The Water Safety Continuum

A Practical Way to Implement a Health Based Target for Microbial Water Quality

By Richard Walker

1. Scene Setting

1.1 The Australian Drinking Water Guidelines

The National and Health Medical Research Council (NHMRC) is responsible for producing and updating the Australian Drinking Water Guidelines (ADWG), the authorative reference in Australia for drinking water quality. Guiding principle number one in the ADWG states that "the greatest risk to consumers of drinking water are pathogenic microorganisms". However, the only numerical target for microbial water quality in the ADWG is that routine samples should not contain the indicator *E.coli* bacteria.

In the early 2000's Australia lead the way with the introduction of a risk based approach to water quality management. However, over the past decade Australia has lagged behind other jurisdictions such as USA, Canada, New Zealand and WHO which have introduced a health based target (HBT) for microbial water quality. In 2009, NHMRC produced a discussion paper on the introduction of an HBT for Australia.

1.2 Why we need a HBT

The Australian Water Industry has generally embraced the risk based approach to water quality as documented in the Framework for Management of Drinking Water Quality in the ADWG (the Framework).
With respect to the adequacy of water treatment, the Framework sets out a general approach requiring a utility to assess the pathogen risk in the catchment, assess the water treatment plant (WTP) capacity to provide a barrier to these pathogens entering the water supply system and therefore whether the "residual risk" to customers is satisfactory. It also nominates the WTP as a critical control point and requires continuous monitoring to confirm effective operation.

The absence of specific Australian guidance on how to assess the adequacy of water treatment has resulted in many utilities deferring to overseas publications such as USEPA Long Term Surface Rule or developing their own "rules" to assist with

a) Source risk assessment
b) Water treatment process selection
c) Operational performance targets for WTPs

This means an inconsistency of approach and outcomes across Australia. In his findings from the Royal Commission into the Sydney water quality incident in 1998, Justice McClellan noted that *no water treatment plant can guarantee removal of all Cryptosporidium and Giardia.* The Centers for Disease Contol and Prevention also notes that *apart from boiling, few water treatment methods are 100% effective in removing all pathogens*. This means that no matter how good the treatment, there will always be some pathogens entering the water supply and some resultant level of disease (highly protected and confined groundwater being a possible exception). In order to answer the question about 'what treatment is necessary' one has to first answer the question about ‘what level of disease is acceptable’. This is referred to as the ‘tolerable disease burden’. Obviously, the lower the ‘tolerable disease burden’ the more stringent are the water treatment requirements. The HBT merely quantifies the “tolerable disease burden”.

1.3 Is an HBT the Answer?

Other jurisdictions have already set tolerable disease burdens or HBTs. USEPA has adopted a target of 1 infection/10,000 people pa. This is an easy concept to grasp. However, the result of any infection could range from mild inconvenience to lifetime impairment (eg. kidney damage) to even death in rare cases. The USEPA metric takes no account of this.

WHO has adopted a target of one DALY/million people pa.

DALY stands for Disability Adjusted Life Year and it attempts to quantify the frequency of infection and the duration and severity of the illness. This is a better measure of the burden of disease in the community but involves many assumptions and is very difficult to explain to the public.

While a HBT for microbial water quality in Australia has not been set, most discussions point to adoption of the WHO target. Regardless of which metric is chosen, the major attraction of including a HBT in the ADWG is that it provides an opportunity to introduce a consistent approach to water treatment process selection and operation. Accordingly, the HBT proposal has received widespread but cautious support from the majority of water quality professionals in Australian utilities. Concerns include costs to implement and how the HBT will be interpreted and applied by health and other regulators.

2. WSAA Involvement

2.1 Strategic Significance of a HBT

The Water Services Association of Australia (WSAA) is the peak body representing the majority of water service providers in Australia. Following an NHMRC organised workshop on HBTs in May 2012, WSAA recognised that –

a) The introduction of a HBT was potentially beneficial to the water industry in discharging its primary responsibility to supply safe drinking water
b) The concept of a HBT had widespread support in principle from utility water quality professionals
c) The introduction of an HBT was potentially the most significant change to water quality management since the Framework was included in the 2004 ADWG and therefore of strategic significance,

2.2 HBT working Group

Consequently, in August 2012, the WSAA HBT Group was formed with the objective of assessing the impact on water utilities if an HBT of one micro DALY was adopted and to influence NHMRC to obtain a cost effective public health outcome and a practical operational and regulatory arrangement for the water industry.

The HBT Group comprises Richard Walker, (Water Corporation of Western Australia,Chair), Arran Caning (South East Queensland Water), Mark Angles (Sydney Water), Andrew Ball (Sydney Catchment Authority), Melita Stevens (Melbourne Water), Cliff Liston/Jason West (South Australia Water), Greg Ryan (South East Water), Peter Spencer/Steve Capewell (Water Corporation of Western Australia).

The Working Group had two primary questions to answer

1. How do you determine whether a water supply system has achieved the HBT?
2. What are the consequences if the HBT is not achieved?

The development of the concept known as the "Water Safety Continuum" was instrumental in not only answering question 2 but also providing the confidence to proceed with the very detailed work to answer question 1.

3. Water Safety Continuum Development

3.1 Disease Burden versus Alternative HBTs

If a utility fails to achieve the HBT of one micro DALY then the community bears an increased disease burden. However, because the DALY is a "derived" metric then the significance of this increase is not intuitive. Table 7.4 of the WHO Guidelines for Drinking Water Quality (2011) explains how the health outcome is calculated. For example, for the reference pathogen Cryptosporidium the risk of diarrheal illness is 6.7×10^{-4} pa per person if the HBT of one micro DALY is achieved.

This means that in a city of one million people, there would be 670 cases of waterborne Cryptosporidiosis pa (or 1.8 cases pd) if the HBT of one micro DALY was achieved. This type of outcome has meaning to not only water quality and health professionals, but also the general public.

Table 1 below lists the incidence of waterborne Cryptosporidiosis for alternative HBTs for a city with a population of one million people.

Table 1. Incidence Waterborne GI for Alternative HBTs

HBT (micro DALY)	Illness pa (pop 1M)	Illness pd (pop 1M)
1	670	1.8
10	6700	18
100	67,000	180
1,000	670,000	1,800

10,000	6,700,000	18,000

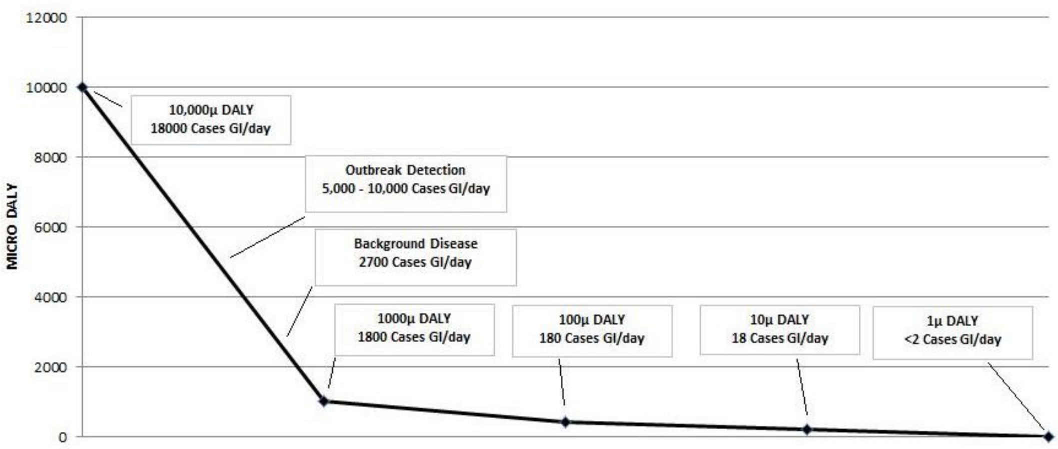
As a benchmark, the background level of gastro intestinal illness (GI) in the community is notionally about 1 case per annum per person or about 2700 cases per day in a city of one million people. Recent research by Gibney et al indicates the actual GI rate in Australia is actually about 0.8 cases pa per person but this does not change the principles associated with the Water Safety Continuum development and application.

Health surveillance is generally considered not capable of picking up "outbreaks" until they are 2-4 times the background disease level (ie. 5-10,000 cases per day for a city of 1 million people).

3.2 Interpretation

Figure 1 plots the data in Table 1 together with the background and outbreak detection levels of community GI.

FIGURE 1 THE WATER SAFETY CONTINUUM FOR CRYPTOSPORIDIUM – EXAMPLE FOR 1M PEOPLE



This figure illustrates some key points. While achieving one micro DALY means the water supplied is unquestionably safe, the converse is not true. For example, achieving two micro DALY would add 1.8 cases of GI per day to a background disease burden of 2700 cases per day. This cannot be detected in reality and certainly does not mean the water supplied is unsafe.

It would be unjustified to consider an intervention such as a boil water advisory in this case and illustrates clearly that a HBT such as one micro DALY cannot be used as a pass/fail measure.

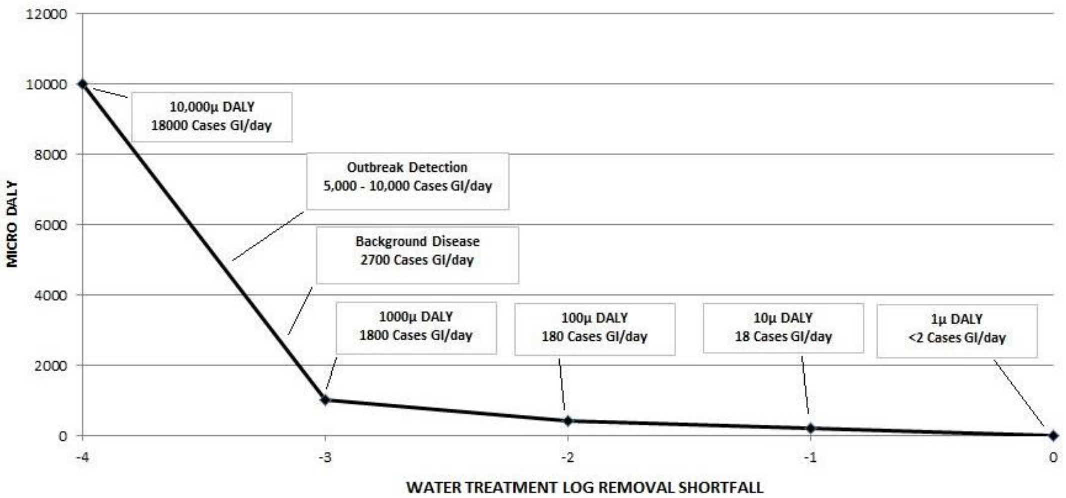
Furthermore, it illustrated that water safety should be considered as a continuum rather than a fixed-point outcome. In that context the one micro DALY must be viewed as an aspirational target because it cannot be verified by health data. At the other end of the scale, consider the left hand side of the graph (10,000 micro DALY).

The disease burden of 18,000 cases per day is six times the background GI for the community. Within two weeks. 250,000 people will be ill. This is an outbreak of Milwaukee-like proportions.

3.3 Application to Water Supply Systems

Figure1 can be applied to water supply systems by making the X axis a "log reduction shortfall". The "short fall" is the log reduction required (based on the source risk assessment) minus the log credits achieved by the water treatment plant (based on operational performance). Thus, a system which has adequate water treatment to deliver one micro DALY has zero short fall. If the water treatment has a one log shortfall it will deliver 10 micro DALY etc as shown in Figure 2 below.

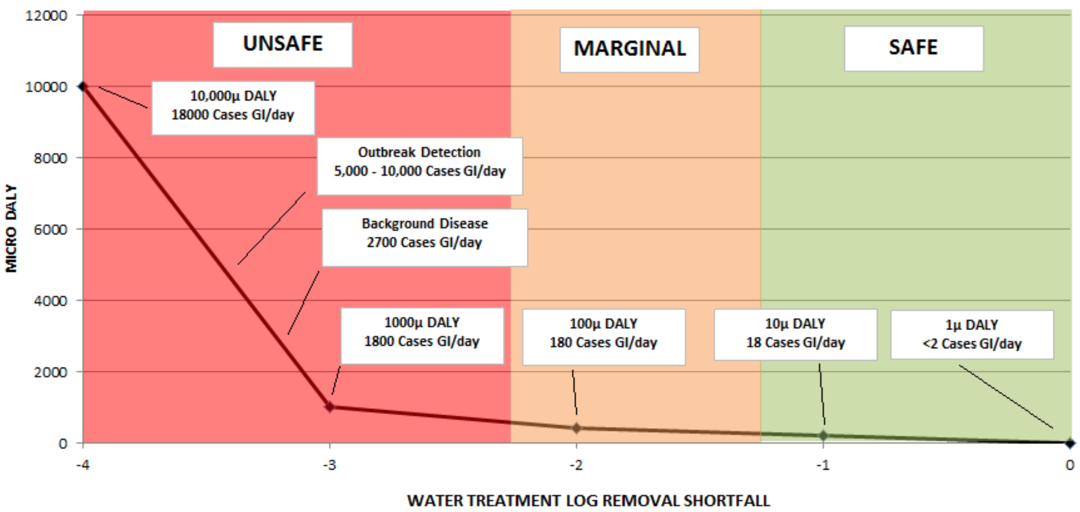
FIGURE 2 WATER SAFETY OUTCOMES FOR CRYPTOSPORIDIUM – EXAMPLE FOR 1M PEOPLE



3.4 Bands of Safety

Assessing the safety of a water supply scheme requires making an estimate of the pathogen challenge from the source water and the pathogen reduction performance of the water treatment plant. Clearly such calculations have unavoidable imprecision. As an extension of the water safety continuum approach, it is proposed that water safety be considered as three bands of safety as shown in Figure 3 below. While there will always be uncertainty about expressing the water safety performance of a water supply system as an absolute number, utilities can be much more confident about which band applies to each scheme.

FIGURE 3 BANDS OF SAFETY – EXAMPLE FOR CRYPTOSPORIDIUM FOR 1 M PEOPLE



These bands could be defined as unsafe, marginal and safe. As an example in Figure 3 they have been defined as:

Safe – is anywhere in the band from 1 to 15 micro DALY. This means that less than 1% of the background community GI is waterborne. On this basis the water supply is unquestionably "safe" and there is a big buffer between the normal operation of the scheme and an "outbreak' situation. This means the scheme is very robust and can withstand an unusually high source challenge (eg mobilisation of pathogens in the catchment following heavy rain) or short term WTP underperformance without a significant increase in community waterborne disease. There are most likely adequate barriers in place and the scheme can be moved towards achieving 1 micro DALY by pursuit of good practice source and WTP operations. The "safe" part of the continuum is a great place to be.

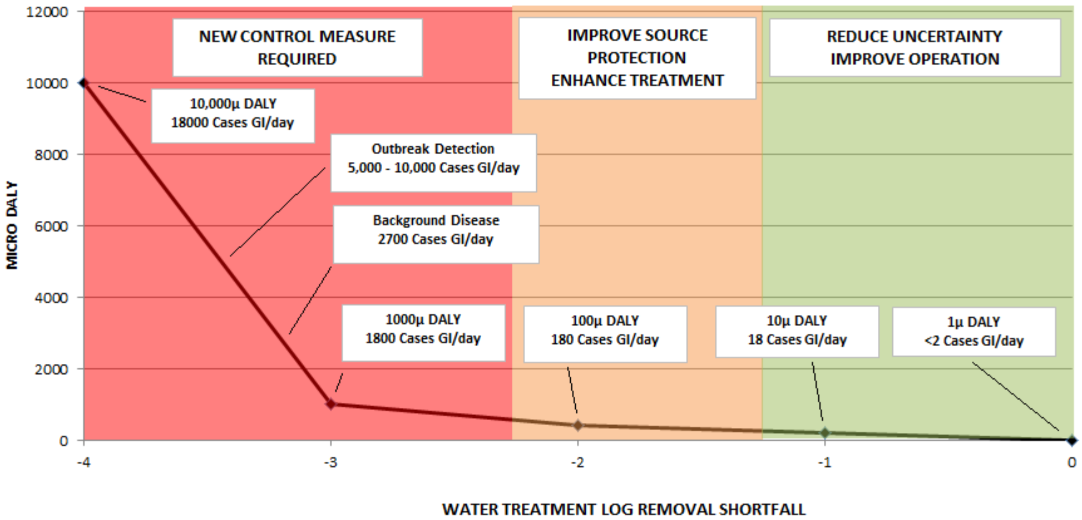
Marginal – is anywhere in the band 15-150 micro DALY. This means that up to 10% of community GI could be waterborne. The water supplied is NOT therefore unquestionably "safe". There is not much buffer between normal operating conditions and an outbreak situation. Accordingly, this scheme cannot be considered robust and it is vulnerable to an unusually high source challenge or WTP underperformance. The marginal zone is not a comfortable place to be for any length of time and improvements are required as soon as practicable to move the scheme into the "safe" zone..

Unsafe – is anywhere greater than150 micro DALY. More than 10% of the community GI is waterborne and more than 10% of the population will be infected each year from their drinking water. The water supply is unquestionably unsafe and an outbreak is imminent at any time. Immediate intervention (eg boil water advisory) is required to protect public health. No utility ever wants to be in the "unsafe' zone.

4. Benchmarking

The water safety assessment for a water supply system involves determining whether the pathogen log reduction requirements arising from the source risk assessment is less than or equal to the log reduction achieved by the water treatment plant. If so, then it is likely that the HBT has been achieved. If not, the difference between the log reduction required and achieved can be plotted on the water safety continuum to give a visual indication of how far away the scheme is from achieving the "benchmark" of one micro DALY. In addition the location on the Continuum gives an immediate indication of the public health implications and urgency for improvement action as illustrated in Figure 4 below.

FIGURE 4 CONTINUUM LOCATION VS IMPROVEMENT ACTION



5. Improvement Program

The Water Safety Continuum provides a valuable tool to manage water quality improvements. The nature and timing of improvements is influenced by where a scheme plots on the continuum.

5.1 Schemes in the 'Safe' Sector of the Continuum

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

There is often some uncertainty about the source risk assessment and water treatment performance (particularly the first time these assessments are undertaken). 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 uncertainty is not the real issue and the gap is more 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 is always the preferred option and 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, fencing etc.
- implementing 'good practice' to reduce contamination from legal activities in the catchment
- purchasing land.

Improving the performance of existing water treatment facilities is often the quickest option to move to the right of the continuum. It may require modest investments to improve chemical dosing, backwash management, plant instrumentation, etc. Staff training and performance reporting are also important measures to maximise WTP performance.

Where the utility is satisfied that performance of existing facilities has been optimised, and source risk cannot be reduced, then there is no alternative but to implement an additional treatment barrier. Since the scheme is "safe", these improvements can be programmed over a 5-10 year timeframe to minimise "price shock" for customers.

5.2 Schemes in the "Marginal" Sector of the Continuum

Schemes in the 'marginal' sector of the continuum require more urgent action. While a public health incident is still unlikely, there is little buffer should the source experience an unusually high challenge or the WTP performance deteriorate. 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 1–2 log shortfall in performance and urgent action is required in this case to move the scheme towards the 'safe' sector. Once again, the best chance to improve water safety quickly is usually to improve the performance of the existing treatment plant.

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 and certainly within 3-5 years.

5.3 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 Health Department.

6. Linking Operational Performance to Health Outcomes

6.1 Water Supply Systems are Dynamic

The HBT is usually regarded as an annual target. However, the Water Safety Continuum allows the water quality manager in a utility to link the short term operational performance of a water supply system with public health outcomes. Water supply systems are rarely stable. The pathogen challenge in the source water is highly variable and influenced by rainfall, catchment activity, reservoir storage volumes etc.

Similarly water treatment processes such as media filtration achieve variable pathogen reduction with factors such as pre-treatment effectiveness and filter ripening affecting performance.

It can now be appreciated that even for schemes which nominally achieve the annual target of one micro DALY there will be times when performance will be better than the target and times when it is less. In other words systems run up and down the continuum on a daily basis. However, for well designed and operated systems the excursions to the left on the continuum are minimal during normal operations.

By using the Continuum, operators can see the public health consequences of their day to day activities and decisions.

6.2 Incident Management

Every scheme experiences periodic incidents eg. partial loss of control of the treatment process. The Continuum provides a useful tool to gauge the public health consequences when managing such situations.

For example, take a media filtration plant which normally operates with a filtrate turbidity of 0.15 NTU (3.5 log protozoa reduction). If there was a process problem and filtrate turbidity rose to 0.3 NTU then protozoa reduction would reduce to a nominal 2.5 log reduction. This means the water safety performance has moved to the left on the Continuum by one log. For a scheme operating at one micro DALY the consequences in the short term are minimal. By referring to Figure 3 or 4 it can be inferred that the average rate of GI will increase from 1.8 to 18 cases per day in a city of 1 M people which is insignificant compared to the background rate of 2700 cases per day.

However, for a scheme operating in the “marginal” part of the Continuum (say 100 micro DALY) the consequences are more of a concern. In this case the nominal waterborne GI rate may increase from 180 to 1800 cases per day which is significant even against a background rate of 2700 cases per day. Intervention to protect public health should be considered in this case.

In the example above, if filtration performance continued to deteriorate and filtrate turbidity exceeded 0.5 NTU then the filtration process could not be relied upon to provide any protozoa reduction. If filtration was the only barrier to protozoa then the scheme performance would have slipped into the “unsafe” portion of the Continuum and intervention would be required to protect public health.

However, for poorly protected sources a typical water treatment train would be filtration (3.5 log reduction of protozoa) together with ultra violet (UV). The UV is only required to achieve 2 log reduction of protozoa to deliver one micro DALY but is typically designed and operated to achieve 4 log. In this case, despite loss of filtration, the UV could keep the scheme in the safe part of the Continuum subject to suitable turbidity and colour of water pre UV. This may avoid the need for a public advisory. Discussion would be required with the local Department of Health to confirm operating with this single barrier is acceptable for a short period (NB. absence of pathogen removal process).

The key point is that the Water Safety Continuum provides a basis for meaningful dialogue between the Health Dept and the utility by linking current WTP performance to community health outcomes.

7. Summary

- The introduction of a HBT for microbial water quality in Australia has the potential benefit for utilities of providing a mechanism to determine adequacy of water treatment processes and setting consistent operational performance targets.

- The most likely HBT is one micro DALY. This is the best metric to quantify disease burden but is a difficult concept to understand and there is no “feel” currently for the consequences if the HBT is not met.

- The water industry can appreciate the advantages of a HBT but has concerns about how it will be interpreted and applied by health and other regulators in Australia.

- The WSAA HBT Working Group has developed a concept known as the “Water Safety Continuum” to help understand the consequences of not meeting the HBT and how the HBT may be used to improve water quality outcomes for consumers.

- The Continuum plots incidence of community disease for alternative water safety outcomes. Context is provided by comparison with background GI levels, detection of outbreaks by health surveillance and well known water quality incidents such as “Milwaukee”.

- Bands of safety have been superimposed on the continuum in recognition of the inherent uncertainty associated with water safety calculations.

- When considered in the context of the Continuum it is concluded that

  a) Achieving the HBT if one micro DALY means the drinking water is unquestionably safe

b) However, the converse is not true and therefore the HBT should not be considered a pass/fail metric
c) The HBT of one micro DALY should be retained as an aspirational target while remaining cognisant that it cannot be verified by health surveillance
d) The HBT is best used in conjunction with the Water Safety Continuum as a benchmarking tool – it indicates the quantum and type of improvement required
e) The Continuum is a valuable tool to manage utility water quality improvement programs. The further to the left a scheme is located on the Continuum, the more significant and urgent is the improvement required
f) The Continuum can be used to link the operation of catchments and water treatment plants to public health outcomes. Operators can appreciate the public health impacts of their day to day decisions
g) The Continuum can also be used as a tool to help with management of water quality incidents.

The development of the Continuum has provided confidence that an HBT can be implemented in a pragmatic fashion in Australia. If adopted, the benefit of a consistent approach to water treatment adequacy can be achieved without unwieldy and impractical regulatory arrangements.

References

Centers for Disease Control and Prevention *A Guide to Drinking Water Treatment and Sanitation for Backcountry and Travel Use*

Gibney,K., Sinclair,M.,O'Toole,J.&Leder,K.2013 *Using disability-adjusted life years to set health based targets: a novel use of an established burden of disease metric. J. Public Health Policy 34 (3), 439- 446*

McClellan, Peter 1998 *Sydney Water Enquiry: Final Report*, Sydney, NSW Premier's Dept

NHMRC and NRMMC *2011 Australian Drinking Water Guidelines*

NHMRC 2009 *Health Based Targets For Microbial Safety Of Drinking Water Supplies Draft Discussion Paper*

USEPA 1989 *National Primary Drinking Water Regulations: filtration, disinfection, turbidity, Giardia lamlia, viruses, Legionella, and heterotrophic bacteria: final rule. Fed. Regist. 54(124),27845-27541*

WHO *2011 Guidelines for Drinking Water quality.* World Health Organisation, Geneva