Semi Quantitative Assessment of Microbial Source risk

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NOVEMBER 2015

Water Research Australia

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Australian Experience from Pilots of Implementing a Health Based Target for Microbial Water Quality

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Occasional Paper, November 2015

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1. Background

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. In 2009, NHMRC produced a discussion paper on the introduction of a health based target (HBT) for microbial water quality.

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 The HBT proposal was considered by WSAA water quality professionals at a meeting in December 2011. The adoption of a HBT provides the opportunity to introduce a consistent approach to water treatment process selection and operation across Australia. Accordingly, it received widespread, but cautious, support from the majority of water quality professionals at that meeting. An important water industry condition for supporting a HBT was that pathogen monitoring should not be mandatory for all water utilities. Some of the concerns with pathogen monitoring include:

a) It is very expensive (approximately $1000 per *Cryptosporidium* test)

b) It is impractical for most smaller and remote utilities to transport samples to the laboratories which are primarily located in capital cities

c) The expertise to design sampling programs, interpret results and complete a quantitative microbial risk assessment based on the results cannot reasonably be held in house by smaller utilities, and

d) The analysis of environmental samples for presence of human infectious viruses and bacteria is not well established, and alternative assessment methods must be developed for these pathogens.

2. WSAA Health Based Target Working Group

In August 2012, the WSAA HBT Working Group was formed with the objective of assessing the impact on water utilities if an HBT of one micro DALY, considered the most likely HBT, was adopted. The HBT Working Group comprises of Richard Walker (Water Corporation of West Australia, chair), Arran Canning (South East Queensland Water), Mark Angles (Sydney Water), Andrew Ball (Sydney Catchment Authority), Melita Stevens (Melbourne Water), Cliff Liston/Jason West (South Australian Water), Greg Ryan (South East Water), Peter Spencer/Steve Capewell (Water Corporation of West Australia), Dan Deere (Water Futures).

The primary objective of the Working Group was to produce a guidance manual so that Australian drinking water providers can consistently assess the source risk, the effectiveness of water treatment barriers and ultimately the safety of water delivered to customers.

One of the key tasks for the Working Group was to develop a process for assessing source risk which does not rely on pathogen monitoring.

3. Source Risk Assessment Model

The source risk assessment model adopted by the Working Group was first developed by Keith Cadee, in 2002, when he was General Manager of Water Technologies Division in the Water Corporation of West Australia. It is based on Section 10.3 of the 1996 WHO Drinking Water Guidelines and adapted for Australian conditions. The process had been successfully implemented at over 100 surface water sources across Western Australia and was therefore well “road tested”. The inputs to the assessment process are catchment and reservoir description, together with results from raw water *E. coli* sampling.

It has been a requirement of the ADWG since 2004 that water utilities complete a sanitary survey of their catchments and monitor raw water *E. coli* concentrations. Therefore, the proposed model was attractive since utilities should be able to implement it without needing to undertake additional activities, beyond existing requirements in the ADWG.

4. Vulnerability Assessment

This first step in the source assessment process is to use information from the catchment sanitary survey to determine:

a) Sources of faecal contamination from humans and stock

b) The intensity of likely contamination from the identified sources

c) The proximity of contamination to the reservoir and main feeder streams and

d) The availability of barriers to contamination, such as reservoir exclusion zones, riparian vegetation and fencing.

The "Vulnerability Assessment" involves taking the key information above and placing the source into the best fit of one of 4 "Categories" as set out in Table 1.

Table 1 – Source Categorisation

Source Category	Degree of Protection from Microbial Contamination
1	Well Protected
2	Moderately Protected
3	Poorly Protected
4	Unprotected

The typical characteristics for each category of catchment have been documented in the WSAA HBT Manual to assist water utilities undertake the assessment.

5. Microbial Indicator Assessment

Since the sanitary survey may miss some sources of contamination 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 bands have been defined based on Section 10.3 of WHO (1996) as shown in Table 2. These were reviewed in WHO (2003) which noted that many studies have looked at the relationship between microbial indicators of faecal pollution and pathogens in surface water. Although this has been subject to much debate, the consensus appears to be that there is a general, coarse relationship between the indices of faecal pollution and pathogen concentrations. 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 direct measurement of pathogens, but is considerably better than relying on no monitoring data at all.

Table 2: Summary *E. coli* bands for surface water intended for drinking water (adapted from WHO, 1996)

Description of Faecal Contamination	**E. coli‡ concentration/100mL (max of samples)**
Negligible	≤ 20
Moderate	≤ 2,000
Heavy	≤ 20,000
Gross	>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 for drinking water.

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 full range of conditions likely to be encountered (e.g. drought through to flood).

The Working Group deliberated for some time on the most appropriate way to analyse the microbial data. It was decided that the maximum value should be used since:

a) This worked well, based on Water Corporation experience

b) Water Research Australia Report 1036 (Treatment requirements for Australian source waters to meet health-based target) indicated good correlation between *Cryptosporidium* and maximum *E. coli* concentrations from raw water samples across Australian sources

c) Case studies undertaken by the Working Group on schemes with which they were familiar indicated that using the maximum *E. coli* value for the available dataset gave reasonable outcomes, and

d) There was a concern that smaller utilities may not have sufficient samples to undertake statistically reliable percentile analysis.

The microbial assessment process requires raw water *E. coli* data to be plotted with the intention of determining which band contains the maximum *E. coli* result i.e. ≤20, 21-2000, 2001-20,000 or >20,000 *E. coli* /100ml.

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. Where sampling is less frequent than weekly it is probable that the maximum *E. coli* load has been underestimated and this should be taken into account in the final source categorisation described below in Section 6.

Some strains of *E. coli* are able to grow in the environment and blooms of these environmental *E. coli* (EEC) have been reported in Australian lakes. As EEC are not of faecal origin they neither indicate faecal contamination nor present a risk to health. It would be appropriate to discount these data from the Microbial Indicator Assessment if the strains are shown to be EEC.

6. Aggregating Vulnerability and Microbial Assessments and Assigning Source Category

Table 3 illustrates how the Microbial Assessment can be used in conjunction with the Vulnerability Assessment to determine the source category.

Table 3: Comparison of *E. coli* concentration with sanitary inspection category as an independent reality check

Source category **Vulnerability Assessment** **Category**	**Microbial indicator concentration category** **Maximum *E. coli*‡ per 100 ml**			
	≤ 20	> 20 - ≤ 2,000	>2,000 - 20,000	> 20,000
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 a better alignment or a better understanding of 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 useful. In the interim the precautionary principle should be applied and the most conservative source category option under consideration should be adopted**.**

7. Pathogen Monitoring

All schemes must be assessed by the sanitary survey method described in the preceding sections. This process is fundamental to “knowing your system” and cannot be replaced by pathogen monitoring alone.

However, pathogen monitoring can be used to refine the log reduction requirements for protozoa described in Table 4. Designing pathogen monitoring programs, interpreting the results of pathogen analysis and undertaking a quantitative microbial risk assessment (QMRA) requires expertise rarely found outside the large urban utilities in Australia. Accordingly, pathogen monitoring is not common in Australia. However, a limited study of seven schemes has shown good correlation with the source categorisation described earlier. In all but one case, the log reduction requirements fitted within the “band” expected. For example, for Category 4 sources, the protozoa log reduction requirement by QMRA was in the range 3.5-5.5 log.

The maximum reduction allowed following pathogen monitoring is to the bottom of the range for each source category as determined in Section 6 (ie after Vulnerability and Microbial assessments).

8. Water Treatment Requirements

The water treatment log reduction requirements for each source category are tabulated below in Table 4. They have been derived from WHO and USEPA guidelines.

Table 4 – Log Reduction Requirements

Source Category	Log Reduction Required		
	Viruses	Bacteria	Protozoa
1	0	4	0
2	3	5	2.5
3	4	5	3.5
4	6	6	5.5

9. WSAA HBT Pilots

The Working Group documented the source and water treatment assessment processes into a HBT Manual. The Manual enables water providers to evaluate water safety for each scheme and compare to the HBT.

During 2014 WSAA member utilities volunteered to participate in pilots to test the implementation of the HBT Manual.

The objectives of the pilots were to determine

a) How well the Manual could be understood and implemented by utilities, and

b) Whether the outcomes were reasonable.

The participating utilities were midsize urban and regional utilities, together with local council water suppliers. As many of these water suppliers are at the “small” end of the Australian spectrum it was considered a good test for the HBT process.

The utilities were provided with a copy of the WSAA HBT Manual but it was not possible to provide any formal training. Assistance was available via a “help line” provided by the chairman of the WSAA Working Group who responded to questions via email or phone. About six utilities made use of this facility.

The pilots were mostly completed over a 6-8 week period in late 2014. A total of 18 utilities completed their pilots and 71 schemes were evaluated.

10. Results of Surface Water Assessments

The majority of the schemes assessed had surface water sources and only the results for these systems are reported in this paper.

Table 5 below summarises the “initial” results from the Vulnerability and Microbial Assessments for the 58 surface water schemes assessed in the pilots.

Table 5 - Results of Initial Vulnerability and Microbial Assessments

Source Category	No. schemes by Vulnerability Assessment	No. of Vulnerability Assessments supported by Microbial Assessment	% of Vulnerability Assessments Supported by Microbial Assessment
1	1	1	100
2	19	18	94
3	21	16	75
4	17	13	72
TOTAL	**58**	**48**	**83%**

These results need to be viewed in the context that this was the first time an assessment of this kind had been completed by any of these utilities. Furthermore, no training had been provided. For the most part assessors had read the Manual and applied their own judgements. Only about half a dozen utilities used the "help line" service.

All HBT reports were reviewed by the Chair of the WSAA Working Group, who provided feedback on whether the process in the HBT Manual had been followed and whether the interpretation of the data was appropriate. Based on this review and subsequent discussions with utility staff, some minor amendments to the initial assessments were justified. Table 6 below updates Table 5 by incorporating these changes.

Table 6 - Results of Updated Vulnerability and Microbial Assessments

Source Category	No Schemes by Vulnerability Assessment	No Vulnerability Assessments Supported by Microbial Assessment	% Vulnerability Assessments Supported by Microbial Assessment
1	**2**	**2**	**100**
2	**16**	**16**	**100**
3	**21**	**19**	**90**
4	**19**	**14**	**74**
TOTAL	**58**	**51**	**88%**

11. Review of Results

When dealing with "natural" systems, and analysis by semi quantitative methods, it is unrealistic to expect all systems to comply with the source categorisation process outlined in the WSAA HBT Manual. Nevertheless, a very high correlation was achieved for both "initial" and "updated" results.

The seven schemes where the Vulnerability Assessment did not correlate with the Microbial Assessment have been examined in more detail. This showed the following:

a) Two sources were assessed at Category 3 by vulnerability but had raw water results greater than 2000 *E. coli*/100ml. This indicates heavy faecal contamination indicative of an "unprotected" Category 4 source.

   In both cases the sources were "run of the river" meaning raw water is pumped straight from a river to the treatment plant. High *E. coli* results for run of the river schemes are not unexpected. The HBT Manual warns that when operating without a "storage" barrier (which allows settling, die off and dilution of pathogens) then it is possible that *E. coli* counts will

result in a higher scheme risk than indicated by the vulnerability assessment. In cases like these, priority should be given to the Microbial Assessment and the source should be classified as Category 4. The WSAA HBT Manual requires Category 4 sources to have a multiple water treatment barrier (e.g. filtration plus Ultraviolet irradiation). For unprotected Category 4 sources it is reasonable that an extra water treatment barrier will be required to compensate for the lack of a storage barrier.

In response to this assessment one utility has decided to employ selective pumping from the river and retain the Category 3 rating by avoiding the use of the run-of-river source at times of heavy faecal loading. This is a common sense approach supported by the HBT Manual.

In the other case, further investigation of the catchment is being undertaken to better understand the sources of contamination and how the catchment responds to heavy rainfall events which are usually the precursor to high *E. coli* counts in the raw water.

b) Five sources were classified as Category 4 by vulnerability but there were no raw water *E. coli* results greater than 2000 *E. coli* /100ml as expected from an unprotected catchment.

In all cases the raw water *E. coli* monitoring occurred monthly rather than weekly as recommended in the HBT Manual. It is therefore likely that the maximum *E. coli* load has been underestimated.

In one case, pathogen monitoring was available and confirmed the Category 4 classification for protozoa.

In another case supply was via a large storage dam. It is conceivable that this storage is providing sufficient mitigation (i.e. pathogen settling and die off) to allow “discounting” the source from Category 4 to Category 3. However, assurance is required that this storage barrier is effective at all times and under all circumstances (e.g. after very heavy rainfall and when the dam is experiencing very low storage volumes) before finally adopting the Category 3 classification.

There was insufficient information provided for 2 schemes to verify the vulnerability assessment. The vulnerability assessment for the remaining scheme seemed appropriate based on the catchment description. This result is anomalous, notwithstanding the issue of monthly sampling.

As raw water monitoring occurred monthly for all 7 schemes described above (rather than weekly as recommended in the HBT Manual), it is likely that the faecal load had been underestimated in all cases. The sensitivity of the microbial assessment to monthly monitoring of *E. coli* is examined in Section 12 below.

12. Sensitivity of Microbial Assessment to Frequency of *E.coli* Monitoring

Category 4 sources have unprotected catchments and it is expected that raw water sampling prior to water treatment will show counts >2000 *E. coli* /100ml. The microbial assessment is based on the maximum *E. coli* result from raw water monitoring. Table 7 below gives the distribution of available *E. coli* results from the pilots for sources assessed as Category 4 by the Vulnerability Assessment.

Table 7 - Distribution of Raw Water *E. coli* for Category 4 Sources by Vulnerability Assessment

System	Sampling Frequency	Total No. Samples	Distribution of *E. coli* Results		
			<20/100mL	20-2000/100ml	>2000/100ml
1	Monthly	240	N/A	N/A (Max 690)	0
2	Monthly	72	N/A	N/A (Max 780)	0
3	Monthly	72	N/A	N/A	7
4	Weekly	260	1	255	4
5	Weekly	269	32	226	2
6	Weekly	260	250	10 (max 820)	0
7	Weekly	260	15	242	3
8	Weekly	160	60	199	1
9l	N/A	N/A	N/A	N/A	≥1
10	Monthly	548	252	294	2
11	Monthly	120	N/A	N/A	10
12	Monthly	120	N/A	N/A	3
13	Monthly	120	N/A	N/A	2
14	Monthly	160	0	159	3
15	Monthly	62	2	60(Max 1200)	0
16	Monthly	62	1	59	1
17	Monthly	61	24	34	3
18	Monthly	61	3	56	2
19	Monthly	61	49	12(Max 1300)	0

Red Text – Vulnerability assessment is not supported by Microbial assessment for these schemes.
N/A – Data not available

It can be seen that raw water samples containing *E. coli* at concentrations > 2000/100ml are not common for the majority of the sources, even though the catchment has been assessed as "unprotected". It is postulated that this is a function of catchment hydrology and rainfall distribution. Heavy rain co-incident with "wet" catchments resulting in heavy runoff (and the mobilisation of significant concentrations of pathogens) are rare and short lived events for much of Australia. It is conceivable such instances will not be identified by monthly sampling.

It can be concluded that the microbial assessment is likely to be sensitive to the frequency of sampling. Therefore, the recommendation in the HBT Manual for utilities to undertake weekly raw water sampling together with more intensive sampling following heavy runoff events is appropriate.

It is probable that the correlation between Vulnerability Assessment and Microbial Assessment would be further strengthened if weekly sampling had been undertaken.

13. Conclusions

The WSAA HBT pilots have shown that:

- The maximum *E. coli* result from raw water sampling can be used as a reliable check to confirm the source risk category based on a vulnerability assessment (sanitary survey)
- The *E. coli* bands of ≤20, 20-2000, >2000 organisms/100mL align well with the catchment categories described in the WSAA HBT Manual (well protected, moderately protected, poorly protected and unprotected)
- *E. coli* monitoring of raw water at the intake should be carried out weekly and after events (eg. heavy rainfall)
- If the *E. coli* monitoring does support the Vulnerability Assessment then utilities can be confident that the source category is correct
- If the *E. coli* monitoring does not support the vulnerability assessment then this is a trigger to more fully investigate sources of contamination, catchment performance and pathogen mitigation from storages (if applicable), together with the representativeness of the *E. coli* dataset. The objectives are to better understand the system and explain results and outcomes so that source risk can be justifiably characterised, and
- The WSAA HBT pilots have shown the source risk assessment process described in the WSAA HBT Manual:
    a) Produces consistent and reasonable outcomes
    b) Can be applied to the wide range of surface water sources found in Australia, and
    c) Can be readily implemented by water quality professionals across the spectrum of water utilities in Australia, including regional utilities and local councils.

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Drinking Water Source Assessment and Treatment Requirements: Manual for the Application of Health Based targets, September 2015 Water Services Association of Australia.

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