

CHAPTER 4. HEALTH RISK ASSESSMENT

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4.1 WORK PACKAGE 4 AIM

The aim of the work package was to assess the human health risks due to micro-organisms and trace chemical contaminants found in recycled water delivered via managed aquifer recharge (MAR).

This risk assessment is only considering MAR for non-potable uses, e.g. irrigation. However, the chemical screening risk assessment uses drinking water guidelines to allow a conservative comparison of chemicals, in the absence of any other health-based chemical guidelines.

4.2 WORK PACKAGE 4 OBJECTIVE

The objectives of the work package were the identification and quantification of chemical and microbiological health risks associated with the use of recycled water and MAR and an assessment of appropriate management practices to minimise these risks. This objective was achieved by the following:

- a) Developing a risk assessment of selected microbial and chemical contaminants in treated wastewater
- b) Undertaking a quantitative microbial risk assessment of water recycled through MAR
- c) Undertaking a screening health risk assessment of trace chemical contaminants in secondary treated wastewater (source water)
- d) Developing a risk assessment for key chemical contaminants in water recycled through MAR.

4.3 RECYCLED WATER HEALTH RISK ASSESSMENT

Water quality assessment was conducted for: Subiaco Wastewater Treatment Plant secondary treated wastewater ('Subiaco wastewater'); recycled water entering the Floreat Infiltration Galleries (FIG); the aquifer down-gradient of the galleries; and through column experiments (see Chapter 2). Various parameters of significance to human health were assessed by sampling.

The Subiaco Wastewater Treatment Plant is designed to treat up to 61.4 megalitres per day (ML/d). The wastewater is predominantly from household kitchens, bathrooms, toilets and laundries. The primary treatment process consists of four primary sedimentation tanks to remove gross solids. The advanced secondary treatment process consists of a conventional activated sludge process with biological nutrient removal, but no chemical nutrient removal. Subiaco treated wastewater is the source water used for the Floreat Infiltration Galleries.

The two aquifer systems assessed were a superficial aquifer consisting of Spearwood sands with a high limestone content (into which the Floreat Infiltration Galleries recharged) and a

sandy confined aquifer material sourced from the Leederville aquifer (assessed using column studies).

4.4 HEALTH RISK ASSESSMENT

Health risk assessment is defined by enHealth (2002) as 'The process of estimating the potential impact of a chemical, biological, physical or social agent on a specified human population system under a specific set of conditions and for a certain timeframe'.

Undertaking health risk assessment usually involves four steps:

- Hazard identification
- Dose-response characterisation
- Exposure assessment
- Risk characterisation.

Within the health risk assessment framework, it is necessary to determine what the risks are and what measures are available to define illness in relation to the burden of disease. One such measure is the use of the disability adjusted life year (DALY). For more details on the application of DALYs see Appendix 4A. The use of this measure is shown in Section 4.6.

This risk assessment only considers the human health aspects and does not address the potential consequences or impacts of environmental risks associated with MAR.

The assessment of the chemical health risk assessment was undertaken through the review data collected from:

- Subiaco Wastewater Treatment Plant – secondary treated wastewater (chemicals)
- Floreat Infiltration Galleries (chemicals)
- Column experiments (chemicals)

The development of the Quantitative Microbial Risk Assessment (QMRA) was done through the use of data on the hydrogeology at the infiltration gallery site and pathogen decay data provided in Chapter 1 along with assumed pathogen loads in the treated Subiaco wastewater.

4.5 METHODOLOGY DEVELOPMENT

Secondary treated wastewater used for recycled water purposes contains numerous microbiological and chemical contaminants which are of public health concern. To assess the significance of these contaminants the following risk assessment methodologies specific to this project were both microbiological and chemical.

4.5.1 Microbiological

Determination of microbial exposure was based on the principles of risk assessment using Quantitative Microbial Risk Assessment (QMRA). This well-validated approach considers the estimate of consequences from a planned or actual exposure to infectious microorganisms. The QMRA approach is detailed in Section 4.6.

4.5.2 Chemical

A screening human health risk assessment was conducted to assess what chemicals had potential to be a health risk. The only health-based chemical guidelines available are for drinking water purposes. Lower exposure to recycled water through irrigation is unlikely to result in any significant risk to human health from chemicals; however, the risk quotient approach using drinking water guidelines allows comparison of risk associated with different chemicals, (and would also provide a baseline from which design of further treatment to provide recycled water for drinking water could occur if considering this end use). Chemical contaminants are of concern only where recycled water is used for drinking purposes.

4.6. QUANTITATIVE MICROBIAL RISK ASSESSMENT

Quantitative microbial risk assessment (QMRA) of water recycling and Managed Aquifer Recharge (MAR) systems requires the quantification of pathogen occurrence in source water and their removal through various treatment barriers. When pathogen occurrence is combined with exposure scenarios and pathogen dose-response relationships, the risk to human health can be estimated.

The end point of the human health risk assessment used in this report was expressed as Disability Adjusted Life Years (DALYs). DALYs have been used extensively by agencies such as the World Health Organization (WHO) to assess disease burdens and to identify intervention priorities associated with a broad range of environmental hazards (WHO, 2004). For example, one DALY per million people a year roughly equates to one cancer death per 100 000 in a 70 year lifetime, a benchmark often used in chemical risk assessments (WHO, 2004). The DALY is calculated as the product of the probability of each illness outcome with a severity factor and the duration (years). The advantage of using DALYs over an infection risk end point is that it not only reflects the effects of acute end-points (e.g. diarrhoeal illness) but also the likelihood and severity of more serious disease outcomes (e.g. Guillain-Barré syndrome associated with *Campylobacter*).

4.6.1 QMRA Objectives

The general framework for estimating human health risks from pathogens used in this report is based on the approach described in NRMCC-EPHC-NHMRC (2008). The hypothesis to be

tested was that risk attributable to using water from the Floreat Infiltration Galleries (FIG) for irrigation of public open spaces resulted in a disease burden of 1×10^{-6} DALYs per year or less.

The specific objectives were:

- to conduct a QMRA with available data on reference pathogen numbers reportedly found in reclaimed water then infiltrated through the Floreat Infiltration Galleries site
- to evaluate and quantify the potential risk posed to human health for three public green space irrigation scenarios
- to determine the relative significance of key factors affecting risk including numbers of pathogens in source waters, pathogen decay rates and aquifer residence times
- to identify knowledge gaps in determining the microbiological safety of reclaimed water for future research.

4.6.2 QMRA Methodology

QMRA typically incorporates the following steps (NRMMC-EPHC-NHMRC, 2006):

- Hazard identification – identification of the pathogens and the associated disease burden on human health; this step also includes consideration of effects of treatment such as MAR and variability in pathogen counts.
- Dose-response – the relationship between the dose of the pathogen and the likelihood of illness.
- Exposure assessment – determination of the size and nature of the population exposed to the hazard, and the route, volume and frequency of exposure.
- Risk characterisation – integration of data on hazard presence, dose-response and exposure, obtained in the first three steps.

Hazard identification

The scope of the assessment was limited to three reference pathogens, which act as surrogates for the three main microbiological groups: bacteria, protozoa and viruses as described by NRMMC-EPHC-NHMRC (2006): *Campylobacter*, *Cryptosporidium parvum* and rotavirus respectively. These pathogens were selected as they are known to be present in secondary treated wastewater and contribute the greatest population health burden in terms of DALYs (NRMMC-EPHC-NHMRC, 2006).

Dose-response

Information on relationships between doses of pathogens and incidence or likelihood of illness is generally obtained from investigations of outbreaks or from experimental human-feeding studies (WHO, 2004). The ingestion dose-response models and the DALYs per infection used in this report for the hazards identified above are extensively detailed in WHO (2004) and NRMMC-EPHC-NHMRC (2006).

Exposure assessment

The main route of exposure to microbial hazards is ingestion, including ingestion of droplets produced by sprays, garden irrigation and accidental intake. The three exposure scenarios of the extracted Floreat Infiltration Galleries water were assessed in this report. The point estimate exposure volumes and frequencies of exposures per person are provided in Table 4-1 (NRMMC-EPHC-NHMRC, 2006). In assessing the risk to human health, each of the three index pathogens was assessed for each of the three scenarios.

Table 4-1. Irrigation exposure scenarios assessed

Scenario	Frequency of exposure (n/yr)	Exposure volume (mL)
Ingestion of sprays	90	0.1
Garden irrigation	90	1
Accidental ingestion	1	100

Risk characterisation

The last step in risk assessment is to integrate information from hazard identification, dose-response and exposure assessment, to determine the magnitude of risk. In all cases, the variables in determining the magnitude of risk for the reference pathogens are counts of the organisms and exposure.

4.6.3 QMRA Conceptual Model

The conceptual model underpinning this risk assessment assumes that pathogens contained in secondary treated effluent from Subiaco Wastewater Treatment Plant are infiltrated into the Floreat Infiltration Galleries at a steady rate for an average of 4 days. The recharged effluent then remains in the subsurface for an average of 70 days prior to recovery from a bore and used for irrigation of public green spaces (see exposure scenarios in Table 4-1). There is assumed to be no filtration of pathogens during passage through the aquifer, only decay as described by Sidhu (2008). Similarly, there is no mixing of the reclaimed water with native groundwater (dilution). This model has a number of probability distribution function assumptions associated with the initial pathogen counts, decay rates, infiltration time and residence time in the aquifer (Table 4-2).

In all simulations, the range of pathogen numbers, exposure scenarios, pathogen dose-response relationship and DALYs per case of infection values were defined from the NRMMC-EPHC-NHMRC (2006).

The NRMMC-EPHC-NHMRC (2006) define a tolerable level of risk as $<10^{-6}$ DALYs per person per year. Table 4-3 provides an example of risk characterisation calculations used in this report. This example deals with the risk posed by *Cryptosporidium* through the ingestion of spray exposure scenario with water from the Floreat Infiltration Galleries extraction bore.

Table 4-2. Stochastic parameters used in the QMRA simulations

Factor	Mean (SD)	Distribution	Reference
<i>Campylobacter</i> count in effluent (n/L)**	1 – 10 ³ *	Uniform	NRMMC-EPHC-NHMRC (2006)
<i>Cryptosporidium</i> count in effluent (n/L)**	28 (52)	Normal	Gennaccaro et al. (2003); Huffmann et al. (2006)
Rotavirus count in effluent (n/L)**	26 (77)	Lognormal	Sedmak et al. (2005)
<i>Campylobacter</i> T90 decay rate (days)	2 (0.2)***	Normal	Sidhu (2008)
<i>Cryptosporidium</i> T90 decay rate (days)	31 (1)	Normal	Sidhu (2008)
Rotavirus T90 decay rate (days)	42 (8)****	Normal	Sidhu (2008)
Infiltration time (days)	4 (1)	Normal	Bekele (2008)
Travel time to extraction bore (days)	70 (20)	Normal	Bekele (2008)

* values given represent a range.

** assumes secondary treatment with no disinfection such as is used at Subiaco Wastewater Treatment Plant (Toze, 2008).

*** decay rate used for *E. coli* in the absence of *Campylobacter* data

**** decay rate used for adenovirus in the absence of rotavirus data

Table 4-3. Example QMRA calculation for *Cryptosporidium* in the accidental ingestion scenario

Initial count in effluent	26 oocysts/L	Sampled from range of <i>Cryptosporidium</i> count from Table 4-2
Infiltration time	4 days	Sampled from range of times from Table 4-2
Aquifer residence time	70 days	Sampled from range of distances from Table 4-2
Total time	74 days	Calculated from addition of infiltration and residence times
Decay rate (T90)	31 days	Sampled from range of decay rates from Table 4-2
Total removal	2.4 log	Calculated using decay rate of 0.41 log/day
Final count in bore	0.1 oocysts/L	Calculated from initial count and log removal
Risk of infection	7.4×10^{-5}	Calculated from exponential dose-response curve at 90 exposures per year Table 4-1
DALYs	1.1×10^{-8}	Risk characterised as using a DALYs/infection of 1.5×10^{-03}

In the example given above, the deterministic analysis is one that does not involve the use of estimated or random values, whereas a stochastic analysis does involve some use of such values. The example shown in Table 4-3 applies a deterministic approach, using a single-point estimate for *Cryptosporidium* count, infiltration rate, residence time in the aquifer, *Cryptosporidium* decay rate, exposure volume and numbers of exposure events. The advantage of this approach is that it is relatively simple and can be done using desktop calculators. However, the use of single-point estimates does not address variability and uncertainty; also, the estimates are often based on conservative or even worst-case values. To address this, a QMRA Monte Carlo simulation was performed using the point estimates of Table 4-3 and the variable parameters of Table 4-2.

4.6.4 QMRA Simulation Settings

The QMRA models were developed to facilitate Monte Carlo simulation, which entails generating hypothetical scenarios in terms of the values attributed to the factors in the risk characterisation step. The simulation represents the inherent variability in the process of initial pathogen counts, transport and decay through the subsurface and influence on expectant risk as well as the variability in the mathematical model of the process. Ten thousand iterations were performed for each simulation, using Latin Hypercube sampling, with @RISK Industrial v4.5 [Palisade, Newfield, NY] and Microsoft Excel [Microsoft Corp., CA] software. The outcome is a statistical distribution of risk experienced by the diverse members of the exposed population expressed as the mean, median and 95th percentile values.

4.6.5 QMRA Results

The risk characterisation results for each of the three exposure scenarios are shown in Table 4-4, values which exceed the upper limit of 10^{-6} DALYs per person per year are shown in bold.

In most scenarios the mean risk to human health posed by rotavirus was greater than that of *Cryptosporidium*, which in turn was greater than that of *Campylobacter*. The mean human health risks arising from the ingestion of sprays and accidental ingestion scenarios from *Campylobacter* and *Cryptosporidium* were acceptable ($<1.0 \times 10^{-6}$ DALYs) whereas the risk from rotavirus was unacceptable. For the garden irrigation scenario the risks were unacceptable for rotavirus and *Campylobacter*.

The median value is seen as a better indication of the central tendency of the risk characterisation results in Table 4-4. For the median human health risk, only rotavirus was of an unacceptable risk.

Table 4-4. Risk Characterisation Results for three exposure scenarios (DALYs)

Ingestion of sprays			
Pathogen	Mean	Median	95 th percentile
<i>Campylobacter</i>	4.6×10^{-7}	$<1.0 \times 10^{-10}$	$<1.0 \times 10^{-10}$
<i>Cryptosporidium</i>	6.2×10^{-8}	1.6×10^{-8}	2.5×10^{-7}
Rotavirus	4.3×10^{-6}	4.9×10^{-7}	7.0×10^{-4}
Garden irrigation			
Pathogen	Mean	Median	95 th percentile
<i>Campylobacter</i>	1.5×10^{-6}	$<1.0 \times 10^{-10}$	$<1.0 \times 10^{-10}$
<i>Cryptosporidium</i>	6.2×10^{-7}	1.6×10^{-7}	2.5×10^{-6}
Rotavirus	2.8×10^{-5}	4.0×10^{-6}	1.4×10^{-4}
Accidental ingestion			
Pathogen	Mean	Median	95 th percentile
<i>Campylobacter</i>	1.2×10^{-7}	$<1.0 \times 10^{-10}$	$<1.0 \times 10^{-10}$
<i>Cryptosporidium</i>	6.8×10^{-7}	1.8×10^{-7}	2.8×10^{-6}
Rotavirus	4.2×10^{-5}	3.9×10^{-6}	1.6×10^{-4}

The 95th percentile can be used as a measure of the robustness of the ‘mean’ human health risk assessment. Where both the mean and the 95th percentile are at acceptable risk levels, it can be determined that the risk assessment is reasonably robust. Hence, the risk characterisation mean results were considered robust for the garden irrigation and accidental ingestion scenarios, but less so for the spray ingestion scenario.

As far as it was possible to determine, the average annualised risk was greater than 10^{-5} DALYs per person per year for all scenarios for at least one pathogen. The issue of whether management intervention is required would depend on how risk averse the exposed community and supply manager were and how much of a safety margin they desired. The latter might be based on the 95th percentile in which case *Cryptosporidium* and rotavirus exposure should still be further investigated.

4.6.6 QMRA Sensitivity Analysis

QMRA coupled with stochastic Monte Carlo simulations can provide a sensitivity analysis of the factors that most significantly influence risk, i.e. those factors which are highly correlated with increased or decreased risk. This analysis helps prioritise risk management efforts and for subsequent improvement of the QMRA model by focusing investigation priorities. Figure 4-1 shows a representative tornado diagram calculated for the highest risk scenario: rotavirus exposure through accidental ingestion.

Figure 4-1 illustrates that the residence time in the aquifer was the most influential factor negatively correlated to the mean risk. This relationship is further expanded for rotavirus (the highest risk pathogen) for each of the three scenarios in Figure 4-2.

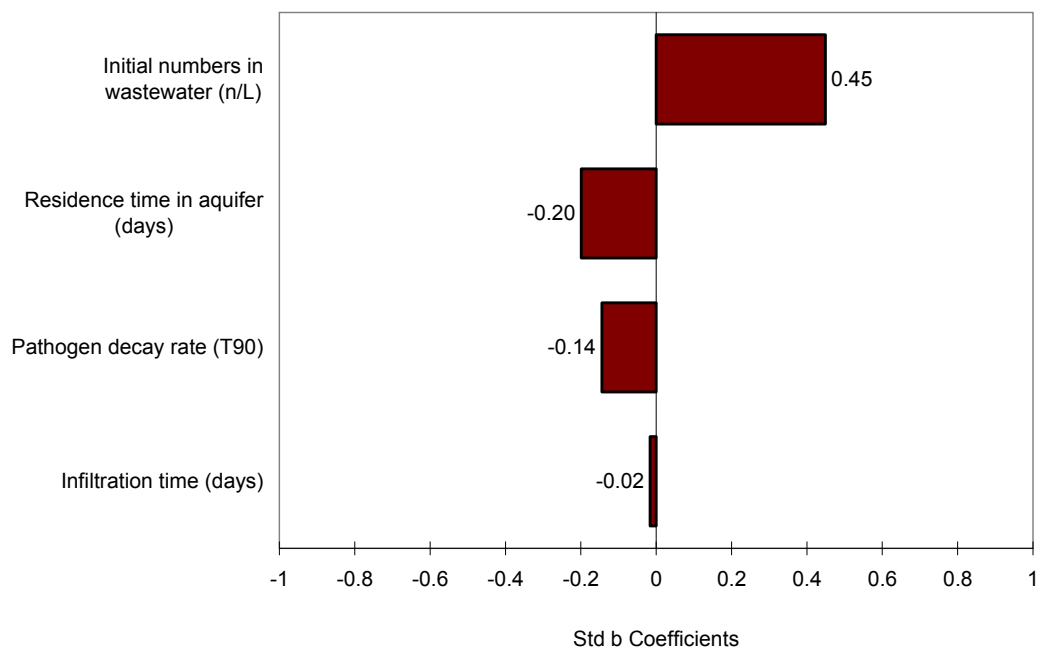


Figure 4-1. Sensitivity analysis for rotavirus accidental ingestion scenario

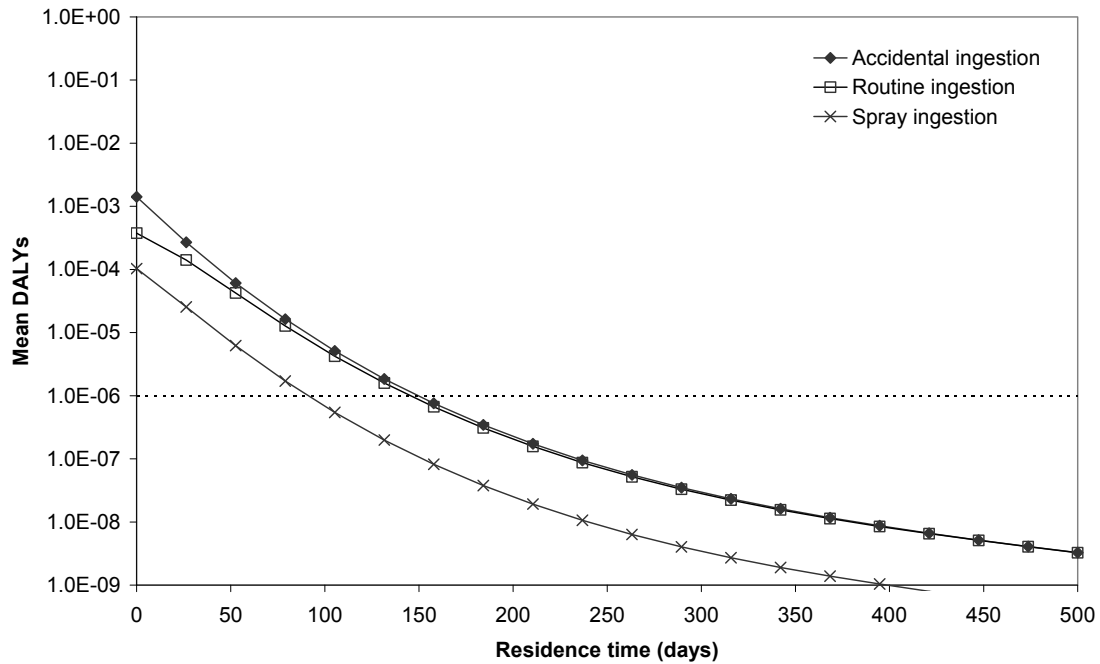


Figure 4-2. Mean DALYs from rotavirus as a function of aquifer residence time

Figure 4-2 illustrates that to obtain a mean risk for each of the scenarios below the guideline value ($<1 \times 10^{-6}$ DALYs in Figure 4-2) the residence time in the aquifer would need to be ~150 days.

The second most important factor negatively correlated with mean risk was the pathogen decay rate. All the pathogen risks in each of the scenarios followed a similar rank order trend in the sensitivity analysis. In each case the aquifer residence time between the Floreat Infiltration Galleries infiltration site and the extraction bore was the single most important factor in reducing overall risk. The longer the residence time of the reclaimed water in the subsurface, the lower the risk.

The initial pathogen count in the secondary treated effluent was the single most important factor positively correlated with mean risk. Toze (2008) suggested that the initial numbers of pathogens in the secondary treated effluent (Table 4-2) may not reflect the actual conditions at the Subiaco Wastewater Treatment Plant. The numbers used in the risk assessment (Table 4-2) were derived from the international literature and are potentially very high compared to Australia. As such, a further sensitivity analysis was performed on the highest risk pathogen (rotavirus) to determine the relationship with the calculated risk (Figure 4-3).

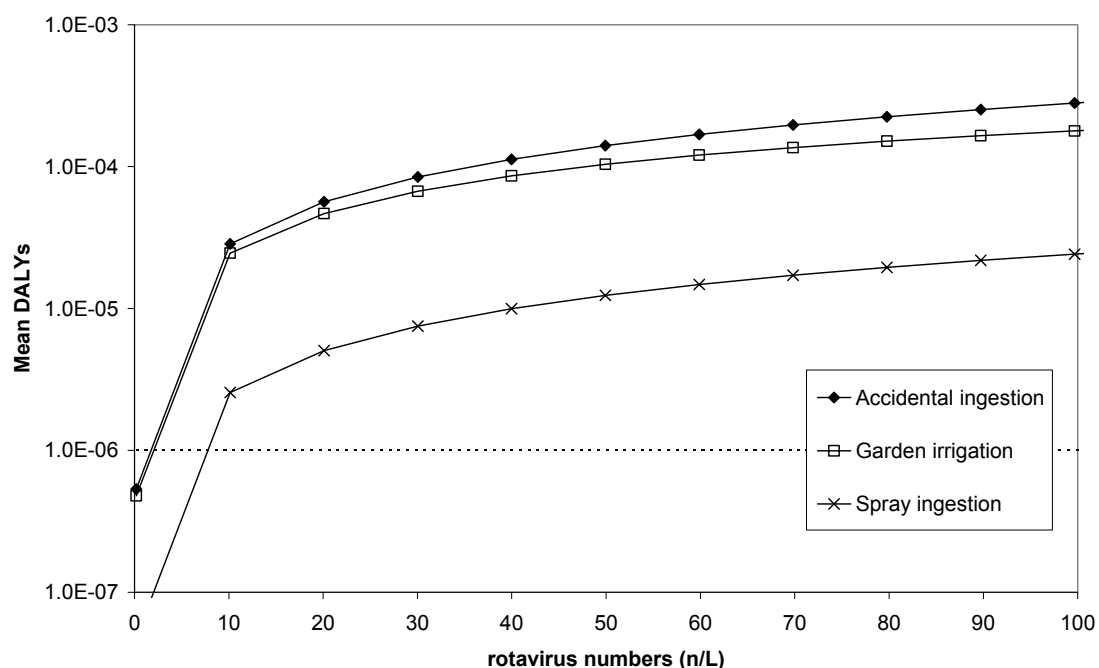


Figure 4-3. Mean DALYs from rotavirus as a function of pathogen numbers in the secondary treated effluent

Figure 4-3 illustrates that rotavirus numbers of ~10 /L are sufficient to increase the risk above the tolerable level (represented as a dashed line in Figure 4-3). Although pathogen numbers in the effluent are not necessarily amenable to management measures, these pathogen counts can be used in the selection of appropriate preventive measures, such as additional treatment barriers. They can also be used in some validation monitoring to support the risk assessment; however, method sensitivities and volume restrictions generally limit suitability for this purpose. An alternative approach is to use surrogates such as faecal indicators, for example thermotolerant coliform bacteria and F-RNA phage numbers. Direct testing for pathogens is unsuitable for operational monitoring and of very limited use in verification monitoring because of the complexity and cost of tests, and the time required to complete them.

4.6.7 QRMA Discussion

The QMRA results suggest that reclaimed water extracted from the Floreat Infiltration Galleries poses an unacceptable microbial risk to human health if it were to be used for open space irrigation without further treatment. However, the results are only marginally above the level of acceptable risk, indicating that additional work is required to determine if the results are truly significant. The results are consistent with the NRMCC-EPHC-NHMRC (2006) suggested log removals for pathogens in wastewater used for irrigation: 4.6, 4.4 and 5.8 for *Campylobacter*, *Cryptosporidium* and rotavirus respectively. This compares to the calculated total mean log removals in the QMRA (the product of the residence times and the pathogen decay rates) for this study of >10, 2.4, 1.8. This implies that the risk posed by *Campylobacter* may be acceptable, and corroborates that the risks from *Cryptosporidium* and rotavirus are unacceptable.

Importantly, this work highlights that the QMRA approach can be used as a predictive tool to assist in identifying key constraints and requirements for full-scale MAR schemes (e.g.

setting a residence time, and thus abstraction rate and distance between recharge and extraction) which ensure adequate pathogen log removal.

4.6.8 Limitations of QMRA Approach

QMRA simulations are only models. Thus the input probability distribution functions and output human health risks should not be seen as final fixed representations of water quality, but rather best approximations which need ongoing revision and which will always have a level of associated uncertainty and variability.

Accordingly, the QMRA results should be viewed as output risk estimates not as absolute guides to water management to be used in isolation but rather as information to be interpreted in light of other information such as the system hydrogeology and water quality monitoring data. Consideration of data variability and uncertainty and model assumptions should be routine.

With the current study several assumptions were used in the calculation of the QMRA (e.g. those in Table 4-2). These variables as well as other non-variables (e.g. exposure frequency and volumes) all determine how well the QMRA models represent reality. Future work outlined in the next section can address these limitations and give confidence of an improved estimate of the risk.

While recognising these limitations, the strengths and potential of QMRA simulations undertaken here are also clear. For all its limitations, QMRA still appears to provide the most credible quantitative synthesis of currently available data and knowledge on risks. Easily conceived endpoint risk measurements (DALYs) which address the primary concern of minimising risks to human health provide clear targets for management actions. This contrasts with older risk assessments (for example, coliform-based targets) which did not have as clear a quantitative relationship to risk levels. In this way, a water quality monitoring program can directly be used to improve future quantitative microbial risk assessments of the Floreat Infiltration Galleries site.

4.6.9 Future Studies to Inform Future Development of the QMRA

Future studies to refine the QMRA of the Floreat Infiltration Galleries site include:

- Sampling of the local secondary treated wastewater from the Subiaco Wastewater Treatment Plant to refine the distributions of pathogen numbers in the treated wastewater.
- Determining an improved model for estimating travel time between the infiltration gallery and the extraction bore. This may be achieved using a tracer test to assess aquifer residence time. In addition, the effects of filtration on the removal of pathogens, as well as potential for dilution with the native groundwater, should be considered. When coupled with bore long-term pump test data, flow analysis and groundwater numerical and/or analytical models will give an improved estimate of the potential for pathogens to reach the extraction bore and the expectant risk.
- Conducting additional pathogen attenuation chamber studies using *Campylobacter* and rotavirus will give better estimates of the pathogen decay rates in the subsurface.

It should be noted that the residence time associated with the Floreat Infiltration Galleries was assumed to be 70 days, as estimated from assessment during the project (see Chapter 1). However, the abstraction rates were much greater than recharge rates due to the experimental nature of the work. In a full scale project, abstraction rates are unlikely to be so much greater than recharge rates, so the hydraulic gradient will be not as large and travel times may be longer.

The outcomes of the QMRA assessment has shown how an MAR site can be assessed to determine if the recovered water meets acceptable health risks for microbial pathogens. The results also demonstrate that if details are known on the hydrogeological condition at a proposed MAR site; information is available on pathogen types and numbers in the water to be used for recharge and the rate of pathogen decay in the aquifer; the QMRA assessment during the design phase of an MAR scheme can be a valuable tool in the final design of the scheme and the management protocols to ensure that the MAR scheme is constructed to meet acceptable health risk assessments (Toze et al., 2009).

4.6.10 Conclusions of QMRA

The QMRA determined that:

- The mean human health risk of using Floreat Infiltration Galleries extraction bore water for three exposure scenarios was unacceptably high for one or more pathogens for each scenario.
- The results were only marginally over the acceptable risk threshold, and small changes to the QMRA model may have significant impacts to the calculation of the risk. As such, the results should be treated with caution.
- The most important factor in reducing risk was the residence time of the reclaimed water in the aquifer. A residence time of ~150 days is required for each pathogen in each scenario for the risk to be acceptable.
- Further work is needed to refine the conceptual model and parameters used in the QMRA including:
 - tracer tests to more accurately determine aquifer residence times
 - additional sampling of the secondary treated wastewater to determine pathogen numbers
 - assessment of the filtration and native groundwater dilution potential of the Floreat Infiltration Galleries system
 - additional pathogen attenuation studies using the reference pathogens used in the QMRA.

4.7. TRACE CHEMICAL CONTAMINANTS

4.7.1 Trace Chemical Contaminants Objectives

A screening health risk assessment (SHRA) for trace chemical contaminants was conducted for Subiaco wastewater and for pharmaceuticals analysed in the Floreat Infiltration Galleries.

The specific objectives in conducting an SHRA for trace chemical contaminants in recycled water used as recharge water for MAR were:

- to determine the health significance of the analysed trace chemical contaminants at concentrations found in Subiaco wastewater
- to determine the relative significance of chemical degradation of selected contaminants through the Floreat Infiltration Galleries
- to identify knowledge gaps in determining the chemical safety of recycled water for future research.

4.7.2 SHRA Methodology for Chemicals

Many chemical contaminants (both inorganic and organic) found in wastewater have guideline values which indicate the acceptable level if found in a drinking water supply. The term 'Trace Organics' more specifically refers to a range of emerging chemicals, such as: pharmaceuticals, endocrine disrupters, disinfection by-products and flame retardants. These emerging contaminants pose a challenge to public health regulation as in many cases there is no toxicological data or guideline value from which to derive the potential risk to human health.

Therefore, to evaluate the potential health risks of trace chemical contaminants, an SHRA methodology was developed by our team (Rodriguez et al., 2007). This SHRA is a systematic desktop assessment of potential adverse health effects of pollutants at the concentrations observed in the recycled water assuming that that water was available for drinking. The assessment requires the quantification of trace chemical contaminants in the treated Subiaco wastewater (source water) and their removal through the infiltration galleries. Full details on the methodology are shown in Appendix 4B.

The main elements of the methodology are:

- a three-tiered approach to establish benchmark values
- threshold of toxicological concern (TTC)
- risk quotient (RQ) calculation.

The three-tiered approach for the levels of assessment is indicated below:

- Tier 1: Regulated contaminants: the RQ will be calculated between the observed concentration in recycled water and the maximum contaminant level.
- Tier 2: Unregulated contaminants with toxicity information: the RQ will be calculated between the observed concentration and the Health Base Level.

- Tier 3: Unregulated contaminant without toxicity information: the RQ will be calculated between the observed concentration and the benchmark value calculated based on the threshold of toxicological concern (TTC).

The TTC is a 'concept that refers to the establishment of a human exposure threshold value for all chemicals, below which there would be no appreciable risk to health' (Kroes et al. 2005). TTCs were calculated for all chemicals classified in tier 3 using the Cramer rules (Cramer et al., 1978) and Toxtree version 1.51 software (Ideaconult Ltd, 2008).

Risk quotients (RQ) are the most widely used method of assessing risk from trace chemical contaminants by comparing the measured chemical concentrations with health values. Health values are concentrations below which no adverse health effects are expected if the water is consumed over a lifetime. The health values are calculated assuming an average daily intake of 2 litres of water for an individual with a 70kg body weight over 70 years of water consumption. All values were calculated using the equations used in the Australian Guidelines for Water Recycling phase 2: Augmentation of Drinking Water Supplies (NRMCC EPHC & NHMRC, 2008)

The quantification of the screening human health risk assessment used in this report is expressed as a screening RQ for each one of the chemicals under analysis. Screening RQs below 1 are considered of low health significance. Screening RQs above 1 indicate that more data on occurrence and fate and therefore, a complete health risk assessment, is required.

4.7.3 Sampling Methodology and Sampling Dates

Results from the Premier's Collaborative Research Project (PCRP) 'Characterising Treated Secondary Wastewater for Drinking Purposes Following Reverse Osmosis Treatment' (conducted at the same time as the MAR project) are included in section 4.6.1 of the report (Government of Western Australia, 2009). A Sampling and Analysis Plan (SAP) was developed for the PCRP to record the outputs of the sampling program. The major elements of SAP are derived from 'Guidance for Quality Assurance Project Plans (US EPA, 1992) and the Australian Guidelines for Water Quality Monitoring and Reporting (NWQMS, 2000).

A total of four samples of Subiaco wastewater were collected in May/June 2007 (Thursday 24/05/07, Tuesday 12/06/07 & Thursday 19/06/07) and a further sampling event on Thursday 03/04/08. The samples were collected from a composite sampler by CSIRO personnel. Samples were preserved and analysed by Curtin University Water Quality Centre, Chemistry Centre of Western Australia, National Measurement Institute, or the Australian Radiation Protection and Nuclear Safety Agency. Details of the SAP and the Quality Assurance/Quality Control can be found in the PCRP report (Government of Western Australia, 2009).

Detailed analytical methods for the Subiaco wastewater characterisation are reported elsewhere (PCRP Report: Government of Western Australia, 2009). Analytical methods for the Floreat Infiltration Galleries sampling are reported in Chapter 2.

4.7.4 Defining the List of Target Chemicals

In 2005/2006, a comprehensive literature search of relevant articles and reports was conducted to identify potential hazards relevant for ingestion of secondary treated wastewater to inform the selection of the target chemicals.

The criteria for the selection of parameters for screening health risk assessment were based on the following points:

- contaminant occurrence in water (mainly for chemicals known or anticipated to occur in wastewater, groundwater after injection of advanced treated water, drinking water and after microfiltration/reverse osmosis (MF/RO) treatment)
- known or anticipated toxicity from animal experimental studies and/or epidemiological studies
- persistence in the environment
- volume of use
- public concern
- available analytical methods or capacity to develop methods during the project timeframe.

After the chemicals were analysed, the three-tiered approach was used to establish the health value of each compound. Chemicals with established guideline values, from the Australian Drinking Water Guidelines (NHMRC and ARMCANZ, 2004), US EPA (US EPA, 2006) or World Health Organization (WHO, 2003), were classified in tier 1. Chemicals with an acceptable daily intake (ADI), reference dose (RfD), risk specific dose (RSD) or no observed effect level (NOEL) were classified in tier 2. Chemicals without toxicity data had health values calculated using the TTC and were classified in tier 3.

4.7.5 Chemical SHRA Results

A total of 355 chemicals were analysed for in the Subiaco wastewater. The list of chemicals tested for is shown in Appendix 4C. A total of five polar pharmaceuticals were analysed in the Floreat Infiltration Galleries. The results of the various chemicals tested in the Subiaco wastewater, the Floreat Infiltration Galleries, and the health implications of the column experiments are detailed below.

Subiaco wastewater characterisation

Of the 355 chemicals tested for, 88 were detected in at least one of the four samples taken from the Subiaco wastewater. The list of chemical groups analysed for include a broad range of chemical groups with different physico-chemical characteristics and toxic effects (Table 4-5). All trihalomethanes (THMs), complexing agents and gross alpha and gross beta particle activity analytes tested for were detected in the Subiaco wastewater (Table 4-5).

N-nitrosamines tested for included: N-nitrosodimethylamine (NDMA), N-nitrosoethylmethylamine (NEMA), N-nitrosodiethylamine (NDEA), N-nitrosodi-n-propylamine (NDPA), N-nitrosodi-n-butyldiamine (NDBA), N-nitrosopiperidine (NPIP), N-nitrosopyrrolidine (NPYR), N-Nitroso-morpholine (NMOR), N-Nitrosodiphenylamine (NDPhA). Eight of the nine N-nitrosamines (88.9%) were found in the Subiaco wastewater. Of the pharmaceuticals tested for, those detected included antibiotics (80%), iodinated contrast

media compounds (62.5%) and 'other' pharmaceuticals (60%). The category 'other' pharmaceuticals included, for example, carbamazepine and diclofenac. Of the 29 metals analysed for, 17 were detected (Table 4-5). However, none of the most toxic metals such as mercury, beryllium, cadmium or arsenic were detected in reportable amounts. None of the 117 pesticides analysed were detected in any of the samples.

Table 4-6 summarises the SHRA performed for the detected chemicals in the Subiaco wastewater. All chemical groups except N-nitrosamines, complexing agents and disinfection by-products (DBPs) have screening RQs (median) below 1.

For bromodichloroacetaldehyde, the calculated screening RQ (median) was above 1 (RQ = 1.5); however, the value was calculated using the TTC, which is a conservative approach, given that no toxicity information was available for this DBP. Similarly, RQs for the complexing agents DTPA and DPTA were above 1 when calculated using the TTC. Again, the use of the TTC seems to be very conservative (health value = 0.7 µg/L) compared to the health value of regulated complexing agents, which have similar chemical structure, for example, the health value for EDTA= 250 µg/L.

Table 4-5. Total number of chemicals analysed for in Subiaco wastewater and the percentage of detections

Parameter	n	Detected (%)	Parameter	n	Detected (%)
DBPs			Volatile Organic Compounds (VOCs)	59	13.6
Trihalomethanes (THMs)	6	100	Polycyclic aromatic hydrocarbons (PAHs)	17	29.4
Haloacetic acids (HAAs)	9	44.4	Dioxin and Furans	17	5.9
Haloacetonitriles	6	16.7	Polychlorinated biphenyls (PCBs)	12	16.7
Haloaldehydes	6	16.7	Gross alpha and gross beta particle activity	2	100
Haloketones	4	50	Hormones	4	25
Chloropicrin	1	0	Complexing agents	4	100
N-Nitrosamines	9	88.9	Anions	3	
Pharmaceuticals			Other chemicals	12	8.3
Antibiotics	10	80	Metals	29	58.6
Iodinated contrast media	8	62.5	Pesticides	117	0
Other pharmaceuticals	20	60			

The screening RQ for NDMA was below 1 (RQ = 0.8). However, the screening RQ was above 1 for five of the nine N-nitrosamines (NDBA, NDPA, NEMA, NPIP and NMOR). All N-nitrosamines have the same mechanism of action and therefore it is possible to assume an additive model which indicates a risk for human health if the water was used for drinking purposes.

All metals had screening RQ (median) values below 1. The calculated screening RQs were one to four orders of magnitude below 1 except for aluminium (RQ = 0.3), iron (RQ = 0.3), manganese (RQ = 0.1) and nickel (RQ = 0.1). Few volatile organic carbon compounds (VOCs) were detected in the Subiaco wastewater and the screening RQs of those detected were below 1, indicating very low health significance.

Numerous pharmaceuticals were detected in the secondary wastewater. However, health values are set in the $\mu\text{g/L}$ concentrations, whereas the measured concentrations in the wastewater were in the ng/L levels. The exceptions were the iodinated contrast media compounds which had maximum concentrations between 3 and 17 $\mu\text{g/L}$ (Table 4-6). Therefore, screening RQs for all the pharmaceutical compounds were one to three orders of magnitude below 1. Diclofenac was the pharmaceutical with the highest screening RQ (median) = 0.2. The only estrogenic compound detected was oestrone, with a median concentration of 19.3 ng/L , a health value of 30 ng/L and a screening RQ (median) = 0.64.

All DBPs (except N-nitrosamines as listed above) had screening RQ values that were below 1. For haloacetic acids the screening RQ(median) values were 1 or 2 orders of magnitude below 1 except for dichlorobromoacetic acid (RQ = 0.57). For THMs, screening RQs were one to two orders of magnitude below 1 except for dibromomethane (RQ = 0.37). Anions, haloacetonitriles and halo ketones detected in the Subiaco wastewater all have screening RQ (median) values below 1.

The only chemical detected in the group classified as other chemicals was 1,4-dioxane which is used as a solvent in chemical synthesis, laboratory applications and in adhesive products. The screening RQ(median) = 0.12 is below health significance.

For PAHs, dioxins, furans and dioxin-like PCBs, the SHRA was conducted using the toxic equivalency factors (TEF) (Van den Berg et al., 2006). The corresponding RQs were 0.0004 and 0.004 for dioxins and PAHs respectively.

Table 4-6. SHRA of trace chemical contaminants in Subiaco wastewater

Parameter	%	n	Units	LOR	Median	mean	max	Tier	Health value	Source	Screening RQ (median)
Metals											
Aluminium	100	4	mg/L	0.005	0.03	0.03	0.04	1	0.1	ADWG	0.3
Antimony	100	4	mg/L	0.0001	0.0002	0.0002	0.0002	1	0.003	ADWG	0.07
Barium	100	4	mg/L	0.002	0.04	0.04	0.06	1	0.7	ADWG	0.05
Boron	100	4	mg/L	0.02	0.26	0.29	0.39	1	4	ADWG	0.06
Cobalt	25	4	mg/L	0.0001	0.005	0.004	0.005	2	0.01	Cal PRG	0.50
Copper	100	4	mg/L	0.0001	0.008	0.007	0.008	1	2	ADWG	0.004
Iron	100	4	mg/L	0.005	0.10	0.10	0.10	1	0.3	ADWG	0.3
Lead	100	4	mg/L	0.0001	0.0003	0.0003	0.0003	1	0.01	ADWG	0.03
Lithium	100	4	mg/L	0.0001	0.007	0.007	0.008	2	0.135	LTD	0.05
Magnesium	100	1	mg/L	0.1	7.7	7.7	7.7	2	180	AGDHA	0.04
Manganese	100	4	mg/L	0.001	0.03	0.02	0.03	1	0.5	ADWG	0.1
Molybdenum	100	4	mg/L	0.001	0.004	0.004	0.005	1	0.05	ADWG	0.08
Nickel	100	4	mg/L	0.001	0.002	0.002	0.002	1	0.02	ADWG	0.1
Silicon	100	1	mg/L	0.05	5.7	5.7	5.7	2	350	LTD	0.02
Strontium	100	4	mg/L	0.0001	0.18	0.17	0.2	2	4	USEPA	0.04
Tin	100	4	mg/L	0.0001	0.0003	0.0003	0.0004	2	14	WHO	0.00002
Zinc	100	4	mg/L	0.005	0.047	0.053	0.076	2	3	ADWG	0.02
Disinfection by-products											
<i>Trihalomethanes</i>											
Bromochloromethane	75	4	µg/L	0.03	0.17	0.18	0.32	2	70	USEPA	0.002
Bromodichloromethane	100	4	µg/L	0.02	0.12	0.15	0.27	1	60	WHO	0.002
Bromoform	100	4	µg/L	0.09	0.25	0.27	0.59	1	100	WHO	0.002
Chlorodibromomethane	100	4	µg/L	0.1	0.33	0.37	0.62	1	100	WHO	0.003
Chloroform	100	4	µg/L	0.06	1.08	1.32	2.7	1	200	WHO	0.01
Dibromomethane	75	4	µg/L	0.03	0.26	0.26	0.46	3	0.7	TTC	0.37
<i>Haloacetic acids</i>											
Dibromoacetic acid	33.3	3	ug/L	40	0.1	0.27	0.6	1	60	USEPA	0.002
Dichloroacetic acid	66.7	3	ug/L	60	0.4	0.4	0.6	1	100	ADWG	0.004
Dichlorobromoacetic acid	66.7	3	ug/L	40	0.4	0.4	0.6	3	0.7	TTC	0.57
Trichloroacetic acid	100	3	ug/L	40	3.6	3.33	4.4	1	100	ADWG	0.04
<i>Haloacetonitriles</i>											
Dichloroacetonitrile	75	4	µg/L	0.05	0.025	0.025	0.04	1	2	WHO	0.01
<i>Haloaldehydes</i>											
Bromodichloroacetaldehyde	50	4	µg/L	0.28	1.05	0.87	1.2	3	0.7	TCC	1.5
<i>Haloketones</i>											
1,1-dichloropropanone	50	4	µg/L	0.07	0.18	0.19	0.33	3	0.7	TTC	0.3
1,3-dichloropropanone	25	4	µg/L	0.08	0.04	0.04	0.05	3	0.7	TTC	0.06
<i>N-nitrosamines</i>											
NDMA	100	3	ng/L	1.3	8	9.67	16	1	10	WHO	0.8
NDBA	33.3	3	ng/L	4.03	12.7	9.47	12.7	2	6	IRIS	2.1
NDPA	100	3	ng/L	1.88	18	16.67	29	2	5	Cal DPH	3.6

Parameter	%	n	Units	LOR	Median	mean	max	Tier	Health value	Source	Screening
											RQ (median)
NDEA	33.3	3	ng/L	2.12	5	4.67	5	2	10	Cal DPH	0.5
NEMA	100	3	ng/L	2.08	5	10.67	24	2	2	IRIS	2.5
NPIP	33.3	3	ng/L	2.43	5.9	4.6	5.9	2	4	OEHHA	1.5
NMOR	33.3	3	ng/L	3.58	5.8	5.87	6	2	5	OEHHA	1.2
NPYR	33.3	3	ng/L	2.17	4.9	3.6	4.9	2	20	IRIS	0.25
Anions											
Chlorate	50	4	µg/L	9.8	43	43.1	80	1	700	WHO	0.06
Chlorite	25	4	µg/L	13.8	30	25.3	35	1	300	ADWG	0.1
Complexing Agents											
DTPA	50	4	µg/L	2.32	2.45	4.1	9.8	3	0.7	TTC	3.5
EDTA	100	4	µg/L	0.64	218.5	226.3	267	1	250	ADWG	0.87
NTA	100	4	µg/L	0.08	1.5	1.7	2.7	1	200	ADWG	0.01
PDTA	25	4	µg/L	4.36	9.1	7.6	9.1	3	0.7	TTC	13
Pharmaceuticals											
Antibiotics											
Azithromycin	100	2	µg/L	0.04	0.19	0.19	0.22	2	35	ADI	0.005
Clarithromycin	100	3	µg/L	0.03	0.26	0.29	0.34	2	225	LTD	0.001
Clindamycin	66.7	3	µg/L	0.03	0.04	0.04	0.05	2	270	LTD	0.0002
Erythromycin	66.7	3	µg/L	0.05	0.75	0.93	1.29	2	15	ADI	0.06
Metronidazol	100	3	µg/L	0.05	0.12	0.12	0.17	2	47	LTD	0.003
Roxithromycin	100	3	µg/L	0.03	0.28	0.32	0.35	2	135	LTD	0.002
Sulfamethoxazole	100	3	µg/L	0.05	0.61	0.60	0.68	2	32	ADI	0.02
Trimethoprim	100	3	µg/L	0.05	0.69	0.55	1.04	2	63	ADI	0.009
ICM											
Amidotrizoic acid	100	1	µg/L	0.8	9.4	9.4	9.4	2	360	LTD	0.03
Iodipamide	33.3	3	µg/L	0.4	0.25	0.25	0.4	2	540	LTD	0.0005
Iohexol	100	3	µg/L	1	12.26	15.1	17.2	2	650	LTD	0.02
Iopamidol	100	3	µg/L	0.4	4.62	5.4	7.56	2	360	LTD	0.01
Iopromide	100	3	µg/L	0.3	1.88	2.21	3.3	2	680	LTD	0.003
Other											
Atorvastatin	33.3	3	µg/L	0.04	0.13	0.15	0.15	2	5	LTD	0.03
Carbamazepine	100	3	µg/L	0.03	0.70	0.70	0.71	2	90	LTD	0.008
Cyclophosphamide	33.3	3	µg/L	0.12	0.15	0.13	0.22	2	3	LTD	0.05
Diclofenac	100	3	µg/L	0.01	0.35	0.33	0.40	2	1.6	ADI	0.2
Fluoxetine	66.7	3	µg/L	0.02	0.04	0.03	0.07	2	9	LTD	0.004
Gemfibrozil	100	3	µg/L	0.04	0.22	0.27	0.28	2	540	LTD	0.0004
Ifosfamide	33.3	3	µg/L	0.12	0.13	0.10	0.20	2	3	LTD	0.04
Indomethacin	100	3	µg/L	0.03	0.14	0.16	0.17	2	22	LTD	0.007
Morphine	33.3	3	µg/L	0.12	0.18	0.10	0.35	2	14	LTD	0.01
Naproxen	66.7	3	µg/L	0.14	0.26	0.25	0.32	2	200	LTD	0.001
Phenytoin	66.7	3	µg/L	0.05	0.11	0.14	0.15	2	135	LTD	0.001
Warfarin	33.3	3	µg/L	0.01	0.02	0.02	0.02	2	0.5	LTD	0.03
Hormones											
Oestrone	33.3	3	ng/L		19.27	20	20	2	30	LTD	0.64

Parameter	%	n	Units	LOR	Median	mean	max	Tier	Health value	Source	Screening RQ (median)
VOCs											
1,2-dichlorobenzene	100	4	µg/L	0.03	1.8	1.83	3.1	1	1500	ADWG	0.001
1,2-dichloroethane	25	4	µg/L	0.02	0.02	0.02	0.05	1	3	ADWG	0.007
1,2-dichloroethene, cis	25	4	µg/L	0.03	0.05	0.06	0.12	1	60	ADWG	0.001
Carbon disulfide	100	1	µg/L	0.04	0.02	0.02	0.02	2	700	IRIS	0.00003
Chloromethane	25	4	µg/L	0.07	0.12	0.09	0.12	2	14	USEPA	0.009
Tetrachloroethene	100	4	µg/L	0.11	1.34	8.75	32	1	50	ADWG	0.03
Trichloroethene	25	4	µg/L	0.03	0.05	0.24	0.85	1	50	ADWG	0.001
o-xylene	25	4	µg/L	0.04	0.08	0.06	0.08	1	600	ADWG	0.00013
Other											
1,4-Dioxane	100	1	µg/L		0.36	0.36	0.36	2	3	OEHHA	0.12
PAHs											
TEF											
2-chloronaphthalene	100	1	ng/L		3	3	3	2	0		0
Fluorene	100	1	ng/L		3	3	3	2	0.001	Nisbet	0.003
Phenanthrene	100	1	ng/L		7	7	7	2	0.001	Nisbet	0.007
Pyrene	100	1	ng/L		6	6	6	2	0.001	Nisbet	0.006
Carbazole	100	1	ng/L		5	5	5	2	0.005	EPA	0.025
										TEQ	0.041
										RQ	0.004
Dioxins											
TEF											
PCB 105	50	2	pc/L	10	8.4	8	11	2	0.00003	WHO	0.0003
PCB 118	100	2	pc/L	20	29	29	29	2	0.00003	WHO	0.0009
Octadioxin (OCDD)	50	2	pc/L	20	18.7	18	26	2	0.00003	WHO	0.006
										TEQ	0.007
										RQ	0.0004
Radionuclides											
Gross alpha		2	Bq/L		0.025	0.025	0.025	1	0.5	ADWG	0.05
Gross beta		1	Bq/L		0.026	0.026	0.026	1	0.5	ADWG	0.052

%, percentage of detection; n, number of samples; ADI, acceptable daily intake; LOR, limit of reporting; LTD, lowest therapeutic dose; TEF, toxic equivalency factor; TEQ, toxic equivalent; WHO, World Health Organization; ADWG, Australian Drinking Water Guidelines; Cal PRG, California Preliminary Remediation Goals; IRIS, Integrated Information System; USEPA, US Environmental Protection Authority; OEHHA, Office of Environmental Health Hazard Assessment; TTC, Threshold of Toxicological Concern; DTPA (diethylenetrinitriolpentaacetic acid); EDTA (Ethylenediamine tetra-acetic acid); NTA (nitritotriacetic acid); PDTA (1,3-propylenedinitrioltetraacetic acid). In bold, RQ(median) above 1.

Floreat Infiltration Galleries

Due to restrictions to the analytical methods at the time of this study, it was determined the concentrations of the majority of the chemicals detected in the wastewater (described above) were too low in the groundwater within the MAR scheme to be accurately studied. Despite this, five pharmaceuticals (carbamazepine, temazepam, oxazepam, diazepam, and phenytoin) were found to be easily detected in the groundwater within the MAR scheme and were therefore used as an example of the behaviour of trace organics in an aerobic aquifer used for MAR. Due to difficulties in studying the other chemicals under field conditions, research on the persistence and behaviour of selected trace organics was undertaken in laboratory columns where concentrations and other variables could be controlled. This research is reported in detail in Chapter 2.

A total of 691 measurements, excluding field blanks, were received from the Chemistry Centre of Western Australia corresponding to the five pharmaceuticals tested at the Floreat Infiltration Galleries. The results of the field testing are presented in Section 1.3.5 of Chapter 1.

Risk quotients – Floreat Infiltration Galleries

Screening RQs were calculated using the mean concentration RQ(mean) and the maximum concentration RQ(max) for the detected pharmaceuticals. Screening RQs were calculated using the Limit Of Reporting (LOR) for the undetected pharmaceuticals as a worst-case scenario. Health values were calculated using the Lowest Therapeutic Dose (LTD) from the pharmacopeia and using the AGWR equations in the Australian Guidelines for Water Recycling: Phase 2 Augmenting Drinking Water Supplies (NRMMC-EPHC-NHMRC, 2008). Health values were calculated assuming a proportion of intake from water of 90% instead of 100% to account for other potential sources of intake such as food. Calculated RQs were one to three orders of magnitude below 1 (Table 4-7), indicating very low health risk.

Screening RQ(mean) values in the extraction bore: temazepam (RQ = 0.03), oxazepam (RQ = 0.008) and carbamazepine (RQ = 0.001) were lower compared with the screening RQs in the infiltration galleries indicating a decreased concentration of the pharmaceuticals in water recycled through the Floreat Infiltration Galleries.

Table 4-7. Risk Quotients of Pharmaceuticals at the Floreat Infiltration Galleries

Pharmaceutical	LOR (µg/L)	LTD (µg/L)	Health Value (µg/L)	% detection	Detected in FIG (µg/L)		RQ mean	RQ max
					mean	max		
Temazepam	<0.1	10	5	86.6	0.21	0.31	0.04	0.06
Oxazepam	<0.1	30	13.5	87.9	0.24	0.34	0.02	0.03
Diazepam	<0.1	5	2	0	0.1		0.05	
Phenytoin	<0.1	300	135	0	0.1		0.0007	
Carbamazepine	<0.05	200	90	85	0.27	0.46	0.003	0.005

LOR, limit of reporting; LTD, Lowest therapeutic dose. RQs for phenytoin and diazepam calculated assuming measured concentration = LOD.

4.7.6 Discussion and Conclusions

Subiaco wastewater characterisation

A comprehensive characterisation of Subiaco wastewater was conducted including metals and other inorganic compounds, nutrients, natural anthropogenic organics (disinfection by-products, pesticides and endocrine disruptors), persistent organic pollutants and radionuclides. Trace chemical contaminants tested for were found in low concentrations, which indicate that secondary wastewater treatment is consistent in terms of quality as source water for recycling. Toxic contaminants are often a function of the industrial effluent component of the wastewater (IAH-MAR and UNESCO, 2005), and therefore secondary wastewater quality is primarily determined by the presence and nature of industries discharging waste and the treatment processes applied. The Subiaco catchment area is mainly residential and commercial although the wastewater treatment plant (WWTP) also receives waste from a major hospital complex in the city.

Of the 355 chemicals analysed for, 25% (~90) were detected in at least one of four samples taken from the Subiaco wastewater. Pharmaceuticals were commonly detected in low concentrations (ng/L to low µg/L) in the Subiaco wastewater and the results are consistent with conducted national and international studies. Despite the common detection of pharmaceuticals, the SHRA indicates low health significance. Metals were also commonly detected but with calculated screening RQs all below 1.

The results of the SHRA, based on the calculated screening RQs, indicate that the source water for infiltration is below health guideline values for most of the trace chemical contaminants tested for, except for N-nitrosamines and complexing agents. Five of the nine detected N-nitrosamines had screening RQs above 1. In addition, an additive effect could be assumed given that N-nitrosamines have the same mechanism of action. Therefore this chemical group is of particular health concern if the recycled water was to have potential exposure pathways that could potentially include inadvertent ingestion.

NDMA is considered the chemical representative of the group and is the best characterised N-nitrosamine. NDMA is a hydrophilic polar, uncharged organic compound that is frequently present in secondary wastewater.

Floreat Infiltration Galleries

A reduction of screening RQ(mean) values was observed for carbamazepine and oxazepam and to a lesser extent for temazepam through the Floreat Infiltration Galleries. As discussed in Chapter 2 the removal appears to be predominantly through processes of dilution and adsorption rather than degradation. These results are consistent with other studies reporting natural filtering and attenuation of pharmaceuticals and other pollutants within the sand aquifer (Stuyfzand et al., 2009). However, the removal efficiency was different for each compound in the Floreat Infiltration Galleries. When biological degradation occurs, redox (e.g. the presence or absence of oxygen) can have a significant impact (Ying et al., 2008). Some organic chemicals are most effectively removed under aerobic conditions while others are only removed under anoxic conditions (Dillon et al., 2009; Stuyfzand et al., 2009). Given the strong influence of redox conditions on removal rates of many organic micro-pollutants, it is better to have different zones in the aquifer such that water is exposed to both conditions to obtain optimal water quality (Stuyfzand et al., 2007; Dillon et al., 2009).

It is expected that in a full-scale scheme, with a longer natural water residence time, greater removal of the tested pharmaceuticals through abiotic or biological processes could be achieved, compared with the results presented here from experimental conditions. More in-depth studies targeting the chemicals that have high screening RQs are needed, however, to further ascertain the removal efficiencies in the aquifer.

Phenytoin was observed in the secondary wastewater but was below the limit of detection (LOD) in the Floreat Infiltration Galleries. This may be due to different analytical methods used by the two laboratories; Curtin University reported the results from the Subiaco wastewater and Chemistry Centre reported the results for the Floreat Infiltration Galleries. Diazepam was not detected in the Floreat Infiltration Galleries or in the Subiaco wastewater although it was detected in other WWTPs in Perth (Government of Western Australia, 2009).

Column experiments

The results from the column experiments given in Chapter 2 indicate that no additional degradation could be expected through MAR for some pharmaceuticals or DBPs and therefore source protection initiatives are critical to achieve reliable and high quality secondary wastewater for MAR. The results from the column studies are inconsistent with other studies reporting biodegradation of NDMA in unsaturated and saturated soil samples under both aerobic and anaerobic conditions (Zhou et al., 2009). As noted in Chapter 2, this suggests that more research may be required to determine if these observed differences in decay of NDMA are due to differences in the aquifer characteristics in Perth from the soils used by Zhou et al., 2009).

N-nitrosamines are the chemical group with the highest potential health impacts if considering use of the water for drinking purposes. Thus, as long as the recycled water passaged through the aquifer via MAR is only used for non-potable purposes then the persistence of NDMA presents a low health risk. Should there be the potential for greater exposure and potential for significant ingestion, more will need to be known about the occurrence and fate of NDMA in the source water, and the behaviour of NDMA in Perth aquifers. It is currently considered that NDMA gaseous diffusion and volatilisation in unsaturated soils may effectively impede significant leaching of NDMA (Arienzo et al., 2006; Gan et al., 2006). However, factors that enhance the leaching risk of NDMA in soils are: high hydraulic conductivity, low NDMA adsorption constant and high infiltration intensity (Haruta et al., 2008). Moreover, the relative persistence of NDMA in recycled water used for irrigation has been inversely correlated with soil organic matter content, soil microbial biomass, and soil dehydrogenase activity, suggesting the importance of microorganisms in NDMA degradation in these soils (Yang et al., 2005). Other N-nitrosamines are also biodegradable under oxic and anoxic conditions. Microorganisms have been identified as a key aspect for the complete removal of N-nitrosamines in MAR through soil aquifer treatment (Drewes et al., 2006).

4.7.7 Concluding Remarks

The major human health risk of recycled water for **non-potable uses** is related to **pathogens** and not to chemicals. This is highlighted in the Australian Guidelines for Water Recycling (Phase1) (NHMRC-EPHC, 2006) and also in the health risk assessment using recycled water for fire fighting purposes (WSAA, 2004). Chemical contaminants are of

concern only where recycled water is used for drinking purposes. In effect there is no requirement for human chemical standards specific to non-potable uses.

Recycled water has been used for irrigation and similar purposes throughout Western Australia and in other Australian states for decades. The usual form of treatment has been direct disinfection. To date there has been no evidence of chemical contaminants presenting any risk to human health from such applications.

The National Water Quality Management Strategy (NWQMS) provides the framework for guiding MAR in order to protect human and environmental health. The results presented in the SHRA were evaluated against Australian Drinking Water Guidelines (NHMRC and ARMCANZ, 2004) and Australian Guidelines for Water Recycling Phase 2: Augmentation of Drinking Water Supplies (NRMMC-EPHC-NHMRC, 2008) which represents the highest end use of the recycled water

4.7.8 Limitations

In consideration of the chemical health risk assessment for this MAR project, there are several limiting factors which will have an influence on the outcome of the results presented. These factors are:

1. The Floreat Infiltration Galleries site as it currently operates is a research site and not a full-scale trial, and as such residence times in the aquifer and the concentrations applied in the column experiments would not normally be the case in a standard pilot trial.
2. The Floreat Infiltration Galleries were loaded at 50 kL/day with a recovery bore located 50 m downstream from which 250 kL/day was extracted. This five-fold extraction rate over a short distance will impact on the physical/chemical/biological treatment processes that normally occur within the soil profile. These mechanisms are important in attenuating both microbial and chemical contaminants under normal conditions. Therefore the very short residence time in this trial will not be indicative of pathogen die-off potential.
3. The SHRA is only a screening tool to identify trace chemical contaminants that require further analysis for a more comprehensive risk assessment. The approach used is a chemical-by-chemical analysis and therefore does not take into consideration potential health effects of chemical mixtures (note that the Australian Guidelines for Water Recycling indicate that where chemicals in mixtures are at concentrations far below a screening RQ of 1, any additive or antagonistic effects are unlikely to contribute significantly to overall risk (NRMMC-EPHC-NHMRC, 2008)). However, where the screening RQ approaches or exceeds 1, mixture effects may need to be considered.
4. Data from the Floreat Infiltration Galleries study were not available for NDMA and other N-nitrosamines due to limitations in the analytical methods available at the time of the study. NDMA was not degraded in the column experiments but it was not possible to correlate this result with the Floreat Infiltration Galleries field study.

5. Column experiments to investigate the fate of trace organic chemicals were conducted using concentrations from 140 to 10,000 times the analytical detection limits. It is not possible to extrapolate the potential health implications at the settled experimental conditions. However, the column experiments could provide an indication of the likelihood of degradation through MAR.

4.8. SUMMARY

The health risk assessment undertaken for this MAR research project examining the non-potable use of recycled water for irrigation purposes used a screening health risk assessment for trace chemical contaminants and a quantitative microbial risk assessment for microorganisms. Only human health risks were considered and the assessment does not address the environmental risk that may result from the contaminants detected.

The assessment reviewed data from the Subiaco Wastewater Treatment Plant (chemicals), groundwater from the Floreat Infiltration Galleries (chemicals) and extracted water from the column experiments (chemicals). Microbiological assessment for pathogen risk was undertaken by QMRA.

The MAR project was conducted as a research site where the various systems were tested at loading rates which had a substantial bearing on the results. Therefore, the findings in this Chapter must be viewed accordingly and not taken as the basis for accepting or rejecting an MAR project. The important consideration in planning for MAR is the understanding of the proposed system, its design features and management. The capability of the aquifer system and its capacity to attenuate the recharge water will determine whether additional barriers may be necessary for the system. The outcome to be achieved is a system that is designed to be 'fit-for-purpose'.

The conclusions from the health risk assessment are summarised below.

4.8.1 Quantitative Microbial Risk Assessment (Section 4.6)

Microbial contaminants are important public health concerns in any recycled water application, and are the main health consideration with irrigation and similar non-potable practices.

The QMRA modelling used the reference pathogens *Campylobacter*, *Cryptosporidium* and rotavirus to estimate the risk to human health. The end point of the human health risk assessment is determining the burden of disease. This is expressed as Disability Adjusted Life Years with a disease burden of 1×10^{-6} DALYs per year or less.

The exposure assessment considered microbial hazards through ingestion of sprays, garden irrigation and accidental ingestion, and then provided a risk estimate after taking into account a number of probability distribution function assumptions associated with the initial pathogen counts, decay rates, infiltration time and residence time in the aquifer. The residence time was based on an average of 70 days prior to recovery and use for irrigation.

The QMRA results indicated that the log removal for *Cryptosporidium* and rotavirus were significantly below the recommended levels set out in the Australian Guidelines for Water Recycling Phase1 (NRMMC-EPHC-NHMRC, 2006). For the risk to be acceptable, under this model, a residence time of ~150 days is required. This must be considered in light of the trial conditions where the recovery rate was five times that of the injection rate and at a distance of 50 m between the injection and extraction points.

These results should be viewed as output risk estimates for the particular system in question, and although the approach is transferable, the actual assessed risk will change with various system parameters. The information should be interpreted in light of other information such as system hydrogeology and site-specific water quality monitoring data.

The QMRA approach is a useful method which can contribute to design of 'fit-for-purpose' MAR schemes.

4.8.2 Trace Chemical Contaminants (Section 4.7)

Subiaco wastewater

Treated wastewater from the Subiaco WWTP was tested for 355 chemicals. These included: metals, inorganic compounds, nutrients, natural anthropogenic organics (disinfection by-products, pesticides and endocrine disruptors), persistent organic pollutants and radio-nuclides. A total of 88 chemicals were detected from all the chemical groups, except for pesticides, which were not detected.

The Risk Quotient (RQ) with a drinking water guideline level was used as a screening assessment of risk by comparing the measured chemical concentration with health values. A screening RQ below 1 is considered of low significance to health. A screening RQ above 1 indicates a requirement for more data on occurrence and fate and the development of a full health risk assessment.

All chemical groups had screening RQ(median) values below 1, apart from NDMA and complexing agents. Although pharmaceuticals were detected, the RQs were one to three orders of magnitude below 1 (e.g. 0.1–0.001). Only oestrone was detected with a median concentration of 19.3 ng/L. The health value for drinking water is 30 ng/L.

All metals detected had screening RQ(median) values below 1. Some volatile organic compounds were detected and had screening RQ values below 1, indicating very low significance for health.

Five out of nine N-nitrosamines had screening RQs above 1. This implies that these levels would be significant as a public health concern if the wastewater was to be a source for drinking water purposes. Under these circumstances it is recommended that pre-treatment of the source water (e.g. via reverse osmosis membranes, advanced oxidation or activated carbon) be utilised as an additional treatment barrier if the water is to be used for drinking purposes.

Complexing agents also had RQ(median) values above 1. However, using the TTC approach, and considering the health value for these agents, they are of low significance to human health.

Based on the various chemicals analysed, the use of Subiaco wastewater as source water for non-potable MAR schemes as proposed in this project does not present a health risk from trace chemical contaminants when the recycled water is intended for irrigation purposes. There are only a few parameters that would require further treatment if the treated wastewater were to be considered as a drinking water source.

Floreat Infiltration Galleries

Five pharmaceuticals were tested at the Floreat Infiltration Galleries site. A total of 691 measurements were taken from the various bores situated between the infiltration galleries and the recovery bore (BH17), at a distance of 50 m. Only carbamazepine, oxazepam and to a lesser extent temazepam were detected in the bores. The levels of these three pharmaceuticals detected showed a gradual attenuation as the water moved away from the infiltration galleries. This is most likely to be due to dilution and dispersion within the aquifer as the column experiments in Chapter 2 indicated that there was no degradation of these chemicals in the aquifer below the infiltration galleries.

The screening RQ(mean) values in the extraction bore were: temazepam (RQ = 0.03), oxazepam (RQ = 0.008) and carbamazepine (RQ = 0.001). These represent one to three orders of magnitude below 1, indicating very low health risk.

Column experiments

Nine trace organic chemicals were loaded into columns filled with either Leederville sediment or Spearwood. These experiments were designed to elucidate rates of degradation in the aquifer should it occur. The concentrations used in the experiments were 140 to 10,000 times higher than median Subiaco wastewater concentrations. Therefore, there is some question as to the validity of extrapolating the data to inform human health risk. That NDMA and NMOR were not degraded under the experimental conditions, and that the screening risk assessment indicated they may be of concern, indicates the need for further evaluation of wastewater treatment processes and the use of additional barriers if there is a likelihood of significant ingestion of the water (e.g. if the intended use was for drinking purposes).

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Appendix 4A. Applications of Risk Assessment Methods and DALYS to Water Contaminants

Evaluation of the health risks of water contamination often uses some form of risk assessment. For example, microbial agents in water supplies are often evaluated using a combination of observational and experimental data together with mathematical models to accurately predict the level of reference pathogens in the key pathogen groups (bacteria, viruses and protozoa) in source waters (Havelaar and Melse, 2003). Most models are based upon the principles of:

1. Hazard assessment
2. Exposure assessment
3. Dose-response analysis
4. Risk characterisation.

The model of choice in Australia is Quantitative Microbial Risk Assessment (QMRA). QMRA is a mathematical risk assessment model that can accurately predict the risk associated with exposure to the reference pathogens. QMRA assessments are easier and less expensive to perform than epidemiological studies, they do not require large study groups or follow up periods, nor are they subject to the influences of confounding and bias.

The QMRA stages account for attributable pathogen reductions that may be achieved through various treatment processes, and also consider the potential for re-contamination and microbial regrowth (Havelaar and Melse, 2003). In light of all of this, an estimate is able to be made of the likely number of organisms that the consumer is likely to ingest.

The Stockholm Framework

A further extension of the risk assessment model was the development of the Stockholm Framework, which was designed to integrate both risk assessment and risk management to control waterborne diseases (World Health Organization, 2006). The framework was developed following an expert meeting that occurred in Stockholm, Sweden, subsequent to which the World Health Organization (WHO) published *Water quality: Guidelines, standards and health – Assessment of risk and risk management for water-related infectious disease*. (Bartrom et al., 2001).

The Stockholm Framework involves the assessment of health risks prior to the setting of health targets and the development of guideline values. Further, it defines the basic control or management systems necessary to evaluate the impact of these approaches on public health (World Health Organization, 2006, p.13).

The World Health Organization (2006) notes that the framework can accommodate local, social, cultural, economic and environmental circumstances that may contribute to potential confounding exposures, such as food borne pathogens as well as traditional water and sanitation exposure routes. Intrinsically, this facilitates the management of infectious diseases in an integrated holistic manner, incorporating other diseases and exposure routes. Key elements and considerations of the Stockholm Framework are indicated in Figure 4A-1 and Table 4A-1 from Aertgeerts and Angelakis (2003, p.188).

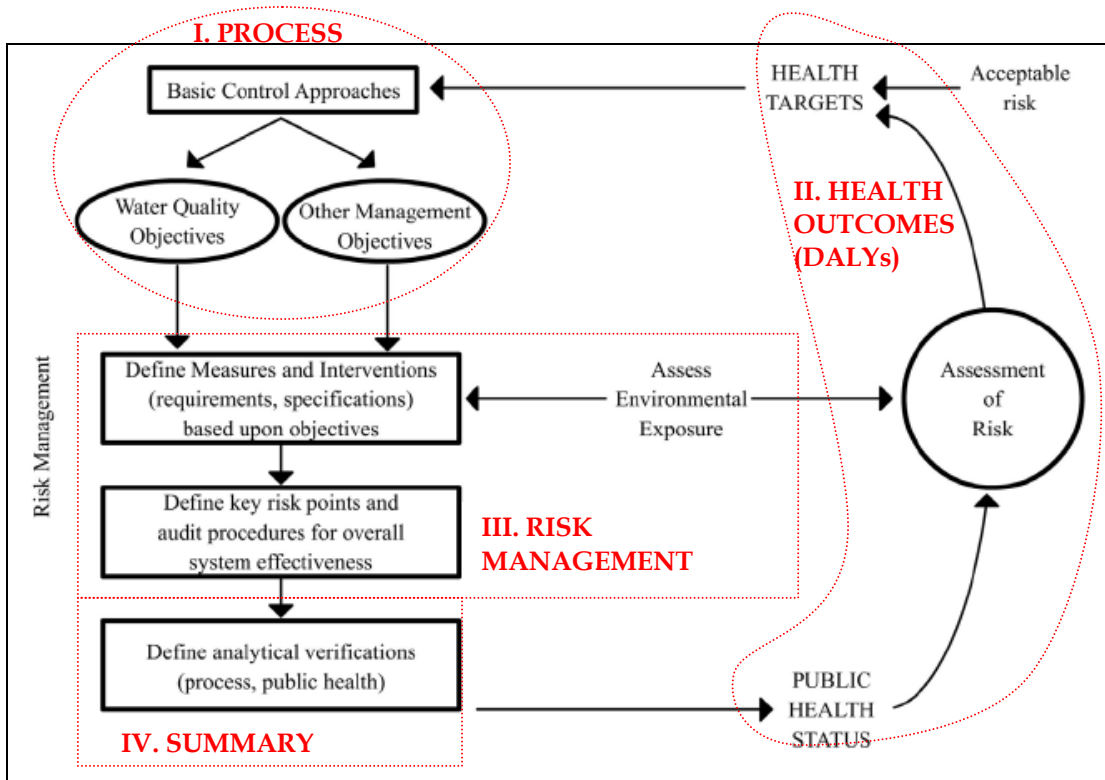


Figure 4A-1. Stockholm Framework (Source: Bartram et al., 2001, p.9)

Table 4A-1. Key elements and considerations of the Stockholm Framework

Framework component	Process	Considerations
Assessment of health risk	<p>Hazard assessment</p> <p>Environmental exposure assessment</p> <p>Dose-response analysis</p> <p>Risk characterization</p>	<p>Best estimate of risk — not overly conservative</p> <p>Equivalence between risk of infection and risk of disease</p> <p>Health outcomes presented in disability adjusted life years (DALYs); facilitates comparison of risks across different exposures and priority setting</p> <p>Risk assessment is an iterative process — risk should be periodically reassessed based on new data or changing conditions</p> <p>Risk assessment is a tool for estimating risk and should be supported by other data (e.g. outbreak investigations, epidemiological evidence, microbiological risk assessment and studies of environmental behaviour of microbes)</p> <p>Process depends on quality of data</p> <p>Risk assessment needs to account for short-term under-performance</p>
Tolerable risk/health targets	<p>Health-based target setting based on risk assessment</p> <p>Define water quality objectives</p>	<p>Need to be realistic and achievable within the constraints of each setting</p> <p>Set using a risk-benefit approach; should consider cost-effectiveness of different available interventions</p> <p>Should take sensitive subpopulations into account</p> <p>Index pathogens should be selected for relevance to contamination, control challenges and health significance (more than one index pathogen may be needed)</p>
Risk management	<p>Based on health-based targets:</p> <p>Define other management objectives</p> <p>Define measures and interventions</p> <p>Define key risk points and audit procedures</p> <p>Define analytical verifications</p>	<p>Risk management strategies need to address rare or catastrophic events.</p> <p>A multiple barrier approach should be used.</p> <p>Monitoring — overall emphasis should be given to periodic inspection/auditing and to simple measurements that can be rapidly and frequently made to inform management.</p> <p>Hazard analysis critical control point (HACCP)-like principles should be used to anticipate and minimize health risks.</p>
Public health status	Public health surveillance	<p>Need to evaluate effectiveness of risk management interventions on specific health outcomes (both through investigation of disease outbreaks and evaluation of background disease levels)</p> <p>Establish procedures for estimating the burden of disease, to facilitate monitoring of health outcomes due to specific exposures</p> <p>Burden of disease estimates can be used to place water-related exposures in the wider public health context, to enable prioritization of risk management decisions</p> <p>Public health outcome monitoring provides the information needed to fine-tune risk management through an iterative process</p>

Source: Adapted from Bartram, Fewtrell & Stenström (2001)

The Stockholm Framework considers the risks associated via environmental exposure to pathogenic micro-organisms, which is of particular interest if attributing a disease outbreak to drinking water when other potential routes of exposure may be implicated (Bartram et al., 2001). Accordingly greater public health benefit may be able to be obtained by planning interventions that manage these other potential routes of exposure. The framework incorporates the DALY metric to assess health outcomes from different disease exposure routes in terms of the overall assessment of health risk (World Health Organization, 2006). DALYs also facilitate the comparison of risks across different exposures and priority settings, as in indicated in Table 4A-1.

Applying the Stockholm Framework to recycled water

The National Water Quality Management Strategy – Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) (NRMMC-EPHC-NHMRC, 2006), defines recycled water as ‘*Water generated from sewage, greywater or stormwater systems and treated to a standard that is appropriate for its intended use*’. As applied to recycled water exposure, assessment of health risks within the Stockholm Framework is an iterative process that considers the environmental conditions – the currency and integrity of available data on such conditions – within which recycled water systems are operating (Bartram, et al., 2001). Underpinning the risk assessment for such waters are data input tools such as epidemiological evidence, communicable disease investigations, microbial risk assessment studies and studies of environmental behaviour of microbes that could be extrapolated to the human population setting (Bartram, et al., 2001).

The current Australian model incorporates many of these concepts, particularly the utilisation of quantitative microbial risk assessment (QMRA) to determine the likelihood of illness or infection associated with recycled water exposure and the production of DALYs to convert these likelihoods into burdens of disease (NRMMC-EPHC-NHMRC, 2006, p.84). The DALY approach for assessing public health outcomes to allow risk management decisions to be prioritised is largely equivalent to the model that has been adopted in both phases of the *Australian Guidelines for Water Recycling* (NRMMC-EPHC-NHMRC, 2006 and 2008).

Calculating DALYs for drinking water contaminants

The DALY is a metric that considers health burden in terms of years of life lost and years lost to disability. DALY calculations, which have been developed and extensively applied by the Global Burden of Disease (GBD) project, reflect severity of illness to determine the quality of the life that has been lost as well as the quantity. This measure provides a standardised means by which disease can be assessed and compared using disease weightings in a range from zero (for sound health status) to one (for death).

DALYs may be formally calculated by incorporating the following two components:

$$\text{DALYs} = \text{YLL (years of life lost)} + \text{YLD (years lived with a disability or illness)}$$

YLL is defined by Murray and Lopez (1997) as years of life lost, while YLD is defined by Guerrant et al. (2002) as years lost to disability with nonfatal conditions, injuries and diseases.

DALYs have been applied to a number of diseases arising from water contamination. Traditional quantitative risk assessment models determine a risk profile associated with the likelihood of infection or illness occurring in the exposed population (Havelaar and Melse, 2003), whereas DALYs convert these likelihoods into burdens of disease (NRMMC-EPHC-NHMRC, 2006, p.84). When deriving DALYs for individual hazards both acute public health effects (such as diarrhoeal disease and even death) and chronic public health effects (such as cancer) are considered (NRMMC-EPHC-NHMRC, 2006, p.84). For waterborne disease, the most commonly associated illness is gastroenteritis, with classical symptomology of diarrhoea and vomiting. It has been estimated that waterborne diseases are the primary reason for DALY accrual in developing countries and are ranked eighth out of twelve in developed countries, totalling 79,490 and 5,610 DALYs per million of their respective populations (assuming that 80% of the infectious diseases are waterborne) (Zehnder et al., 2003, p.6). Prüss et al. (2002) estimate the disease burden from water, sanitation, and hygiene to be as high as 4.0% of all deaths and 5.7% of the total disease burden (DALYs) when a variety of diarrhoeal disease are considered.

Given their utility in these related contexts, it has been suggested that DALYs may be used to evaluate the health impact of various microbial and chemical hazards that may exist within recycled water (NRMMC-EPHC-NHMRC, 2006, p.84). To calculate DALYs for adverse outcomes from a drinking water contaminant or any other agent, the number of people experiencing each outcome is required (Havelaar and Melse, 2003). This information may be sourced from a variety of sources including medical registries, surveys, and epidemiological studies and can also be estimated from combining attributable risks with existing data on adverse health outcomes (Havelaar and Melse, 2003, p.14). Data on exposures and dose-response relationships can also be utilised (Havelaar and Melse, 2003).

Examples of DALY calculations

An Australian example from the National Water Quality Management Strategy – Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) (NRMMC-EPHC-NHMRC, 2006) for rotavirus infection is as follows:

- mild diarrhoea (severity of illness weighting 0.1) lasting 3 days in 97.5% of cases
- severe diarrhoea (severity of illness weighting 0.23) lasting 7 days in 2.5% of cases
- rare deaths (severity of illness weighting 1.0) of very young children in 0.015% of cases.

Thus:

$$\begin{aligned}
 \text{DALY per case} &= (0.1 \times 3 / 365 \times 0.975) + (0.23 \times 7 / 365 \times 0.025) + (1 \times 80 \times 0.00015) \\
 &= 0.0008 + 0.0001 + 0.012 \\
 &= 0.013
 \end{aligned}$$

Cryptosporidium, which can also cause watery diarrhoea (severity weighting of 0.067) lasting for 7 days, with extremely rare deaths in 0.0001% of cases, equates to a DALY of 0.0013 as follows:

$$\begin{aligned}
 \text{DALY per case} &= (0.067 \times 7 / 365) \\
 &= 0.0013
 \end{aligned}$$

Tolerable (acceptable) risk and DALYs

Previously tolerable or 'acceptable' risk has been defined as maximum levels of infection or disease in the community. Aertgeerts and Angelakis (2003, p.189) cite Hunter and Fewtrell (2001) in elucidating criteria for determining whether a risk is acceptable. They argue that a risk is acceptable if it complies with the following:

- it falls below an arbitrary predefined probability
- it falls below a level that is currently tolerated
- it falls below an arbitrary defined attributable fraction of total disease burden in the community
- the cost of reducing the risk would exceed the costs saved
- the cost of reducing the risk would exceed the costs saved when the 'costs of suffering' are considered
- funds could be better allocated to other public health priorities
- public health professionals are satisfied that it is acceptable
- the general public are satisfied that it is acceptable
- the politicians are satisfied that it is acceptable.

Tolerable risks are dynamic and are subject to a number of external influences, such as improvements in managing water-related disease transmission pathways, failures in water treatment and safety systems and documented cases of water related disease outbreaks. In the Netherlands, in December 2001, 200 people contracted gastroenteritis from norovirus infection as a result of a greywater dual supply system, cross-connected into a new housing estate. The resultant action from the Netherlands Government was to subsequently ban all large-scale dual pipe water supply schemes for households based upon concerns for the possibly of misuse of the water by householders and the unacceptable risk that it poses to public health (CRC for Water Quality and Treatment, 2003). This is an obvious example of government or politicians changing the tolerable or acceptable risk setting based upon an adverse experience.

In the context of water contaminants, the 'acceptable' risk approach in its most basic form fails to consider or identify the potential severity or sequelae associated with different hazards such as the differences between mild diarrhoea, typhoid, haemolytic uraemic syndrome and cancer (NRMCC-EPHC-NHMRC, 2006, p.83). DALYs overcome this shortcoming by providing a metric for severity in terms of cumulative consideration of years lived with the disease or disability and years of life lost. Aertgeerts and Angelakis (2003, p.190) cite the WHO (2003) where the WHO has determined that for water-related exposures, a disease burden of 1×10^{-6} DALYs (called 1 micro-DALY) per person per year (from a chemical or pathogen source transmitted via drinking water) is a tolerable risk. The level of health burden is equal to a mild case of diarrhoea with a low mortality rate (1 in 100 000) with an annual incidence risk of disease of 1 in 1000, which equates to 1 in 10 over an average lifespan (Aertgeerts and Angelakis, 2003, p.190, cite WHO, 1996 and Havelaar and Melse, 2003). Comparatively, the US Environmental Protection Agency (US EPA) sets tolerable risk level using risk of infection rather than the manifestation of the disease (Aertgeerts and Angelakis, 2003, p.190). For example for *Giardia intestinalis* infection, the US EPA sets a tolerable risk of less than 1 in 10 000 people per year (10^{-4}) risk from drinking water, which Aertgeerts and Angelakis (2003, p.190) cite Haas (1996) as describing as too low, given the rates of gastrointestinal disease in the general population.

Approaches to assessing recycled water risk

1. Epidemiological investigations
2. Qualitative risk assessment (with risk ranking)
3. Quantitative Microbial Risk Assessment

Epidemiological investigations

Most epidemiological data for waterborne disease are provided from outbreak investigations which provide valuable data for the assessment of risk. Hunter et al. (2003) comment on the ability of outbreak investigations to provide useful information regarding which failures in the water supply and distribution chain lead to the risk to public health, such as the Milwaukee *Cryptosporidium sp.* outbreak in 1993. Outbreak investigations will also provide information on non-water exposure pathways that could be related to the outbreak pathogen.

According to Hunter et al. (2003) who cite Andersson and Bohan (2001) outbreak data is somewhat limited in that it does not provide any context as to what proportion of the burden of disease has been contributed via sporadic spread from the water route. Nor is it clearly established that the factors that are responsible for the failure leading to outbreaks are the same as those for the sporadic disease occurrence (Hunter et al., 2003). Hunter (2000) refers to investigations of epidemiological investigations of water-related disease being biased by prior knowledge of cases and controls concerning the cause of the outbreak.

The most common types of epidemiological study that have been used in risk assessments of waterborne disease are indicated in Table 4A-2 below:

Table 4A-2. Common types of epidemiological study used in risk assessments of waterborne disease

Study Type	Description	Advantages and Disadvantages
Ecological study	Determining relationship between disease and risk factors by comparing the incidence of disease in different communities with varying exposure to risk factors.	Relatively inexpensive to carry out providing that disease rates and data on risk factors are already available. Because data is only available for groups, it is not known whether individuals with disease are exposed to risk factor. Good for generating hypotheses, but cannot be used for epidemiological proof.
Time series study	Determining relationship between disease incidence in a population and variation in a risk factor over time.	A type of ecological study and subject to the same advantages and disadvantages.
Case-control study	Determining relationship between disease and risk factors by comparing the incidence of disease in exposed individuals to matched controls.	Relatively inexpensive to carry out. Generates data on individuals exposed to the risk factors in comparison with health individuals, but often relies upon retrospective estimates of exposure that may be inaccurate or biased.
Cohort Study	Comparing rate of disease in two, or more, populations with different levels of exposure over a specific period of time on randomly selected individuals.	Relatively expensive to carry out. Generates data on the risk factors in the populations by comparing groups of randomly selected individuals
Intervention (RCT) study	Comparing the rates of disease in two or more groups (cohorts) of randomly chosen individuals after intervening to change the level of exposure.	The gold standard for epidemiological proof, but can be time consuming and very expensive to carry out.

Hunter et al., 2003, p.83.

There have been limited epidemiological analyses of recycled water. Hunter et al., (2003) cite Isaacson and Sayed (1988) who conducted a population-based study on the consumption of recycled water in Namibia and did not observe an increased risk of gastrointestinal illness. The Namibia direct potable recycled water scheme is one of the most widely studied recycled water schemes in the world today.

Qualitative risk assessment

The target value of 10^{-6} DALYs that has been set in The National Water Quality Management Strategy – Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) (NRMMC-EPHC-NHMRC, 2006) is a value that is regarded if exceeded as a potentially unacceptable risk. The extent of exceedance of DALYs or guideline values (in the case of chemicals) for recycled water and the frequency of those exceedances can be used to estimate risk as outlined in the following tables that were adapted from the Australian Guidelines for Water Recycling Augmentation of Drinking Water Supplies (NRMMC-EPHC-NHMRC, 2008):

Table 4.5 Qualitative measures of likelihood

Level	Descriptor	Example description
A	Rare	May occur only in exceptional circumstances; may occur once in 100 years
B	Unlikely	Could occur within 20 years or in unusual circumstances
C	Possible	Might occur or should be expected to occur within a 5 to 10 year period
D	Likely	Will probably occur within a 1 to 5 year period
E	Almost certain	Is expected to occur, with a probability of multiple occurrences within a year

Table 4.6 Qualitative measures of consequence or impact

Level	Descriptor	Example description
1	Insignificant	Insignificant impact or not detectable
2	Minor	Health — Minor impact for small population Environment — Potentially harmful to local ecosystem with local impacts contained to site.
3	Moderate	Health — Minor impact for large population. Environment — Potentially harmful to regional ecosystem with local impacts primarily contained to on-site.
4	Major	Health — Major impact for small population Environment — Potentially lethal to local ecosystem. Predominantly local, but potential for off-site impacts.
5	Catastrophic	Health — Major impact for large population. Environment — Potentially lethal to regional ecosystem or threatened species. Widespread on-site and off-site impacts.

Table 4.7 Qualitative risk estimation

Likelihood	Consequences				
	1 — Insignificant	2 — Minor	3 — Moderate	4 — Major	5 — Catastrophic
A — Rare	Low	Low	Low	High	High
B — Unlikely	Low	Low	Moderate	High	Very high
C — Possible	Low	Moderate	High	Very high	Very high
D — Likely	Low	Moderate	High	Very high	Very high
E — Almost certain	Low	Moderate	High	Very high	Very high

Quantitative Microbial Risk Assessment

Quantitative Microbial Risk Assessment (QMRA) is the application of risk assessment principles to estimate the outcomes from planned or actual exposure to pathogenic microorganisms (Haas et al., 1999). Both Phase I and Phase II of The National Water Quality Management Strategy – Australian Guidelines for Water Recycling (NRMMC-EPHC-NHMRC, 2006 and 2008) indicate QMRA as the preferred method for assessing microbial risks associated with recycled water supplies. The application of this method is detailed in Section 4.6.

Appendix 4B. Screening Health Risk Assessment Methodology

Trace chemical contaminants

A new methodology has been developed for these chemicals as they apply in recycled water based on similar methodologies used for the assessment of pesticides, pharmaceuticals etc.

The potential health risks of trace chemical contaminants will be evaluated using a health risk assessment methodology and is based on the calculation of a risk quotient (RQ). The RQ is the ratio between the observed concentration and the calculated benchmark value. All benchmark values for the calculation of RQ are health based, systematically defined, consistent for a given contaminant, scientifically based, simple to use and clear to interpret.

A three-tiered approach is proposed in the methodology. As the benchmark value is different for each one of the levels of assessment, the approach will be as indicated below:

- Tier 1: Regulated contaminants: the RQ will be calculated between the observed concentration in recycled water and the maximum contaminant level.
- Tier 2: Unregulated contaminants with toxicity information: the RQ will be calculated between the observed concentration and the Health Base Level.
- Tier 3: Unregulated contaminant without toxicity information: the RQ will be calculated between the observed concentration and the benchmark value calculated based on the Threshold of Toxicological Concern (TTC).

The TTC is a 'concept that refers to the establishment of a human exposure threshold value for all chemicals, below which there would be no appreciable risk to health' (Rodriguez et al. 2007).

Three-tiered approach

The proposed three-tiered approach is a preliminary health risk assessment (HRA) methodology for the identification and evaluation of contaminants that may pose an increased risk to human health. A decision tree for the allocation of chemicals to their respective tier is based on two steps. The first step is to identify compounds with an established drinking water guideline or standard value, which are allocated to 'Tier 1'. The need to develop additional tiers arises because there are no current guidelines for many of the chemicals that can be detected in recycled water. Therefore, the second step is to identify chemicals without drinking water standards, but for which toxicity information is available – those chemicals are allocated to 'Tier 2'. Those chemicals for which toxicity information is not available are allocated to 'Tier 3'. This classification system is summarised in Figure 4B-1.

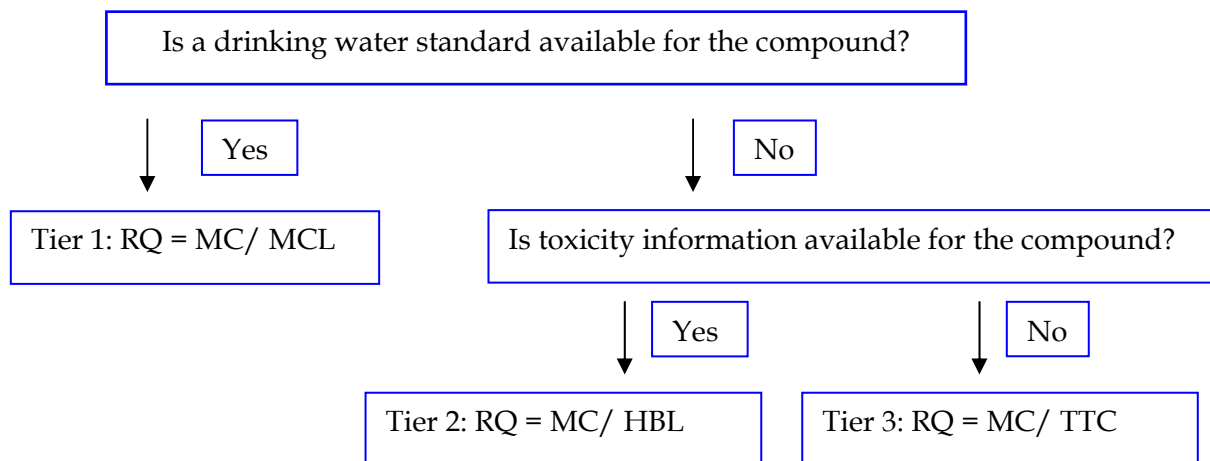


Figure 4B-1. Flowchart indicating the three-tiered approach. RO, risk quotient; MC, measured concentration; MCL, maximum contaminant level; HBL, health based level; TTC, threshold of toxicological concern.

Priority for the HRA has been given to chronic toxicological studies, because ingestion of low concentrations of chemicals throughout the consumer's lifetime is the most plausible exposure scenario. The measured concentrations of each specific chemical within each tier are used to determine their associated health risk by calculating the *risk quotient (RQ)*. Risk quotients are the most widely used method of assessing risk, in which the measured (exposure) concentration of a given chemical is compared to a benchmark value (non-effect) concentration. The benchmark value is derived differently for each one of the levels of assessment as indicated in Figure 4B-1. Contaminants identified as potentially 'problematic' in this preliminary assessment would then be subjected to more comprehensive risk assessments. The emphasis of the tiered approach is to provide a practical framework for the evaluation of the suite of contaminants in recycled water.

Tier 1: Regulated Compounds

Traditionally water quality has been evaluated by comparing the measured concentration of a particular substance with the respective benchmark value based on drinking water standards or guidelines. The chemicals with regulations constitute the first tier in the proposed three-tier approach.

Because different states or nations regulate different chemicals, or may even assign their own standard values for the same chemical, it is necessary to define the guidelines pertinent to a specific context. Therefore in the Western Australia context, maximum contaminant levels (MCL) will be taken from the following drinking water guidelines, in order of priority: The Australian Drinking Water Guidelines (ADWG) (NHMRC and ARMCANZ, 2004), Guidelines for Drinking Water Quality (WHO, 2003), the US Environmental Protection Agency (US EPA) Drinking Water Standards (US EPA, 2006) and the California Department of Health Services (DHS) California Code of Regulations (Title 22) (California Office of Administrative Law, 2006).

Some contaminants may have more than one MCL in the same guideline. It is proposed to use the lower value to calculate the RQ to account for both cancer and non-cancer related effects. In all cases, the latest reported MCL from the selected guideline (following the stated

priority) is recommended because it includes the evaluation of most recent toxicological and epidemiological studies.

Tier 2: Unregulated compounds with toxicity values

Tier 2 comprises those chemicals with toxicity information, but for which no regulated standards in drinking water have been set. The methods for comparing measured concentrations of contaminants and toxicity values have been used previously (Toccalino et al., 2003).

A critical step in assigning compounds within Tier 2 is the carcinogenic classification of contaminants as presented in Figure 4B-2. This is because the allocation of a chemical as carcinogenic or not defines the further procedures to calculate the health based level (HBL). In most situations, the International Agency for Research on Cancer (IARC) and the US EPA classifications are consistent in the cancer classification of a given contaminant. However, if differences occur it is recommended to use the IARC classification, which more closely aligns with Australian methods for the hazard identification of carcinogens (enHealth, 2002). The IARC cancer classification and the number of chemicals in each group are presented in Table 4B-1.

Table 4B-1. IARC Cancer Classification and number of chemicals per group

Group	Description	Number of chemicals
1	Carcinogenic to humans	99
2A	Probably carcinogenic to humans	66
2B	Possibly carcinogenic to humans	246
3	Not classifiable as to its carcinogenicity in humans	516
4	Probably not carcinogenic to humans	1

Non-carcinogenic compounds have been defined as contaminants assigned to IARC Group 4. Compounds not classifiable as carcinogenic (Group 3) in the IARC classification have by default been treated as non-carcinogens. For non-carcinogenic compounds without guidance values, but for which toxicity values exist, such as Tolerable Daily Intake (TDI), Acceptable Daily Intake (ADI) or a Reference Dose (RfD), the values will be used to calculate the guidance value. The algorithm and equations to calculate the guidance values or lifetime health advisory (LHA) are presented in Figure 4B-2. The terms ADI, TDI or RfD have similar definitions and are estimates, with an uncertainty value, of the daily exposure likely to be without deleterious health effects in the human population (including those with possible sensitivities) over an individual's lifetime (Toccalino et al., 2003). For compounds classified as 'possible carcinogens' (IARC, Group 2B), the HBL will be calculated by using its LHA with an additional uncertainty factor of 10.

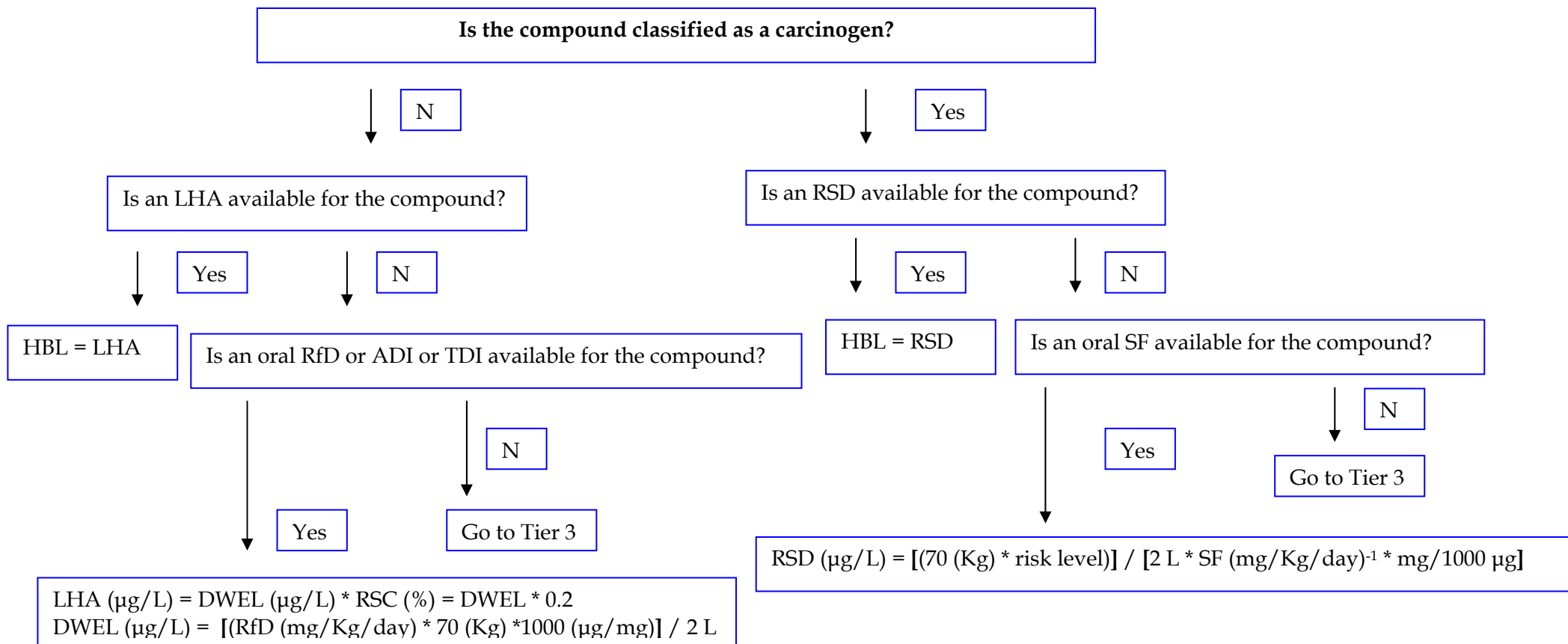


Figure 4B-2. Flowchart indicating the decision tree for the development of Tier 2 (HBL). LHA, lifetime health advisory; HBL, health based level; RfD, reference dose; ADI, acceptable daily intake; TDI, tolerable daily intake; DWEL, drinking water equivalent level; RSC, relative source contribution. 70= Kilograms body weight; RSC=assumed to be 20%; 2 L=2 litres water consumed per day

Carcinogenic compounds are defined as contaminants assigned to Group 1 or Group 2A by IARC. For carcinogens without a guideline dose or a risk specific dose (RSD), but with a Slope Factor (SF) value, the latter is used to calculate the RSD. The SF value reflects the cancer potency estimated for a compound as derived from the slope of a dose-response data curve extrapolated to zero using an appropriate mathematical model. The HBL concentration range corresponds to an acceptable cancer risk range between one-in-a-million (lower limit) to one-in-a-thousand (upper limit).

Risk assessments need to incorporate conservative assumptions about body weight, drinking habits, and lifespan. The calculations in Tier 2 assume that, on average, two litres of water per day are consumed by an individual of 70 kilograms of body weight, and that 20% of the total exposure of the compound occurs through drinking water. Given that some compounds may have both carcinogenic and non-carcinogenic effects, the lowest toxicity value (LHA or RSD) should be selected to estimate the RQ.

Primary sources of toxicity values are provided in datasets and documents from the World Health Organization (WHO) and Australia. As a first stage in the evaluation, the hierarchy of sources by enHealth is recommended for the selection of toxicity data. Other reliable sources may be used if no toxicity data for a given compound are available in any of the primary sources.

Tier 3: Unregulated compounds without toxicity values

In the absence of chemical-specific toxicity data, the Threshold of Toxicological Concern (TTC) is proposed as a benchmark for the RQ calculation in Tier 3. The TTC provides a method to estimate levels of long-term oral exposure below which there is likely to be very low probability of health risk. The TTC principle is based on establishing a human exposure threshold value for all chemicals with or without toxicity data available (Kroes et al., 2000). The concept – that there is a level of exposure to a given substance below which no significant risk is reasonably expected to exist – has been widely accepted, and the establishment of ADI is based on it. In practical terms, the TTC of a given contaminant is based on its similarity to structurally related groups of compounds with known toxic properties (Renwick, 2005).

Relevant applications of the TTC concept have been underway for more than a decade. In 1995 the US Food and Drug Administration (FDA) applied the same TTC concept as the 'Threshold of Regulation' for indirect food additives (Renwick, 2005). In 1996, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) applied the TTC concept to the evaluation of 1259 flavouring substances (Renwick, 2004). In 2002, the International Life Sciences Institute (ILSI)-Europe expert group examined the TTC principle for its applicability in food safety evaluation, and by 2005 had developed a systematic approach for the assessment of chemicals present at low levels in the diet (Kroes et al., 2000; Barlow, 2005). In 2004, a TTC approach for the safety evaluation of natural flavour complexes was published (Smith et al., 2004); and in the following year, two papers using the TTC were published: one for the application to pharmaceutical impurities (Dolan et al., 2005); the other for the application to ingredients in personal and household care products (Blackburn et al., 2005).

Figure 4B-3 illustrates the application of the TTC approach to benchmark values for both cancer and non-cancer endpoints in water using the decision tree described by Kroes et al.

(2004). The decision tree incorporates a series of increasing TTC values into a step-wise approach. As for Tier 2, the first step is the classification of potentially genotoxic carcinogens based on the presence or absence of structural alerts for genotoxicity/carcinogenicity. Compounds without structural alerts for genotoxicity/carcinogenicity are allocated to one of the three 'Cramer Classes' (Cramer et al., 1978), a system based upon thirty-three questions relating to chemical structure. The RQ is then calculated by comparing the measured concentration with a TTC-derived value, using data from chronic and sub-chronic toxicity studies on compounds in the same structural class (Figure 4B-3). The TTC values are derived by the application of a 100-fold uncertainty factor to the 5th percentile of the distribution of no-observable effects levels (NOEL) from a large group of tested chemicals sharing similar structural characteristics (Renwick, 2004; Kroes et al., 2005). This approach tends to be conservative, because it is based on the assumption that the NOEL for a given chemical will not lie significantly below the 5th percentile NOEL for compounds with the same structural class.

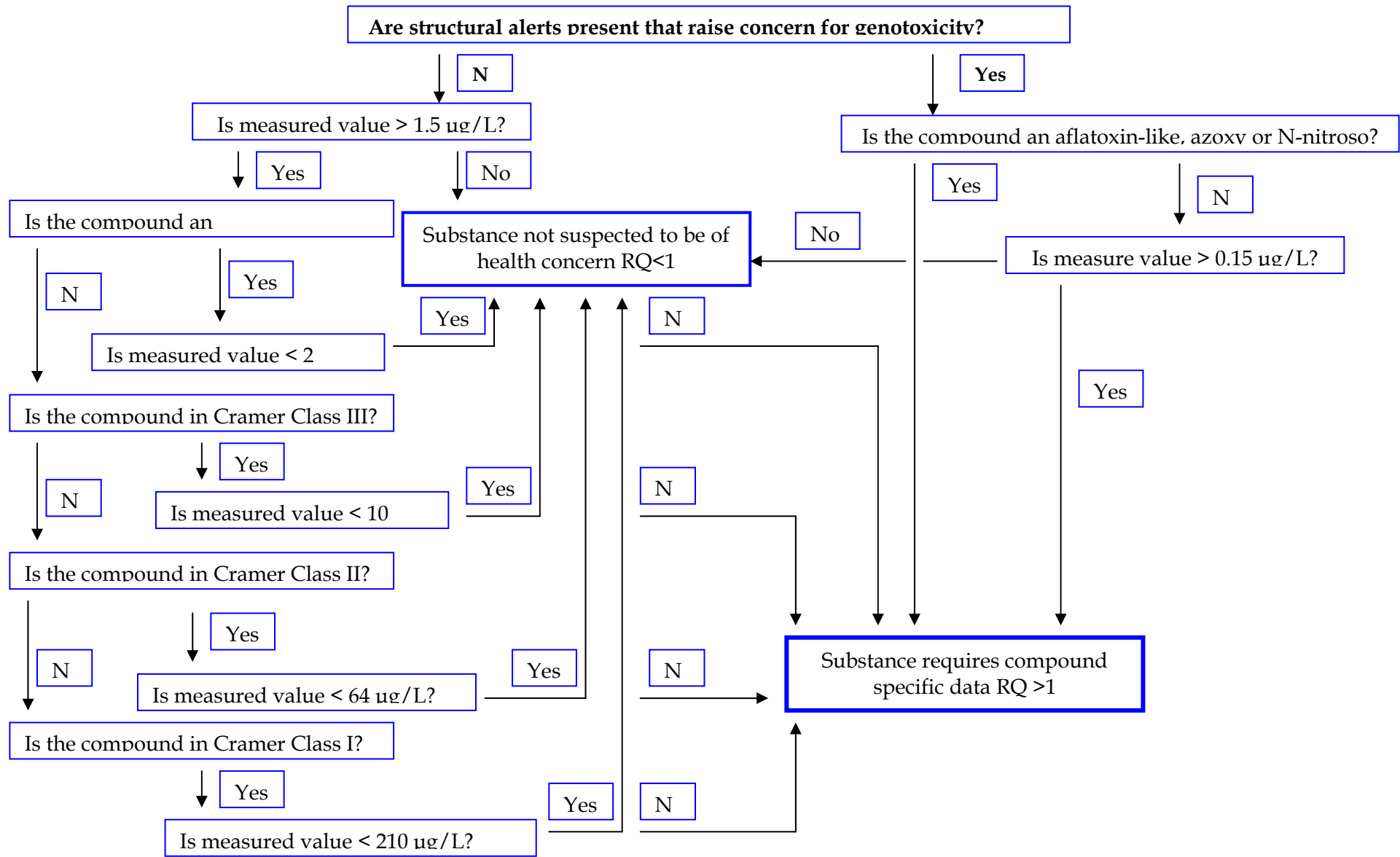


Figure 4B-3. Flowchart indicating the decision tree for the development of Tier 3 (TTC) [RQ, risk quotient; µg/L, micrograms per litre]

Calculation and interpretation of the risk quotient

For the calculation of the RQ, the measured concentration is compared with the corresponding published or calculated benchmark value. Measured concentration used in the calculation could be the mean, median or the maximum concentration for each contaminant. Given that values below analytical limits of reporting (LOR) are expected for a large number of chemicals, it is necessary to implement a systematic approach for the evaluation of non-detections depending upon the proportion of data below the LOR. For non-detections, the exact concentration of the chemical is unknown but will lie between the bounds of zero and the LOR. If less than 15% of data are below the LOR, it is recommended replacing the LOR by half of its value (LOR/2). If between 15% and 50% (inclusive) of data are below the LOR, Cohen's method is recommended to calculate the corresponding LOR value (US EPA, 2003). If between 50% and 90% (inclusive) of the data are below LOR, the test of proportions should be used.

The mean-detected and median-detected concentrations (which exclude not detected concentrations) could also be used to calculate the RQ. However, the use of this approach may increase the probability of type I error (that is, of a false positive measurement) and can lead to the implementation of expensive monitoring of chemicals that may pose a low threat to humans (Ritter et al., 2002).

For each analyte, the frequency and proportion of RQs above 1 and below 1 is calculated. A RQ below 1 indicates that no adverse effects are anticipated and therefore no detailed risk assessment of those compounds is required. A RQ equal to or above 1 in the preliminary risk assessment indicates that a specific monitoring program is required, and that further analyses on the fate, transport, removal and physico-chemical properties of the contaminant are necessary. However, a RQ above 1 does *not* necessarily imply that the exposed population will be adversely affected because of the following factors: (1) the conservative nature of the models used to derive benchmark values; (2) the potential for overestimation in the life-time exposure assumption, when in reality the elevated exposure may only occur for a fraction of the life span or the RQ could be above 1 only for certain periods; and (3) the additional treatment barriers that are used for the recycled water before its entry into supplementary drinking water sources.

If the LOR is close to the benchmark value, and the calculated RQ is close to 1, the uncertainty increases. In such situations, it is recommended that a precautionary approach be used, in which chemicals with RQs between 0.8 and 1 should be considered as candidates for specific monitoring and assessment. The validity of the calculated RQ requires rigorous data on both measured concentrations and toxicity in order to adequately characterise potential risks of contaminants to human health. Emphasis then needs to be placed on the state of quality assurance/quality control of the analytical methods, and on the rigour and applicability of any toxicological studies used for the derivation of the benchmark values. A critical appraisal of the quality of the studies used to derive the denominators of the RQ needs to be included in any assessments.

Table 4B-2 illustrates the application of the tiered approach for the establishment of benchmark values for seven potential contaminants in water.

Table 4B-2. Calculation of benchmark values for selected contaminants in water using the three-tiered health risk assessment approach and calculation of RQs using hypothetical measured concentrations in water.

CAS Number	Chemical	Tier	Benchmark value (µg/L)	Source	IARC*	Measured concentration (µg/L)	Risk Quotient
127-18-4	Tetrachloroethylene (PCE)	1	50	MCL= 0.05 mg/L (NHMRC and ARMCANZ, 2004)	2A	7.2	0.144
738-70-5	Trimethoprim	2	140	ADI =0.02 mg/Kg/day (Therapeutic Goods Administration, 2008)	NE**	0.4	0.003
85-68-7	Butyl benzyl phthalate	3	210	Cramer Class I (Cramer et al., 1978)	3	4.6	0.022
83463-62-1	Bromochloroacetonitrile (BCAN)	3	10.5	Cramer Class III (Cramer et al., 1978)	3	0.71	0.068
298-46-4	Carbamazepine	3	10.5	Cramer Class III (Cramer et al., 1978)	NE	0.87	0.082
50-18-0	Cyclophosphamide	3	1.5	Structural alerts that raise concerns for Genotoxicity	1	0.011	0.007
134-62-3	N,N-diethyl-m-toluamide (DEET)	3	10.5	Cramer Class III (Cramer et al., 1978)	NE	0.06	0.006

CAS, chemical abstract services; IARC, International Agency for Research on Cancer; MCL, maximum contaminant level; ADI, acceptable daily intake.

* IARC monographs September 2006. **NE: No evaluated to date.

For non-carcinogenic chemicals in Tier 3, the assignment of the toxicity level was based upon the decision tree as reported by Cramer et al. (1978). Each chemical was allocated to one of three structural classes and the benchmark value was assigned as reported in Table 4B-3. RQs were calculated using hypothetical measured concentrations in water.

Table 4B-3. Distribution of chemicals based on the Munro et al. (1996) database with the corresponding fifth percentile NOEL, RfD and LHA for each structural class.

Cramer structural class	Toxicity	N*	Structural feature	5 th Percentile of the NOEL (mg/Kg/d)	RfD (mg/Kg/d)	LHA (µg/L)
I	Low	137	Simple (e.g. propylene glycol, mannitol)	3.0	0.03	210
II	Medium	28	Less simple than class I but not suggestive of toxicity (e.g. β Carotene, diallyl phthalate)	0.91	0.0091	64
III	High	448	Does not permit strong initial presumption of safety or have reactive functional groups (e.g. chlorobenzene, acetonitrile, 2,4-dinitrotoluene)	0.15	0.0015	10.5
Other*	Neurotoxicity	31		0.03	0.0003	2.1
All chemicals		613***	Includes both genotoxic and non-genotoxic compounds	0.02143	0.0002143	1.5

NOEL, No observable effects levels; RfD, Reference dose; LHA, Lifetime health advisory; N*, Number of chemicals in the structural class category; **, Neurotoxicity endpoint from Kroes et al. (2000); ***, Total number based on Munro et al. (1996); RfD = 5th Percentile of NOEL /100; LHA (µg/L) = [(RfD (mg/Kg/d) * 70(Kg) * 1000 (µg/mg)) / 2 L] *0.2.

Appendix 4C. Complete List of Chemicals Tested for in Subiaco Wastewater

CAS = Chemical Abstracts Service

CAS	Pesticides (ug/L)	CAS	Pesticides (ug/L)
309-00-2	Aldrin	1912-24-9	Atrazine
57-74-9?	Chlordane	122-34-9	Simazine
60-57-1	Dieldrin	886-50-0	Terbutryn
72-20-8	Endrin	139-40-2	Propazine
76-44-8	Heptachlor	834-12-8	Ametryn
959-98-8	Endosulfan I (alpha)	51235-04-2	Hexazinone
33213-65-9	Endosulfan II (beta)	21087-64-9	Metribuzin
1031-07-8	Endosulfan sulfate	64902-72-3	Chlorsulfuron
115-32-2	Dicofol	330-54-1	Diuron
50-29-3	DDT (total isomers)	2164-17-2	Fluometuron
72-43-5	Methoxychlor	74223-64-6	Metsulfuron-methyl
58-89-9	Lindane	25057-89-0	Bentazon
56-38-2	Parathion-ethyl	314-40-9	Bromacil
298-00-0	Parathion-methyl	5902-51-2	Terbacil
23505-41-1	Pirimiphos-ethyl	94-75-7	2,4-D
29232-93-7	Azinphos-methyl	1702-17-6	Clopyralid
60-51-5	Dimethoate	1918-00-9	Dicamba
122-14-5	Fenitrothion	94-74-6	MCPA
121-75-5	Malathion	7085-19-0	Mecoprop
62-73-7	Dichlorvos	93-72-1	Fenoprop
563-12-2	Ethion	52756-25-9	Flamprop-methyl
950-37-8	Methidathion	1918-02-1	Picloram
4824-78-6	Bromophos-ethyl	93-76-5	2,4,5-T
470-90-6	Chlorfenvinphos	55335-06-3	Triclopyr
299-84-3	Fenchlorphos	145-73-3	Endothall
115-90-2	Fensulfothion	1194-65-6	Dichlobenil
2540-82-1	Formothion	28434-01-7	Bioresmethrin
13457-18-6	Pyrazophos	51630-58-1	Fenvalerate
35400-43-2	Sulprofos	52645-53-1	Permethrin
3383-96-8	Temephos	116-06-3	Aldicarb
22224-92-6	Fenamiphos	63-25-2	Carbaryl (Sevin)
786-19-6	Carbophenothion	1563-66-2	Carbofuran
41198-08-7	Profenofos	2032-65-7	Methiocarb
13071-79-9	Terbufos	16752-77-5	Methomyl
22248-79-9	Tetrachlorvinphos	23103-98-2	Pirimicarb

298-04-4	Disulfoton	2631-37-0	Promecarb
13194-48-4	Ethoprophos	759-94-4	EPTC
640-15-3	Thiometon	2212-67-1	Molinate
333-41-5	Diazinon	1114-71-2	Pebulate
30560-19-1	Acephate	1929-77-7	Vernolate
52-68-6	Trichlorfon	51-03-6	Piperonyl butoxide
7786-34-7	Mevinphos	298-02-2	Phorate
2921-88-2	Chlorpyrifos	55-38-9	Fenthion
5234-68-4	Carboxin	10265-92-6	Methamidophos
1897-45-6	Chlorothalonil	34014-18-1	Tebuthiuron
60168-88-4	Fenarimol	330-55-2	Linuron
60207-90-1	Propiconazole	18691-97-9	Methabenzthiazuron
43121-43-3	Triadimefon	94-81-5	MCPB
10605-21-7	Carbendazim	52918-63-5	Deltamethrin
23564-05-8	Thiophanate-methyl	52315-07-8	Cypermethrin
40487-42-1	Pendimethalin	82657-04-3	Bifenthrin
82-68-8	Quintozene	204-043-8	Propoxur (Baygon)
51338-27-3	Diclofop-methyl	120068-37-3	Fipronil
957-51-7	Diphenamid	94-82-6	2,4-DB acid
27314-13-2	Norflurazon	133-06-2	Captan
15299-99-7	Napropamide	29232-93-7	Pirimiphos-methyl
1861-32-1	Propanil	15972-60-8	Alachlor
23950-58-5	Propyzamide	5598-13-0	Chlorpyrifos-methyl
19044-88-3	Oryzalin	919-86-8	Demeton-S-methyl
1582-09-8	Trifluralin	72-55-9	p,p-DDE
2312-35-8	Propargite	36734-19-7	Iprodione
1918-16-7	Propachlor	68359-37-5	Cyfluthrin
51218-45-2	Metolachlor	10285-06-9	tau-Fluvalinate

CAS	Metlas (mg/L)	CAS	Metlas (mg/L)
7429-90-5	Aluminium	7782-49-2	Selenium
7440-36-0	Antimony	7440-22-4	Silver
7440-38-2	Arsenic	7440-28-0	Thallium
7440-39-3	Barium	7440-61-1	Uranium
7440-41-7	Beryllium	7439-89-6	Iron
7440-42-8	Boron	7440-48-4	Cobalt
7440-43-9	Cadmium	7439-93-2	Lithium
7440-43-9	Chromium (Total)	7440-24-6	Strontium
7440-50-8	Copper	7440-62-2	Vanadium
7439-92-1	Lead	7440-66-6	Zinc

7439-96-5	Manganese	7440-31-5	Tin
7439-97-6	Mercury	7440-21-3	Silicon
7439-98-7	Molybdenum	7440-20-2	Scandium
7440-02-0	Nickel	7439-95-4	Magnesium

CAS	PCBs (pg/L)	CAS	PCBs (pg/L)
32598-13-3	PCB 77	57465-28-8	PCB 126
70362-50-4	PCB 81	38380-08-4	PCB 156
32598-14-4	PCB 105	69782-90-7	PCB 157
74472-37-0	PCB 114	52663-72-6	PCB 167
31508-00-6	PCB 118	32774-16-6	PCB 169
65510-44-3	PCB 123	39635-31-9	PCB 189

CAS	Dioxins and Furans	CAS	Dioxins and Furans
1746-01-6	TetraCDD(2,3,7,8-TCDD)	57117-41-7	PentaCDF (2,3,4,7,8-PeCDF)
40321-76-4	PentaCDD (1,2,3,7,8-PeCDD)	70648-26-9	HexaCDF (1,2,3,4,7,8-HxCDF)
39227-28-6	HexaCDD (1,2,3,4,7,8-HxCDD)	57117-44-9	HexaCDF (1,2,3,6,7,8-HxCDF)
57653-85-7	HexaCDD (1,2,3,6,7,8-HxCDD)	60851-34-5	HexaCDF (2,3,4,6,7,8-HxCDF)
19408-74-3	HexaCDD (1,2,3,7,8,9-HxCDD)	72918-21-9	HexaCDF (1,2,3,7,8,9-HxCDF)
35822-46-9	HeptaCDD (1,2,3,4,6,7,8-HpCDD)	67562-39-4	HeptaCDF (1,2,3,4,6,7,8-HpCDF)
3268-87-9	Octadioxin (OCDD)	55673-89-7	HeptaCDF (1,2,3,4,7,8,9-HpCDF)
51207-31-9	TetraCDF (2,3,7,8-tetraCDF)	39001-02-0	Octafuran (OCDF)
57117-31-4	PentaCDF (1,2,3,7,8-PeCDF)		

CAS	Radiactivity	CAS	Radiactivity
	Gross alpha		Gross beta

CAS	VOCs (ug/L)	CAS	VOCs (ug/L)
71-43-2	Benzene	87-61-6	1,2,3-Trichlorobenzene
56-23-5	Carbon tetrachloride	96-18-4	1,2,3-Trichloropropane
108-90-7	Chlorobenzene	95-63-6	1,2,4-trimethylbenzene
95-50-1	1,2-dichlorobenzene	108-67-8	1,3,5-trimethylbenzene
106-46-7	1,4-dichlorobenzene	541-73-1	1,3-dichlorobenzene
75-34-3	1,1-dichloroethane	142-28-9	1,3-Dichloropropane
107-06-2	1,2-dichloroethane	594-207	2,2-Dichloropropane
75-35-4	1,1-dichloroethene	95-49-8	2-Chlorotoluene
156-59-2	1,2-dichloroethene, cis	106-43-4	4-Chlorotoluene
156-60-5	1,2-dichloroethene, trans	75-00-3	Chloroethane
75-09-2	Dichloromethane	74-87-3	Chloromethane
100-41-4	Ethylbenzene	75-71-8	Dichlorodifluoromethane

87-68-3	Hexachlorobutadiene	98-82-8	Isopropyl benzene
100-42-5	Styrene (vinylbenzene)	104-51-8	n-butyl benzene
79-34-5	1,1,2,2-Tetrachloroethane	103-65-1	n-propyl benzene
127-18-4	Tetrachloroethene	99-87-6	4-Isopropyltoluene
108-88-3	Toluene	98-06-6	tert butyl benzene
71-55-6	1,1,1-Trichloroethane	108-86-1	Bromobenzene
79-00-5	1,1,2-Trichloroethane	91-20-3	Naphthalene
120-82-1	1,2,4-Trichlorobenzene	75-01-4	Vinyl Chloride (chloroethene)
79-01-6	Trichloroethene	74-83-9	Bromomethane
75-69-4	Trichlorofluoromethane (Freon 11)	563-58-6	1,1-dichloropropene
76-13-1	Freon 113	108-38-3	m-xylene
106-93-4	Ethylene Dibromide	106-42-3	p-xylene
96-12-8	1,2-dibromo-3-chloropropane	95-47-6	o-xylene
78-87-5	1,2-Dichloropropane	563-54-2	1,2-dichloropropene
542-75-6	1,3-Dichloropropene	28729-54-6	2-propyltoluene
630-20-6	1,1,1,2-Tetrachloroethane	75-15-0	Carbon disulfide

CAS	DBPs (ug/L)	CAS	DBPs (ug/L)
67-66-3	Chloroform	76-06-2	Chloropicrin
75-27-4	Bromodichloromethane	15541-45-4	Bromate
124-48-1	Chlorodibromomethane	7758-19-2	Chlorite
75-25-2	Bromoform	7775--09-9	Chlorate
74-95-3	Dibromomethane	3252-43-5	Dibromoacetonitrile
74-97-5	Bromochloromethane	3018-12-0	Dichloroacetonitrile
79-11-8	Chloroacetic acid	107-14-2	Monochloroacetonitrile
79-08-3	Bromoacetic acid	545-06-2	Trichloroacetonitrile
79-43-6	Dichloroacetic acid	590-17-0	Bromoacetonitrile
650-51-1	Trichloroacetic acid	115-17-3	Tribromoacetaldehyde
5589-96-8	Bromochloroacetic acid	04316-11-6	Dibromochloroacetaldehyde
631-64-1	Dibromoacetic acid	78-95-5	Chloroacetone
71133-14-7	Dichlorobromoacetic acid	513-88-2	1,1-dichloropropanone
5278-95-5	Dibromochloroacetic acid	534-07-6	1,3-dichloropropanone
75-96-7	Tribromoacetic acid	921-03-9	1,1,3-trichloropropanone

CAS	Nitroso DBP (ng/L)	CAS	Nitroso DBP (ng/L)
62-75-9	N-Nitrosodimethylamine (NDMA)	100-75-4	N-nitrosopiperidine (NPIP)
10595-95-6	N-nitrosoethylmethylamine (NEMA)	930-55-2	N-nitrosopyrrolidine (NPYR)
55-18-5	N-nitrosodiethylamine (NDEA)	59-89-2	N-nitrosomorpholine (NMOR)
621-64-7	N-nitrosodi-n-propylamine (NDPA)	86-30-6	N-nitroso-diphenylamine
924-16-3	N-nitrosodi-n-butylamine (NDBA)		

CAS	PAHs	CAS	PAHs
83-32-9	Acenaphthene (acenaphthene)	218-01-9	Chrysene
208-96-8	Acenaphthylene (acenaphthylene)	53-70-3	Dibenzo-ah-anthracene
65996-91-0	Anthracene (oil)	206-44-0	Fluoranthene
50-32-8	Benzo-a-pyrene (PAH)	86-73-7	Fluorene
56-55-3	Benzo-a-anthracene	193-39-5	Indeno (1,2,3-cd) pyrene
205-99-2	Benzo-b-fluoranthene	91-58-7	2-chloronaphthalene
191-24-2	Benzo-ghi-perylene	85-01-8	Phenanthrene
207-08-9	Benzo-k-fluoranthene	129-00-0	Pyrene
CAS	Hormones (ng/L)	CAS	Hormones (ng/L)
50-27-1	Estriol	50-28-2	17-beta estradiol
57-63-6	Ethinyl estradiol	53-16-7	Oestrone
CAS	Chelating Agents (ug/L)	CAS	Chelating Agents (ug/L)
60-00-4	EDTA	140-01-2	DTPA
139-13-9	NTA		PDTA
CAS	Other (ug/L)	CAS	Other (ug/L)
107-02-8	Acrolein		hexachlorocyclobutadiene
107-13-1	Acrylonitrile	77-47-4	hexachlorocyclopentadiene
7005-72-3	4-chlorophenoxybenzene	103-33-3	azobenzene
123-91-1	1,4-Dioxane	101-55-3	4-bromophenylphenylether
1634-04-4	Methyl-Tertiary Butyl Ether	118-74-1	hexachlorobenzene
103-33-3	azobenzene	86-74-8	carbazole
101-55-3	bromophenoxybenzene	85-68-7	butylbenzylphthalate
118-74-1	hexachlorobenzene	117-81-7	dioctylphthalate
86-74-8	carbazole	85-68-7	butylbenzylphthalate
CAS	Pharmaceuticals (ng/L)	CAS	Pharmaceuticals (ng/L)
882-09-7	clofibrac acid	81103-11-9	clarithromycin
41859-67-0	bezafibrate	114-07-8	erythromycin H2O
25812-30-0	gemfibrozil	80214-83-1	roxithromycin
134523-00-5	Atorvastatin (Lipitor)	723-46-6	sulfamethoxazole
298-46-4	carbamazepine	21462-39-5	clindamycin
57-41-0	Phenytoin (Dilantin)	443-48-1	metronidazol
15307-86-5	diclofenac (sodium salt)	738-70-5.	trimethoprim
15687-27-1	ibuprofen	50-18-0	cyclophosphamide
50-78-2	acetylsalicylic	3778-73-2	ifosfamide

69-72-7	salicylic acid	81-81-2	warfarin
53-86-1	indometacine	54910-89-3	fluoxetine (prozac)
22071-15-4	ketoprofen	439-14-5	Diazepam
22204-53-1	naproxen	57-27-2	morphine
103-90-2	Acetaminophen	1401-69-0	tylosin
83905-01-5	azithromycin	26787-78-0	amoxicillin

CAS	Iodinated contrast media (ug/L)	CAS	Iodinated contrast media (ug/L)
62883-00-5	iopamidol	606-17-7	iodipamide
2276-90-6	iotalamic acid	66108-95-0	iohexol
117-96-4.	amidotrizoic / Diatrizoic acid	73334-07-3	iopromide
59017-64-0	ioxaglic acid	78649-41-9	iomeprol