers guidance on compliance issues for each treatment process that earns protozoal log credits, plus some that don't. The concept is based on the USEPA (2003a, 2006a) *Long Term 2 Enhanced Surface Water Treatment Rule* (known as the LT2ESWTR). Additional information is available in the *Long Term 2 Enhanced Surface Water Treatment Rule, Toolbox Guidance Manual Review Draft* (USEPA 2009). Chapters 12–15 of the Guidelines discuss the technical and operational aspects of these treatment processes.

Because the approach adopted in the DWSNZ for demonstrating protozoal compliance is a relatively new concept, some of the background studies that the USEPA used in developing the log credits and associated criteria have been included in the following sub-sections. Some of the studies give useful information about treatment performance and efficiency. The World Health Organization (eg, WHO 2011) is moving in the same direction, being a logical extension of their long-held belief in the value of multiple barriers.

Section 8.4.5 covers treatment processes not included in the DWSNZ.

Water supplies using any of the following removal or inactivation processes, but not for the purpose of gaining protozoa log credits, do not need to satisfy the protozoal compliance criteria.

## 8.4.1 Pretreatment processes

### 8.4.1.1 Bankside filtration

#### Process description

Bank filtration is a water treatment process that makes use of surface water that has naturally infiltrated under the ground via the riverbed or bank(s) and is recovered via a pumping well. Bank filtrate is water drawn into a pumping well from a nearby surface water source which has travelled through the subsurface, either vertically, horizontally or both, mixing to some degree with other groundwater.

It is envisaged that the greatest benefit of this process may be for water suppliers using turbid or flashy rivers.

Operational aspects of bankside filtration and infiltration galleries are discussed in Chapter 12: Treatment Processes, Pretreatment, section 12.3.1. Refer also to Chapter 4 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to bank filtration.

#### DWSNZ criteria

See section 5.3 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for the 0.5 or 1.0 log credit. If the bank filtration process is not being operated for the purpose of protozoal compliance, these requirements do not need to be met.

The DWSNZ (requirement 5 in section 5.3.1) state that for manual sampling:

- there is documented evidence that the turbidity (of the abstracted water) does not exceed 2.0 NTU during the week after a flood.

This does not require on-going turbidity measurement. A survey of turbidity levels (a minimum of 30 data points) and river flows/depths over a week following a major flood is sufficient; the rainfall leading up to the flood should be recorded as well. The survey may need to be repeated if a large flood causes the river to flow down a new channel.

Wells near rivers do not always deliver river water. It is possible that they intercept shallow groundwater (most probably from an unconfined aquifer), and in this case, the process does not qualify for log credits. Therefore it needs to be demonstrated that the water abstracted by the bank filtration process is in fact from the river. This can be done by comparing water analyses, or can be confirmed by a hydrogeological survey.

#### Further information

Most of the following discussion has been taken from the LT2ESWTR (USEPA 2003a). Most of the data assessed by the USEPA were from studies of aquifers developed in Dutch North Sea margin sand dune fields and, therefore, represent optimal removal conditions consistent with a homogenous, well sorted (by wind), uniform sand filter, conditions not that common in New Zealand.

Only granular aquifers are eligible for bank filtration credit. Granular aquifers are those comprising sand, clay, silt, rock fragments, pebbles or larger particles and minor cement. The aquifer material is required to be unconsolidated, with subsurface samples friable upon touch.

The aquifer at the well site must be characterised to determine aquifer properties. At a minimum, the aquifer characterisation must include the collection of relatively undisturbed, continuous, core samples from the surface to a depth equal to the bottom of the well screen. The proposed site must have substantial core recovery during drilling operations; specifically, the recovered core length must be at least 90 percent of the total projected depth to the well screen.

Samples of the recovered core must be submitted to a laboratory for sieve analysis to determine grain size distribution over the entire recovered core length. Each sieve sample must be acquired at regular intervals over the length of the recovered core, with one sample representing a composite of each metre of recovered core. Because it is anticipated that wells will range from 15 to 30 metres in depth, a metre sampling interval will result in about 15 to 30 samples for analysis. Each sampled interval must be examined to determine if more than ten percent of the grains in that interval are less than 1.0 mm in diameter.

The length of core with more than 10 percent of the grains less than 1.0 mm in diameter must be summed to determine the overall core length with sufficient fine-grained material so as to provide adequate removal. An aquifer is eligible for removal credit if at least 90 percent of the sampled core length contains sufficient fine-grained material as defined.

*Cryptosporidium* oocysts have a natural affinity for attaching to fine-grained material. The value of 1.0 mm for the bounding size of the sand grains was determined based on calculations performed by Harter using data from Harter et al (2000). Harter showed that for groundwater velocities typical of a bank filtration site (1.5 to 15 m/day), a typical bank filtration site composed of grains with a diameter of 1.0 mm would achieve at least 1.0 log removal over a 50 foot transport distance. Larger-sized grains would achieve less removal, all other factors being equal.

A number of devices are used for the collection of groundwater including horizontal and vertical wells, spring boxes, and infiltration galleries. Among these, only horizontal and vertical wells are eligible for log removal credit.

Horizontal wells are designed to capture large volumes of surface water recharge. They typically are constructed by the excavation of a central vertical caisson with laterals that extend horizontally from the caisson bottom in all directions or only under the riverbed. Groundwater flow to a horizontal well that extends under surface water is predominantly downward. In contrast, groundwater flow to a vertical well adjacent to surface water may be predominantly in the horizontal direction. For horizontal wells, the laterals must be located at least 7.5 m distant from the normal-flow surface water riverbed for 0.5 log removal credit and at least 15 m distant from the normal-flow surface water riverbed for 1.0 log *Cryptosporidium* removal credit. The groundwater flow path to a horizontal well is the measured distance from the bed of the river under normal flow conditions to the closest horizontal well lateral.

A spring box is located at the ground surface and is designed to contain spring outflow and protect it from surface contamination until the water is utilised. Often, localised fracturing or solution-enhanced channels are the cause of the focused discharge to the spring orifice. These fractures and solution channels have significant potential to transport microbial contaminants so that natural filtration may be poor. Thus, spring boxes are not proposed to be eligible for bank filtration credit.

An infiltration gallery is typically a slotted pipe installed horizontally into a trench and backfilled with granular material. The gallery is designed to collect water infiltrating from the surface or to intercept groundwater flowing naturally toward the surface water. The infiltration rate may be manipulated by varying the properties of the backfill or the nature of the soil-water interface. Because the filtration properties of the material overlying an infiltration gallery may be designed or purposefully altered to optimise oocyst removal or for other reasons, this engineered system is not bank filtration, which relies solely on the natural properties of the system. The protozoal log removal requirement for river water drawn from a non-qualifying infiltration gallery can be assessed by sampling for oocysts in the raw water instead of the river. An infiltration gallery designed to the requirements of bankside filtration and performs accordingly, may earn protozoal log credits.

#### 8.4.1.2 Off-river storage

The 2001 draft of LT2ESWTR acknowledged the benefits of off-river raw water storage, when it was intended to give 0.5 log and 1 log presumptive credits for reservoirs with hydraulic detention times of 21 and 60 days, respectively.

The USEPA (2003a) subsequently concluded that the data they assessed illustrated the challenge in reliably estimating the amount of removal that will occur in any particular storage reservoir. Because of this variability and the relatively small amount of available data, they decided it was too difficult to extrapolate from these studies to develop nationally applicable criteria for awarding removal credits to raw water storage.

See section 12.3.2 in Chapter 12: Treatment Processes: Pretreatment for further discussion on off-river storage.

Section 8.2 discusses the *Cryptosporidium* monitoring requirements for determining the protozoal risk categorisation of source waters. The benefit of any *Cryptosporidium* die-off during off-river storage will be acknowledged by sampling the water arriving at the treatment plant. Refer also to Chapter 3 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to alternative sources and intakes.

#### 8.4.1.3 Presedimentation (only with chemical coagulation)

The USEPA (2003a) proposed in its draft LT2ESWTR to award a presumptive 0.5 log *Cryptosporidium* treatment credit for presedimentation that meets the following three criteria:

- 1 the presedimentation basin must be in continuous operation and must treat all of the flow reaching the treatment plant

- 2 the system must continuously add a coagulant to the presedimentation basin
- 3 the system must demonstrate on a monthly basis at least 0.5 log reduction of influent turbidity through the presedimentation process in at least 11 of the 12 previous consecutive months. This monthly demonstration of turbidity reduction must be based on the arithmetic mean of at least daily turbidity measurements in the presedimentation basin influent and effluent.

Note that in the DWSNZ, the 0.5 log reduction has been equated to 70 percent removal, in order to make the arithmetic easier; see section 8.3 for how to convert percent removal to log reduction.

The criteria were based on an assessment of data relating mean turbidity reduction and the percent of months when mean aerobic spore removal was at least 0.5 log. Data indicate that aerobic spores may serve as a surrogate for *Cryptosporidium* removal by sedimentation, provided optimal chemical dosage conditions apply. Satisfying the criteria appears to provide approximately 90 percent assurance that average spore (and hence oocyst) removal will be 0.5 log or greater.

In most parts of the world, presedimentation is usually no more than a pond that has been dug out between the intake and the plant for the purpose of reducing the gross solids load on the sedimentation tanks. Sometimes alum is dosed crudely into the presedimentation basin to enhance settling. To distinguish between these two types of presedimentation, the DWSNZ discuss the USEPA concept of presedimentation in section 5.4, where it is more commonly termed sedimentation in New Zealand.

Refer to Chapter 12: Treatment Processes, Pretreatment, section 12.3.3 for a discussion on operational and performance aspects of presedimentation. Refer also to Chapter 5 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to presedimentation.

Section 8.2 discusses the *Cryptosporidium* monitoring requirements for determining the protozoal risk categorisation of source waters. The benefit of any *Cryptosporidium* removal by using presedimentation (with or without coagulation) will be acknowledged by sampling the water arriving at the treatment plant.

#### 8.4.1.4 Watershed control

The LT2ESWTR Final Rule (USEPA 2006) allows a 0.5 log credit for water supplies where an approved 'watershed control programme' has been implemented and carried out. The criteria required for compliance are not particularly quantitative and consequently fairly difficult to apply and assess. In developing the DWSNZ, it was decided that it would be more practicable to incorporate the benefit of any watershed enhancement by monitoring the *Cryptosporidium* oocysts at the raw water intake or as the water reaches the water treatment plant.

Protecting source water quality should be standard water supply practice. Chapter 2 of the *LT2ESWTR Toolbox Guidance Manual Review Draft* (USEPA 2009) discusses aspects related to watershed control in detail; it includes a large, useful list of references.

## 8.4.2 Coagulation processes

### 8.4.2.1 Coagulation, sedimentation, filtration

#### Process description

Sometimes called full or conventional treatment, the coagulation, flocculation, sedimentation and filtration process involves dosage of a chemical, most commonly aluminium sulphate or PAC (polyaluminium chloride), that forms a floc which attracts to it particulate and colloidal matter before separating out in a basin or tank by sedimentation or flotation. Settled water is then passed through rapid gravity (or sometimes pressure) granular (usually sand) filters.

Coagulation and sedimentation without (or prior to) filtration is what the USEPA refers to as presedimentation. See section 8.4.1.3.

Note that sand filtration without chemical coagulation does not remove protozoa from water with any reliability, so does not qualify for protozoal log credits. Some very fine media proprietary filter systems are on the market; they need to be validated and are covered in section 5.17 of the DWSNZ; see section 8.4.5 of these Guidelines.

Operation of the process is discussed in Chapter 13: Treatment Process, Coagulation. Refer also to Chapters 5 and 6 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discuss issues related to sedimentation and lime softening processes.

#### DWSNZ criteria

- Coagulation, sedimentation without filtration: 0.5 log.
- Coagulation, sedimentation with rapid gravity sand filtration: 3.0 log.

See section 5.4 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for log credits. In the unlikely event that the process is not being operated for the purpose of protozoal compliance, these requirements do not need to be met; theoretically, a water supply could achieve 3 log credits for disinfecting with ozone or UV even if the coagulation, sedimentation and filtration process fails to comply.

The success or failure in satisfying the criteria for this process depends very much on the skill in the collection and testing of samples for turbidity. Turbidity monitoring is discussed in section 8.6.2.1.

Particle counting or particle monitoring can be used instead, but these tests are not easy to perform, see section 8.6.2.2. The DWSNZ do not include a criterion for the size or number of particles. Results tend to be instrument specific, so the performance can be assessed either by the absolute number or the log removal of particles, or a combination. Any water supplier electing to use particle counting or particle monitoring should contact the Ministry of Health for further information.

## Further information

The Southern Milwaukee water treatment plant consistently produced final water with turbidity <0.25 NTU. During the massive *Cryptosporidium* outbreak, daily turbidities were 0.45 NTU or higher, with peaks of 1.7 NTU. They were recycling filter washwater (McKenzie et al 1994).

In its proposed LT2ESWTR, the USEPA (2003a) surveyed studies of the performance of treatment plants in removing *Cryptosporidium*, as well as other micron-sized particles (eg, aerobic spores) that may serve as indicators of *Cryptosporidium* removal. They concluded that these studies supported an estimate of 3 log (99.9 percent) for the average *Cryptosporidium* removal efficiency in conventional water treatment plants. Nearly all of the filter runs evaluated in the survey exhibited spikes where filtered water particle counts increased, and pilot work showed that pathogens are more likely to be released during these spike events.

Full-scale plants in these studies typically demonstrated 2–3 log removal of *Cryptosporidium*, and pilot plants achieved up to almost 6 log removals under optimised conditions. In general, the degree of removal that can be quantified in full-scale plants is limited because *Cryptosporidium* levels following filtration are often below the detection limit of the analytical method. Pilot studies overcome this limitation by seeding high concentrations of oocysts to the plant influent, but extrapolation of the performance of a pilot plant to the routine performance of full-scale plants is uncertain. *Cryptosporidium* removal efficiency in these studies was observed to depend on a number of factors including: water quality, coagulant application, treatment rates and optimisation, filtered water turbidity, and the filtration cycle. The highest removal rates were observed in plants that achieved very low effluent turbidities.

Due to the shortage of data relating to oocysts, the USEPA (2003a) evaluated data provided by water suppliers on the removal of other types of particles, mainly aerobic spores, in the sedimentation processes of full-scale plants. Data indicate that aerobic spores may serve as a surrogate for *Cryptosporidium* removal by sedimentation provided optimal chemical dosage conditions apply (Dugan et al 2001).

Data on the removal of spores (*Bacillus subtilis* and total aerobic spores) during operation of full-scale sedimentation basins were collected independently and reported by three water suppliers. A summary of this spore removal data is shown in Table 8.1.

**Table 8.1: Mean spore removal for full-scale sedimentation basins**

Water treatment plant	Mean spore removal
St Louis	1.1 log ( <i>B. subtilis</i> )
Kansas City	0.8 log ( <i>B. subtilis</i> ) 0.46 log ( <i>B. subtilis</i> ) without coagulant
Cincinnati (lamella plates)	0.6 log (total aerobic spores)

The USEPA (2003a) analysed the relationship between removal of spores and reduction in turbidity by sedimentation for the three water supplies that provided these data. Results of this analysis are summarised in Table 8.2, which shows the relationship between monthly mean turbidity reduction and the percent of months when mean spore removal was at least 0.5 log.

**Table 8.2: Relationship between mean turbidity reduction during sedimentation and the percent of months when mean spore removal was at least 0.5 log**

Log reduction in turbidity (monthly mean)	Percent of months with at least 0.5 log mean reduction in spores
Up to 0.1	64%
Up to 0.2	68%
Up to 0.3	73%
Up to 0.4	78%
Up to 0.5	89%
Up to 0.6	91%
Up to 0.7	90%
Up to 0.8	89%
Up to 0.9	95%
Up to 1.0	96%

To simplify the arithmetic, the DWSNZ adopted a 70 percent turbidity reduction criterion instead of the 0.5 log, in order for the sedimentation process to qualify for the 0.5 log credit, see section 5.4 of DWSNZ. The 0.5 log credit only applies when the coagulation, sedimentation process is not followed by rapid gravity sand filtration; normally it does, in which case 3 log credits are possible.

When the raw water turbidity is low, most coagulation/sedimentation processes may have some difficulty achieving 70 percent reduction. For example, if the raw water turbidity averages 3 NTU for a few months of the year, the average settled water turbidity would have to be less than 0.9 NTU for those months, which could be difficult for some plants to achieve.

One study (Dugan et al 2001) evaluated the ability of conventional treatment to remove *Cryptosporidium* under varying water quality and treatment conditions, and assessed turbidity, aerobic spores, and total particle counts (TPC) as indicators of *Cryptosporidium* removal. Under optimal coagulation conditions, oocyst removal across the sedimentation basin ranged from 0.6 to 1.8 log, averaging 1.3 log, and removal across the filters ranged from 2.9 to greater than 4.4 log, averaging greater than 3.7 log. Removal of aerobic spores, TPC, and turbidity all correlated with removal of *Cryptosporidium* by sedimentation, and these parameters were conservative indicators of *Cryptosporidium* removal across filtration. Suboptimal coagulation conditions (underdosed relative to jar test predictions) significantly reduced plant performance. Under those conditions, oocyst removal in the sedimentation basin averaged 0.2 log, and removal by filtration averaged 1.5 log.

Harrington et al (2001) studied the removal of *Cryptosporidium* by sedimentation and dissolved air flotation (DAF) using bench scale jar tests and pilot scale conventional treatment trains. In the bench scale experiments, all run at optimised coagulant doses, mean log removal of *Cryptosporidium* was 1.2 by sedimentation and 1.7 by DAF.

Lime softening is a water treatment process that uses precipitation with lime and other chemicals to reduce hardness and enhance clarification prior to filtration. A single-stage softening plant, which is used to remove calcium hardness, includes a primary clarifier and filtration components. The USEPA (2003a) has determined that lime softening plants achieve a level of *Cryptosporidium* removal equivalent to conventional treatment plants (ie, average of 3 log).

## 8.4.2.2 Coagulation, direct filtration

### Process description

This process is similar to full or conventional treatment as described in section 8.4.2.1, except that there is no sedimentation or flotation step. Because all the particulate and colloidal matter is removed by rapid gravity or sometimes pressure sand filters, this process is only appropriate for relatively clean raw waters, particularly if they do not experience sudden changes in quality.

Operation of the process is discussed in Chapter 13: Treatment Process, Coagulation.

### DWSNZ criteria

See section 5.5 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for the 2.5 log credits. In the unlikely event that the process is not being operated for the purpose of protozoal compliance, these requirements do not need to be met; theoretically, a water supply could achieve sufficient log credits for disinfecting with ozone or UV, even if the coagulation and filtration process fails to comply.

Refer to section 8.6.2.1 and 8.6.2.2 for comments about turbidity monitoring and particle counting.

There have been reports of direct filtration plants failing without the operator noticing. This can happen when alum is added to a low turbidity raw water (say 0.35 NTU) at the wrong dose or wrong pH. The filtered water turbidity may be slightly lower than the raw water (say 0.30 NTU) but little floc has formed so the filters are largely ineffective, allowing protozoa (oo)cysts to pass through, while the water appears to comply with the DWSNZ. Plants where this has happened often have raw water with low turbidity but high colour, usually occurring when the water is cold (say <10°C). It may be advisable at plants where this can happen to include residual aluminium or UV absorbance monitoring to help indicate when these circumstances have arisen.

The filter washing process is not continued until the filter is 100 percent clean. As a result, filtrate for several minutes after backwashing can have an elevated turbidity, even if the filter has a slow start mechanism. Modern filter design usually arranges to waste filtered water for the first 10–20 minutes. The turbidity of this water does not need to be monitored for compliance purposes. However, it would be useful to monitor it for operational reasons.

### Further information

The USEPA (2003a) has concluded that the majority of available data support a lower estimate of *Cryptosporidium* removal efficiency for direct filtration plants. Pilot and full-scale studies demonstrate that sedimentation basins, which are absent in direct filtration, can achieve 0.5 log or greater *Cryptosporidium* reduction.

Emelko et al (2000) investigated *Cryptosporidium* removal during vulnerable filtration periods using a pilot scale direct filtration system. The authors evaluated different operational conditions: stable, early breakthrough and late breakthrough. During stable operation, effluent turbidity was approximately 0.04 NTU and *Cryptosporidium* removal ranged from 4.7 to 5.8 log. In the early breakthrough period, effluent turbidity increased from approximately 0.04 to 0.2 NTU, and *Cryptosporidium* removal decreased significantly, averaging 2.1 log. For the late breakthrough period, where effluent turbidity began at approximately 0.25 NTU and ended at 0.35 NTU, *Cryptosporidium* removal dropped to an average of 1.4 log.

## 8.4.2.3 Second stage filtration

### Process description

In the proposed LT2ESWTR, the USEPA (2003a) states that only water treatment plants that include chemical coagulation and rapid sand or dual media filtration, with or without sedimentation, qualify for log credits when using secondary filtration. Secondary filtration (called second stage filtration in the DWSNZ) consists of rapid sand, dual media, granular activated carbon (GAC), or other fine grain media in a separate filtration stage. The USEPA (2003a) considered that secondary filtration log credits were appropriate based on the theoretical consideration that the same mechanisms of pathogen removal will be operative in both a primary and secondary filtration stage. Therefore, shallow bed, coarse media, high rate filtration systems cannot comply. A cap, such as GAC or anthracite, on a single stage of filtration will not qualify for this credit.

The DWSNZ also allow the use of cartridge and membrane filtration when used as secondary filters, provided they also follow chemical coagulation and rapid sand or dual media filtration, with or without sedimentation. The rationale is that these filters are fine enough to trap particles as small as protozoa that pass through the primary filter. It was decided to award these filtration processes 0.5 log credits also. See section 8.3 for further discussion. Secondary filters that are coarser than the primary filters will not noticeably enhance further removal of protozoa.

Operation of the rapid sand or dual media filtration process is discussed in Chapter 13: Treatment Process, Coagulation. Cartridge and membrane filtration are discussed in Chapter 14: Treatment Process, Filtration. Refer also to Chapter 9 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to second stage filtration.

### DWSNZ criteria

See section 5.6 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for the additional 0.5 log credit. Note that sand or carbon grain size (or their effective sizes and uniformity coefficients), bed depth, and filtration rates are not specified; log credits are awarded on the ability to achieve a specified filtrate turbidity. Refer to sections 8.6.2.1 and 8.6.2.2 for comments about turbidity monitoring and particle counting.

In responding to the draft USEPA LT2ESWTR proposal, all commenters opposed setting regulatory design standards for secondary filters on the basis that water suppliers and states need the flexibility to determine appropriate treatment designs. Consequently, the USEPA did not establish filter design criteria in their final rule (USEPA 2006a), but required that states approve the second-stage filtration design. Similarly, any New Zealand water supplier wishing to qualify for log credits for second-stage filtration will need to have the filter design checked by a DWA.

### Further information

Data on increased removal resulting from a second stage of filtration are limited, and there is uncertainty regarding how effective secondary filtration will be in reducing levels of microbial pathogens that are not removed by the first stage of filtration.

The USEPA (2003a) received data from the City of Cincinnati, Ohio, on the removal of aerobic spores through a conventional treatment plant using GAC contactors for DBP, taste, and odour control after rapid sand filtration. During 1999 and 2000, the mean values of reported spore concentrations in the influent and effluent of the GAC contactors were 35.7 and 6.4 cfu/100 mL respectively, indicating an average removal of 0.75 log across the contactors. Approximately 16 percent of the GAC filtered water results were below detection limit (1 cfu/100 mL) so the actual log spore removal may have been greater than indicated by these results.

## 8.4.2.4 Combined filtration

### Process description

The enhanced combined filtration category is for water treatment plants that practise continuous chemical coagulation, with or without sedimentation. Only rapid granular or dual media filters qualify for log credits when using combined filtration for protozoa removal. The additional 0.5 log credit is awarded for achieving and maintaining a lower turbidity in the combined filtered water than required in section 5.3 of the DWSNZ. Refer also to Chapter 7 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to combined and individual filter performance.

## DWSNZ criteria

See section 5.7 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for the additional 0.5 log credit. Refer to section 8.6.2.1 for comments about turbidity monitoring and 8.6.2.2 for particle counting.

## Further information

In its proposed LT2ESWTR, the USEPA (2003a) reviewed studies that evaluated the efficiency of granular media filtration in removing *Cryptosporidium* when operating at different effluent turbidity levels.

The USEPA considered that plants attempting to meet a turbidity standard of 0.15 NTU in 95 percent of samples will consistently operate below 0.10 NTU in order to ensure continuous compliance. (This could in effect be their control limit.) Therefore the USEPA compared *Cryptosporidium* removal efficiency when effluent turbidity was 0.10 NTU or less with removal efficiency in the range of 0.11 to 0.20 NTU.

Patania et al (1995) conducted pilot-scale studies at four locations to evaluate the removal of seeded *Cryptosporidium* and *Giardia*, turbidity, and particles. Treatment processes, coagulants, and coagulant doses differed among the four locations. Samples of filter effluent were taken at times of stable operation and filter maturation.

Emelko et al (1999) used a bench scale dual media filter to study *Cryptosporidium* removal during both optimal and challenged operating conditions. Water containing a suspension of kaolinite clay was spiked with oocysts, coagulated in-line with alum, and filtered. Oocyst removal was evaluated during stable operation when effluent turbidity was below 0.10 NTU. Removal was also measured after a hydraulic surge that caused process upset, and with coagulant addition terminated. These later two conditions resulted in effluent turbidities greater than 0.10 NTU and decreased removal of *Cryptosporidium*.

Dugan et al (2001) evaluated *Cryptosporidium* removal in a pilot scale conventional treatment plant. Sixteen filtration runs seeded with *Cryptosporidium* were conducted at different raw water turbidities and coagulation conditions. Eleven of the runs had an effluent turbidity below 0.10 NTU, and five runs had effluent turbidity between 0.10 and 0.20 NTU.

The results from these three studies are summarised in Table 8.3. *Cryptosporidium* removal when the turbidity was 0.10 NTU or lower was markedly better than when in the 0.11–0.20 NTU range (mean improvement 0.85 log, minimum improvement 0.5 log).

**Table 8.3: Studies of *Cryptosporidium* removal at different filtrate turbidity levels**

Micro-organism	Log removal found in turbidity range of:		Study
	Up to 0.10 NTU	0.11–0.20 NTU	
<i>Cryptosporidium</i>	4.4	3.6	Patania
<i>Giardia</i>	4.2	3.2	
<i>Cryptosporidium</i>	4.1	3.6	Emelko
<i>Cryptosporidium</i>	3.7	2.6	Dugan

## 8.4.2.5 Individual filtration

### Process description

The enhanced individual filtration category is for water treatment plants that practise chemical coagulation, with or without sedimentation. Only rapid granular or dual media filters qualify for log credits when using individual filtration for protozoa removal. The additional 1 log credit is awarded for achieving and maintaining a lower turbidity in the water leaving each filter than required in section 5.3 of the DWSNZ. Refer also to Chapter 7 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to combined and individual filter performance.

### DWSNZ criteria

See section 5.8 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for the additional 1.0 log credit. Refer to section 8.6.2.1 for comments about turbidity monitoring and 8.6.2.2 for particle counting.

One of the criteria that has to be met is that the turbidity of the water leaving any filter does not exceed 0.30 NTU for more than 1 percent of the time, over the compliance period; 1 percent of a 30-day month is a total of 7.2 hours or an average of 14.4 minutes per day. This criterion implies that if filters are washed daily, they will need a run-to-waste facility to avoid the period when filters traditionally produce their dirtiest water.

### Further information

Refer to the discussion in the Combined Filtration section above.

In its proposed LT2ESWTR the USEPA (2003a) considered that modestly elevated turbidity from a single filter may not significantly impact combined filter effluent turbidity levels, but may indicate a substantial reduction in the overall pathogen removal efficiency of the filtration process. Consequently, water supplies that continually achieve very low turbidity in each individual filter are likely to provide a significantly more effective microbial barrier. The USEPA expects that supplies that select this toolbox option will have achieved a high level of treatment process optimisation and process control, and will have both a history of consistent performance over a range of raw water quality conditions and the capability and resources to maintain this performance long-term.

## 8.4.3 Filtration processes

The following subsections discuss diatomaceous earth, slow sand, bag, cartridge and membrane filtration.

Filtration processes such as roughing filters and microstrainers are not discussed in this chapter because they do not earn log credits for the removal of protozoa. Refer to Chapter 12: Pretreatment Processes. Sand filters used without chemical coagulation do not earn protozoal log credits.

It is possible to demonstrate that other filtration processes can achieve satisfactory removal of protozoa. Section 5.17 of the DWSNZ covers the requirements for new treatment processes, written mainly for larger processes. Section 8.4.3.4 details the procedure to be followed to show whether a cartridge filter meets the requirements of the DWSNZ. This procedure allows for challenge testing to meet acceptable international standards, such as AS/NZS 4348:1995 in conjunction with AS/NZS 3497:1998 (updated 2001)). The MoH may accept use of this approach for treatment processes other than cartridge filters.

### 8.4.3.1 Diatomaceous earth

#### Process description

Diatomaceous earth filtration is a process in which a precoat cake of filter medium is deposited on a support membrane and additional diatomaceous earth (DE) is usually added continuously to the feed water to maintain the permeability of the filter cake. The process can operate under vacuum or pressure. Normally there is no upstream coagulation process, so to avoid uneconomically short filter runs, the process is limited to fairly consistently clean raw waters, ie, fairly low turbidity and low colour.

Operation of the process is discussed in Chapter 14: Treatment Process, Filtration.

#### DWSNZ criteria

See section 5.9 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for the 2.5 log credits. In the unlikely event that the process is not being operated for the purpose of protozoal compliance, these requirements do not need to be met; theoretically, a water supply could achieve sufficient log credits for disinfecting with ozone or UV, even if the filtration process fails to comply.

One of the requirements is that the minimum DE precoat thickness that is needed before protozoa are removed reliably in different raw water conditions is to be determined by turbidity testing. This will involve (where applicable) testing a range of raw water conditions such as after rain, during droughts, warm and cold water, and when algae are near their maximum numbers. The tests should also include a period of maximum flow conditions at different precoat loading rates. While this is happening the water leaving the filters should be run to waste or returned to the raw water. The results of these trials should be documented.

The DWSNZ also include a clause that exempts some water supplies from meeting various turbidity requirements. This was added for the very small number of water supplies that have fine colloidal silica, sometimes called glacial flour, in their raw water. This material is a fraction of the size of (oo)cysts and most will pass through the filters. Therefore turbidity stops being a reliable measure of the filter's ability to remove (oo)cysts. It is possible in the future that the MoH will conduct a survey of these plants, using particle counters.

Section 5.9.1, note 1, states: “All water passes through the process, which is continuous while producing filtrate”. Restarting the plant after a shutdown can dislodge the material built up on the septum, so on/off operation should be avoided, or the filtrate should be recycled until the turbidity is satisfactory.

Particles trapped in the filter are held rather tenuously, so whenever the filtrate turbidity exceeds the influent turbidity, the very real risk of a discharge of oocysts must be accepted, and handled appropriately.

### Further information

The USEPA (2003a) considered that a study of DE filtration by Ongerth and Hutton (2001) supported the findings of earlier studies in showing that a well-designed and operated DE plant can achieve *Cryptosporidium* removal equivalent to a conventional treatment plant (ie, average of 3 log). In developing the DWSNZ it was considered DE filtration was more like the coagulation, direct filtration process than a full scale conventional treatment plant because neither include the sedimentation stage, which has been shown to achieve 0.5 log or greater *Cryptosporidium* reduction.

## 8.4.3.2 Slow sand filtration

### Process description

Slow sand filtration is a process involving passage of raw water through a bed of sand at low velocity, generally less than 0.4 m/h (which compares with say 20 m/h in rapid granular media filtration) resulting in substantial particulate removal by physical and biological mechanisms. Removal of microbial pathogens in slow sand filters is complex and is believed to occur through a combination of physical, chemical, and biological mechanisms, both on the surface (schmutzdecke) and in the interior of the filter bed.

Operation of the process is discussed in Chapter 14: Treatment Process, Filtration.

### DWSNZ criteria

See section 5.10 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for the 2.5 log credits. In the unlikely event that the process is not being operated for the purpose of protozoal compliance, these requirements do not need to be met; theoretically, a water supply could achieve sufficient log credits for disinfecting with ozone or UV, even if the filtration process fails to comply.

Particles trapped on the sand grains are held rather tenuously, so whenever the filtrate turbidity exceeds the influent turbidity, the very real risk of a discharge of oocysts must be accepted, and handled appropriately.

## Further information

Hall et al (1994) examined the removal of *Cryptosporidium* with a pilot scale slow sand filtration plant. *Cryptosporidium* removals ranged from 2.8 to 4.3 log after filter maturation, with an average of 3.8 log (at least one week after filter scraping). Raw water turbidity ranged from 3.0–7.5 NTU for three of four runs and 15.0 NTU for a fourth run. Filtered water turbidity was 0.2–0.4 NTU, except for the fourth run which was 2.5 NTU.

Fogel et al (1993) evaluated removal efficiencies for *Cryptosporidium* and *Giardia* with a full-scale slow sand filtration plant. The removals ranged from 0.1–0.5 log for *Cryptosporidium* and 0.9–1.4 log for *Giardia*. Raw water turbidity ranged from 1.3–1.6 NTU and decreased to 0.35 NTU after filtration. The authors attributed the low *Cryptosporidium* and *Giardia* removals to the relatively poor grade of filter media and lower water temperature. The sand had a higher uniformity coefficient than recommended by design standards. This creates larger pore spaces within the filter bed that retard biological removal capacity. Lower water temperatures (1°C) also decreased biological activity in the filter media.

The study by Fogel et al is significant because it indicates that a slow sand filtration plant may achieve less than 2 log removal of *Cryptosporidium* removal while still being in compliance with filtrate turbidity requirements. This is why the compliance criteria in the DWSNZ include water temperature monitoring with a lower limit of 6°C.

### 8.4.3.3 Bag filtration

#### Process description

The USEPA (2003a) defined bag filters as pressure driven separation processes that remove particulate matter larger than 1 micrometre using an engineered porous filtration medium through either surface or depth filtration.

Bag filters are typically constructed of a non-rigid, fabric filtration media housed in a pressure vessel in which the direction of flow is from the inside of the bag to the outside.

Operation of the process is discussed in Chapter 14: Treatment Process, Filtration. The testing protocol for the verification of equipment performance is described in EPA/NSF ETV (2005). See USEPA (2012a) for an update. Refer also to Chapter 8 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to bag and cartridge filtration.

#### DWSNZ criteria

See section 5.13 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for the 1 log credit. In the unlikely event that the process is not being operated for the purpose of protozoal compliance, these requirements do not need to be met; theoretically, a water supply could achieve sufficient log credits for disinfecting with ozone or UV, even if the filtration process fails to comply.

To obtain 1 log credit, bag filters must be validated to achieve 2 log removals of *Cryptosporidium*. This factor of safety, which has been adopted from the USEPA (2003a, 2006a), is applied to the removal credit because:

- the removal efficiency of bag filters over the course of a filter run has been observed to vary by more than 1 log
- bag filters are not routinely direct integrity tested during operation, so there is no means of verifying the removal efficiency of filtration units during routine use.

Validated bags can also earn 0.5 log credits if used (but highly unlikely) as secondary filters after a coagulation process, and 0.5 log credits when used as secondary filters after diatomaceous earth or slow sand filters, also unlikely (see Table 5.2 DWSNZ).

The DWSNZ also include a clause that exempts some water supplies from meeting various turbidity requirements. This was added for the very small number of water supplies that have fine colloidal silica, sometimes called glacial flour, in their raw water. This material is a fraction of the size of (oo)cysts and most will pass through the filters. Therefore turbidity stops being a reliable measure of the filter's ability to remove (oo)cysts. It is possible in the future that the MoH will conduct a survey of these plants, using particle counters.

Particles trapped in the bag are held rather tenuously, so whenever the filtrate turbidity exceeds the influent turbidity, the very real risk of a discharge of oocysts must be accepted, and handled appropriately. Restarting the plant after a shutdown can dislodge the material built up on the filter, so on/off operation should be avoided, or the filtrate should be recycled until the turbidity is satisfactory.

An investigation is required, if in any day, the pressure drop across the bag filter increases by more than 5 percent of the total allowable. Also, if the pressure differential does not increase over a reasonable time span, consideration must be given to the possibility that the water is short-circuiting via faulty seals etc. Refer to Chapter 14: Treatment Processes: Filtration, section 14.5 for further information.

### Performance validation/certification

Manufacturers commonly rate fabric filters by pore size or pore distribution. However, there is no industry standard for measuring or reporting these characteristics. This lack of standardisation causes problems for establishing design criteria to ensure that a given bag filter will effectively remove a given percentage of *Cryptosporidium*. Furthermore, an oocyst has different structural characteristics than the markers used to determine pore size; thus, the rate of rejection may differ for an oocyst versus the test markers used to determine pore size or molecular weight cut-off. To compensate for these factors of uncertainty for *Cryptosporidium* removal, the LT2ESWTR requires bag filters to be challenge tested to determine removal credit.

The log removal validation is based on challenge testing. The equipment supplier or manufacturer must perform challenge tests before the water supplier purchases the plant. Certificates of performance are to be supplied. The Medical Officer of Health may also require challenge tests to check that a treatment (or other) problem has been rectified. Challenge testing must be conducted on a full-scale filter element identical in material and construction to the filter elements proposed for use in full-scale treatment facilities.

Water suppliers may adopt the equipment or appliance supplier’s certification provided:

- a) it meets one of the following:
  - the *Membrane Filtration Guidance Manual* (USEPA 2005), which contains detailed guidance on developing challenge test protocol and conducting the test for membrane processes that relate to these requirements
  - the *Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants* (NSF 2005), which has a chapter for testing bag and cartridge filters (Chapter 4). See USEPA (2012a) for an update
  - a standard formally recognised by the Ministry of Health as being equivalent
- b) an appropriately accredited inspection body performs the testing
- c) the tests are made on entire units, including filtration media, seals, filter housing and other components integral to the process
- d) the installed equipment is identical (or validated as equivalent) to the equipment tested during the certification process.

### Further information

A limited amount of published data is available regarding the removal efficiency of bag filters with respect to *Cryptosporidium* oocysts or suitable surrogates. The relevant studies identified by the USEPA (2003a) in the literature are summarised in Table 8.4.

**Table 8.4: Results from studies of *Cryptosporidium* (or surrogate) removal by bag filters**

Organism/surrogate	Log removal	Study
<i>Cryptosporidium</i>	3.0	Cornwell and Le Chevalier 2002
<i>Cryptosporidium</i>	0.5 to 3.6	Li et al 1997
4.5 micron spheres	0.5 to 2.0	Goodrich et al 1995

These data demonstrate highly variable removal performance, ranging from 0.5 log to 3.6 log.

Li et al (1997) evaluated three bag filters with similar pore size ratings and observed a 3 log difference in *Cryptosporidium* oocyst removal among them. These results indicate that bag filters may be capable of achieving removal of oocysts in excess of 3 log, but performance can vary significantly among products, and there appears to be no correlation between pore size rating and removal efficiency.

Based on available data, specific design criteria that correlate with removal efficiency cannot be derived for bag filters. The removal efficiency of these proprietary devices can be impacted by product variability, increasing pressure drop over the filtration cycle, flow rate, and other operating conditions.

The removal efficiency of some bag filtration devices has been shown to decrease over the course of a filtration cycle due to the accumulation of solids and resulting increase in pressure drop. As an example, Li et al (1997) observed that the removal of 4.5 micrometre microspheres by a bag filter decreased from 3.4 log to 1.3 log over the course of a filtration cycle.

The data in Table 8.4 were generated from studies performed under a variety of operating conditions, many of which could not be considered conservative (or worst-case) operation. These considerations led to the challenge testing requirements which are intended to establish a product specific removal efficiency rather than site-specific.

Only a few bag filtration studies have attempted to correlate turbidity removal with removal of *Cryptosporidium* oocysts or surrogates. Li et al (1997) found that the removal efficiency for turbidity was consistently lower than the removal efficiency for oocysts or microspheres for the three bag filters evaluated. None of the filters was capable of consistently producing a filtered water turbidity below 0.3 NTU for the waters evaluated.

#### 8.4.3.4 Cartridge filtration

##### Process description

The USEPA (2003a) defined cartridge filters as pressure driven separation processes that remove particulate matter larger than 1 micrometer using an engineered porous filtration medium through either surface or depth filtration.

Cartridge filters are typically constructed as rigid or semi-rigid, self-supporting filter elements housed in pressure vessels in which flow is from the outside of the cartridge to the inside.

Although all filters classified as cartridge filters share similarities with respect to their construction, there are significant differences among the various commercial devices. An important distinction is the ability to directly test the integrity of the filtration system in order to verify that there are no leaks that could result in contamination of the filtrate. Any membrane cartridge filtration device that can be direct integrity tested according to the criteria specified in the membrane filtration section of DWSNZ (section 5.11) is eligible for protozoal removal credit as a membrane, subject to the criteria specified in that section.

Operation of the process is discussed in Chapter 14: Treatment Process, Filtration. The testing protocol for the verification of equipment performance is described in EPA/NSF ETV (2005). See USEPA (2012a) for an update. Refer also to Chapter 8 of the LT2ESWTR Toolbox Guidance Manual review draft (USEPA 2009) which discusses issues related to bag and cartridge filtration.

## DWSNZ criteria

See section 5.12 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for the 2 log credits. In the unlikely event that the process is not being operated for the purpose of protozoal compliance, these requirements do not need to be met; theoretically, most water supplies could achieve sufficient log credits for disinfecting with ozone or UV, even if the filtration process fails to comply.

To obtain 2 log credits, cartridges must be validated to achieve 3 log removals (cyst reduction) of *Cryptosporidium*. This 1 log factor of safety is applied to the removal credit for cartridge filters because:

- the removal efficiency of some cartridge filters has been observed to vary by more than 1 log over the course of operation
- cartridge filters are not routinely subjected to direct integrity testing during operation, so there is no means of verifying the removal efficiency of filtration units during routine use.

Qualifying for 2 log credits means that cartridge filtration may be a particularly suitable process for use on a non-secure bore water supply. This can then be followed by chlorination in order to achieve bacterial compliance, and to protect the distribution system.

Validated cartridge filters can also earn 0.5 log credits if used (but highly unlikely) as secondary filters after a coagulation process, and 0.5 log credits when used as secondary filters after diatomaceous earth or slow sand filters, also unlikely (see Table 5.2 DWSNZ).

The DWSNZ also include a clause that exempts some water supplies from meeting various turbidity requirements. This was added for the very small number of water supplies that have fine colloidal silica, sometimes called glacial flour, in their raw water. This material is a fraction of the size of (oo)cysts and most will pass through the filters. Therefore turbidity stops being a reliable measure of the filter's ability to remove (oo)cysts. It is possible in the future that the MoH will conduct a survey of these plants, using particle counters.

Particles trapped in the cartridge are held rather tenuously, so whenever the filtrate turbidity exceeds the influent turbidity, the very real risk of a discharge of oocysts having occurred must be accepted, and handled appropriately. Restarting the plant after a shutdown can dislodge the material built up on the filter, so on/off operation should be avoided, or the filtrate should be recycled until the turbidity is satisfactory.

An investigation is required, if in any day, the pressure drop across the cartridge filter increases by more than 5 percent of the total allowable. Also, if the pressure differential does not increase over a reasonable time, consideration must be given to the possibility that the water is short-circuiting via faulty seals etc. Refer to Chapter 14: Treatment Processes: Filtration, section 14.5 for further information.

See section 8.4.2.3 for a discussion relating to the use of cartridge filtration when used as secondary filters.

## Performance validation/certification

Manufacturers commonly rate fabric filters by pore size or pore distribution, usually 'defined' as being absolute or nominal. However, there is no industry standard for measuring or reporting these characteristics. This lack of standardisation causes problems for establishing design criteria to ensure that a given cartridge filter will effectively remove a given percentage of *Cryptosporidium*. Furthermore, an oocyst has different structural characteristics than the markers used to determine pore size; thus, the rate of rejection may differ for an oocyst versus the test markers used to determine pore size or molecular weight cut-off. To compensate for these factors of uncertainty for *Cryptosporidium* removal, the LT2ESWTR requires cartridge filters to be challenge tested to determine removal credit, see section 8.5.

The log removal validation is based on challenge testing. The equipment supplier or manufacturer must perform challenge tests before the water supplier purchases the plant. Certificates of performance are to be supplied. The Ministry of Health may also require challenge tests to check that a treatment (or other) problem has been rectified. Challenge testing must be conducted on a full-scale filter element identical in material and construction to the filter elements proposed for use in full-scale treatment facilities – **except** see d) and e) below.

Water suppliers may adopt the equipment or appliance supplier's certification provided:

- a) it meets one of the following:
  - the *Membrane Filtration Guidance Manual* (USEPA 2005), which contains detailed guidance on developing challenge test protocol and conducting the test for membrane processes that relate to these requirements
  - the USEPA (2010) *Long Term 2 Enhanced Surface Water Treatment Rule: Toolbox Guidance Manual Part 8: Bag and Cartridge Filters*
  - the (oo)cyst reduction conditions of *Drinking Water Treatment Units: Health effects*, NSF/ANSI 53 (NSF and ANSI 2002a, and subsequent revisions)
  - the Ministry of Health is currently assessing the of suitability of ANSI/NSF 419 2015
  - a standard formally recognised by the Ministry of Health as being equivalent (eg, AS/NZS 4348:1995 in conjunction with AS/NZS 3497:1998 (updated 2001)). If a whole cartridge cannot be tested, the portion submitted for testing must be of sufficient size to allow accurate testing and scalability. The calculation that derived the factor used to relate the flow through the test portion and the complete cartridge must be provided, and will be peer reviewed.
- b) an appropriately accredited inspection body has performed the testing
- c) the installed equipment is identical (or validated as equivalent) to the equipment tested during the certification process
- d) the tests are made on entire units, including filtration media, seals, filter housing and other components integral to the process; **this USEPA requirement is usually impracticable for larger units, so see e)**

- e) a certificated cartridge filter can easily fail due to its assembly, ie, 'its seals and other components integral to the process'. Using a cartridge that satisfies the challenge test requirements is acceptable if:
- the cartridge is single-open-ended (SOE), plug-in style, sealed in the housing with o-rings
  - scaling up to multiple cartridges, the field cartridge is the same diameter and construction as the test cartridge and the cartridge is of uniform construction over its entire length with no joins or joiners; heat-bonded joins are suitable
  - an automatic air release valve sized and rated for the assembly is installed on the top of the filter housing to release any trapped air
  - a default maximum headloss of 150 kPa is set unless the manufacturer can demonstrate that performance is maintained beyond that. Cartridges must be replaced before the terminal pressure drop is reached
  - new/replacement cartridges and plants that operate an on/off regime are run to waste for the first five minutes they come online
  - all components are made from materials approved for use in water supply, eg, ANSI/NSF Standard 61 or equivalent.

As a result of the above clarification, use of the following template is required.

**Template for assessing cartridge filter compliance**

5.12.1 Log credit assessment of – ..... cartridge filter

To obtain 2.0 protozoa log credits for cartridge filtration, the following requirements must be met during periods when the filtered water is being produced.

DWSNZ requirement	Status
<p>Requirement 1: Each cartridge has a certified <i>Cryptosporidium</i> or cyst removal efficiency of at least 3 log. Water suppliers may adopt the supplier's certification provided:</p> <p>a) it meets one of the following:</p> <ul style="list-style-type: none"> <li>i) the <i>Membrane Filtration Guidance Manual</i> (USEPA 2005), which contains detailed guidance on developing challenge test protocol and conducting the test for membrane processes that relate to these requirements</li> <li>ii) the (oo)cyst reduction conditions of <i>Drinking Water Treatment Units: Health effects</i>, NSF/ANSI 53 (NSF and ANSI 2002a, and subsequent revisions)</li> </ul> <p>or</p> <p>a standard formally recognised by the Ministry of Health as being equivalent, eg, AS/NZS 4348:1995 in conjunction with AS/NZS 3497:1998 (updated 2001).</p> <p>b) an appropriately accredited inspection body has performed the testing</p> <p>c) the installed equipment is identical (or validated as equivalent) to the equipment tested during the certification process</p> <p>d) the tests are made on entire units, including filtration media, seals, filter housing and other components integral to the process. Because this is usually impracticable for larger units, see e)</p> <p>e) a certificated cartridge filter can fail due to its operation or its assembly, ie, "its seals and other components integral to the process". Using a cartridge that satisfies the challenge test requirements is acceptable if:</p> <ul style="list-style-type: none"> <li>• the cartridge is single-open-ended (SOE), plug-in style, sealed in the housing with o-rings</li> <li>• scaling up to multiple cartridges, the field cartridge is the same diameter and construction as the test cartridge and the cartridge is of uniform construction over its entire length with no joins or joiners; heat-bonded joins are suitable</li> <li>• an automatic air release valve is installed on the top of the filter housing to release any trapped air</li> <li>• a default maximum headloss of 150 kPa is set unless the manufacturer can demonstrate that performance is maintained beyond that. Cartridges must be replaced before the terminal pressure drop is reached</li> <li>• new/replacement cartridges and plants that operate an on/off regime are run to waste for at least the first 5 minutes they come online</li> <li>• all components are made from materials approved for use in water supply, eg, ANSI/NSF Standard 61 or equivalent.</li> </ul>	No. Used the alternative e), as follows
Requirements 2, 3, and 4 relate to filtrate monitoring	
Requirement 5 is covered in 1c)	NA
Requirement 6: A slow opening/closing valve is fitted ahead of the cartridge filter plant, and the filtrate passes either through a pressure surge valve or directly to a tank before any subsequent process or pumping.	
Requirement 7: The flow through each housing is measured. A restrictor that maintains the flow below the certified maximum operating rate is fitted to each housing.	
Requirement 8: Differential pressure measurements across the housing are recorded to confirm that the minimum differential pressure always exceeds the differential pressure corresponding to a clean filter established during commissioning, and are kept within the manufacturer's recommendations.	

## Further information

A limited amount of published data is available regarding the removal efficiency of cartridge filters with respect to *Cryptosporidium* oocysts or suitable surrogates. The relevant studies identified by the USEPA (2003a) in the literature are summarised in Table 8.5.

**Table 8.5: Results from studies of *Cryptosporidium* (or surrogate) removal by cartridge filters**

Organism/surrogate	Log removal	Study
<i>Cryptosporidium</i>	3.5 average	Enriques et al 1999
<i>Cryptosporidium</i>	3.3 average	Roessler 1998
<i>Cryptosporidium</i>	1.1 to 3.3	Schaub et al 1993
5.7 micron spheres	0.5 to 3.6	Long 1983

These data demonstrated highly variable removal performance, ranging from 0.5 log to 3.6 log.

Results of these studies also show no correlation between the pore size rating established by the manufacturer and the removal efficiency of a filtration device. In a study evaluating two cartridge filters, both with a pore size rating of 3 micrometres, a 2 log difference in *Cryptosporidium* oocyst removal was observed between the two filters (Schaub et al 1993).

Another study evaluated 17 cartridge filters with a range of pore size ratings from 1 to 10 micrometres and found no correlation with removal efficiency (Long 1983). It has been noted that although *Cryptosporidium* is 4 to 6 microns in size, it can still pass through an absolute 3-micron size filter by deforming and squeezing through (USEPA 2003b).

Based on available data, specific design criteria that correlate to removal efficiency cannot be derived for cartridge filters. The removal efficiency of these proprietary devices can be impacted by product variability, increasing pressure drop over the filtration cycle, flow rate, and other operating conditions. The data in Table 8.5 were generated from studies performed under a variety of operating conditions, many of which could not be considered conservative (or worst-case) operation. These considerations led to the challenge testing requirements which are intended to establish a product specific removal efficiency, rather than site-specific.

### 8.4.3.5 Membrane filtration

#### Process description

In their proposed LT2ESWTR, the USEPA (2003a) defined membrane filtration as a pressure or vacuum driven separation process in which particulate matter larger than 1 µm (micrometre) is rejected by a nonfibrous, engineered barrier, primarily through a size exclusion mechanism, and which has a measurable removal efficiency of a target organism that can be verified through the application of a direct integrity test.

This definition is intended to include the common membrane classifications: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). MF and UF are relatively low pressure membrane filtration processes that are primarily used to remove particulate matter and microbial contaminants. NF and RO are membrane separation processes that are primarily used to remove dissolved contaminants through a variety of mechanisms, but which also remove particulate matter via a size exclusion mechanism. MF and UF are the more common larger processes. The others tend to be used for individual supplies (eg, point-of-use) or for special purposes.

MF membranes are generally considered to have a pore size range of 0.1–0.2 microns or micrometres (nominally 0.1 microns), although there are exceptions. For UF, pore sizes generally range from 0.01–0.05 microns (nominally 0.01 microns) or less, decreasing to an extent at which the concept of a discernible ‘pore’ becomes inappropriate, a point at which some discrete macromolecules can be retained by the membrane material. In terms of a pore size, the lower cut-off for a UF membrane is approximately 0.005 µm. Because some UF membranes have the ability to retain larger organic macromolecules, they have been characterised historically by a molecular weight cut-off (MWCO) rather than by a particular pore size. Typical MWCO levels for UF membranes range from 10,000 to 500,000 Daltons, with most membranes used for water treatment at approximately 100,000 MWCO.

The critical distinction between membrane filtration processes and bag and cartridge filters is that the integrity of membrane filtration processes can be tested directly. Based on this distinction, membrane material configured into a cartridge filtration device that meets the definition of membrane filtration and that can be direct integrity tested according to the criteria specified in this section is eligible for the same removal credit as a membrane filtration process.

Membrane devices can be designed in a variety of configurations including hollow-fibre modules, hollow-fibre cassettes, spiral-wound elements, cartridge filter elements, plate and frame modules, and tubular modules among others.

The generic term module is used to refer to all of these various configurations and is defined as the smallest component of a membrane unit in which a specific membrane surface area is housed in a device with a filtrate outlet structure. A membrane unit is defined as a group of membrane modules that share common valving that allows the unit to be isolated from the rest of the system for the purpose of integrity testing or other maintenance.

Operation of the process is discussed in Chapter 14: Treatment Process, Filtration. Refer also to Chapter 14 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to membrane filtration.

### DWSNZ criteria

It is possible to earn 3 or more log credits by using membrane filtration as the sole treatment process. Membrane filtration can also earn its full number of log credits when used in place of rapid gravity sand filters in a chemical coagulation plant. See section 8.4.2.3 for a discussion relating to the use of membrane filters used as secondary filters.

Because membrane filters have a pore size range of 0.1–0.2 microns or smaller, other filtration systems used in a secondary role are not likely to remove the particles that pass through the membrane filter, so they cannot earn secondary filtration log credits.

See section 5.11 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for log credits. In the unlikely event that the process is not being operated for the purpose of protozoal compliance, these requirements do not need to be met; theoretically, a water supply could achieve 3 log credits for disinfecting with ozone or UV, even if the filtration process fails to comply.

In systems that operate on/off, the filtrate is recycled or wasted until the approved upper control limits of the indirect integrity monitoring (eg, turbidity or particle counting) are no longer exceeded. If air routinely affects the online measurement of turbidity and/or particle counting on restart, and it has been demonstrated that the turbidity and/or particle count on restart is falsely indicating inadequate performance of the membranes, then on return to service the turbidity must be less than 0.10 NTU or the particle count below the upper control limit within 15 minutes. If this is not achieved the filtrate must be recycled or wasted until this level of performance has been achieved.

### Performance validation/certification

The Membrane Filtration Guidance Manual (proposal: USEPA 2003c, and final rule: USEPA 2005a) sets out a procedure for challenge testing, see section 8.5 of these Guidelines. The requirement for challenge testing is intended to be product-specific such that site-specific demonstration of *Cryptosporidium* removal efficiency is not necessary. Once the log removal of a membrane has been established through a challenge test that meets the requirements of LT2ESWTR, additional challenge testing is not required unless significant modifications are made to the membrane process.

The maximum number of protozoal log credits that a membrane filtration process is eligible to receive depends upon the manufacturer's certification of the log removal that the filter plant can deliver, see section 5.11.1 of the DWSNZ. So far, all MF plants in New Zealand have been assigned 4 log credits. Although some models have validation for up to 7 log removals, these results have usually been achieved under short term trial conditions, rather than continuously running with variable raw water quality and operating conditions.

The testing protocol for the verification of equipment performance is described in a 246-page publication of EPA/NSF ETV (2002), and in the Membrane Filtration Guidance Manual (USEPA 2005a).

### Procedure for older plants

Data from challenge studies conducted prior to promulgation of the DWSNZ 2005 can be considered in lieu of additional testing. However, the prior testing must have been conducted in a manner that demonstrates removal efficiency for *Cryptosporidium* greater than the treatment credit awarded to the process.

The Membrane Filtration Guidance Manual (USEPA 2005a) states in section 3.15 that as a general guide, the following challenge test conditions have been identified as potentially yielding results that do not satisfy the intent of the rule:

- challenge testing conducted on obsolete products. Refer to section 3.14 for guidance on the re-testing of modified membrane modules
- challenge testing conducted on small-scale modules. Small-scale module testing is permitted under the LT2ESWTR if certain criteria are met. Refer to section 3.8 for guidance regarding the testing of small-scale modules

- challenge testing using unacceptable surrogates for *Cryptosporidium*. The challenge particulate used in a grandfathered test must provide equivalent or sufficiently conservative removal efficiency relative to *Cryptosporidium* oocysts. Refer to section 3.9 regarding the selection of surrogates for use in challenge testing
- challenge particulate enumeration using unacceptable methodology. The challenge particulate must have been quantified using an acceptable method. Specifically, gross measurements are generally considered unacceptable. Refer to section 3.9 regarding methods for enumerating various challenge particulates
- unavailable quality control release value (QCRV). If non-destructive performance testing was not used to establish a suitable QCRV in a previous study, it may be difficult or impossible to relate the demonstrated removal efficiency to the non-destructive performance test results for untested modules that are produced.

Section 3.15 of the Membrane Filtration Guidance Manual adds that there may also be cases in which deviations from challenge testing requirements under the LT2ESWTR may not be significant, such that additional testing would not be required.

### Further information

A number of studies have been conducted which have demonstrated the ability of membrane filtration processes to remove pathogens, including *Cryptosporidium*, to below detection levels. A literature review summarising the results of several comprehensive studies was conducted and reported by the USEPA (2001a) and is presented in Low Pressure Membrane Filtration for Pathogen Removal: Application, Implementation, and Regulatory Issues.

Many of these studies used *Cryptosporidium* seeding to demonstrate removal efficiencies as high as 7 log. The collective results from these studies demonstrate that an integral membrane module, ie, a membrane module without any leaks or defects, with an exclusion characteristic smaller than *Cryptosporidium*, is capable of removing this pathogen to below detection in the filtrate, independent of the feed concentration.

Although it is not uncommon for a membrane plant (MF and UF) to demonstrate up to 6 or more protozoal log credits in the challenge test, most are assigned 4 log credits by the US regulatory bodies. Therefore to be assigned other than 4 log credits would require unusual circumstances. The most likely reason for going under 4 would probably be due to the use of a direct integrity test (DIT) of lower resolution and sensitivity than those commonly used today. Maybe more than 4 log credits could be assigned to NF or RO plants, but so far their use in New Zealand has been limited to very small supplies. In the very improbable event of a New Zealand source water being of such poor quality that it is categorised as needing more than 4 protozoal log credits, the multiple barrier principle would suggest that a membrane plant on its own would offer insufficient confidence about the final product being safe to drink.

## 8.4.4 Disinfection processes

### 8.4.4.1 Chlorine dioxide

#### Process description

The disinfectant chlorine dioxide ( $\text{ClO}_2$ ) is made on site and can be dosed into the water supply to inactivate micro-organisms, including bacteria, viruses, and protozoa such as *Cryptosporidium*.

Operation of the chlorine dioxide disinfection process is discussed in section 15.5.3 of Chapter 15: Treatment Process, Disinfection; C.t values are discussed in section 15.2.1; contact tanks and hydraulic residence time (t) are discussed in section 15.2.9. Refer also to Chapter 10 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to disinfection using chlorine dioxide.

#### DWSNZ criteria

See section 5.14 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for log credits. In the unlikely event that the process is not being operated for the purpose of protozoal compliance, these requirements do not need to be met; theoretically, a water supply could achieve 3 log credits for disinfecting with ozone or UV, or could earn 3 log credits using chemical coagulation, sedimentation, filtration, or membrane filtration, even if the chlorine dioxide process is non-complying.

The chlorite ion ( $\text{ClO}_2^-$ ) is the predominant by-product when chlorine dioxide is used as a disinfectant. About 50–70 percent of the chlorine dioxide dosed into the water may be converted to chlorite. On this basis, the maximum dose that can be used without chlorite exceeding its 0.8 mg/L MAV is about 1.2–1.6 mg/L. As a result, impractically long contact times may be needed to achieve protozoal compliance. Pilot trials to determine the chlorite levels that will form should be undertaken.

#### Further information

The C.t table in the DWSNZ for protozoal compliance using chlorine dioxide was taken from Table IV.D–4 in the LT2ESWTR (USEPA 2006a). It was based on Clark et al (2003) who employed data from Li et al (2001) to develop equations for predicting inactivation, and used data from Owens et al (1999) and Ruffell et al (2000) to validate the equations. The following equation can be used to determine the log credit between the indicated values in Table 5.5 in the DWSNZ:

$$\log \text{ credit} = 0.001506 \times 1.09116^{\text{temp}} \times \text{C.t}$$

C.t values are described in Chapter 15: Disinfection, sections 15.2.1 and 15.2.9.

Another step in developing the C.t values for *Cryptosporidium* inactivation involved consideration of the appropriate confidence bound to apply when analysing the inactivation data. A confidence bound represents a safety margin that accounts for variability and uncertainty in the data that underlie the analysis. Confidence bounds are intended to provide a high likelihood that water supplies operating at a given C.t value will achieve at least the corresponding log inactivation level in the C.t table. Two types of confidence bounds that are used when assessing relationships between variables, such as disinfectant dose and log inactivation, are confidence in the regression and confidence in the prediction. USEPA (2003a, 2006a) discusses these in the LT2ESWTR. The use of confidence bounds probably explains why the C.t values have increased, particularly at higher temperatures, since DWSNZ (2000).

Since the available data are not sufficient to support the C.t calculation for an inactivation level greater than 3 log, the use of the C.t table in the DWSNZ is limited to inactivation less than or equal to 3 log. In addition, the temperature limitation is 1–25°C. If the water temperature is higher than 25°C, the temperature should be set to 25°C for the log inactivation calculation.

#### 8.4.4.2 Ozone

##### Process description

The disinfectant ozone (O<sub>3</sub>) is made on site and can be dosed into the water supply to inactivate micro-organisms, including bacteria, viruses, and protozoa such as *Cryptosporidium*.

Operation of the process is discussed in Chapter 15: Disinfection, section 15.5.4. Refer also to Chapter 11 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to disinfection using ozone.

##### DWSNZ criteria

See section 5.15 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for log credits. Disinfecting with ozone can cause bromate to exceed its MAV of 0.01 mg/L, so pilot trials are needed to determine acceptable dosage conditions. Alternatively, if the raw water bromide content is less than 0.006 mg/L, the bromate concentration should not exceed the MAV. In the unlikely event that the process is not being operated for the purpose of protozoal compliance, these requirements do not need to be met; theoretically, a water supply could achieve 3 log credits for disinfecting with chlorine dioxide or UV, or could earn 3 log credits using chemical coagulation, sedimentation, filtration, or membrane filtration, even if the ozone process is non-complying.

Section 5.15.2(6) of the DWSNZ states that flow measurements must be made continuously for supplies serving more than 500 people. Flow is an important component in calculating C.t. If a plant is said to be constant flow, the water supplier needs to be able to demonstrate that the flow is maintained within 10 percent of that flow for 95 percent of the time.

## Performance validation/certification

The validation process is reasonably complex so it would be expected that ozone appliances would be validated by the manufacturers. The appliance needs to comprise more than one reaction chamber (see Table 8.6).

The residual ozone is measured at a prescribed point in the ozone contactor to validate by challenge testing that it is able to achieve the required inactivation of test organisms. Chapter 5: Disinfection, section 15.5.4.3 discusses the sampling techniques, test methods and calibration procedure.

Chapter 11 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) discusses issues related to the measurement of contact time in different types of ozone generators and contactors.

Section 8.6.2.5 discusses C.t values and how to determine t in an ozone contactor.

## Determining ozone C.t

The protozoa log credits for various C.t values at different temperatures are given in Table 5.6 in the DWSNZ, taken from Table IV.D-3 in the LT2ESWTR (USEPA 2006a). See section 15.2.1 of the Guidelines for a fuller description of C.t. For ozone, the value used for C depends on the design of the reaction vessel/contactor.

<b>Turbine</b>	<b>Co-current flow</b>	<b>Counter-current flow</b>	<b>Reactive flow</b>
$C_{out}$	$C_{out}$ or $(C_{in} + C_{out})/2$	$C_{out}/2$	$C_{out}$

C.t can be calculated for an entire ozone contactor or for individual segments. The C.t for the individual segments can be summed to give a total C.t for all of the segments. C is measured at the beginning and end of an individual segment or at the end of the segment.

Chapter 11.3 of the review draft Ozone Toolbox Guidance Manual (USEPA 2009) describes how protozoa log credits are calculated for various ozone contactors. These are summarised in Table 8.6 (which is Table 11.2 in USEPA 2009).

**Table 8.6: Methods and terminology for calculating the log inactivation credit when using ozone**

a) **No tracer data**

Section description	Terminology	Method for calculating log-inactivation credit	Restrictions
<b>Chambers where ozone is added</b>			
First chamber	First dissolution chamber	No log-inactivation credit is recommended	None
Other chambers	Co-current or counter-current dissolution chambers	CSTR* method in each chamber with a measured effluent ozone residual concentration	No credit is given to a dissolution chamber unless a detectable ozone residual has been measured upstream of this chamber
<b>Reactive chambers</b>			
≥ 3 consecutive chambers	Extended-CSTR zone	Extended-CSTR method in each chamber	Detectable ozone residual should be present in at least three chambers in this zone, measured via in-situ sample ports Otherwise, the CSTR method should be applied individually to each chamber having a measured ozone residual
< 3 consecutive chambers	CSTR reactive chambers	CSTR method in each chamber	None

Note: CSTR is continuously stirred tank reactor.

b) **With tracer data**

Section description	Terminology	Method for calculating log-inactivation credit	Restrictions
<b>Chambers where ozone is added</b>			
First chamber	First dissolution chamber	No log-inactivation credit is recommended	None
Other chambers	Co-current or counter-current dissolution chambers	T <sub>10</sub> or CSTR method in each chamber with a measured effluent ozone residual concentration	No credit is given to a dissolution chamber unless a detectable ozone residual has been measured upstream of this chamber
<b>Reactive chambers</b>			
> = 3 consecutive chambers	Extended-CSTR zone	Extended-CSTR method in each chamber	Detectable ozone residual should be present in at least three chambers in this zone, measured via in-situ sample ports Otherwise, the T <sub>10</sub> or CSTR method should be applied individually to each chamber having a measured ozone residual
< 3 consecutive chambers	CSTR reactive chambers	T <sub>10</sub> or CSTR method in each chamber	None

## Further information

The C.t table for ozone in the DWSNZ was taken from the LT2ESWTR (USEPA 2006a). It was based on Clark et al (2002) who used data from studies of ozone inactivation of *Cryptosporidium* in laboratory water to develop predictive equations for estimating inactivation (Rennecker et al 1999, Li et al 2001), and data from studies in natural water to validate the equations (Owens et al 2000, Oppenheimer et al 2000). The following equation can be used to determine the log credit between the indicated values in Table 5.6 in the DWSNZ:

$$\log \text{ credit} = 0.0397 \times 1.09757^{\text{temp}} \times \text{C.t}$$

Another step in developing the C.t values for *Cryptosporidium* inactivation involved consideration of the appropriate confidence bound to apply when analysing the inactivation data. A confidence bound represents a safety margin that accounts for variability and uncertainty in the data that underlie the analysis. Confidence bounds are intended to provide a high likelihood that water supplies operating at a given C.t value will achieve at least the corresponding log inactivation level in the C.t table. Two types of confidence bounds that are used when assessing relationships between variables, such as disinfectant dose and log inactivation, are confidence in the regression and confidence in the prediction. USEPA (2003a, 2006a) discusses these in the LT2ESWTR. The use of confidence bounds probably explains why the C.t values have increased at higher temperatures and decreased at lower temperatures since DWSNZ (2000).

Since the available data are not sufficient to support the C.t calculation for an inactivation level greater than 3 log, the use of the C.t table in DWSNZ is limited to inactivation less than or equal to 3 log. In addition, the temperature limitation is 1–25°C. If the water temperature is higher than 25°C, the temperature should be set to 25°C for the log inactivation calculation.

It has been reported that turbidities up to 5 NTU did not affect disinfection (Walsh et al 1980). However, economic problems are likely at this level of turbidity. Blakemore (personal communication) has noted that at Timaru she found the ozone demand increases dramatically with increasing turbidity, and an added problem at 5 NTU occurs when chlorine is added to maintain FAC in the distribution system. Therefore the DWSNZ set a limit of 1 NTU.

### 8.4.4.3 Ultraviolet light

#### Process description

UV disinfection is a physical process relying on the transference of electromagnetic energy from a source (lamp) to an organism's cellular material.

Operation of the process is discussed in Chapter 15: Treatment Process, Disinfection, section 15.5.5. A great deal of information appears in the Ultraviolet Disinfection Manual (USEPA 2006c), over 500 pages in fact, that covers every aspect of the use of the UV disinfection process for water supply. Refer also to Chapter 13 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to using UV disinfection.

## DWSNZ criteria

See section 5.16 of the DWSNZ for the protozoal compliance requirements that need to be satisfied in order to qualify for the claimed log credits. In the unlikely event that the process is not being operated for the purpose of protozoal compliance, these requirements do not need to be met.

UV disinfection can also be used to achieve bacterial compliance. Section 8.5 describes how UV appliances can be validated using either MS2 or T1 organisms. If the appliance is installed to inactivate bacteria as well as protozoa, the validation must have tested appropriate (eg, MS2) organisms.

## Performance validation/certification

UV disinfection systems do not produce a chemical residual, so a direct C.t approach as used for chlorine dioxide and ozone cannot be used. UV appliances used for protozoal compliance need to be validated or certified to demonstrate the dose that they are capable of delivering at different water qualities and flow rates.

The UV disinfection equipment manufacturer is responsible for obtaining and providing certification of validation; the equipment must be validated to meet the required log credit using one of:

- the *Ultraviolet Disinfection Guidance Manual* (USEPA 2006b): variable log credits
- DVGW Technical Standard W294 (DVGW 2006): 3 log credits
- öNORM M5873 (Osterreichisches Normungsinstitut 2001): 3 log credits
- NSF/ANSI 55\* for Class A systems (for populations of up to 5000): 3 log credits
- a validation procedure acceptable to the Ministry of Health.

\* UV disinfection systems that meet this standard can be found on the website <http://nsf.com/Certified/DWTU/>.

Note that at the time of writing the DWSNZ (2008 update), appliances covered by (a) mainly delivered a fixed dose (fluence) and claimed 3-logs, whereas appliances covered by (b) can claim 0.25 to 3.0 protozoal log credits, depending on the validated dose and operating conditions. The fixed dose of 40 mJ/cm<sup>2</sup> allows the appliance to be used to inactivate both bacteria and protozoa (oo)cysts, whereas using the UVDGM, a 12 mJ/cm<sup>2</sup> dose can earn 3 protozoal log credits (see Table 8.7 and section 8.5). The British Standards Institute produced BS EN 14987 (2006/07), an adaptation of the öNORM Standard, but without the requirement to allow for uncertainty in the UVI sensor readings; it only applies to UV devices treating water that has come from the public water supply.

Since the 2008 DWSNZ were published, the US National Water Research Institute (NWRI), in collaboration with the Water Research Foundation (WRF) has produced UV disinfection guidelines for drinking water and water reuse (NWRI 2012). These are based largely on procedures adopted by the California Department of Public Health for the review and approval of UV disinfection systems and implicitly apply to large-scale installations. They apply to LP and MP UV systems. These guidelines do not quantify specific pathogen inactivation or UV dose requirements, leaving it to appropriate regulatory agencies to determine these on a case-by-case basis. Performance standards are specified for UV intensity sensors. Validation by biosimetry is required. MS2 phage is the recommended challenge micro-organism where expected dose >20 mJ/cm<sup>2</sup>, and bounds are defined within which the calibration sensitivity curve for

MS2 phage must fall. To simulate lamp ageing, the output must be reduced to 50 percent unless some other value can be demonstrated by the manufacturer as representative of lamps at the end of their specified service life (DWI 2016).

The WQA in the US operates a Certification Scheme: Drinking Water Treatment Units which establishes product certification criteria for Point-of-Entry (POE), Point-of-Use (POU), and components that are categorised as Drinking Water Treatment Units (DWTUs). The requirements that the products will be assessed against are contained in DWTU standards, including: NSF/ANSI 42, NSF/ANSI 44, NSF/ANSI 53, NSF/ANSI 55, NSF/ANSI 58, NSF/ANSI 62, NSF/ANSI 177, NSF/ANSI 222, USEPA Microbiological Standard, CSA B483.1, WQA S-100, WQA S-200, WQA S-300, WQA S-400, NSF Protocol P231, and WQA ORD 0901. The WQA website ([www.wqa.org/](http://www.wqa.org/)) leads to 'Find Certified Products'. WQA is involved in other verification schemes too, so it is important to ensure that it is clear what standards any water treatment equipment is being tested against.

In most cases in New Zealand, UV appliances are validated off-site due to the complexities of onsite validation. Onsite validation is not discussed in these Guidelines. The manufacturer's validation is only applicable when the installed appliance is identical to the appliance that was tested, and the inlet and outlet hydraulic conditions are equal to or better than the conditions used in the validation process. Appliances will need to be revalidated if they are modified.

Validation testing of UV appliances must determine a range of operating conditions the appliance can monitor and under which the appliance delivers the required UV irradiance (dose), as measured by the UV intensity meter (UV sensor), to achieve the target log credit for a range of flows. These operating conditions must include, at least:

- flow rates
- UV intensity (fluence rate) as measured by a UV intensity sensor
- UV lamp status
- minimum UV transmittance of the water for which the UV appliance has been validated to achieve the target inactivation.

The validation procedure must take account of uncertainties in the disinfection system including uncertainties related to the velocity distribution, lamp aging and UV intensity sensors.

The validation certificate must:

- be an original, written in English, unique to the model of appliance
- have been written by the certifying authority, and describe the validation procedure
- state the qualifications of the certifying authority that conducted the validation. The validation testing must have third-party verification by an agency accredited to ISO/IEC 17025 (IANZ 2005) or by the New Zealand National Metrology Institute (or accreditation to an equivalent standard accepted by the Ministry of Health). The National DWAs Coordination team maintains a list of agencies that have been accepted by the MoH
- provide a detailed list of the components and dimensions of the appliance that had been validated and relate to the parts comprising the water supplier's appliance and to its name plate (or data plate) fixed to the appliance

- define what type of UV lamps are installed in the reactor, and clarifies the reasons for the choice of the aging/fouling factor, which is equal to the fouling factor multiplied by the aging factor and typically ranges from 0.4 to 0.9 (see section 5.4.6 of the UVDGM)
- show clearly the means by which the appliance was shown to comply with the requirements of the standard that it was tested against; these requirements will include the number of UV intensity sensors, the position of the sensors, the spectral response of the sensors, the variation in lamp UV output and the sensor uncertainty
- contain statements, graphs or tables clearly showing the range of UV transmittance and flow that the validation covered; where appropriate these graphs should also show the target dose (usually measured in  $\text{mJ}/\text{cm}^2$ ) that was certified for each UV transmittance and flow combination
- contain statements, graphs or tables showing clearly the UV intensity (ie, the sensor reading, usually in  $\text{mWs}/\text{cm}^2$ ) that is required at a given flow to produce a given target dose
- contain a detailed description of the inlet and outlet hydraulic conditions
- include a description of the measured headloss across the UV appliance
- include a description of the challenge micro-organism used and its dose response curve that was generated as part of the validation
- include a description of how uncertainty arising from the number of experimental data points has been taken into account in setting the target dose and related sensor reading.

The end-user should use the validation report to ensure that all aspects of the validation process are applicable to the specifics of the proposed application. This review at a minimum should cover the inlet and outlet piping configurations and the operating range of UV transmittance and flow to provide the required dose.

The performance of the equipment when installed should be verified against the validation at the end of lamp life. The time to reach the end of lamp life condition is itself an important performance criterion for a UV system. The end-user should require that the UV equipment pass a performance test at the end of lamp life, typically this will occur after at least 12 months of operation. The appliances will also include a system that continuously monitors lamp status.

Note: The amount of inactivation that is achieved is a function of the amount of UV light that the micro-organisms receive. This is called the UV dose, or more correctly, the fluence. The SI units of UV dose are  $\text{J}/\text{m}^2$ . The units of  $\text{mJ}/\text{cm}^2$  are also used.  $1 \text{ mJ}/\text{cm}^2$  is equal to  $10 \text{ J}/\text{m}^2$ . The dose is the product of the intensity of UV light and the time that the micro-organisms are exposed to it (which means related to flow). The unit of intensity is watts (W). The unit of time is seconds (s). Consequently the dose is sometimes referred to as  $\text{mW}\cdot\text{s}/\text{cm}^2$  or  $\text{W}\cdot\text{s}/\text{m}^2$ . One  $\text{mJ}/\text{cm}^2$  is equal to  $1 \text{ mWs}/\text{cm}^2$ .

UV equipment manufacturers are increasingly claiming that their validation documentation (and some exceed 300 pages) is commercially sensitive and not available to regulatory bodies. Instead they offer much abbreviated reports or simply state that the appliance meets requirements. In conjunction with the major New Zealand importers of UV equipment, the MoH has developed a template questionnaire to overcome this difficulty. It is reproduced below, and is followed by explanations.

## Template for UV disinfection: evidence of validation

### 1. The water being disinfected

- a. Water treatment plant
- b. WINZ number
- c. Water supplier
- d. Protozoal log credit categorisation
- e. Target protozoal log credits by UV
- f. For protozoal compliance (5.16) or both protozoal and bacterial (5.16 plus 4.3.5)
- g. Design UVT range, %T (10 mm)

### 2. The UV disinfection system

- a. Manufacturer
- b. Model
- c. Serial number(s)
- d. Number of reactors
- e. Lamp type
 

LP, or
LPHO, or
MP, or
Other
- f. Importer/New Zealand agent; contact name
- g. Water supplier's consultants; contact name
- h. Installed by, and date commissioned

### 3. The validation

- a. 'Standard' validated to, under which compliance is sought
 

i) DVGW
ii) ÖNORM
iii) NSF
iv) UVDGM
v) Other (specify)
- b. Relevant validation testing body
- c. Validation certificate/report signed by, and date
- d. The validation testing body has third-party verification by an agency accredited to:
 

i)
ii)
- e. Challenge micro-organism used for standard under which compliance is sought:
 

<b>Microorganism(s)</b>	<b>RED range tested</b>
<i>Bacillus subtilis</i>	mJ/cm <sup>2</sup>
MS-2 coliphage	
T1	
T7	
Other	
- f. UVT (% , 10 mm) and flow range covered in validation
 

<b>UVT</b>	<b>Flow (units)</b>
------------	---------------------
- g. Components in use during validation:
 

Part numbers:
---------------

  - Lamp
  - Sleeve
  - Ballast
  - Duty sensor
  - Sensor window

Evidence:
i) Sighted validation report:
ii) Declaration – append
- h. Number of lamps per reactor
- i. Number of sensors per reactor

- j. Change lamps at x hours run time
- k. Do hydraulics of installed appliance meet the validation conditions? Yes:  
No:  
Comment:

#### 4. Dosage control

Either: **The UV Intensity Setpoint Approach**

- a. UVT measured online or in lab?
- b. Define the relationship between flow, UVT and intensity

Or: **The Calculated Dose Approach**

- c. Describe how a DWA can be certain that the appliance is operating within its validated condition
- i) A signed declaration from manufacturer's senior management – append
- ii) Other:
- d. What is the dose alarm setpoint?  
What is the maximum validated flow?

#### 5. Standardisation

##### Sensors

- a. How is the duty sensor checked that it is within specification? Append as required.
- i) vs reference sensor
- ii) Other traceable procedure
- b. What tolerance is allowed before remedial action is required?
- c. What action is specified for when the duty sensor is out of specification?
- d. What supporting documentation describes original reference sensor standardisation? Append if possible.
- Standard:  
Issued by:  
Date:
- e. How is the reference sensor standardised at the water treatment plant?
- i) As per UVDGM
- ii) Other traceable procedure
- iii) Replaced annually

##### UVT

- f. How is UVT instrument standardised?
- i) Manual UVT:
- ii) Online UVT:
- g. At what frequency?

#### 6. Alarms

- a. How is the UV appliance set to warn of transgressions?
- UV dose:  
UV sensor (intensity meter):  
UVT:  
Turbidity:  
Flow:  
Other (describe):

#### 7. Monitoring

(water supplier to complete those questions that are not appropriate for the UV vendor to complete)

- a. Where are the results of standardisations recorded?
- b. What remedial action will be followed when the duty sensor is out of specification?
- c. At what frequency will each alarm condition be verified?
- d. Monitoring results have to be reported. Who is responsible?
- i) The UV people:
- ii) Consultants/contractors:
- iii) The water supplier:
- e. Will the reporting requirements of section 3.2 of DWSNZ be met?
- i) Third party verification:
- ii) Other:

## Commentary on items in the template

- **General:** The USEPA's UVDGM is a guidance manual, but in this document it is treated as though it were a 'standard', because referencing it in the DWSNZ effectively makes it a standard.
- **1c:** The MoH has allocated a unique identifier to every water source and treatment plant.
- **1d:** Protozoal log credit categorisations are determined or signed off by DWAs.
- **2a:** Some UV appliances are made by more than one manufacturer – list equivalents.
- **2b:** Some models of UV appliances go by more than one name – list equivalents.
- **2f:** This question relates only to UV disinfection.
- **3 (general):** DVGW and ÖNORM include an expiry date on their certificates. The MoH accepts that if an appliance continues to meet the original validation, the expiry date may be ignored.
- **3a:** Some appliance models are validated to more than one standard. Where this is so, record both, but indicate which one applies to this water treatment plant.
- **3e:** RED is reduction equivalent dose, a term used in North America. It is the same as REF which is reduction equivalent fluence, a term used in Europe. ÖNORM describes it as the "average microbiocidal fluence measured by the biosimulator according to Annex d in the irradiation chamber, in J/m<sup>2</sup>". The UVDGM describes it as 'see UV dose', which reads: "the UV energy per unit area incident on a surface, typically reported in units of mJ/cm<sup>2</sup> or J/m<sup>2</sup>. The UV dose received by a waterborne microorganism in a reactor vessel accounts for the effects on UV intensity of the absorbance of the water, absorbance of the quartz sleeves, reflection and refraction of light from the water surface and reactor walls, and the germicidal effectiveness of the UV wavelengths transmitted". Note that 40 mJ/cm<sup>2</sup> = 400 J/m<sup>2</sup> = 40 mW-s/cm<sup>2</sup> (also written as 40 mWs/cm<sup>2</sup>).
- **3f:** If units are SSK-254/m, convert to %T (10 mm), but enter both.
- **3g:** A DWA needs to know that the installed appliance comprises the same parts as the appliance that was validated, hence the need for part numbers. If the part numbers have changed between validation and delivery, some form of verification from the manufacturer will be required. If the delivered parts are not the same, a new validation certificate will be required. If the validation report/certificate is not sighted in New Zealand, the manufacturer needs to provide a signed declaration that the parts supplied are the parts that underwent validation. If the New Zealand agents have the validation report/certificate but it is not available to others, the New Zealand agent/importer needs to provide a signed declaration that the parts supplied are the parts that underwent validation.
- **3j:** The hours run meter must incorporate the effect of on/off switching.
- **3k:** Flow patterns can exert a major effect on inactivation efficacy.
- **4:** Section 5.16.2 of DWSNZ includes: "The validation certificate must define the operating conditions under which the reactor can deliver the UV dose required by the validation procedure".
- **4a:** Population based – see Table 5.7 in DWSNZ.
- **4b:** This can be in the form of an appended graph, equation or table.

- **4c:** The Calculated Dose Approach uses a dose-monitoring equation or algorithm to estimate the UV dose, based on operating conditions (typically flow rate, UV intensity, and UVT). The dose-monitoring equation is usually developed during validation testing, and is incorporated in the 'black box' that controls dosage. Using the Calculated Dose Approach makes it difficult to check that the operating conditions under which the reactor delivered the UV dose in the validation procedure are actually being met.
- A declaration from senior management of the manufacturer that the algorithm/program used during validation has been incorporated in the control system, followed by a declaration from senior management of the importer/New Zealand agent that the algorithm/program has not been changed should suffice.
- **5a, b, c and d:** The manufacturer/importer/agent needs to set these up for the water supplier.
- **5e:** The reference sensor must have appropriate documentation, traceable to ISO 17025 or equivalent standard accepted by MoH.
- **5f:** This can be by following the manufacturer's procedure, or cross-checking against a lab bench instrument. If an online UVT monitor takes more than 15 minutes to standardise or maintain (eg, for cleaning) it shall not be deemed to have failed to comply with section 5.16.1, part 5a(i)C (which refers to a three-minute period).
- **5g:** The manufacturer needs to tell the water supplier how often to standardise the UVT.
- **6 (general):** This section refers to alarms that indicate transgressions, non-compliances and failures etc. It is expected a lower level of alarm will warn the operation of impending transgressions or maintenance requirements, etc.
- **6a:** Whether these alarms are provided will depend on the dosage control system in operation.
- **6b:** If the alarm system is part of the procedure that is involved in indicating compliance, it needs to be sufficiently sensitive, and of course, still 'alive'. The manufacturer/importer/ agent needs to include this facility. An alarm that indicates just 'on' or 'off' is not sufficient. A more sensitive technique is needed, eg, noting the response when a sensor is removed slightly, or a slight reduction in lamp power.
- **7 (general comments):** The procedure used for monitoring compliance may be provided by the UV appliance manufacturers, the New Zealand importers/agents, consultants/ contractors, or the water supplier. But ultimately, it is the responsibility of the water supplier to ensure that the monitoring requirements of the DWSNZ are met.

Section 3.2 of the DWSNZ includes:

Compliance with the DWSNZ requires some determinands not to exceed a certain value for more than three, five or 15 minutes. This requires accuracy in time measurement and recording to ensure no short-term transgressions go unrecorded. Generally, for remote measurements, unless a high-speed communications network is used, this requires the remote terminal unit to time-stamp the data as it is recorded. The sampling frequency must be as specified above. Where this cannot be achieved at present, suitable equipment must be installed and operating as stated in section 69C of the Act.

The data records may be compressed using a procedure that preserves the accuracy of the original measurements. Data must be reported as a percentage of the time (or duration, where required) that the value was exceeded (or met) during the compliance monitoring period.

In section 5.16, the compliance monitoring period for continuously monitored parameters is one month; for all other measurement frequencies the compliance monitoring period is one year. DWAs cannot be expected to analyse thousands of data points – for example, there are 43,200 minutes in a 30-day month. If the data cannot be presented in a summarised format that readily shows compliance, the DWA will deem it as failing to comply.

- **7e:** The accuracy of the procedure used to convert online monitoring data to the compliance report sent to the DWA needs to be verified by an appropriately qualified third party.

## Calibration and monitoring

The 2005 DWSNZ required the UV dose (fluence) to be not less than the reduction equivalent dose (RED) target required for the claimed log credit .... The 2008 DWSNZ require the UV irradiance (intensity or sensor reading) to be not less than the value established by validation required to achieve the claimed log credit .... The switch from UV dose to UV intensity was because the dose is 'what comes out of the lamp' while intensity (dose delivery) is 'what hits the most distant (oo)cyst', which is more logical operationally. However, the approach used, which depends on the manufacturer, is not the critical point. What is important is that the monitoring system indicates that the appliance is being operated within the conditions of its validation.

### UV intensity sensors

UV intensity sensors measure the intensity of the germicidal UV light at a specified distance from a set of UV lamps. Sensors are discussed further in section 8.6.2.6 (this chapter).

The reference sensor must be standardised at least annually in accordance with *Ultraviolet Disinfection Guidance Manual* (USEPA 2006c) or other traceable procedure, with third-party verification given by an agency accredited to ISO/IEC 17025 (IANZ 2005) for this type of standardisation, or by the Measurement Standards Laboratory of New Zealand (or accreditation to an equivalent standard accepted by the Ministry of Health).

A UV disinfection appliance (called reactor by USEPA) may contain one or more UV lamps. Appliances may contain one or more UV sensors. Section 6.3.2.2 of USEPA (2006c) states:

UV lamp output differs for each lamp, depending on lamp age and lot. However, a UV sensor cannot measure lamp output variability unless each lamp has a UV sensor. Water suppliers that have UV reactors with a UV sensor monitoring more than one lamp should assess the UV lamp variability every two months for MP lamps or every three months for LP and LPHO lamps. If all the lamps monitored by a UV sensor are close in age (ie, their age varies by less than 20 percent), it is not necessary to check the output of each lamp. In this case, the oldest lamp should be placed in the position nearest the UV sensor.

There should be at least one UV intensity sensor for every 10 LP or LPHO lamps (see DVGW) and the number and type of intensity sensors must be the same as for the unit that was certified or validated. These sensors are called duty sensors and are in continuous use.

All UV appliances will have at least one duty UV intensity sensor as an integral part; they all need to be calibrated against the reference sensor at regular intervals as required by the standard that they were certified to, or monthly as per section 5.16.2(b) in the DWSNZ, whichever is the more frequent.

The reference sensor is to be calibrated at least annually, in accordance with the validating authority, eg, USEPA 2003d/2006c. The calibration must be done by an accredited person or organisation, see section 5.16.3 of DWSNZ. However, due to the cost of sending a sensor overseas for recalibration, the DWSNZ allow reference sensors to be used as duty sensors (in lieu of recalibration) and a new calibrated sensor can be purchased for use as a replacement reference sensor. DVGW W294.3 allows duty sensors to be used up to two years if they remain within tolerance.

#### UV intensity sensor measurement uncertainty

Duty sensor calibration is discussed in section 6.4.1.1 of USEPA (2006c). The duty sensor is considered to be operating satisfactorily if it reads less than 20 percent lower than the reference sensor reading (preferably mean values of several readings). If it is outside the 20 percent allowance, immediately check that the reference sensor is still correct. If it is, then change the duty sensor. USEPA states that it is permissible to continue using the duty sensor with a correction factor. However, this is said to be not energy-efficient. It is not acceptable for the duty sensor to read as much as 20 percent higher than a calibrated reference sensor, 10% would be the absolute maximum.

#### UV transmittance

Some UV disinfection systems automatically adjust the UV dose as the UV transmittance (measured at 253.7 nm) of the water flowing through the appliance varies. The UV transmittance requirements in section 5.16.1(5) of the DWSNZ do not apply to these appliances.

Other appliances rely on the UV transmittance of the water not being less than that noted during the validation. UV transmittance needs to be monitored when using appliances of this type. If the population served is more than 10,000, UV transmittance is required to be monitored continuously. Only one UV transmittance meter that monitors the combined water that passes into or out of the UV disinfection plant is required.

The DWSNZ require less frequent monitoring for systems that serve fewer than 10,000 people, but the end-user should investigate the cost and benefit of installing a continuous UV transmittance monitor.

Water suppliers must take care to note the units for UV transmittance on their validation certificate. The readings are not always reported for the traditional 10 mm path length. Annex C in ÖNORM (2001) is a table that relates UV transmittance readings at 100, 50 and 10 mm path lengths; it includes a column headed SSK per metre (spectral attenuation coefficient) which we call UV absorbance (10 mm) except SSK per metre is numerically 100 times larger. Appendix A1.5.9 in the DWSNZ shows how to convert UV absorbance to UV transmittance. Examples follow:

- say the absorbance is 0.0721 (as measured in a 10 mm cell), ie,  $A_{10\text{ mm}} = 0.0721$
- to convert to transmittance, see DWSNZ Appendix A1.5.9, which states  $A = -\log T$
- therefore  $0.0721 A = 0.847 T$ , or 84.7%T.

Using ÖNORM:  $84.7\% T_{10\text{ mm}} = 43.6\% T_{50\text{ mm}} = 19\% T_{100\text{ mm}} = 7.212 \text{ SSK/m}$   
(=  $0.0721 A_{10\text{ mm}}$ ).

That is:  $\%UVT = 10^{-(SSK/100)}$  where SSK is SSK/m and measured at 254 nm.

USEPA (2006a) states in section 6.4.1.2 that online UVT analysers be standardised at least weekly by comparing the online UVT measurements with UVT measurements using a bench-top spectrophotometer. The bench-top spectrophotometer should be maintained and standardised at the frequency required by the manufacturer. The standardisation monitoring frequency can be decreased or increased based on the performance demonstrated over a one-year period. USEPA considers the online reading to be satisfactory if it is within 2 percent of the bench-top spectrophotometer reading.

### Turbidity

Section 5.16.1 of the DWSNZ stipulates the turbidity requirements for the water passing through the UV appliances.

### Flow measurement

The DWSNZ requires that all appliances serving more than 500 people have a dedicated flow meter and the flow through the appliance needs to be limited to not more than the flow for which the appliance was validated. The flow through appliances serving a smaller population also needs to be limited to less than the flow for which the appliance was validated.

### Alarms

Monitoring equipment should be connected to alarm devices to notify when operators are required. All alarm events should be recorded. USEPA (2006c) discusses (section 4.3.3) the use of minor, major and critical alarms.

### Records

To avoid misinterpretation over meeting validation requirements, it is strongly recommended that a detailed diary be kept of plant operations, calibrations, maintenance and replacement of lamps etc. See Annex G in ÖNORM (2001) for further information.

## Further information

The USEPA (2003a, 2006a) considered that a major recent development was the finding that UV light is highly effective for inactivating *Cryptosporidium* and *Giardia* at low doses. Research prior to 1998 had indicated that very high doses of UV light were required to achieve substantial disinfection of protozoa, ie, to kill them. These results were based largely on the use of in vitro assays, which were later shown to substantially overestimate the UV doses required to prevent infection (Clancy et al 1998, Bukhari et al 1999, Craik et al 2000). Research using in vivo assays (eg, neonatal mouse infectivity) and cell culture techniques to measure infectivity has provided strong evidence that both *Giardia* and *Cryptosporidium* are highly sensitive to low doses of UV, ie, are inactivated.

USEPA (2006a) stated that even though microbial repair can occur, neither photorepair nor dark repair is anticipated to affect the performance of drinking-water UV disinfection.

These studies demonstrated that a dose of 10 mJ/cm<sup>2</sup> was able to achieve *Cryptosporidium* inactivation of at least 3 log, compared with a typical UV dose for general water supply disinfection being about 30–40 mJ/cm<sup>2</sup> (or 300–400 J/m<sup>2</sup> in ISO units). Table 8.7 (taken from Table 1.4 of USEPA 2006c) shows the relationship between UV dose and available log credits for protozoa inactivation.

Qian et al (2004) performed a meta-analysis of a number of drinking-water UV efficacy studies and concluded that doses up to 20 mJ/cm<sup>2</sup> are necessary to achieve at least a 3-log (99.9 percent) reduction of *Giardia* cysts and *Cryptosporidium* oocysts, with at least 95 percent confidence (ie, no more than a 5 percent risk of failing to meet that level of reduction).

**Table 8.7: UV dose requirements for *Cryptosporidium* inactivation credits**

Log credit	UV dose (mJ/cm <sup>2</sup> )
0.5	2
1.0 (90% removal)	3
1.5	4
2.0 (99% removal)	6
2.5	9
3.0 (99.9% removal)	12
3.5	15 (not applicable in DWSNZ 2008)
4.0 (99.99% removal)	22 (not applicable in DWSNZ 2008)

These doses (rounded to whole numbers) are based on UV light at 254 nm as delivered by a low pressure mercury vapour lamp. The doses can be applied to other lamps such as medium pressure through reactor validation testing.

USEPA (2003a) states that to receive disinfection credit for a UV reactor, manufacturers are required to demonstrate through validation testing that the reactor can deliver the required UV dose. The USEPA developed dose requirements for *Cryptosporidium* that account for the uncertainty associated with the dose-response of the micro-organisms in controlled experimental conditions. In practical applications, other sources of uncertainty are introduced due to hydraulic effects, UV reactor equipment, water quality, and sensor quality. The validation protocol applies a safety factor to the dose requirements to account for these areas of uncertainty and variability.

DWI (2010) states that the absorbance of UV light by nitrate (at wavelengths below 240 nm) can lead to the formation of nitrite by photolysis. This can be managed through the selection of UV lamp or sleeve type.

## 8.4.5 Other processes and other log credit determinations

The USEPA included in their LT2ESWTR Final Rule (USEPA 2006a) a section called *Demonstration of Performance*, basically to cover processes and procedures not specified in detail in the LT2ESWTR. Refer also to Chapter 12 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009).

As a consequence, the 2008 DWSNZ include a new section, section 5.17: Alternative processes: treatment compliance criteria, whereby water suppliers may apply to the Ministry of Health to have other treatment processes assessed for a log credit rating. This approach allows water suppliers to apply for a log credit rating (or a variation to the prescribed log credits) for a treatment plant or process:

- a) not covered in sections 5.1–5.16 of the DWSNZ
- b) that performs demonstrably better than its compliance criteria
- c) that performs to a lesser, but reliable, level than specified in its compliance criteria.

### a) Treatment processes not covered in sections 5.1–5.16 of the DWSNZ

Any water supplier or equipment supplier that wishes to use a treatment process not covered in sections 5.1–5.16 of the DWSNZ, and it is considered to be effective in the removal or inactivation of protozoal (oo)cysts, can apply to the Ministry of Health for an assessment to decide whether the process qualifies for any log credits.

If it appears to qualify, then the next step will be to determine the number of log credits allowed, and the criteria that will need to be satisfied in order to qualify for those log credits.

The application will need to be made before installing the equipment or process. The information that will be needed with the application will include:

- a description of the quality of the raw water that will be treated
- a detailed description of the treatment process and its limitations
- the intended maximum (and minimum if relevant) treatment rates
- results from a bench-scale and/or pilot plant challenge test
- the operating parameters that need to be met in order to confirm the claimed log removal
- and where possible a quantitative description of the performance of the full-scale process elsewhere, including details of (oo)cyst removal/inactivation or equivalent, including:
  - a description of the water the process treated
  - the treatment rates or loading rates the data provided relate to
  - monitoring results.

The supporting data supplied must have been generated by organisations accredited by appropriate agencies acceptable to the Ministry of Health.

As shown by the USEPA (2006a) when assessing treatment processes in developing their LT2ESWTR, any water treatment plant using a new process should earn fewer log credits than it achieved in bench-scale or pilot plant challenge tests. Reasons include:

- variations in treatment rate can affect treatment performance
- variable raw water composition can affect treatment requirements and performance
- variable water temperature can affect treatment performance
- whether all plants using the new process will operate similarly
- deterioration in treated water quality as a treatment cycle progresses
- wear and tear/maintenance problems of the process
- the skill level required by operators
- the degree of difficulty in maintaining optimum performance
- the time for the process to recover after a problem has been identified and rectified.

The number of log credits a new process is awarded would probably relate more closely to the results presented from a full-scale plant, provided it was operating 'normally' during the testing. However, there will be difficulties if the full-scale plant is producing drinking-water, because, in general, the degree of removal that can be quantified in full-scale plants is limited because *Cryptosporidium* oocyst levels following filtration are often below the detection limit of the analytical method. Due to the shortage of data relating to oocysts, the USEPA (2003a, 2006a) evaluated data provided by water suppliers on the removal of other types of particles, mainly aerobic spores, in the sedimentation processes of full-scale plants. Data indicate that aerobic spores may serve as a surrogate for *Cryptosporidium* removal by sedimentation provided optimal chemical dosage conditions apply (Dugan et al 2001). This is discussed further in section 8.5, along with other monitoring techniques such as particle counting.

Due to the above, a regulatory authority is likely to err on the side of safety. Safety measures include requiring another treatment to be included while the new process undergoes in situ evaluation. For example, if a source water needs 3 log removals, the new process could be evaluated while the water was being disinfected by UV light, equivalent to a 3-log dose. If the new process is awarded say 2 log credits, the UV disinfection dose rate could then be reduced.

If a new process satisfies the above, compliance criteria specific to that process and site will be developed.

## b) Treatment that performs demonstrably better than its compliance criteria

The prescribed log credits for treatment processes in the DWSNZ are based on conservative estimates of mean *Cryptosporidium* removal efficiencies. Due to site-specific conditions, some treatment plants may consistently achieve greater *Cryptosporidium* removal than reflected in the prescribed log credits. Water suppliers may receive log credits for a water treatment plant or a treatment process within a plant that is based on demonstration of *Cryptosporidium* removal efficiency. Demonstration of performance testing will be specific to a particular site and will depend on the treatment processes being tested, water quality, plant infrastructure, technical and management resources, and other factors. Demonstration of performance testing should encompass the full range of expected operating conditions, and cover at least a year's continuous operation.

Demonstration of *Cryptosporidium* removal efficiency will usually not be possible, so indirect techniques will generally be needed. These may include monitoring the removal of aerobic or anaerobic spores, or using particle counting, see section 5.5. The supporting data supplied must have been generated by organisations accredited by appropriate international agencies acceptable to the Ministry of Health. If the supporting data is satisfactory, compliance criteria specific to that process and site will be developed.

Treatment plants cannot claim additional log credits by this process if they are already claiming log credits for individual processes. For example, a coagulation/sedimentation/filtration plant (DWSNZ section 5.4) cannot claim demonstration of performance log credits if it is also claiming log credits for enhanced combined filter performance (DWSNZ section 5.7).

Treatment plants claiming 3 log credits for an existing disinfection process cannot increase this by demonstration of performance. If a water supply needs more than 3 log credits for protozoal compliance, a filtration technique should provide the additional log credits, ie application of the multiple barrier principle.

### c) Treatment that performs to a lesser but reliable level specified in its compliance criteria

Some treatment processes may fail to satisfy the compliance criteria prescribed for that process by a small margin. It is considered unreasonable to award zero log credits for that process if it can still demonstrate a measurable, but lesser, consistent removal of *Cryptosporidium*. This option is only available to processes that fail to satisfy their compliance criteria by a small margin. It does not apply to plants that cannot cope with peak flows, turbid water after heavy rain, cold water, power failures or other conditions that a process or plant would be expected to handle effectively.

Also, some treatment processes may be validated for a higher log credit than the source water requires. For example, source water that requires 3 log removals may be treated by a membrane filtration plant that is validated to remove 4.0 logs if it achieves a specified particle removal rate. A water supplier may be able to demonstrate 3.5 log removals (for example) if it achieves a slightly less demanding particle removal rate.

Demonstration of *Cryptosporidium* removal efficiency will usually not be possible, so indirect techniques will generally be needed. These may include monitoring the removal of aerobic or anaerobic spores, or using particle counting, see section 8.5. The supporting data supplied must have been generated by organisations accredited by appropriate international agencies acceptable to the Ministry of Health. If the supporting data is satisfactory, compliance criteria specific to that process and site will be developed.

Demonstration of performance testing should encompass the full range of expected operating conditions, and cover at least a year's continuous operation.

## Iodine

Although disinfection by iodine is not covered in the DWSNZ, some field treatment units use the process (see Chapter 15). Most (oo)cysts appear to be more resistant to iodine disinfection than are bacteria or viruses. Iodine is capable of providing a 3-log *Giardia* cyst inactivation, but additional contact time or higher doses are necessary at colder water temperatures and more turbid waters. Warmer waters (>20°C), both clear and cloudy, with pH levels ranging from 6–9, resulted in >2.7 log *Giardia* cyst inactivation with C.t values ranging from 45–241 mg-min/L. As water temperatures decreased C.t values for >2.7 log *Giardia* cyst inactivation increased, ranging from 123–600 mg-min/L (clear and cloudy waters; pH ranged from 6–9). Pentaiodide resins are much more effective at inactivating *Giardia* cysts than triiodide resins. A pentaiodide resin achieved 3-log *Giardia* cyst inactivation compared with 0.2–0.4-log inactivation achieved by triiodide resin under identical experimental conditions (temperatures of 4 and 25°C). From USAPHC.

## Boiling

WHO (2015) states that *Cryptosporidium parvum* oocysts are inactivated in less than one minute once temperatures exceed 70°C. The data for *Giardia* cysts are more limited, but inactivation at temperatures ranging from 50°C to 70°C has been reported.

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.

## 8.5 Challenge testing

Normally it would be expected that the manufacturer of the treatment process would conduct the challenge test. However, for some treatment processes, there is no reason why a water supplier cannot arrange to have this done in New Zealand.

### 8.5.1 Using *Cryptosporidium* oocysts

Although use of *Cryptosporidium* as the challenge particulate offers the advantages of directly measuring removal efficiency, and eliminates issues regarding the appropriateness of a surrogate, it may not be practical or feasible due to economic considerations (particularly in large plants), or to health concerns about working directly with the pathogen. Thus the use of surrogates may be the most viable option for challenge testing.

The use of other organisms and molecular markers is discussed in the Membrane Filtration Guidance Manual (USEPA 2003c, 2005a).

### 8.5.2 Using microspheres

Microspheres can be used for measuring the removal efficacy of filtration processes. EPA/NSF ETV (2002) describes the technique in detail, in their sections 12.3.3, 12.4.2 and 14.9. For testing involving microscopic enumeration, fluorescent microspheres and an optical microscope equipped with ultraviolet illumination are used.

### 8.5.3 Using naturally occurring bacteria

Rice et al (1996) stated:

Monitoring for indigenous spores of aerobic spore-forming bacteria represents a viable method for determining treatment plant performance. Comparison of spore levels in source water and filter effluents provides an indication of biological particle removal efficiency.

Section 8.4.1.2 Challenge Particulate in the LT2ESWTR Toolbox Guidance Manual Review Draft discusses the use of surrogates for challenge testing, examples being *P. dimunita* and *S. marcessans* (USEPA 2009).

The heterotrophic plate count may be a suitable (and cost-effective) test. A membrane filtration laboratory method is needed so large volumes can be filtered. Trials would be needed for each water supply to see how much water needs to be filtered. With low turbidity water it should be possible to filter 5–10 litres to ensure a reasonable number of bacteria grow. Also, the optimum incubation temperature and time will need to be determined. Some may need to be incubated at 22°C (or even room temperature if an incubator is not available) for 72 hours. An example follows:

- say 25 mL of raw water is filtered through the membrane and incubated, and 200 colonies are counted = 8000 CFU/L
- say 5 L of treated water is filtered through the membrane and incubated, and 40 colonies are counted = 8 CFU/L
- that equals 99.9 percent removal (3 log), which should give confidence that the treatment process was removing the larger protozoa effectively.

## 8.5.4 Bag and cartridge filter challenge

Bag and cartridge filter manufacturers commonly rate their products by pore size or pore distribution. However, there is no industry standard for measuring or reporting these characteristics. This lack of standardisation causes problems for establishing design criteria to ensure that a given bag or cartridge filter will effectively remove a given percentage of *Cryptosporidium*. Furthermore, an oocyst has different structural characteristics than the markers used to determine pore size; thus, the rate of rejection may differ for an oocyst versus the test markers used to determine pore size or molecular weight cut-off.

To compensate for these factors of uncertainty for *Cryptosporidium* removal, the DWSNZ require bag or cartridge filters to be challenge tested, a process in which a known quantity of *Cryptosporidium* oocysts (or an acceptable surrogate) is added to the filter influent and the effluent concentration is measured to determine the removal capabilities of the filter. This testing is product-specific, not site-specific, meaning it does not have to be tested at every water supply seeking removal credit. Instead, a manufacturer (or independent third party) must challenge test each of its products in order to obtain a 2 or 3 log *Cryptosporidium* removal rating. Details for the challenge test that relate specifically for bag and cartridge filtration appear in section 8 of the review draft Toolbox Guidance Manual (USEPA 2009). More general requirements are the same as membrane filtration.

## 8.5.5 Membrane filter challenge

The material below has been taken from the Membrane Filtration Guidance Manual (USEPA 2003c, 2005a). The introduction has been copied in full. The chapters' titles are listed to indicate the information that is available in the Guidance Manual (about 330 pages).

### 3.1 Introduction

The LT2ESWTR requires that any membrane filtration system used to comply with the *Cryptosporidium* treatment requirements of the rule undergo challenge testing. The primary purpose of this challenge testing is to establish the log removal that an integral membrane can achieve.

Under the LT2ESWTR, the maximum removal credit that a membrane filtration system is eligible to receive is the lower of the two values established as follows:

- the removal efficiency demonstrated during challenge testing; or
- the maximum log removal that can be verified by the particular direct integrity test used during the course of normal operation.

The requirement for challenge testing under the LT2ESWTR is intended to be product-specific such that site-specific demonstration of *Cryptosporidium* removal efficiency is not necessary. Once the log removal of a membrane has been established through a challenge test that meets the requirements of LT2ESWTR, **additional challenge testing is not required unless significant modifications are made to the membrane process** (as discussed in section 3.14). The rule specifies criteria for the following aspects of challenge testing:

- full-scale vs small-scale module testing
- appropriate challenge particulates
- challenge particulate concentrations
- test operating conditions
- calculation of removal efficiency
- verifying characteristic removal efficiency for untested modules
- module modifications.

The discussion of challenge testing applies similarly to microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, except as otherwise noted.

Although the primary focus of challenge testing as required under the LT2ESTWR is demonstration of *Cryptosporidium* removal, the general framework for challenge testing developed in this guidance manual may be adapted for use in establishing removal efficiencies for other microbial pathogens of concern, including bacteria, viruses, and other protozoa such as *Giardia*.

Chapter 3 is organised into sections that describe the various issues to be considered in the design and implementation of a challenge test.

- Section 3.2: Summary of challenge testing requirements
- Section 3.3: Test organisation qualification
- Section 3.4: General procedure for developing a challenge test protocol
- Section 3.5: Module specifications
- Section 3.6: Non-destructive performance testing
- Section 3.7: Selection of modules for challenge testing
- Section 3.8: Small-scale module testing
- Section 3.9: Target organisms and challenge particulates
- Section 3.10: Challenge test solutions
- Section 3.11: Challenge test systems
- Section 3.12: Sampling
- Section 3.13: Analysis and reporting of challenge test results
- Section 3.14: Re-testing of modified membrane modules
- Section 3.15: Grandfathering challenge test data from previous studies

## 8.5.6 UV appliance challenge

The validation protocol in the UV Guidance Manual (USEPA 2003d, 2006c) builds on well-established protocols used in Europe and North America: see also DVGW Technical Standard W294, öNORM M5873 (Osterreichisches Normungsinstitut 2001/2003), and NSF/ANSI 55-2002 (NSF and ANSI 2002b) for Class A systems.

A UV disinfection appliance manufacturer typically delivers a UV appliance to a test facility. Test personnel inspect the UV appliance and document features of the design that impact dose delivery and monitoring (eg, appliance dimensions and sensor properties). The UV appliance is installed within a biosimetry test stand with inlet and outlet piping that should result in equal or worse dose delivery than with the appliance installed at the treatment plant site. The UV appliance is operated under various test conditions of flow, UVT, and lamp power. The test condition of UVT is typically obtained using a UV-absorbing compound injected into the flow upstream of the UV appliance. A challenge micro-organism is injected into the flow upstream of the UV appliance. The concentration of viable challenge microorganisms is measured in samples collected at the appliance's inlet and outlet. The results are used to calculate the log inactivation of the challenge microorganism achieved by the UV appliance.

The UV dose-response of the challenge micro-organism present in the inlet sample is measured using a bench-scale device termed a collimated beam apparatus. The UV dose-response curve is used to relate the log inactivation observed through the appliance to a UV dose value termed the Reduction Equivalent Dose (RED). A safety factor is applied to the results to account for any bias and random uncertainty associated with the validation of the UV appliance and the online monitoring approach used to indicate dose delivery both during validation and during operation at the water treatment plant. Lastly, a validation report is prepared that describes the UV appliance tested, the test protocol, the test results, and the inactivation credits that can be assigned to the UV appliance under given conditions of flow, UVT, and lamp output. Refer also to section 8.4.4.3.

Section 5.3 of USEPA (2006) *UV Disinfection Guidance Manual for the Final LT2ESWTR* (UVDGM) allows different test organisms to be used for validation, the choice being dependent on the target pathogen. Table 5.2 in UVDGM shows the delivered UV dose required to inactivate a range of micro-organisms.

Successfully challenging with MS2, for example, means the appliance is validated to deliver a 40 mJ/cm<sup>2</sup> dose which is the same dose specified in DVGW, öNORM and NSF, which means the appliance is validated for bacterial disinfection (and of course protozoal compliance).

Successfully challenging with T1, for example, means the appliance is validated to achieve 3 log inactivation of *Cryptosporidium* and *Giardia* delivering a dose of at least 12 mJ/cm<sup>2</sup>.

The validation certificate must state the conditions, ie, UVT, and in this context, particularly the flow rate. A UV disinfection appliance has now been marketed in New Zealand with validation using **both** MS2 and T1. That particular appliance has been validated to achieve 3 log inactivation of *Cryptosporidium* and *Giardia* at 80 USGPM, but is validated for bacterial disinfection at only 50 USGPM.

So, if this appliance is installed at a water treatment plant that achieves bacterial compliance by dosing with chlorine (say), protozoal compliance can be achieved at a flow up to 80 USGPM. But if the UV appliance is meant to achieve bacterial **and** protozoal compliance, the flow rate cannot exceed 50 USGPM.

The ETV UV Protocol was developed in conjunction with NSF through the ETV Drinking Water Systems (DWS) Center to clarify vague aspects of the USEPA's "Ultraviolet Disinfection Guidance Manual" (USEPA 2011).

WRF (2015) states that recent research shows significant differences between the wavelength responses or action spectra of validation test microbes and regulated pathogens, namely *Cryptosporidium*, *Giardia*, and adenovirus. These differences impact the interpretation of UV validation data used to define UV dose monitoring algorithms and disinfection credit with UV systems using polychromatic MP UV lamps. While the USEPA UV Disinfection Guidance Manual (UVDGM) accounts for these differences, it does not account for the UV transmittance spectrum of the quartz sleeve housing the MP lamp, the UV absorbance spectra of the water passing through the reactor, or the configuration of the lamps within the UV reactor. As such, the UVDGM approach can be overly conservative with many commercial UV systems. The approach is also limited by the quality of the action spectra data in the peer-reviewed literature, which show a high degree of variability due to the methods used, and do not extend over the full germicidal range (from 200 to 300 nm). Understanding the action spectra over the full germicidal range is important for the calculation with many MP UV reactors. Currently UV sensors used with today's commercial MP UV reactors do not monitor UV intensity at wavelengths below 240 nm. In due course these observations will be integrated into validation procedures. Research is needed though; for example, although MS2 is accepted as a good surrogate for *Cryptosporidium*, that statement is only true for wavelengths above 240 nm. Below 240 nm, published data indicates that validation using MS2 phage is overstating *Cryptosporidium* dose by as much as 50 percent.

## 8.5.7 General

USEPA (2005a) notes: although the primary focus of challenge testing as required under the LT2ESTWR is demonstration of *Cryptosporidium* removal (or inactivation), the general framework for challenge testing developed in the membrane filtration guidance manual may be adapted for use in establishing removal efficiencies for other microbial pathogens of concern, including bacteria, viruses, and other protozoa such as *Giardia*.

# 8.6 Sampling and testing for protozoa and substitute compliance tests

## 8.6.1 *Giardia* and *Cryptosporidium* testing

The log credits derived in the LT2ESWTR (USEPA 2006a) for the various treatment processes used for protozoa removal or inactivation were based on the use of Methods 1622 and 1623 (USEPA 2001b and 2001c). Method 1623 was also used when categorising raw waters according to the number of *Cryptosporidium* present. The latest version of Method 1623 appears in USEPA (2005b).

The USEPA developed Method 1622 (detects *Cryptosporidium*) and 1623 (detects *Cryptosporidium* and *Giardia*) to achieve higher recovery rates and lower inter- and intra-laboratory variability than previous methods. These methods incorporate improvements in the concentration, separation, staining, and microscope examination procedures.

The performance of these methods was tested through single-laboratory studies and validated through round robin studies. To assess method recovery, matrix spike samples were analysed on five sampling events for each plant. The protozoa laboratory spiked the additional sample with a known quantity of *Cryptosporidium* oocysts and *Giardia* cysts (the quantity was unknown to the laboratory performing the analysis) and filtered and analysed both samples using Methods 1622/23. Recovery averaged 43 percent for *Cryptosporidium* with a relative standard deviation of 47 percent (Connell et al 2000).

Although Methods 1622 and 1623 have several advantages over the earlier method, they also have some of the same limitations. These methods do not determine whether a cyst or oocyst is viable or infectious, and both methods require a skilled microscopist and several hours of sample preparation and analyses.

The minimum sample size for raw water categorisation purposes is 10 litres. The USEPA has prepared draft guidance for sampling and testing (USEPA 2006b and 2006d). The final version appears as USEPA (2006b).

Laboratories must meet the quality control requirements in Methods 1622 and 1623. For compliance testing, laboratories need to be accredited by IANZ.

Because it is impractical to use *Cryptosporidium* or *Giardia* testing of water treatment plants to demonstrate compliance with the protozoal MAV in the DWSNZ, various operational performance requirements are used instead. These include turbidity (or particle counting), direct integrity testing, indirect integrity testing, pressure differential, UV intensity, and C.t values for ozone and chlorine dioxide disinfection.

## 8.6.2 Turbidity measurement

The water industry has used turbidity as a marker of consistency and quality of water effluent from water treatment plant filters. In the DWSNZ, turbidity monitoring is an operational requirement for bacterial and protozoal compliance. An increase in turbidity measurement is perceived as deterioration in the performance of the treatment process, with a potential for the breakthrough of pathogens from the filters, or a reduction in disinfection efficacy. Conversely, as a generalisation, the lower the turbidity, the lower the pathogen risk.

Nephelometry is the only method of determination to be used for turbidity measurements. It is a method-defined parameter that can detect the presence of a wide variety of particles in water (eg, clay, silt, mineral particles, organic and inorganic matter, and micro-organisms).

Turbidity is not a direct measurement of suspended particles in water. Turbidimeters detect the intensity of light scattered from particles at one or more angles to an incident beam of light. The angular distribution of scattered light depends on a number of conditions, including the wavelength of the incident light, as well as particle size, shape, opacity and composition. It is difficult to correlate the turbidity with the number or concentration of particles in suspension. The results are expressed in nephelometric turbidity units (NTU). Other methods of measurement use different principles of measurement and yield results in units that cannot be converted to NTU. Some early models used absorptiometry so also measured some of the dissolved organic matter.

See datasheets for turbidity and suspended solids.

Some ISO 7027 instruments read turbidity as formazin nephelometric units (FNU) which are equivalent to NTU although derived from different measurement techniques. Note that DWI (2014) describes two turbidity units:

- 1 FTU (Formazine Turbidity Unit) is 1/400th of the turbidity of a standard suspension prepared under the correct standard conditions
- 1 NTU (Nephelometric Turbidity Unit) is taken to mean turbidity measured using a 90° scatter instrument calibrated using formazine prepared under correct standard conditions.

Small particles less than one-tenth of the light wavelength will scatter light uniformly in both forward and backward directions. As the particle size approaches and exceeds the wavelength of the incident light, more light is transmitted in the forward direction. Because of this intensity pattern, the angle at which the light is measured is a critical factor; the current international standards (eg, USEPA Method 180.1 and ISO 7027) have determined the most appropriate angle to be 90 degrees.

Turbidimeters with scattered light detectors at 90° to the incident beam are called nephelometers. Hach instruments satisfy USEPA Method 180.1. The Great Lakes Instrument model Accu4 Turbidity system operates in accordance with GLI Method 2 and ISO 7027 (1999).

Two types of online and bench turbidimeters may have the capability to measure low levels of turbidity: conventional, and laser turbidimeters. Conventional turbidimeters typically use a tungsten lamp or other light-emitting diode (LED) as a light source (some use infrared light); laser turbidimeters use a laser light source.

Manufacturer specifications indicate that laser turbidimeters may have increased sensitivity in excess of two orders of magnitude over conventional turbidimeters. There are cases where laser turbidimeters are measuring drinking-water quite successfully at less than 0.05 NTU; conventional turbidimeters become increasingly difficult to maintain reliability below 0.20 NTU. Some laser turbidimeters measure in mNTU (milliNTU). Laser turbidimetry is covered by USEPA Method 10133. The Hach FilterTrak 660 sc Laser Nephelometer claims to have the ability to detect a 0.3 mNTU or 0.0003 NTU change in turbidity with a repeatability of <1% or ± 0.002 NTU.

Since most microfiltration and ultrafiltration systems produce filtrate water consistently in the range of 0.03 to 0.07 NTU as measured by conventional turbidimeters, laser turbidimeters or particle counters (see section 8.2.2.2) may be better suited for monitoring membrane filtrate.

When the 2005/08 DWSNZ were published there were four USEPA-approved analytical methods for the measurement of turbidity. These are as follows:

- 1) USEPA Method 180.1, Determination of Turbidity by Nephelometry (USEPA 1993a) uses nephelometric technology, which measures light scatter at a 90° angle from the initial light path. The photodetector must be centred at that angle, and cannot extend more than 30° from that centre point. To minimise differences in light scatter measurements, the method states that the incident and scattered light cannot travel more than 10 cm from the light source to the photodetector. The light source used in each turbidimeter be a tungsten lamp with a colour temperature between 2,000 K and 3,000 K. This means that the tungsten output is polychromatic, or broadband in spectrum. When the light reaches the photodetector, the spectral peak response should be between 400–600 nm.

- 2) Great Lakes Instrument Method 2 (called GLI 2 or USEPA Method 180.2) (USEPA 1993b) doubles the number of photodiodes and photodetectors used in the average turbidity instrument. It also doubles the number of measurements taken. As such, this design is also known as a modulated four-beam turbidimeter. By using two measurements, two light sources, and two detectors, this method can compare results between the detectors and cancel out errors. This method requires 860 nm LEDs, which allows for colour compensation, much as the single beam ISO 7027 method does. The LEDs alternate light pulses every half second. The photodetectors take simultaneous readings, providing an “active signal” and “reference signal”.
- 3) Hach FilterTrak Method 10133 (also called USEPA Method 10133) (USEPA 2002) is also based on nephelometric technology (90°), but uses a laser light source as opposed to a tungsten lamp or infrared LED. It is not recommended for use when turbidity levels exceed 5.0 NTU. The laser diode must emit red light, with a wavelength between 630 nm and 690 nm. As with the EPA Method 180.1 and the ISO 7027 method, the total distance that the light beam travels cannot exceed 10 cm. The detector must be set at 90° from the incident light path, and must be connected to a photomultiplier tube via a fibre-optic cable. It is designed for on-line, or process monitoring.
- 4) Standard Method 2130B, Turbidity – Nephelometric Method, American Public Health Association (APHA 2012) is nearly identical to USEPA Method 180.1. 2130B clearly defines the basis of nephelometric technology, as well as the methods for creating a proper primary calibration standard. Established two years apart, (1993 and 1995), both methods maintain the same physical requirements for compliant turbidity meters. According to Standard Methods, the only acceptable primary standard is formazin, made by the user, following specific instructions. This includes the specified filter size of 0.1 µm if the prepared formazin needs to be diluted (Method 180.1 allows a filter size of 0.45 µm). However, method 2130B states that user-prepared formazin should be a last resort due to the use of carcinogenic compounds in its preparation. Instead, Standard Methods strongly recommends using a commercial or manufacturer-supplied calibration solution, whether made from a commercial stock suspension of formazin, styrene-divinylbenzene copolymers, latex suspensions or other polymer suspensions, all considered secondary standards. The USEPA Method 180.1, on the other hand, considers user-prepared formazin, commercial formazin and AMCO-AEPA-1 styrene-divinylbenzene polymer standards all to be primary standards. Only manufacturer-supplied latex suspensions and metal oxide/polymer gel suspensions are called secondary standards by this method.

The DWSNZ allow turbidimeters that comply with any other system approved by the USEPA for drinking-water compliance monitoring. USEPA (2009) approved four alternate test procedures (ATP) for drinking water that produce comparative results relative to EPA Method 180.1, Fondriest Environmental Inc (2014); the publication includes excellent discussion on many aspects of turbidity and its measurement. The four methods are:

- 1) **Mitchell Method M5271** is similar to Hach Method 10133 as it uses laser nephelometry to determine turbidity in an online or process monitoring instrument. The laser light source must emit a wavelength of  $650 \pm 30$  nm. This is a shift of  $10^\circ$  from the Hach method, which uses a laser diode at 630-690 nm. It is also very similar to EPA Method 180.1, as it limits light travel to 10 cm and allows the photodetector to extend  $\pm 30^\circ$  from the  $90^\circ$  centre. This method requires a bubble trap and anti-fog windows. To be compliant, the turbidity sensor must be able to withstand up to 30 psig of pressure. The method is applicable in the range from 0–40 NTU.
- 2) **Mitchell Method M5331** uses an LED as a light source. The LED must emit a wavelength of  $525 \pm 15$  nm. All other requirements match Mitchell Method 5271.
- 3) **Orion Method AQ4500** was developed by Thermo Scientific and is based on their Thermo Orion AQUAfast Turbidimeter Model AQ4500. This method follows all the requirements of EPA Method 180.1 except for the specified light source. Instead of using a polychromatic tungsten lamp as a light source, the AQ4500 uses a “white” LED. To achieve a broad band output with a typically narrow band LED, this method uses a phosphorus coated blue LED. This expands the spectral output from the blue 450 nm wavelength to a wide spectrum response similar to a tungsten source/cadmium sulphide detector combination. Use of an LED light source allows for rapid pulsing operation. Pulsing the light permits synchronous detection. This means that any stray light or electronic-induced errors can be reduced and nearly cancelled out. This method also reduces errors due to colour absorption by using two photo detectors.
- 4) **AMI Turbiwell** is unique in that it is an EPA-approved turbidity monitoring method for a non-contact turbidimeter. As a non-contact, or surface scatter, nephelometer, the AMI Turbiwell is intended for continuous monitoring, like other process or on-line monitoring instruments. Until 2009, no surface-scatter design was approved by the USEPA. This design requires that the light source be an LED with a spectral response between 400 and 600 nm. The incident light beam should be angled to reach the water’s surface at a  $45^\circ$  angle,  $\pm 5^\circ$ . A beam splitter should be used to deflect a small portion of this light beam before it hits the water. This deflected beam is used as a reference signal to monitoring light intensity. The primary photodetector is set at a right angle to the light source, and should have a peak spectral response between 400–600 nm. An algorithm determines turbidity levels based on the light intensity of the scattered and reference signals.

Guidance on the installation, standardisation, operation, and maintenance of online turbidimeters is usually provided by the manufacturer but is also provided in the *Guidance Manual for Compliance with the Interim Enhanced Surface Water Treatment Rule: Turbidity Provisions* (USEPA 1999). Appendix 2 of DWSNZ covers some general compliance requirements for continuous monitoring. Appendix A2.3 of the DWSNZ discusses standardisation and verification of online, bench top and portable turbidimeters.

The ETV Advanced Monitoring Systems Center (USEPA 2012) developed a protocol for implementing a verification test for the performance of online turbidimeters. In order for turbidimeters to be used for compliance monitoring in the US, the technology and method must gain acceptance under the USEPA Alternate Test Procedure (ATP) program (<http://water.epa.gov/scitech/methods/cwa/atp/>). This acceptance is based on the performance of the vendor's turbidimeter against an EPA Method 180.1 compliant turbidimeter. For these applications, the turbidimeters must be accurate ( $\pm 10\%$ ) relative to the reference measurement (in this case, a Method 180.1 compliant turbidimeter) used for reporting, and must be precise ( $\pm 10\%$ ). Since these technologies are intended for use online for compliance purposes, they should be reliable and exhibit stability to avoid frequent or unscheduled offline maintenance. The verification test is designed to address and quantify these performance characteristics.

Because the turbidity reading will depend in some way on the design of the turbidimeter ASTM D7315 is very specific about reporting procedures – units must indicate exactly which instrument design is being used.

### Light sources

Tungsten lamps fitted with monochromators and filters, diodes and lasers may be used as sources of monochromatic radiation. However, some older apparatus fitted with tungsten lamps, but without monochromators or filters, are still in use (polychromatic sources) and, while the reproducibility of such apparatus may be less than that of apparatus providing monochromatic radiation, they can be used for the daily control and monitoring of turbidity at waterworks and treatment plants. Results cannot, however, be compared when using different apparatus. Lamps used by ISO instruments have light requirements with incident light outputs of 860 nm and a spectral bandwidth of less than 60 nm. The detector and filter system, if used, that conform to USEPA 180.1 measure between 400 and 600 nm.

Tungsten light sources are generally more sensitive to small particles but sample colour interferes, particularly as the turbidity increases; LED light sources are not as sensitive to small particles but are not likely to have colour interferences. However, colour in good quality drinking-water should have a minimal effect on turbidity measurements. Some laboratory and portable turbidimeters using the tungsten filament lamp employ a ratio optical system to compensate for colour.

### Bubble trap

Air bubbles will measure as turbidity. This can be a problem if the water being tested is drawn from a point near turbulence, and after backwashing. Samples tested manually will produce air bubbles if the water is near dissolved oxygen saturation and the temperature has increased at the time of testing.

Not all process (online) turbidimeters use bubble traps. Some use baffles or positive pressure to reduce bubbles. Some use vacuum. Bubble traps have varied efficiencies depending on the installation and the instrument. Bubble traps should not be added to some models; check with the manufacturer. Generally, a slow flow rate will assist in better bubble removal, and hence more accurate results. However, slow flow rates are not always ideal, ie, particles may settle out. Conversely, high flow rates may scour build-up off pipe surfaces.

With reference to the membrane filtration process (in particular), turbidimeters are subject to air entrainment error. Any air bubbles introduced into the system during production, backwashing, chemical cleaning, or integrity testing may artificially increase the turbidity reading. After backwash or chemical cleaning (particularly if air is used in the process), turbidity measurements may not be representative of filtrate quality until any entrained air is purged from the system. This purge time will vary between different filtration systems and their respective operations. Bubble traps may be used with conventional and laser turbidimeters to minimise or eliminate this error.

### Sampling (ETV 2002)

The method for collecting grab samples shall consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimise bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity. In the case of cold water samples that cause the vial to fog preventing accurate readings, the vial shall be allowed to warm up by partial submersion in a warm water bath for approximately 30 seconds.

It is possible to have extremely good correlation between online and laboratory turbidimeters. Correct technique is extremely important with both standardisation and sample measurement. Sample cells are a well-known source of error. Scratches, stray light, dirt, fingerprints, orientation, etc, contribute to these errors.

### Standardisation and verification

Standardisation of turbidimeters (sometimes called calibration) comprises three components:

- a) standardisation (or primary standardisation)
- b) verification (or secondary or check standardisation)
- c) zero calibration (or zero check).

### Primary standardisation

Bench top turbidimeters may be used for compliance testing of manual samples in laboratories recognised by the Ministry of Health. The turbidimeter must be standardised and used according to the conditions of their accreditation. Otherwise standardisation of bench top and portable instruments should be performed to manufacturer's recommendations. With the availability of stabilised formazin standards (StablCal) any errors from making or diluting standards have been reduced significantly. However, care of the cells still must be observed rigidly.

Appendix A2.3 of the DWSNZ states that standardisation of bench top turbidimeters used as field instruments, and portable and online turbidimeters must be undertaken by personnel approved to do so by the DWA, and in accordance with the instrument manufacturer's specified procedures and frequency or three-monthly whichever is more frequent. Standardisation must be performed using traceable standards such as StablCal (Hach) or PrimeTime (HF Scientific) (or other MoH-approved stabilised formazin preparation); or AMCO-AEPA-1 styrene divinylbenzene microsphere suspensions (Advanced Polymer Systems). Alternatively, user-diluted formazin preparations may be used provided:

- 1) the calibration point is 20 NTU or greater
- 2) the 4000 NTU formazin preparation is obtained from a quality certified manufacturer
- 3) the dilution is done immediately prior to use for calibration.

Re field testing, the quality assurance procedures associated with standardisation and verification must be approved by the DWA.

The StablCal, PrimeTime (both stabilised formazin preparations) and AMCO-AEPA-1 standards can only be used before their expiry dates, where applicable.

The user-diluted standard must be made from a stock 4000 NTU formazin standard diluted with low turbidity water. 'Turbidity-free' water should be prepared as specified by the instrument manufacturer, or by APHA (2005), or in the method of determination being followed. Formazin is the only standard that can be prepared reproducibly from traceable raw materials. The particle size distribution of formazin is 0.01 to 10 µm, similar to the particle size distribution found in most natural water samples.

Only the use of formazin, stabilised formazin, and styrene divinylbenzene (SDVB) are accepted for reporting by the USEPA. SDVB standards are microscopic beads with narrow size distribution. However, due to the mono-dispersed nature of the size distribution, incident light may over-scatter into the forward direction and result in inaccurate calibrations. Therefore, SDVB standards are instrument-specific, and some manufacturers may recommend not using them.

### Why standardise at 20 NTU? (ie, when using formazin suspensions)

To make an accurate low level turbidity standard is extremely difficult and fraught with errors. The relationship between nephelometric detector response to turbidity is highly linear in the range of 0 to 40 NTU, if no colour exists or is very low. This linearity requires only two points for standardising over this range. Criteria are:

- 20 NTU is the midpoint
- the standard is prepared easily with a high degree of accuracy
- accuracy is maintained from the standard to the lowest measurement levels because the relationship between nephelometric light scatter and turbidity is linear
- errors due to stray light are negligible at 20 NTU and do not affect the level of accuracy of the standard curve.

## Verification of process instruments

Verification that the performance of portable instruments has not changed since standardisation must be carried out daily, or each time the instrument is switched on.

Verification of online turbidimeters must be carried out at least weekly using the manufacturer's secondary or check standard. If the instrument reading is outside the limits specified for the check standard, then that instrument must be restandardised using the standardisation method; or replaced. Table 8.8 summarises some methods for the standardisation and verification of turbidimeters.

Check standards have been developed by manufacturers to duplicate light scatter. The devices are instrument specific and are usually traced back to formazin. Their use for standardisation is not acceptable for compliance reporting by the USEPA (or in the DWSNZ), ie, must not be used for standardisation. However, they can be used for verification, ie, QA purposes.

**Table 8.8: Summary of some methods for standardisation and verification of turbidimeters**

Standard	Type	Particle size	Comments
User prepared formazin 4000 NTU	Standardisation	0.01 to 10.0 µm	May be difficult to provide traceability. Lower dilution limit is 2 NTU.
Commercially prepared formazin 4000 NTU	Standardisation	0.01 to 10.0 µm	Test performed by manufacturer to ensure complete reaction and therefore able to provide traceability. Lower dilution limit is 2 NTU.
Stabilised formazin – eg, StablCal, PrimeTime	Standardisation or verification	0.01 to 10.0 µm	Traceable. Standards ready to use down to 0.10 NTU.
SDVB	Standardisation or verification	0.1 to 1 µm	Not recommended for standardisation. Can be used for verification below 1.0 NTU. Instrument specific.
Optomechanical check standard	Verification	NA	Instrument specific standards. Verification down to 0.5 NTU.

These devices, along with other check standards (eg, latex or gel) need to be referenced back to a formazin standard on a regular basis. It is recommended to standardise each turbidimeter, then to insert the check standard and record the value for the specific turbidimeter. Check standards need to be reassigned new values after each comparison with the standard because they may have become scratched; also the lamp of the optical system in the instrument may have changed, eg, due to dust or lamp aging.

Verification that the performance of the instrument has not changed since standardising must be carried out on

- online turbidimeters: weekly, or after any interruption to continuous reading
- manual turbidimeters: daily, or each time it is switched on.

If the value displayed is outside the specified limits (commonly  $\pm 10$  percent) of the reference value previously established from standardisation, eg, outside by more than 1.98 NTU of a reference value of 19.8 NTU, then a new primary calibration is needed.

## Verification of laboratory and field instruments

If a check standard is not available, the instrument should be verified against a laboratory instrument that has been standardised recently. This will involve checking the range of turbidities that the samples will fall into. This is not the preferred method because APHA (2012, Method 2130) says to report to the nearest 0.05 NTU if the turbidity is in the 0–1 NTU range; this is not very practical, particularly if the water being monitored has a turbidity less than 0.20 NTU. However, ISO 7027 allows readings less than 0.99 NTU to be reported to the nearest 0.01 NTU, which is more appropriate for the newer instruments.

## Zero check

Some instruments automatically 'fix' the zero point. This is sometimes done by turning off the incident light. Others require a 'turbidity-free' blank. Although it is impossible to produce 'turbidity-free' water, it is possible to produce a blank with a turbidity of about 0.02 NTU; when standardising with 20/40 NTU formazin this small error at the zero point is insignificant. DWI (2014) states that pure water scatters light equivalent to a turbidity of 0.008 NTU at 860 nm, the standard ISO 7027 operating wavelength, or 0.02 NTU at 550 nm, the approximate centre wavelength of a white light source. Since the objective is to measure the particulates in the sample, a turbidimeter zero should be set to the scattered light of particle-free water rather than zero scattered light.

## Monitoring and reporting

The DWSNZ stipulate that for online monitors:

- the signal averaging time is to be one minute or less
- where discrete readings are recorded, the interval between readings is not to be more than one minute.

The previous paragraph discusses rounding of readings from manual instruments. Online instruments will report the readings 'as is' where there is a maximum turbidity that must never be exceeded. Where compliance is related to the percent of time, turbidimeters will report the percent of time the turbidity is non-complying, rather than absolute values.

Ensure that the analyser 4–20 mA output scan matches the PLC/SCADA digital output. Check that the SCADA display mimics the instrument display. See Chapter 17: Monitoring, section 17.4.4 for a discussion on reporting results and storing data, and section 17.6 for how to compare test results against a MAV or operational requirement.

## Turbidity measurement

With practice, it is not unrealistic to expect reasonably good correlation between most good laboratory turbidimeters and process turbidimeters if based on the same primary standard. When measuring low-level turbidity in the laboratory, rigorous care must be taken to eliminate errors.

DWI (2014) states that there has long been a perception that online turbidity readings on final water are lower than the laboratory readings, and this is true for 10 out of 13 of the datasets analysed for this project. There are numerous possible reasons for this associated with the laboratory method, the online method or differences between them. Possible reasons are given (see DWI's pp 34–36, 44–45).

Sample cells are the biggest source of error in turbidity measurements. Cells should be matched or indexed, clean, and scratch free. The appropriate silicon oil should be applied to mask any scratches that the eye cannot see.

Bubbles can be removed by applying a vacuum to the cell. A syringe with a rubber bung is an easy solution to this.

To avoid any problems with condensation on the cell, allow the sample to reach room temperature, this will also assist with bubbles dissipating.

### Measurement of low level turbidity

An important aspect of awarding additional protozoa removal credits for lower finished water turbidity is the performance of turbidimeters when measuring turbidity below 0.3 NTU or even below 0.10 NTU. The following paragraphs from the proposed LT2ESWTR (USEPA 2003a) summarise results from several studies that evaluated low level measurement of turbidity by different online and bench top instruments. The USEPA believes that results from these studies indicate that currently available turbidity monitoring equipment is capable of reliably assessing turbidity at levels below 0.10 NTU, provided the instruments are approved for compliance monitoring, are well-calibrated and well-maintained.

A performance evaluation (USEPA 1998), was carried out to address concern regarding the ability to reliably measure low turbidity levels. The study involved distribution of different types of laboratory-prepared standard solutions with reported turbidity values of 0.150 NTU or 0.160 NTU. The data indicated a positive bias for all instruments when compared against a reported true value. Online instruments in this study had a larger positive bias and higher standard deviation (RSD approximately 50 percent). The positive bias is consistent with previous studies (USEPA 1998) and suggests that error in turbidimeter readings may be generally conservative (ie, water supplies will operate at lower than required filtered water turbidity levels).

Letterman et al (2001) evaluated the effect of turbidimeter design and calibration methods on inter-instrument performance, comparing bench top with online instruments and instruments within each of those categories from different manufacturers. Reported filtered water turbidity values ranged from 0.05 to 1.0 NTU. The results were consistent with those of the earlier study, specifically the positive bias of online instruments. Letterman et al found generally poor agreement among different online instruments and between bench-top and online instruments. The authors observed that results were independent of the calibration method, though certain experiments suggested that analyst experience might have had some effect on turbidity readings from bench-top instruments.

Sadar (1999) conducted an intra-instrument study of low level turbidity measurements among instruments from the same manufacturer. This study was performed under well-controlled laboratory conditions. Intra-instrument variation among different models, and between bench top and online instruments, occurred but at significantly lower levels than the Letterman et al inter-instrument study. Newer instruments also tended to read lower than older instruments, which the author attributed to a reduction in stray light and lower sensitivities in the newer instruments. Sadar also found a generally positive bias when comparing online with bench-top and when comparing all instruments with a prepared standard.

The American Society for Testing and Materials (ASTM) has issued standard test methods for measurement of turbidity below 5 NTU by online (ASTM 2001) and static (ASTM 2003) instrument modes. These standards are not used very often in New Zealand. The methods specify that the instrument should permit detection of turbidity differences of 0.01 NTU or less in waters having turbidities of less than 1.00 NTU (ASTM 2001) and 5.0 NTU (ASTM 2003), respectively. Inter-laboratory study data included with the method for a known turbidity standard of 0.122 NTU show an analyst relative deviation of 7.5 percent and a laboratory relative deviation of 16 percent (ASTM 2003).

In summary, the data collected in these studies indicate that currently available monitoring equipment can reliably measure turbidity at levels of 0.10 NTU and lower. This requires rigorous standardisation and verification procedures, as well as diligent maintenance of turbidity monitoring equipment (Burlingame 1998, Sadar 1999). Systems that pursue additional protozoal credit for lower finished water turbidity must develop the procedures necessary to ensure accurate and reliable measurement of turbidity at levels of 0.10 NTU and less.

### 8.6.3 Particle counting and particle monitoring

A simple conversion factor relating particle counting and turbidity measurements is not possible because the two techniques differ fundamentally in terms of discernment. Particle counting measures two characteristics of particulates: numbers of particles and particle size. Samples with identical clarity can be distinguished on the basis of these two features; one sample may contain many small particles, whereas another may contain few large particles. Turbidity, on the other hand, cannot distinguish between two samples of identical clarity and different particulate composition.

Online particle counters use a laser-based light scattering technique to count particles and group them according to size.

Particle monitors also operate on the principle of light obstruction; however, rather than counting particles and grouping them by size, particle monitors measure particulate water quality on a dimensionless scale relative to an established baseline. The instrument measures fluctuations in intensity of a narrow light beam that is transmitted through the sample. The monitor does not count particle sizes, but provides an index (ranging from 0 to 9999) of the water quality. No calibration is required for this instrument since the output is a relative measurement of water quality. The potential advantages of this monitor are its low cost and ease of operation compared with particle counters, but little information has been published regarding the use of particle monitors in potable water treatment applications.

Particle counters convey information about particle size. Any significant increase in the number of particles exceeding 3 micrometres may indicate that a breach may have occurred allowing the passage of *Cryptosporidium* oocysts. Any particle counters that are used for the purpose of filtrate monitoring to satisfy the continuous indirect integrity monitoring requirement should be calibrated to detect particles in the size range of *Cryptosporidium* oocysts (ie, 3 to 8 micrometres).

Although Adham et al (1995) determined that particle counting was the most sensitive of the three common methods of continuous indirect integrity monitoring (ie, conventional turbidity monitoring, particle counting, and particle monitoring), particle counting instruments have a number of well-established operational problems that potentially can distort both the accuracy and precision of their measurements.

Either particle counting or particle monitoring may be used for compliance with the continuous indirect integrity monitoring requirements of the DWSNZ, ie, for membrane, cartridge or bag filtration. They can also substitute for monitoring the turbidity of water leaving a filter where a coagulation process is used. Due to the range of instruments, and the small amount of use of the technique in New Zealand, details have not been prescribed in the DWSNZ. Water suppliers wishing to use particle counting need to submit their monitoring plan to the DWA for approval.

Some relevant references on the use of particle counters in water treatment applications that may serve as a useful source of additional information are:

- *Fundamentals of Drinking Water Particle Counting* (AWWARF 2000)
- *Particle Count Method Development for Concentration Standards and Sample Stabilisation* (American Water Works Association Research Foundation, AWWARF 2000).

The former publication was prepared by Erica Hargesheimer, and is available from NZWWA. It is very thorough and covers virtually everything that is needed for deciding whether to use particle counting, and how to use it, once installed.

Advantages of particle counting and particle monitoring are generally similar, and include the following:

- more sensitive to smaller integrity breaches than conventional turbidimeters
- widely used in surface water treatment plants (particle counters)
- absolute (as opposed to relative) measure of water quality (particle counters)
- ability to yield information regarding test resolution (particle counters).

Limitations of particle counting and particle monitoring include:

- imprecision between instruments at low particulate concentrations
- susceptible to air entrainment error
- susceptible to coincidence and clogging error at higher particle concentrations
- more expensive instrumentation (particle counters) than conventional turbidimeters
- only relative measure of water quality (particle monitors)
- more operation and maintenance support needed than conventional turbidimeters.

Online particle sensors must have capabilities for measurement of particles as small as 2 microns and have a coincidence error of less than 10 percent. The resolution should be at least 10 percent at 10 microns. Flow control shall be within 5 percent of the designed rate.

The particle counter must be delivered to the water supplier pre-standardised, and subsequent standardisations shall be performed at least every 18 months. The particle counter manufacturer or an independent third party shall provide data and methods that the online particle sensors meet these criteria.

APHA (2005) includes Method 2560 on the use of particle counters and size distribution, with a section on quality control.

Two time intervals are important with online particle counters:

- the count time or interval, which is the time the instrument takes to analyse a sample
- the count frequency, which is the time between samples.

Count times are typically 30–60 seconds, and count frequencies are typically 5–6 minutes (AWWARF 2000a).

There are many variables related to particle counters. Ideally the following should be satisfied:

- the particle counter is an optical particle counter
- standardisation to be done in accordance with manufacturer's specification but not less than every 18 months
- resolution to be 10 percent at 10 microns or better
- sensitivity to be 2 microns
- range from 2 to 400 microns
- flow cell size must be not less than 700 microns
- type of flow cell must be of the volumetric type
- coincidence to be 10 percent at 16,000 particles per mL
- must be operated with an appropriate quality assurance programme
- minimum two channel (most affordable for small systems)
- flow control shall be at manufacturer's specified flow rate  $\pm 5$  percent or better
- plumbed to minimise interference due to air bubbles
- must be properly maintained (cleaned) to manufacturer's specification
- must replace with approved tubing annually.

## 8.6.4 Direct integrity test (membrane filtration)

Because it is impractical to use *Cryptosporidium* testing of membrane filtration plants to demonstrate compliance with the protozoal MAV in the DWSNZ, a performance requirement is used instead. Direct integrity testing is described in the Membrane Filtration Guidance Manual (USEPA 2003c, 2005a), in Chapter 4 (50 pages). However, the supplier or manufacturer of the plant, in accordance with the conditions of their validation, will dictate the test to be used by any membrane filtration plant owner.

The following has been taken from the introduction to direct integrity testing in the Membrane Filtration Guidance Manual.

In order for a membrane process to be an effective barrier against pathogens and other particulate matter, the filtration system must be free of any leaks or defects resulting in an integrity breach. Thus, it is critical that operators are able to demonstrate the integrity of this barrier on an ongoing basis during system operation. Direct integrity testing represents the most accurate means of assessing the integrity of a membrane filtration system that is currently available.

A direct integrity test is defined as a physical test applied to a membrane unit in order to identify and isolate integrity breaches. The removal efficiency of a membrane filtration process must be verified routinely during operation using direct integrity testing. This must be applied to the physical elements of the entire unit, including membranes, seals, potting material, associated valves and piping, and all other components which could result in contamination of the filtrate under compromised conditions.

There are two general classes of direct integrity tests commonly used in membrane filtration facilities: pressure-based tests and marker-based tests. The pressure-based tests are based on bubble point theory and involve applying a pressure or vacuum to one side of a membrane barrier and monitoring for parameters such as pressure loss or the displacement of air or water in order to establish whether an integrity breach is present.

The various pressure-based tests include the pressure- and vacuum-decay tests, the diffusive airflow test, and the water displacement test.

Marker-based tests use either a spiked particulate or molecular marker to verify membrane integrity by directly assessing removal of the marker, similar to a challenge test.

The direct integrity test used must meet the specified performance criteria for resolution, sensitivity, and frequency. Thus, a water supply may use an appropriate pressure- or marker-based test or any other method that both meets the performance criteria and is approved by the state. The performance criteria for direct integrity tests are summarised as follows:

- **resolution:** the direct integrity test must be responsive to an integrity breach of the order of 3 micrometres or less
- **sensitivity:** the direct integrity test must be able to verify a log removal equal to or greater than the removal credit awarded to the membrane filtration
- **frequency:** a direct integrity test must be conducted on each membrane unit at a frequency of no less than once every 24 hours of operation.

In addition to the performance criteria, the rule also requires the establishment of a control limit for the direct integrity test that is indicative of an integral membrane unit capable of achieving the removal credit awarded. If the results of the direct integrity test exceed this limit, the rule requires that the affected membrane unit be taken offline for diagnostic testing and repair.

See Chapter 14: Filtration Processes, section 14.4.5 for a discussion on some operational aspects of direct integrity testing.

## 8.6.5 Indirect integrity testing (continuous)

Used for membrane, bag and cartridge filtration. Note that bag and cartridge filtration does not currently undergo direct integrity testing for compliance with DWSNZ.

The various indirect integrity monitoring methods are not physical tests applied specifically to a filter, but involve monitoring some aspect of filtrate quality as a surrogate measure of integrity. These are discussed in the 17 pages of Chapter 5 of the Membrane Filtration Guidance Manual (USEPA 2003c, 2005a). The information therein also applies to bag and cartridge filtration.

Most direct integrity tests require the membranes to be taken offline, so direct tests are limited to periodic application. A failed direct integrity test indicates that an integrity breach occurred at some time between the most recent direct test in which integrity has been verified and the failed test, but indicates nothing about integrity over the period between direct test applications. Currently, continuous direct integrity monitoring techniques are not available.

Continuous indirect integrity testing is defined as monitoring some aspect or component of filtrate quality that is indicative of the removal of particulate matter. The DWSNZ specify turbidity monitoring of the filtrate as the default methodology for continuous indirect integrity monitoring.

Turbidity was selected because it is an accepted monitoring technology within the water treatment industry, and it is used as both a relative and an absolute indicator of water quality. However, because particle counting is more sensitive than turbidity monitoring, the DWSNZ contain a provision to allow it as an alternative.

Other surrogate measures of integrity are possible, such as dissolved solids or conductivity for the indirect integrity monitoring requirements for nanofiltration and reverse osmosis.

This chapter of the Membrane Filtration Guidance Manual is divided into the following sections:

- Section 5.2: Turbidity monitoring
- Section 5.3: Particle counting and particle monitoring
- Section 5.4: Other indirect monitoring surrogates
- Section 5.5: Data analysis and reporting.

Note that a non-continuous indirect method (eg, a silt density index (SDI) test) has limited value for integrity monitoring, offering neither the ability to directly test the membranes nor the advantage of online monitoring. As a result, non-continuous indirect methods do not satisfy the indirect integrity monitoring requirements of the LT2ESWTR and are not addressed in this chapter.

## 8.6.6 C.t values for chlorine dioxide and ozone

The C.t value is the residual concentration (C) of disinfectant (mg/L) multiplied by the hydraulic residence time (in t minutes). The origin of the concept is discussed in Chapter 15: Disinfection, section 15.2.1. Refer to Chapter 15: Disinfection, section 15.2.9 for a discussion about contact tanks, mixing conditions and measuring the residence time.

The procedure for measuring the hydraulic residence time (t) is described in Chapter 15: Disinfection, section 15.2.9.

For chlorine dioxide (ClO<sub>2</sub>), this involves continuous measurement of the residual chlorine dioxide (measured as ClO<sub>2</sub>) at a predetermined sample site, somewhere upstream of the first consumer. When used for protozoal compliance, the test method must not include FAC. The time the ClO<sub>2</sub> has been in contact with the water up to that point is calculated. The product of the two must exceed the value in the C.t table for the relevant water temperature. If the contact tank also acts as a storage tank, the contact time must be adjusted for when the tank is not full.

For ozone, this involves continuous measurement of the residual ozone at a point in the ozone contactor that has been validated by challenge testing as being able to achieve the required level of inactivation (log credit) of test organisms.

Chapter 11 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) discusses issues related to the measurement of contact time in different types of ozone generators and contactors.

If no tracer study data are available for determining t, the USEPA recommends using the continuous stirred tank reactor (CSTR) approach or the Extended-CSTR approach. The t<sub>10</sub>/t ratios are based on baffle characteristics from hydraulic studies of clearwells and basins.

The guidance manual presents three methods for calculating C.t:

- 1 **t<sub>10</sub>**: calculates C.t through a contactor assuming hydraulic conditions similar to plug flow and can be used with or without tracer study data; t<sub>10</sub> is the time it takes for 90 percent of the water to pass the contactor. Even in well-baffled contactors, the t<sub>10</sub> is most often less than 65 percent of the average hydraulic detention time through the contactor, and generally underestimates the true C.t achieved.
- 2 **CSTR**: calculates log inactivation credit using hydraulic detention time. It is applicable to contactors that experience significant back mixing or when no tracer study data are available.
- 3 **Extended CSTR**: a combination of the CSTR and segmented flow analysis approaches. It uses the hydraulic detention time for the contact time and incorporates the ozone decay rate to calculate concentration. It is not applied to chambers into which ozone is introduced.

These methods differ in the level of effort associated with them and, in general, the ozone dose required to achieve a given level of inactivation. Selecting the appropriate method(s) to use depends on the configuration of the ozone contactor and amount of process evaluation and monitoring that a water supplier wishes to undertake. Combinations of two or more methods may also be used. For example, contactors with multiple segments may have one or two segments with their C.t calculated using either the  $t_{10}$  or CSTR methods, while the C.t for the remaining segment is calculated using the Extended-CSTR approach. The  $t_{10}$  and CSTR are the simplest methods.

The sample site and collection requirements are described in USEPA (2009).

The ozone contactor will have been rated in validation tests by the manufacturer or supplier for the water being treated, so the flow, ozone concentration at the monitoring point, and the general operating conditions must be maintained at no worse than the conditions that applied in the validation.

The product of the flow and residual must exceed the value in the C.t table for the relevant water temperature and target log credit.

## 8.6.7 UV intensity measurement

UV intensity sensors are photosensitive detectors that measure the UV intensity at a point within the UV reactor. Sensors are used to indicate dose delivery by providing information related to UV intensity at different points in the reactor. The measurement responds to changes in lamp output due to lamp power setting, lamp aging, lamp sleeve aging, and lamp sleeve fouling. Depending on sensor position, UV intensity sensors may also respond to changes in UV absorbance of the water being treated.

The proposed Ultraviolet Disinfection Manual (USEPA 2003d) stated UV appliances with MP lamps should be equipped with one UV intensity sensor per lamp. USEPA (2006c) requires a minimum of one UV sensor per UV reactor; the actual number should be identical to the UV reactor that was, or will be, validated.

UV sensors are photosensitive detectors that measure UV intensity. UV sensors used in drinking-water UV applications, particularly those with MP or other polychromatic lamps, should be germicidal. Germicidal sensors are defined as having the following properties:

- a spectral response (ie, UV intensity measured at various wavelengths) that peaks between 250 and 280 nanometers (nm)
- less than 10 percent of its total measurement is due to light above 300 nm when mounted on the UV reactor and viewing the UV lamps through the water that will be treated.

Section 5.16.3(2) of DWSNZ specify the requirements for calibration of UV intensity sensors. Further information is included in section 8.4.4.3 (this chapter). Annex A and B of ÖNORM (2001) also cover sensor requirements.

## 8.6.8 Pressure differential

There are no generally accepted direct integrity tests for bag and cartridge filtration. The best technique for assessing the efficiency in removing particles the size of protozoa is particle counting; at present this is difficult and expensive. The commonest indirect integrity test, turbidity, is often of little practical value in demonstrating bag and cartridge compliance because:

- often the raw water has a very low turbidity, for example spring water with a turbidity of say 0.4 NTU. So an operational requirement of 0.5 NTU for compliance purposes could be achieved even if the filter is ruptured or being by-passed!
- some raw waters have a high turbidity due to very fine particles, for example due to silica from glacial flour. These particles may be 10–100 times smaller than protozoa, and will mostly pass through bag or cartridge filters, so are not a good indicator of the filter's ability to remove protozoa.

Therefore another operational requirement is needed to show whether the filter is likely to be performing satisfactorily. Experience has shown that monitoring the pressure differential across the filter housing is a good indicator of performance. The gauge readings and electrical signals from differential pressure transmitters can be verified by using a pressure meter. See Chapter 14: Treatment Processes, Filtration, Figure 14.4 for a recommended layout.

Sections 5.12 and 5.13 of DWSNZ specify the pressure differential monitoring requirements.

## 8.6.9 Microscopic particulate analysis

DWSNZ 2000 included microscopic particulate analysis (MPA) as a method for assessing the efficacy of cartridge, bag, diatomaceous earth and slow sand filters in removing protozoa. The test has not been mentioned in subsequent DWSNZ. However, MPA can still be a useful tool, either quantitatively or qualitatively. A good description of its usefulness appears in a paper by Hancock (1999).

The methodology is described in Vasconcelos (1992), Harris et al (1996), Hancock (1999).

Analysing raw and filtered samples allows the log reduction of organisms to be calculated.

Large volumes, say 2000 litres, of sample can be passed through a filter to trap the organisms. This can be arranged various ways, such as monitoring an entire filter run.

## 8.7 Transgressions

### 8.7.1 Response

Refer to Chapter 17: Monitoring, section 17.6 for a discussion on how to compare a test result against a MAV or operational requirement.

In the DWSNZ, Figure 5.1: Response to turbidity transgression in water after treatment, and Figure 5.2: Response to disinfectant (chlorine dioxide, ozone, UV) transgression in drinking-water leaving a treatment plant, clarify at what stage the DWA is to be consulted, and at what stage routine monitoring can be resumed.

The DWSNZ state that well-managed water supplies will have established a control limit for each MAV or operational requirement. Control limits are discussed in Chapter 17: Monitoring. The preventive actions that are to be considered when a control limit is approaching or reached are to be documented in the PHRMP. The purpose of control limits and the preventive actions is to avoid reaching the transgression level of the MAV or operational requirement, thereby reducing the risk of non-compliance.

Table 5.2 (in DWSNZ) lists the protozoal inactivation or removal processes. Operational aspects of each of these are discussed in Chapters 12–15 of the Guidelines, where relevant. These chapters offer water suppliers some guidance relating to preventive and remedial actions that may be appropriate for inclusion in their PHRMPs. However, there are so many different raw water qualities, treatment processes, modes of operation, and staffing arrangements that it is not possible to cover all contingencies in these Guidelines.

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 protozoal transgression or non-compliance. These will tend to be supply-specific but will include matters such as dealing with emergencies such as power cuts, earthquakes and floods, as well as running out of coagulant or disinfectant, failure of the filtration or disinfection system, disinfection demand exceeding the maximum dose rate, labour problems, breach of security, spills of wastewater or other contamination. Apart from the obvious, these situations may be detected during catchment assessments (ie, what affects the source water), sanitary inspections (of the water supply), or bore head protection inspections.

Some general comments may offer helpful advice for when a control limit is reached or when a transgression occurs:

- unusual weather or water temperatures may have caused raw water conditions to change to the extent that the treatment process is no longer effective (includes algal growth)
- upstream activities such as discharges, gravel extraction, or changes in land use may have modified the raw water quality
- the raw water is possibly being extracted from the wrong depth or position

- screening or other pretreatment may need inspection or maintenance
- bore head protection or screening may have failed
- recycled wash water or sludge supernatant may be affecting the treatment process
- new plant may not have been commissioned correctly
- the water demand may be too high for parts of the treatment process to cope
- various components of the treatment process may require more maintenance or replacement
- the flow through the plant may be unbalanced resulting in some components being overloaded
- the dose of a coagulant, polyelectrolyte, diatomaceous earth, disinfectant or UV may be incorrect
- hydraulic operations may cause a surge through filters, which may then discharge particles
- chemical supplies, spares, and other consumables may be purchased or delivered too late
- monitoring equipment may not be standardised correctly, or may be inappropriate
- water storage tanks may have been interfered with, or have cracked/split
- alarm systems, or the response to them, may be inadequate
- there may be insufficient back up to cover unusual events
- staff may need further training
- a standby electricity generator may be needed
- water may need to be diverted to waste briefly.

Further information is available in the Ministry of Health's Water Safety Plan Guides that can be accessed on [www.health.govt.nz/water](http://www.health.govt.nz/water) and clicking on Publications, then on Water Safety Plans, then selecting the relevant Guide. These have been referenced in the treatment chapters.

## 8.7.2 Reporting

Section 1.6.15 of these Guidelines lists the general compliance criteria for records; these originally appeared in the 2005 DWSNZ and 2008 revision.

All compliance monitoring programmes must be documented, giving details of sample sites, sample collection techniques, sample handling or storage, tests to be conducted, methods used, times and dates. Any variations to the programme or procedure should be noted.

Details relating to instrument calibration, maintenance, and replacements should be recorded.

Results from participating in interlaboratory testing programmes should be retained, along with reports of investigations into the cause of any unsatisfactory test results.

Water suppliers will need to consider how to store test results, particularly those generated by online instruments. A lot of information is generated a year! Ideally, online instruments will only report transgressions, or the percent of time (or samples) that comply. Guidance is offered in Chapter 17: Monitoring: section 17.4.4.

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# Appendix: Guidance Notes: Interpretation of Catchment Protozoal Risk Category

To be read in conjunction with section 8.2.

This guidance document aims to provide additional information to enable interpretation of Table 5.1a in situations where it is not entirely clear which log credit category is most appropriate.

Although the DWSNZ refer to either *Cryptosporidium* monitoring or Catchment Assessment as being the 'standard approach' dependent on population served, it should be noted that the *Cryptosporidium* monitoring option is considered the more accurate and therefore the preferred method for assigning log credits to source waters. Table 5.1a is necessarily conservative and its use may lead to overdesign of capital works for treatment and extra ongoing running costs for a community.

## Part 1: Surface waters

Water from forest, bush, scrub or tussock catchments with no agricultural or human activity	3 Log
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This category does not present interpretation difficulties. It is generally clear which catchments fit into this category. No further guidance is considered necessary.

Water from pastoral catchments that always has low concentration of cattle, sheep, horses or humans in immediate vicinity or upstream	4 Log
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Water from pastoral catchments with frequent high concentrations of cattle, sheep, horses or humans, or a waste treatment outfall nearby or upstream	5 Log
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The 4 and 5 log surface water categories have caused some interpretation difficulties, particularly the descriptions 'frequent high' and 'always low'. Unfortunately defining these terms by providing absolute numbers or stock densities (eg, stock units, or numbers of animals per unit area) is not in itself beneficial in terms of establishing the associated risk.

Preliminary results from raw water *Cryptosporidium* monitoring in New Zealand catchments indicate that there are likely to be very few catchments in New Zealand that present a protozoal risk great enough to require 5 log protozoal removals. It is on the basis of this information that the following guidance is provided. The aim is to ensure that water suppliers are not unreasonably burdened with the requirement for 5 log treatment (as the precautionary approach in Table 5.1a appears to direct) when the risk may not warrant it.

These guidelines contain a list of 'alert criteria' that should be considered in situations where it is difficult to determine whether a catchment fits into the 4 or 5 log category. The alert criteria are land use activities and discharges known to be associated with greater protozoal contamination. Interpretation difficulties generally arise in situations where the influence of animals in the catchment is unclear. For example, Table 5.1a states that the 5 log category should be assigned in situations where a waste treatment outfall is 'nearby or upstream'. The proximity of the point source discharge to the intake is critical and therefore these guidelines propose that distance from the intake be considered prior to the 5 log category being automatically assigned to such sources.

If none of the alert criteria are met the catchment should be assigned 4 log category.

## Alert criteria (surface waters in 4 or 5 log categories)

### Point source<sup>1</sup> discharges

- Waste treatment discharge to water (eg, sewage outfall, meatworks effluent discharge) up to 1000 m upstream of intake or 100 m downstream.
- Stormwater discharges (via discharge pipe) up to 1000 m upstream of intake or 100 m downstream.

### Non-point source<sup>2</sup> discharges

- Animal effluent disposal (to land) up to 500 m upstream of intake (eg, dairy shed effluent, pig effluent, truck effluent disposal).
- Animal (cattle, sheep, deer, horse) access to waterway (no fencing or riparian boundary) within 1000 m upstream of intake.
- Sewage disposal to land (if there are concerns about the effectiveness of treatment) within 500 m upstream of intake.
- Large numbers of feral animals within 500 m of intake.
- Any other activity that results in high concentrations of animals being present (other than on hard stand areas where effluent is collected for treatment) eg, livestock sale yards, animal transport company holding yards within 500 m of intake, farm practices such as 'sacrifice' or 'wintering off' paddocks used at high stocking rates to protect other pasture during wet periods, strip grazing of livestock herds).

<sup>1</sup> Point source = a stationary point of pollution, such as a discharge pipe.

<sup>2</sup> Non-point source = diffuse pollution sources (ie, without a single point of origin or not introduced into the receiving water from a specific outlet).

Where contaminating land uses are present take into consideration the slope of the land to determine likelihood of impact on the intake area.

### Mitigating factors for surface waters

These are factors that may reduce the likelihood of high levels of protozoa contamination reaching a treatment plant intake despite factors above being present. Mitigating factors include, but may not be limited to:

- the flow rate of the river or stream relative to the discharge rate of a point source – high river flows coupled with low discharge rates will help dilute contaminant levels
- a well-designed, managed and maintained riparian strip
- impoundment of some description before abstraction – the longer the residence time the greater the reduction in microbial contaminants
- for lakes and reservoirs – the distance between the shore and intake
- the level to which wastewater or meatworks effluent has been treated before discharge.

### Response if one or more of 'alert criteria' met and no mitigating factors

Drinking water assessors should not immediately assign a 5 log categorisation to water sources that meet one or more of the alert criteria (and no mitigating factors in place). Water suppliers with sources in this category (or in circumstances where the supplier disagrees with the log credit category assigned as a result of the assessment) should be strongly encouraged/advised to undertake raw water *Cryptosporidium* monitoring to confirm the appropriate log credit.

It should be noted that any drinking water supply eligible for DWAP is not likely to be recommended for subsidy funding if 5 log credits have been assigned to it and that this has not been confirmed by raw water *Cryptosporidium* monitoring.

## Part 2: Bore water supplies

Bore water drawn from >10 m deep: the bore water section of Table 5.1a is clear.

Bore water drawn from <10 m deep: Table 5.1a is difficult to apply to groundwater <10 m deep. Source waters in this category are directed into the surface water section of the table, but these categories are unhelpful in assessing the risk associated with groundwaters that have no hydraulic link<sup>3</sup> to a surface water source. The surface water categories of Table 5.1a should be directly applied to groundwaters that are known to be hydraulically linked to a nearby surface water source.

<sup>3</sup> Hydraulic link = this is when surface water and groundwater are directly linked. When water is pumped from a well that is hydraulically connected to a nearby stream, it reduces the flow in the stream. Where turbidity increases in groundwater after heavy rain has increased the turbidity in nearby surface water, this is an indication of a hydraulic link.

Part 2 of this guidance document aims to provide additional guidance on assigning a log removal category for bore water drawn from <10 m deep.

The DWA should request that the water supplier provides information about land use activities and discharges occurring in two zones around the well: a 5–50 m 'inner' buffer zone and a 50–250 m 'wider' buffer zone. The water supplier also needs to provide information on the soil and sub-surface materials. This type of information may be available through the regional council. The DWA should then consider the impact of activities occurring within the two zones and determine the applicable log removal category by reference to Tables 1 and 2 below. An additional set of mitigating factors (outlined below) can be considered for bore water drawn from <10m deep that fall into the 5 log category (and may enable them to be reduced to 4 log).

### 'Impact of activity' descriptions

None: no sources of animal or human faecal contamination.

Low: livestock and/or feral animal and/or human faecal contamination sources are present but do not meet the level(s) of intensity described under the 'high' impact description below.

High: one or more of the following land use activities is present:

- on-site sewage disposal (eg, septic tanks, soakage/boulder pits)
- offal pits
- effluent storage ponds / effluent spraying / effluent disposal by border dyke irrigation
- high stocking rates<sup>4</sup> (eg, 'sacrifice' or 'wintering off' paddocks used at high stocking rates to protect other pasture during wet periods, strip grazing of livestock herds)
- any other activity that results in high concentrations of animals being present (other than on hard stand areas where effluent is collected for treatment) eg, livestock saleyards, animal transport company holding yards.

Note: Drinking water suppliers should endeavour to exclude high risk sites when selecting a location for a new drinking water source. The Resource Management (National Environmental Standards for Sources of Human Drinking Water) Regulations 2007 should be consulted where new contaminating land uses are proposed that may impact on existing water sources. Obtaining a higher quality source water may be a better option than investing in more extensive treatment.

<sup>4</sup> Definitions for stocking rates vary. Average stocking rate for dairy cattle in New Zealand in 2010 was 2.8 cows per hectare (DairyNZ). Definitions vary, but generally rates above 3.5–4.0 cows per hectare are considered high. Stocking rates are calculated over the area of the farm. Farm practices that concentrate large numbers of animals into small areas are of more significance in terms of contaminant runoff and leaching into groundwater.

**Table 8A1: Log removal requirements for bore waters <10 m deep based on land use activities and soil / sub-surface material permeability**

Fenced exclusion zone (5m)	Impact of activity in inner buffer zone (refer to definitions above) (5–50m)	Impact of activity in wider buffer zone (refer to definitions above) (50–250m)	Soil permeability (refer to Table 2 below)		Sub-surface permeability (refer to Table 2 below)		Log treatment requirement
			Low	High	Low	High	
Yes	None	None	N/A	N/A	N/A	N/A	3
Yes	None	Low	✓		✓		3
Yes	None	Low	✓			✓	4
Yes	None	Low		✓	✓		3
Yes	None	Low		✓		✓	4
Yes	None	High	✓		✓		4
Yes	None	High	✓			✓	5
Yes	None	High		✓	✓		4
Yes	None	High		✓		✓	5
Yes	Low	Low	✓		✓		3
Yes	Low	Low	✓			✓	3
Yes	Low	Low		✓	✓		4
Yes	Low	Low		✓		✓	4
Yes	Low	High	✓		✓		4
Yes	Low	High	✓			✓	5
Yes	Low	High		✓	✓		4
Yes	Low	High		✓		✓	5
Yes	High	N/A	✓		✓		4
Yes	High	N/A	✓			✓	4
Yes	High	N/A		✓	✓		5
Yes	High	N/A		✓		✓	5
No							5

**Table 8A2: Sub-surface media and soil categories**

	Sub-surface media	Soils
High filtration* media/soils	Pumice sand Clay	Raw and recent soils Semiarid soils Pumice soils Allophanic soils
Low filtration media/soils (some of these are more accurately described as 'medium' filtration materials but for the purposes of categorising for Table 1 they are considered 'low filtration')	Gravel Alluvial sand Coastal sand Sandstone Fractured rock Silt Ash Peat	All other types of soils

\* A 'high filtration' media/soil indicates that water that passes through the media will have been subjected to a high level of filtration. Not to be confused with soils that are 'free draining', meaning that liquids pass through the media easily.

## Mitigating factors for bore waters <10 m deep in 5 log category

Bore waters <10 m deep that Table A1 identifies as requiring 5 log treatment may be reduced to 4 log if the DWA considers that sufficient mitigating factors are in place that reduce the likelihood of the high risk activity causing contamination of the source. The following are examples of mitigating factors that should be considered:

**On-site sewage disposal:** systems that incorporate newer treatment technology are far less likely to present a risk to groundwater than older style systems. Consider also the nature of the disposal field (boulder pit / soakage pits present much higher risk than trickle irrigation systems).

**Groundwater flow:** good information on groundwater flow may alleviate concerns about some potentially contaminating land-use activities (that have been identified within the buffer zone) if the direction of groundwater flow shows the land use will not impact on water drawn in by the well.

**Soil thickness:** the greater the soil thickness, the greater the removal of oocysts.

**Soil type:** allophanic and pumice soils are extremely efficient in removing microbes from water permeating through them. If it is determined that these types of soil are present, a 3 log requirement can be assigned to the system.

Drinking water assessors should not immediately assign a 5 log categorisation to any groundwater source. Water suppliers with sources in this category (or in circumstances where the supplier disagrees with the log credit category assigned as a result of the assessment) should be strongly encouraged/advised to undertake raw water *Cryptosporidium* monitoring to confirm the appropriate log credit.

It should be noted that any drinking water supply eligible for DWAP is not likely to be recommended for subsidy funding if 5 log credits have been assigned to it and that this has not been confirmed by raw water *Cryptosporidium* monitoring.

## Part 3: Five-yearly reassessment of protozoa risk category

The DWSNZ require that water suppliers >10,000 redo their protozoa monitoring programme every five years and that water suppliers <10,000 redo their catchment assessment every five years. A water supplier <10,000 that has elected to do protozoa monitoring to establish their initial log credit requirement may choose to do catchment assessments for the subsequent five yearly reassessments. Suppliers in this category may remain on the original log credit (determined by protozoa monitoring) if the catchment assessment confirms that no changes in the catchment have occurred that would have altered the protozoa risk. See section 8.2.6.