



WATER SERVICES
ASSOCIATION OF AUSTRALIA



Manual for the application of

HEALTH-BASED TARGETS FOR DRINKING WATER SAFETY

September 2015



Overview of WSAA

WSAA is the industry body that supports the Australian Urban Water Industry

Its members provide water and wastewater services to over 20 million Australians and many of Australia's largest industrial and commercial enterprises.

The Association facilitates collaboration, knowledge sharing, networking and cooperation within the urban water industry. It is proud of the collegiate attitude of its members, which has led to industry-wide approaches to national water issues. WSAA can demonstrate success in the standardisation of industry performance monitoring and benchmarking, as well as many research outcomes of national significance. The Executive of the Association retain strong links with policy-makers and legislative bodies and their influencers, to monitor emerging issues of importance to the urban water industry. WSAA is regularly consulted and its advice sought by decision makers when developing strategic directions for the water industry.

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Foreword



The importance of safe drinking water to Australia's standard of living is unquestionable and the key role water utilities play in protecting public health by supplying safe water can never be taken for granted. WSAA and its water utility members are committed to providing safe drinking water. The water and health industries have worked collaboratively for many years to improve water quality management in Australia. In the early 2000s, Australia led the world with the introduction of a risk-based approach to drinking water quality management (the Framework).

In 2009, the National Health and Medical Research Council (NHMRC) produced a discussion paper on the introduction of a health-based target (HBT) for microbial water quality in Australia. WSAA recognised that such a step was a quantum leap for the industry but necessary to keep up with the rest of the world. This would address a gap in the current Australian Drinking Water Guidelines (ADWG) around the adequacy of water treatment for pathogen reduction.

WSAA gave conditional support for the concept of an HBT provided there were no:

- unwieldy and impractical regulatory arrangements
- unnecessary public concerns about water safety, given the significant shift in approach and the very high levels of trust customers already have in the safety of drinking water
- investments in infrastructure and subsequent price increases that are not substantiated.

A proactive and collaborative approach with the NHMRC ensured these concerns were addressed and that the approach was well aligned.

The HBT Group of WSAA formed in late 2012. The group's objectives were to:

- assess the impact on utilities if an HBT of one μ DALY was adopted
- work with the NHMRC to obtain a cost effective public health outcome
- ensure a practical operational and regulatory arrangement for the water industry.

This Manual is an important step to enable the water industry to consider adopting an HBT from a position of knowledge. The process of development also helped dispel many of the initial concerns. For example, it is now clear that the HBT should not be considered a pass/fail metric and pathogen monitoring is not essential to characterise source risk.

The HBT group worked closely with WSAA members to see how their well characterised (including through pathogen testing) water supplies should be treated, and compared those requirements to catchment characteristics and microbial monitoring data. The Water Corporation's Surface Water Treatment Manual provided an important reference point. The Corporation has approximately 250 water supplies covering a full range of source water types. The Corporation's manual was conceived and authored originally by Keith Cadee in 2004. It drew from the approaches used in the World Health Organization (WHO) Guidelines for Drinking-water Quality, the USEPA Surface Water Treatment Rule, the NZ Ministry of Health Drinking Water Standards New Zealand and the Australian Guidelines for Water Recycling.

The HBT group retained the overall approach adopted by Water Corporation and broadened it to capture some of the variations and conditions found in other states/territories. Desktop pilot assessments by WSAA members and associated feedback helped to fine-tune the Manual.

THE HBT Committee included:

Richard Walker, Water Corporation (Chair)
Mark Angles, Sydney Water
Melita Stevens, Melbourne Water
Arran Canning, Seqwater
Cliff Liston, Jason West, SA Water
Andrew Ball, WaterNSW
Peter Spencer, Steve Capewell, Rachael Miller, Water Corporation
Dan Deere, Water Futures

Additional support:

Greg Ryan, WSAA	Clairly Lance, Water Corporation
Jennifer Bartle-Smith, WSAA	Meghan Andrews, Water Corporation
Kristy Drzewucki, WSAA	Jill Davies, Water Corporation
Jill Fagan, WSAA	David Halliwell, Water Research Australia
Alan Shea, Western Water	

The preparation of this document has drawn from the experience of WSAA members. WSAA expresses its gratitude to the HBT Working Group, other utilities that piloted and provided feedback on manuals. In particular, we wish to acknowledge the valuable contribution from Richard Walker for leading this initiative and the Water Corporation for providing the start point and sharing its experience.

Pilot evaluations of this tool formed a vital part of its development, and WSAA gratefully acknowledges the following utilities for completing pilot evaluation studies:

Stage 1 Pilots

Barwon Water
Hunter Water Corporation

Stage 2 Pilots

Coliban Water	Gosford City Council
South Gippsland Water	Tweed Shire Council
Goulburn Valley Water	Eurobodalla Shire Council
East Gippsland Water	Taswater
North East Water	Power and Water (NT)
Westernport Water	Icon Water (ACT)
Lower Murray Water	Wide Bay Water Corporation
Gippsland Water	Cairns Regional Council

The Manual remains a living document and will be further improved as new information comes to hand. Regardless of whether HBTs are or not adopted in Australia, the WSAA HBT Manual will be a valuable resource for assessing source risk and the adequacy of water treatment.

Adam Lovell
Executive Director, WSAA

1. Background

The National Health and Medical Research Council (NHMRC) released a discussion paper in 2009 on introducing a health-based target (HBT) for microbial water quality in the Australian Drinking Water Guidelines (ADWG). In December 2011, WSAA's Water Quality Network considered the HBT proposition at their annual meeting. Outcomes from that meeting formed the basis of a subsequent WSAA submission to NHMRC.

The HBT favoured by WSAA is one micro DALY (μ DALY) per person per annum. For further background on Health Based Targets and Disability Adjusted Life Years (DALYs) refer to the fact sheet produced by Water Research Australia <http://www.waterra.com.au/publications/fact-sheets/>

In May 2012, WSAA presented its viewpoint at a NHMRC National HBT workshop in Canberra. The workshop generated many questions concerning the introduction of HBTs. It revealed considerable variation in the understanding of HBTs and preparedness for their introduction across the water industry and health sector.

Despite this variation and uncertainty, there was strong support at the workshop for HBTs from water quality professionals within the water industry. One of the attractions of including an HBT in the ADWG was that it provided an opportunity to introduce a consistent approach to water treatment across Australia.

Recognising its strategic significance, WSAA decided in mid-2012 to take a proactive approach to HBTs. An HBT Working Group was formed to assess the implications of introducing HBTs and to influence NHMRC to obtain a cost effective public health outcome and a practical operational and regulatory arrangement for the water industry.

The application of a Health Based Target in this manual is restricted to consideration of the source challenge and water treatment capability and performance. This is in line with the 2009 NHMRC discussion paper and overseas practice (e.g. WHO and USEPA). The objective of the guidance in this Manual is to ensure that drinking water entering the distribution system meets the HBT.

This Manual should not be interpreted as diminishing the responsibility and obligation for utilities to manage water quality risks from catchment to consumer. The obligation still rests with utilities to prevent deterioration of water quality in distribution systems by implementing appropriate safeguards and practices to maintain a sealed system and manage ingress, cross connection and backflow risks.

1.1 Key Decision-Making Principles

This Manual should only be used to supplement the ADWG rather than replace it. It is important to keep a number of key ADWG decision-making principles in mind when making decisions on drinking water treatment requirements.

Within Australia, the water industry is entrusted with exercising professional judgement in the application of a risk-based approach to drinking water quality management. Many other jurisdictions and many other non-water sector product-delivery industries have instead been forced to adopt higher-cost, compliance-based and prescriptive approaches to product safety management.

Above all, the Guiding Principles set out in the ADWG should be applied. Arguably, the second and sixth of these principles are most directly relevant to this Manual i.e. the multiple barrier principle by definition means that just getting across the line is not sufficient if failure of principal barriers is reasonably foreseeable (see Figure 1).

Figure 1: The Multiple Barrier Principle (ADWG)

The drinking water system must have, and continuously maintain, robust multiple barriers appropriate to the level of potential contamination facing the raw water supply.

The multiple barrier approach is universally recognised as the foundation for ensuring safe drinking water. No single barrier is effective against all conceivable sources of contamination, is effective 100 per cent of the time or constantly functions at maximum efficiency. Robust barriers are those that can handle a relatively wide range of challenges with close to maximum performance and without suffering major failure.

Although it is important to maintain effective operation of all barriers, the advantage of multiple barriers is that short-term reductions in performance of one barrier may be compensated for by performance of other barriers. Prevention of contamination provides greater surety than removal of contaminants by treatment, so the most effective barrier is protection of source waters to the maximum degree practicable. Knowing how many barriers are required to address the level of potential contamination in individual systems is important. This requires a thorough understanding of the nature of the challenges and the vulnerabilities of the barriers in place. In terms of reliability, there is no substitute for understanding a water supply system from catchment to consumer, how it works and its vulnerabilities to failure.

Finally, a robust system must include mechanisms or failsafes to accommodate inevitable human errors without allowing major failures to occur.

The precautionary principle by definition means that a conservative position should be adopted if there is uncertainty (see Figure 2).

Figure 2: The Precautionary Principle (ADWG)

Ensuring drinking water safety and quality requires the application of a considered risk management approach.

The process of keeping drinking water safe is one of risk management. This requires steering a sensible course between the extremes of failing to act when action is required and taking action when none is necessary. Lack of action can seriously compromise public health, whereas excessive caution can have significant social and economic consequences. Corrective action or system upgrades should be undertaken in a considered, measured and consultative manner. Failure to act when required (e.g. failing to shut down a system when disinfection is not working effectively) may lead to an outbreak of waterborne disease. Acting when not required (e.g. issuing a 'boil water' notice when that is not necessary) is usually less severe in the short term, but repeated occurrences waste resources and are likely to cause complacency in the long term, leading to failure to respond when it is truly necessary. Similarly, failing to install a treatment process when required could lead to waterborne disease; however, installing treatment processes that are not required could have a high financial cost and divert funds needed elsewhere.

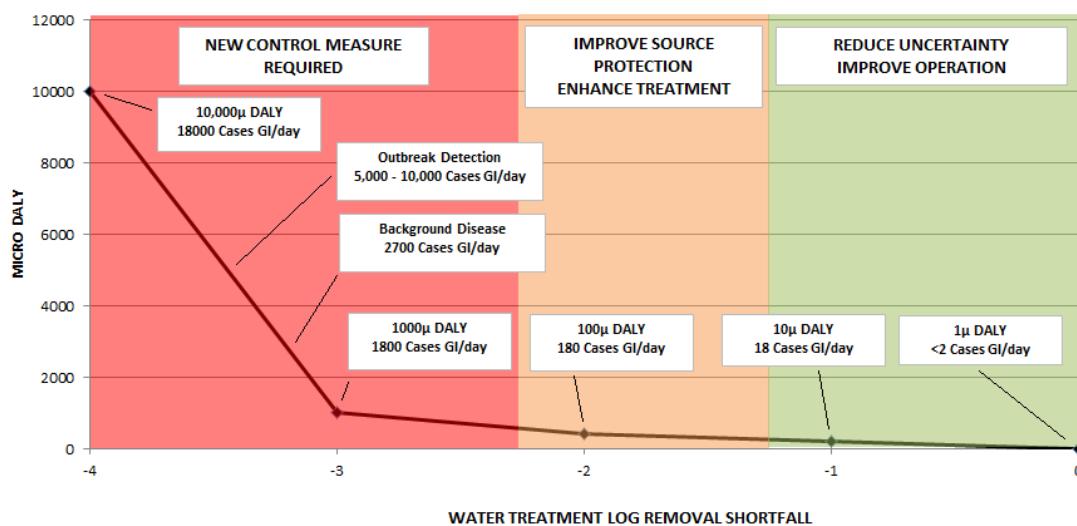
Risk management is about taking a carefully considered course of action. As the obligation is to ensure safe water and protect public health, the balancing process must be tipped in favour of taking a precautionary approach.

In making decisions on treatment requirements, the implementation of additional barriers and redundancy, combined with conservatism where there is doubt, is not considered gold-plating. For something as fundamental as the safety of the public water supply, this is the basic standard of duty.

1.2 Water Safety Continuum

The development of the Water Safety Continuum by the HBT Working Group was important in understanding how an HBT could be pragmatically introduced in Australia (Figure 3). The key point is that the HBT is the objective that should be aimed-for and represented unequivocally safe water. Being marginally below the HBT (see Figure 3 – Log Removal Shortfall) does not mean that the water is necessarily unsafe but rather that there is justifiable opportunity for improvement.

Figure 3: Illustrative example of the Water Safety Continuum for *Cryptosporidium* for a city with 1 M people)



Some key lessons from the development of the continuum include:

- The HBT (e.g. one µDALY) is an aspirational target, which should be achievable for well-designed and operated systems and be the ultimate goal for all water supply systems.
- The HBT is not a pass/fail target.
- Water safety can be considered a continuum, with bands of safety.
- When estimating source challenge and water treatment performance it is acknowledged that there will always be a level of uncertainty. The continuum makes it possible to develop a high level of confidence that water supplied is safe, or indicates the type and urgency of improvement.
- Implementing good-practice water treatment operations is critical to supplying safe drinking water.

1.3 Water Safety Assessment Guidelines

Following positive feedback from a range of stakeholders, the WSAA Board endorsed the HBT Working Group to proceed with development of a manual that allows members to assess scheme performance against an HBT and for this to be trialled by members in a pilot project.

This Manual discusses the approach and assumptions used to quantify the health risk associated with treated drinking water.

2. Water Safety Assessment Overview

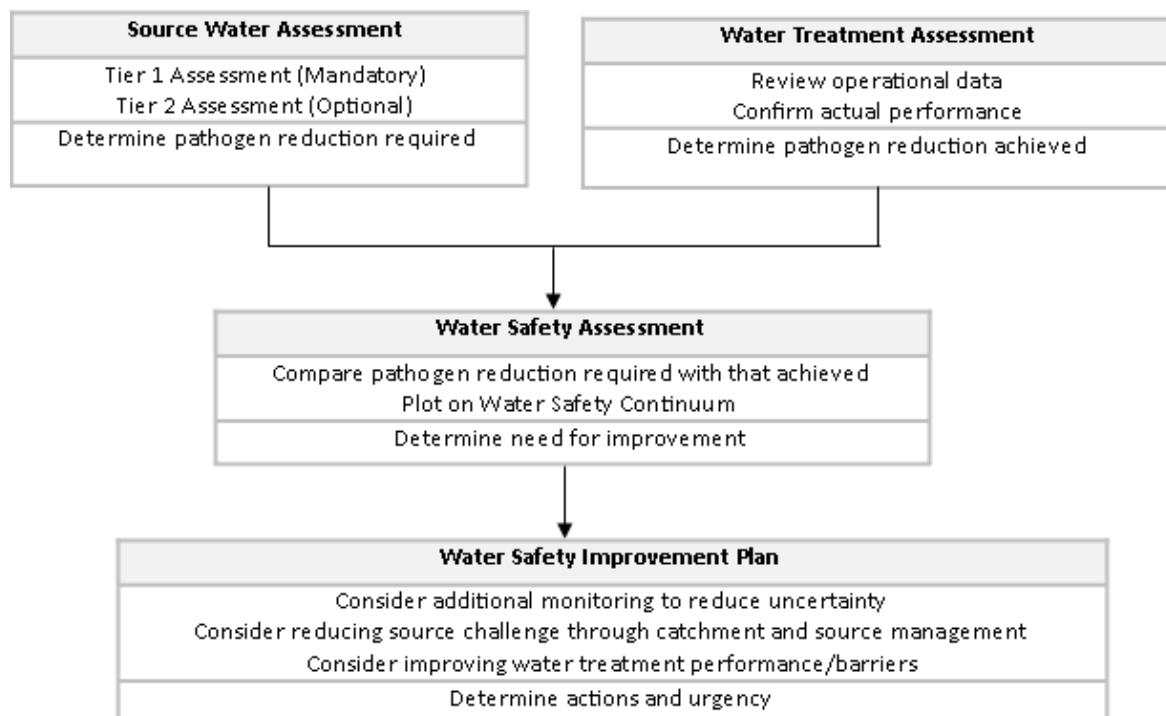
2.1 Background

Since the ADWG Framework for Management of Drinking Water Quality (the Framework) was adopted in 2004, utilities have been required to undertake a source risk assessment plus a water treatment assessment and determine whether the residual risk is acceptable. The proposed HBT assessment process is consistent with the Framework and includes guidance on estimating the quantitative, residual risk through a series of guidelines that are based on internationally accepted standards and which deliver consistency across Australian utilities.

2.2 Process Overview

The water safety assessment process includes a number of elements as shown in Figure 4.

Figure 4: Water safety assessment process



2.3 Source Water Assessment

Within the source water assessment, two tiers of assessment are possible:

1. Tier 1 is mandatory for all sources. Sanitary survey information together with raw water microbial indicator levels is used to place the source challenge into one of four broad vulnerability assessment categories. The pathogen reduction requirements for reference bacteria, viruses and protozoa are described for each of these source categories.
2. Tier 2 is optional and can be used if suitable raw water pathogen data is available. Default assumptions have been developed to allow a quantitative microbial risk

assessment (QMRA) to be performed on the source and the result is used to complement (not replace) the Tier 1 Assessment.

The Tier 1 and 2 assessments are combined to produce the final source assessment and pathogen reduction requirements for bacterial, viral and protozoan reference pathogens.

2.4 Water Treatment Assessment

The water treatment assessment involves assigning estimates of pathogen reduction to the treatment processes deployed at a source. Because pathogen reduction requirements are usually so great, expressed in hundreds to millions-fold, for simplicity, a logarithmic scale is used to describe them. Processes for crediting a pathogen log₁₀ reduction value (LRV) to a treatment process have been developed for all commonly used water treatment processes. To claim the LRV credit a water treatment process must meet defined relevant operational performance. This performance will form the basis of design for new water treatment plants (WTPs). For existing WTPs, records of critical control points (CCPs) should be reviewed to confirm acceptable performance. Adherence to good practice operation of the WTP is also a prerequisite to claiming LRVs.

2.5 Water Safety Assessment

The water safety assessment involves comparing the log reduction required from the source assessment with the log reduction values claimable from the water treatment assessment:

- Where treatment log reduction values > source log reduction required then the HBT (one µDALY) is achieved.
- Where treatment log reduction values < source log reduction required then the HBT (one µDALY) is not achieved.

2.6 Water Safety Improvement Plan

The water safety improvement plan involves planning improvements to improve water safety. Where the HBT is not achieved, the water supplier should undertake improvements. The urgency of these actions is determined by distance from the one µDALY target on the water safety continuum.

The sections that follow provide more detail on how to implement each step in the water safety assessment process.

3. Source Water Assessment – Surface Water

3.1 Tier 1 Source Water Assessment – Surface Water

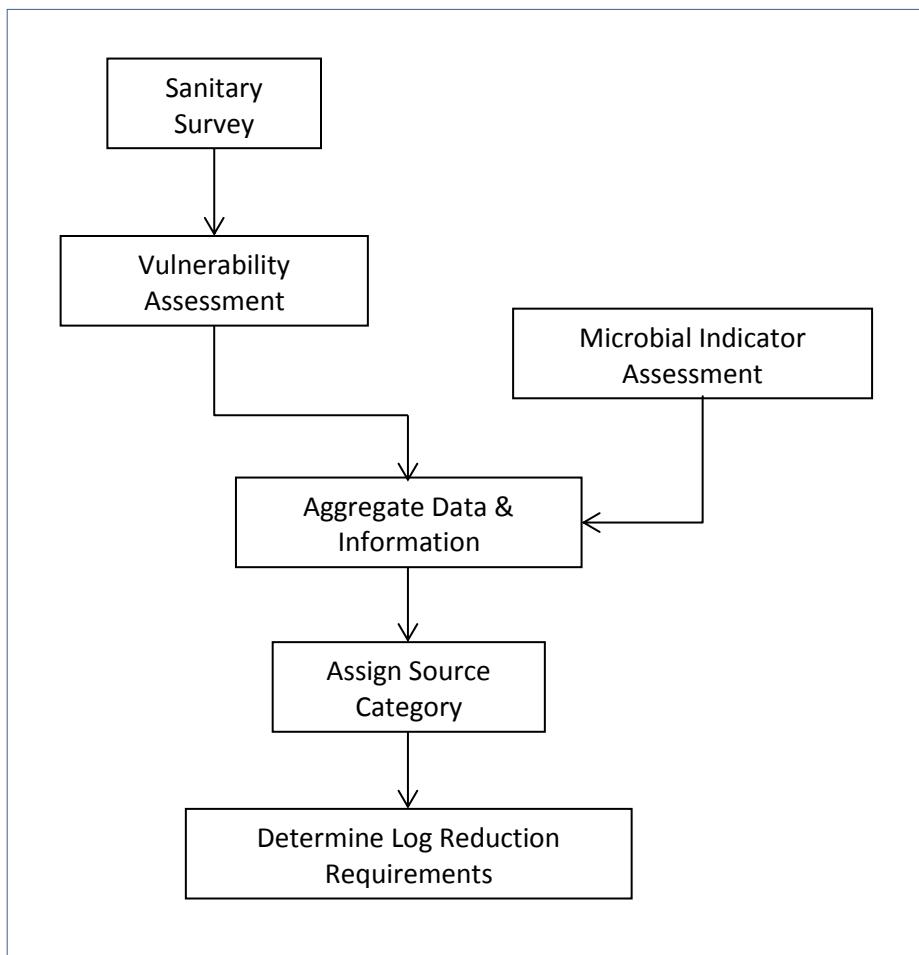
3.1.1 Background

The Tier 1 source water assessment is required for all systems or schemes. It supports the long-standing water quality management requirement to know your system and assists with implementation of Elements 2 and 3 of the Framework.

Properly applied, the Tier 1 source water assessment when matched to the water treatment assessment is adequate to demonstrate achievement of the HBT of one µDALY for many water supply systems without the need for expensive additional monitoring.

The process to be followed in a Tier 1 source water assessment is summarised in Figure 5.

Figure 5: Tier 1 Source Water Assessment – Process Summary



The background and detailed process for undertaking a Tier 1 source water assessment is attached as Appendix A. A summary of the process is detailed below.

3.1.2 Sanitary Survey

The first step in the Tier 1 source water assessment is a sanitary survey of the water supply catchment. Sanitary surveys are commonly used in the Australian water industry following adoption of the Framework and advice on their preparation is not provided in this Manual. The key outputs required from the sanitary survey are an understanding of the following:

- pathogen sources arising from the presence of people and cattle
- intensity of these developments/activities
- proximity to feeder streams and water storage
- presence of *in situ* barriers such as riparian vegetation, fencing and detention in storage.

3.1.3 Vulnerability Assessment

The outputs from the sanitary survey must be aggregated to produce a vulnerability assessment for the source. This step involves placing the source into one of four vulnerability assessment categories according to the table below.

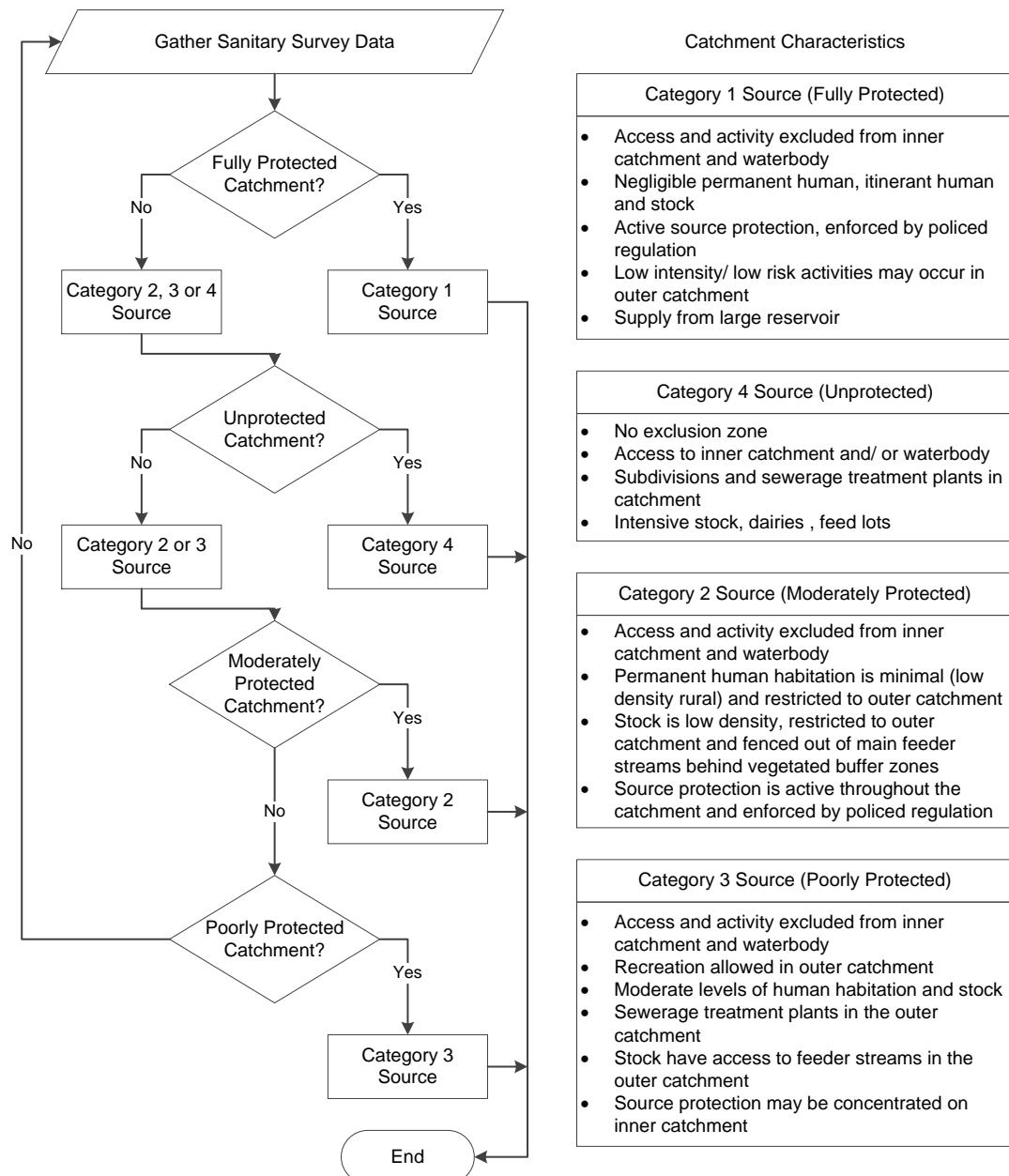
Table 1: Vulnerability assessment categories for drinking water sources

Category	Land use challenge	Intensity	Proximity	Protection
1. Protected catchment	Permanent human	<ul style="list-style-type: none"> • Negligible • No STPs • Minimal, well-managed on-site sewage management systems 	Human settlements and recreation excluded from the whole area of influence, typically the whole hydrological catchment and reservoir	<ul style="list-style-type: none"> • Natural bushland • Protection enforced by policed regulation • Low intensity/low risk activities may be allowed in the outer catchment but active source protection (e.g. ranger patrols) is practiced to ensure negligible contamination risk • Supply is from a large reservoir
	Itinerant human	<ul style="list-style-type: none"> • Negligible • Minimal essential entry for rangers, pest controllers, fire managers • Minimal illegal entry 		
	Stock animals	<ul style="list-style-type: none"> • Negligible • No farms • Limited (controlled) populations of feral animals 		
2. Moderately protected catchment	Permanent human	<ul style="list-style-type: none"> • Minimal • No STPs • Low density rural developments with well-managed on-site sewage management systems 	Human settlements excluded from inner catchment (Typically 2-3km from full supply level)	<ul style="list-style-type: none"> • Bushland inner catchment, low density rural outer catchment • Stock fully fenced out of main feeder streams behind vegetated buffer zones. • Protection enforced by policed regulation • Low level and low intensity activities may be allowed within the outer catchment but active source protection (e.g. ranger patrols) is practiced to minimise contamination risk.
	Itinerant human	Low level, low intensity recreation	<ul style="list-style-type: none"> • Recreation excluded from inner catchment • No recreation close to or on the main water body 	
	Stock animals	<ul style="list-style-type: none"> • Low density • No dairies, feedlots, etc. 	Farming excluded from inner catchment	
3. Poorly protected catchment	Permanent human	<ul style="list-style-type: none"> • Moderate • May include limited sewerered urban areas and STPs within outer catchment 	Human settlements excluded from inner catchment	<ul style="list-style-type: none"> • Medium density rural outer catchment possibly including some limited areas of urban development.

Category	Land use challenge	Intensity	Proximity	Protection
4. Unprotected catchment	Itinerant human	Moderate level of land-based recreation	No recreation on the main water body	<ul style="list-style-type: none"> Any STP effluent is filtered and disinfected and sewer spills are actively minimised. Major sewer overflows or STP failures would lead to a downstream water treatment shut down or boil water alert. Stock may have access to main feeder streams in the outer catchment. Protection enforced by policed regulation within inner catchment.
	Stock animals	<ul style="list-style-type: none"> Medium density No dairies, feedlots, etc. 	Farming excluded from inner catchment	
	Permanent human	<ul style="list-style-type: none"> High Includes sewerered urban areas and STPs 	No exclusion zone	<ul style="list-style-type: none"> Although there are urban inputs, the total quantity of treated sewage or stormwater effluent flowing into the catchment is sufficiently limited that the Phase 2 AGWR are not applicable. Reasonable upper limits are 10% treated sewage effluent and 30% stormwater runoff. Any sewage or intensive agricultural effluent is treated (filtered and disinfected) and spills are actively minimised. Major spills would lead to a downstream water treatment shut down or boil water alert.
	Itinerant human	<ul style="list-style-type: none"> High Intense land-based recreation May include water based recreation on reservoirs/rivers 		
	Stock animals	Intensive Includes dairies, feedlots, etc.		

The vulnerability assessment is most easily completed by a process of elimination as shown below:

Figure 5: Source Vulnerability Assessment Process



3.1.4 Microbial Indicator Assessment

Most utilities routinely collect *E. coli* data on raw water immediately prior to treatment. This data can be used to confirm the vulnerability assessment or help decide between categories when the vulnerability assessment is not conclusive. Table 2 illustrates how the microbial indicator assessment can be used in conjunction with the vulnerability assessment to determine the source category.

Table 2: Comparison of *E. coli* concentration with sanitary inspection category

Source category Vulnerability Assessment Category	Microbial indicator concentration category Maximum <i>E. coli</i> [†] per 100 ml			
	≤ 20 Category 1	> 20 ≤ 2,000 Category 2 & 3	> 2,000 ≤ 20,000 Category 4	> 20,000 Not suitable for drinking
1	Source = Cat 1	Source = Cat 2	Anomalous	Not suitable
2	Source = Cat 2	Source = Cat 2	Anomalous	Not suitable
3	Anomalous	Source = Cat 3	Source = Cat 4	Not suitable
4	Anomalous	Source = Cat 4	Source = Cat 4	Not suitable

[†] Thermotolerant coliforms can be used for this categorisation if *E. coli* data are not available.

If the *E. coli* data and vulnerability assessment plots in a green box then the two assessments are consistent and support each other. This means there is a high likelihood that the source category is correct.

If the data plots in an amber box then this result is still feasible but has a lower degree of confidence. The *E. coli* data and sanitary survey data should be re-examined to achieve better alignment or better understand the reasons for this result. For example, if the microbial assessment indicates a higher level of risk than inferred from the vulnerability assessment then the sanitary survey should be repeated to determine if there are sources of contamination not previously identified.

If the data plots in the red area then this is an anomalous outcome and should not be accepted. The process needs reassessment and pathogen monitoring may be necessary to better define the source risk. In the interim, the precautionary principle should be applied and the most conservative source category option under consideration should be adopted.

3.1.5 Interpreting Results

The following guidance is provided on interpreting the results from the microbial assessment.

Category 1 sources should always have less than 20 *E. coli* per 100 ml in the raw water prior to treatment. If counts exceed 20 *E. coli* per 100 ml then the storage barrier is not effective under all circumstances and the source should be classified as Category 2.

Both Category 2 and Category 3 vulnerability categories can fit into the 20-2,000 *E. coli* per 100 ml microbial indicator assessment category. Therefore, it is the vulnerability assessment that splits them. It is important to note that Category 2 treatment provides only a modest barrier to *Cryptosporidium* so the catchment should have minimal sources of *Cryptosporidium* and those sources should be remote from the water body or streams and well-buffered. Category 2 is typically a well-protected catchment that sees higher *E. coli* counts and turbidity due to a small storage or being run of the river.

Categories 3 and 4 can be split by the microbial indicator assessment. Any source which experiences greater than 2,000 *E. coli* per 100 ml should assign to Category 4 unless an explanation for the possible anomaly can be identified.

If a source is classified as Category 4 by vulnerability assessment, but *E. coli* counts are less than 2000 organisms per 100 ml, then the vulnerability assessment should have priority and the source should be classified as category 4.

The only exception to this is where supply is via a large reservoir (i.e. volume exceeds 1 GL and is greater than the annual average through flow). The source assessment methodology does not provide credits for storage. However, in this case the *E. coli* counts of less than 2000 organisms per 100 ml may indicate the storage barrier is sufficiently effective that the vulnerability assessment can be discounted from Category 4 to Category 3. This discounting should only occur if there is convincing evidence that the storage barrier is effective (i.e. 2 log reduction of protozoa) under all circumstances.

Such evidence might include:

- a) Event sampling for *E. coli* after extreme rainfall events confirms counts are less than 2000 *E. coli* per 100 ml.
- b) When Dam storages are low and raw water counts are less than 2000 *E. coli* per 100 ml after heavy rainfall.
- c) Hydrodynamic modelling of the reservoir indicates water age is always more than 3 months at the reservoir outlet under all scenarios.

3.1.6 Water Treatment Assessment

The pathogen reduction requirements recommended for each source category are summarised in Table 3. The background to the development of this table is outlined in Appendix B. These are default starting requirements that may need to be adjusted up or down based on sanitary survey or sampling data.

Table 3: Recommended minimum pathogen log reduction requirements

Source water category	Minimum pathogen log reduction required		
	Bacteria	Viruses	Protozoa
1	4.0	0	0
2	5.0	3.0	2.5
3	5.0	4.0	3.5
4	6.0	6.0	5.5

3.1.7 Typical Treatment

Typical treatment processes for each source category are given in Table 4.

Table 4: Example of treatment recommendations and typical treatment trains for each source category

Category	Min Pathogen LRV Recommended			Typical Treatment Train
	Bacteria	Viruses	Protozoa	
1	4.0	0	0	Chlorination (possibly following clarification)
2	5.0	3.0	2.5	Direct filtration ¹ Chlorination
3	5.0	4.0	3.5	Conventional treatment ² Chlorination
4	6.0	6.0	5.5	Conventional treatment ² . UV disinfection Chlorination
Potable reuse	Refer to the stormwater and sewage potable reuse guidance given in the Phase 2 Australian Guidelines for Water Recycling series for water sources that have in excess of the stormwater and/or treatment sewage inflows tolerable for a Category 4 water source.			

Notes: ¹ Direct filtration means coagulation, flocculation and filtration.

² Conventional treatment means coagulation, flocculation, sedimentation and filtration.

3.1.8 Judgement Required

There is great diversity across Australia in terms of water sources and catchment protection. Accordingly, the advice provided in this Manual is general rather than specific. A Tier 1 source water assessment alone should produce an accurate result and is usually more conservative than if pathogen data is used to refine the source risk assessment. However, the assessment will require considerable judgement when choosing between source categories, particularly for borderline situations. The assessor needs to be mindful that the objective is to achieve appropriate treatment for the source pathogen challenge.

The water treatment section of this Manual provides detailed information on water treatment performance. Note that the pathogen reduction performance increases in steps to match Category 1 to 4 sources. Knowledge of these steps can be helpful when trying to finalise the source category. The following points are useful to note in finalising decisions on categories.

Category 1 sources have negligible sources of contamination from humans and stock animals. This means treatment is not required to deal with human infectious viruses or protozoa. Contamination by bacteria from native animals and birds is unavoidable. However, natural inactivation, dilution and settling in the large storages associated with a Category 1 source means *E. coli* levels in the raw water are less than 20 units per 100 ml. This is indicative of a very low level of bacterial contamination, easily dealt with by chlorination alone. However, chlorination at the doses (concentration x time, or Ct) realistic for bulk water treatment will not inactivate *Cryptosporidium* so it is critical that the sanitary survey confirms negligible sources of protozoan pathogens.

Category 2 sources have minimal sources of contamination. There may be some low density housing or low intensity stock grazing in the outer catchment. There is therefore a risk of low levels of human infectious viruses, bacteria and protozoa in the raw water. Catchment activities and/or the absence of a large storage mean Category 2 sources typically experience *E. coli* in the raw water in the range

20–2000 per 100 ml. Filtration is required to remove protozoa, viral and bacterial pathogens, followed by chlorination. However, the performance requirements for Category 2 filtration provide only modest removal of protozoa, so it is important that the sanitary survey confirms minimal sources of protozoa and that these are in the outer catchment and buffered from feeder streams.

Note that where a large storage barrier is absent, filtration is usually required to reduce turbidity to ensure effective disinfection by chlorine and/or UV disinfection.

Category 3 sources typically have moderate sources of faecal contamination. For example, there may be rural or urban subdivisions, extensive stock grazing on cleared pastures and catchment recreation. However, all these activities are confined to the outer catchment and there are effective measures in place to protect the inner catchment and water body from contaminating activities. *E. coli* levels in the raw water typically fall in the range 20 – 2000 per 100 ml. The pathogen risk from a Category 3 source requires filtration with a higher performance specification than that required for Category 2 sources to ensure sufficient reduction of protozoa prior to chlorination.

Category 4 sources are typically unprotected with high contamination risk from humans (urban developments), stock (intensive grazing) and industry (piggeries, dairies). The inner catchment is not protected and recreation may occur throughout the catchment and on the water body.

The absence of a source protection barrier and often a storage barrier, means a double treatment barrier is required to not only achieve the required log credits but also the multiple barriers to contamination required by the ADWG. Typical treatment is filtration followed by ultra violet disinfection followed by chlorination

3.2 Tier 2 Source Water Assessment – Surface Water

3.2.1 Background

The Tier 2 assessment involves the use of source water pathogen data to confirm or refine the pathogen risk for sources that are assessed as Category 4 by the Tier 1 assessment. Undertaking QMRA on sources that rate as Category 2 or 3 based on the Tier 1 risk assessment is not warranted because:

- the good practice operation of conventional and direct filtration plants is sufficient to meet the required LRVs for these source categories
- multiple barriers are present to reduce risk, for example, catchment protection and storage and hence there is typically no need for capital upgrades to treatment to supply additional barriers.

While pathogen monitoring is time consuming and expensive it may be justified to better define the treatment requirements for a Category 4 source. This will assist in informing options for treatment planning and operations. The background and detailed process for undertaking a Tier 2 source water assessment is attached at Appendix C. A summary of the process is provided in the following text.

3.2.2 Reference Pathogens

The HBT approach uses protozoan, bacterial and viral reference pathogens. In Australia, source water monitoring data is largely confined to *Cryptosporidium* (protozoan reference pathogen) and *Giardia*. Given the difficulty in determining the concentration of reference viruses and bacteria in environmental waters, this situation is unlikely to change in the near future. Accordingly, this Manual addresses only *Cryptosporidium*, but the principles can be applied to other pathogens should appropriate data become available in the future. Pending this, the Tier 1 source water assessment should be used to establish water treatment requirements for bacteria and viruses.

3.2.3 Approach

The Tier 2 approach is based on the characterisation of annual risk (Component 1) that includes events (Component 2). Both components need to be assessed to complete the Tier 2 assessment. The two component approach is based on the observation that in some cases, high risk events tend to be sporadic with relatively lower risk conditions prevailing for the majority of the time. This approach provides a wider range of options to operators while better describing risk.

3.2.4 QMRA

A full quantitative microbial risk assessment (QMRA) or Tier 2 analysis can be undertaken in those situations where greater definition of the pathogen risk is required. It is recommended that Tier 2: Analysis of Pathogen Data is only undertaken for Category 4 sources. It may also be considered for Category 3 sources that are run of river and the capacity for pathogen inactivation through storage is reduced.

A quantitative microbial risk assessment (QMRA) can be undertaken where suitable *Cryptosporidium* monitoring data is available. An adequate level of expertise is required to undertake a QMRA. Furthermore, in order to ensure a meaningful QMRA outcome, the quantity and quality of data is essential, as described in Appendix C.

It needs to be appreciated that any analysis will be limited by uncertainty, namely:

- the inability to fully determine the identity or human infectivity of pathogen isolates
- the uncertainty of recovery from environmental samples
- the uncertainty of pathogen monitoring data that only reflects concentrations at a fixed spatial and temporal point in a relatively small volume, against a highly variable true concentration.

A large number of estimates and assumptions are necessary to complete the QRMA. Table 5 lists default assumptions for use in the absence of site-specific information. The table includes some terminology related to protozoan pathogen testing and is intended to support suitably expert interpretation.

Table 5: Summary of recommended default QMRA assumptions

Parameter	Default Calculation/Assumption	Comments
<i>Cryptosporidium</i> concentration	Arithmetic mean of confirmed oocysts by DAPI and/or DIC. Both methods must be used. Adjust for recovery and volume	Cells that are negative for both DAPI and DIC are not confirmed oocysts. Use the presumptive IFA count if the confirmed count is not reported. Avoid double counting confirmed oocysts when using DAPI/DIC.
Human pathogenicity	Assume 100% <i>C. parvum</i> or <i>C. hominis</i> unless it can be shown otherwise	Default: use 100% human-pathogenic oocysts. Reduction in the 100% human pathogenicity criteria can be justified through extensive genotyping. Note: 100% human-infectivity would be assumed for fresh sewage samples in water recycling projects.

Parameter	Default Calculation/Assumption	Comments
Infectivity	<p>For Cat 4 sources and Cat 3 sources that are run of river assume 30% infectivity, unless it can be shown otherwise.</p> <p>For Cat 2 & 3 surface water sources assume 10% infectivity, unless it can be shown otherwise.</p>	<p>Source Category based on outcomes of Tier 1 semi-quantitative risk assessment</p> <p>Default: use 30% infectivity e.g. risk inputs are close to abstraction points, run of river sources, high human impacts in close proximity to abstraction points. Assumes Tier 2 being carried out for Cat 4 sources and Cat 3 run of river sources.</p> <p>Default values can be discounted based on extensive infectivity testing.</p>
Mean (Component 1)	Arithmetic mean of a dataset that contains either 12 positive samples or a minimum of 100 samples collected over at least one year, whichever comes first	<p>Do not include results from untreatable events when water is not supplied.</p> <p>Include maximum event oocyst concentrations as a point value and one of the twelve positive samples.</p> <p>Maintain sampling with a rolling average. Frequency of sampling must be linked to an annual review of the Tier 1 assessment but monthly sampling is advised.</p>
Maximum (Component 2)	Use maximum oocyst concentrations from each of at least 2 events and preferably more events as a point value in the Tier 2 monitoring dataset	<p>Individual event samples are discrete rather than composite.</p> <p>Events are described temporally.</p> <p>Sampling is based on appropriate triggers determined by Tier 1 assessment.</p> <p>Event program to include at least one high risk period related to the risk sources identified by the Tier 1 assessment.</p> <p>Ongoing event monitoring is required.</p>
Non-detects	Non-detects to be replaced with zero (0)	More sophisticated statistical techniques, expertly applied, can be used in some cases and this may be worthwhile for borderline situations using stochastic QMRA.
Exposure per event	1 L	<p>Based on the estimate of drinking cold drinking water (Mons <i>et al.</i>, 2005).</p> <p>Note that in northern Australia, exposures closer to 1.5 or 2 L are more likely to be correct.</p>
Probability of infection	0.2	WHO Guidelines for Drinking-water Quality (2011). This is not the most conservative value available but is considered by the WHO expert group (Medema <i>et al.</i> , 2009) to be the most appropriate for drinking water.
Proportion of infection leading to illness	0.7	WHO Guidelines for Drinking-water Quality (2011)
DALYs per <i>Cryptosporidium</i> case	2.46×10^{-3}	As described in 'Establishing Australian Health based targets for microbial water quality' (Leder <i>et al.</i> , 2012)
Proportion of population susceptible to illness	1	Assume 100% of population is susceptible to illness

3.2.5 Calculation of Log Reduction Requirements

Table 6 illustrates how the log reduction required for water treatment can be calculated, once an assessment has been made of the concentration of *Cryptosporidium* oocysts in the source water.

Table 6: Example of source water QRMA and required treatment log reduction calculation

	Factor	Values	Notes	Formula
a	Oocysts per L in source water (IFA positive)	0.273	A	
b	Exposure per event (litres)	1	B	
c	Dose per event (orgs)	0.273		a x b
d	Number of events per year	365		
e	Dose per year	99.645		c x d
f	Probability of infection per organism	0.2	C	
g	Probability of infection per year	19.929		e x f
h	Proportion of infection leading to illness	0.7	D	
i	Probability of illness per year	13.950		g x h
j	DALYs per case	0.00246	E	
k	Proportion of population susceptible to illness	1	F	
l	Source water DALYs per person per year	3.43×10^{-2}		i x j x k
Required treatment log reduction		4.5	G	$\log(l/10^{-6})$

Notes:

A arithmetic mean = 0.273 oocysts/L from 100 weekly routine samples over at least one year*, non-detects as '0', presumptive IFA count (only DAPI used for confirmation) adjusted for volume and recovery, 100% human pathogenicity, 30% infectivity based on sanitary survey.

B 1L of drinking water consumer per day

C WHO Guidelines for Drinking-water Quality (2011)

D WHO Guidelines for Drinking-water Quality (2011)

E As described in Establishing Australian Health based targets for microbial water quality (Leder *et al.*, 2012)

F Assume 100% of population is susceptible to illness

G Required treatment log reduction to meet one µDALY

* Tier 1 = Category 4 source. This dataset contains oocyst concentrations from fourteen positive samples with three of the data points representing the maximum oocyst concentration from each of three events. The data set was collected under non-drought conditions (2011-2013).

3.2.6 Final Comments on Pathogen Monitoring

Some utilities have been monitoring *Cryptosporidium* for many years and recommend caution before embarking on a pathogen monitoring program. Apart from the sources of uncertainty outlined in the introduction, Australian experience is that Category 3 run of river supplies and even some 'high risk' or Category 4 sources may only return a low percentage of positive samples.

It is important to note that there is a small risk that a data set of even 100 samples could contain no positive samples. In this case it would be impossible to undertake a QMRA and hard to justify the expense of pathogen monitoring. As a result, utilities embarking on a pathogen monitoring program to reduce uncertainty of the Tier 1 source risk assessment need to make this decision with due consideration.

This situation emphasises the need for expert interpretation of pathogen results and their statistical analysis as stated in 3.2.3.

It is possible to have no or a very low number of *Cryptosporidium* detections from catchments carrying obvious sources of pathogens. Such monitoring outcomes should not justify classifying the source as no or low risk. To counter this scenario this Manual requires the Tier 1 and Tier 2 assessments to support each other. Where this is not the case, further investigation should be carried out to better understand the system. As a further safeguard the Manual allows the vulnerability assessment (Tier 1) to be discounted to the bottom of the water treatment band indicated by the Tier 1 vulnerability assessment i.e. Category 4 Sources can be discounted down to 3.5 log reduction for protozoa but no further.

3.2.7 Final Source Water Assessment

The final source assessment requires integration of the information from the Tier 1 and Tier 2 Assessments. It is quite likely that the QMRA will indicate a lower level of *Cryptosporidium* challenge than expected from the Tier 1 assessment since some conservatism was built into the Tier 1 process. Before adopting the lower risk, it is necessary to undertake some due diligence checks such as the following:

- Was the sampling period representative or unusual (e.g. drought)? A larger dataset over a longer time-period will provide more confidence than the minimum prescribed; particularly as the Australian climate is variable e.g. droughts in Australia often last much longer than two years.
- Cross check with the sanitary survey. Did the sampling period capture events of concern such as sewerage or wastewater treatment system overflows or bypasses? The sanitary survey may have correctly identified major pathogen sources but if, for example, stock numbers were lower than usual (e.g. due to market or drought conditions) or wastewater containment systems were working well, then possible pollution events may have been missed. That does not mean those pollution events will not occur in the future.

Assuming these checks provide confidence in the QMRA result then *Cryptosporidium* treatment requirements can be discounted to the LRV value indicated by the QMRA with a limit of the bottom of the Category 4 treatment band (3.5 log reduction).

In order to be consistent with the longstanding guiding principles of the ADWG, the precautionary principle should apply. Where there is uncertainty with the source risk assessment the more conservative from the plausible options should be adopted. In all the cases, the final assessment should be clearly justified and documented.

4. Source Water Assessment – Groundwater

4.1 Overview

The process for groundwater source water assessment is similar to that for surface water, with two Tiers.

Tier 1 is mandatory for all sources. Sanitary survey information and source water microbial indicators are used to determine if ground water is under the direct influence of surface water.

Tier 2 is optional but can be used if suitable raw water pathogen data is available. In this case, a QMRA can be performed on the source and the result used to complement (not replace) the Tier 1

assessment. The Tier 1 and Tier 2 assessments are combined to produce the final source water assessment and hence the log reduction requirements for bacteria, virus and protozoa as per the surface water assessment.

4.2 Tier 1 Assessment Overview - Groundwater

The primary objective of the Tier 1 assessment is to determine if the groundwater extracted is under direct influence of surface water. As subterranean processes are difficult to confirm, the Tier 1 process relies on building a body of evidence about water quality from observations in the catchment and raw water quality together with the knowledge of bore configuration and the hydrogeological characteristics of the aquifer.

4.2.1 Sanitary Survey

The sanitary survey should cover aspects such as:

- hydrogeology - nature and thickness of strata, transmissivity (flux), recharge areas
- bore characteristics - depth to groundwater, depth to bore pump, drawdown characteristics
- pathogen sources - point and diffuse
- well-head protection - sealing, fencing, flooding.

4.2.2 Vulnerability Assessment

Groundwater NOT under the influence of surface water will typically have the following characteristics:

- protected headworks (fenced, above flood level)
- bore sealed from ingress (including flood events)
- depth to groundwater >10 m
- depth to bore pump >15 m
- overlying material homogenous, sand, gravel
- TDS does not decrease following rainfall, high flow or floods
- turbidity does not increase following rainfall, floods etc.

4.2.3 Microbial Indicator Assessment

Where the vulnerability assessment indicates the source is not under the influence of surface water then this can be confirmed by raw water testing if it shows zero *E. coli* detected in raw water samples over a long period, including event-based samples.

4.3 Tier 2 Assessment

A Tier 2 assessment can be carried out where pathogen data is available. The process is the same as that for surface water.

4.4 Water Treatment

Where the source water assessment indicates the groundwater is not under direct influence of surface water then the only treatment required is chlorination to provide a barrier to contamination in the bulk water/distribution system and to provide a final pathogen barrier to support the groundwater protection barriers under the multiple barrier principle of the ADWG.

4.5 Groundwater Under the Influence of Surface Water

Where the source water assessment indicates the groundwater is under the direct influence of surface water (or there is uncertainty) then the source should be assessed as if it were surface water. Experience from around Australia indicates that *E. coli* concentrations in groundwater under the influence of surface water are often lower than expected for similarly classified surface water. For example, the maximum *E. coli* concentrations from a Category 4 surface water source are expected to be >2000 per 100 ml. However, groundwater sources under the influence of surface water from Category 4 catchments often show maximum *E. coli* concentrations much less than 2000 per 100 ml. This means the microbial indicator assessment used to confirm the vulnerability assessment for surface waters does not apply well to groundwater under the influence of surface water and the classification must be based on the vulnerability assessment alone. It is considered that lower *E. coli* concentrations indicate some natural filtration and attenuation is occurring in the aquifer.

A reasonable question arises as to whether some credit should be applied to the treatment requirements in such cases. Ideally such a credit would be applied. Application of a credit where groundwater is under the influence of surface water is problematic due to the difficulties in estimating attenuation and assessing the reliability of such attenuation. Fractured rock and karstic limestone aquifers are particularly problematic and caution should be exercised before discounting the risk for these sources. Viruses in particular are poorly indicated by *E. coli* in groundwater systems. Additionally, without undertaking very detailed site-specific studies, it is difficult to estimate the level of attenuation and credit that should be applied.

However, in pragmatic acknowledgement of the broad body of evidence of at least some attenuation being provided in many circumstances, it is recommended that as a default, groundwater sources under the influence of surface water classified as Category 3 and Category 4 by the vulnerability assessment may have their water treatment requirements discounted by one treatment level providing the following conditions are met:

The maximum *E. coli* result is ≤ 20 per 100 ml (noting that this represents the best microbial assessment category) and:

- a minimum of 5 years regular raw water sampling is available from each bore
- the sampling frequency should preferably be weekly and must cover any high risk periods that represent treatable events
- that there is no other evidence of fresh, un-attenuated surface water ingress, such as regular turbidity monitoring during and after storm events revealing no turbidity spikes above 5 NTU; that disinfection achieves free chlorine to a suitable Ct, (noting that free chlorine is highly effective on viruses), or a, virucidal validated UV dose.

Category 1 and 2 sources cannot be discounted.

For sources with a final Category of 2 and 3, the requirement for the treatment train to include a removal process is waived in recognition of the natural filtration *is* occurring in the aquifer provided there is no other evidence of fresh, un-attenuated surface water ingress, such as regular turbidity monitoring during and after storm events revealing no turbidity spikes above 5 NTU. Thus, protozoa log credits may be met by UV alone.

5. Water Treatment

5.1 Background

Many water treatment processes are used to remove and inactivate pathogens. Their performance is often quoted as a log reduction value (LRV) which assists comparison between processes. To achieve the nominal LRV a water treatment process must be operated within strict performance envelopes. This envelope typically involves identifying one or more parameters that can be continuously measured (such as filtrate turbidity) and a performance target for those parameters. Often a time-based criterion is included relating to the duration that any deviation can be tolerated. A common example in water filtration plants is to continuously monitor filter effluent turbidity against a target of less than 0.15 NTU that must be achieved for 95% of the time within any one month and where that turbidity must not exceed 0.3 NTU, measured at the outlet of individual filters.

The ADWG Framework elements three and four, and chapters nine and ten of the ADWG, provide further and more detailed guidance on setting and monitoring critical limits and target criteria.

A summary of the LRVs recommended, together with default guidance on associated performance criteria, is provided in Table 7 for filtration processes and Table 8 for other common types of water treatment. The background to the development of the default LRVs adopted in this Manual are provided in Appendix D.

5.2 Default LRV

The LRVs quoted in this Manual are based on a review of other guidelines from the USA and NZ as well as the ADWG. For media filtration a key feature of this Manual is to require monitoring of filtrate turbidity at the outlet of individual filters (rather than combined) in all cases. This is based on the advice of experienced water treatment practitioners.

Where individual filter monitoring is not currently available, utilities can report combined filtrate performance for an interim period while arrangements are made for the monitoring of individual filters.

It is intended that the LRVs in this Manual be used as default values. This means utilities can claim the LRV without on-site validation. However, such validation would be required if an LRV greater than the default value is claimed or for alternative technologies not listed in Tables 7 and 8.

Table 7: Default recommended LRVs for conventional water treatment

Process	Log reduction value			Process critical limits
	Bacteria	Virus	Cryptosporidium	
Coagulation, Flocculation & Dissolved Air Flotation	1.0	1.0	1.0	Under-float or settled water turbidity < 2 NTU for 95% of month. Alternate target is 70% reduction in turbidity on average over the month where raw water turbidity is very high, the key being consistent quality pre filtration. ⁽¹⁾
Coagulation, Flocculation & Sedimentation	1.0	1.0	0.5	
Direct Filtration ^(2 & 3)	1.0	1.0	2.5	Individual filter turbidity ≤ 0.3 NTU for 95% of month and not > 0.5 NTU for ≥ 15

Process	Log reduction value			Process critical limits
	Bacteria	Virus	Cryptosporidium	
				consecutive minutes Combined filtrate turbidity < 0.2 NTU for 95% of the month and not > 0.5 NTU for 15 consecutive minutes. ⁽⁵⁾
	1.0	1.0	3.0	Individual filter turbidity ≤ 0.2 NTU for 95% of month and not > 0.5 NTU for ≥ 15 consecutive minutes
	1.0	1.0	3.5	Individual filter turbidity ≤ 0.15 NTU for 95% of month and not > 0.3 NTU for ≥ 15 consecutive minutes
Conventional Treatment ^(3 & 4)	2.0	2.0	3.0	Individual filter turbidity ≤ 0.3 NTU for 95% of month and not > 0.5 NTU for ≥ 15 consecutive minutes Combined filtrate turbidity < 0.2 NTU for 95% of the month and not > 0.5 NTU for 15 consecutive minutes. ⁽⁵⁾
	2.0	2.0	3.5	Individual filter turbidity ≤ 0.2 NTU for 95% of month and not > 0.5 NTU for ≥ 15 consecutive minutes
	2.0	2.0	4.0	Individual filter turbidity ≤ 0.15 NTU for 95% of month and not > 0.3 NTU for ≥ 15 consecutive minutes
Second Stage Filtration ⁽⁶⁾	1.0	1.0	0.5	Individual filter turbidity ≤ 0.15 NTU for 95% of the month and not > 0.3 NTU for ≥ 15 consecutive minutes

- (1) Target only, not a critical limit. Log credits for pre-treatment can only be claimed when followed by filtration
 - (2) Direct filtration means coagulation and flocculation followed by granular media filtration
 - (3) Includes GAC/BAC media filters when used as primary filters
 - (4) Conventional treatment means coagulation, flocculation and sedimentation followed by granular media filtration
 - (5) LRVs for combined filtrate monitoring apply for a grace period while arrangements are made to monitor individual filters
 - (6) Secondary filtration can consist of rapid sand, dual media, GAC or other fine media in a separate stage following granular media filtration. The treatment train must contain chemical coagulation before the first filters and both filter stages must treat all the water flow continuously.
- NB The LRV can only be claimed when:
- a. The WTP is operated in accordance with good practice principles
 - b. Process performance is monitored with on line continuous monitoring

Table 8: LRVs for other water treatment processes likely to be used in Australia

Process	Log reduction value			Process critical limits	
	Bacteria	Virus	Cryptosporidium		
Micro-Filtration (MF) ⁽¹⁾⁽²⁾	3.0	1.0	3.0	Individual filter turbidity ≤ 0.1 NTU for 95% of month and not > 0.15 NTU for ≥ 15 consecutive minutes	
				Membrane Integrity Test (MIT) to manufacturer's specification for the required LRV and/or certified to a recognised standard	
Ultra-Filtration (UF) ⁽¹⁾⁽²⁾	3.0	2.5	3.0	Individual filter turbidity ≤ 0.1 NTU for 95% of month and not > 0.15 NTU for ≥ 15 consecutive minutes	
				Membrane Integrity Test (MIT) to manufacturer's specification for the required LRV and/or certified to a recognised standard	
Disinfection					
Chlorination	4.0	4.0	0	Ct > 15 mg/L min with pH < 8.5 at all water temps Feed water turbidity < 1.0 NTU ⁽³⁾	
Chloramination	2	2	0	Ct > 857mg/L min at pH 6-9, water temperature 5°C	
	4	4	0	Ct > 1988mg/L min at pH 6-9, water temperature 5°C	
Ultraviolet Disinfection ⁽⁴⁾	4.0	0.5	4.0	UV dose > 40 mJ/cm ²	Feed water: Turbidity < 1.0 NTU ⁽³⁾ UVT% > Manufacturer's specification
	4.0	1.0	4.0	UV dose > 60 mJ/cm ²	
	4.0	4.0	4.0	UV dose > 190 mJ/cm ²	
Ozonation	2	2	0	Ct > 0.6mg/L minute at pH <8, turbidity < 1NTU water temperature 5°C	
	4	4	0	Ct > 1.2 mg/L minute at pH <8, turbidity < 1NTU water temperature 5°C	

- (1) Membrane Integrity Test should be daily and automated. An alarm limit should be set nominally 10-20% prior to the target turbidity to initiate operational intervention (e.g. pressure decay test to check membrane integrity). Failure of the critical limit should result in immediate shutdown of the relevant membrane unit.
- (2) LRVs are nominal. Membranes can be purchased for local conditions with factory validation. The MF units should have certification to a recognised standard confirming pathogen reduction capability with the USEPA 2005 Membrane Filtration Guidance Manual being the current global industry standard of practice. By agreement with the local Health Department it may be possible to claim higher LRVs from suitably validated membrane WTPs.
- (3) See Table E5 in this Manual
- (4) Feed water quality for both Chlorination and UV disinfection should have turbidity of less than 1 NTU unless a higher value can be validated.
- (5) LRVs are nominal. UV dose should be based on a Reduction Equivalent Dose (RED) for *Cryptosporidium* or viruses, as applicable. The UV units should have certification to a recognised standard confirming RED capability with the USEPA 2006 UV Disinfection Guidance Manual being the current global industry standard of practice. By agreement with the local Health Department it may be possible to claim higher LRVs from suitably validated UV WTPs

5.3 Good Practice Design

There are several core principles that must be applied when selecting processes to match a source risk level including:

- The sum of process unit LRVs from the LRV tables above shall be equal to or greater than the minimum log reduction required based on source risk assessment.
- Final disinfection shall always be included in the water treatment process selection.
- No one process unit shall be given an LRV >4.0 to avoid excessive reliance on any single barrier.
- Treatment trains for Category 2 - 4 sources shall include at least one physical pathogen removal processes for protozoa, bacteria and virus (e.g. filtration) in addition to any final disinfection for further pathogen reduction.

5.4 WTP Performance Monitoring and Data Management

In Tables 7 and 8 the parameter which must be achieved for 95% of the month should be considered the target. The parameter which must not be exceeded for more than 15 minutes should be considered the critical limit. The reference to 15 minutes in Tables 7 and 8 is to provide an operational buffer to prevent false alarms and provide the opportunity for a quick investigation before initiating an incident response. It should not be regarded as sanctioning the deliberate operation of a CCP in exceedance of its critical limit. For further information on setting targets and limits refer to Chapters 9 and 10 of the ADWG and Section 7 of this Manual.

For continuous monitoring of parameters that are used to assess performance against process targets and critical limits, the following practices are recommended:

- If continuous data is sampled as a series of discrete values for compliance measurement, the sampling period should not exceed 1 minute. If plant operation is discontinuous, the data sampling period should be adjusted such that, in general, there are at least 150 data points to represent one day of production.
- Continuous monitors must be calibrated at least as frequently as recommended by the equipment suppliers and records should be kept of all maintenance and calibration checks.
- For reporting and performance assessment purposes, the monitoring data set should be cleansed to ensure that it excludes monitoring during the period that the process unit was off-line and not supplying water, and when the instrument was being calibrated or otherwise maintained.

5.5 Good Practice Operation

It is important not to focus on CCP performance to the detriment of good practice operation of the WTP. Assuring pathogen removal also requires sound management of filters, backwash effluent, instrumentation, operator training and a host of other issues. These have recently been documented in the WaterRA publication ‘Good Practice Guide to the Operation of Drinking Water Supply systems for Management of Microbial Risk’.

6. Water Safety Assessment and Improvement Plan

6.1 Water Safety Assessment

This step involves comparing whether the log reduction requirements determined from the source assessment are less than or equal to the log reduction achieved by the water treatment plant. If so, then it is probable that the HBT of one μ DALY is being achieved. If not, then one μ DALY will not be achieved. The difference between the log reduction required and achieved can be plotted on the water safety continuum to give a visual indication of the public health implications and the urgency for action.

6.2 Water Safety Improvement Plan

Where the water safety assessment indicates that the HBT of one μ DALY is not being achieved, the water supplier needs to prepare and implement a Water Safety Improvement Plan. The nature and timing of improvements will be influenced by where the scheme plots on the water safety continuum.

6.2.1 Schemes in the Safe Sector of the Continuum

Schemes that plot in the safe sector of the continuum should be in no danger of an imminent public health incident. These schemes are typically addressing a 0.5 – 1 log shortfall in scheme performance over time. That gap could be either an uncertainty or a genuine gap in source protection or treatment.

There is often some uncertainty about the source risk assessment and water treatment performance (particularly the first time these assessments are undertaken). Since the uncertainty is likely to only be of the order 0.5 – 1 log it is reasonable for the utility to undertake targeted information gathering to reduce this uncertainty and revisit the water safety assessment within a year.

Where the shortfall is related to an excessive source water challenge relative to the treatment capability the utility can pursue reducing source challenge and/or improving water treatment performance. Reducing source challenge can be achieved in many ways including:

- not operating the source in periods of high challenge if an alternative is available
- tightening source protection by better policing of existing statutes or introducing tighter controls
- improving *in situ* catchment barriers such as vegetation and fencing
- implementing good practice to reduce contamination from activities in the catchment
- purchasing land.

Improving the performance of existing water treatment facilities is often the easiest option to move further into the safe sector of the continuum. This may require modest investments to improve chemical dosing, backwash management or plant instrumentation. Staff training and performance reporting are also important measures to maximise WTP performance.

Where the water supplier is satisfied that performance of existing facilities has been optimised and source risk cannot be reduced in order to be within the safe sector, then implementation of an additional treatment barrier is required. This improvement should be commissioned in good time, usually within one five-year price path horizon.

6.2.2 Schemes in the Marginal Sector of the Continuum

Schemes in the marginal sector of the continuum require urgent action. While a public health incident is unlikely, there is no buffer should the source experience an unusually high challenge or the WTP performance deteriorates. The first action required is to recognise this vulnerability and implement

operational measures to closely monitor source and WTP performance with appropriate contingency plans to protect public health should source or WTP performance deteriorate.

These schemes typically have 1.5 – 2.5 log shortfall in performance. While the comments in the above paragraphs about uncertainty and improved source protection also apply here, more urgent action is required to move the scheme towards the safe sector. Once again, the best option to improve water safety quickly is usually to improve the performance of the existing treatment plant. Utilities are able to draw support from water treatment and catchment management experts (consultants and other utilities) to help them improve WTP and source protection performance in order to do this.

It is conceivable that optimising the existing WTP operations could improve performance in the order of one log. If this places the scheme in the safe sector then further improvements can proceed in accordance with the advice provided in the preceding section. However, if the scheme remains in the marginal sector after optimising existing facilities then additional treatment should proceed promptly (within one to two years).

6.2.3 Schemes in the Outbreak Sector of the Continuum

These schemes are seriously deficient. It is unlikely that operational improvements can render such schemes acceptable for continued supply to the public. Short-term measures to protect public health should be discussed urgently with the local health department.

6.2.4 Schemes with Excess Water Treatment Credits

It is feasible that the water safety assessment could indicate a surplus of water treatment credits. This may result in pressure to relax source protection or water treatment. The following guidance is designed to assist water supplies in this situation.

1. ADWG Guiding Principles

The Health-based Targets (HBT) approach for microbial safety is a decision support tool that assists with the implementation of the Australian Drinking Water Guidelines (ADWG) by enabling the water industry to be more confident when assessing pathogen risk and treatment capability. The HBT approach should not be used in isolation of the ADWG Framework. Although the HBT approach is designed to be used to assess risks from the source water and catchment in their current state, and focus on ensuring adequate treatment barriers to meet the HBT, the approach should only ever be adopted within the context of all of the principles in the ADWG.

The first guiding principle of the ADWG states that '*The greatest risks to consumers of drinking water are pathogenic microorganisms. Protection of water sources and treatment are of paramount importance and must never be compromised.*'

The second guiding principle of the ADWG states that '*The drinking water system must have, and continuously maintain, robust multiple barriers appropriate to the level of potential contamination facing the raw water supply.*'

The ADWG further states that '*the prevention of contamination provides greater surety than removal of contaminants by treatment, so the most effective barrier is protection of source waters to the maximum degree practicable.*'

Given these principles, it is clear that if there is an excess between the treatment requirements implied from the source water assessment and the treatment capability then all reasonable effort should be used to maintain and enhance that excess to the maximum degree practicable. This involves continual improvement and optimisation of treatment and source protection and catchment management in order to comply with the multiple barrier approach.

The HBT is a guideline value. The ADWG clearly states that '*water suppliers should adopt a preventive risk management approach, as stipulated in the ADWG, to maintain the supply of water at the highest practicable quality. The guideline values should never be seen as a licence to degrade the quality of a drinking water supply to that level.*'

These principles support the assumption that the adoption of HBTs should not be used as an excuse to compromise (by accepting degradation of, or actively degrading), the quality of a catchment or raw water source through the introduction of additional pathogen risks to allow those risks to increase to the HBT guideline value.

2. Accuracy of assessment

It must be remembered that source risk assessments and water treatment pathogen reduction assessment have unavoidable imprecision. It could be argued that estimates are at least plus or minus one log. Therefore, if a water supply is not plotted on the safe part of the continuum there is no reason to panic – the performance may be better than initially estimated. Similarly, if performance is calculated to be better than one µDALY source protection or treatment should not be reduced.

3. Minimum requirements

One µDALY corresponds to the minimum acceptable disease burden (endemic disease still relates to several hundreds of cases of waterborne disease per million population per year). A utility achieving better than the minimum disease burden, particularly when the source of supply experiences significant variation in pathogen loads, is a worthwhile goal.

4. Annual vs daily performance

One µDALY is an annual HBT. However, variations in performance occur from day to day. When higher pathogen loads are experienced or water treatment performance is not optimum, then higher levels of disease in the community will occur. The excess credits provide a buffer that assist in maintaining performance at closer to one µDALY at all times.

5. ADWG advice

The ADWG clearly states in Section 1.3.2 that *guideline values should never be seen as a licence to degrade the quality of a drinking water supply to that level.* As noted above, source protection should not be relaxed where there are excess treatment credits.

6. Redundancy

When the excess credit arises from a discrete process (e.g. UV) then the value of redundancy should not be under estimated. Water treatment plants need to operate within strict envelopes at all times in order to achieve effective pathogen reduction. Clearly, there are many opportunities for things to go wrong (mechanical, electrical, instrumentation, environmental and human). The redundant process improves the likelihood of maintaining high quality safe water for customers under such circumstances i.e. scheme reliability is enhanced.

7. Rural and remote supplies

Rural supplies are often remote and unmanned. These circumstances increase the likelihood of problems and that may go unnoticed for some time. Operators of such schemes have reported that a redundant process such as UV is inexpensive insurance and has avoided many incidents or supply of unsafe water to customers.

8. Financial issues

The capital for the process providing the excess credits has already been sunk. There may be operating budget savings by shutting the process off (e.g. UV power savings) or operating at a lower

standard e.g. reducing coagulation dose. Such savings are often incidental compared to the total cost of treatment and scheme operations, but not always. From the community view, disease also comes at a cost.

9. Attitude to risk

A utility's attitude to risk will influence how they deal with excess credits. A major water quality incident is usually classified as an extreme risk by utilities. The more barriers and redundancy the more likely a catastrophic event can be avoided. Similarly, if a major water quality incident occurred and the media and public became aware that it could have been avoided if the redundant process had been operating then considerable reputation damage is likely. The cost savings from shutting down the redundant process must be sufficient for the utility to mount a credible argument that it justified the risk to public health.

7. Integrating HBTs into Routine Water Quality Management

7.1 Introduction

The previous sections have been written from the viewpoint of a utility doing an initial assessment of an existing system to determine if it is capable of achieving the annual HBT of one µDALY. This is the situation for most WSAA members. Water utilities have been required to undertake this type of analysis since 2004 when the Framework was included in the ADWG (see 3.2 and 3.3). This Manual provides guidance on how to undertake such an assessment.

In the 2011 revision of the ADWG the Monitoring chapters 9 and 10 were revised to provide guidance on the important role that operational monitoring plays in continuously verifying water safety e.g. that water treatment performance is adequate to meet the source challenge. This process was summarised in Figure 9.2 of the 2011 ADWG and is reproduced in Figure 7.

Figure 6: Generic process for monitoring activities (as per ADWG 2011, Figure 9.2)

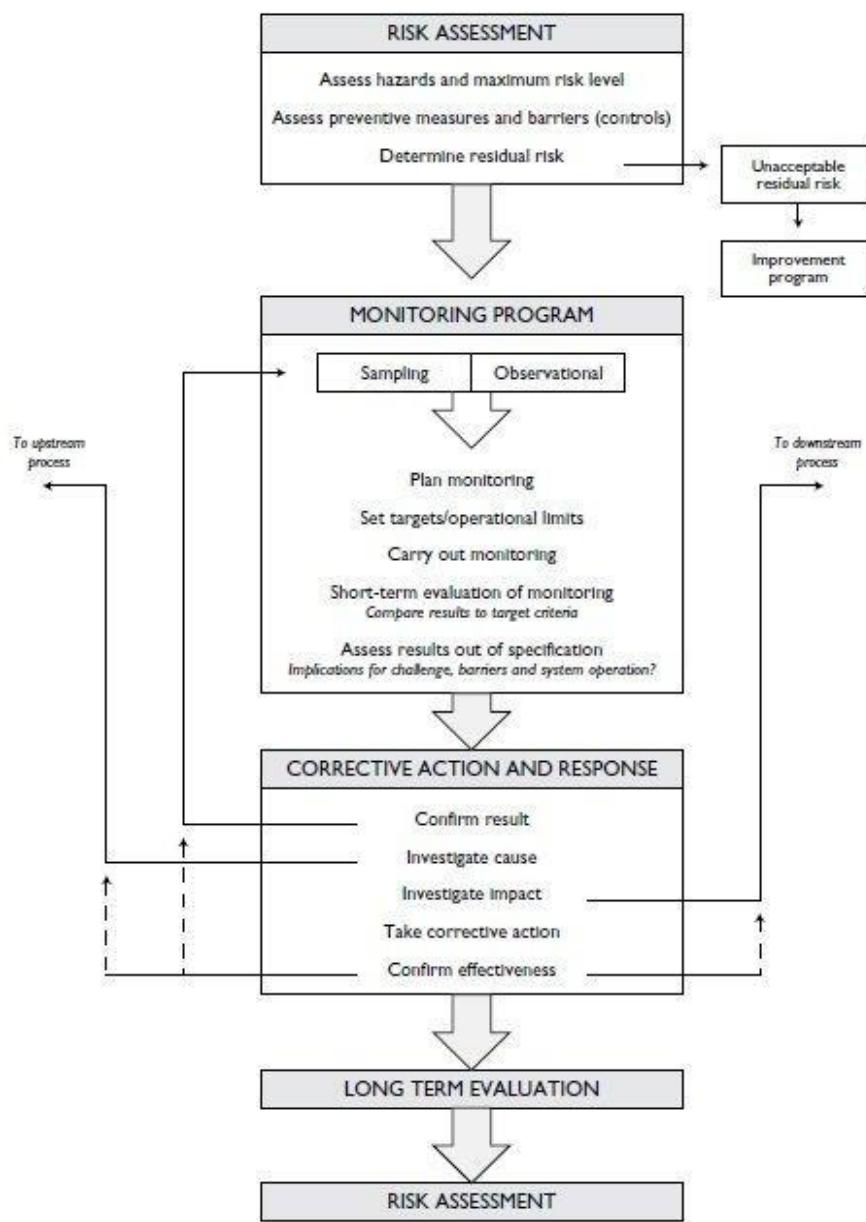


Figure 7 shows that the process outlined in Sections 1-4 of this Manual corresponds only to the first step of the ADWG process i.e. Risk Assessment. To be compatible with the ADWG, the HBT assessment should not stand alone but be integrated into routine water quality operations as shown in Figure 7. The process to achieve this is detailed in the next section.

7.2 Developing a Monitoring Program

7.2.1 Background

Having determined that a scheme is capable of achieving an acceptable HBT, an operational monitoring program should be developed to confirm that the water treatment plant continues to meet the source

challenge. The operational monitoring program should be a combination of sampling and observations as described in Figure 7.

7.2.2 Source Monitoring

Source monitoring should be directly related to the source risk assessment described in Section 3. Table 2 can be used to set an operational limit for raw water *E. coli*. For example, if a source has been assessed as Category 1, the operational limit should be set at 20 *E. coli* per 100 ml. A result greater than 20 *E. coli* is a warning that the challenge has exceeded that expected from a Category 1 source and corrective action should be initiated to confirm the result and investigate the cause and its impact as required in Figure 7.

Observational monitoring in the catchment also needs to be aligned with Table 1 – Vulnerability Assessment. For example, a Category 1 source should have no human access in the protection zone and on the water body. Catchment surveillance is required to provide ongoing assurance. If patrols uncover evidence of illegal camping or fishing near the water body then a corrective action could involve an increase in surveillance.

7.2.3 Water Treatment Monitoring

The treatment processes described in this Manual are all deemed critical control points. The operational envelopes described in Tables 7 & 8 should be used to set up operational limits for each process. For example, a conventional filtration plant deemed to achieve 3.5 log reduction of protozoa is required to achieve filtrate turbidity < 0.2 NTU for 95% of the month and not > 0.5 NTU for ≥ 15 consecutive minutes (see Table 7). This requirement can be translated into operational limits as set out in Table 9 below.

Table 9: Example Operating Limits for Filtration (3.5 log reduction for protozoa)

Filtrate Turbidity	Operational Limit
0.1 NTU	Alarm for pending target breach
0.2 NTU	Target turbidity (should be less than target 95% month)
0.4 NTU	Alarm for pending critical limit breach
0.5 NTU	Critical limit (trigger for filter shutdown)

Observational monitoring encompasses implementation of good practice operation. For example, regular calibration of turbidity meters to assure filtration performance data is reliable.

Calibration performance reporting should include:

- % meters calibrated on time
- Number of meters not meeting calibration target
- Remedial actions and results.

7.3 Short Term Review of Performance

In Chapter 10.1, the ADWG states that, '*in the short term, monitoring results should be reviewed promptly to assess performance against target criteria and critical limits, guideline values and agreed levels of service. Where results indicate that established criteria, such as critical limits, have been exceeded or deviated from, or control of the process has been lost, immediate corrective action is required.*'

In Chapter 10.2 of the ADWG considerable attention is given to CCP evaluation with some key advice reproduced below.

Target criteria breach

Any breach of target criteria should be regarded as a warning or indication of a change in system status and possibly the start of a trend towards loss of control of the process, which may ultimately result in a breach of a critical limit. Investigation and appropriate corrective actions to resolve any potential problems should be immediately undertaken to ensure a critical limit is not breached.

Critical limit breach

Breaching a critical limit indicates control of a process has been lost, probably resulting in an unacceptable health risk. The health regulator should be notified without delay, corrective action should be taken immediately to resume control and normal operation of the process, and implementation of an emergency response plan should be considered.

In this Manual the specification of filtration performance states that the critical limit should not be exceeded for 15 minutes. The 15 minutes is to provide an operational buffer to prevent false alarms and an opportunity for brief investigation before incident response is initiated. Short term responses to critical limit exceedances should be as per this section and ADWG Chapters 9 and 10.

7.4 Long Term Evaluation of Performance

In Chapter 10.3 the ADWG states that '*the systematic review of monitoring results over an extended period of time (typically 12 months) is necessary to evaluate whether existing system management practices are effective in reducing risk and identify opportunities for improvement.*'

With respect to CCPs, the ADWG suggest *performance of CCPs over the long term should be assessed against the specified target criteria and critical limits by reviewing and reporting*, for example:

- percentage of time, or volume of water supplied, where critical limits were met
- percentage of time, or volume of water supplied, where target criteria were met
- number of alarms that occurred over the review period and
- number of shut downs to operation that occurred over the review period due to critical limit breaches.

The ADWG chapter 10.1 suggests that a long-term evaluation typically occurs for a 12 month period. This is also the timeframe envisaged for an HBT review. However, the ADWG suggests a shorter review period for CCPs. The need for more frequent review of CCPs has been a key lesson from the HBT case studies and pilots. Continuous data from CCPs contains significant spikes and variations. It cannot be determined in hindsight if these variations are a true indication of plant performance or instrument errors or periods of maintenance. Accordingly, considerable uncertainty can arise about whether relevant log credits can be claimed.

One way to reduce this uncertainty is to:

- require close management of CCPs daily by plant operators with alarms, target and critical limit breaches investigated and reported
- monthly oversight at the line manager/governance committee level of CCP performance with particular attention given to criteria to be evaluated in a 12 month review.

This reporting regime provides assurance that:

- CCP performance is satisfactory or
- if not satisfactory, incident management has been invoked to protect public health

- timely investigation has occurred and remedial action has been initiated.

7.5 Twelve Monthly Review

Initial scheme risk assessment typically involves an intense review of at least 12 months of historical data. It is not intended that this process be repeated annually for each scheme. The 12 monthly review should not be a mathematical exercise that generates a pass/fail result with respect to one µDALY. With respect to water treatment performance, the 12-monthly review should involve collation and assessment of the individual monthly reports and reviews to confirm adequacy of performance. It is a chance to identify adverse trends or repeat problems which might not be apparent in a monthly review. It is an opportunity to reflect on the achievement of good practice and identify priorities for improvement.

The 12 monthly review also must include the source challenge and incorporate catchment surveillance information and update the source risk assessment. The review may generate questions which require additional monitoring to reduce uncertainty. Where the 12 monthly review indicates a long term and adverse shift in source risk or water treatment performance, a new risk assessment should be undertaken with a view to confirming the need for additional barriers.

8. Implementation Summary

Implementing the water treatment management outlined in this Manual can be summarised in the eight steps below.

1. The source risk assessment will determine the minimum LRV's required for virus, bacteria and protozoa.
2. CCP performance for the WTP should be reviewed to determine the log reduction achieved.
3. Source LRVs and WTP log credits should be compared and an improvement program initiated where residual risk is unsatisfactory (e.g. where one µDALY not achieved).
4. The performance requirements from Steps 1 and 2 need to be translated into target, critical limit and alarm set points for the source and WTP. These should be incorporated into local process control, SCADA systems etc.
5. Day-to-day operation should be in line with these set points. Alarm, target and critical limit breaches require an operational response and should be recorded, investigated, remediated and documented.
6. Target and critical limit breaches are significant events. They should be treated as incidents and have predetermined response protocols. Health regulator notification is required for a critical limit breach.
7. CCP performance should be reported monthly to line managers and for utility governance as set out in Section 9 of this Manual.
8. An annual review of system performance should be carried out. The review incorporates sampling and observational data collected at the source and WTP and builds on the monthly reviews in item (6) above. This is not a pass/fail exercise but one that seeks to confirm adequacy of WT performance with respect to source challenge and identify adverse trends and opportunities to improve.

The objective is to determine if the system is sufficiently robust to continuously deliver water with acceptable residual risk (e.g. one µDALY).

9. Governance for Microbial Water Safety

9.1 Background

Implementing this Manual provides the opportunity for consistent determination of adequacy of water treatment processes across the Australian water industry. In addition, monitoring performance targets for source water and water treatment operations based on the risk assessments detailed in the Manual provides the basis for ongoing assurance of microbial water safety.

The current ADWG points out that drinking water quality monitoring (e.g. *E. coli* monitoring) cannot prevent unsafe water being supplied to consumers (Section 9.5.2, ADWG, 2011). In addition, the ADWG states that '*the continuous operation of critical control points (CCPs), such as disinfection and filtration, within target criteria and critical limits is the single most important factor in ensuring the supply of water which is free of microbial pathogens*' (Section 10.3, ADWG, 2011).

A recent survey indicated that operational monitoring is inconsistently reported across utilities. In addition, while *E. coli* monitoring is universally reported to utility executives and boards, operational indicators of CCP performance are rarely reported to executives.

To deliver on their duty of care to protect customers from foreseeable harm, it is necessary that members of a utility executive and board have an understanding of CCPs and that appropriate reporting of operational performance of source and water treatment processes is available for their review. This section of the Manual provides minimum reporting requirements for the governance of drinking water quality across all layers of a water utility.

9.2 Governance Model

The governance model has three aspects:

1. Location of each water supply system on the Water Safety Continuum.
2. Management of the Water Quality Improvement Program.
3. Reporting of operational performance of source waters and water treatment plants.

These aspects are explained in the following sections.

9.3 Location of each scheme on the Water Safety Continuum

The location of each water supply on the Water Safety Continuum (the Continuum) is fundamental knowledge for the governance model and ultimately the discharge of a utility's duty of care to its customers.

The location of each scheme on the Continuum directly links to any utility's corporate risk profile. The likelihood of a serious water quality incident is a function of location on the Continuum as tabulated below.

Continuum Location	Likelihood of Serious Incident
1 micro DALY	Rare
Safe	Unlikely
Marginal	Possible
Unsafe	Almost certain

The location of a scheme on the Continuum will change based on completion of improvement projects and long term reviews of source water and water treatment plant performance. For governance purposes, each scheme should be checked at least annually to gauge if its location on the Continuum has changed.

9.4 Management of the Water Quality Improvement Program

Location of each water supply system on the Continuum indicates the degree of improvement required to achieve the HBT benchmark of one micro DALY. In general terms the further to the left on the Continuum a water supply scheme is located the more substantial and urgent is the improvement required.

Operational improvements can usually be implemented quicker than capital improvements and where feasible should be implemented as soon as possible. Where capital improvements are necessary, the following table can be used for guidance.

Location on the Continuum	Timing of Capital Improvement
Unsafe	Immediate
Marginal	Within 3-5 years
Safe	Within 5-10 years

The progress with each improvement project needs to be reviewed at least twice per year by the utility representatives responsible for governance of water quality and the executive. Executives should consciously consider their duty of care obligations in the decision making process.

9.5 Reporting the Operational Performance of Source Water and Water Treatment Plants

A layered approach to reporting of water quality operational performance should be followed as set out below.

9.5.1 Individual WTPs and Catchments

- a) Location on the Continuum
Operators of WTPs and catchments should know where the scheme they are operating sits on the Continuum. Schemes in the marginal zone have reduced buffer to deal with WTP under performance and high source water challenge
- b) Performance Targets
WTP performance should be comprehensive and cover the full range of reporting indicators including performance against:
 - critical limits
 - targets

- good practice operation.

For full details refer to Appendix E.

Source performance should be comprehensive and cover the full range of performance indicators for:

- observational monitoring in the catchment
- raw water *E. coli* monitoring
- raw water pathogen monitoring (if applicable).

For full details refer to Appendix E.

9.5.2 Management Reporting

This involves reviewing performance across multiple catchments and WTPs. The performance targets for individual sources and WTPs are summarised and reported by exception in terms of non-conformance with required performance. Note that this covers both sampling and observational monitoring.

Further details are provided in Appendix E.

In addition, reporting should confirm that the response to any breach was appropriate and suitable action has been taken to prevent a recurrence. Reporting provides an opportunity to compare performance across catchments and WTPs and identify common weaknesses and adverse trends. At some point in the management review the performance of source and WTP must be considered concurrently to determine the water supply system performance.

9.5.3 Executive Reporting

Reports to the water supplier executive should contain sufficient information to provide confidence that water supplied has been continuously safe and they have met their duty of care to protect customers from foreseeable harm. They need to be assured that:

- a) Installed water treatment processes are adequate to meet the pathogen challenge.
- b) They were operated effectively.

In terms of adequacy of treatment processes reporting should include the number of schemes in the safe, marginal and unsafe parts of the water safety continuum together with any changes since the previous report. This will capture changes resulting from any long term evaluation and commissioning of capital and operational improvements. With respect to WTP operation, reporting should cover performance against critical limits and target criteria as well as good practice operations. With respect to source water operations, reporting should include any change to source category as this is a significant event.

For full details, refer to Appendix E.

Commentary would usually be provided for any schemes where an adequate assurance of the safety of water supplied cannot be provided (e.g. supply in breach of the critical limit occurred for more than 15 minutes) together with short and long term actions to assure water safety.

9.6 The Need for Teamwork and Clear Accountabilities

The continuous supply of safe drinking water to customers relies on teamwork and exercise of personal accountability across all levels of the water supplier. The executive may only see a handful of indicators of water safety and rely on a high level of scrutiny by managers. Likewise, managers rely on the knowledge and expertise of operators to optimise operations and trouble shoot problems.

To avoid inadvertent omissions, utilities should document the expectations they have for the preparation and review of performance reports in line with Element 10.2 of the Framework in the ADWG.

10. References

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11. Abbreviations

ADWG	Australian Drinking Water Guidelines
AGWR	Australian Guidelines for Water Recycling
BAC	Biological Activated Carbon
CCP	Critical Control Point
cm	centimetre
Ct	Concentration x time
DAF	Dissolved Air Flotation
DAPI	the stain 4',6-diamidino-2phenylindole
DE	Diatomaceous Earth
DIC	Differential Interface Contrast microscopy
GAC	Granular Activated Carbon
GIS	Geographical Information System
GL	Gigalitre
HBT	Health Based Target
IFA	Immunofluorescence Assays
kL	kilolitre
km	kilometre
L	Litre
LOD	Limit Of Detection
LRV	Log Reduction Valve
MF	Micro-Filtration
mg/L	milligrams/litre
MIT	Membrane Integrity Test
ml	millilitre
NF	Nanofiltration
NHMRC	National Health and Medical Research Council
NOM	Natural Organic Matter
NTU	Nephelometric Turbidity Unit
PDT	Pressure Decay Test
PT	Proficiency Testing
QMRA	Quantitative Microbial Risk Assessment
RED	Reduction Equivalent Dose
RO	Reverse Osmosis
STP	Sewerage Treatment Plant

UF	Ultra-Filtration
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
WHO	World Health Organisation
WSAA	Water Services Association of Australia
WTP	Water Treatment Plant

Appendix A – Tier 1 Source Risk Assessment Guidance

Source Risk: Assessing Treatment Requirements

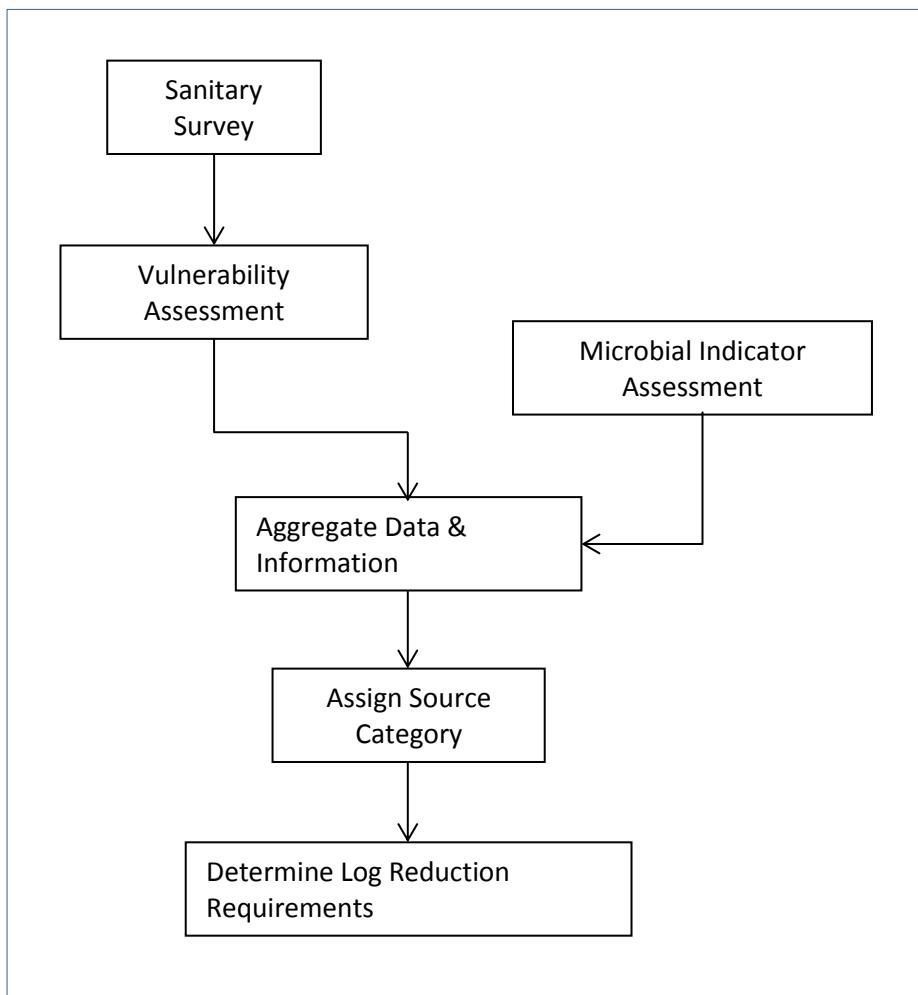
Water suppliers can select from one of two tiers of assessment in identifying drinking water treatment requirements for their source water.

Tier 1 Assessment

All water suppliers should undertake this assessment for all water supply schemes. The assessment is consistent with the recommendation in the ADWG to understand the system and the traditional sanitary survey that should be regularly undertaken for all water supplies. Even water supply systems with favourable pathogen monitoring results should undertake this Tier 1 assessment. Reliance on Tier 2 assessment alone can omit to reveal some high-risk periods, for instance infrequent events, such as wastewater treatment plant overflows. The Tier 1 assessment involves a six-step process for determining water treatment requirements:

1. *Sanitary Survey Assessment*: To identify specific pathogen pollution sources within the catchment as well as preventive measures and barriers within the catchment.
2. *Vulnerability Assessment*: To aggregate what is known about the pathogen pollution sources to assess the source vulnerability.
3. *Microbial Indicator Assessment*: To provide an independent evaluation of water quality.
4. *Aggregate Data and Information*: Assemble the above information, review and explain any anomalies
5. *Source Category*: Assign the Source Category based on the preceding analysis.
6. *Log Reduction Requirements*: Based on Table A1 in this section.

Figure A1: Tier 1 Source Water Assessment – Process Summary



Tier 2 Assessment

The second, optional, assessment involves gathering reliable pathogen data for a specific water source to help define treatment requirement empirically.

In some cases, pathogen monitoring is useful and justified to provide greater certainty about source challenge and therefore health outcomes as well as to assist with large investment decisions.

The Tier 2 assessment inherently requires a high level of relevant expertise to design credible pathogen monitoring programs, conduct the analysis and interpret the results. The high level of sophistication and costs associated with undertaking a credible level of pathogen testing means that it is not anticipated that it would be cost effective for small water supplies, although it can be used for any water supply.

Sanitary Survey Assessment

Introduction

The sanitary survey assessment is the first step in the Tier 1 assessment. The survey should identify all point and non-point sources of pathogens. Associated with each pathogen source should be an assessment of the likely intensity of the input and its proximity to the water source, receiving water and

feeder streams. There are a variety of sanitary survey approaches in use within the water industry and the purpose of this tool is to provide general guidance, not replace or choose among approaches.

Delineating the area of influence

Given sufficient time, processes of inactivation, predation and sedimentation combine to reduce pathogen concentrations significantly within natural environments. The time required for a given level of pathogen reduction varies according to pathogen type and key process variables such as temperature, UV intensity and substrate. However, in general, several log₁₀ orders of pathogen inactivation occur over weeks to months following pathogens entering the natural environment. Therefore, the first step is to define the area of influence and focus the sanitary survey on those areas.

Initially, all catchments of all water inputs to the drinking water supply intake, both within the natural catchment and those that are transferred from other catchments need to be considered. However, after consideration of pathogen travel time, some inputs can be excluded from the survey.

For large river systems or systems with large dams, it is reasonable to exclude distant catchment areas from the survey simply due to the pathogen inactivation that would occur within that travel time. Similarly, in some landscapes, much of the land is well buffered by intact understory vegetation and/or pasture making them hydraulically disconnected from flowing water.

Once the area of influence has been defined, the detailed sanity survey can be undertaken and should focus on that area.

Pathogen types

The ADWG refers to three pathogen groups when discussing the HBT concept. These are:

- bacteria
- viruses
- protozoa.

When considering waterborne faecal-oral pathogens, the sources of each type of pathogen group differ. The objective of the sanitary survey is to establish the extent of contamination and, therefore, the extent of catchment risk, for each of these pathogen types.

Sources of bacteria

All surface water sources, including fully protected sources, are subject to waterborne faecal-oral bacterial pathogen contamination, primarily from animals. Only confined and fully protected aquifers are theoretically free from relevant pathogens, however even these sources can become re-contaminated, or may be warm enough to support opportunistic pathogens.

The risks associated with bacterial pathogens tend to increase with increasing development density. More intensive development tends to increase the total bacterial input, as evidenced by increased microbial faecal indicator concentrations in such catchments. In addition, human and agricultural animal inputs are more likely to carry human-infectious types of bacteria than are wildlife.

Sources of viruses

Viruses represent the other extreme from bacteria. Human faecal contamination is the only important source of waterborne faecal-oral viral enteric pathogens. Therefore, the risk associated with waterborne faecal-oral viral enteric pathogens increases along with the development and intensity of human development, but is not influenced by non-human inputs.

For any water source that has significant human presence within the relevant area of influence, it is necessary to explicitly locate and identify all significant sources of viruses within this area along with their associated catchment preventive measures.

Sources of protozoa

As with viruses, humans represent the most important source of waterborne faecal-oral protozoan pathogens. However, unlike viruses, some animals, particularly pre-weaned ruminants (e.g. cattle and sheep), can also shed significant quantities of waterborne faecal-oral protozoan pathogens. More intensive development tends to increase the risk by increasing both the concentration and the propensity for human-infectious types to be present. Therefore, the risks associated with waterborne faecal-oral protozoan pathogens increases along with the development density and intensity for both human and agricultural inputs.

For any water source that has significant human and/or stock animal presence within the relevant area of influence, it is necessary to explicitly locate and identify all significant sources of protozoa within this area along with their associated catchment preventive measures.

Catchment preventive measures

Another factor of relevance in assessing treatment requirements relates to the presence of key preventive measures. The presence of large reservoirs is a partial mitigation for risks associated with pathogens. The definition of a large reservoir is not precise, and all reservoirs can short-circuit to some extent. However, as a working definition, a reservoir volume of ≥ 1 year of flowthrough and a minimum volume of 1 GL is considered large for the purposes of this assessment.

Pathogens have limited capability to move across landscapes. Well-vegetated land can provide an effective barrier to protozoan transport within surface flows. Sub-surface flow within soils and groundwater can provide an effective barrier to both protozoan and viral pathogen transport. The fate and transport of pathogens across and through the landscape is highly variable according to pathogen, soil, vegetation and rock type as well as water chemistry. However, in general, tens of metres of transport across well-vegetated surfaces will tend to entrap protozoan pathogens and transport across similar distances in the sub-surface will tend to entrap both protozoa and viruses.

Capturing specific details

Specific pathogen sources should be surveyed in order to allow their presence to be considered. In the absence of a state-of-the-art hydrodynamic catchment and reservoir model, populated with reliable information on pathogen fate and transport, there is little value in attempting to quantify pathogens numerically. Even then, there is significant variability and uncertainty in relation to pathogen modelling within catchments and water bodies, rendering such quantitative assessments of limited value. However, some broad semi-quantitative information on pathogen sources is essential in order to assess pathogen risks. The following provides an overview of the type of information that should be captured

General information, such as:

- name and location of water source
- type of water source (river, weir, reservoir, etc.)
- date of assessment
- identity of assessment person/team.

Land use categories – features such as:

- catchment protection native bushland areas
- national parks

- forestry
- broad scale grazing, low density, usually unimproved pasture, typically sheep or beef
- intensive grazing, high density, usually improved pasture, typically dairy
- other intensive agriculture, e.g. piggeries and poultry
- rural residential
- horticulture and cropping
- urban
- recreation.

Specific contamination sources, such as:

- wastewater discharges
- sewerage systems
- sewer overflow points
- recycled sewage application areas
- reused biosolids application areas
- urban stormwater discharges
- on-site sewage management systems
- run-off from agricultural activities
- land-based recreation
- water-based secondary contact recreation
- water-based primary contact recreation
- landfills
- wildlife congregations.

Connectivity and influence of sources, such as:

- identity and nature of preventive measures present (if any) e.g.
 - fencing
 - riparian buffers
 - exclusion zones
 - source protection activities
 - waste containment systems
 - treatment systems
- distance of the input from the water supply intake (linear and hydraulic distance)
- nature of the input (piped, pumped, overland flow, sub-surface flow)
- timing of the input (continuous, intermittent, event-based)
- approximate flow rate (if known)
- pathogen sources (virus, protozoa, bacteria)
- extent of connectivity between the pathogen source and the water source (given the above).

Sanitary survey report

The above information should be collated into a sanitary survey report. There is no standard format for producing such reports with each water supplier likely to have their own preferred approach. GIS-based systems, worksheets and documented reports are all used to support a sanitary survey. The report should be of a living format to allow updates at regular intervals, at least every three years or when new catchments are introduced to the water supply or if existing catchments are subject to significant change.

The data from the sanitary survey can be summarised using the table shown at A1. This will assist with the vulnerability assessment which follows.

Table A1: Template for Summarising Sanitary Survey Data

Pathogen Source	Pathogen Intensity/Load				Proximity to		Presence of in-situ Barriers		Comment
					Water Body >2 km Y/N	Feeder Streams >20 m Y/N	Vegetation Buffer Y/N	Fencing Y/N	
Permanent Human Rural properties Urban properties	Nil	L	M	H					
Itinerant Human land based recreation water based recreation									
Stock/animals Livestock grazing Livestock industry									
Specific Contamination Wastewater discharges Sewer overflows Biosolids application Stormwater discharge Wildlife congregations									

Vulnerability Assessment

Introduction

With the sanitary survey complete, the next step is to aggregate the information in a more descriptive form in order to assign the drinking water source to a treatment category. This section of the report discusses how the vulnerability assessment is arranged into categories.

In deciding upon specific categories, the working group considered how drinking water sources grouped from a treatment perspective and as a result, four general water categories were identified:

- chlorination-only (possibly following filtration for turbidity reduction)
- conventionally operated filtration and chlorination
- enhanced filtration (tightly operated conventional filtration or membrane filtration) and chlorination
- filtration and UV or ozone disinfection plus chlorination.

The above four categories are examples, but from a pathogen reduction perspective they represent the treatment categories considered in this Manual. The purpose of this Manual is to define the types of water sources that would be suitable for treatment by these methods or others with equivalent, validated pathogen reduction performance.

Treatment can be required for more contaminated water sources, such as those heavily influenced by sewage, stormwater or greywater, either by design (planned indirect potable reuse) or incidentally (incidental indirect potable reuse). Such water sources trigger the need to apply the Australian Guidelines for Water Recycling, which provide health-based targets.

Categories

Four drinking water source protection categories have been described. These sources are numbered from 1 to 4 and are categorised in Table A2.

These categories are based on the Water Corporation Surface Water Treatment Matrix as adapted by the HBT working group.

Table A2: Categories of drinking water source

Category	Land use challenge	Intensity	Proximity	Protection
1. Protected catchment	Permanent human	<ul style="list-style-type: none"> • Negligible • No STPs • Minimal, well-managed on-site sewage management systems 	Human settlements and recreation excluded from the whole area of influence, typically the whole hydrological catchment and reservoir.	Natural bushland-protection enforced by policed regulation. Low intensity/low risk activities may be allowed in the outer catchment but active source protection (e.g. ranger patrols) is practiced to ensure negligible contamination risk.
	Itinerant human	<ul style="list-style-type: none"> • Negligible • Minimal essential entry for rangers, pest controllers, fire managers • Minimal illegal entry. 		Supply is from a large reservoir.

Category	Land use challenge	Intensity	Proximity	Protection
	Stock animals	<ul style="list-style-type: none"> • Negligible • No farms • Limited (controlled) populations of feral animals. 		
2. Moderately protected catchment	Permanent human	<ul style="list-style-type: none"> • Minimal • No STPs • Low density rural developments with well-managed on-site sewage management systems. 	Human settlements excluded from inner catchment. *	<p>Bushland inner catchment, low-density rural outer catchment</p> <p>Stock are fully fenced out of main feeder streams behind vegetated buffer zones.</p>
	Itinerant human	<ul style="list-style-type: none"> • Low level, low intensity recreation. 	<ul style="list-style-type: none"> • Recreation excluded from inner catchment • No recreation close to or on the main water body 	<p>Protection enforced by policed regulation.</p> <p>Low level and low intensity activities may be allowed within the outer catchment but active source protection active source protection (e.g. ranger patrols) is practiced to minimise contamination risk.</p>
	Stock animals	<ul style="list-style-type: none"> • Low density • No dairies, feedlots, etc. 	Farming excluded from inner catchment.	
3. Poorly protected catchment	Permanent human	<ul style="list-style-type: none"> • Moderate • May include limited sewerered urban areas and STPs within outer catchment 	Human settlements excluded from inner catchment	<p>Medium density rural outer catchment possibly including some limited areas of urban development.</p> <p>Any STP effluent is filtered and disinfected and sewer spills are actively minimised.</p> <p>Major sewer overflows or STP failures would lead to a downstream water treatment shut down or boil water alert</p>
	Itinerant human	<ul style="list-style-type: none"> • Moderate level of land-based recreation 	No recreation on the main water body	<p>Stock may have access to main feeder streams in the outer catchment.</p>
	Stock animals	<ul style="list-style-type: none"> • Medium density • No dairies, feedlots, etc. 	Farming excluded from inner catchment	<p>Protection enforced by policed regulation within inner catchment.</p>

Category	Land use challenge	Intensity	Proximity	Protection
4. Unprotected catchment	Permanent human	<ul style="list-style-type: none"> • High • Includes seweraged urban areas and STPs 	No exclusion zone	Although there are urban inputs, the total quantity of treated sewage or stormwater effluent flowing into the catchment is sufficiently limited that the Phase 2 Australian Guidelines for Water Recycling need not be applied.
	Itinerant human	<ul style="list-style-type: none"> • High • Intense land-based recreation • May include water-based recreation on reservoirs 		Reasonable upper limits are 10% treated sewage effluent and 30% stormwater runoff.
	Stock animals	<ul style="list-style-type: none"> • Intensive • Includes dairies, feedlots, etc. 		Any sewage or intensive agricultural effluent is treated (filtered and disinfected) and spills are actively minimised. Major spills would lead to a downstream water treatment shut down or boil water alert.

*The demarcation between inner catchment and outer catchment varies. Typical surface water inner catchment reservoir protection zones within Australia are 2 to 3 km from reservoir high water level. In other jurisdictions the concept of time-of-travel and/or linear distance is used and a range of different values are assigned to those criteria.

Guidance for vulnerability selection

Australia has diverse catchments and it is not unusual for a catchment to include more than one category. In such cases it is normal to adopt the category of the highest land use challenge.

In addition, the following general guidance may assist in deciding the appropriate source category.

Category 1 sources are essentially free of sources of faecal contamination from humans and stock i.e. no sources of human infectious virus and protozoa. Bacterial contamination from native animals and birds cannot be avoided but is mitigated in a large storage which allows die off and settling. Turbidity is low enough to ensure effective disinfection.

Category 2 sources have minimal levels of faecal contamination. They may have:

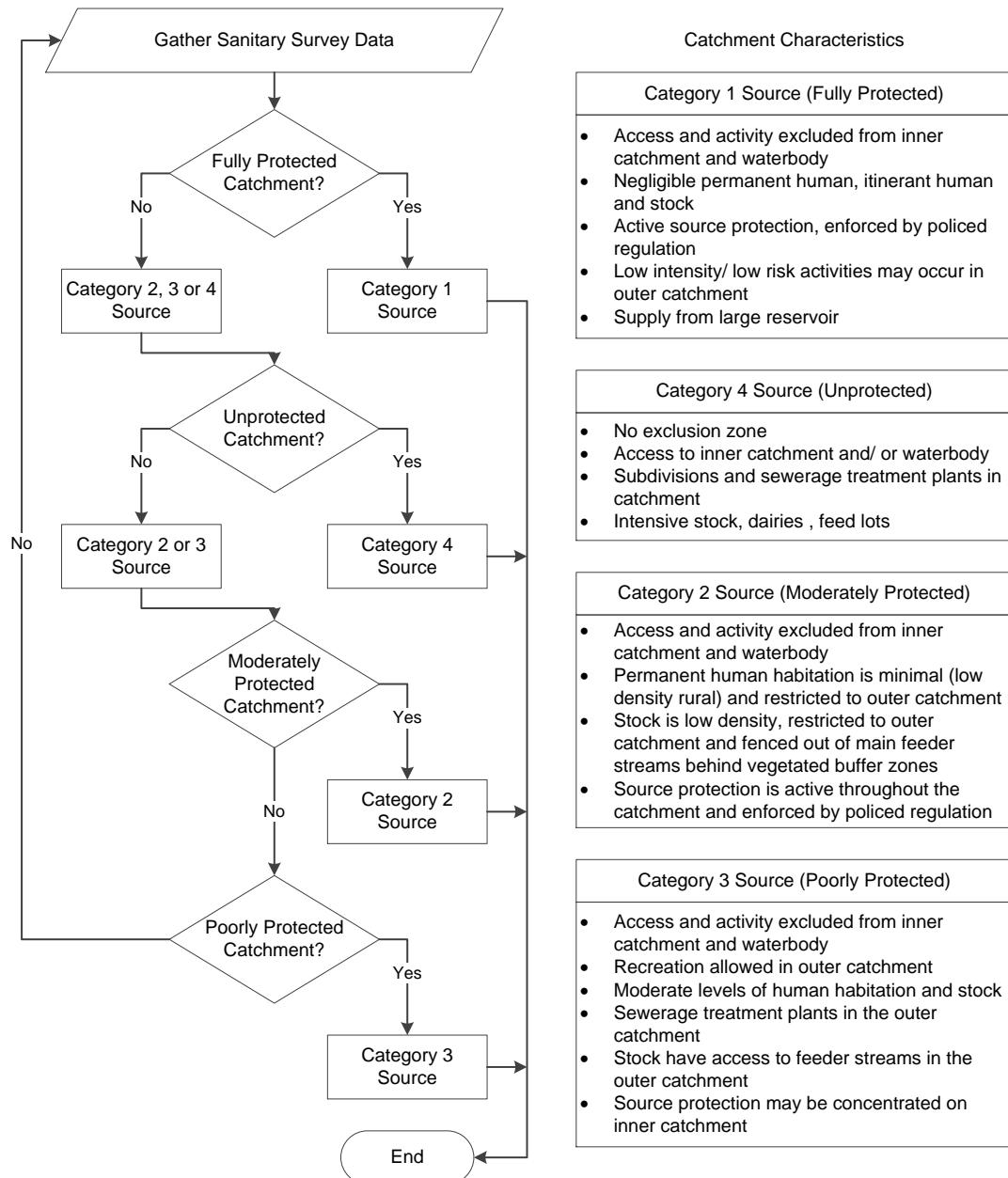
- Similar catchments to a Category 1 but higher levels of bacterial contamination due to the absence of a large storage; or
- Some minor sources of human (e.g. rural subdivisions) and stock contamination in the outer catchment which are distant or well buffered by natural vegetation from feeder streams and the water body.

Category 3 sources have moderate levels of faecal contamination from humans (e.g. urban subdivisions) and extensive stock in the outer catchment. The inner catchment and water body are protected from contamination.

Category 4 sources have high levels of faecal contamination from human and agricultural activities. The inner catchment is not protected and recreation may occur throughout the catchment and on the water body.

Vulnerability assessments are more easily conducted by a process of elimination as shown in Figure A2.

Figure A2: Vulnerability Assessment Process Flow Chart



Water sources that exceed Category 4

Some water sources would lie outside of the range of source water categories that are associated with conventional drinking water sources within Australia. For instance, the presence of untreated sewage, untreated effluent from dairies, feedlots etc. and untreated biosolids cannot be tolerated within a conventional drinking water catchment. Guidelines such as the Phase 2 of the Australian Guidelines for

Water Recycling can be used to assist in meeting health-based targets for these more highly contaminated source waters.

Microbial Indicator Assessment

Background

The evidence from catchment assessment may miss unknown sources of contamination. Therefore, it is important to gather independent evidence of the microbial quality of source waters using microbial monitoring data. Microbial indicators have their limitations but arguably remain the best readily available option to independently inform the source categorisation.

Four microbial monitoring categories have been defined in this paper. These were based on the long-established and widely cited European regulation Drinking Water Abstraction Directive (consolidated) (EC 1975). The EC approach has been cited by WHO (2003) and has been adapted slightly and applied within Australia by Water Corporation in its Surface Water Treatment Matrix.

The categories are given in Table A3. These categories are reviewed in WHO (2003) who note that many studies have looked at the relationship between microbial indices of faecal pollution and pathogens in surface water. Although this has been subject of much debate, the consensus appears to be that there is a general, coarse relationship between the indices of faecal pollution and pathogen concentrations. No alternative categories to EC (1975) are provided by WHO.

Catchments are typically large and complex enough that pollution could potentially occur without being evident from catchment categorisation and sanitary inspection alone. Therefore, the use of microbial indicators to infer pathogen risk is not as good as the use of pathogens, but is considerably better than relying on no monitoring data at all.

Table A3: Summary *E. coli* standards for surface water intended for the abstraction of drinking water (adapted from EC, 1975)

Surface Water Category	<i>E. coli</i> [†] concentration per 100 ml (max of routine samples)
A	≤ 20
B	≤ 2,000
C	≤ 20,000
D	>20,000*

[†] Thermotolerant coliforms can be used for this categorisation if *E. coli* data are not available.

*Water with *E. coli* concentrations >20,000 are not considered suitable as a drinking water source.

Data assessment

The *E. coli* results used in this assessment are those taken from the raw water immediately prior to treatment. To characterise the contamination challenge for the source, raw water is typically sampled weekly at surface water sources in Australia. The minimum period of monitoring required is 2 years which should provide about 100 data points. Ideally the monitoring period should be 5-10 years to cover the range of conditions likely to be encountered. As the criteria for this analysis is the maximum *E. coli* result then samples from event based monitoring (e.g. heavy rainfall) should be included in the data set.

Where sampling is less frequent than weekly it is probable that the maximum *E. coli* load has been underestimated and this needs to be kept in mind when using Table A4. In such cases caution should be exercised before down-rating the source category based on *E. coli* data.

Historical raw water *E. coli* data (minimum 2 years) should be plotted with the intention of determining which band contains the maximum *E. coli* result i.e. <20, 20-2000, 2000-20,000 or >20,000 organisms per 100 ml.

Usually results from long term monitoring cluster in a band. However, care is required if a single result is pushing the microbial assessment into a higher band. Investigation is required to confirm that the result is representative of the realistic maximum bacterial contamination.

It is difficult to validate data retrospectively. Looking forward, the upper limits for the band in which a source is placed should become a *process control point* for the raw water. Any exceedance should be considered out of specification and managed according to Figure 9.2 of the ADWG (2011).

Aggregating the Assessments

Most utilities routinely collect *E. coli* data on raw water immediately prior to treatment. This data can be used to confirm the vulnerability assessment or help decide between categories when the vulnerability assessment is not conclusive. Table 2 illustrates how the microbial indicator assessment can be used in conjunction with the vulnerability assessment to determine the source category.

Table A4: Comparison of *E. coli* concentration with sanitary inspection category as an independent reality check

Source category Vulnerability Assessment Category	Microbial indicator concentration category Maximum <i>E. coli</i> [†] per 100 ml			
	≤ 20 Category 1	> 20 ≤ 2,000 Category 2 & 3	> 2,000 ≤ 20,000 Category 4	> 20,000 Not suitable for drinking
1	Source = Cat 1	Source = Cat 2	Anomalous	Not suitable
2	Source = Cat 2	Source = Cat 2	Anomalous	Not suitable
3	Anomalous	Source = Cat 3	Source = Cat 4	Not suitable
4	Anomalous	Source = Cat 4	Source = Cat 4	Not suitable

[†]Thermotolerant coliforms can be used for this categorisation if *E. coli* data are not available.

If the *E. coli* data and vulnerability assessment plots in a green box then the two assessments are consistent and support each other. This means there is a high likelihood that the source category is correct.

If the data plots in an amber box then this result is still feasible but has a lower degree of confidence. The *E. coli* data and sanitary survey data should be re-examined to achieve better alignment or better understand the reasons for this result. For example, if the microbial assessment indicates a higher level of risk than inferred from the vulnerability assessment then the sanitary survey should be repeated to determine if there are sources of contamination not previously identified.

If the data plots in the red area then this is an anomalous outcome and cannot be accepted. The process needs complete rework and pathogen monitoring may be necessary to define the source risk. In the interim the precautionary principle should be applied and the most conservative source category option under consideration should be adopted.

Interpreting results

The following guidance is provided on interpreting the results from the microbial assessment.

Category 1 sources should always have less than 20 *E. coli* /100 ml in the raw water prior to treatment. If counts exceed 20 *E. coli* per 100 ml then the storage barrier is not effective under all circumstances and the source should be classified as Category 2.

Both Category 2 and Category 3 vulnerability categories can fit into the 20-2000 *E. coli* per 100 ml microbial indicator assessment category. Therefore, it is the vulnerability assessment that splits them. The point is that Category 2 treatment provides only a modest barrier to *Cryptosporidium* so the catchment should have minimal sources of *Cryptosporidium*, and those sources should be remote from the water bodystreams and well-buffered to fit into Category 2. Category 2 is typically a well-protected catchment that sees higher *E. coli* counts and turbidity due to a small storage or being run off the river.

Categories 3 and 4 can be split by the microbial indicator assessment. Any source which experiences greater than 2,000 *E. coli* per 100 ml ought to go into Category 4 unless a very good explanation for the possible anomaly can be identified.

If a source is classified as Category 4 by vulnerability assessment, but *E. coli* counts are less than 2000 organisms/100 ml then the vulnerability assessment should be given priority and the source should be classified as category 4.

The only exception allowed is where supply is via a large reservoir (i.e. volume exceeds 1 GL and is greater than the annual average through flow). The source assessment methodology does not provide for any direct ‘credit’ for storage. However, in this case the *E. coli* counts of less than 2000 organisms/100 ml may indicate the storage barrier is sufficiently effective that the vulnerability assessment can be discounted from Category 4 to Category 3. This discounting should only occur if there is convincing evidence that the storage barrier is effective (e.g. 2 log reduction of protozoa) under all circumstances.

Such evidence might include:

- a) event sampling for *E. coli* after extreme rainfall events confirms counts are less than 2000 *E. coli* per 100 ml
- b) when Dam storages are low and raw water counts are less than 2000 *E. coli* per 100 ml after heavy rainfall
- c) hydrodynamic modelling of the reservoir indicates water age is always more than 3 months at the reservoir outlet under all scenarios.

Multiple catchments and pump-backs

Where a dam is supplied from multiple catchments, it is necessary to carry out a source risk assessment for each catchment. The final risk assessment for the scheme requires amalgamation of the individual assessments.

If the final dam has the highest risk rating then this source category should be adopted for the scheme.

If the final dam has a lower risk rating than some of the catchments which feed into the dam then the starting point is to use the highest risk catchment as the source category for the scheme. This is a conservative approach and the risk may be discounted if justified by knowledge and understanding of the system.

Dilution and selective harvesting from sources are common strategies used to reduce risk in the final dam. Monitoring and modelling are techniques commonly used to better understand water age, dilution and pathogen fate and in some cases justify a lower source risk rating for the system.

The concern with pump backs is the risk of short-circuiting, especially if the discharge pipe is located close to the outlet from the dam. If the catchment supplying the pump back is a higher risk than receiving the water, then the starting point is to assume the pump back risk for the whole system. This is a conservative approach and the risk can be discounted if justified by knowledge and understanding of the system. Monitoring and modelling are techniques commonly used to better understand water age, dilution and pathogen fate and in some cases justify a lower risk rating for the whole system.

Run of the river sources

There are two cases to consider for run of the river sources.

Case 1

A well-defined catchment and water is drawn from a small dam, which contains less than 1GL or one year's through flow. The catchment can be assessed using the vulnerability assessment outlined in this Manual. When using raw water *E. coli* samples as a reality check it is likely that *E. coli* results will push the source into a higher category. This is not unexpected as the absence of a storage barrier will result in high *E. coli* results. Nor is it unreasonable that additional treatment is required to compensate for the absence of a storage barrier.

Note that Category 1 sources must always have a large dam to provide an effective storage barrier.

Case 2

Water is drawn from a large river that may have a local catchment as described in Case 1 but the river is also fed by other catchments, which may be hundreds or even thousands of kilometres away.

This case requires judgement on 'delineating the area of influence' as set out earlier in this Appendix (see Sanitary Survey Assessment).

The local catchment can be assessed as per Case 1 above. The influence of upstream catchments needs to be incorporated in the final assessment. The area of influence will vary from river to river dependant on travel time and dilution. It is a question of know your system to make sound judgements on the source vulnerability. *E. coli* monitoring can be helpful in deciding the source category but only if sampling is frequent enough to pick up peak contamination loads. In addition, it must be remembered that protozoa will survive longer than bacteria in environmental waters so low *E. coli* counts do not mean low protozoa risk if there are potential human and animal sources of *Cryptosporidium* which could reach the offtake within 4-8 weeks of travel.

Appendix B – Background to Water Treatment Requirements

Treatment recommendations

Purpose of these recommendations

As noted in the foreword and introduction, this Manual is intended as guidance and not as a standard. Therefore, the recommendations given here for treatment are provided as advice on what would be reasonably expected to reduce pathogen concentrations in particular source water categories to low enough levels that potable water is extremely safe. In this context, extremely safe means that it would be expected to approximately meet the HBT of one micro DALY (μ DALY).

It should be noted that the HBT of one μ DALY is not an absolute value that can be measured. The HBT is a guiding value for what a potable water supply should be designed and operated to achieve. Similarly, the treatment recommendations given here are not absolute values. The recommendations given here should be considered intelligently within that context.

Recommendations

The pathogen reduction requirements recommended for each source category are summarised in Table B1.

Table B1: Recommended minimum LRV requirements

Source Category	Minimum Pathogen Log Reduction Required		
	Bacteria	Virus	<i>Cryptosporidium</i>
1	4.0	0	0
2	5.0	3.0	2.5
3	5.0	4.0	3.5
4	6.0	6.0	5.5

Basis for the Recommendations

Examples of international guidance on water treatment requirements are shown in Figures B1, B2 and B3.

Application of HBTs requires consideration of bacteria, virus and protozoan pathogens. However, there is no reference, which specifies treatment requirements in one table similar to Table B1 above. Table B1 has been produced by consolidating information from a number of international sources and then applying the reasonableness test.

The latest WHO guidelines rely solely on pathogen monitoring to determine water treatment requirements. In Australia, only *Cryptosporidium* data is available for source water and this is expensive to acquire and requires expertise to interpret. It is not practical to acquire data for pathogenic viruses or bacteria. However, earlier versions of WHO (e.g. 1996) provided solid advice for water treatment requirements for the source categories adopted in the Tier 1 Assessment.

With respect to virus reduction, Section 10.2 of the 1996 WHO guidelines specified a minimum virus reduction of 4 log for Category 1 sources, 5 log for Category 2, 6 log for Category 3 and 7 log for Category 4 as shown in Table B2.

Table B2: Minimum Pathogen Reduction Requirement (WHO 1996)

Type of Source	Recommended Treatment ^(A)
Ground Water	
Protected, deep wells; essentially free of faecal contamination	Disinfection ^(B)
Unprotected, shallow wells; faecally contaminated	Filtration and disinfection
Surface water	
Protected, impounded upland water; essentially free of contamination	Disinfection
Unprotected impounded water or upland river; faecal contamination	Filtration and disinfection
Unprotected lowland rivers; faecal contamination	Pre-disinfection or storage, filtration, disinfection
Unprotected watershed; heavy faecal contamination	Pre-disinfection or storage, filtration, additional treatment and disinfection
Unprotected watershed; gross faecal contamination	Not recommended for drinking water supply

Notes:

- A** For all sources, the median value of turbidity before terminal disinfection must not exceed 1 nephelometric turbidity unit (NTU) and must not exceed 5 NTU in single samples.
 - Terminal disinfection must produce a residual concentration of free chlorine of 0.5 mg/litre after at least 30 minutes of contact in water at pH < 8.0, or must be shown to be an equivalent disinfection process in terms of the degree of enterovirus inactivation (>99.99%).
 - Filtration must be either slow sand filtration or rapid filtration (sand, dual or mixed media) preceded by adequate coagulation-flocculation (with sedimentation or flotation). Diatomaceous earth filtration or a filtration process demonstrated to be equivalent for virus reduction can also be used. The degree of virus reduction must be > 90%.
 - Additional treatment may consist of slow sand filtration, ozonation with granular activated carbon absorption, or any other process demonstrated to achieve >90% enterovirus reduction.
- B** Disinfection should be used if monitoring has shown the presence of *E. coli* or thermotolerant coliform bacteria.

With current knowledge of typical log reduction values for water treatment processes, the WHO recommendations have been back engineered and applied to the source categories used in this Manual to produce Table B3.

Table B3: LRVs Inferred from 1996 WHO Guidelines

Source Category	Minimum Pathogen Log Reduction Requirements		
	Bacteria	Virus	<i>Cryptosporidium</i>
1	4.0	4.0	0
2	5.0	5.0	2.5
3	6.0	6.0	3.5
4	7.0	7.0	5.0

Over the past decade, much work has been carried out by the USEPA in developing their surface water treatment rules. These rules concentrate on *Cryptosporidium* reduction requirements. The USEPA places sources into bins with required LRVs for *Cryptosporidium* of 2.5, 4, 5 and 5.5 log reduction values

for bins 1-4 respectively. (See *National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule*, p 675.)

With respect to virus, USEPA requires disinfection to achieve a minimum of 4 log reduction for virus and 3 log reduction for Giardia.

The USEPA does not specify treatment requirements for bacteria presumably on the basis that any requirement will be met if the virus criteria is achieved. The USEPA requirements could be summarised in Table B4.

Table B4: LRVs Inferred from USEPA Regulations

Bin	Minimum Pathogen Log Reduction Requirements		
	Bacteria	Virus	Cryptosporidium
1	N/A	4	2.5
2	N/A	4	4.0
3	N/A	4	5.0
4	N/A	4	5.5

Note that the bins apply to supplies which are filtered. Thus Bin 1 aligns with Category 2 in the Tier 1 Assessment in this Manual.

The WHO and USEPA guidance has been adapted for Australia according to the following rationale.

Cryptosporidium

Category 1 sources by definition have negligible sources of human infectious *Cryptosporidium* and therefore filtration is not required. USEPA suggest LRVs between 2.5 – 5.5 for *Cryptosporidium* in sources requiring filtration, while WHO infers 2.5 – 5.0 log.

This Manual has suggested LRVs between 2.5 – 5.5 log.

The treatment requirements recommended are broadly supported by evidence obtained within WaterRA Project 1036. This project showed that treatment requirements for protozoa ranged from 0 log to approximately 5.5 log for the several dozen water sources characterised in detail. Sources that had negligible human and stock activity in their catchments were essentially free of protozoa. Less protected catchments required reductions in the range 2.5 to 5 log which is a close match with the recommendations in this Manual.

The final recommendations in this Manual are consistent with those from the USEPA and other relevant jurisdictions, such as the New Zealand Ministry of Health. The close alignment between the requirements in these various jurisdictions provides some valuable mutual verification between these approaches.

The Category 3 requirements in this Manual have been chosen to allow the *Cryptosporidium* LRV to be met by a well-run conventional treatment plant.

Virus

The basic virus LRV in most jurisdictions seems to be 4 log. This is deemed too conservative for a Category 1 source where by definition there are negligible sources of human faecal contamination (and therefore human infectious virus). This Manual does not require virus reduction for Category 1 sources.

It seems logical that as source protection is relaxed the risk of contamination by human virus increases. Accordingly, requiring 4 log reduction for all source categories (as per USEPA) is not considered logical. For Category 2, 3 and 4 sources the virus LRVs proposed are 0.5 log higher than the *Cryptosporidium* requirements. This is broadly in line with published results, which show concentrations of enteric virus range from 0.7 to 4 times those of *Cryptosporidium* (NRMMC – EPHC 2006, Rose *et al.*, 1996, 2001)

Bacteria

Bacterial pathogens are present in all catchments, even those well-protected from human and agricultural activities. WHO infers a minimum of 4 log reduction for all sources. As for virus, it seems logical that bacterial pathogen load will increase as source protection is relaxed and more contaminating activities occur in the catchment. The maximum bacteria LRV has been aligned with the maximum virus LRV (6 log) and an intermediate LRV adopted for Category 2 and 3 sources.

Discounting Water Treatment Requirement

The Tier 1 approach attempts to match appropriate treatment to source challenge. This involves balancing international practice, recent research and reasonable assurance of water safety with unnecessary expenditure by utilities on additional treatment.

The Tier 1 approach to source assessment is inherently conservative and provides a high probability that when combined with the recommendations for water treatment in this Manual will provide safe drinking water which should meet an HBT of one µDALY.

It is possible to discount the generic LRVs in Table B1 if justified based on system knowledge. For example, to discount the virus requirement in a Category 3 source it would be necessary to demonstrate (via sanitary survey) that there were minimal sources of human faecal contamination in the catchment. Alternatively, if *Cryptosporidium* sampling had been carried out and genotyping showed no human sources then this too would provide justification for discounting the virus LRV requirement. It is a case of having sufficient knowledge of your system to justify modification of the generic requirements.

Thus, it is possible to end up with a mix and match scenario across categories e.g. Category 2 for viruses and Category 3 for bacteria and *Cryptosporidium*.

Conclusion

The LRVs proposed in Table B1 are logical and seem reasonable compared to international guidance. They are broadly in line with suggested LRVs in HBT discussion papers produced by NHMRC.

Table B5: Summary of guidance and requirements for treatment to control microbial pathogens in relevant Australian and overseas guidance and regulations

Current document	Type of source	Microbial group	Treatment requirements	Notes	
WHO GDWQ Guidelines for Drinking-water Quality 2011	Any potentially affected source used for potable water	Bacteria	Reduce to < 1/10 kL	Recommends jurisdictions refine this approach for their own context	
		Protozoa	Reduce to < 1/77 kL		
		Viruses	Reduce to < 1//91 kL		
AGWR Phase 2 Australian Guidelines for Water Recycling - Augmentation of Drinking Water Supplies 2008	Potable water derived from sewage	Bacteria	Reduce to < 1/18 kL	In regulation in Qld	
		Protozoa	Reduce to < 1/50 kL		
		Viruses	Reduce to < 1/395 kL		
USEPA LT2 Long-term 2 Enhanced Surface Water Treatment Rule 2006 [For supplies serving 10,000 people or more]	Surface water, or ground water under the influence of surface water	Protozoa (<i>Cryptosporidium</i>)	If mean < 0.075/L raw: 3 log reduction	Has a treatment and catchment protection log credit system to provide log credits for various measures.	
			If mean < 1/L raw: 4 log reduction		
	Protected catchment		If mean < 3/L raw: 5 log reduction		
			If mean ≥ 3/L raw: 5.5 log reduction		
	Any source water or uncovered source water storage		As evidence proves	Must use at least one additional disinfectant if beyond the 4-log reduction category	
CDWG Canadian Drinking Water Guidelines 2004: Supporting Documents	Any potentially affected source	Protozoa (<i>Cryptosporidium</i> and Giardia)	3 log reduction	There appears to be no get out for protected catchments, even uncovered reservoirs are included	
		Viruses	4 log reduction Must use either filtration and disinfection, or at least two different disinfectants		
DWSNZ Drinking Water	Human sewage-influenced	Viruses	None set, but noted as a risk	Insufficient evidence, but will include in future	

Current document	Type of source	Microbial group	Treatment requirements	Notes	
Standards New Zealand 2005 (revised 2008)	Secure bore water drawn from an unconfined aquifer 10 to 30 m deep	Protozoa (<i>Cryptosporidium</i> and <i>Giardia</i>)	3 log reduction	Defaults for supplies serving < 10,000 people.	
	Secure bore water drawn from deeper than 30 m		2 log reduction		
	Secure, interim secure, and provisionally secure bore water		0 log reduction		
	Springs and non-secure bore water 0 to 10 m deep		3 - 5 log reduction As per surface water in the overlying catchment (below)		
	Water from pastoral catchment with frequent high concentrations of cattle, sheep, horses or humans, or a waste treatment outfall nearby or upstream		5 log reduction		
	Water from pastoral catchment that always has low concentrations of cattle, sheep, horses or humans in immediate vicinity or upstream		4 log reduction		
	Water from forest, bush, scrub or tussock catchments with no agricultural activity		3 log reduction		
	Surface waters, springs, and non-secure bore water 0–10 m deep		5 log reduction [$\geq 1/L$ raw]	For supplies serving > 10,000 people. Requires sanitary inspection, <i>E. coli</i> and turbidity data to develop a more evidence-based revision, and seek to reduce pathogen monitoring requirements. Provides a log credit system for treatment, similar to USEPA.	
			4 log reduction [$< 1/L$ raw]		
			3 log reduction [$< 0.75/L$ raw]		

Figure B1: Example of the USEPA Long-term 2 Enhanced Surface Water Treatment Rule setting out the water treatment requirements to meet health-based targets

TABLE IV.B-2.—TREATMENT REQUIREMENTS FOR LT2ESWTR BIN CLASSIFICATIONS			
If your bin classification is . . .	And you use the following filtration treatment in full compliance with the SWTR, IESWTR, and LT1ESWTR (as applicable), then your additional treatment requirements are . . .		
	Conventional filtration treatment ¹ , diatomaceous earth filtration, or slow sand filtration	Direct filtration	Alternative filtration technologies
Bin 1	No additional treatment	No additional treatment	No additional treatment.
Bin 2	1-log treatment ²	1.5-log treatment ²	As determined by the State ^{2,4}
Bin 3	2-log treatment ³	2.5-log treatment ³	As determined by the State ^{3,5}
Bin 4	2.5-log treatment ³	3-log treatment ³	As determined by the State ^{3,6}

¹ Applies to a treatment train using separate, sequential, unit processes for coagulation/flocculation, clarification, and granular media filtration. Clarification includes any solid/liquid separation process following coagulation where accumulated solids are removed during this separate component of the treatment system.

² PWSs may use any technology or combination of technologies from the microbial toolbox in section IV.D.

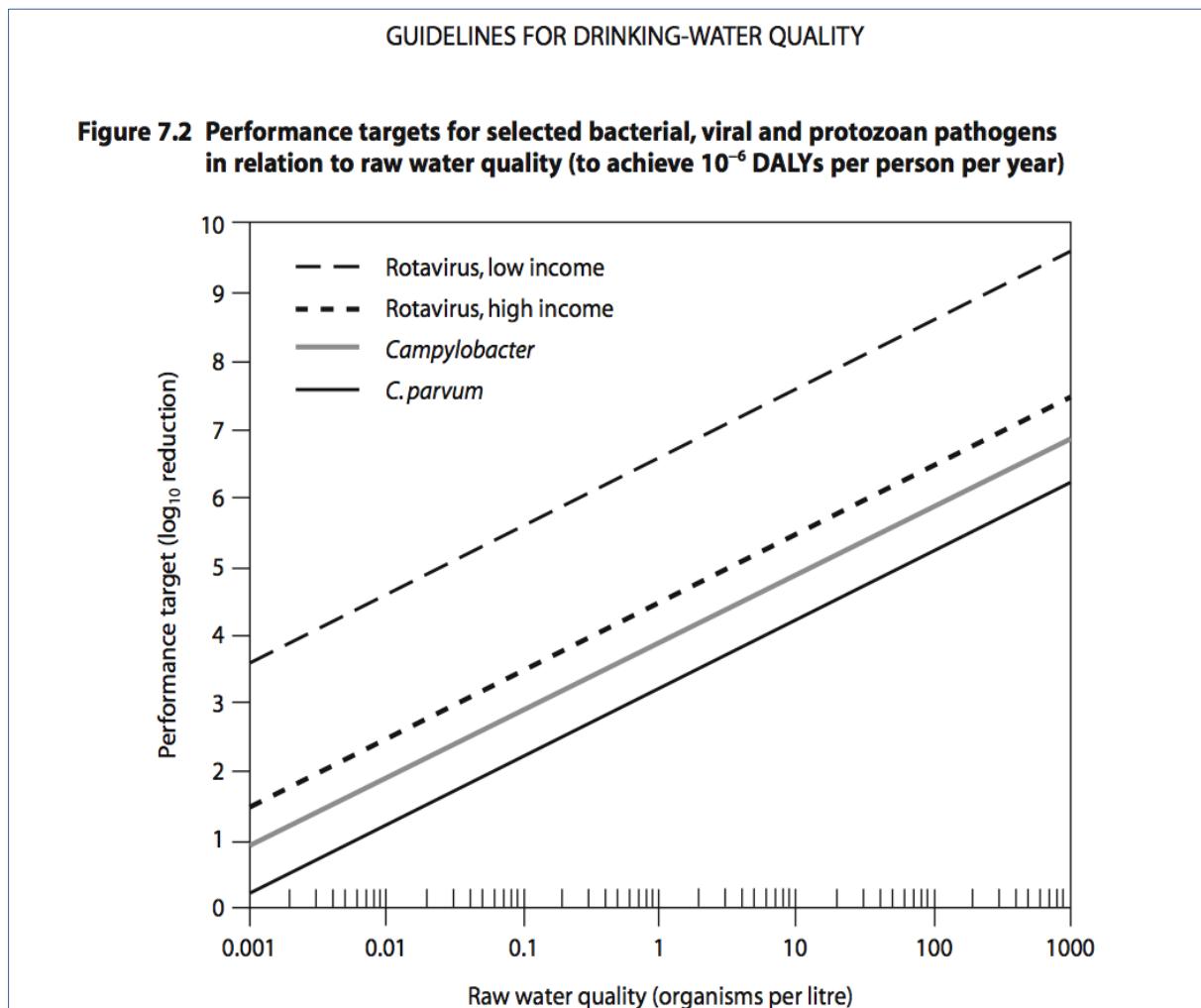
³ PWSs must achieve at least 1-log of the required treatment using ozone, chlorine dioxide, UV, membranes, bag filtration, cartridge filtration, or bank filtration.

⁴ Total Cryptosporidium removal and inactivation must be at least 4.0 log.

⁵ Total Cryptosporidium removal and inactivation must be at least 5.0 log.

⁶ Total Cryptosporidium removal and inactivation must be at least 5.5 log.

Figure B2: Example of the WHO Guidelines for Drinking-water Quality summary figure setting out the water treatment requirements to meet health-based targets



Appendix C – Tier 2: Analysis of Pathogen Data

Introduction

Risk characterisation of catchments and source waters is the first step in implementing microbial HBTs. This is consistent with the know-your-system approach adopted in the Australian Drinking Water Guidelines (ADWG) (NHMRC/NRMMC, 2011) Framework for Management of Drinking Water Quality.

As a mandatory requirement, water utilities should undertake a sanitary survey of their catchments and assess this together with data on raw water quality including *E. coli* and turbidity loads. The assumptions made in the Tier 1 risk assessment should tend to be conservative in the face of uncertainty, consistent with the well-established precautionary principle. This process is discussed under Tier 1: Source Water Assessment Guidance (see Appendix A).

A full quantitative microbial risk assessment (QMRA) or Tier 2 analysis can be undertaken in those situations where greater definition of the pathogen risk is required. It is recommended that Tier 2: Analysis of Pathogen Data is only undertaken for Category 4 sources. It may also be considered for Category 3 sources that are run of river and the capacity for pathogen inactivation through storage is reduced. The uncertainty around the pathogen risk in these situations may prompt the undertaking of a Tier 2 risk assessment. Undertaking QMRA on sources that rate as Category 2 or 3 based on the Tier 1 risk assessment that have adequate storage is not warranted because:

- the good practice operation of conventional and direct filtration plants is sufficient to meet the required LRVs for these source categories
- multiple barriers are present to reduce risk i.e. catchment protection and storage and hence there is typically no need for capital upgrades to treatment to supply additional barriers.

In contrast, even well run direct filtration and conventional filtration treatment plants will require additional treatment barriers (e.g. UV) to meet the default LRVs of a Category 4 source (e.g. 5.5 log reduction for *Cryptosporidium*). This is in addition to not meeting the multiple barrier requirements of the ADWG due to the absence of catchment and storage barriers. This has capital and operating cost implications. In these cases, better definition of risk by QMRA may be required for planning decisions.

The Tier 2 approach provides for the characterisation of annual risk (Component 1) that includes event data (Component 2). Both components need to be undertaken to complete the Tier 2 assessment.

The two component approach is based on the observation that in some cases, high risk events tend to be sporadic with relatively lower risk conditions prevailing for the majority of the time. A two component risk characterisation based on QMRA allows plant operators choices in the way plants can be operated to reduce risks by:

- providing an understanding of treatment requirements under ‘normal’ risk conditions
- identifying opportunities for avoidance by turning the plant off during high risk events
- optimising multiple barrier operation to reduce risk to an acceptable level cost effectively
- avoiding the use of additional barriers if the risk can be shown to be low enough during ‘normal’ conditions and taking into account peak risk events.

A QMRA requires well managed, targeted and extensive monitoring for the relevant pathogens in order to obtain robust and meaningful datasets for analysis. Given the level of expertise required, cost of pathogen analysis and laboratory availability, this option is not available or cost effective for some

water utilities. In this case, operational and capital treatment improvements should be based on the default values obtained through the Tier 1 risk assessment.

It should also be noted that even a QMRA will be limited by uncertainty namely:

- the inability to fully determine the infectivity or human pathogenicity of pathogen isolates
- the uncertainty of pathogen recovery from environmental samples
- the uncertainty of pathogen data which reflects concentrations at a fixed temporal and spatial point in a relatively small volume, against a highly variable true concentration.

In cases where a water utility intends to undertake a Tier 2 QMRA assessment, some consideration needs to be given to appropriate data handling and risk calculation. This will address and reduce the inherent uncertainties and ensure that the risk outcome is suitably conservative. It is important that the calculation of risk is standardised across water utilities to ensure the consistent application of HBTs. Some of the assumptions that should be used in a QMRA are discussed below. Default values and assumptions are summarised in Table C1. An example QMRA is also included for reference.

This Appendix discusses the approach and assumptions used to quantify the health risk associated with treated drinking water. The primary focus of this Appendix is *Cryptosporidium* but the same approaches can be used for the other reference pathogens, *Campylobacter* and *rotavirus* (or *norovirus*), provided the assumptions around infectivity, probability of infection and probability of illness are adjusted to suit the pathogen. Table 7.4 of the WHO Guidelines for Drinking-water Quality (WHO, 2011) has guidance on some of these assumptions for *Campylobacter* and *rotavirus* (or *norovirus*).

Tier 2 Monitoring

Component 1 Annual risk characterisation monitoring

The first component of the Tier 2 approach involves assessing the annual risk under average conditions. Undertaking any meaningful QMRA analysis requires extensive and robust water quality datasets. In particular, datasets need to contain sufficient positive samples to allow the calculation of a mean value that provides some level of certainty of the challenge to treatment. It is proposed that at least 12 positive samples (including the maximum value obtained from each Component 2 event sampling occasion – see below) should be included in the annual risk calculation dataset.

In addition, the number of positive samples obtained from existing Category 4 source *Cryptosporidium* monitoring datasets, was between approx. 7% and 14%. Based on this detection rate, around 100 samples would be required to provide a minimum number of positive samples to characterise pathogen concentrations and their variability with any real certainty.

In order to account for seasonality and changing raw water conditions, the initial sampling program to describe treatment requirements must be undertaken over at least one year based on evenly spaced samples.

Recommendation: It is recommended that the initial monitoring program, to determine the annual risk (Component 1), continues until 12 positive samples (including the maximum value obtained from each Component 2 event sampling occasion) are obtained or 100 samples are taken over at least one year, whichever comes first.

The monitoring program should not be a one-off undertaking. This is particularly relevant for a Category 4 source where the mean value may change over time with varying catchment and environmental conditions. It is therefore recommended that the annual risk monitoring program be maintained to add

to the dataset and identify any change in annual risk at reduced sampling frequency. This will also add to the robustness of the dataset and hence the accuracy of the risk assessment.

It is recommended that an ongoing monitoring program be undertaken with a rolling mean to monitor trends over time. This monitoring program should include the provision to capture treatable events (see Component 2 Event risk characterisation below). The monitoring program should be accompanied by a yearly review of the Tier 1: Source Water Assessment. The outcomes of the review may dictate the frequency of ongoing sampling but monthly sampling is suggested as best practice.

If the Tier 1 assessment review identifies a significant increase in potential *Cryptosporidium* inputs in a catchment or ongoing monitoring identifies an increase in the mean oocyst concentrations, the annual risk characterisation monitoring program should be reinitiated based on the assumptions outlined above.

It is essential that the prevailing conditions during sampling periods are reviewed. It may be that conditions were unusual in some respect, e.g. much wetter or much drier than normal, or some specific source of pathogens have been included or excluded. The review of prevailing conditions should be highlighted and discussed as part of the QMRA to identify if further monitoring and a revision of the QMRA is required. This is a particular problem in Australia where water catchments behave very differently during La Niña and El Niño or wet and dry period scenarios, with those periods often lasting for many years each.

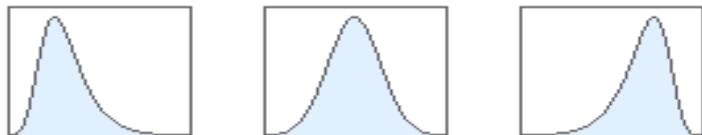
Recommendation: It is recommended that an ongoing monitoring program be undertaken with a rolling mean and that the program includes the capture of ‘treatable’ events. The frequency of monitoring should be linked to an annual review of the Tier 1 Source Water assessment but monthly sampling should be considered as best practice. A change in risk inputs or mean oocyst concentration should initiate an annual risk characterisation monitoring program.

Component 2 Event risk characterisation

The second component of the Tier 2 assessment involves determining the maximum *Cryptosporidium* oocyst concentration during a treatable event. A treatable event is where a water treatment plant may be challenged but can still treat and supply water within critical limits. It is important to include the maximum oocyst concentration in the dataset as this increased exposure risk contributes to the annual disease burden. The prevailing conditions which lead to a peak risk event should be identified during the Tier 1 assessment but are usually derived from wet weather events when pathogens are more likely to be mobilised in catchments.

The maximum oocyst concentration observed during each occasion of event monitoring is included in the annual risk monitoring dataset as a point value. In order to ensure the maximum oocyst concentration has been defined, it is important that the shape of the event risk curve is described in terms of pathogen concentration. This approach also assists in describing risk events to support treatment management decisions (e.g. establishing predictors for avoidance and trigger set points). The distribution of event pathogen concentrations may take three forms (Figure C1). As an example, right skewed distributions may represent a ‘first-flush’ scenario where the initial inflow to a system represents the greatest risk and the ideal time to avoid treatment if possible.

Figure C1: Examples of event pathogen concentration distributions



Event characterisation monitoring programs should therefore be designed to maximise the chance of capturing the maximum oocyst concentration for that event. This may include capturing discrete time based samples over the event. The timing between samples should be established based on expert judgement and historical evidence for each source. The trigger for commencing the sampling should be based on the risk conditions identified through the Tier 1 assessment. For example, if wet weather events are identified as the greatest risk then an increase in flows or river level would be an appropriate trigger to commence event sampling, which may be hourly at the start of the event and less frequent towards the end.

Composite sampling should not be used as it:

- prevents the shape of the event from being described
- produces an average event pathogen concentration rather than a maximum
- leads to an underestimation of the peak risk and hence treatment requirement.

Experience suggests that each event could be unique and so cause a different risk level. For this reason it is recommended that at least two and preferably more events are characterised as part of the initial Tier 2 analysis. At least one of the events should target sampling around those times when pathogens are most likely to be present to maximise the risk characterisation. This should be based on the outcomes of the Tier 1 analysis. For example, if the main source of risk is intensive stock farming event monitoring to describe the peak *Cryptosporidium* risk could be focused around the time of calving/lambing in spring. Similarly if the main risk from *Cryptosporidium* is identified as STPs, event sampling could target summer months to include the increased incidence of cryptosporidiosis in the community.

As for Component 1 of the Tier 2 analysis, it is recommended that event sampling continue as part of an ongoing monitoring regime, particularly if only two events have been captured in the annual risk monitoring dataset.

Outcomes of Component 2 Event risk characterisation monitoring should also be considered in their own right as representing periods of greatest risk that could potentially be avoided or may require greater focus on operational parameters.

Recommendation: It is recommended that the monitoring program to characterise event risks (Component 2) includes at least two and preferably more events and that the program includes the ability to describe an event temporally. At least one event sampling occasion should be during a time of greatest risk based on outcomes of the Tier 1 assessment. Event sampling should continue as part of an ongoing monitoring regime, particularly if only two events have been captured in the initial Tier 2 monitoring dataset.

Extreme Events

An extreme event is defined as an untreatable period when a source water challenge results in a water filtration plant's critical limits being exceeded to the point that the source water is closed off, the treatment plant is shut down or a boil-water advisory is issued. Such events should not be included in

the assessment of a plant's ability to produce water that meets an annual health based target as water is not being supplied.

Nevertheless, these extraordinary event circumstances can be characterised under Component 2 based on pathogen concentration data up to the point that water supply is stopped. This will assist in characterising pathogen risks while water was being supplied and also assist in the development of event management procedures.

Data quality

Existing or historical data

Existing or historical datasets can only be used if they comply with the requirements outlined in the recommendations for Component 1 and Component 2 of the Tier 2 Monitoring. This is the mean value determined from a dataset containing either 12 positive samples or 100 samples, and the maximum oocyst concentrations from at least two and preferably more events where the event has been described temporally. At least one event should be during a high risk period based on likely pathogen inputs from the Tier 1 analysis. In addition to these conditions, existing or historical datasets are only suitable for Tier 2 assessment if the data complies with the quality requirements outlined in this section.

Data quality requirements

Pathogen data used in both components of the QMRA must reflect the challenge to a water filtration plant and should be taken from the plant inlet. Using catchment or source water storage samples in a QMRA would exclude the inactivation and reduction credits that are provided by catchment processes and may lead to an overestimation of the risk.

The recovery efficiency from samples can have a substantial impact on the calculated concentrations of pathogens in the water and hence the treatment LRVs required to meet the HBT. There is typically a wide range of pathogen recovery efficiencies from environmental waters and to account for this every sample needs to include an internal recovery control for the concentration step of the process.

Data quality is critical to QMRA rigour by reducing inherent error. It is essential that test data and laboratory quality control performance are regularly reviewed (e.g. weekly) and discussed by the water utility and laboratory during the sampling program. This will assist in identifying any anomalies that may require timely corrective action and avoid wasting resources.

To further ensure confidence in the data, the QMRA sampling program contract should require a laboratory to participate in a proficiency testing (PT) program accredited to ISO 17043 that includes analytes, analyte concentrations and water matrices relevant to the samples being tested. Blank samples should be included in the PT program. The water utility should discuss proficiency testing performance with the laboratory.

Statistical analysis of Tier 2 monitoring datasets

Various statistics could be used to calculate the concentration of pathogens in inflow waters to a plant and hence the log reductions required to reduce the annual risk to meet the HBT. These include the mean, median or 95th percentile.

Given the nature of environmental pathogen datasets (typically only a small number of positive results with the majority of results being not detected, less than the limit of detection (LOD) or zero),

calculation of the median would provide a nonsensical value of <LOD, or zero, which is of little use in calculating the required log reductions for a treatment process.

Similarly, the calculation of the 95th percentile can result in an overly conservative assessment of the risk as it tends to reflect only the one or two positive samples with the greatest pathogen concentration. Whilst it is arguable that this indicates the worst case for a plant, it should be noted that the one µDALY target is an annual average and that for the majority of the time the challenge to a plant is relatively low.

There is now broad agreement that the most appropriate statistic to use is the arithmetic mean of the data, including all samples with a non-detect result. There is, however, some debate around how to handle non-detect results. The two approaches most used include replacing non-detects with half the limit of detection and replacing non-detects with zero.

While using half the limit of detection is often proposed as an acceptable way to deal with non-detect results, the approach typically results in an overly conservative estimated mean value. This is particularly the case in datasets where there is a high proportion of non-detects that are replaced with a relatively large estimated value dependent on the recovery rate and sample volume analysed. Indeed the ADWG 2011 (NHMRC/NRMMC 2011) recommends that this approach only be used when the proportion of substituted data is relatively low, which is usually not the case with pathogen data in source waters.

The approach used by the USEPA LT2ESWTR (USEPA, 2006) is to substitute non-detect results with zero. In contrast to the half-the-limit-of-detection approach, replacing non-detects with zero will provide an underestimation of the true mean. This is because it is assumed that the pathogen concentration in a sample would be greater than zero if a sufficiently large sample volume was analysed. Nevertheless, replacing non-detects with zero will provide an estimated mean which is likely to be closer to the true mean compared to that of the half-the-limit-of-detection approach, particularly when there is a high proportion of non-detects.

The calculation of the arithmetic mean should be sufficiently robust unless treatment requirements emerging from this calculation are at a borderline level for decision-making. In this case more robust statistical methods should be applied to provide a closer estimate of the true mean. Methods such as boot strapping to provide a data distribution and Monte Carlo simulation to calculate risk can be used to provide a more accurate risk estimate. These techniques are available in commercial statistical packages. This approach, however, requires specialist analysis due to the peculiarities of fitting appropriate frequency distributions to microbial count data. While the generic statistical methods and approaches are reasonably commonplace, and the mathematical tools are easy to use, there are many traps for the inexperienced in this area. For more details refer to the WHO QMRA water-related QMRA monograph (WHO in preparation).

Assumption: The arithmetic mean should be used to calculate the annual risk. Non-detect values should be replaced by zero.

Statistical Analysis of event risk datasets

The maximum value for each event monitoring occasion should be included in the Tier 2 Monitoring dataset as a single value input.

Assumption: The maximum value obtained during each event monitoring occasion should be included in the Tier 2 Monitoring dataset.

Recovery, human pathogenicity and infectivity of *Cryptosporidium* recovery

All positive samples should be adjusted for recovery. In the case of *Cryptosporidium*, this is possible with the introduction of an internal control, which allows the recovery for each sample to be determined.

The HBT risk calculation is based on the concentration of *Cryptosporidium* per litre (volume of cold water consumed per day). Given that volumes of source water greater than one litre are typically analysed, oocyst concentrations should be reported per litre for each sample.

Assumption: Adjust all positive results for recovery and volume. Source-water pathogen concentrations should be calculated per litre.

Human pathogenicity

Not all oocysts found in source water can infect humans. Out of the numerous *Cryptosporidium* species that may be found in source waters only two, *C. parvum* and *C. hominis*, cause the majority of waterborne disease. Based on this, the survey of *Cryptosporidium* species in a catchment can provide important information of the risk posed by this pathogen. For example, if an extensive genotyping program shows that no human pathogenic species are present in a catchment the public health risk from *Cryptosporidium* in treated water would be not significant regardless of the oocyst concentration in the source water. In contrast, genotyping of isolates may confirm high risk inputs of *C. parvum* and *C. hominis*, such as from dairy farms, intensive ruminant rearing, farming and processing operations, wastewater treatment plant discharges and/or areas relying on on-site sanitation, as identified during the Tier 1: Source Water Assessment.

Genotyping of oocyst isolates should therefore be undertaken as a priority to establish the risk profile of a source water and can potentially lead to reductions in the treatment requirements to meet the HBT. However, the lack of national genotyping data (genotyping is not accessible to or routinely performed by most water utilities) and the variation of inputs on a catchment-by-catchment basis makes it difficult to set defendable assumptions on the pathogenicity of isolated *Cryptosporidium*. In the absence of any recognised catchment-by-catchment assumption values, it should be assumed that 100% of isolated oocysts are human pathogenic. It is acknowledged that a default position of 100% human pathogenic may be overly precautionary but there is insufficient data to provide a defendable lower default value.

This default value can be revised down from 100% on a case-by-case basis through genotypic characterisation of oocysts. Such characterisation, however, needs to cover several years and the full range of treatable events in order to be credible. It can be safely assumed that oocysts isolated from human sewage sources are 100% human pathogenic.

Assumption: Individual positive results should be calculated assuming oocysts are 100% human-pathogenic. The default value can be adjusted down based on extensive genotyping of catchment oocyst isolates.

Infectivity

If genotyping has shown that there are no human pathogenic *Cryptosporidium* present then there is little value in determining infectivity. In the absence of genotyping, however, infectivity testing can be used to demonstrate reduced risk.

Not all oocysts isolated from the environment are able to cause infection. Oocyst infectivity will be reduced by environmental factors such as temperature, sunlight and storage residence time, while

effective treatment of wastewater discharges to source water catchments (e.g. by UV disinfection) will also result in reduced oocyst infectivity.

A number of methods have been used to determine oocyst infectivity including excystation, mouse infectivity, propidium iodide/DAPI staining and cell culture infection. It is now widely acknowledged that neither excystation nor propidium iodide/DAPI staining are appropriate measures of oocyst infectivity. Mouse infectivity assays are highly specialised and typically not available to the majority of water utilities. Cell-culture methods are currently considered the best measure of *Cryptosporidium* infectivity but cannot be performed easily or routinely on the low numbers of *Cryptosporidium* typically isolated from source waters.

Nevertheless, some adjustment for infectivity needs to be included in a health based target risk calculation to avoid defaulting to the false assumption that all detected oocysts are infectious.

For source waters derived from run of the river supplies (shorter residence times) or catchments with intensive stock farming, high urbanisation and hence wastewater impacts (particularly poorly treated wastewater) in close proximity to source water off takes, a default adjustment of 30% oocyst infectivity is appropriate. This would apply to source waters that fall into the Category 4 (unprotected catchment) from a Tier 1: Water Treatment Requirement Assessment or potentially higher risk Category 3 run of river sources.

Similar to the human pathogenicity correction, the default value can be revised based on extensive infectivity screening of oocyst isolates by cell-culture techniques. Such characterisation, however, needs to cover several years of annual or background monitoring (Component 1) and treatable event monitoring (Component 2) in order to be credible.

Note that where the recycled water guidelines apply to potable reuse or reuse of wastewater, an assumption of 100% infectivity remains appropriate since the infectious proportion of oocysts in fresh wastewater is approximately the same as the infectious proportion of oocysts used for human feeding trials, and hence for the dose-response relationships that underpin the QMRA.

Assumption: Individual positive results should be adjusted by a default value of 30% oocyst infectivity based on a Category 4 source determined by Tier 1: Source Water Assessment. It should also be applied to data from higher risk Category 3 source where the pathogen risk is uncertain and a Tier 2 has been undertaken. The default adjustment value can be revised based on extensive infectivity screening of isolates using cell-culture methods.

Presumptive vs. confirmed oocyst counts

The *Cryptosporidium* detection method provides a presumptive total oocyst count based on immunofluorescence antibody staining (presumptive IFA count). There is some potential, however, for cross-reaction of the antibody with other *Cryptosporidium*-like organisms leading to the overestimation of risk. For this reason, additional steps have been included in routine methods to confirm the presence of *Cryptosporidium*. A confirmed count is based on 4',6-diamidino-2-phenylindole (DAPI) staining of the internal nucleic acid and the observation of typical internal structures by differential interference contrast microscopy (DIC), as described in Method 1623: *Cryptosporidium and Giardia in Water by Filtration/IMS/FA* (USEPA, 2005). *Cryptosporidium* counts can then be expressed as either presumptive IFA counts, confirmed IFA counts or as DAPI and DIC counts of confirmed oocysts.

Using the DAPI confirmation step only in a risk calculation will tend to underestimate the number of actual oocysts isolated from a sample, and hence the risk. This is because the success of the DAPI confirmation method to stain oocysts is variable and fresh oocysts with robust oocyst walls are less

likely to take up the stain, resulting in a negative confirmation result. The current USEPA 1623 method (USEPA, 2005) addresses this by using both DAPI and DIC to confirm the identity of IFA positive oocysts. While more time consuming to perform, the DIC method relies on visualising the internal structures of oocysts by light microscopy and is not reliant on stain penetrating the oocyst wall. Ideally the assessment of IFA positive isolates should therefore involve examining intact, whole oocysts by DAPI first and then using DIC as a further confirmation step for those intact whole oocysts that are DAPI negative. This dual approach reduces the underestimation of the oocyst count based on DAPI alone. The confirmed count comprises all intact oocysts that are confirmed by DAPI and/or DIC. Cells that are negative for both DAPI and DIC are not confirmed oocysts. Care should be taken not to double-count oocysts that are both DAPI and DIC positive.

For the purpose of calculating the mean oocyst concentration for QMRA, the confirmed count should be used. It is acknowledged that not all routine laboratories perform both DAPI and DIC confirmation. In this case, the positive IFA (presumptive) oocyst count should be used to avoid underestimation. It should be noted that analysis of large datasets has found that although conservative, the difference between the means estimated from the presumptive IFA count compared to the confirmed count is often quite small in practice and therefore this approach is not considered excessively conservative.

Assumption: Preferably, the arithmetic mean oocyst concentration should be calculated based on the confirmed oocyst count. Double counting of confirmed oocysts by the two methods must be avoided. Where confirmed oocyst counts are not available the presumptive IFA count should be used to calculate the oocyst concentration.

Other pathogens

Together with *Cryptosporidium*, the health-based targets also include a reference pathogenic bacterium (*Campylobacter*) and a reference pathogenic virus (either *norovirus* or *rotavirus*). There is very little source water data for these organisms in Australia and limited laboratory capability to assess their infectivity (there is no current method to determine the infectivity of *norovirus*). In practice, reliable disinfection using adequate chlorine dose and contact time (adjusted for pH and temperature) in low-particulate water (ground water or filtered or well-settled surface water) will decisively and reliably inactivate these pathogens. Effective water filtration will also physically reduce bacterial and viral concentrations. An estimate of the filtration and disinfection requirements can be obtained from Tier 1: Source Water Assessment.

Where pollution sources are excessive with respect to viral and bacterial pathogens, these conditions would also present a high risk from protozoan pathogens. When disinfection treatment alone might be inadequate for viruses and bacteria, the requirement for protozoa treatment would be expected to trigger the types of additional treatment that would mitigate any elevated viral and bacterial risks. Therefore, the protozoan pathogens become the limiting factor and the focus of attention. In the absence of major point source pollution inputs, such as proportionally significant sewage discharges and others that trigger the need for protozoan pathogen treatment, reasonably foreseeable source water concentrations of bacterial and viral pathogens will be readily inactivated to below levels that could potentially lead to disease burdens exceeding the one µDALY target.

Table C1: Summary of recommended QMRA assumptions

Parameter	Default Calculation/Assumption	Comments
<i>Cryptosporidium</i> concentration	Arithmetic mean of confirmed oocysts. Adjust for recovery and volume	Use the presumptive IFA count if the confirmed count (defined above) is not reported. Avoid double counting confirmed oocysts when using DAPI/DIC.
Human pathogenicity	Assume 100% <i>C. parvum</i> or <i>C. hominis</i> unless it can be shown otherwise	Default: use 100% human-pathogenic oocysts. Reduction in the 100% human pathogenicity criteria can be justified through extensive genotyping. Note: 100% human-infectivity would be assumed for fresh sewage samples in water recycling projects.
Infectivity	For Cat 4 sources and Cat 3 sources that are run of river assume 30% infectivity, unless it can be shown otherwise. For Cat 2 & 3 surface water sources assume 10% infectivity, unless it can be shown otherwise.	Source Category based on outcomes of Tier 1 Semi-quantitative risk assessment Default: use 30% infectivity e.g. risk inputs are close to abstraction points, run of river sources, high human impacts in close proximity to abstraction points. Assumes Tier 2 being carried out for Cat 4 sources and Cat 3 run of river sources. Default values can be discounted based on extensive infectivity testing.
Mean (Component 1)	Arithmetic mean of a dataset that contains either 12 positive samples or a minimum of 100 samples collected over at least one year, whichever comes first	Do not include results from untreatable events when water is not supplied. Include maximum event oocyst concentrations as a point value and one of the twelve positive samples. Maintain sampling with a rolling average. Frequency of sampling must be linked to an annual review of the Tier 1 assessment but monthly sampling is advised.
Maximum (Component 2)	Use maximum oocyst concentrations from each of at least 2 events and preferably more events as a point value in the Tier 2 monitoring dataset	Individual event samples are discrete rather than composite. Events are described temporally. Sampling is based on appropriate triggers determined by Tier 1 assessment. Event program to include at least one high risk period related to the risk sources identified by the Tier 1 assessment. Ongoing event monitoring is required.
Non-detects	Non-detects to be replaced with 0	More sophisticated statistical techniques, expertly applied, can be used in some cases and this may be worthwhile for borderline situations using stochastic QMRA.

Parameter	Default Calculation/Assumption	Comments
Exposure per event	1 L	Based on the estimate of drinking cold drinking water (Mons <i>et al.</i> , 2005). Note that in northern Australia, exposures closer to 1.5 or 2 L are more likely to be correct.
Probability of infection	0.2	WHO Guidelines for Drinking-water Quality (2011). This is not the most conservative value available but is considered by the WHO expert group (Medema <i>et al.</i> , 2009) to be the most appropriate for drinking water.
Proportion of infection leading to illness	0.7	WHO Guidelines for Drinking-water Quality (2011)
DALYs per <i>Cryptosporidium</i> case	2.46×10^{-3}	As described in 'Establishing Australian Health based targets for microbial water quality' (Leder <i>et al.</i> , 2012)
Proportion of population susceptible to illness	1	Assume 100% of population is susceptible to illness

Calculations

Component 1 Annual or background risk characterisation

The required treatment LRV is determined by calculating the DALYs per person per year for the source water (Table C2) based on the mean oocyst concentration at the inlet to the water treatment plant and taking into account the various assumptions noted above. The difference between the calculated DALYs and the one μ DALY health based target provides the required LRVs from treatment.

Table C2: Example of annual or background risk QMRA and required treatment log reduction calculation

	Factor	Values	Notes	Formula
a	Oocysts per L in source water (IFA positive)	0.273	A	
b	Exposure per event (litres)	1	B	
c	Dose per event (orgs)	0.273		a x b
d	Number of events per year	365		
e	Dose per year	99.645		c x d
f	Probability of infection per organism	0.2	C	
g	Probability of infection per year	19.929		e x f
h	Proportion of infection leading to illness	0.7	D	
i	Probability of illness per year	13.950		g x h
j	DALYs per case	0.00246	E	
k	Proportion of population susceptible to illness	1	F	
l	Source water DALYs per person per year	3.43×10^{-2}		i x j x k
	Required treatment log reduction	4.5	G	$\log(l/10^{-6})$

Notes:

A arithmetic mean = 0.273 oocysts/L from 100 weekly routine samples over at least one year*, non-detects as '0', presumptive IFA count (only DAPI used for confirmation) adjusted for volume and recovery, 100% human pathogenicity, 30% infectivity based on sanitary survey.

B 1L of drinking water consumer per day

C WHO Guidelines for Drinking-water Quality (2011)

D WHO Guidelines for Drinking-water Quality (2011)

E As described in Establishing Australian Health based targets for microbial water quality (Leder *et al.*, 2012)

F Assume 100% of population is susceptible to illness

G Required treatment log reduction to meet one μ DALY

* Tier 1 = Category 4 source. This dataset contains oocyst concentrations from fourteen positive samples with three of the data points representing the maximum oocyst concentration from each of three events. The data set was collected under non-drought conditions (2011-2013).

Final comments on pathogen monitoring

Some utilities have been monitoring *Cryptosporidium* for many years and recommend caution before embarking on a pathogen monitoring program. Apart from the sources of uncertainty outlined in the introduction, Australian experience is that even some high risk or Category 4 sources may only return a low percentage of positive samples.

It is important to note, therefore, that there is a small but real risk that a data set of even 100 samples could contain no positive samples. In this case it would be impossible to undertake a QMRA and hard to justify the expense of pathogen monitoring. As a result, utilities embarking on a pathogen monitoring program to reduce uncertainty of the Tier 1 source risk assessment need to make this decision with due consideration. This situation emphasises the need for expert interpretation of pathogen results and their statistical analysis as stated in 3.2.3

The HBT Group identified that it is possible to have no or a very low number of *Cryptosporidium* detections from catchments carrying obvious sources of pathogens. Such monitoring outcomes should not justify classifying the source as no or low risk. To counter this scenario this Manual requires the Tier 1 and Tier 2 assessments to support each other. Where this is not the case, further investigation should be carried out to better understand the system. As a further safeguard the Manual allows the vulnerability assessment (Tier 1) to be discounted to the bottom of the water treatment band indicated by the Tier 1 vulnerability assessment i.e. Category 4 Sources can be discounted down to 3.5 log

reduction for protozoa but no further. Table C3 provides mean *Cryptosporidium* oocyst concentrations that may be expected for each of the log reduction requirements (in 0.5 log increments) for a Category 4 source (Table C3).

Table C3: Examples of recovery adjusted mean *Cryptosporidium* oocyst concentrations relevant to Category 4 log reduction requirements

Mean oocysts per 10 L at inlet to plant	LRV required
80	5.5
24	5.0
8	4.5
2.4	4.0
0.8	3.5

Note: LRVs required based on 50 samples, adjusted for 50% recovery from each sample but not adjusted for infectivity.

As a further example, in order to achieve the lowest LRV for a Category 4 source i.e. 3.5 LRV, a maximum concentration of 3 oocysts/10L one occasion, 2 oocysts/10L on 4 occasions and 1 oocyst/10L on 7 occasions resulting in 12 positives out of 50 samples (with a 50% recovery for each positive sample) would provide a mean oocyst concentration of 0.024/L and a required LRV of 3.5.

References

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Appendix D – Water Treatment Log Reduction Guidance

Background

Many water treatment processes are used to remove and inactivate pathogens. Their performance is often quoted as a log reduction value (LRV) which allows comparisons between processes and also matching treatment to different source categories.

To achieve the nominal LRV the particular water treatment process must be operated to achieve a strict performance envelope. This envelope typically involves a parameter which can be continuously measured (such as filtrate turbidity) and the duration that the particular performance must be achieved (e.g. filtrate turbidity less than 0.15 NTU for 95% of the month, and not greater than 0.3 NTU for more than 15 consecutive minutes at any time during the month (measured on the outlet of individual filters).

It was understood from the outset that individual validation of pathogen reduction by the thousands of water treatment plants across Australia was not practical. As an alternative, it would be necessary to agree on default LRVs for typical treatment processes. Provided a WTP was operated within strict criteria, it would be possible to claim the default LRV. The role of the HBT working group was therefore to establish these default LRVs, primarily by reviewing what had already been accepted by reputable overseas agencies.

Review of International Guidance

LRVs adopted by USEPA, Health Canada, NZ Guidelines and ADWG were reviewed. Table D1 summarises the default LRVs recommended by the WSAA working group. Further details are provided in the sections below.

Table D1: Recommended Pathogen Log Reduction Values (LRVs)

Process	Log Reduction Value		
	Bacteria	Virus	Cryptosporidium
Coagulation, flocculation, sedimentation ⁽¹⁾	1.0	1.0	0.5
Coagulation, flocculation, DAF (well operated) ⁽¹⁾	1.0	1.0	1.0
Granular Media filtration (including GAC, BAC, FRP, Gyrosand, Dynasand) following well operated coagulation and flocculation (see Section 5.4)	1.0	1.0	2.5-3.5 ⁽²⁾
Direct Filtration ⁽³⁾	1.0	1.0	2.5-3.5
Conventional Filtration ⁽⁴⁾	2.0	2.0	3-4
Slow Sand Filtration (after filter ripening)	2.0	2.0	3.0 (as 1st stage) 2.5 (as 2nd stage)
Diatomaceous Earth Filtration	1.0	1.0	3.0
Micro-filtration ⁽⁵⁾	3.0	1.0	3.0
Ultra-filtration ⁽⁵⁾	3.0	2.5	3.0
Second stage granular media filtration (typically GAC), following solids removal & filtration or direct filtration as first stage	1.0	1.0	0.5
Chlorination Ct>15mg/L min	4.0	4.0	0
Ozone ⁽⁶⁾ Ct>1.6mg/L min	4.0	4.0	0
Ct>9.9mg/L/min	4	4	1
Ct>20mg/L/min	4	4	2

	Ct>30mg/L/min	4	4	3
UV	>40 mJ/cm ²	4.0	0.5 ⁽⁷⁾	4.0
	>60 mJ/cm ²	4.0	1.0	4.0
	>190 mJ/cm ²	4.0	4.0	4.0

- (1) Coagulation, flocculation and sedimentation or DAF process units may be given Pathogen Reduction Credits when followed by other downstream process units that provide a physical barrier (i.e. Filtration). When used as a stand-alone process unit Pathogen Reduction Credits for bacteria and virus are not always applicable. This level of conservativeness is based on the principle that pathogen removal by solids removal treatment prior to filtration is as much a consequence of improved filter performance than performance of the solids removal itself.
- (2) Refer to Section 5 and 6
- (3) Direct filtration means coagulation & flocculation followed by granular media filtration
- (4) Conventional filtration means coagulation, flocculation and sedimentation followed by granular media filtration
- (5) Membrane filtration should be preceded by coagulation/flocculation or other appropriate pre-treatment where raw water quality dictates. A validated membrane integrity testing regime should also be in place.
- (6) At water temp = 10°C, See USEPA (2006) Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), USEPA, 71 Federal Register 654, January 5, 2006 Vol. 71, No 3
- (7) Based on double stranded DNA viruses such as Adenovirus which are more resistant to UV inactivation (refer Section 14).

Coagulation, Flocculation, Sedimentation

When properly designed and operated the combined process of coagulation, flocculation and sedimentation can achieve 1-2 log reductions for bacteria, viruses and protozoa (Le Chevallier *et al.*, 2004).

For viruses and *Cryptosporidium*, the conservative USEPA (1989, 1990 and 2006a) reduction credits have been assumed which are based on the achievement of at least 0.5 log turbidity reduction based on the monthly mean of daily measurements (USEPA, 2006a). The reduction of bacteria has been conservatively assumed to be the same as for virus reduction.

These log reduction credits are applicable when the process unit forms part of a treatment train and is followed by downstream barriers (e.g. Filtration as per Section 5) This is based on the principle that pathogen reduction by solids removal treatment prior to filtration is as much a consequence of improved filter performance due to the turbidity removal performance of the solids removal process. These log reduction credits are not intended for use as a stand-alone treatment process.

Coagulation, Flocculation, Dissolved Air Flotation (DAF)

DAF is particularly effective in removing *Cryptosporidium* and algae with well operated plants commonly achieving 2-3 log reduction of *Cryptosporidium* at water temperatures (>10C) commonly found in Australia (Le Chevallier *et al.*, 2004, Edzwald *et al.*, 2001).

For *Cryptosporidium*, a conservative log reduction credit of 1.0 log has been assumed. This is higher than USEPA (2006a) which assumes that DAF performs no better than sedimentation (i.e. 0.5 log reduction), but this is considered to be excessively conservative for Australian conditions. The removal of bacteria and viruses are assumed to be the same as for sedimentation in the absence of better information.

Filtration unit operations

Single or First Stage Filtration in traditional water treatment practice is applied after coagulation, flocculation and sedimentation for colour, turbidity and pathogen removal. The objective of the coagulation, flocculation and sedimentation processes are to reduce the turbidity (and to some extent pathogen) load on the granular media filtration process. Well operated coagulation, flocculation and sedimentation processes achieve turbidity's which are desirably less than 1NTU, and no greater than 2NTU in the influent to the filters. Consistency of performance is important.

Improvements in filter design and polyelectrolytes over the past 30-40 years have enabled the sedimentation stage to be omitted where raw water turbidity and coagulant dose are low (Twort *et al.*, 2000). This is known as Direct Filtration, however, effective coagulation and flocculation (but no clarification) are still essential for the proper operation of the granular media filtration process (Al-Ani *et al.*, 1986).

For the purpose of assigning a pathogen log reduction credit, Granular Media Filtration also includes Granular Activated Carbon (GAC) and Biological Activated Carbon (BAC) filters. Alternatives to granular media filtration as the single or first stage filtration barrier include slow sand filtration, diatomaceous earth filters and membrane filters (discussed in following sections).

Unprotected, high risk water sources which are heavily contaminated with faecal material, require extensive treatment beyond conventional water treatment practice and Second Stage Filtration should be considered. WHO (1996) recommend that the additional treatment appropriate in the situation may consist of slow sand filtration or ozonation with granular activated carbon (GAC) absorption, or any other process demonstrated to achieve greater than one log reduction of enteric viruses. The merits of these processes and other equivalent alternatives are discussed below.

Granular media filtration

When properly operated, the combination of coagulation, flocculation, sedimentation and granular media filtration can result in 4 log or greater removal of *Giardia* and *Cryptosporidium* and more than 3 log removal of bacteria and viruses (Le Chevallier *et al.*, 2004). To achieve these high removals, the filtered water must be consistently low in turbidity (and particles) with dedicated operator attention to initial breakthrough (filter ripening period) and terminal breakthrough at the end of the filter run.

While filtered water turbidity is not the perfect indicator for filter performance, it has become the de facto measure.

Table D2 summarises international guidance on filtrate turbidity vs LRVs. Following review of this information and incorporation of the working group's experience and advice from water treatment experts, recommendations are listed in the following sections.

Table D2: Review of International Guidance

Process	USEPA LT2 Rule	Health Canada	NZ Guidelines	Water Corp (2008)	ADWG
Return Flows	Must be returned through all treatment processes Return flow at rate that minimises impact on filtered water quality		- Must be returned through all treatment processes - Flow equalisation, such that flow doesn't exceed 10% of raw water inflow - Does not apply to filter waste - Continuously monitor return flow turbidity	NA	
Conventional Treatment	3 Log Combined Filtrate Turbidity $\leq 0.3\text{NTU}$ for 95% month Not $> 1\text{NTU}$ for ≥ 30 minutes	3 Log Individual Filter Turbidity $\leq 0.3\text{NTU}$ for 95% month $\leq 1\text{NTU}$ at all times	3 Log Individual Filter Turbidity $\leq 0.3\text{NTU}$ for 95% month $\leq 0.5\text{NTU}$ for 99% month Not $> 1\text{NTU} \geq 3$ minutes	3 Log Combined Filtrate Turbidity $\leq 0.3\text{NTU}$ for 95% month $< 1\text{NTU}$ at all times Settled Water Turbidity $\leq 2\text{NTU}$ typically	? Log Individual Filter Turbidity Target $< 0.2\text{NTU}$ $\leq 0.5\text{NTU}$ at all times
Enhanced Conventional Treatment	3.5 Log Combined Filtrate Turbidity $\leq 0.15\text{NTU}$ for 95% month Not $> 1\text{NTU}$ for ≥ 30 minutes	NA	3.5 Log Meet 3 log requirements plus: Combined Filtrate Turbidity $\leq 0.15\text{NTU}$ for 95% month $\leq 0.3\text{NTU}$ for 99% month Not $> 0.5\text{NTU} \geq 3$ minutes	3.5 Log Combined Filtrate Turbidity $\leq 0.15\text{NTU}$ for 95% month $< 0.3\text{NTU}$ at all times Settled Water Turbidity $\leq 2\text{NTU}$ typically	? Log Individual Filter Turbidity Target $< 0.2\text{NTU}$ $\leq 0.5\text{NTU}$ at all times
	4 Log Individual Filter Turbidity $\leq 0.15\text{NTU}$ for 95% month Not $> 0.3\text{NTU}$ for ≥ 30 minutes	NA	4 Log Individual Filter Turbidity $\leq 0.1\text{NTU}$ for 95% month $\leq 0.3\text{NTU}$ for 99% month Not $> 0.5\text{NTU} \geq 3$ minutes	4 Log Individual Filtrate Turbidity $\leq 0.15\text{NTU}$ for 95% month Not $> 0.3\text{NTU}$ for ≥ 30 minutes Settled Water Turbidity $\leq 2\text{NTU}$ typically	
Direct Filtration	2.5 Log Combined Filtrate Turbidity $\leq 0.3\text{NTU}$ for 95% month Not $> 1\text{NTU}$ for ≥ 30 minutes	NA	2.5 Log Individual Filter Turbidity $\leq 0.3\text{NTU}$ for 95% month $\leq 0.5\text{NTU}$ for 99% month Not $> 1\text{NTU} \geq 3$ minutes	2.5 Log Combined Filtrate Turbidity $\leq 0.3\text{NTU}$ for 95% month $\leq 1\text{NTU}$ at all times	
Enhanced Direct Filtration	3 Log Combined Filtrate Turbidity $\leq 0.15\text{NTU}$ for 95% month Not $> 1\text{NTU}$ for ≥ 30 minutes	NA	3 Log Meet 2.5 log requirements plus: Combined Filtrate Turbidity $\leq 0.15\text{NTU}$ for 95% month $\leq 0.3\text{NTU}$ for 99% month Not $> 0.5\text{NTU} \geq 3$ minutes	3 Log Combined filtrate turbidity $\leq 0.15\text{NTU}$ for 95% month	
	3.5 Log Individual Filter Turbidity $\leq 0.15\text{NTU}$ for 95% month Not $> 0.3\text{NTU}$ for ≥ 30 minutes	NA	3.5 Log Individual Filter Turbidity $\leq 0.1\text{NTU}$ for 95% month $\leq 0.3\text{NTU}$ for 99% month Not $> 0.5\text{NTU} \geq 3$ minutes	3.5 Log Individual Filtrate Turbidity $\leq 0.15\text{NTU}$ for 95% month Not $> 0.3\text{NTU}$ for ≥ 30 minutes	

Conventional Treatment

4 Log *Cryptosporidium* LRV reduction

All international benchmarks required individual filtrate monitoring with performance consistently requiring <0.15 NTU for 95% of the time and not greater than 0.3 NTU for 15 - 30 consecutive minutes.

This benchmark was adopted by WSAA while acknowledging the difficulty of its achievement.

3 Log *Cryptosporidium* LRV reduction

International benchmarks consistently required filtrate turbidities to be less than 0.3 NTU for 95% time and not greater than 0.5 to 1 NTU.

USEPA requires measuring the combined filtrate turbidity while NZ and Canada apply the performance targets to individual filters.

The HBT Group was concerned that adopting the USEPA standards would be a relaxation of current industry practice. In addition, the Group received strong advice from Water Treatment experts that filters should be monitored individually to assure pathogen removal performance and to assist with troubleshooting. The cost of installing turbidity monitors (where they do not exist on individual filters) is modest compared to the benefit attained.

Accordingly, the HBT Group recommends the performance target for 3 log reduction should be <0.3 NTU for 95% of the month and not greater than 0.5 NTU for ≥ 15 consecutive minutes measured at individual filters.

3.5 Log *Cryptosporidium* removal

Given the book end requirements for 3 and 4 log removal and the commitment to individual filter monitoring it is recommended that performance for 3.5 log removal should be individual filtrate turbidity <0.2NTU for 95% of the time and not greater than 0.5 NTU for 15 consecutive minutes. These requirements do not correlate with any international benchmarks (which all use combined filtrate turbidity) but are a logical target given the 3 and 4 log targets. In addition, they correspond to the target in the 2011 ADWG fact sheet on turbidity and are consistent with the research paper from Xagoraki which showed setting turbidity targets below 0.2 NTU resulted in significantly improved pathogen reduction.

This Manual requires adherence to good practice in order to claim the default LRVs.

Pre-treatment

Included in the LRVs for conventional treatment is a credit of 0.5 log for the coagulation, flocculation and sedimentation step. Other pre-treatment such as DAF can achieve higher log credits.

Direct filtration

Direct filtration is conventional treatment with pre-treatment by flocculation and coagulation only. For consistency, it is recommended that identical performance criteria for direct filtration and conventional treatment, with direct filtration down rated by 0.5 log to account for lack of sedimentation.

Thus *Cryptosporidium* LRVs and performance requirements for direct filtration are –

2.5 log =	<0.3 NTU for 95% month Not greater than 0.5 NTU for ≥ 15 consecutive minutes
3.0 log =	<.2 NTU for 95% month Not greater than 0.5 NTU for ≥ 15 consecutive minutes
3.5 log =	<.15 NTU for 95% month Not greater than 0.3 NTU for ≥ 15 consecutive minutes

All filtrate turbidities are measured on individual filters.

The requirement to implement good practice before claiming LRVs also applies.

Combined filtrate concession

The working group is reluctant to recommend criteria for combined filtrate turbidities as this would go against expert advice and further complicate filter management with ‘extra numbers’. However, given that many WTPs currently have combined filter monitoring only, it is proposed to offer a short ‘grace’ period while utilities transition to monitoring individual filters. In this period utilities can claim a LRV of 2.5 log for media filtration if the combined filtrate turbidity is <0.2 NTU for 95% of the month and not greater than 0.5 NTU for 15 consecutive minutes.

Summary of LRV and performance requirement

The LRVs and performance requirements for media filtration recommended by the WSAA HBT Working Group are summarised in Table D3.

Table D3: LRVs for conventional water treatment

Process	Log Reduction Value			Process Critical Limits
	Bacteria	Virus	Cryptosporidium	
Direct Filtration ⁽¹⁾	1	1	2.5	Individual filter turbidity ≤ 0.3NTU for 95% month and not > 0.5NTU for ≥ 15 consecutive minutes Combined filtrate turbidity ≤ 0.2NTU for 95% month and not > 0.5NTU for ≥ 15 consecutive minutes
	1	1	3.0	Individual filter turbidity ≤ 0.2 NTU for 95% month and not > 0.5NTU for ≥ 15 consecutive minutes
	1	1	3.5	Individual filter turbidity ≤ 0.15NTU for 95% month and not > 0.3NTU for ≥ 15 consecutive minutes
Conventional Filtration ⁽²⁾	2	2	3.0	Individual filter turbidity ≤ 0.3NTU for 95% month and not > 0.5NTU for ≥ 15 consecutive minutes Combined filtrate turbidity ≤ 0.2NTU for 95% month and not > 0.5NTU for ≥ 15 consecutive minutes
	2	2	3.5	Individual filter turbidity ≤ 0.2 NTU for 95% month and not > 0.5NTU for ≥ 15 consecutive minutes
	2	2	4.0	Individual filter turbidity ≤ 0.15NTU for 95% month and not > 0.3NTU for ≥ 15 consecutive minutes

(1) Direct filtration = coagulation and flocculation followed by granular media filtration

(2) Conventional filtration = coagulation, flocculation and sedimentation followed by granular media filtration

Slow sand filtration

Slow sand filters are not normally preceded by coagulation processes but can achieve significant pathogen reductions (2-4 log reductions) after the development of a biologically active layer (Schmutzdecke) on the top of the sand bed (Le Chevallier *et al.*, 2004 and Twort *et al.*, 2000).

The virus and *Cryptosporidium* reduction credits are based on USEPA (1989, 1990 and 2006a). Bacterial reductions have been conservatively assumed to be the same as viral reductions (WHO, 1996).

Slow sand filtration has been used for nearly 200 years as an effective process to significantly reduce pathogen loads. It is restricted to applications where raw water colour, natural organic matter removal (NOM) and turbidities are low (Twort *et al.*, 2000). They are rarely used in new facilities, but it should always be considered as an option where raw water characteristics and land availability make it a potential option.

Slow sand filtration as a second stage of filtration is still used widely in Europe (London, Belfast, Paris, Zurich, Stockholm and many other cities) where slow sand filters from an earlier era have been refurbished and used to polish water from more contemporary pre-

treatment processes (Twort *et al.*, 2000). Slow sand filters are robust and reliable pathogen removers, after ripening and can achieve at least a further two log reduction of viruses. In addition, they can be used to improve other water quality parameters such as iron, manganese and assimilable organic carbon.

Diatomaceous earth filtration

Diatomaceous earth filters are particularly effective in removing protozoan pathogens, but are less effective in removing smaller pathogens without the aid of chemical pre-treatment (Le Chevallier *et al.*, 2004).

The virus and *Cryptosporidium* credits are based on USEPA (1989, 1990 and 2006a). Bacterial reductions have been conservatively assumed to be the same as viral reductions.

Diatomaceous earth (DE) filters were first used for drinking water treatment by the US Army during World War II as a means of removing the protozoan pathogen *Entamoeba histolytica* (cause of amoebic dysentery) which was prevalent in the Pacific War zone (Le Chevallier *et al.*, 2004).

DE filters have been used successfully for many decades to treat the water supplies of small communities (particularly in the north east of the USA). The technology is robust and reliable and well suited to small systems where a conscientious operator can consistently produce very high quality drinking water with limited technical support. While some new DE filtration systems are still constructed, membrane filtration processes have replaced DE filters for most drinking water applications.

Activated carbon filters

Granular Activated Carbon (GAC) or Biological Activated Carbon (BAC) with ozone is more commonly used in modern water treatment practice than slow sand filtration specifically where there is a need to remove pesticides or other industrial organic compounds (particularly in Europe). In addition to pesticide removal the combination of ozone ($Ct > 0.3$ mg/L min for temperatures $> 5C$) and BAC filters can achieve greater than two log reduction of viruses. The reduction of *Cryptosporidium* will not however be as high as achieved through the use of slow sand filtration and pre-treatment processes should be designed to provide effective protection from protozoan pathogens.

When GAC filters are used without ozone, either as biological filters or as NOM absorbers, following coagulation, flocculation, sedimentation (or flotation) and filtration, they also provide a further barrier to pathogens. In this mode of operation, these second stage filters ensure that the filtered water turbidity is consistently very low, provided the upstream processes are well operated and can achieve at least a further one log reduction of viruses. A 0.5 log reduction credit for *Cryptosporidium* has been assumed for second stage GAC filtration following coagulation, flocculation and first stage filtration (USEPA 2006a). Second stage GAC filtration is expected to perform in a similar manner to coagulation, flocculation and sedimentation. For this reason, a 1.0 log reduction credit for bacteria and viruses has been assumed.

Pressure media filters

Pressure filters have historically been seen as providing a lower level of filtration to gravity media filters. Typically filtration rates are much higher in pressure filters and the primary target has been coarse solids or turbidity reduction such as required in irrigation applications. Because of their simplicity and suitability for smaller and/or remote area applications, pressure filters that are conservatively designed and operated are gaining acceptance as a pathogen barrier.

Performance assessment undertaken in the US (EPD Alternative Filtration Technology, Bob Hultquist, June 2001 and Sverdrup/Serck Baker Hi-Rate Pr Filtration, Kurt Souza, June 2001) demonstrated a log reduction capacity of 2.0 for *Cryptosporidium* and 1.0 for virus. In general, pressure filters designed at filtration rates below 10 m³/m².hr and capable of meeting turbidity targets equivalent to gravity media filters can be assumed to provide similar pathogen barrier capability to gravity media filters. Where possible, validation against a recognised certification process or Standard is desirable.

Cartridge filters

Cartridge filters have traditionally been seen as a coarse pre-filtration step to subsequent finer filtration (e.g. UF or RO membranes) or as a simple, but non-critical, stand-alone filtration for non-health applications. The characteristics of cartridge filters (akin to woven material) do not lend themselves to bacteria or virus reduction, but they have proven themselves as efficient barriers to *Cryptosporidium* and Giardia. There are now several suppliers in the market able to provide cartridge filters with validation against USEPA standards for *Cryptosporidium* reduction in the order of 2.0 – 3.0 log (Harmsco, 2012, www.harmsco.com).

Cartridge filters do offer many benefits of convenience, simplicity and small scale, which are ideal for remote area applications, and they may be considered for such. Their inability to provide a barrier against bacteria or virus, however, means that other filters may still be needed thereby making the cartridge filters redundant.

Second stage filtration

Secondary filtration can consist of rapid sand filtration, dual media, GAC or other fine media in a separate stage following granular media filtration. The treatment train must contain chemical coagulation before the first stage filters and both sets of filters must treat all the water flow continuously.

In this mode of operation, these second stage filters ensure that the filtered water turbidity is consistently very low, provided the upstream processes are well operated and can achieve at least a further 0.5 log reduction of viruses and bacteria. A 0.5 log reduction credit for *Cryptosporidium* has been assumed for second stage filtration following coagulation, flocculation and first stage filtration (USEPA 2006a).

Membrane filtration

Membrane filtration processes have superior pathogen removal capabilities compared to most conventional granular media filters because of their consistent pore size. For this reason a large number of membrane filtration processes have been used as an alternative to granular media filtration over the past decade. This is particularly the case in North America. The effectiveness of membrane processes for pathogen removal is only as good as the integrity of the membranes themselves, hence reliable membrane integrity monitoring and testing is essential when membrane processes are used.

Membrane integrity testing is best done by a Pressure Decay Test (PDT) which can be set up to run daily. The PDT has been proven to be an accurate verification of log reduction performance, however, it is not continuous. Turbidity has been accepted as a suitable on-line indicator of membrane performance.

Hence, as for media filters, on line turbidity measurements are used to continuously confirm CCP operation. However, turbidity monitoring for a membrane filtration plant is a surrogate to confirm membrane integrity, not pathogen removal whereas turbidity monitoring at a media filtration plant is a surrogate for filtration performance (with lower turbidity corresponding to higher pathogen reduction).

The turbidity target for membrane plants has been set at 0.1 NTU because this target is comfortably achieved in normal operations. If turbidity exceeds 0.1 NTU it usually indicates a significant problem requiring immediate investigation, including a pressure decay test to check membrane integrity.

Microfiltration (MF) and ultrafiltration (UF) membrane process can achieve very high removals of bacteria and protozoan cysts where the membranes provide a physical barrier to the transmission of the bacteria and protozoan cysts, but for smaller pathogens such as viruses, the removal efficiency is not as high (Le Chevallier *et al.*, 2004). The removal of viruses by microfiltration can be improved significantly with good coagulation and flocculation prior to filtration (Zhu *et al.*, 2005).

Although the water industry has largely standardised to UF, higher removals may be possible with different types of membranes and membrane manufacturers. Specific information for particular membranes should be used where possible and validated by performance testing of the full-scale facility.

Nanofiltration (NF) and reverse osmosis (RO) membranes can achieve almost complete removal of viruses, bacteria and protozoan cysts (> 6 log reduction under ideal conditions). To ensure such high removal, the membrane integrity is critical with leakage at seals and joints the most common cause of failure. Continuous monitoring of integrity via conductivity, UV absorbance or on-line TOC meters has been adopted in recent years. These parameters provide only limited assurance of membrane integrity and therefore it is not prudent to assume more than 3 to 4 log reduction credits for NF and RO processes unless validated by performance or challenge testing of the full-scale facility.

Chlorination

While there are a variety of different methods of disinfection that may be used, primary chlorination using (free chlorine) is preferred due to its effectiveness against bacterial and viral pathogens, and its widespread and standardised practice. Where it is desirable to maintain disinfection residual throughout all distribution systems, secondary chlorination (or chloramination) should be the final treatment step before water enters the distribution system.

For protected surface water sources, essentially free from faecal contamination, disinfection is provided as a barrier to infrequent and unexpected contamination events. Free chlorination ($Ct > 15\text{mg/L min}$) is generally preferred and can provide residual disinfection with a single process.

WHO (1996) recommend that the Ct for free chlorination should be $> 15\text{mg/L min}$ to achieve at least 4 log reduction of viruses. The data published by the USEPA (2003) (see Table D4) confirms that the WHO (1996) requirement of a free chlorine Ct $> 15\text{mg/L min}$ will achieve greater than 4 log reduction of virus for pH 6-9 and at all water temperatures, with some

margin of safety. The reduction of bacteria has been conservatively assumed to be the same as for virus reduction.

More recent Ct values from recent Australian research is shown in Table D5.

In the expression Ct, the contact time is the time that chlorine remains in contact with the micro-organisms. In all real tanks, there is some short-circuiting and some of the water will pass through in less than the theoretical retention time. It is customary to use t10 in the Ct calculation, where t10 is the time for 10% of the water to pass through the tank (Twort *et al.*, 2000). Values of t10/t for typical situations are shown in Table D6 – Baffle Classifications. (USEPA, 1999 and 2003)

Chloramination

Chloramination is not recommended for primary disinfection as it is generally not feasible to obtain sufficient contact time to achieve 4 log reduction of virus and bacteria (see Table D4). Since chloramines persist much longer than free chlorine then chloramination is extremely effective in long pipelines and large networks where it is necessary to maintain a residual. In such situations chlorine should be dosed initially (often into a contact tank) to achieve a Ct of 15 (minimum) and ammonia then added to provide a chloramine residual.

Table D4: Ct Values for Inactivation of Enteric Viruses at pH Values 6-9 (After USEPA, 2003)

		Ct values at water temperature					
Disinfectant	Log inactivation	≤1C	5C	10C	15C	20C	25C
Free residual chlorine	2	6	4	3	2	1	1
	4	12	8	6	4	3	2
Ozone	2	0.9	0.6	0.5	0.3	0.25	0.15
	4	1.8	1.2	1.0	0.6	0.5	0.3
Chlorine dioxide	2	8.4	5.6	4.2	2.8	2.1	1.4
	4	50.1	33.4	25.1	16.7	12.5	8.4
Chloramines (pre-formed)	2	1243	857	643	428	321	214
	3	2063	1423	1067	712	534	356
	4	2883	1988	1491	994	746	497

Table D5: Ct values based on more recent Australian data

C.t values in mg.min/L at 5°C increments from 10 to 20°C (inclusive) modified by linear extrapolation for 1 to 4 log₁₀ inactivation of CB5 at pH 7.2, 7.5, 7.8 and 8.0. Shown in italics, for comparison, are the results obtained at 5°C, for the same series of experiments. At the bottom of the table, for comparison, is shown the USEPA Ct values for 2,3, and 4 log inactivation of Hepatitis A virus at pH between 6 and 9.

pH	Log ₁₀ inactivation	Temperature (°C)					
		0*	5	10	15	20	25
		C.t (mg.min/L)					
7.2	1	ND	ND	2.0	1.8	1.5	ND
	2	ND	ND	3.5	3.1	2.6	ND
	3	ND	ND	4.7	4.1	3.4	ND
	4	ND	ND	5.8	5.0	4.2	ND
7.5	1	ND	ND	2.1	1.8	1.6	ND
	2	ND	6.6	3.6	3.2	2.8	ND
	3	ND	8.9	5.0	4.4	3.8	ND
	4	ND	11.0	6.3	5.5	4.7	ND
7.8	1	ND	ND	2.6	2.2	1.8	ND
	2	ND	ND	4.6	3.9	3.1	ND
	3	ND	ND	6.4	5.3	4.3	ND
	4	ND	ND	8.0	6.6	5.3	ND
8.0	1	ND	ND	3.1	2.6	2.0	ND
	2	ND	ND	5.6	4.6	3.6	ND
	3	ND	ND	7.7	6.3	5.0	ND
	4	ND	ND	9.7	7.9	6.2	ND
9.0	1	ND	ND	ND	ND	ND	ND
	2	ND	13.6	ND	ND	ND	ND
	3	ND	18.8	ND	ND	ND	ND
	4	ND	23.6	ND	ND	ND	ND
USEPA data (for comparison)							
6-9	2	6.0*	4.0	3.0	2.0	1.0	1.0
	3	9.0*	6.0	4.0	3.0	2.0	1.0
	4	12.0*	8.0	6.0	4.0	3.0	2.0

*0.5°C for USEPA data

ND: not determined

Table D6: Baffle classifications

Baffling Condition	t10/t	Baffling Description
Unbaffled (mixed flow)	0.1	None, agitated basin, very low length to wide ratio, high inlet and outlet flow velocities.
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intrabasin baffles.
Average	0.5	Baffled inlet or outlet with some intrabasin baffles.
Superior	0.7	Perforated inlet baffle, serpentine or perforated intrabasin baffles, outlet weir or perforated launders.
Excellent	0.9	Serpentine baffling throughout basin, very high length to wide ratio.
Perfect (plug flow)	1.0 (1)	Very high length to width ratio (pipeline flow), perforated inlet, outlet, and intrabasin baffles.

At perfect plug flow conditions, t10 is equal to t.

UV Disinfection

The minimum UV dose for effective bacterial disinfection (> 3 log reduction) is generally agreed to be 16mJ/cm² (at 253.7 nm). When viral reduction is required, dosages of 30-40 mJ/cm² are considered more appropriate. At dosages greater than or equal to 40mJ/cm² a 4 log reduction of bacteria, many viruses and *Cryptosporidium* is achieved (Twort *et al.*, 2000).

While UV is an effective disinfectant for many viruses (e.g. Hepatitis A and Polio in particular), double standard DNA viruses such as Adenoviruses are very resistant to UV inactivation (Le Chevallier *et al.*, 2004 and USEPA 2006b). For this reason, UV disinfection should not be used as the primary disinfectant unless the UV fluence is significantly increased when the risks from human viral pathogens are high.

The *Cryptosporidium* LRVs in Table D1 are nominal and conservative. It is common practice now to purchase manufacturer validated units, which can be tailored to achieve the required LRV for specific local conditions.

Table D7: UV Dose Requirements for *Cryptosporidium*, Giardia, and Virus Inactivation Credit (After USEPA 2006a)

Log credit	<i>Cryptosporidium</i> UV dose (mJ/cm ²)	<i>Giardia lamblia</i> UV dose (mJ/cm ²)	Virus UV dose (mJ/cm ²)
0.5	1.6	1.5	39
1.0	2.5	2.1	58
1.5	3.9	3.0	79
2.0	5.8	5.2	100
2.5	8.5	7.7	121
3.0	12	11	143
3.5	15	15	163
4.0	22	22	186

Table D8: Required UV Dose

	Required Dose (mJ/cm ²)			
Log Reduction Value required:	1	2	3	4
<i>Bacillus subtilis</i> a	56	111	167	222
<i>Adenovirus</i> type 40	56	111	167	- b
<i>Clostridium perfringens</i> a	45	95	145	- b
<i>Adenovirus</i> type 2, 15, 40, 41	42	83	125	167
<i>Acanthamoeba</i> c	40	71	119	167
<i>Adenovirus</i> a (no type 40)	25	50	- b	- b
<i>Calicivirus canine</i>	10	21	31	41
<i>Rotavirus</i> SA-11	10	20	29	39
<i>Calicivirus feline</i>	9	19	28	38
<i>Coxsackie virus B5</i>	8	17	25	34
<i>Streptococcus faecalis</i> a	9	16	23	30
<i>Legionella pneumophila</i> d	8	15	23	30
<i>Poliovirus</i> type 1	7	15	22	30
<i>Shigella sonnei</i> d	6	13	19	26
<i>Salmonella typhi</i> a	6	12	17	51
<i>Hepatitis A</i>	6	11	17	22
<i>Calicivirus bovine</i>	5	11	16	21
<i>E. coli</i> 0157d	5	9	14	19
<i>E. coli</i> a	5	9	14	18
<i>Cryptosporidium</i> USEPA c	3	6	12	- e
<i>Giardia</i> USEPA c	2	5	11	- e
<i>Campylobacter jejuni</i> d	3	7	10	14
<i>Yersinia enterocolitica</i> d	3	7	10	13

Good practice design

There are several core principles that must be applied when selecting processes to match a source risk level, as follows:

- the sum of process unit LRVs from Tables D1 and D3 shall be equal to or greater than the minimum log reduction required based on source risk assessment
- final disinfection shall always be included in the water treatment process selection
- no one process unit shall be given an LRV >4.0
- treatment trains for Category 2 – 4 sources shall include at least one physical pathogen removal process for protozoa, bacteria and virus in addition to final disinfection.

Good practice operation

It is important not to focus on CCP performance to the detriment of good practice operation of the WTP. Assuring pathogen removal also requires sound management of filters, backwash effluent, instrumentation, operator training and a host of other issues. These have recently been documented in the WaterRA publication '*Good Practice Guide to the Operation of Drinking Water Supply systems for Management of Microbial Risk*'.

WTP performance monitoring

In Table D3 the parameter which must be achieved for 95% of the month should be considered the target. The parameter which must not be exceeded for more than 15 minutes should be considered the critical limit. The reference to 15 minutes in Table D3 is to provide an operational buffer to prevent false alarms and provide the opportunity for a quick investigation before initiating an incident response. It should not be regarded as sanctioning the deliberate operation of a CCP in exceedance of its critical limit. For further information on setting targets and limits refer to Chapters 9 and 10 of the ADWG and Section 7 of this Manual.

For continuous monitoring of parameters that are used to assess performance against process targets and critical limits, the following practices are recommended:

- If continuous data is sampled as a series of discrete values for compliance measurement, the sampling period should not exceed 1 minute. If plant operation is discontinuous, the data sampling period should be adjusted such that, in general, there are at least 150 data points to represent one day of production.
- Continuous monitors must be calibrated at least as frequently as recommended by the equipment suppliers and records should be kept of all maintenance and calibration checks.
- For reporting and performance assessment purposes, the monitoring data set should be cleansed to ensure that it excludes monitoring during the period that the process unit was off-line and not supplying water, and when the instrument was being calibrated or otherwise maintained.

Appendix E –Governance Guidance for Australian Utilities

Background

Supply of safe drinking water is an expectation of Australian consumers. There are many risks to be mitigated by utilities to ensure the continuous supply of safe drinking water. The industry has done such a good job meeting these challenges that serious water quality incidents are indeed rare. However, history shows that incidents which result in unexpected harm to a community prompts a sense of outrage and disbelief. Just as occurs with airplane crashes and bushfires, scrutiny is applied to management to determine if the incident could have been anticipated and prevented. In other words – have they discharged their duty-of-care to customers to prevent foreseeable harm.

Investigations into serious incidents often show the latent conditions for disaster have existed for some time. The surprise is not that the failure occurred, but that it took so long to happen. Any water quality governance system must minimise the chance of any foreseeable water quality incident.

Until the turn of the century, water safety was assured by retrospective review of sampling results. The shortfall with this approach includes:

- a) sampling limitations – infrequent sampling and only a minuscule proportion of water supplied is tested
- b) testing limitations – no test is 100% reliable or accurate and pathogen testing is cost prohibitive and impractical
- c) time-line limitations – it usually takes days for completion of laboratory testing, meaning customers have already consumed the water before the results are available.

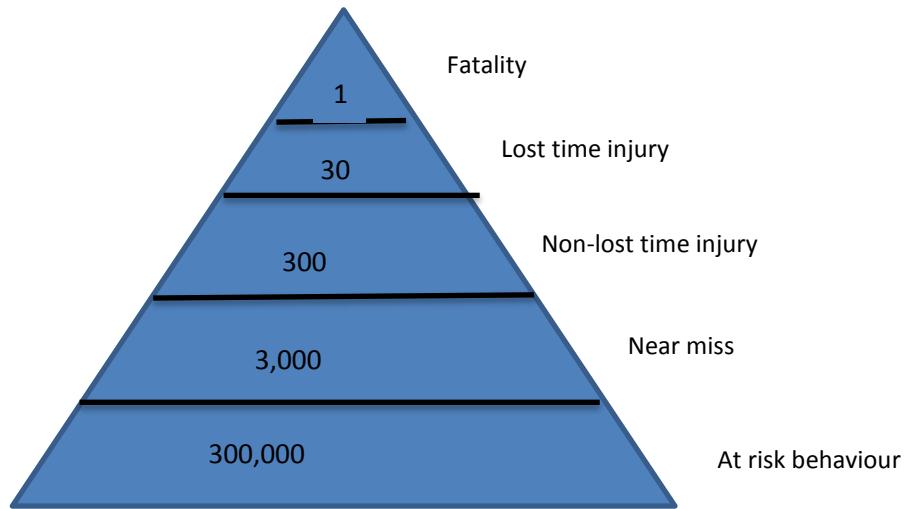
Utilities cannot rely on such testing to assure continuous water safety and therefore discharge of their duty of care to customers. Since 2004, the ADWG has required utilities to adopt a proactive, risk-based approach to water quality management. This means utilities must use operational monitoring to confirm the contamination challenge stays within the capability of barriers. The 2011 ADWG further expanded on these requirements, linking operational monitoring directly to risk assessments and emphasising the need for continuous monitoring of critical control points and corrective action requirements when targets and critical limits are breached.

The move toward a health based target (HBT) for microbial water quality puts additional focus on determining and assuring water safety. An HBT brings the benefit of a national consistency of approach to determining water treatment adequacy and operational performance targets. To fully capitalise on this opportunity, it is desirable that the water industry adopt a common governance model. Utility boards and senior executives can then draw comfort that they have discharged their duty of care to customers if they follow this guidance.

Current State

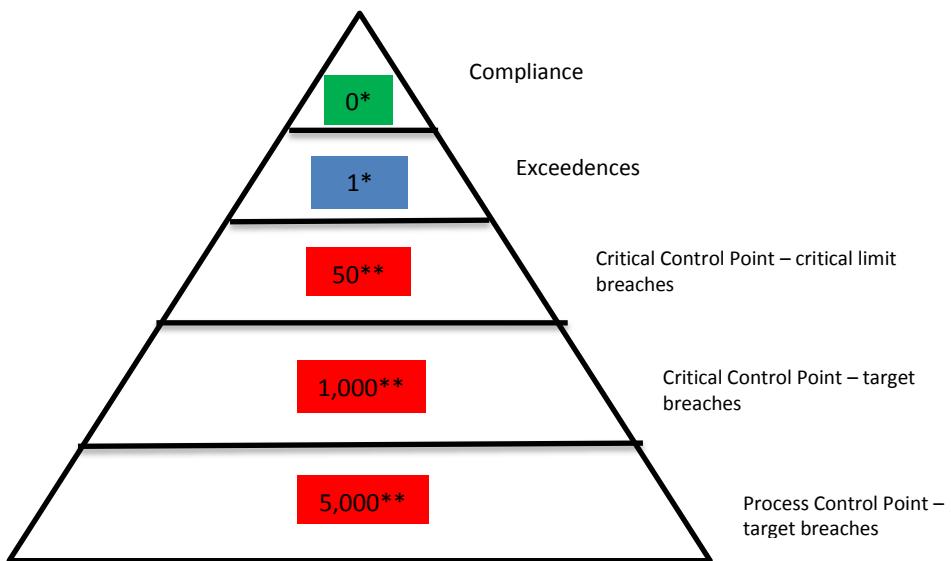
Safety Analogy

Most managers are familiar with the safety triangle shown below.



The point of the triangle is to illustrate that major injuries are rare events and that many opportunities are presented by the more frequent, less serious events to take actions to prevent major injuries from occurring.

A similar triangle can be constructed for water quality management as shown below.



*Actual 2011/12 for Water Corporation

**Estimate 2011/12 for Water Corporation

Green	Currently reported	Retrospective snapshot, limited value does not assure water safety
Blue	Now needs to be reported as per 2011 ADWG	Limited value Triggers in depth investigation Does not assure water safety
Red	Not generally reported currently	Does assure water safety

E. coli reporting cannot assure safety

What has been traditionally visible to a utility/executive is the green portion of the triangle, usually in the form of *E. coli* compliance. Just as the absence of a death or disabling injury in the top portion of the safety triangle does not mean a safe workplace, the same applies to water safety. *E. coli* grab samples cannot assure water safety.

Desired state

A well-managed workplace health and safety program relies on reporting of near misses and minor injuries so that action can be taken to proactively reduce instances of serious injury. Similarly, an appropriate water safety program has targeted operational monitoring to warn of loss of process control.

Any of these minor process control point breaches (e.g. high source turbidity or reduced chlorine residual in the reticulation) have the potential to develop into more serious problems. The ADWG requires utilities to identify each Critical Control Point (CCP) in a water supply scheme. These are the barriers to contamination, which are so important that should they fail the water would be unsafe to drink. These are typically water treatment processes such as disinfection and filtration.

A CCP must be operated within a tight performance envelope, which features a target that should be achieved for most of the time. If a target is breached it means some loss of control of the CCP process which requires urgent action to restore control. Every CCP also has a critical limit. Breaching this limit means total loss of control of the CCP process. This means water supplied may not be safe, requiring shut down of supply or a public health advisory. The ADWG requires strict management of CCPs, including continuous monitoring of performance and use of alarms to forewarn operators of pending target and critical limit breaches.

Providing that the installed water treatment processes are adequate to meet the pathogen challenge in the source waters **and** the water treatment processes are operated within the performance envelopes set for the CCPs (i.e. target and critical limit conditions are met) **then** there is a very high probability that all water supplied was safe. Under these circumstances a utility can be very confident it has met its duty of care to protect customers from foreseeable harm.

Any Senior Management governance reporting should be seeking to assure that as a minimum:

- a) barriers to contamination are adequate
- b) their operation was effective.

Role of senior management

Successful water quality management requires all involved to take personal accountability for their actions.

In addition, the Framework for Management of Drinking Water Quality in the ADWG recognises the critical role of senior management as outlined below.

a. Element 1

Element 1 of the Framework for Management of Drinking Water Quality (the Framework) covers

'Commitment to drinking water management' and notes that,

'Organisational support and long-term commitment by senior executive is the foundation to implementation of an effective system for drinking water quality management.'

Successful implementation requires:

- *An awareness and understanding of the importance of drinking water quality management and how decisions affect the protection of public health;*
- *The development of an organisational philosophy that fosters commitment to continual improvement and cultivates employee responsibility and motivation;*
- *The ongoing and active involvement of senior executive to maintain and reinforce the importance of drinking water quality management to all employees as well as those outside the organisation.*

Senior executive should ensure that its actions and policies support the effective management of drinking water quality (e.g. appropriate staffing, training of employees,

provision of adequate financial resources, active participation and reporting to the board of chief executive).'

b. Element 11

Element 11 covers 'Evaluation and audit.' With respect to long-term evaluation of results, Element 11.1 suggests,

'Evaluation of results should be reported internally to senior executive, and externally to consumers, stakeholders and regulatory authorities in accordance with established requirements (see Section 3.10.2). Providing assurance that data are reviewed regularly and that improvements are made in response to identified problems will contribute to consumer confidence.'

c. Element 12

Element 12 of the Framework covers 'Review and continual improvement.' It suggests that,

'Senior executive support, commitment and ongoing involvement are essential to the continual improvement of the organisation's activities relating to drinking water quality. Senior executive should regularly review its approach to drinking water quality management, develop action plans, and commit the resources necessary to improve operational processes and overall drinking water quality performance'.

Element 12.1 covers 'Review by Senior Executive' and notes that,

'In order to ensure continual improvement, the highest levels of the organisation should maintain oversight of the effectiveness of the drinking water quality management system and evaluate needs for change.'

Senior executive should review reports from audits, drinking water quality performance and previous management reviews.

Element 12.2 covers the 'Drinking Water Quality Improvement Plan'. It advises that,

'An improvement plan should be developed to address identified needs for full implementation of the drinking water quality management system. The improvement plan should be endorsed by senior executive'.

Proposed governance framework

A survey of WSAA members indicated:

- a) operational indicators were inconsistently reported across the industry
- b) *E. coli* sampling performance was universally reported to all Executives/Boards of utilities
- c) critical control point performance was rarely reported to an Executive/Board
- d) disparity of views on assessment of water quality risks.

There is clearly a need for improvement in this area.

Any governance framework must take into consideration:

- a) the advice in the ADWG about the role of senior management in overseeing water quality performance and management
- b) the now long standing advice in the ADWG that *E. coli* monitoring cannot guarantee safe drinking water
- c) the personal responsibility senior officers in a utility carry to protect customers from foreseeable harm (duty of care)
- d) the community expectation that their drinking water is continuously safe unless advised otherwise
- e) the now long standing advice in the ADWG that it is CCP performance which is the primary determinant of continuous water safety
- f) publications going back as far as 2011 which point out the responsibility for members of a utility Executive/Board to understand the importance of CCPs in the supply of safe drinking water and to satisfy themselves of satisfactory CCP performance (see feature article by A Davison, B Burford and S Alden in November 2011 edition of 'Water', journal of the AWA). Key considerations for water utilities from this article are listed in Attachment 4.

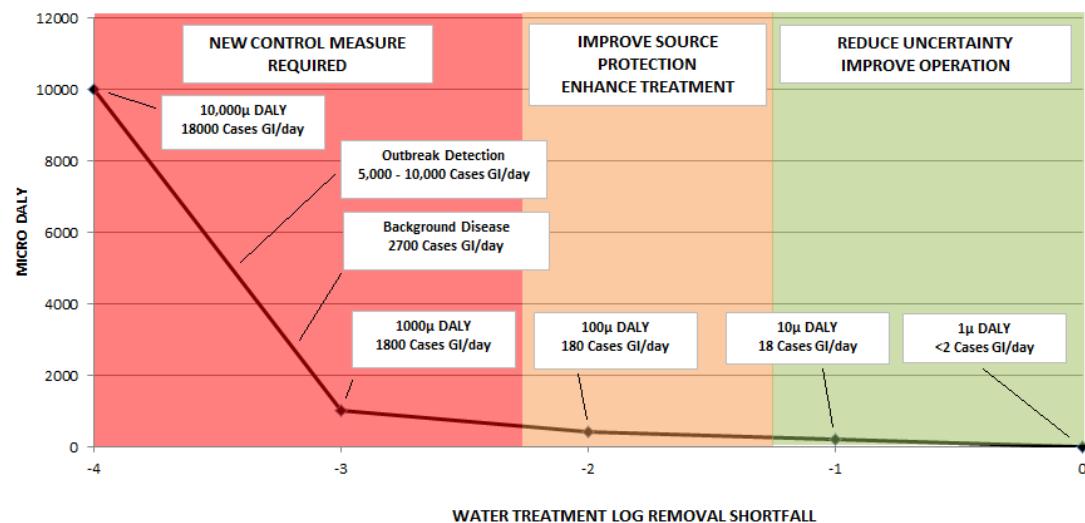
The water quality governance framework for microbial water quality has three pillars:

- a) location of each scheme on the Water Safety Continuum (the Continuum)
- b) management of the water quality improvement program
- c) reporting of operational performance.

Location of each scheme on the continuum

Applying the WSAA HBT Manual enables the residual risk for each supply system to be determined. Accordingly, the scheme can be located on the Water Safety Continuum as illustrated below.

Figure E1: Illustrative example of the ‘Water Safety Continuum’ for Cryptosporidium (for a city with 1 M people)



Such information should flow directly to the utility’s corporate risk profile. These profiles usually comprise a 2 x 2 matrix of consequence versus likelihood. A serious water quality incident (such as a contamination event resulting in sickness or a boil-water advisory) would normally be considered a catastrophic consequence.

The likelihood of such an event is a function of the location of each scheme on the Continuum as tabulated below.

Continuum Location	Likelihood of Serious Incident
1 micro DALY	Rare
Safe	Unlikely
Marginal	Possible
Unsafe	Almost certain

The further to the left a scheme sits on the continuum the higher the disease burden under normal operating conditions and the less buffer is available to deal with unusual conditions such as water treatment under performance and/or unusually high source challenge.

Such an understanding is fundamental to duty of care considerations and routine monthly, quarterly and annual reporting should always list the number of schemes in each portion of the Continuum. In addition, the location of each scheme on the Continuum will influence the improvement program and operations as explained below.

The location of a scheme on the Water Safety Continuum is not expected to move very often but should be reviewed from a governance perspective at least annually. Completion of an improvement project may cause a shift. The ADWG also provides for regular Long Term Evaluations of scheme risks. This too could cause a re-evaluation of location on the continuum based on operational performance of the source water or water treatment plant.

Water quality improvement program

Rather than a pass/fail metric the HBT risk assessment process is best employed as a benchmarking process. The objective is to achieve the HBT target of one micro DALY. Location on the Water Safety Continuum indicates the degree of improvement required to achieve this benchmark. In general terms the further to the left on the Continuum, that a scheme is located the more substantial and urgent is the improvement required.

Operational improvements can be usually implemented quicker than capital improvements and where feasible should be implemented as soon as possible. Where capital improvements are necessary, the following table can be used for guidance.

Location on Continuum	Timing of Improvement
Unsafe	Immediate
Marginal	Within 3-5 years
Safe	Within 5-10 years

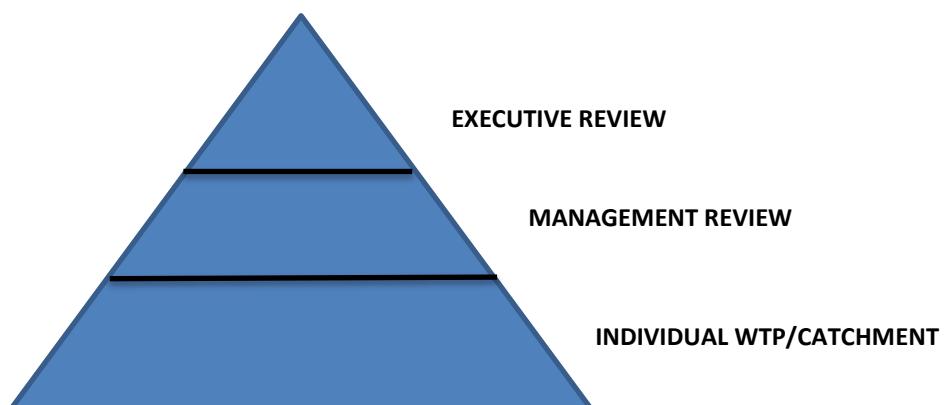
It is important to record the date when the need for improvement is first identified. The improvement timings in the table above apply from that date.

The earlier schemes are returned to the safe part of the continuum (and preferably one micro DALY) the sooner utility management can be confident of the discharge of their duty of care.

Progress with each project in the Improvement Program needs review at least twice per year by the utility managers and executives. Actions which result in slippage beyond the timings suggested above should be managed carefully and with transparency. The executive should consider their duty of care obligations in the decision making process.

Reporting of operational performance – Source water and WTP's

Governance for water quality performance can be managed as a reporting triangle as shown below.



The lower portion of the triangle represents individual WTPs and catchments. Each WTP should have its own individual comprehensive performance report. The Management section of the triangle is where performance of individual WTPs and catchments are aggregated for review by management. Depending on the organisational arrangements in a utility, there may be multiple Management level reports.

The Executive section of the triangle represents the reports required by the Executive of the Utility and the Board. Utilities that operate a Water Quality Governance Committee would likely augment the Executive report with key info from the Management Report.

At the Executive level and usually at the Management level, source water and associated WTP operation need to be reported concurrently to determine the overall performance of the scheme and hence the safety of water supplied to customers.

Reporting WTP operational performance

As mentioned in Section 3, operation of CCPs within specified performance envelopes is fundamental to achieving an effective barrier to pathogens and therefore the supply of safe drinking water. Water treatment performance can change very quickly (e.g. power failure, filter breakthrough) which is why continuous monitoring and time based reporting is required to provide assurance on water treatment performance.

Individual WTP reporting

Managers of water treatment plants should be aware of where the scheme they are operating fits on the water safety continuum. Schemes in the marginal zone have reduced buffer to deal with WTP underperformance or high source challenge and this may affect operation of the WTP at such times. In reality, water treatment operators can rarely influence where a scheme sits on the Continuum. All that can be asked of them is that they take personal responsibility to ensure the installed processes are operated at the required standard and they respond to out of spec conditions in accordance with the advice provided in the ADWG.

Operational performance reporting for an individual WTP should be comprehensive and cover the full range of indicators including performance against:

- a) critical limits
- b) targets
- c) good practice operation.

Attachment 1 lists these requirements.

Management reports for WTP performance

Management reports involve reviewing performance across multiple WTPs. Normally the Manager would have line and/or functional responsibility for the WTPs being reported. Attachment 1 lists the minimum reporting requirements for a management report.

It would be normal that the line manager is advised of any breaches as they occur and may be involved in response actions depending on their significance. Therefore, the monthly report should not contain any surprises for management. The monthly report is an opportunity to confirm response to any breach was appropriate and suitable action has been

taken to prevent recurrence. This is also an opportunity to compare performance across WTP's, look for common weaknesses and identify adverse trends. Such reviews need to be carried out in the context of where the scheme fits on the Water Safety Continuum. Schemes in the marginal zone have reduced buffer to deal with WTP under performance and high source challenge. Accordingly, performance expectations should be set at a very high level.

Management review of water treatment performance may result in initiation of the long term review of the log credits where monitoring results are adverse (or improve significantly). The management report should list pending long term reviews of water treatment and their outcome as they become available.

Reporting of operational performance – Source water

Background

According to the HBT Manual, sources can be categorised based on:

- a) degree of source protection
- b) raw water quality

The log removal requirements for a particular source category may be refined where suitable pathogen data is available.

Observational monitoring should be routinely undertaken in the catchment to confirm that sources of contamination and natural barriers to contamination are consistent with the source categorisation. Raw water *E. coli* targets can be set to warn of results which are inconsistent with the current source category. Further advice will be developed on how to set up catchment surveillance programs and report performance.

Similarly, where pathogen monitoring has been used to refine the source risk assessment it would be normal to continue such monitoring to confirm the level of risk has not increased.

Changes in source risk category

Water treatment performance can fluctuate minute by minute. For example, a power failure could mean the *Cryptosporidium* log reduction from a UV plant instantaneously changed from 4 log to 0 log.

Source challenge can change over time but generally not quickly. For example, introduction of more stock or an increase in recreation can push a scheme into a higher category. *E. coli* monitoring can similarly indicate a source has moved into a higher category. Experience from schemes with pathogen monitoring indicates high rainfall events certainly increase pathogen load, but it rarely exceeds ten times the average concentration used in the Tier 2 QMRA calculation. So movement along the continuum would be less than one log for a short time.

Catchment observational monitoring and *E. coli* or pathogen monitoring do not of themselves result in a change of source risk category. They trigger a long-term review which may result in a change of source category after an appropriate deliberative process.

While such changes in source risk are infrequent, they are never the less significant, particularly if the result is that a scheme moves into the marginal part of the Water Safety Continuum.

Source risk reporting for individual catchment

More detailed advice is under development for source monitoring but the general areas to be covered are:

- observational monitoring in the catchment
- raw water *E. coli* monitoring
- raw water pathogen monitoring (where applicable).

These are expanded in Attachment 2.

Management reports for source risk

Management reports involve reviewing performance across multiple catchments. Normally the Manager would have line and/or functional responsibility for the catchments being reported. Attachment 2 lists the minimum reporting requirements for a management report. It would be normal that the line manager is advised of any breaches as they occur and may be involved in response actions depending on their significance. Therefore, the monthly report should not contain any surprises for management.

The monthly report is an opportunity to confirm response to any breach was appropriate and suitable action has been taken to prevent recurrence. This is also an opportunity to compare performance across catchments, look for common weaknesses and identify adverse trends. Such reviews need to be carried out in the context of where the scheme fits on the Water Safety Continuum. Schemes in the marginal zone have reduced buffer to deal with WTP under performance and high source challenge. Accordingly, performance expectations should be set at a very high level.

Management review of source water may result in initiation of the long-term review of the risk where monitoring results are adverse. The report should list long-term reviews of source risk that are pending and their outcome as they become available

Scheme risk review

Sometimes source and water treatment operations are managed by different groups in a utility. At some level in the utility the source water performance and associated water treatment performance must be reconciled to determine water safety for the water supply system (location on continuum). For example, such reconciliation should pick up that deteriorating water treatment performance coupled with increasing source risk could push a scheme into the marginal part of the Continuum.

Executive reporting

Reports to the Executive of a utility should contain sufficient information to provide confidence that water supplied has been continuously safe and they have met their duty of care to protect customers for foreseeable harm.

As outlined in Section 3, they need to be assured that:

- a) Installed water treatment processes are adequate to meet the pathogen challenge.
- b) They were operated effectively.

In terms of adequacy of treatment processes, the report should include the number of schemes in the safe, marginal and unsafe parts of the Water Safety Continuum together with any changes since the previous report. This will capture changes resulting from any long-term evaluation and commissioning of capital and operational improvements.

For WTP operation, reporting should cover critical limit, target and good practice operations. Attachment 3 lists the items to be covered in an executive level report. Commentary would usually be provided for any schemes where an adequate assurance of water safety cannot be provided, (e.g. supply in breach of the critical limit occurred for more than 15 minutes), together with short and long term actions to improve water safety.

The need for teamwork and clear accountability

The establishment of operational performance reporting as recommended in this Manual substantially meets the recommendations of the Framework i.e. it *provides ‘an accountability mechanism and tool and ensures that relevant people receive the information needed to make informed decisions’* (Element 10).

However, the continuous supply of safe drinking water to customers relies on teamwork and exercise of personal accountability across all levels of the utility. The executive gets only a handful of indicators of water safety. Clearly, they are relying on a high level of scrutiny by managers. Likewise, managers are relying on the knowledge and expertise of WT and catchment Operators to optimise operations and trouble shoot problems. To avoid inadvertent omissions, utilities should document the expectations they have for the preparation and review of performance reports in line with Element 10.2 which suggests:

‘Internal reporting requirements should be defined and a system developed for communication between the various levels and functions of the organisation. Documented procedures (including definition of responsibilities and authorities) should be established for regular reporting (daily, weekly, monthly etc). These reports should include summaries of monitoring data, performance evaluation and significant operational problems that occurred during the reporting period’.

Attachment 1 – Layers of Governance for Water Treatment Operations

Governance at the WTP level

Each WTP should report on the following at a maximum frequency of monthly

WTP/Scheme status

1. Scheme status (safe, marginal, unsafe).
2. WTP long-term evaluation.
 - a) Active/inactive?
 - b) Date initiated if active.
 - c) Current log credits.
 - d) Revised log credits.

Critical Control Point (CCP) performance

For every CCP at the WTP, the following performance should be reported.

1. Critical Limit Performance

- Percentage of time water supplied in breach of critical limit (target is zero).
- no. times water supplied in breach of critical limit for longer than 15 minutes. NB. target is zero.
- No. of alarms for imminent critical limit breach.
- No. of actual critical limit breaches (of any duration).
- Comment on reasons for performance, response actions at the time and actions to prevent recurrence.

2. Target Performance

- % time target performance was achieved vs required minimum time.
- No. alarms of imminent target breach.
- No. actual target breaches.
- Comments on reasons, actions taken at the time and to prevent a recurrence.

Good practice performance

1. An observational monitoring program is required for each WTP to demonstrate achievement of good practice operation. The program should comprise discrete activities, each with a target.

2. The following should be reported

- No. observations planned.
- No. (or %) observations completed.
- Reasons for any missed observations.
- No. (or %) observations where target not met.
- List of target breaches.
- Reason for each target breach.
- Action taken to restore acceptable performance.
- Action taken to prevent recurrence.

Explanatory notes

1. Critical limit and target ranges are provided in the WSAA HBT Manual.
2. Alarms are required to provide advance warning of critical limit and target breaches.
3. By definition, water which exceeds a critical limit may not be safe and should not be supplied to customers. The reference to reporting critical limit exceedances of longer than 15 minutes should NOT be interpreted as sanctioning the supply of water to customers which exceeds the critical limit. The reference to 15 minutes is only to provide an operational buffer to prevent false alarms.
4. Where a critical limit is breached it needs reporting even if the WTP fails safe. A critical limit breach indicates total loss of control of the process, a very significant event which needs reporting to management.
5. Where reliance is placed on pre-treatment to claim log credits then it too should be reported as per target performance above.
6. WTP operators should be aware if their WTP is supplying a scheme which is ‘marginal’ on the Water Safety Continuum. Such schemes have reduced buffer and WTP operators should be aware of the need to:
 - a) be especially vigilant and diligent at times of high pathogen challenge in the source water
 - b) achieve excellent performance in terms of good practice WTP operation.
7. If traffic light reporting is used, acceptable performance (green traffic light) should be defined as achieving 100% of required performance for critical limit, target and good practice. Reporting against arbitrary internal targets is not appropriate at the WTP level of reporting.

WTP Governance at the management level

A management level report involves aggregating the performance of multiple plants. The maximum frequency for review should be monthly. It may be feasible to simply aggregate the individual WTP monthly reports where there are not too many. Where that is not practical then exception reporting may be employed. The minimum requirements are outlined below.

Source/Scheme status

1. List WTPs supplying marginal and unsafe schemes.
2. List WTPs currently subject to long-term evaluation.
 - a) WTP.
 - b) Date initiated.
 - c) Current log credits.
 - d) Revised log credits.

Critical Control Point performance

1. Critical Limit Performance
 - List any WTP which supplied water in breach of the critical limit for longer than 15 minutes.
 - List any WTP which had a critical limit breach and % time operated in breach of CL.
 - List any WTP which had an alarm warning of a critical limit breach and number of alarms.

2. Target Performance

- List any WTP which failed to meet the monthly performance requirement.
- List any WTP which had unacceptable number of target breaches (to be determined by utility based on their experience and expectations).

Good practice performance

- List any WTP which did not complete 100% of planned observations.
- List observations missed by WTP.
- List any WTP which had observational target breaches.
- List target breaches by WTP.

Explanatory notes

- 1) The performance should not be a surprise to Management. It is expected that CCP target and critical limit breaches would be treated as incidents and routinely reported at the time of occurrence.
- 2) Similarly, systems should routinely report observational monitoring performance (e.g. missed observations, target breaches).
- 3) Management must satisfy itself that:
 - a) response to breaches has been appropriate
 - b) suitable actions have been initiated to prevent recurrence.
- 4) This is also the opportunity to compare performance across WTPs, look for common weaknesses and identify adverse trends. Review further up the governance chain will be relying on this type of scrutiny and follow-up.
- 5) Reports should indicate if the scheme is in the safe or marginal part of the Water Safety Continuum. Special attention should be given to the performance of any WTP supplying a scheme in the marginal section of the Water Safety Continuum. Very high performance is required from such plants in view of the reduced buffer available to accommodate WTP under performance or high source challenge.
- 6) If traffic light reporting is used then a green light should only apply if all requirements have been met at that WTP (i.e. critical limit, target and good practice).

If reporting by parameter than a green light should only apply for critical limit performance if all WTPs met all the critical limit requirements. Similarly, for target and good practice.

Attachment 2 – Layers of Governance for Source Operations

Source governance at the catchment level

Each catchment should report on the following at a maximum frequency of monthly

Source/Scheme status

Scheme status (safe/marginal/unsafe).

Long term evaluation (active/inactive)

- a) Active/inactive?
- b) Date initiated if active.
- c) Current source category.
- d) Revised source category.

Raw water *E. coli* monitoring

No. samples planned.

No. (or %) samples taken.

Reasons for any missed samples.

No. samples where target breached.

Reason for target breach.

Actions taken to restore performance.

Actions taken to prevent recurrence.

Catchment surveillance

No. observations planned.

No. (or%) observations completed.

Reason for any missed observations.

No. (or%) observations where target not met.

List of target breaches.

Reason for each target breach.

Action taken to restore acceptable performance.

Action taken to prevent recurrence.

Pathogen monitoring (if applicable)

No. samples planned.

No. samples taken.

Reason for any missed samples.

No. samples where target breached.

Reason for target breach.

Actions taken to restore acceptable performance.

Actions taken to prevent recurrence.

Explanatory notes

1. Target for raw water quality should be established, including

a) The highest reading allowed for the source category

i.e. Category 1 = 20 organisms/100 ml

Category 2 & 3 = 2000 organisms/100 ml

Category 4 = 20,000 organisms /100 ml

Any breach indicates possible shift to higher source category and warrants immediate investigation.

b) The previous highest *E. coli* reading. Any breach indicates a higher source challenge than has previously been encountered and reasons should be investigated along with assurance of optimal WTP operation.

2. Targets should be established for all catchment observations.

3. Targets can be established for pathogen monitoring including:

a) The highest previous result. A breach indicates a higher source challenge than previously encountered and the reasons need to be investigated.

b) Ten times the concentration used in the QMRA. A breach means water safety for this scheme should be reassessed.

Source governance at the management level

A management level report involves aggregating the performance of multiple catchments. The maximum frequency shall be monthly.

It may be feasible to simple aggregate individual catchment reports where there are not too many. Where that is not practical the exception reporting may be employed. The minimum requirements are outlined below.

Source/Scheme status

List sources supplying safe, marginal and unsafe schemes.

List sources subject to long-term evaluation:

- source
- date initiated
- current category
- revised category.

List sources which moved to a higher risk category.

Raw water *E. coli* monitoring

List any catchment where 100% planned samples were not taken.

List any catchment where *E. coli* targets were breached together with target and actual results.

Catchment surveillance

List any catchment where 100% planned observations were not completed.

List any catchment which had target breaches together with a list of target breaches.

Pathogen monitoring

List any source where 100% planned samples were not taken.

List any source where pathogen targets were breached together with target and actual results.

Explanatory notes

1. The performance should not be a surprise to management. It is expected that breaches are reported to Management as they occur.
2. Similarly, systems should routinely report observational monitoring performance (missed observations, target breaches etc).
3. Management must satisfy itself that:
 - a) response to breaches has been adequate
 - b) suitable actions have been taken to prevent recurrence
 - c) the opportunity has been taken to better understand source characteristics at times of high challenge.
4. This is also the opportunity to compare performance across catchments, look for common weaknesses and identify adverse trends. Further review up the governance chain will be relying on this type of scrutiny.
5. Adverse results may warrant a long term evaluation of source risk. The management report should include a list of sources where long term evaluation is underway, the date the review was initiated (so it doesn't drag on) and the results when available. If a scheme is placed in a higher risk category then this has implications for water safety and should be reported in executive-level reports.

Attachment 3 – Water Quality Governance at the Executive Level

An executive level report should contain the minimum information to provide assurance that the water supplied has been continuously safe for the reporting period.

Therefore, the following should be reported at the executive level.

Water safety status

Placement of schemes on the water safety continuum:

- No. Safe
- No. Marginal
- No. Unsafe

Changes since last report.

Source risk status

List sources which have moved to a higher or lower category since last report.

Water treatment performance

- Critical limit performance
Number (or %) WTPs achieving required performance
List any WTP which supplied water in breach of the critical limit for 15 minutes for any CCP.
- Target performance
Number (or %) of WTPs achieving required performance
List any WTP which failed to meet the performance requirement for operation within the target band for any CCP.
- Good practice operation
% observational targets met.
- *E. coli* performance
No change to current arrangements.

Explanatory notes

1. Reliance on CCP performance to assure water safety assumes that
 - a) The source risk has not been increased since the last long term evaluation. Since source risk tends to not move very quickly this assumption is reasonable with update following periodic long term evaluation of the scheme.
 - b) The scheme plots in the safe part of the water safety continuum.
2. Where it is known that a scheme plots in the marginal part of the Water Safety Continuum it is necessary that this information is included in every report. It is important that the Executive is continuously aware that such schemes carry less buffer to deal with WTP under performance or high source risk. The information can be conveyed by notes to the report or (preferably) by reporting separately on schemes which are in the safe and marginal part of the continuum.

3. If traffic light reporting is used then green should only be used if 100% of WTP's meet all requirements for critical limit performance/target performance.
4. For good practice reporting at the executive level, utilities may:
 - a) report only against required measures in the WSAA & WRA Good Practice Manual
 - b) adopt an interim target (other than 100%) for traffic light reporting. In this case a note to the report is required so that the Executive does not get the impression that performance is 100% when it is not.
5. Traditional *E. coli* performance reporting should be retained as long as this reporting is still required by the health regulator.
6. Aggregation of performance into a single water quality KPI is not appropriate. Such numbers are meaningless. Members of the executive and board of a water utility require a basic understanding of CCPs and the role played by the critical limit and target in assuring water safety. Reporting performance against these parameters is fundamental to discharge of their duty of care.

Attachment 4 – Duties and Obligations of Directors in Public Utilities

Below is an extract from a feature article titled '*Duties and obligations in public utilities*' in the November 2011 edition of the AWA Journal *Water*. The authors are A Davison, B Burford and S Alden.

The article reviews corporate governance and the duties of directors following action taken by ASIC against the directors of Centro under the Corporations Act. Table 2 from the article is reproduced below. It takes the reasoning from the Centro case and applies it to water utilities.

Table 2. Centro reasoning and its application to state-owned water utilities.

Reasoning	At	Consideration for water utilities
A director is an essential component of corporate governance. Each director is placed at the apex of the structure of direction and management of a company. The higher the office that is held by a person, the greater the responsibility that falls upon him or her. The role of a director is significant as their actions may have a profound effect on the community, and not just shareholders, employees and creditors.		Directors need to have an understanding of water quality, not just of finances, law and water quantity.
This proceeding involves taking responsibility for documents signed-off by, approved, or adopted by the directors. What is required is that such documents, before they are adopted by the directors, be read, understood and focused upon by each director with the knowledge each director has or should have by virtue of his or her position as a director.	14	Decisions of directors in relation to water quality could have a profound effect on the community in terms of public health and wellbeing if the provision of the water product is not fit for purpose
The case law indicates that there is a core, irreducible requirement of directors to be involved in the management of the company and to take all reasonable steps to be in a position to guide and monitor. There is a responsibility, to read, understand and focus upon the contents of those reports which the law imposes a responsibility upon each director to approve or adopt.	15	A director should understand the resourcing implications for the maintenance of continued supply of fit-for-purpose water quality.
....a director should acquire at least a rudimentary understanding of the business of the corporation and become familiar with the fundamentals of the business in which the corporation is engaged; a director should keep informed about the activities of the corporation; whilst not required to have a detailed awareness of day to day activities, a director should monitor the corporate affairs and policies; a director should maintain familiarity with the financial status of the corporation by a regular review and understanding of financial statements; a director, whilst not an auditor, should still have a		A director should understand the community health and environmental implications of the supply of water that is not fit for purpose.
		Directors would not be expected to understand the minutiae of water quality at the coal face but they would be expected to understand where in their systems critical control points existed, ie. where if a process failed, the customer could potentially be supplied with unfit water, and the consequences of this supply of unfit water.
	16	Directors should be asking management to include water quality reports as a separate line item on their board meeting agendas.
		Directors should be seeking out data on water quality, including near hits to critical control points, and not just relying on data that show whether the Australian Drinking Water (or other)

questioning mind.

A board should be established which enjoys the varied wisdom, experience and expertise of persons drawn from different commercial background's. Even so, a director, whatever his or her background, has a duty greater than that of simply representing a particular field of experience or expertise. A director is not relieved of the duty to pay attention to the company's affairs which might reasonably be expected to attract inquiry, even outside the area of the director's expertise.

Guidelines or contractual obligations have been met.

A director, if not conversant in water quality, is obliged to make it his or hers business to at least understand the business of water supply and its relevant requirements.

- 17 A director should have read, understood and compiled with the corporation's relevant water quality Policy as this effectively sets the corporation's standard of duty in this context.
- 18 A utility's board should include those who understand the engineering and scientific aspects of water quality provision, not just the provision of water quantity.