

THE WATER SAFETY CONTINUUM

A PRACTICAL WAY TO IMPLEMENT A HEALTH-BASED TARGET FOR MICROBIAL WATER QUALITY

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INTRODUCTION

The Australian Drinking Water Guidelines

The National Health and Medical Research Council (NHMRC) is responsible for producing and updating the *Australian Drinking Water Guidelines* (ADWG), the authoritative 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 bacteria *Escherichia coli* (*E. coli*).

In the early 2000s Australia led the way with the introduction of a risk-based approach to drinking water quality management. However, over the past decade Australia has lagged behind other jurisdictions, such as the US, Canada, New Zealand, and the World Health Organisation (WHO), which have introduced health-based targets (HBTs) for microbial water quality. In response, in 2009 NHMRC produced a discussion paper on the introduction of a HBT for Australia.

Why We Need A Health-Based Target

The Australian water industry has generally embraced the risk-based approach to drinking water quality as documented in the Framework for Management of Drinking Water Quality (the Framework), as detailed in Chapter 3 of the ADWG.

With respect to the adequacy of water treatment, the Framework sets out a general approach requiring a water service provider 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 acceptable. It also nominates the WTP as a critical control point and requires that continuous monitoring be undertaken to confirm effective operation of the WTP.

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:

- Source risk assessment;
- Water treatment process selection;
- 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 Control and Prevention (2009) 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 passing unchecked through the treatment process, leaving some resultant level of disease (highly protected and confined groundwater being a possible exception). In order to answer the question “what treatment is necessary?” one first has to answer the question “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 the water treatment requirements. The HBT merely quantifies the “tolerable disease burden”.

Is A Health-Based Target The Answer?

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

WHO has adopted a target of one Disability Adjusted Life Year (DALY)/million people per year or one micro DALY per person per year (PPPY). The DALY 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 is a very difficult concept to explain to the public.

While a HBT for microbial water quality in Australia has not been set, most discussions point to the 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 Australia. Concerns include costs to implement, and how the HBT would be interpreted and applied by health and other regulators.

INVOLVEMENT OF WSAA Strategic Significance Of A HBT

The Water Services Association of Australia (WSAA) is the peak body representing the urban water industry in Australia. Its members provide water and sewerage services to over 20 million Australians. 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 water quality professionals;
- c. The introduction of a HBT was potentially the most significant change to drinking water quality management in Australia since the Framework was included in the 2004 ADWG, and therefore of strategic significance.

HBT Working Group

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

The HBT Working Group comprises the author, Richard Walker (Chair, Water Corporation of Western Australia), Arran Canning (South East Queensland Water), Mark Angles (Sydney Water), Andrew Ball (Sydney Catchment Authority), Dan Deere (Water Futures)

Melita Stevens (Melbourne Water), Cliff Liston and Jason West (South Australia Water), Greg Ryan (South East Water), and Peter Spencer and Steve Capewell (Water Corporation of Western Australia).

The Working Group had two primary questions to answer:

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

The development by the HBT Working Group 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 needed to answer Question 1.

WATER SAFETY CONTINUUM DEVELOPMENT

Disease Burden Versus Alternative HBTs

If a water provider fails to achieve the HBT of one micro DALY PPPY, then the community bears an increased disease burden. However, because the DALY is a “derived” metric, 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 diarrhoeal illness is 6.7×10^{-4} per person per year if the HBT of one micro DALY PPPY is achieved.

This means that in a city of one million people there would be 670 cases of waterborne cryptosporidiosis

annually (or 1.8 cases per day on average) if a HBT of one micro DALY PPPY was achieved. This type of outcome has meaning not only to water quality and health professionals, but also to the general public.

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

As a benchmark, the background level of gastrointestinal (GI) illness is notionally about one case per person per annum, or 2,700 cases per day on average. Recent research by Gibney *et al.* (2013) indicates the actual level of GI in Australia is about 0.8 cases per person per annum, but this does not change the application of Water Safety Continuum.

Health surveillance is generally considered not capable of picking up “outbreaks” until they are two to four times the background disease level (say, 5,000–10,000 cases per day for a city of one million people).

Interpretation

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

This figure illustrates some key points. While achieving one micro DALY PPPY means the drinking 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 2,700 cases per day. This cannot be detected in reality and certainly does not mean the drinking water supplied is unsafe.

It would be unjustified to consider an intervention such as a boil water

Table 1. Incidence of waterborne gastrointestinal illness (GI) for alternative HBTs for a city of 1 million population.

HBT (micro DALY PPPY)	Illness cases per year	Illness cases per day
1	670	1.8
10	6,700	18
100	67,000	180
1,000	670,000	1,800
10,000	6,700,000	18,000

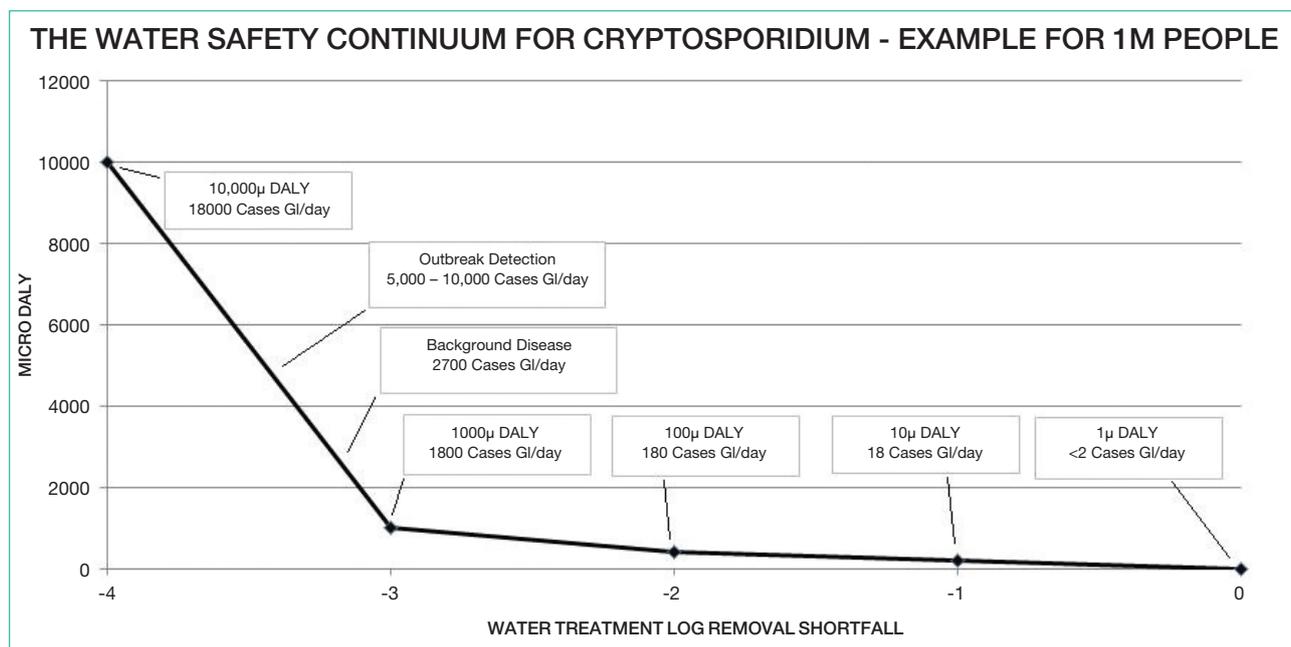


Figure 1. The Water Safety Continuum and Water Safety Outcomes for Cryptosporidium – example for city of one million people.

advisory in this case and illustrates clearly that a HBT such as one micro DALY PPPY cannot be used as a pass/fail measure.

Furthermore, it illustrates that water safety should be considered as a Continuum rather than a fixed-point outcome. In that context the one micro DALY PPPY 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 would be ill. This is an outbreak of disastrous proportions and the health outcomes align with infamous incidents such as Milwaukie and Walkerton.

Application To Water Supply Systems

The key to applying Figure 1 to water supply systems is the X axis – a “log reduction shortfall”. The “shortfall” is the log reduction required (based on a source water risk assessment) minus the log credits achieved by the water treatment plant (WTP) (based on operational performance). Thus, a system that has adequate water treatment to deliver one micro

DALY has zero shortfall. If the water treatment has a 1-log shortfall it will deliver 10 micro DALY etc, as shown in Figure 1.

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 WTP. 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 2. 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.

These bands could be defined as Unsafe, Marginal and Safe. As an example, in Figure 2 they have been defined as:

Safe is anywhere in the band from one to 15 micro DALY PPPY. This means that less than 1% of the background community GI is waterborne. On this basis the drinking 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 (e.g. 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 one micro DALY PPPY by the 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 to 150 micro DALY PPPY. This means that up to 10% of community GI could be waterborne. The drinking 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.

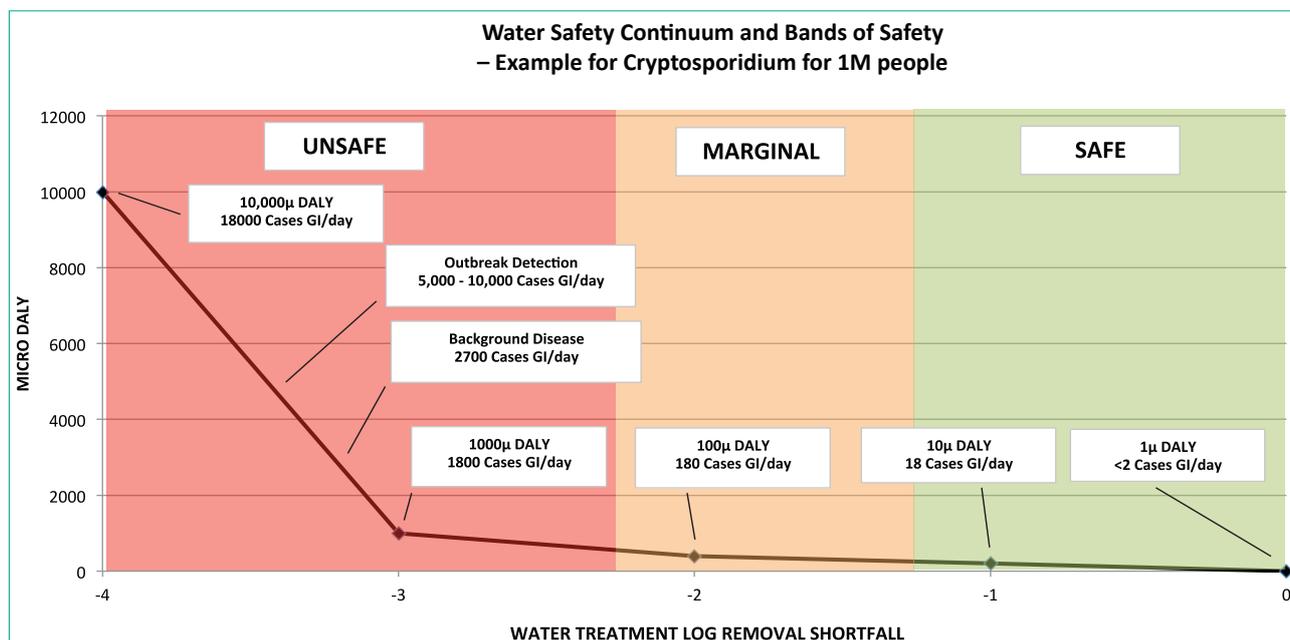


Figure 2. Water Safety Continuum and Bands of Safety – example for *Cryptosporidium* for one million people.

Unsafe is anywhere greater than 150 micro DALY PPPY. More than 10% of the community GI is waterborne and more than 10% of the population will be infected each year from drinking water. The water supply is unquestionably unsafe and an outbreak is imminent at any time. Immediate intervention (e.g. boil water advisory) is required to protect public health. No water provider ever wants to be in the “unsafe” zone.

BENCHMARKING

The water safety assessment for a drinking water supply system involves determining whether the pathogen log reduction requirements arising from the source risk assessment are less than or equal to the log reduction achieved by the current WTP.

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 PPPY. 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 2.

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.

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 related to either uncertainty in the assessment 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 treatment capability, the provider can pursue reducing the source challenge and/or improving

water treatment performance.

Reducing the 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 source 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 the performance of the existing facilities has been optimised, and source risk cannot be reduced, there is no alternative but to implement an additional treatment



No water provider wants to be in the “unsafe” zone of the Continuum.

barrier. Scheduling improvements is a jurisdictional matter, but it is suggested that since the scheme is “safe”, these improvements can be programmed over a five-to-10-year timeframe to minimise any “price shock” for customers.

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 performance of the WTP deteriorate. The first action required is to recognise this vulnerability and implement operational measures to closely monitor the source and WTP performance, with appropriate contingency plans in place to protect public health should source or WTP performance deteriorate.

These schemes typically have 1–2-log shortfall in performance and more 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 WTP.

It is conceivable that optimising existing WTP operations could improve performance in the order of 1 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.

Schemes In The “Unsafe” 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 relevant health department.

LINKING OPERATIONAL PERFORMANCE TO HEALTH OUTCOMES Water Supply Systems Are Dynamic

The HBT is usually regarded as an annual target. However, the Water Safety Continuum allows the water quality manager of a service provider 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, pathogen reductions achieved in water treatment processes, such as media filtration, are variable. Factors such as pre-treatment effectiveness and filter ripening can affect performance.

It can now be appreciated that even for schemes that nominally achieve the annual target of one micro DALY PPPY, there will be times when performance will be better than the target and times when it is worse. 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 likely to be minimal during normal operations.

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

Incident Management

Every scheme experiences periodic incidents, e.g. 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 direct filtration plant that 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 1 log. For a scheme operating at one micro DALY PPPY the consequences of this shift in the short term are minimal. By referring to Figure 2 it can be inferred that the average rate of GI will increase from 1.8 to 18 cases per day in a city of a million people, which is insignificant compared to the background rate of 2,700 cases per day.

However, for a scheme operating in the “marginal” part of the Continuum (say, 100 micro DALY PPPY) the consequences are more of a concern. In this case the nominal waterborne GI rate may increase from 180 to 1,800 cases per day, which is significant, even against a background rate of 2,700 cases per day. Intervention to protect public health should be considered in this case if filtration cannot be brought back under control quickly.

In this example, if filtration performance continued to deteriorate, and filtrate turbidity exceeded 0.5 NTU, then the filtration process could not be relied on 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 ultraviolet (UV) irradiation. UV irradiation is only required to achieve 2-log reduction of protozoa to deliver one micro DALY PPPY, but is typically designed and operated to achieve 4-log. In this case, despite a loss of filtration, the UV could keep the scheme in the safe part of the Continuum, subject

to satisfactory turbidity and colour of water pre-UV. This may avoid the need for a public health advisory. Discussion would be required with the local health regulator to confirm operating with this single barrier is acceptable for a short period of time (i.e. the absence of a pathogen removal process).

The key point is that the Water Safety Continuum provides a basis for meaningful dialogue between departments of health and water providers by linking current WTP performance to community health outcomes.

SUMMARY

- The introduction of a HBT for microbial water quality in Australia has the potential benefit for water providers of providing a mechanism for determining the adequacy of water treatment processes and setting consistent operational performance targets.
- The most likely HBT to be adopted is the WHO target of one micro DALY PPPY. This is the best metric to quantify disease burden, but it 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 improve drinking water quality outcomes for consumers and to help understand the consequences of not meeting the HBT.
- The Continuum plots the incidence of community disease for alternative water safety outcomes. Context is provided by comparison with background GI levels, the 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 of one micro DALY PPPY 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 PPPY 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 improvements 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 the management of water quality incidents.

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

THE AUTHOR



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Richard has a long association with the National Health and Medical Research Council and is currently a member of the Water Quality Advisory Committee, which is responsible for updating the *Australian Drinking Water Guidelines*. He is also a member of the Bonn Network and the IWA panel of Water Safety Planning Experts. Richard is currently leading a project on behalf of WSAA looking at the implications for adopting a health-based target for microbial water quality in Australia.

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