

New Approach to Handling Protozoa Criteria

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Introduction

Due to a number of difficulties in the direct enumeration of protozoa, the approaches used in Drinking-Water Standards New Zealand (DWSNZ) 1995 and 2000 for developing protozoa criteria were based on a treatment process concept rather than protozoa monitoring. The criteria related to the 'water leaving the treatment plant'. There were no criteria for water in the distribution system. There were four categories:

- a) Filtration without coagulation.
- b) Chemical coagulation plus filtration.
- c) Disinfection without filtration.
- d) Secure groundwater.

Compliance involved:

- a) **Filtration without coagulation:** achieving 4 log removal of particles, or integrity testing, or challenge testing, or on-line particle removal, or microscopic particle analysis, or certification of treatment appliances. The 4 log removal was considered excessive so 3 log removal was proposed for DWSNZ 2004.
- b) **Chemical coagulation plus filtration:** by a range of turbidity measurements of water leaving each filter. It was intended to drop the '95% shall not exceed 0.5 NTU' down to 0.1 NTU in DWSNZ 2004 – this was considered equivalent to 4 log removal. This introduces some measurement challenges.
- c) **Disinfection without filtration:** by demonstrating that the ozone or chlorine dioxide C.t satisfies conditions for 2 log removal of *Cryptosporidium*. Intended to require 3 log by 1.1.05.
- d) **Secure groundwater.** by demonstrating that the source is secure and that it remains so. Some changes are intended for DWSNZ 2004 but these are not discussed here.

A new approach

It is proposed to change the approach for DWSNZ 2004 for the following reasons.

- A sounder approach would be to establish risk-based criteria allowing for different qualities of raw water.
- The present categories of treatment processes do not suit all treatment processes used in New Zealand, and do not satisfactorily allow for their various efficacies.
- These efficacies are additive, but the present DWSNZ do not acknowledge this.
- Overseas studies have assessed the log removal of *Cryptosporidium* for a range of treatment processes.
- Some of the monitoring presently required for compliance testing is unsuitable.
- There are inconsistencies in the present Standards for log removals of *Cryptosporidium* for different treatment processes.
- Disinfection using UV light is not included in the present Standards. There is now sufficient information to allow UV.
- Some changes intended for adoption by 1 January 2005 were either not consistent with current knowledge, not consistent with other categories, used monitoring tests that were unsuitable or difficult or without a referee method, or the lower concentrations posed monitoring difficulties.

Raw water quality

In an ideal world we would have at least 12 months of *Cryptosporidium* test results of at least monthly samples for every raw water. Unfortunately, due to different laboratories in New Zealand testing samples for different purposes, using different concentration and elution methods, different lab-bench techniques, and obtaining different recoveries, what data are available are not strictly comparable.

In recognition of the relatively high cost of analysing samples for *Cryptosporidium*, USEPA explored the use of indicator criteria to identify raw waters that may have high levels of *Cryptosporidium* occurrence. The goal was to find one or more parameters that could be analysed at low cost, and to identify those supplies likely to exceed a boundary of 0.075 oocysts/L. Data were evaluated for possible indicator parameters, including fecal coliforms, total coliforms, *E. coli*, viruses, and turbidity. Based on available data, *E. coli* was found to provide the best performance as a *Cryptosporidium* indicator, and the inclusion of other parameters like turbidity was not found to improve accuracy.

It is proposed that we adopt a two-tier raw water quality approach in New Zealand:

1. 'Clean' raw waters. These should average less than 0.075 *Cryptosporidium* oocysts per litre (based on results using USEPA Method 1622). Until sufficient data have been compiled, *E. coli* data may be used as a substitute. The boundary to be used for springs, groundwaters that are not secure, reservoirs and lakes shall be that 95 percent of samples

shall contain fewer than 10/100 mL *E. coli*. The boundary to be used in flowing river and stream systems shall be that 95 percent of samples shall contain fewer than 50/100 mL.

2. 'Dirty' raw waters. Raw waters above these median values shall be called 'dirty' raw waters. Any raw water with insufficient raw water monitoring data shall be assumed 'dirty' until proven otherwise.

These classifications may change when the Ministry for the Environment has issued its National Environmental Standards.

The classification of 'clean' or 'dirty' shall be based on at least 24 samples, collected over a 12- or 24-month period. It will be fairly obvious that some raw waters will be 'dirty' without having to collect samples for *E. coli* testing. Water suppliers may classify their raw water as 'dirty', based on a sanitary survey or existing knowledge.

'Clean' raw waters will need to demonstrate 3 log removal of *Cryptosporidium* to comply with the protozoa criteria, and 'dirty' raw waters will need 4 log removals. **Should there be a third (very dirty) category, requiring a higher level of water treatment eg, 5 log removal? In the US these would need to satisfy the *Cryptosporidium* criteria by using more than one form of treatment.**

Treatment efficacy

The following processes have been evaluated by the EPA for the removal of *Cryptosporidium*.

Conventional treatment plants

Conventional treatment is defined as a series of processes including coagulation, flocculation, sedimentation and filtration.

While *Cryptosporidium* removal at full scale plants is difficult to quantify due to limitations with analytical methods, pilot scale studies show that reductions in aerobic spores and total particle counts are often conservative indicators of filtration plant removal efficiency for *Cryptosporidium*. Surveys of full-scale plants have reported average reductions near 3 log for both aerobic spores and total particle counts.

EPA has concluded that a treatment plant using DAF in place of sedimentation can achieve levels of *Cryptosporidium* removal equivalent to or greater than a conventional treatment plant.

Pilot scale *Cryptosporidium* spiking studies suggest that a conventional treatment plant has the potential to achieve greater than 5 log removal of *Cryptosporidium* under optimal conditions. However, these high removals are typically observed at very low filter effluent turbidity values, and the data show that removal efficiency can decrease substantially over the course of a filtration cycle, or if coagulation is not optimised. Removal efficiency also appears to be impacted by raw water quality. Given these considerations, EPA believes that 3 log is a reasonable estimate of average *Cryptosporidium* removal efficiency for conventional treatment plants.

Direct filtration

Direct filtration, which is typically used on sources with low particulate levels, includes coagulation and filtration but not sedimentation.

Pilot and full scale studies demonstrate that sedimentation basins can achieve 0.5 log or greater *Cryptosporidium* reduction. Studies have shown that direct filtration achieves less *Cryptosporidium* removal than conventional treatment, and a higher incidence of *Cryptosporidium* in the treated water of direct filtration plants has been found. The turbidity of filter effluent can be higher too. Given these findings, EPA has estimated that direct filtration plants achieve an average of 2.5 log *Cryptosporidium* reduction.

Slow sand filtration

Overall, it appears that slow sand filtration has the potential to achieve *Cryptosporidium* removal efficiencies similar to that of a conventional plant, but proper design and operation are critical to realising treatment goals. Slow sand plants are estimated to achieve a 2.5 log average *Cryptosporidium* reduction, in consideration of the absence of a sedimentation process in these plants.

Diatomaceous earth filtration

One new study of DE filtration supports 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). DE plants are estimated to achieve a 2.5 log average *Cryptosporidium* reduction, in consideration of the absence of a sedimentation process in these plants.

Other filtration

EPA is unable to estimate an average log removal for other filtration technologies like membranes, bag filters, and cartridge filters, due to variability among products. As a result, credit for these devices must be determined by product specific testing. Normally this will involve the manufacturer certifying the device by challenge testing, under conditions prescribed by an internationally accepted standard. An appropriately accredited inspection body must conduct the certification.

Ozone and chlorine dioxide

With the completion of several major studies, EPA has acquired sufficient information to develop standards for the inactivation of *Cryptosporidium* by ozone and chlorine dioxide. For both of these disinfectants, C.t tables specify a level of *Cryptosporidium* treatment credit based on the product of disinfectant concentration and contact time. For ozone, the C.t tables were developed from four sets of experimental data. Chlorine dioxide C.t tables are based on three experimental data sets. Together these studies provide a large body of data that covers a range of water matrices, both laboratory and natural. While the data exhibit variability, EPA believes that collectively they are sufficient to determine appropriate levels of treatment credit as a function of disinfection conditions.

Ultraviolet light

A major recent development is 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. However, 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. Recent research using *in vivo* assays and cell culture techniques to measure infectivity has provided strong evidence that both *Cryptosporidium* and *Giardia* are highly sensitive to low doses of UV.

Studies generally demonstrated at least 3 log *Cryptosporidium* inactivation at UV doses of 10 mJ/cm² and higher. In comparison, typical UV doses for drinking water disinfection are 30 to 40 mJ/cm².

UV light did not directly form DBPs, such as trihalomethanes (THM) and haloacetic acids (HAA), and did not alter the concentration or species of DBPs formed by post-disinfection with chlorine or chloramines. A study reported that applying UV light following chlorine disinfection had little impact on THM and HAA formation. In addition, data suggest that photolysis of nitrate to nitrite, a potential concern with certain types of UV lamps, will not result in nitrite levels near the MCL under typical drinking water conditions.

Bank filtration

In recognition of the filtering effect of bank filtration, *Cryptosporidium* credits of 0.5 or 1.0 are available based on specified criteria.

Combined filter performance

EPA examined several studies and concluded that removal of *Cryptosporidium*, *Giardia*, and particles increased by more than 0.5 log when the effluent turbidity improved from 0.1-0.2 NTU to <0.10 NTU. Tests also demonstrated that when the filters suffered a hydraulic surge causing the turbidity to exceed 0.10 NTU, protozoa and particle removal decreased.

Therefore a credit of 0.5 log can be earned provided the turbidity of the combined filter effluent is less than 0.15 NTU for at least 95 percent of measurements. EPA considers that to achieve this, the combined effluent will need to be consistently below 0.1 NTU.

Individual filter performance

This is an extension of the combined filter performance. EPA considers that a modestly elevated turbidity from an individual filter may not impact the combined filter effluent, but that systems that continually achieve very low turbidity in every filter are likely to provide a significantly more effective microbial barrier. To earn the 1.0 log credit, the water from every filter must be <0.10 NTU for at least 95 percent of the time, with no sample >0.3 NTU. EPA considers that to achieve this, the water supplier will have achieved a high level of process optimization and control, and will have a history of consistent performance over a range of raw water conditions and have the capability and resources to meet this performance long-term.

Secondary filtration

EPA has proposed this credit based largely on the theory that the same mechanisms of protozoa removal in a primary filter will occur in a secondary filter. Secondary filtration is defined in the criteria section. Worth 0.5 log credits.

Summary

The log credits available for attempting to satisfy the protozoa criteria are summarised in Table ABC. These are only summaries. Full details of the respective criteria appear in Section 3.2.3. To indicate how the protozoa log credit approach can be applied, some fictional case studies follow.

Case studies

Case 1: A spring or shallow bore (10° C, turbidity <1 NTU) with raw water quality equivalent to 'clean'. Therefore needs 3 log (99.9%) removal of *Cryptosporidium*

To earn 3 log credits, use ozone satisfying a C.t of 30 (note C.t = 25.1 in DWSNZ 2000).

Note: This option would not be allowed in the US because supplies that are not filtered must earn their credits using 2 disinfectants – should we require the same?

Or ozone at C.t of 20 (= 2 logs) plus bag filtration provided it demonstrates a satisfactory challenge test.

Or ozone at C.t of 10 (1 log) plus cartridge filtration if it demonstrates a satisfactory challenge test.

Or use UV at 40 mJ/cm² to earn 3 log credits (the UV dose is higher than needed for *Cryptosporidium* inactivation, but the extra is needed for control of bacteria and viruses). **Again, only a single disinfectant.**

Or use a lower dose of UV but add bag filters or cartridges. If occasional *E. coli* pass through the filter, this option may not result in *E. coli* compliance.

Note that this type of raw water would probably satisfy the EPA rule for avoiding filtration, and as such would only need 2 log removals of *Cryptosporidium* (if the Crypto count is very low). We are not proposing to adopt that option.

Table ABC: Log credits and conditions for control of protozoa

Treatment Process	<i>Cryptosporidium</i> log credit if complying with criteria (which follow)
Bank filtration (infiltration gallery)	0.5 log credit for 7.5 m setback; 1.0 log credit for 15 m setback.
Flocculation coagulation, sedimentation, filtration	3.0 log credit
Coagulation, direct filtration	2.5 log credit
Diatomaceous earth filtration	2.5 log credit
Slow sand filters	2.5 log credit. No prior prechlorination.
Membranes	Credit equivalent to removal efficiency demonstrated in challenge test for device if supported by direct integrity testing. Potentially, 5 or more log removals.
Bag filters	1 log credit with demonstration of at least 2 log removal efficiency in challenge test.
Cartridge filters	2 log credit with demonstration of at least 3 log removal efficiency in challenge test.
Combined filter performance	0.5 log credit for combined filter effluent turbidity ≤ 0.15 NTU in 95% of samples each month.
Individual filter performance	1.0 log credit for demonstration of filtered water turbidity < 0.1 NTU in 95 percent of daily max values from individual filters (excluding 15 min period following backwashes) and no individual filter > 0.3 NTU in two consecutive measurements taken 15 minutes apart.
Second stage filtration	0.5 log credit for second separate filtration stage; treatment train must include coagulation prior to first filter. No presumptive credit for roughing filters.
Chlorine dioxide	Log credit based on demonstration of log inactivation using ClO ₂ C.t table.
Ozone	Log credit based on demonstration of log inactivation using ozone CT table.
UV	Log credit based on demonstration of inactivation with UV dose table; reactor testing required to establish validated operating conditions. If dose high enough to inactivate bacteria and viruses, can earn up to 3.0 protozoa log credits.

Case 2: Raw water abstracted from a stream passing through farmland (sheep, cattle, horses, humans etc) and turbidity $>> 1$ NTU. Considered equivalent to ‘dirty’ raw water so needs 4 log (99.99%) removal of *Cryptosporidium*

Use alum coagulation (direct filtration) filtration to obtain 2.5 log credits. Plus 3 log credits for 40 mJ/cm² UV (the higher than needed UV dose is required to inactivate the bacteria and viruses). The credits earned total 5.5 log, which is advisable – this type of raw water is probably worse than ‘dirty’ raw water. Perhaps the suggested ‘clean’ and ‘dirty’ raw water categories are over-simplified?

Or: use diatomaceous earth filtration, or slow sand filtration, followed by UV as previous option. (The raw water is too dirty for cartridges.)

This is assumed to be a fairly small supply – one that will probably try to avoid the extra cost of settling tanks. If the raw water turbidity is too high, a roughing filter may be needed with these options (but roughing filters earn no credits).

Note that by assigning a maximum of 2.5 log credits to direct filtration processes (other than membrane), the EPA is saying that the process is not good (or reliable) enough for *Cryptosporidium* removal on its own, so needs an additional step. But if the filter is good enough and performs well consistently it may earn additional credits (see criteria for combined filter effluent and individual filter performance).

Case 3: ‘Dirty’ raw water (worst case) river, which in the US would need 5.5 log credits

Although there are only two classes of raw water being proposed, there could be a case for reserving a third category for particularly bad raw waters, such as downstream of sewage effluent discharges. In the US, a raw water would need >3 oocysts per litre to be required to achieve 5.5 log removals of *Cryptosporidium*.

Conventional treatment earns 3 log credits, plus low (4 mJ/cm²) dose of UV (because chlorine is used for bacteria/viruses and distribution system residual) for 1.5 log credits, plus 1.0 log credit because each filter produces water <0.10 NTU for 95 percent of the time, with none >0.3 NTU. If the individual filter requirement is too tough, go for the combined filter performance (0.15 NTU = 0.5 log credit) and increase the UV dose to earn the extra credits. Note that at this low UV dose, chlorine is still needed to inactivate bacteria and viruses.

Case 4: Infiltration gallery near a ‘clean’ river

Needs 3 log credits to satisfy *Cryptosporidium* inactivation. If the wells are more than 15 m from the surface water source and comply with other conditions, the bank filtration system earns 1.0 log credits. The other 2 log credits can be earned by using (in a complying manner) slow sand filters, cartridges, UV (high dose), UV (low dose) + chlorine, or ozone. If the wells are only 7.5 m from the river (0.5 log), cartridge filters are no longer an option.

Note: if this raw water were in the US it would only have needed 2 log removal credits, in which case bag filters would be permitted for the 15 m case.