WATER SERVICES ASSOCIATION
of Australia

Health Risk Assessment of Fire Fighting from Recycled Water Mains

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Prepared by:

Water Futures

32 Sirius Street, Dundas Valley NSW 2117

for

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WATER SERVICES ASSOCIATION
of Australia

MELBOURNE OFFICE
469 LATROBE STREET, MELBOURNE 3000
VICTORIA AUSTRALIA
TEL: 03 9606 0678. FAX: 03 9606 0376
EMAIL info@wsaa.asn.au

SYDNEY OFFICE
321 PITT STREET, SYDNEY, NSW
PO BOX A812, SYDNEY SOUTH, NSW, 1235
TEL: 02 9283 0725. FAX: 02 9283 0799
EMAIL: david.cox@wsaa.asn.au

INTERNET HOMEPAGE http://www.wsaa.asn.au

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Health Risk Assessment of Fire Fighting from Recycled Water Mains

***Authors*:**

Dr. Daniel Deere and **Dr. Annette Davison** of Water Futures

in conjunction with

Dr. Peter Teunis, The National Institute of Public Health, The Netherlands

Dr. David Cunliffe, Department of Human Services, South Australia

Mr Peter Donlon, Water Services Association of Australia

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Executive Summary

Background:

Appropriately treated recycled water can be used in place of potable water to reduce pressure on urban water supplies and reduce the quantities of water extracted from the environment.

Of the many appropriate uses to which treated recycled water can be applied, fire fighting is one which may at first seem trivial due to the small relative volumes likely to be used. However, fire fighting requirements define the hydraulic capacity of urban water reticulation systems making it an important consideration in recycled water system design.

It is, therefore, vital to know whether or not particular classes of recycled water can be used for particular forms of fire fighting at the project concept design and economic analysis stage.

Fire fighters need to be protected from unacceptable levels of risk when using recycled water but there are no specific guidance documents providing an assessment of the level of risk to which fire fighters are exposed.

The Water Services Association of Australia (WSAA) has responded to urgent questions raised by member utilities and health regulators relating to the risks associated with fighting fires with recycled water, by working in collaboration with independent health risk assessors and stakeholders to put together this targeted health risk assessment.

Methodology:

A review of current information and knowledge was undertaken to uncover any extant substantive documents or opinions relating to the health risks associated with the use of recycled water for fire fighting. This review involved scanning the scientific and technical literature, specific guidance, accepted practice and policy documents and calling for information from water sector and health professionals.

To support the information gathered by the review of current information and knowledge, a probabilistic quantitative microbial risk assessment was used to predict the risk profile.

Findings:

National and international guidance: Specific and explicit guidance exists endorsing the use of Australian Class A and, in some cases, Australian Class B, recycled water for fire fighting.

Alternative water sources: Comparison of recycled water quality and management requirements with the requirements and realities of alternative water sources revealed that Australian Class A, and in some cases Class B, recycled water would be expected to be as safe as, or safer than, many alternative water sources used for fire fighting, such as urban streams and private swimming pools.

Epidemiology: Reported health effects from various forms of exposure to raw, diluted and treated sewage were reviewed. Based on this evidence, Australian Class A, and in some cases Class B, recycled water would not be expected to lead to observable adverse effects when used for fire fighting. The exposures considered were:

- Bathing in sewage contaminated beaches;
- Working with recycled water in agriculture and consuming the products; and
- Occupational exposure to sewage.

Risk assessment: Quantitative microbial risk assessment revealed that health risks to fire fighters using Australian Class A, and in many cases Class B, recycled water would be below the international (WHO 2004 Guidelines for Drinking Water Quality) and national (NHMRC draft revised Australian guidelines for Use of Recycled Water) reference levels for acceptable risk based on the disease burden (disability adjusted life years) metric.

Conclusion:

Properly treated and managed Australian Class A, and in some cases Class B, recycled water is acceptably safe for fire fighting use.

1. Introduction

In an effort to achieve sustainable use of water resources a number of water utilities are pursuing alternative methods of water supply to urban developments. One such method of alternative supply is through the provision of high quality recycled water through a third pipe for non potable water uses including garden and plant watering, car washing, ornamental water use, toilet flushing and emergency fire fighting.

In developing recycled water third pipe systems, both health regulators and utilities have been approached by fire fighting organisations to assess the health risks to fire fighters in using recycled water. While some state health agencies have formally approved its use, detailed information on health risk assessment is not transparent. Therefore decision makers may be left with some uncertainty about the level of risk to fire fighters.

The issue is of some importance to water utilities as a number wish to downsize the potable supply system for Water Sensitive Urban Developments (as part of a holistic integrated water resources' management approach) and use water from the recycled water main for fire fighting. This design makes considerable sense from a cost effectiveness perspective.

The work was required to address the following:

- Review available literature (national and international) on health risk assessment of fire fighting from recycled water;
- Review any health regulatory guidance (national and international) on use of recycled water (for Class A, B, C and D) for fire fighting;
- Carry out an estimate of exposure of fire fighters to water during fire fighting or fire testing for ingestion, dermal (skin, mucous membrane – e.g. eyes) and inhalation contact;
- Carry out a health risk assessment of fire fighting with recycled water (for Class A, B, C and D) for gastrointestinal, dermal and inhalation contact for both microbial aspects and chemical aspects; and
- Carry out a comparative risk assessment with other commonly used water sources for fire fighting (e.g. household swimming pools, local storages, rivers, dams).

Aspects of fire fighting were discussed with senior members of fire fighting agencies (both metropolitan and rural) to ensure all aspects of the exposure assessment were addressed.

The work was carried out in a manner consistent with, and in support of, any work being carried out to assess fire fighting risk in the determination of the revised National Guidelines for Recycled Water use. Where possible and consistent with the National Guidelines process, the methodology considered the use of quantitative microbial and chemical risk assessment. The appropriate desirable risk level was determined in consultation with Dr. David Cunliffe who leads the health working group for the national guidelines process and who is involved at the international level on several water cycle World Health Organization working groups.

2. Guidance on fire fighting with recycled water

2.1 Domestic Guidance

2.1.1 Guidance examined

Australian national, state and territory recycled water guidelines were reviewed for all jurisdictions except Western Australia and Northern Territory for which specific guidelines do not exist.

Recycled water guidance was assessed to determine:

- Did the guidance specifically refer to fire fighting uses?
- If fire fighting uses were not specifically referenced, were there any uses permitted that would have similar exposures to fire fighting and for what classes of recycled water?
- If fire fighting was specifically referenced, what classes of recycled water were considered acceptable or unacceptable? and
- What were the water quality and system management requirements for recycled water of the classes mentioned?

Based on this assessment, a summary of the national, state and territory guidance on recycled water as it relates to fire fighting is given in Table 1.

2.1.2 Directly relevant statements in guidance

Four of the seven domestic guidelines specifically mention fire fighting and all permit the use recycled water for fire fighting, none oppose it:

- NSW (open access conditions, no class hierarchy given in this guidance which is based on California Title 22 which is equivalent to the highest class effluent where classes are given);
- Queensland (Class A+ for recycled water derived from municipal sewage treatment processes);
- Tasmania (Class A); and
- South Australia (Class A and Class B)[1].

In summary, fire fighting is an explicitly foreseen and acceptable use of the highest classes (typically described as Class A) of recycled water in the majority of domestic recycled water guidelines and in some cases this acceptable use includes Class B.

2.1.3 Indirectly relevant statements in guidance

One of the three domestic guidelines that does not specifically mention fire fighting, does in fact permit the highest class of recycled water to be used for similar purposes:

- Victorian (use in sprinkler systems).

In addition, all guidelines generally permit their highest class recycled water to be used for unrestricted uses such as:

- Ornamental water bodies;
- Municipal dust suppression;
- Passive recreation;
- Municipal irrigation; and
- Irrigation of crops to be eaten raw.

During such uses, exposures anticipated and considered acceptable are:

- Occasional accidental direct ingestion;
- Occasional accidental direct inhalation; and
- Inevitable indirect ingestion.

In summary, the exposures foreseen and considered acceptable for the highest classes of recycled water are analogous, or greater than, those foreseen during fire fighting. Fire fighting would be an acceptable use of the highest class of recycled water and, in some cases, the second-highest class.

[1] *The South Australian Class B water, requiring full secondary treatment plus disinfection, can be used for a number of uses. On the other hand, the guidelines state that "When spray irrigation is used with Class B or C recycled water additional words should be added indicating: RECYCLED WATER BEING USED – NO ACCESS WHEN SPRINKLERS IN OPERATION." (p21). This additional precaution implies that the use of Class B water needs to be more carefully controlled, such as with fire fighters using it being made aware of any additional precautions that are recommended.

2.1.4 Requirements of recycled water acceptable for fire fighting

The highest classes of recycled water are described in detail in the guidance documents themselves. These documents should be referred to in order to appreciate the full range of water quality and management requirements. A summary of the key requirements is provided in Table 2.

In contemporary guidance, many jurisdictions are advocating the use of a risk management system in their recycled water guidelines[1]. Therefore, water quality targets are being supported by barrier performance requirements, i.e. quality assurance and risk management.

There are some differences between terminology and requirements between guidelines. Therefore, for the purposes of this study, the most recent guidance finalised was considered the standard. As a result, the Victorian guidance will be considered to provide the default definition of "Australian" Class A and B recycled water when they are referred to in the general sense in this report.

The Victorian guidance has been selected since it is the most recent and is no less stringent than any other guidance and would, therefore, be considered the current standard of duty for those providing Class A or B recycled water acceptable for fire fighting use.

2.2 International Guidance

2.2.1 Guidance examined

An internet search was conducted to review international guidance on fire fighting and recycled water with the results of the downloads from this search presented in Table 3.

2.2.2 Directly relevant statements in guidance

The most substantive international guidance on the use of recycled water that specifically permitted its use in fire fighting is that from California (the "Title 22" process).

2.2.3 Indirectly relevant statements in guidance

Singapore has recently adopted its NEWater approach to reclaiming sewage effluent. There was no specific mention of fire fighting but the use of NEWater in fire sprinklers was permitted.

2.3 Recommendation

- Based on existing domestic and international guidance, the highest class of recycled water envisaged in each jurisdiction, (for ease of reference referred to as "Australian Class A"), can reasonably be permitted for fire fighting use; and
- For the same reasons, Australian Class B recycled water may be acceptable for fire fighting provided that this use, or uses leading to equivalent levels of exposure to the recycled water, are explicit intended uses of the scheme.

Table 1. Summary of domestic guidance in relation to recycled water and specifically in relation to fire fighting.

Jurisdiction	Lead Agency	Guidance	Fire-fighting ?	Implications
ACT (1999)	Urban Services	ACT Wastewater Reuse For Irrigation Environment Protection Policy	No	Does include some information on *uncontrolled public access* uses i.e. municipal irrigation, dust suppression, ornamental water bodies.
NSW (1993)	NSW Recycled Water Co-ordination Committee (RWCC) (a NSW Government Interdepartmental Committee)	NSW Guidelines For Urban And Residential Use Of Recycled Water	Yes	Sets out guideline values for "open access" use of recycled water (p5-6). Water meeting these guidelines is specifically stated (p10) as being suitable for: • Residential garden irrigation; • Toilet flushing; • Car washing and similar outdoor uses (e.g. washing paths and walls); • Fire fighting; • Water bodies for passive recreation activities not involving water contact; and • Ornamental water bodies.
National (2000)	ARMCANZ/ ANZECC/ NHMRC	National Water Quality Management Strategy #14, Guidelines for Sewerage Systems: Use of Recycled Water	No	Only industrial use is mentioned and where open systems might allow a degree of contact, effluent should have secondary treatment followed by tertiary treatment such as filtration and pathogen reduction.
May (2004) Draft sighted	Multi-jurisdictional committee of health and environmental experts	Framework for Management of Recycled Water Quality (revision of ARMCANZ/ ANZECC/ NHMRC, 2000)	No	Fires only mentioned in relation to stormwater use and fire fighting chemicals that could enter the stormwater system (Table 2.3). States that : *"For each type of recycled water supplied to the public, the intended uses must be defined in order to determine the water quality to be achieved and the management measures that need to be implemented."*
QLD (2004) Draft	Queensland EPA	Queensland Guidelines for the Safe Use of Recycled Water (Public Consultation Draft)	Yes	Use of stormwater and recycled water for fire fighting specifically mentioned as long as water meets Class A (for stormwater harvested on site, p57-58) and Class A+ for recycled water produced from municipal systems (p59, p64, section 8.5.2.1). Importantly, stress is placed on "fitness for purpose" for intended water use.
SA (1999)	South Australian Environment Protection Agency & Department of Human Services	South Australian Recycled Water Guidelines (ISBN 0 642 320217)	Yes	Table 1.1, p7, under section 7 where it is quoted as an "Industrial Use" and must be "fit for purpose". Microbial quality noted as the most important parameter to meet. Water must meet Class B (typically requiring full secondary treatment plus disinfection with an assurance that suspended solid levels are not exceeded, p8) Note on p14 that: *"Instruct all employees and others exposed to effluent in appropriate health and safety procedures pursuant to the* Occupational Health Safety and Welfare Act 1986 *and Regulations."*
TAS (2002)	Department of Primary Industries Water and Environment	Environmental Guidelines for the use of Recycled Water in Tasmania	Yes	Emergency fire fighting (p12), Class A (p16)
VIC (2002)	Victorian EPA	Guidelines For Environmental Management Use Of Recycled Water (ISBN 0 7306 7622 6)	Partial	Discusses use of recycled water for fire protection (such as in sprinklers, p35). Where "open system" industrial reuse occurs, i.e. where there is potential for worker exposure due to ingestion or inhalation of aerosols, then Class A recycled water is suggested to protect worker health (p35). In summary, the following are noted in relation to fire protection systems: • Standby reticulated sprinkler systems; & • Non emergency access situations (p50).

2. Guidance on fire fighting with recycled water
Continued

Table 2. Guideline recommendations for microbial quality targets to be achieved for the highest class of recycled water.

Guideline	Statements	Interpretation
ARMCANZ/ANZECC/NHMRC (2000) National Water Quality Management Strategy #14, Guidelines for Sewerage Systems: Use of Recycled Water	Page 21 (Section 4.3) and pages 25, 26 and 27 (Table 3) refer to: • Secondary treatment and pathogen reduction • ≤ 2 NTU turbidity • > 1 mg l^{-1} Cl_2 residual or equivalent level of disinfection • pH 6.5 – 8.5 • < 10 cfu 100 ml^{-1} thermotolerant coliforms • < 5 mg l^{-1} suspend solids Associated with the Table are footnotes: • Pathogen reduction beyond secondary treatment is defined as being accomplished by disinfection eg. chlorine or by detention e.g. ponds or lagoons. • Turbidity value is 24-hour mean prior to disinfection with absolute maximum of 5 NTU. • Cl_2 residual is defined as total chlorine residual after a minimum contact time of 30 minutes. • pH is 90% compliance.	The presence of pathogen reduction processes are required post secondary treatment, the use of lagoons or ponds is specifically noted and a number of other variables with guideline values are given.
Government of the ACT (1999) Wastewater Reuse for Irrigation Environment Protection Policy (1999) Environment ACT (BDM 99/0415).	Page 4 (Table 1) states: • Thermotolerant coliforms - median value of <10 cfu/100 ml • ≥ 1 mg/L Chlorine residual after 30 min or equivalent level of pathogen reduction • pH 6.5 - 8.0 (90% compliance) • Turbidity ≤ 2 NTU prior to disinfection. 24 hour mean value. 5 NTU maximum. • Secondary + pathogen reduction by disinfection, ponding or filtration	The presence of pathogen reduction processes are required post secondary treatment, the use of ponding is specifically noted and a number of other variables with guideline values are given.
NSW Recycled Water Coordination Committee (1993) NSW Guidelines for Urban and Residential use of Recycled Water. 1st Edition.	Page 5 provides targets as follows: • Faecal Coliforms < 1 in 100mL • Coliforms < 10 in 100mL (in 95% of samples) • Virus < 2 in 50L • Parasites < 1 in 50L • Turbidity < 2 NTU geometric mean and < 5 NTU in 95% of samples • pH 6.5 to 8.0 allowable range (7.0 to 7.5 desirable range) Pages 7-8 describe a single and conventional treatment train and then page 8 states that: • *"Proposed process trains and disinfection systems which differ from the above will require a proof of process study acceptable to the EPA and the Department of Health to demonstrate that the process meets the requirements of these guidelines."*	These guidelines do provide water quality targets in terms of expected pathogen, indicator, turbidity and disinfection concentrations. However, importantly, they defer all schemes that do not adopt conventional filtration followed by free chlorine disinfection to the EPA and Department of Health.
Queensland Government Environmental Protection Agency (2004) Queensland Guidelines for the Safe Use of Recycled Water – Public Consultation Draft	Page 34 (Table 5.1) identifies the requirements for Class A+ classification as including: • <10 cfu/100mL *E. coli* median value (although existing monitoring, if using thermotolerant coliforms, may continue to do so) • Turbidity set alarm for >2 NTU and automatic shutoff >5 NTU • Chlorine residual >1mg/L 100%ile (min. contact time of 30 min) • pH 6-8.5 • Treatment train that will achieve 5 log removal of viruses and protozoa in primary settled wastewater	These guidelines contrast with the NSW guidelines in that they provide more comment on process and less on specific water quality targets. Specific pathogen concentrations are not identified [presumably because of the difficulty in monitoring reliably] but, rather, pathogen reduction orders of magnitude are given. However, it is stated that the target viruses and protozoa are those that commonly cause disease in humans in Australia in accordance with section 5.1.1.

Table 2 continued over page

2. Guidance on fire fighting with recycled water
Continued

Table 2. Guideline recommendations for microbial quality targets to be achieved for the highest class of recycled water.
Continued from previous page

Guideline	Statements	Interpretation
EPA Victoria (2002) Use of Recycled Water. Publication 464.1. ISBN 0 7306 7622 6	Page 18 and page 21 (Table 1) identifies the requirements for Class A classification as including: • *"The principal focus for schemes requiring Class A recycled water is demonstrating that the treatment train process can achieve sufficient log removal of pathogens from raw sewage to final effluent to achieve median quantitative standards of:"* • less than ten *E. coli* per 100 millilitres; • less than one helminth per litre; • less than one protozoa per 50 litres; and • less than one virus per 50 litres. • Turbidity < 2 NTU 24-hour median and < 5 NTU maximum • < 10 / 5 mg/L BOD / SS • pH 6 to 9 90^{th} percentile (or higher for lagoon effluent provided disinfection can be maintained) • 1 mg/L Cl_2 residual *"(or equivalent disinfection)"*	These guidelines are the most comprehensive and include the most stringent water quality requirements and defer all Class A schemes to both the EPA and DHS.
Tasmanian Environmental Guidelines for the use of Recycled Water in Tasmania (2002)	Class A is defined as: • < 10 median thermotolerant coliforms per 100mL • pH 5.5 – 8.0 • BOD <10mg/L • Nutrient, toxicant and salinity controls	Approach is risk-based.

Table 3. Summary of international guidance in relation to recycled water and specifically in relation to fire fighting

Location	Document	Fire fighting?	Comments
USA, California, Los Angeles County	www.swrcb.ca.gov/rwqcb6/Adopted_Orders/2004/6-00-57-A01_LACSD20_AMD_WDR.pdf (accessed 12 July 2004) California Regional Water Quality Control Board Lahontan Region Board Order No. 6-00-57A01 WDID No. 6B190107069 Amended Waste Discharge Requirements For Los Angeles County Sanitation District No. 20 and The City Of Los Angeles World Airports Palmdale Water Reclamation Plant	Yes	Structural and non-structural fire fighting allowed . ARTICLE 3. USES OF RECYCLED WATER (Section 60307): water *"shall be disinfected tertiary recycled water, except that for filtration being provided pursuant to Section 60301.320(a) coagulation need not be used as part of the treatment process provided that the filter effluent turbidity does not exceed 2 NTU, the turbidity of the influent to the filters is continuously measured, the influent turbidity does not exceed 5 NTU for more than 15 minutes and never exceeds 10 NTU, and that there is the capability to automatically activate chemical addition or divert the wastewater should the filter influent turbidity exceed 5 NTU for more than 15 minutes."* Water reclamation plant had to show compliance with Title 22, California Code of Regulations water recycling regulations.
USA, California	http://www.lodi.gov/eir/4.4public_health.htm#_Toc502625941 (accessed 12 July 2004) Title 22, California Code of Regulations	Yes	California's regulations permit the *"use of disinfected tertiary treated recycled water for "structural fire fighting" (Title 22, California Code of Regulations §60307), for example to supply fire hydrants."*
WHO	http://www.who.int/water_sanitation_health/wastewater/en/ (accessed 12 July 2004) World Health Organization (WHO) Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture (1989)	No	However, two things need to be noted: • The WHO guidelines for the safe use of wastewater and excreta in agriculture and aquaculture are currently under revision with expected publication in 2004; and • The WHO is moving towards a risk assessment/management philosophy to water management in general rather than strict adherence to numerical guidelines (WHO's 3rd Edition of Drinking-water Quality Guidelines (expected for release late 2004), see also Davison *et al.* (2003) and WHO/FAO (2003)).
Singapore	(Example only, most hits viewed were of this ilk) http://asia.news.yahoo.com/031118/5/singapore57709.html News item on the use of NEWater: *"The Singapore Environment Achievement Award was given to the hospital for its green initiatives, including the use of NEWater for air-conditioning coolers and fire sprinkler systems."*	Partial	Only use in fire sprinklers noted.

3. Hazards found in recycled water

There are a number of different approaches and paradigms that can be applied to water-related health risk assessment (Deere *et al* 2001). Common to most of these approaches is a first step that involves identifying the hazards (agents that can cause disease) that might be present and an analysis of how risks might arise. This helps limit the scope of the remaining risk assessment to those hazards that might reasonably be expected to be relevant.

One of the difficulties in translating information on the health effects of exposure to untreated or only partially treated effluent is that the exposures anticipated for fire fighting are to highly treated Australian Class A or B recycled water. Therefore:

- Hazards known to occur at hazardous concentrations in raw or only partially treated sewage might not remain at hazardous concentrations in Australian Class A or B recycled water; and
- Adverse health effects associated with exposure to raw or only partially treated sewage exposure would not necessarily be associated with similar exposures to Australian Class A or B recycled water.

Therefore, in identifying the hazards relevant to fire fighters exposed to treated recycled water it is important to consider:

- The hazards that might be found in effluent; and
- The effect of treatment on those hazards.

Furthermore, in assessing evidence regarding the health effects of exposure to raw or partially treated effluent, any extrapolation to the case of treated recycled water needs to consider:

- The potentially lower concentration of hazards that are likely to be found in recycled water; and
- The potentially briefer and reduced exposure to that water.

3.1 Microbial hazards

Microbial hazards are generally considered the higher priority for control in the case of both chronic and acute waterborne exposures (WHO 2004, Hrudey and Hrudey 2004). Most of the observed health effects in occupational and environmental exposures to sewage effluent are attributed predominantly to the microbial hazards (see Section 5). There are three principal categories of microbial hazards found in raw sewage:

- Enteric microbial pathogens, such as rotavirus and *Cryptosporidium parvum*, are known to be released into sewers, primarily from faecal deposits into toilets. Indeed, the primary purpose of sewerage is to capture, remove and treat the enteric pathogens (shed in faeces) that are known to occur in raw sewage and that cause gastroenteritis if ingested;
- Opportunistic pathogens, such as *Pseudomonas aeruginosa* and *Legionella pneumophila* can grow in environmental water, including potentially in sewage, and these can cause eye, ear, skin, and respiratory symptoms as well as wound infections if sufficient numbers are present and contact with the contaminated water or aerosols occurs; and
- Microbial endotoxins have been identified as a possible but debatable cause of illness among sewer workers exposed to raw sewage (see Section 5.2.3). Endotoxins arise from Gram-negative microorganisms which where abundant, such as in raw wastewater, have been associated with non-specific and general symptoms (such as fevers, aches and pains) arising from inflammatory responses where aerosols have been inhaled.

3.1.1 Enteric pathogens

3.1.1.1 Plausibility of cause-effect

The ability of sewage-borne enteric pathogens to cause waterborne disease is well established and forms the primary consideration in health-related guidelines referring to both potable water and recycled water and will not be discussed further in this report (Rowe and Abdel-Magid 1995, NHMRC 1996, 2004, WHO 2003, 2004, Vaidya *et al* 2002, Le Cann *et al* 2004).

3.1.1.2 Effectiveness of barriers

Many of the treatment processes applied during water recycling are specifically and primarily designed to remove and inactivate enteric pathogens. As a result, provided systems are appropriately designed in proportion to the microbial challenge presented, and the systems are consistently operated as designed in practice, recycled water can be made safe from hazardous concentrations of enteric pathogens.

A number of detailed recent reviews report the ability of treatment systems to remove and inactivate enteric pathogens (Toze 2004, Parkinson and Roddick 2004, Gerba *et al* 2003, Jacangelo *et al* 2002, USEPA 1999 and Jacangelo *et al* 1997).

There is no question about the capability of properly designed and operated treatment systems in terms of the removal of enteric pathogens. There is extensive evidence relating to the effectiveness of lagooning, disinfection and filtration systems in terms of their ability to remove enteric pathogens contaminated water.

3.1.1.3 Design criteria

The design criteria used in developing recycled water schemes are generally specified, and the systems validated once in place, using “log removals”. The term refers to the $\log_{10}$ of the concentration of microorganisms in the influent divided by that in the effluent for the unit process under consideration. For multiple unit processes, the log removals are summed to provide the total removal attributable to that treatment train.

The processes used to treat recycled water to attain Australian Class A standards are designed for the most resistant type of organism in the category of pathogens of interest for the treatment technique under consideration. For example:

- Chlorine and chloramine disinfection design criteria for viruses are based on the sensitivity of the most resistant: hepatitis A virus (Sobsey, 1988, USEPA, 1999); and
- UV design criteria for viruses are based on the indicator MS-2 coliphage (for validation) and the most resistant: adenovirus (for system design) (USEPA, 2003).

Therefore, design criteria for unit processes applied in reclamation schemes are conservative and based on the most resistant enteric pathogens (USEPA 1999). As a result, properly designed and operated Australian Class A recycled water should be fully compliant with the guideline requirements set out for enteric pathogens in those guidelines.

The treatment requirements for Australian Class B standards are less specific and specific pathogen targets are generally not indicated. Instead the guidance generally refers to appropriate levels of pathogen removal given a particular end use, such as Helminth removal where cattle grazing is envisaged and bacterial indicator organism (*E. coli*) inactivation.

3.1.1.4 Significance of enteric pathogens for fire fighting with recycled water

A subsequent section of this report (Section 6) describes in detail the quantitative assessment of the health risks from enteric pathogens when fire fighting with recycled water complying with Australian Class A guidelines. The assessment found that the predicted risks were less than the reference level of risk for acceptable disease burden (WHO 2004, NHMRC draft revised Australian guidelines for Use of Recycled Water). The risks could be acceptable for Australian Class B recycled water schemes but this would depend on the pathogen concentration assumptions applied which would vary according to the specific scheme - pathogen targets are not necessarily defined for Class B schemes.

Another section of this report (Section 5) compared the risks associated with fire fighting with water complying with the Australian Class A and Class B recycled water guidelines to other water sources. The assessment found that the risks arising from the use of the recycled water were generally equivalent to, or less than, those likely to be associated with fire fighting with some alternative water sources.

Overall, risks from enteric pathogens to fire fighters using Australian Class A recycled water were found to be low enough that its use need not be opposed on health grounds. The situation is similar for Australian Class B recycled water provided that the pathogen removal that is in place is adequate – pathogen concentration targets are not specified for Class B schemes so any firm assessment would need to be case specific.

3.1.2 Opportunistic pathogens

3.1.2.1 Plausibility of cause-effect

The treatment that removes enteric pathogens will also remove the opportunistic pathogens. However, this latter group is capable of re-growing in the treated sewage. A variety of respiratory, aural, ocular and wound infection effects have been associated with relevant bacterial genera such as *Pseudomonas*, *Mycobacterium*, *Burkholderia* and *Legionella* as well as protozoan genera such as *Naegleria* and *Acanthameoba* (NHMRC 1996, Currie *et al* 2000, Moen 2000).

3. Hazards found in recycled water
Continued

The extent to which regrowth can take place is variable and related:

Positively to:

- temperature;
- residence time; and
- nutrient concentration; and

Negatively to:

- residual disinfectant concentration.

For hazardous concentrations of these opportunistic pathogens to arise in treated water, there needs to be sufficient residence time and nutrients under the conditions of temperature and residual disinfectant present:

- The relevance to health of opportunistic bacterial pathogens growing in good quality drinking water has been downgraded after a major international conference and review (Bartram *et al* 2003). Therefore, distribution with a disinfectant residual is not considered essential provided water quality is good and temperatures don't approach or exceed 30ºC; and
- Recycled water typically has higher levels of nutrients than drinking water and could potentially carry higher levels of opportunistic pathogens. Therefore, distribution with a disinfectant residual would be considered prudent in the absence of certainty here, at least in until current research provides sound evidence either way.

3.1.2.2 Effectiveness of barriers

Despite the reduced concerns in drinking water, Australian Class A recycled water needs to have a disinfectant residual (chlorine or chloramine) in the larger distribution mains during distribution. During fire fighting, the high flows will rapidly draw this water from the larger reticulation mains which will contain this disinfectant residual.

The concentrations of residual recommended to control the growth of such hazardous organisms are typically from 0.5 to 1 mg/l (NHMRC 1996) and these are the target levels to be achieved for most of the time in the main distribution mains of Australian Class A recycled water schemes. Occasional brief failure to achieve these levels does not lead to a significant increase in risk because the opportunistic pathogens are generally slow growing enough that provided the residual is maintained for most of the time, their growth is adequately controlled. Therefore, properly operated Australian Class A recycled water should be free from unsafe concentrations of opportunistic pathogens and safe for fire fighting use.

3.1.2.3 Significance of opportunistic pathogens to fire fighting with recycled water

Risks from opportunistic pathogens to fire fighters using Australian Class A recycled water were found to be low enough that its use need not be opposed on health grounds.

Australian Class B recycled water is not necessarily reticulated with a disinfectant residual to control the growth of opportunistic pathogens. Where an adequate residual is applied, the risks would be expected to be acceptable, as is the case for Australian Class A recycled water. Where an inadequate residual is applied, there is uncertainty in relation to these health risks and there is current CRCWQT research investigating this question (Blackbeard 2004).

3.1.3 Endotoxins

3.1.3.1 Plausibility of cause-effect

Aerosolised water and wastewater have the potential to carry hazardous substances. The inhalation and ingestion of aerosolised hazards from a range of materials has been associated with health effects (Pillai and Ricke 2002):

- The risks associated with the ingestion of enteric pathogens would be managed through recycled water treatment, as described above; and
- Another hazard of concern in aerosolised water is the "endotoxins" which is a general name for certain lipopolysaccharide components of Gram-negative bacterial (including cyanobacterial), outer membranes (Thorn and Kerekes 2001).

Endotoxins can cause several effects:

- Dangerous, even lethal, acute effects can be observed in dialysis patients or through intravenous injection, and endotoxins need to be removed from water prior to such therapy (Anderson *et al* 2003a); and
- Intravenous exposure and the associated severe effects are not of concern to fire fighters but milder symptoms arising from possible entry of endotoxins *via* dermal abrasions, ingestion or aerosolisation (Anderson *et al* 2003a) (or, presumably, burns) might be a potential exposure route if levels are high enough.

There are credible reports linking aerosolised endotoxin exposure with observed health effects. However, larger aerosols tend not to reach the deeper alveolar regions of the lungs and are less of a concern whereas smaller aerosols < 5 µm are associated with greater risks due to their greater penetration. Therefore, to assess risks to fire fighters from aerosolised endotoxin in recycled effluent, it is necessary to consider:

- The concentration of endotoxins in recycled effluent;
- The formation of small size-class aerosols during fire fighting; and
- The level of exposure to the aerosols during fire fighting.

Furthermore, dose response relationships between purified endotoxin compounds and health effects have been observed during controlled human exposure trials (Michel *et al* 1997) leaving no doubt about the plausibility of the relationship.

3.1.3.2 Endotoxins in water

There is some evidence of an association between endotoxin in sewage effluent aerosols and health effects. Exposure to endotoxins in raw sewage aerosols at sewage treatment plants has been proposed as a possible cause of observed ill health among exposed sewage workers (Thorn and Kerekes 2001) and linked to generalised symptoms including fever, diarrhoea, headache, cough, vomiting and irritation (Thorn and Kerekes 2001).

Inhalation of drinking water, pool water and humidifier water aerosols, has been associated with ill effects attributable to inhalation of endotoxin-laden aerosols (Anderson *et al* 2002). Surface water can harbour significant densities of Gram-negative bacteria resulting in endotoxin levels within the ranges associated with observed health effects if appropriately aerosolised, even reaching the concentration ranges found in raw sewage (Anderson *et al* 2002).

To cause ill effects, there must be a high enough concentration of endotoxin, aerosols of small enough size must be generated and sufficient endotoxin must be inhaled through exposure. Many sewage workers do not suffer ill health effects and are not exposed to unsafe levels of endotoxin in the workplace because the aerosols generated are too large and/or exposures are too low to cause ill effects (Prazmo *et al* 2003). Indeed, exposures in many industrial plants are much higher than those in sewage treatment plants.

In summary, the levels of endotoxin present in raw sewage could, if aerosolised into small size-class aerosols, and inhaled in sufficient quantities, cause ill health effects.

3.1.3.3 Effectiveness of barriers

Although not specifically targeted for this purpose, recycled water treatment trains do reduce both the concentration and potency of endotoxins to some extent. The limited data available were reviewed by Anderson *et al* (2002) who reported that:

- Recycled water and drinking water treatment trains generally reduce endotoxins by between 59-99%, varying according to the treatment process and its efficacy;
- Highly treated recycled water showed reductions in endotoxin removals of between 91 and 99%; and
- The Anderson *et al* (2002) observations were supported by those of Rapala *et al* (2002) who studied the removal of endotoxin in nine different surface water treatment plants (i.e. producing water for potable use) and found 59-97% removal.

This result is not unexpected since endotoxins are non-specifically associated with the bulk biological material including the biomass of Gram-negative bacteria present in sewage. Such material is specifically targeted for removal.

3.1.3.3.1 Primary and secondary treatment

The main function of the early stages of sewage treatment processes, primary settling and secondary treatment, that are almost universally found in sewage treatment plants, is to reduce suspended solids and organic matter. Bacterial cells and free endotoxins will associate with flocs in secondary treatment processes, such as activated sludge plants, and cells and endotoxins will settle out of suspension and become part of the sludge stream.

The mass of this total biological material is crudely measured in terms of biological oxygen demand (BOD) and suspended solids (SS) and an assessment of their concentrations could be useful to estimate approximate upper limiting estimates of removals that might be expected for endotoxins during these stages (upper limiting because endotoxins are likely to be smaller than many of the particles that are removed):

- Incoming BOD and SS in raw sewage varies depending on its strength with typical values being in the 300 to 500 mg/l range for both (quoted ranges are BOD: 120 – 1,000, average 200-350 and SS: 160-1,350 (Helmer and Hespanhol 1997, Rowe and Abdel-Magid 1995));

3. Hazards found in recycled water
Continued

- Australian Class A recycled effluent guidelines require final effluent quality of 10 mg/l BOD and 5 mg/l SS. This represents a reduction in BOD and SS from raw sewage to final effluent of over 95% for most schemes; and
- Total endotoxin levels might not drop by quite as much during secondary treatment but are likely to be significantly reduced.

3.1.3.3.2 Filtration

Filtration processes were found to be effective at reducing endotoxin concentrations (Anderson *et al* 2002):

- Media filtration: Both cells and free endotoxins are reduced in concentration by flocculation-coagulation-filtration processes by around 90% and these processes are, in fact, the most capable of the water and waste treatment processes in terms of their removal of endotoxins (Rapala *et al* 2002);
- Membrane filtration: Microfiltration membranes will remove bacterial cells although at least some free endotoxins, released during microbial cell degradation, will pass through (Madaeni 1999). The removal efficiency will progressively increase as pore size decreases with reverse osmosis removing all endotoxins. Endotoxins are generally present as part of cells and cellular debris of micron size but as they degrade they can break down to particles as small as the monomeric units of 0.002 µm (Anderson *et al* 2002).

3.1.3.3.3 Disinfection

Disinfection processes do chemically modify and inactivate endotoxins to some degree.

- Chlor(am)ine: Anderson *et al* (2003a) showed that monochloramine and chlorine reduced endotoxin units by around 0.9 and 1.3 units (~0.1-0.2 ng)/ml•h respectively at disinfectant concentrations likely to be found in recycled effluent treatment. Importantly, the reaction was highly time- rather than concentration-dependent with inactivation rates being very similar for the lower concentrations used (2 or 3 mg/l for chlorine and monochloramine respectively) and the higher concentrations (around 100 mg/l). Importantly the decay kinetics were linear with time unlike microbial inactivation which is log inactivation with linear time. In terms of total reductions the time taken to reach 50% from the starting concentration was approximately 2 days and 4 days for chlorine and monochloramine respectively. With lower starting concentrations the time taken to reach 50% inactivation would have been lower. Where contact times are long and residuals are maintained, and starting concentrations reasonably low, this reduction will become appreciable but it is likely to make only a negligible contribution to the overall reductions in endotoxin levels in recycled water after only a few hours, even with very high oxidant concentrations.
- UV: Anderson *et al* (2003b) investigated the effect of UV on endotoxin concentrations and found a much simpler relationship than for chlor(am)ine with dose being linearly related to linear reduction. However, endotoxin was not particularly sensitive to UV with a response of around 0.55 endotoxin units (~0.05-0.1 ng)/ml being reduced for every mJ/cm^2 dose of UV. This level of inactivation would see a plant operating at 40 mJ/cm^2 removing around 50% of the endotoxin present if input levels were low at around 50 EU (5 to 10 ng)/ml but have little relative effect if input levels were high.
- Ozone: Anderson and co-workers have not reported a specific study on ozone although one is probably underway or planned. There is evidence from the Rapala *et al* (2002) study that ozone made only a minor contribution (quoted as "little effect") to reduction in endotoxin. However, the specifications of the ozone plant were not given. It is reasonable to expect that only relatively high ozone doses will have a significant effect on endotoxin removal.

3.1.3.3.4 Overall treatment train performance

In practice the bulk of the endotoxin removal (> 90%) from raw sewage will probably need to be achieved through secondary treatment and filtration:

- A relatively conventional recycled water plant, as defined in the California Title 22 process or the NSW recycled water guidelines, involving secondary treatment followed by coagulation-flocculation-filtration would be expected to produce low levels of endotoxin when operating properly. Since this would be the most common type of treatment process used for Class A water recycling, it is reasonable to state that most Class A schemes would present low levels of endotoxin that would not be expected to lead to significant adverse health effects when used for fire fighting;
- It is not clear from the literature whether or not microfiltration plants would be as effective although as pore sizes decrease effectiveness will increase; and
- The commonly applied disinfectants used in water

3. Hazards found in recycled water
Continued

reclamation do reduce endotoxin levels and can be used to drive levels below certain target values. However, they are only likely to make a significant contribution (> 5%) to the total removal from sewage if used for long periods (many hours to days for halogen oxidants) or at high doses (UV or ozone).

Raw sewage often contains significant levels of endotoxins such that inhalation of sufficient quantities of very small raw sewage aerosols has the potential to cause generalised symptoms of ill health.

Wastewater treatment does significantly reduce these levels, typically by more than one order of magnitude, making the risks associated with inhalation of aerosols from Australian Class A or Class B recycled water considerably lower than those for raw effluent.

Since health effects in sewage workers are often not observed (Prazmo *et al* 2003), and the effects observed tend to be relatively mild with the statistical associations being relatively weak (Thorn and Kerekes 2001), it is reasonable to expect that symptoms of excessive exposure to endotoxins among fire fighters using Australian Class A or Class B recycled water with much lower endotoxin levels will not be observed during similar exposures.

3.1.3.4 Significance of endotoxins to fire fighting with recycled water

Although risks are expected to be negligible, a conclusive statement verifying the safety of Australian Class A and Class B recycled water for fire fighting with respect to endotoxins is not made in this report for several reasons:

- The removal of endotoxins varies according to the treatment process applied such that the actual endotoxin concentration in each recycling scheme could be different. The reports reviewed revealed that levels of around 10-20 ng/ml will be typical and would be expected for the most common, "conventional" treatment trains (the Title 22 or NSW Guidelines). These levels are consistent with those found in urban surface water (5-25 ng/ml) and even abut the higher end of the range reported in treated potable water and pristine surface water (< 1-15 ng/ml). Much higher levels have been reported in raw sewage (200-1,000 ng/ml) and in some of the rivers and lakes used for raw drinking water sources (up to more than 400 ng/ml) (Anderson *et al* 2002, Rapala *et al* 2002);
- No standard is in place for endotoxin concentrations in recycled water or drinking water or other natural waters to be used for fire fighting. If one were implemented, it would probably be somewhere between 20-50 ng/ml although would probably be expressed in endotoxin units (EU) and could range somewhere above 100 EU. Importantly, risks associated with using many other waters with similar levels of Gram-negative bacteria, including many dams, ponds and streams, would be expected to present very similar or higher levels of endotoxin risk than might be expected from the use of Australian Class A or Class B recycled water; and
- The duration of exposure to aerosols can be reasonably estimated but data on the concentrations of small size class aerosols produced during fire fighting has not been found and without such data, dose estimates cannot be supported.

Given that Australian Class A and Class B recycled water would be expected to have much lower endotoxin concentrations than raw sewage, and that many of the alternative water sources that might be used for fire fighting could have higher levels of endotoxin than Australian Class A or Class B recycled water (Rapala *et al* 2002, Anderson *et al* 2002), it is reasonable to use recycled water for fire fighting where the treatment train includes both secondary treatment plus a conventional filtration step and is distributed with a disinfectant residual to control Gram-negative regrowth. Health risks for fire fighters due to endotoxins for such systems when properly operating would be low and are probably negligible. The same is probably true for treatment trains passing much of the flow through ultra and nano filtration and is certainly the case for reverse osmosis.

It is not clear how effective microfiltration with 0.2 µm or 0.1 µm would be unless coupled with coagulation or affinity sorbents. Often > 50% of the endotoxin present in water is "free" rather than cell-bound (Anderson *et al* 2002) with Sawada (1986) finding 10% of endotoxin in drinking water was < 0.025 µm and required adsorption rather than physical removal for microfiltration to be effective. Further literature review, plant validation or research is warranted if the larger pore size filtration systems are to be credited with significant endotoxin removal. It is conceivable that raw sewage treated with only the most limited settling, no secondary treatment, 0.2 µm microfiltration and UV could meet the requirements of some definitions of Class A but might have levels of endotoxin that would not be considered acceptable were a standard developed.

3.1.3.4.1 Aerosol exposures

Risks from endotoxin inhalation to fire fighters using appropriately treated Australian Class A, or some schemes carrying Class B, recycled water are probably low enough that the use of such water should not be opposed on health grounds. Importantly, the risks associated with using other surface waters, such as polluted river water, could conceivably be higher.

3. Hazards found in recycled water
Continued

3.1.3.4.2 Dermal and enteric exposures

Skin, including abrasions, exposure to endotoxins is inevitable in most recreational activity in natural waters or through contact with soils and faecal material. Enteric exposure to endotoxins is inevitable during the consumption of any food or drink with appreciable Gram-negative bacterial counts in the raw material – note that the compounds have been shown to be relatively stable to heat (Anderson *et al* 2002). Despite these common exposure routes the effects of dermal and enteric exposure are an area of uncertainty (Anderson *et al* 2003a).

It is possible that health effects from dermal or enteric exposure to endotoxins have not been widely reported because ingestion-related exposure is ameliorated by digestive processes inactivating the endotoxin and abrasion exposure is ameliorated due to clotting processes preventing significant intravenous contamination. Certainly the presence of endotoxin in the human colon is inevitable where Gram-negative bacteria are abundant.

Although the health effects of endotoxin exposure through dermal and ingestion contact are uncertain it is reasonable to predict that such risks to fire fighters using Australian Class A or Class B recycled water will be relatively low or negligible if risks from aerosol exposure are controlled.

Dermal or ingestion exposure has not been associated with ill health even where aerosolisation of the same medium was. For example, there are studies in which symptoms were reported from aerosolised exposure yet the study authors did not report symptoms where endotoxin levels were similar in equivalent non aerosolised environments or from ingestion or dermal contact (Anderson *et al* 2002).

Provided risks from aerosolised exposure are managed, which appears to be the highest risk factor related to endotoxins relevant to fire fighting, the lower or negligible risks from dermal and ingestion exposure will probably be adequately controlled.

3.1.3.5 Developing an endotoxin standard

One way to set guideline values for endotoxins in recycled water to be used for fire fighting is to base them on current information augmented with new data on small size class aerosol generation and inhalation during fire fighting. A generic study of the aerosol generation and exposure during fire fighting could be undertaken (unless such a study has already been carried out – the report authors could not uncover one). A standard for acceptable endotoxin levels in recycled effluent to be used for fire fighting could then be defined.

A number of studies have linked observed symptoms to measured endotoxin concentrations in air and these have been used to set workplace limits relating to exposure limits in terms of ng endotoxin per m^3 of air which range, for different settings, from 4.5 through 10, 25 and 30 up to 100 (Anderson *et al* 2002, Prazmo *et al* 2003).

Michel *et al* (1997) developed a dose-response relationship using inhaled saline (control), 0.5, 5 and 50 µg doses of a purified endotoxin which showed that the inhalation of 50 µg caused significant effects, some effects were even seen at 5 µg.

Tests for endotoxin activity are readily available, not high cost, are widely used, particularly in the pharmaceutical industry, and are reliable. For each recycled water scheme that might be used for fire fighting, specific analysis to establish the levels of endotoxin present after treatment is feasible and could be undertaken during commissioning and then followed by a low level of verification monitoring. If endotoxin levels were found that were considered to be of concern, further treatment would be required to reduce these to acceptable levels before the recycled water could be used for fire fighting.

A more pragmatic but equally supportable approach to setting a guideline value for endotoxins in water for fire fighting would be to monitor endotoxin levels in other water used for the same purpose. Data in the review by Anderson *et al* (2002) show that endotoxin levels in highly treated recycled water can be as low as those in drinking water and are likely to be lower than those in many surface waters.

As a final point, any occupational standard applying to recycled water use should also apply to all water alternatives used for fire fighting, not just recycled water.

3.2 Chemical hazards

As a general principle, due to dilution factors, health effects from exposure to chemicals through exposure to contaminated water tend to manifest as a result of prolonged (chronic) exposure rather than from short-term sporadic (acute) exposure (Deere *et al* 2001).

- Concerns expressed relating to chemical hazards in recycled water or sewage are generally for environmental endpoints (Singh *et al* 2004, Woodworth *et al* 1999, Eriksson *et al* 2002) with the microbial hazards being linked to human health risks (Eriksson *et al* 2002); and
- There are few examples of health effects being attributed to acute exposure to chemicals from sewage (Bridges 2003). However, there have been some

3. Hazards found in recycled water

Continued

incidents reported where acute symptoms, such as vomiting, were attributed to contamination of potable water by chemicals with Calderon (2001) counting some 75 incidents over around a 30 year period in the USA.

The case of fire fighters using recycled water for fire fighting is clearly one of acute exposure. For an acute chemical intoxication to occur from fire fighting with recycled effluent there would need to be some source contaminating the raw or treated recycled water and releasing a chemical in high enough concentrations to still be hazardous after any dilution or treatment effects.

Recycled water originates mostly from domestic sources. Health risks posed by chemical contaminants is typically less than that posed by pathogens (EPA Vic 2002) and is not generally considered significant for acute exposures (Fawell J, pers. comm.). In general, chemicals are not of health concern to fire fighters using appropriately treated recycled water. For example:

- Most of the chemical substances released into sewer are benign everyday compounds such as detergents and personal care products from baths, showers, sinks and toilets. Such compounds are not acutely hazardous at raw product concentrations let alone once diluted;
- A lot of public concern has been raised about pharmaceutically active compounds (Webb *et al* 2003, Schulman *et al* 2002) in water. However these substances are not acutely toxic at the concentrations administered directly let alone once diluted and reduced in sewage;
- Hazards that have been associated with acute health effects, such as volatile organics and H_2S, reported as having possibly caused both chronic (Thorn and Kerekes 2001) and acute effects (Bridges 2003) to raw sewage workers in confined spaces, will be oxidised, volatilised and metabolised during secondary treatment; and
- Metals and many organic and hydrophobic compounds will associate with the sludge stream and are managed as biosolids (Pérez *et al* 2001, EPA Vic 2002).

Where health effects from sewage have been assessed (Bickford *et al* 1999) human health risks were only estimated as significant where extensive and prolonged exposure to consumed aquatic life was modelled using conservative assumptions. There was not evidence that brief exposure to sewage and stormwater discharges in waterways would lead to human health effects from chemicals. When set in the context of other sources of the same chemicals loads from stormwater were typically higher by an order of magnitude than those from sewage. This illustrates that where urban surface water is used for fire fighting, risks to fire fighters, although not necessarily unacceptable, could be higher than those from using Australian Class A or Class B recycled water.

3.2.1.1 Effectiveness of barriers

Trade waste management policies specifically identify and regulate large industrial and other facilities that might release high levels of contaminants into the sewer through trade waste permitting and licensing systems. Chemical discharges that would present unacceptable risks to the health of those working with and near the sewage or that might damage the treatment processes or affect recycled water users are not permitted unless their dilution or prior treatment on site can be shown to reduce such hazards to acceptable concentrations.

3.2.1.2 Significance of chemicals to fire fighting with recycled water

Acute health risks from chemical hazards to fire fighters using Australian Class A or Class B recycled water likely to be low enough that its use should not be opposed on health grounds.

4. Recycled sewage compared to other waters

In considering the difficulty in gaining community acceptance for the use of well treated and managed recycled wastewater, Asano and Cotruvo (2004) remarked that:

> *"The irony is that water derived from the 'natural' but obviously imperfect sources, often receives only basic treatment (filtration and disinfection). The final product might not be as high quality as the recycled wastewater that has been subjected to much more rigorous treatment, water quality control, and management".*

This is an important consideration since fire fighters often draw on water other than municipal tap water. Furthermore, municipal tap water, although "safe", is not completely purified and may have some negligible but non-zero risk associated with its use. It is now technically straightforward for recycled sewage effluent to be treated to a point where it presents an even lower and more negligible risk than many of the sources currently used by fire fighters.

This section of the report does not look at health risks of recycled water *per se* but, rather, compares the quality of recycled water with other water qualities that might be used for fire fighting. If recycled water is as safe, or safer, than other waters that are currently used for fire fighting then, by implication, recycled water should also be acceptable for use.

4.1 Urban surface water

Surface water from urban rivers and estuaries can be used for fire fighting as well as for primary contact recreation and fishing. However, such water will contain many of the same hazards that can be found in raw sewage (Ceballos *et al* 2003). This is because:

- The hazards found in sewage are generally also present in urban stormwater since the waste materials deposited in drains and on hydrologically connected surfaces are often the same as those discharged into sewage; and
- Urban stormwater includes some contributions from raw sewage arising due to dry weather exfiltration and, in wet weather, due to blockage-related sewer overflows, particularly in older cities such as Sydney.

The chemical hazards found in urban surface waters around Sydney were assessed by Bickford *et al* (1999) who noted that:

- Both sewage overflows and stormwater contributed pollutants to the receiving waterways; and
- Urban runoff was the greater contributor of such hazards by around one order of magnitude.

Therefore, any urban surface water source would be expected to contain the same types of hazards that are found in sewage effluent, albeit more dilute than in raw sewage. Importantly, however, when such water is used directly for fire fighting, recreation or fishing, such surface water has not been treated in a controlled environment as would reticulated recycled water (the importance of treatment was discussed in Section 3). Furthermore, the health risk assessment undertaken by Bickford *et al* (1999) did not suggest that chemical hazards were likely to be present at concentrations predicted to be acutely toxic to humans.

The microbial hazards found in drinking water catchments across Australia were assessed recently by Roser and Ashbolt (2004). The concentrations of microbial hazards varied with the level of development with urbanised areas having routinely hundreds to thousands of faecal indicators per 100 ml and pathogen concentrations in the tens per litre (see Table 4). Such concentrations are above those permitted for Australian Class A and, for the indicators specified, Class B recycled water. However, such surface water might well be used for fire fighting in urban environments and is sourced as raw drinking water and used for primary contact recreation.

In summary, urban surface water is likely to be of lower microbial and chemical quality than Australian Class A, and some schemes supplying Class B, recycled water. The risks to health from fighting fires with Australian Class A, and in some cases Class B, recycled water can be lower than the risks from using commonly occurring urban surface waters that are currently accepted.

4.2 Swimming pools

Swimming pool water is used from time to time for fire fighting. The exposure to water during fire fighting would be expected to be less than, or similar to, that experienced during swimming. Therefore, comparison of the risks associated with using swimming pool water and recycled water for fire fighting is useful.

There is a significant body of literature describing outbreaks of disease arising from swimming pools, particularly poorly controlled private pools:

- Thousands of cases of swimming-associated cryptosporidiosis have been reported both in Australia (Lemmon *et al* 1996) and the US (CDC 2001a) and public swimming pools can be temporarily shut down as a result;
- Where water quality and treatment has been inadequate, bacterial infections from *Shigella* (CDC 2001b) and *Escherichia coli* O157:H7 (CDC 1996) have been associated with swimming and spa pools;

4. Recycled sewage compared to other waters
Continued

Infections of surfaces such as skin and ears have been associated with spa pools where disinfection has been inadequate. These infections arise from opportunistic pathogens that are commonly present in water and soils. The pool environment can amplify the concentration of these hazards.

- *Pseudomonas aeruginosa* infection has been associated with a number of skin and ear infections arising from immersion in water with inadequate disinfection (Gustafson *et al* 1983, Ratnam *et al* 1986, CDC 2000). Symptoms have included outer ear and ear canal infections ("Swimmer's Ear" or "Otitis Externa") and skin infections such as dermatitis and folliculitis.
- *Legionella* infections causing outbreaks of legionnaire's disease have been associated with spas (WHO 2001). More recently, mycobacterial infections have been associated with pneumonitis linked to exposure to aerosols from swimming and spa pools (Falkinham 2003, Lumb *et al* 2004).

Importantly, Australian Class A recycled effluent needs to be distributed with a chlorine residual adequate to control the bacterial hazards that are of greatest concern and led to most of the symptoms described above. Furthermore, the risks from cryptosporidiosis from the use of Australian Class A recycled water would be controlled due to the specific targets set for such pathogens.

Therefore, the risks to health associated with the use of swimming pool water for either swimming or fire fighting, particularly for poorly controlled household pools, would be expected to be generally greater than the risks associated with the use of Australian Class A recycled water for fire fighting.

The absence of specific pathogen concentration targets for either swimming pools or Australian Class B recycled water makes a comparison of the two somewhat subjective and such a comparison is not made here.

4.3 Potable water

Drinking water is generally sourced from catchments that have at least some sewage impact (Webb *et al* 2003, Schulman *et al* 2002). Sewage, treated to varying degrees, can constitute 100% of streamflows during dry conditions and often contributes a few percent of total river flows and inputs to raw water sources. As such, indirect potable reuse, (and, therefore, fire fighting with potable water harvested from such sources), takes place worldwide. However, as Asano and Cotruvo (2004) pointed out:

> *"a properly planned and managed water reuse project can produce higher quality finished water than unplanned reuse [through drinking water] as is current common practice".*

This does not mean that drinking water is unsafe, but it does show that hazards from sewage challenge potable water treatment systems. For example:

- In an important recent study the safety of treated water harvested from the Mississippi, subjected to significant sewage pollution during the study period (AWWA 2004), was found to cause no detectable increase in the community disease burden for gastroenteritis after treatment through a well run but conventional water treatment plant (flocculation-coagulation-dual-media-filtration and chloramination) (CRCWQT 2003). Most Australian Class A recycled schemes are likely to employ similar conventional treatment systems (California Title 22 or NSW Guidelines) or similar or enhanced barriers beyond these (microfiltration and UV). Furthermore, the exposures to drinking water would have been orders of magnitude higher than those anticipated with recycled water being used for fire fighting.

The level of control and the extent of treatment applied to drinking water can be less stringent than that applied to Australian Class A sewage recycling schemes. Furthermore, whilst the microbial indicator target is more than two orders of magnitude (528-fold) more stringent for potable water (< 1 *E. coli* in 98% of 100 ml samples for potable water (Poisson parameter of 0.02) compared with a 12-month median of < 10 *E. coli* in 100 ml for Australian Class A recycled water (Poisson parameter of 10.7)) the public health burden for recycled water application may, in fact, be lower or approximately equivalent for recycled water for the following compounding reasons:

- Pathogen-specific targets are set for Australian Class A recycled water and are not required for drinking water. This means that the most infectious and resistant pathogens (viruses and protozoa) could reach levels in relatively less treated potable water that are higher than those specified for Australian Class A recycled water;
- The dose of drinking water through all routes is orders of magnitude higher than that for recycled water for two reasons:
  - consumption of drinking water is measured in litres per day (nominally 2 l) whereas accidental ingestion of recycled water is measured in ml per day (nominally 0.1 ml with up to 100 ml per day during accidental exposures); and
  - exposure to recycled water would be sporadic, a few exposures per year from fire fighting, whereas exposure to drinking water is frequent and at least daily.

4. Recycled sewage compared to other waters
Continued

Therefore, although the guideline value for the primary indicator (*E. coli*) is more than two orders of magnitude lower for potable water compared to Australian Class A recycled water this is more than balanced by the specific and stringent pathogen parameters, the fact that the daily exposure to recycled water would be expected to be more than one order of magnitude lower than for drinking water and that the annual exposure would be a further two orders of magnitude lower again. Furthermore, in practice, experience has shown that Australian Class A recycled water often complies with the *E. coli* guideline values for drinking water.

Comparison between Australian Class B recycled water and potable water is more complex but once again there is some balance between the different guideline values and the exposure. The guideline value (*E. coli*) for Class B recycled water is over three orders of magnitude higher than for potable water. However, anticipated daily exposures to recycled water for fire fighting would be over three orders of magnitude lower than annual exposures to potable water.

4.4 Conclusion

Compared to health risks associated with many other sources of water used for fire fighting, the episodic health risks to fire fighters using Australian Class A, and some schemes supplying Class B, recycled water to fight a fire would be approximately equivalent to, or less than:

- Episodic risks to fire fighters using most alternative sources such as:
  - swimming pools; and
  - urban surface water;
- Annual risks to consumers of high quality potable water supplies; and
- Episodic risks to consumers and fire fighters of using poorer quality potable water supplies.

4.5 Recommendation

Australian Class A recycled water should be permitted to be used for fire fighting since the risks to fire fighters would be expected to be below observable levels and equivalent to, or lower than, risks from many other accepted activities including the fighting of fires with many alternative and accepted water sources. Where specifically treated to allow for such an intended use, Australian Class B recycled water should also be acceptable on the same grounds.

5. Epidemiological risk assessment

No literature was found that contained specific epidemiological analysis of the health risks associated with fire fighting using recycled water. Therefore, this section of the report is limited to epidemiological evidence related to three other types of exposure that might provide an evidence base to infer risks to fire fighters from using recycled water:

- Chronic and acute worker and consumer exposure to recycled water used for unrestricted irrigation of raw foods;
- Acute bather exposure to sewage-contaminated bathing beaches; and
- Chronic and acute occupational exposure to raw and partially treated sewage in sewers and sewage treatment works.

5.1 Use of recycled water for unrestricted irrigation

5.1.1 Epidemiological studies

The use of recycled water for irrigation is widespread internationally and a number of important epidemiological studies have been performed and reviewed in detail by WHO (Blumenthal *et al* 2000) to support the development of the relevant new WHO reuse guidelines (due 2004) to replace the 1989 WHO reuse guidelines (WHO 1989).

More recent epidemiological studies in both developed (Deveux 2001) and developing (Blumenthal *et al* 2001) countries have remained consistent with the Blumenthal *et al* (2000) review. A key part of the approach adopted in setting the revised WHO reuse guidelines is similar to that adopted in setting the WHO recreational guidelines (WHO 2003). The recycled water quality at which adverse health effects would not be expected to, and had not been, observed was selected as acceptable for unrestricted use in agriculture (Table 4). This class of recycled water is also called Class A and in this report is referred to as WHO Class A to distinguish it from Australian Class A. The expected guidelines are:

- WHO guideline limits for faecal coliform bacteria in unrestricted irrigation will remain at ≤1000 geometric mean faecal coliforms/100 ml as per the 1989 WHO guidelines;
- For restricted irrigation this level will remain at ≤10,000 faecal coliforms/100 ml when adult farmworkers are exposed to spray irrigation but drop to ≤1,000 faecal coliform bacteria/100 ml if flood irrigation is used or if children are exposed;
- The guideline limit for nematode eggs for both types of irrigation will be ≤1 arithmetic mean egg/l unless conditions favour the survival of nematode eggs and where children are exposed in which case it will be ≤ 0.1 egg/l; and
- Where the public will be directly exposed, such as tourists on hotel lawns, the faecal coliform target was dropped to ≤ 200/100 ml.

Therefore, the WHO has endorsed the use of water meeting its strictest guideline values of ≤ 200 geometric mean faecal coliforms/100 ml and arithmetic mean of ≤ 0.1 nematode egg/l as its highest class of recycled effluent which is allowable for unrestricted irrigation of raw foods and for exposure to workers, the public and consumers, including children. This effluent quality has been selected based on a review of epidemiological and risk-based studies, neither of which suggested an excess disease risk in practice and allowing for any anticipated withholding periods and other practical, although not necessarily conservative, considerations (Blumenthal *et al* 2000).

Deveaux *et al* (2001) undertook an epidemiological study in France where the use of WHO Class A guidelines is accepted:

- Stabilization pond-treated sewage was being reused and sentinel systems to detect outbreaks were set up to see if the residents and farm workers were subject to detectable increases in disease as the extent of the reuse scheme increased. 800 farm workers living in 8 villages of 17,000 people were exposed to aerosols during maize detasseling. 17 pathologies were assessed at 15 general practices and drug sales were assessed at 7 pharmacists. A follow-up self-reporting questionnaire of field workers was undertaken and irrigation water quality was monitored;
- The frequency of self-reported symptoms, diagnosed pathologies and drug sales did not significantly differ before and after the expansion of the recycling scheme. The water was treated to meet the WHO Class A standard and was applied for unrestricted use with the limits being 1,000 faecal coliform cfu/100 ml. In general the water quality was closer to 100 faecal coliform cfu/100 ml [similar to Australian Class B]; and
- No adverse health effects were detected in this study from the increased use of this water. Importantly, the river water, which would be the alternative water source, was more contaminated with microbial indicators, with between 1,000 and 100,000 faecal coliform cfu/100 ml. If risks from recycling such effluent were extreme, this study could have detected them.

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Continued

The relevant WHO Class A guideline is more than one order of magnitude less stringent than the Australian Class A guideline with respect to the *E. coli* (or faecal/ thermotolerant coliform) parameter (Table 4) and similar in stringency to Australian Class B recycled water.

No limits are given in the WHO guidelines for pathogens other than nematodes yet for nematodes the WHO Class A guideline appears at first to be more stringent than the Australian Class A guideline. However, in practice the Australian Class A guideline, would be expected to yield water with higher quality than the WHO Class A guideline value for nematode parasites for several reasons:

- The treatment barriers required to demonstrate sufficient removal of protozoan and viral pathogens to comply with Australian Class A would be expected to give sufficient removal to readily achieve the relevant WHO Class A guideline for nematodes. Treatment mechanisms that remove and inactivate resistant protozoan cysts are generally effective for nematode ova. Furthermore, the level of nematode infection in Australian communities, and, therefore, levels in sewage, would be expected to be generally lower than those in the lower income countries to whom the WHO guidelines must also apply; and
- The Australian guidelines set a "maximum" value of 1/L whereas the WHO guideline sets an "arithmetic mean" value of 0.1/L. Assuming that the pathogens are Poisson distributed, and that a maximum value is equivalent to a quantile of 95% or greater, then, since the 95^{th} percentile of a Poisson distribution with an arithmetic mean of 0.1/L is 1/L, the Australian Class A Guideline "maximum" value is actually at least as stringent as the WHO arithmetic mean value. In fact, if "maximum" is taken as any quantile $\geq$91% this statement is accurate which should cover any reasonable interpretation of "maximum".

5.1.2 Comparison of fire fighting with agricultural reuse

Both WHO Class A and Australian Class A recycled water is permitted for unrestricted irrigation including spray and surface irrigation of crops to be eaten raw and of publicly accessible areas.

Such unrestricted irrigation leads to aerosol inhalation, skin contact and ingestion of the hazards in the recycled water. This occurs both through inevitable consumption and handling of the raw crops and through accidental exposure during irrigation.

Although it is recommended that crops should not be wet at the time of harvesting, many of the chemical and microbial hazards that are present in the recycled water will remain on the crops since their persistence can be prolonged, particularly during cooler periods. Therefore, agricultural workers and consumers will come into contact with, and ingest, these hazards.

Aerosols from the recycled water can reach both workers and the local community during spray irrigation and pooled water can contact agricultural workers. The exposure would be relatively ongoing for those regularly consuming raw foods wetted by recycled water and those working in and around these fields.

Blumenthal *et al* (2000) predicted no observable adverse effects where the recycled water was used for unrestricted irrigation met the proposed WHO Class A guidelines and the water was properly applied and used, including any required holding periods. Therefore, recycled water that complied with the more stringent Australian Class A, and even the similarly stringent Class B, recycled water guidelines would not be expected to lead to observable effects under similar exposure scenarios and would present an even lower risk.

5.1.3 Conclusion

The use of Australian Class A or Class B recycled water a few times per year for fire fighting would not be expected to lead to heath risks above the episodic and annual risks to the consumers of crops or agricultural workers, who could be exposed daily, if using the same water. Similarly, the risks to fire fighters would be no greater than to those accidentally exposed from time to time to the recycled water in and around the agricultural sites. It is reasonable, therefore, to predict that such recycled water would also be suitable for fire fighting purposes where similar accidental exposures might take place but would not be expected to lead to observable health effects.

5.2 Recreational water

5.2.1 Epidemiological studies

A number of epidemiological studies have examined the relationships between primary contact recreational water exposure (swimming and bathing) of characterised ambient water quality and the health effects on humans (Kay *et al* 2004, Pruss *et al* 1998). The most reliable studies compared the health of bathers recreating in water assumed to be contaminated by sewage discharges with the health of non-bathers *via* randomised interventions trials. Bathing beaches with different levels of sewage pollution were compared (Fleisher *et al* 1998):

- 548 bathers at 4 locations were randomly selected along with 668 non-bather controls;

5. Epidemiological risk assessment
Continued

- Surveys of self-reported eye, respiratory, skin and gastrointestinal symptoms were undertaken and related to exposure to bathing in water with bathers being compared with randomised control groups (non bathers);
- Bathing water quality was in turn characterised using microbial indicator measurements at times and locations representative of bather exposure; and
- Measured microbial indicator bacteria were assumed to be largely of sewage origin;
- Four significant associations found where those exposed to sewage-contaminated water reported more illness than those not exposed. Symptoms significantly associated with bathing included gastroenteritis (<0.018), acute febrile respiratory illness (<0.10 (< 0.001 when ≥60 faecal streptococci in water)), ear (0.0001) and eye ailments (0.048); and
- There were some dose-response relationships observed above the threshold of detection.

Kay *et al* (2004) described how this and similar studies formed the basis of the WHO (2003) recreational guidelines. From a broad review of epidemiological studies, the act of bathing at beaches with enterococci/100 ml of ≤40 (95th percentile) was found to have had no observed adverse effect on health compared to not bathing. These enterococci, and predicted equivalent *E. coli* levels, representing the highest no observed adverse effects were noted and formed the basis of the WHO (2003), Australian ANZECC/ARMCANZ (2000) and Australian NHMRC (2004) recreational water guidelines (see Table 4).

5.2.2 Comparison of fire fighting with primary contact recreation

Primary contact recreation involves direct immersion of the head and body and results in full body exposure, accidental ingestion and inhalation of aerosols. This type of exposure is similar to, or greater than, that expected to be experienced by fire fighters during fire fighting. Therefore, information on the risks associated with primary contact recreation in sewage-impacted bathing waters can be used to help predict possible risks to fire fighters using recycled water for fire fighting.

The seasonal median concentrations of microbial indicators considered acceptable for primary contact recreation in the Australian ANZECC/ARMCANZ (2000) recreational guidelines are higher by more than one order of magnitude than the 12-month medians stated for *E. coli* or faecal/thermotolerant coliforms in the Australian Class A recycled water guidelines and similar to those for Australian Class B recycled water (Table 4).

Comparison with the WHO (2003) and Australian NHMRC (2004) recreational guidelines is less straightforward since these guidelines mention enterococci and not *E. coli* whereas enterococci guideline values are not given in the Australian Class A or B guidelines. Furthermore, the WHO (2003) and Australian NHMRC (2004) recreational guidelines give a 95th percentile value for enterococci of ≤40 which is more stringent than the Australian ANZECC/ARMCANZ (2000) recreational guidelines. However, assuming a Poisson distribution, the arithmetic mean and median enterococci parameters of the WHO (2003) and NHMRC (2004) guidelines with a 95th percentile of 40/100 ml is 31/100 ml, which is very close to the Australian ANZECC/ARMCANZ recreational guideline value of 35/100 ml (see Table 4). In practice, the two Australian and WHO guidelines are, therefore, more or less equivalent and the same general conclusions would apply. Furthermore, for freshwater recreational environments, *E. coli* is still considered a valid indicator and an algebraic equation has been fitted to the observed relationship between *E. coli* and enterococci (NHMRC 2004). This leads to the WHO (2003) and NHMRC (2004) guidelines for enterococci ≤40 95th percentile (or around 31 for the median) of being equivalent to a value of 75 *E. coli*/100 ml 95th percentile (or around 50 for the median). This is higher than the *E. coli* concentration given in the Australian Class A recycled water guidelines of median 10 *E. coli*/100 ml and only just above the Australian Class B recycled water guidelines target of median 100 *E. coli*/100 ml.

Another way of considering this is to estimate likely enterococci densities in Australian Class A recycled water and use this as a basis for comparison. The Australian NHMRC (2004) and the WHO (2003) guidelines give enterococci levels for the most stringent guideline that are likely to be higher than those present in Australian Class A recycled water. The processes required to inactivate viruses and protozoa and yield the required > 5-$\log_{10}$ reduction of pathogens for compliance with Australian Class A recycled water guidelines would yield much more than 5-$\log_{10}$ reduction in the generally more susceptible enterococci. This reduction would drop the enterococci concentration below those set as guideline values in the relevant recreational guidelines. Raw sewage has of the order 10^5 to 10^6 enterococci/100 ml (NHRMC 2004) which once reduced by > 5-$\log_{10}$ would be below the recreational guideline values.

The microbial indicators present in the studies used as the basis for the recreational guidelines were thought to have arisen largely from sewage (Kay *et al* 2004). Therefore, it

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Continued

is reasonable to predict that the risks from fire fighting with Australian Class A or Class B recycled water would be less than, or approximately equivalent to, the risks to bathers recreating in water that complies with the ANZECC/ARMCANZ (2000) Australian recreational water guidelines.

Australian Class A recycled water will be at least as well treated as the lowest risk scoring sanitary inspection category which is for tertiary treated and disinfected effluent described in the NHMRC (2004) as "very low" [risk] for a direct outfall on the beach. Combining the lowest risk "very low" "sanitary inspection category" with the appropriate enterococci indicator values ("microbial water quality assessment category A") would lead to the highest ("very good") bathing beach classification under the NHMRC (2004) guidelines.

Comparison with Australian Class B recycled water is problematic since the NHMRC (2004) guidelines describe the need for specific analysis in categorising the risks associated with secondary treated disinfected effluent contamination. Combining the intermediate risk "moderate" or "high" "sanitary inspection categories" with the appropriate enterococci indicator values ("microbial water quality assessment category B") would lead to intermediate ("good" or "fair" respectively) bathing beach classification under the NHMRC (2004) guidelines.

5.2.3 Conclusion

The exposure during fire fighting would be expected to be comparable to that experienced during primary contact recreation. Therefore, the health risks to fire fighters using Australian Class A and Class B recycled water would be expected to be equivalent to, or less than, the episodic risks to primary contact recreators in the best ("very good"), or intermediate ("good" to "fair"), respectively, categories of sewage impacted bathing beaches (NHRMC 2004). The risks of the former would be expected to be below observable effect levels.

5.3 Occupational exposure to sewage

5.3.1 Epidemiological studies

A reasonably extensive body of literature exists that report on tests for associations between being a sewage worker and the health of those workers. This section of the report presents a review of that literature. A review by Thorn and Kerekes, (2001), a PhD thesis by Friis (2001) and a number of additional primary research articles (Lerman et al 1999, Khuder et al 1998, Thorn and Beijer 2004, Poulsen *et al* 1995, Douwes *et al* 2001, Keeffe 2004, Glas *et al* 2001, Thorn *et al* 2002, Hansen *et al* 2003, Rylander *et al* 1999, Jeggli *et al* 2004, Bonanni *et al* 2001, Bener *et al* 1998, Stampi *et al* 2001, Franco 2003) were analysed to search for information of relevance to the health risks associated with fire fighting using recycled sewage.

5.3.1.1 Reviews

In their 2001 review, Thorn and Kerekes analysed previous studies on the health of sewage workers in detail. Commonly reported symptoms were fatigue, gastroenteritis, airway inflammation and headaches. Health effects associated with endotoxins and enteric pathogens were considered plausible as were effects from H_2S and organic solvents in some specific cases. Associations with cancer and general chemical intoxication were not supported. Exposure to the sheer concentration of naturally occurring Gram-negative bacteria was postulated as the major risk factor facing sewage workers and this was explained in terms of endotoxin exposure. The difficulty in establishing a valid dose-response relationship for endotoxins for setting safe levels was noted. Infectious agents such as hepatitis A virus were also cited as potentially problematic although the immunization of sewage workers was common and reduced this risk.

In a more tightly focused review, Friis (2001) analysed six studies considering the health of sewage workers from across Sweden. Cancer mortality rates were assessed in 712 workers from 17 sewage treatment plants and compared with rates in the general population for a range of cancers with a particular focus on those of the stomach, kidneys and lungs. In addition, *Helicobacter pylori* infection (as serum positive for *H. pylori* antibodies), self-reported gastroenteritis and respiratory complaints were assessed for 151 sewage workers from 10 sewage treatment plants and compared with 138 matched municipal labourer controls. A subgroup of these (38 of each) was assessed for DNA damage in peripheral lymphocytes as a cancer marker. The work did not find plausible statistically significant associations between being a sewage worker and any form of cancer, increased *H. pylori* infection, DNA damage in peripheral lymphocytes or self-reported gastroenteritis symptoms. Associations with increased self-reported asthma were found but not explained. Of the many associations tested for in these studies only the association with increased self-reported asthma was regarded as significant by the study author. However, the importance of sound trade waste management was highlighted in this study to avoid toxic substances being released in high concentrations.

5.3.1.2 Specific cohort studies

Thorn and Beijer (2004) undertook a study comparing the health of sewage workers with controls. Some 59 workers at five sewage treatment plants were compared with 55 drinking water plant and gardening workers. The study focused on endotoxin-related work related symptoms and inflammatory responses. Air quality was measured by air sampling of endotoxins followed using the Limulus assay and health assessed using self-reported questionnaires, spirometry and measurements of H_2S levels. Antibodies to adenovirus and enterovirus were assessed in blood and nasal lavage. Working at sewage plants was significantly associated with mild morbidity in four out of 15 tests. Two out of 16 markers of inflammation or infection were elevated. Symptoms and pathologies significantly associated with being a sewage worker included soft stools (< 0.05), joint pain (<0.05), tiredness (< 0.01), toxic pneumonitis (< 0.01), elevated peripheral neutrophils (< 0.05) and reduced lymphocytes (<0.01). There was some relationship found between some symptoms and inflammatory markers.

Jeggli *et al* (2004) undertook a prospective study comparing the health of 349 sewage workers with 429 municipal worker controls in Zurich, Switzerland. Antibodies to *H. pylori* and hepatitis E virus in serum were compared as were a range of self-reported symptoms although to reduce bias these reports were gathered in a broad medical examination rather than using questionnaires. No significant associations were identified for the antibodies tested for although a weak but statistically significant association was found for one symptom, being gastroenteritis. The cause of this association was not certain but endotoxin exposure was identified as possible. However, other symptoms of endotoxin exposure were not reported any more in workers versus controls so this was by no means a strong conclusion.

Bener *et al* (1998) undertook a comparison of health effects in sewage workers compared to manual workers using self-reporting questionnaires, amino acid analysis and spirometry. In these studies sewage workers reported higher levels of chronic cough (p <0.02), chronic phlegm (p <0.03), chronic bronchitis (p <0.02), asthma (p <0.02), dyspnoea (p <0.001), nasal catarrh (p<0.001), pruritus (p<0.003), tinea (p<0.004), dermatitis (p<0.001), and nose irritation (p<0.005). The spirometric test scores were lower in sewage workers and plasma amino acid concentrations higher. The results suggested a high level of self reported illness among the sewage workers interviewed but the endotoxin levels monitored were not particularly high and a clear understanding of cause and effect was not emergent.

Khuder *et al* (1998) undertook a study comparing the health of 150 sewage workers at 11 plants with 54 maintenance and refinery worker controls. Rates of self-reported general symptoms (24) and diseases (14) were compared and associations with being a sewage worker were tested for. Four significant associations were found in which sewage workers were at higher risk including one disease (GI, < 0.01) and three symptoms (abdominal pain, < 0.04; abdominal bloating, < 0.05 and headache, < 0.02). There was one association (sore throats) for which controls were at higher risk. No dose response was evident.

5.3.1.3 Hepatitis A virus

A number of studies have looked at risks to sewage workers from hepatitis A virus (HAV) and findings have been inconsistent. Lerman *et al* (1999) undertook a review in Israel of workers that are at increased risk of HAV to decide whom to vaccinate. Many professions were at increased risk of HAV but sewage workers were not. A similar result was found by Bonanni *et al* (2001) in which a comparison of the prevalence of serum antibodies to HAV in 65 sewage workers was made with 160 municipal worker controls in Tuscany, Italy. No significant associations with being a sewage worker were found. The prevalence of anti-HAV antibodies was correlated with age as found in other studies. The increased theoretical risk of HAV infection was acknowledged but its absence in practice was attributed to the precautions taken being adequate. Franco (2003) undertook a literature review designed to help inform immunization priorities for HAV and assessed HAV prevalence studies for a range of workers. Most (7/9) studies reviewed revealed an increased risk to sewage workers, the exceptions being the Lerman *et al* (1999) study and the Bonanni *et al* (2001) study described

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Continued

above. It was noted that where endemic HAV infection was high, an increase was not noted. Since Australia has a relatively low endemic HAV prevalence, the Italian and Israeli studies are less relevant than some of the other studies reviewed.

5.3.1.4 Contamination levels in sewage plants

In an attempt to explain some of the observed symptoms, Stampi *et al* (2001) undertook an assessment of the presence of airborne Gram-negative bacteria around a sewage treatment plant. In total 16 sites around the plant were assayed. The settle plate technique was used and isolates included faecal coliforms (43.2% (of sites), mean of 14 colony forming units(cfu)/plate(p) /hour(h)), *Pseudomonas* spp. (53%, 11 cfu/p/h), *Shigella* spp. (46.5%, 13 cfu/p/h), *Legionella* spp. (3%, 2 cfu/p/h), *Salmonella* (2%, < 1 cfu/p/h) and general Gram-negative bacteria such as *Aeromonas hydrophila*, *Serratia marcescens*, *Enterobacter cloacae* (72%). Airborne transport of Gram negative bacteria was clearly demonstrated around the sewage treatment plant.

5.3.1.5 Summary of sewage worker associated health effects

5.3.1.5.1 Self-reported mild illness

Self-reported symptoms statistically significantly associated with being a sewage worker in at least one study included:

- Irritation of eyes, nose and throat;
- Fever;
- Fatigue;
- Headache;
- Toxic pneumonitis (flu-like illness (fever, shivering, headache));
- Gastrointestinal illness;
- Asthma; and
- Joint pains.

5.3.1.5.2 Medically diagnosed health effects

Statistically significant and plausible associations were not found between cancer and being a sewage worker.

Increased postural sway was statistically significantly associated where workers were exposed to sewage containing organic solvents at one particular plant (an isolated report).

Disease markers statistically significantly associated with chronic exposure to raw sewage among sewage workers included:

- Elevated blood neutrophils;
- Elevated anti-HAV antibodies; and
- Elevated marker liver enzymes.

Plausible hazards thought to be associated with observed illness and detected during studies included:

- Gram-negative bacteria;
- Microbial endotoxins (powerful inflammatory agents, found non-specifically in Gram- negative bacteria which can reach hazardous levels);
- H_2S; and
- Organic solvents.

5.3.2 Comparison of fire fighting with occupational exposure

The following points were considered in interpreting the findings from the occupational studies:

- Although the studies found higher levels of self-reported symptoms among sewage workers than among controls, these types of studies are relatively weak and subject to bias. The sewage workers knew that they were involved in a study of their health and they may have over-reported. Where medical examination was used to elicit responses rather than questionnaires, overall disease rates were lower and associations were weaker or absent;
- The self-reported symptoms described were of a general and mild nature and were not diagnosed medically;
- Workers were working around raw or secondary treated sewage and many of the mechanisms proposed as explanations for ill health would imply lower health risk for exposure to treated sewage;
- Most of the associations reported as significant were only just significant (< 0.05) which, with so many statistical tests being undertaken, may have included some that were significant only by chance and were not true associations;

- The studies asked sewage workers and controls about several symptoms and although some appeared more prevalent among the sewage workers, most symptoms did not and some symptoms were less prevalent among sewage workers;
- Dose-response relationships were generally not observed other than being, or not being, a sewage worker;
- Sewage worker exposures to hazards in sewage effluent was chronic and ongoing whereas exposure during fire fighting would be acute and brief, perhaps only a few days per year with a few hours on each day of exposure; and
- On the other hand, the exposure to sewage workers was indirect, via aerosols contacting the skin and being inhaled whereas during fire fighting exposure would be both direct and indirect and the daily exposure would probably be greater.

This body of knowledge reports the results of numerous symptoms of disease being tested for (such as gastroenteritis), infections being assessed (such as the hepatic viruses and some bacterial infections), inflammatory markers being assayed (such as neutrophil responses) and causes of mortality and cancer being tested for. Most associations were not statistically significant. However, there were some statistically significant associations found that appeared plausible since sewage could have been causal.

Hazards that might have been responsible are known to be present in sewage and were often identified at sewage plants through sampling of aerosols. The suspect hazards were of both chemical and microbial origin. The relevance of this becomes clear when the effect of treatment is considered (Section 3) – the key point is that both types of hazards are expected to be at much lower concentrations in treated effluent.

5.3.3 Conclusion

It is probable that some relatively mild health effects are associated with working around raw and secondary treated sewage effluent in some circumstances. However, these studies do not necessarily imply that highly treated sewage effluent is unsafe for fire fighting use because the hazards proposed as probable causes of the observed effects are likely to be very much reduced in treated effluent (see Section 3). Although fire fighters would be exposed to sewage for shorter periods of time, they would be exposed more directly during those periods.

5.3.4 Recommendation

The hazards thought to have been responsible for the observed effects on sewage workers are largely removed during the types of treatment required to reach Australian Class A or Class B recycled water quality and, provided trade waste controls are adequate, other hazards would not be expected to reach acutely unsafe concentrations for fire fighting.

5. Epidemiological risk assessment
Continued

Table 4 Comparison of observed and guideline values for various types of water that might contact, be ingested or inhaled by humans.

Water type	Intended /allowable use	*E. coli* (or equivalent) /100 ml	Enterococci	*Crypto-sporidium* /50 l	Viruses /50 l	Nema-todes/l	Turbidity (NTU)
Victorian Class A tertiary treated sewage effluent with pathogen reduction (EPA Vic 2002)	Unrestricted~ urban, residential, agricultural and industrial use	< 10ª		< 1#	< 1#	< 1#	2$ (< 5#)
Victorian Class B secondary treated sewage effluent with pathogen reduction (EPA Vic 2002)	Restricted industrial and agricultural	< 100ª					
Drinking water (NHMRC/ARMCANZ 1996)	Potable water for any domestic use	< 1£					< 5#
WHO proposed Class A recycled effluent (Blumenthal et al 2000)	Unrestricted~ agricultural use	≤ 200§				≤ 0.1†	
Surface water in bushland area*	Tributary of raw drinking water storage	30 dry 905 wet	17 dry 530 wet	4.5 dry (ND wet)			4.7 (54)
Surface water in urbanized area*	Tributary of raw drinking water storage	450 dry 6300 wet	200 dry 5600 wet	80 dry (490 wet)			4.7 (54)
Surface water in intensive agricultural area*	Tributary of raw drinking water storage	210 dry 13000 wet	91 dry 3800 wet	9.5 dry (13 wet)			9.6 (51)
NHMRC "Very Good" quality disinfected tertiary-treated sewage impacted beach (NHMRC 2004)	Primary contact recreation	[≤ 75&]	≤ 40&				
Australian recreational water guidelines ANZECC/ARMCANZ (2000)	Primary contact recreation	< 150+ (600=)	< 35+ (60-100#)				

ND: not detected

&95 percentile of at least 60 samples over three years

§Geometric mean

+Seasonal median of at least five samples no more than one month apart

=Maximum in four out of five samples taken more than one month apart

*Examples of observed flow-weighted geometric means (Roser and Ashbolt 2004).

†Arithmetic mean

ª12-month median

$24-hour median

#Maximum

£98 percent of samples taken over 12 months at least weekly

~Unrestricted access means that members of the public have unrestricted access to areas where recycled water is in use and the water can be used on crops eaten raw and it is accepted that from time to time skin contact and accidental ingestion will occur to both adults and children and to workers and members of the public

6. Quantitative risk assessment modelling

Quantitative microbial risk assessment (QMRA) is used to assess as quantitatively as possible the “relative” and “actual” risks associated with exposure to microbial pathogens. QMRA involves the use of models to predict the disease burdens associated with specified exposure routes. The models are mathematical and logical expressions of current knowledge fitted to what data is available. As such they can provide a current best-supported estimate of infection or disease rates informed by a variety of data sources and peer judgement.

Variability and uncertainty can be explicitly identified and the effects illustrated. At the very least, (such as when uncertainties are unacceptably large), what emerges is a logical framework for the setting of priorities for the generation of new knowledge to reduce uncertainties and improve future estimates. At best, (when uncertainties are tolerable), what emerges is a sound and defensible basis for decision-making based on an understanding of estimated disease burdens.

The level of sophistication that can be applied in QMRA is almost limitless and can begin with a simple point estimate of risk (e.g. Deere *et al* 1998a) or move through to a full quantitative and probabilistic assessment (e.g. Deere *et al* 1998b, Teunis *et al* 1997).

It is acknowledged that QMRA involves the use of models and, therefore, is subject to all the usual criticisms of modelling, principally:

- The assumptions are not certain; and
- Datasets may include some errors or be less than completely representative.

Criticism of QMRA is valuable if provided in the form of the provision of more accurate data or assumptions or ideas for knowledge generation.

The classical risk assessment paradigm was adopted for the purposes of this risk modeling process (WHO 1999; WHO/FAO 2003) which inolves:

- Problem Formulation;
- Hazard Identification;
- Exposure Assessment
- Dose-response Assessment (Hazard Characterisation in WHO/FAO 2003); and
- Risk Characterisation.

6.1 Inferences from previous QMRAs

A number of QMRAs have been undertaken previously that consider the health risks of exposure to recycled water *via* routes, and with exposure levels, that are analogous to those relevant to fire fighting with Australian Class A recycled water. Two examples will be described, one deterministic and the other probabilistic, and their relevance to fire fighting inferred.

6.1.1 Florida case study

Rose *et al* (1996) applied a deterministic base case and worst case QMRA to estimate health risks for a water recycling plant in Florida, USA, based on data from indicator and pathogen monitoring at the plant. The recycled sewage was treated “conventionally” by biological secondary treatment, sand filtration and chlorination. The plant reduced total and faecal coliforms by > 7 $\log_{10}$ and coliphages and enteroviruses by > 5 $\log_{10}$. Protozoa were reduced by > 3 $\log_{10}$. Final effluent concentrations of viruses and protozoa were between 0.01 and 5 per 100 l. Tracer phage removal by filtration and chlorination was 1.6 and 1.5 $\log_{10}$ respectively.

Maximum and arithmetic average observed pathogen concentrations in final effluent were used as inputs to the risk assessment along with then-current dose response models for the relevant pathogens. The risk of infection predicted from a single exposure to 100 ml of water was between 1 in one million and 1 in 100 million, which was less than the 1 in 10,000 risk reference level (USEPA 1989).

6.1.1.1 Relevance to fire fighting

This Florida study is directly relevant to the present analysis since it predicted that conventionally treated recycled sewage effluent was acceptably safe from the perspective of GI pathogens even if 100 ml is consumed during an accidental exposure event and no inactivation takes place prior to exposure beyond that occurring during treatment. Such an exposure is probably a reasonable estimate for an upper limit of what might be consumed during a fire fighting event such that translating these results to the present study, a fire fighter would not be expected to be exposed to an unacceptable risk if using water from the reasonably conventional water reclamation plant assessed here. Such conventional treatment is quite likely to be found for Australian Class A schemes since it complies with the prevailing NSW recycling guidelines (1993) and the benchmark Californian Title 22 process.

6. Quantitative risk assessment modelling
Continued

6.1.2 California case study

Tanaka *et al* (1998) applied a probabilistic QMRA to assess the risks associated with four exposure scenarios which, of relevance to this study, included recreational impoundments, as well as golf course irrigation, groundwater recharge and food crop irrigation. The assessment looked at the problem from two perspectives: reliability (how often the model predicted the reference risk level would be attained based on observed viral counts reduced according to predicted log removals) and expectation (essentially the reverse, estimating the log removals required to attain particular reference risk levels).

Input data included viral monitoring results fitted to lognormal distributions from unchlorinated secondary effluents from four wastewater treatment plants based on previous work showing that normal and lognormal distributions provide acceptable fits to sewage contaminant occurrence. The effect of further treatment was then estimated to provide simulated pathogen concentrations in the final effluent.

Exposure assessment was based on point estimates of ingested volumes per exposure and frequencies of exposure with inactivation of viruses being estimated where considered relevant. For the scenario most relevant to the present study, 100 ml was assumed to be ingested per swimming event for 40 swimming events per year with no inactivation taking place prior to exposure. Once again, the 100 ml exposure is considered a reasonable worst case estimate of fire fighter exposure although 40 events per year is above what might be expected for fire fighters from recycled effluent because its use is not yet widespread.

The geometric mean virus concentrations differed by four orders of magnitude between four plants (one trickling filter, the same plant converted to activated sludge and two additional activated sludge plants), the range varied across four orders of magnitude within plants, ranges from all four plants overlapped and observed values ranged by more than 5 orders of magnitude for the dataset as a whole. This was offered as evidence of significant heterogeneity in virus concentrations both within and between plants.

The results indicated that if water were fully treated according to a conventional water reclamation facility (coagulation-flocculation-sedimentation-filtration, 2 hr chlorine at 10 mg/l) meeting the California Title 22 recycled water requirements and operating as per specification, all the scenarios modelled would essentially meet the reference risk criteria (all four exposure scenarios based on input data from all four sewage treatment plants). Reversing the assessment, the log removals required to just comply with the acceptable risk criteria varied with each scenario with the recreational impoundment scenario requiring the most treatment at between 4.2 and 6.4 log viral removal for 95% reliability to meet the reference risk level, depending on the plant being represented.

6.1.2.1 Relevance to fire fighting

This most relevant and highest risk assumed 40 swim events per year, a total of 4 l exposure which is more than an anticipated fire fighter's exposure due to recycled effluent schemes. Translating the Californian results to the present study, the assessment indicates that a fire fighter exposed to full California Title 22 treated (also NSW recycling guidelines (1993) or conventionally treated Australian Class A schemes) recycled water during fire fighting would generally not be expected to be exposed to an unacceptable risk from any of the four plants represented.

6.2 Specific risk assessment for fire fighting

A QMRA was undertaken to assess risks to fire fighters using Australian Class A recycled water meeting certain criteria. The assessment was based on up to date and relevant Australian data checked for consistency against international data.

6.2.1 Problem formulation

The first stage in QMRA, problem formulation, involves defining the question and the scope of the assessment. For the purposes of this assessment, two questions were selected, as follows:

- What are the health risks associated with fire fighting with Australian Class A recycled water?; and
- How do the health risks estimated compare to reference levels of risk?

6.2.1.1 Reference level of risk

The World Health Organization has defined a "reference" level of risk (WHO 2004) as benchmark against which estimated risks might be assessed and upon which guideline values for hazardous agents are set:

- WHO (2004) have set a reference level of risk for concentrations of either pathogens or chemicals in

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drinking water that equate to an excess risk of 10^{-6} disability adjusted life years (DALYs) per person per year (DALYs apply to any hazardous agent, not just pathogens) and this is the most recent and broadly applicable health reference criterion in current use. The NHMRC draft revised Australian guidelines for Use of Recycled Water are likely to adopt this as the reference level of risk applicable for recycling and the DALY estimates are used in this report as the primary reference level of risk for risk characterisation; and

- The USEPA (1989) guideline reference risk for waterborne enteric pathogens, such as *Cryptosporidium parvum*, is set at a concentration in water that equates to an annual excess risk of infection of 10^{-4} for an individual consuming that water for one year. To enable comparison with this USEPA reference level, infection probabilities are shown in this report but these are not used to assess the suitability of recycled water for fire fighting.

6.2.1.1.1 DALYs explained

Dose response assessment involves predicting the probability of an adverse health-related outcome from an estimated dose of a hazardous agent. The outcome can be expressed in terms of infection, disease or as disability adjusted life years (DALYs). DALYs are preferred because they provide a single health outcome metric that can aggregate the many possible health outcomes arising from any or a range of single or multiple hazardous agents and *via* various exposure pathways.

The assumptions applied in estimating DALYs were derived from Murray and Lopez (1996) who presented their global burden of disease study. Tools were presented along with examples of their application to compare all health impacts in terms of DALYs. DALYs involve assigning probabilities, durations and severity weights to disease outcomes (Murray and Lopez 1996). Havelaar and Melse (2003) describe the basic principles of the DALY approach as being:

- to weigh each health outcome for its severity, between 0 and 1:
  - death being the most severe outcome with a severity weight of 1; and
  - morbidity (illness) outcomes, such as diarrhoea or cancer, have a severity weight somewhere between 0 and 1;
- to multiply the severity by the duration of the outcome in years:
  - duration of death being the remaining group (usually, the general population) life expectancy; and
  - duration of illness may range from days, (e.g. for diarrhoea) to years, (e.g. for cancer);
- to multiply the above by the population exposed:
  - this can involve determining DALYs for the specific number of people expected to suffer the outcome; or
  - expressing DALYs in a more standardised way, such as the number of DALYs per 1,000 cases (this approach provides DALY scores more likely to be greater than small decimals and is, therefore, easier to work with and report).

In practice, DALYs are used to provide a universal measure of disease burden for estimating the health impacts due to specific hazardous agents as well as to specific exposure routes:

- summing the various disease outcomes caused by a particular agent results in an aggregated estimate of the total burden of disease attributable to that agent; and
- summing the disease outcomes caused by a particular exposure pathway, given estimated concentrations of a range of hazardous agents, enables aggregation of the effects of multiple harmful agents for that exposure pathway.

The DALY scores expressed in this report are given per person per fire fighting event which can be expressed in long form as the estimated additional life years lost by a person attributable to fighting a fire with recycled water.

6.2.2 Hazard Identification

There are over 150 gastrointestinal pathogens that can be classified as waterborne. Undertaking a QMRA for all of these would be an extensive process and for many there would be inadequate data to produce a practically meaningful model. However, pathogens can be grouped with one pathogen being selected from each group as a repre-

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sentative of itself and the others. Selection criteria for reference pathogens include the following:

- Waterborne transmission is an established route (albeit often less significant than other exposure routes);
- High relative resistance to environmental inactivation compared to others in the group (persistent in the environment);
- High relative prevalence in the community of interest compared to others in the group (the frequency of isolation from the faeces of human and animal populations that have the potential to pollute the water);
- High relative specific infectivity compared to others in the group (a small number of organisms has a relatively high probability of causing infection);
- High relative morbidity or mortality (health) consequence compared to others in the group (the disease caused by the pathogen is relatively severe); and
- High relative resistance to water treatment compared to others in the group (hard to treat).

The use of reference pathogens is appropriate because it makes the QMRA more manageable in scope and at the same time focuses on the "worst case" pathogens: those that would be expected to contribution the most to total disease burdens. Reference pathogens have high relative infectivity and symptom severity and high relative source abundance and resistance to removal and inactivation. These factors combined mean a reference pathogen would be expected to provide a dominant contribution to the total burden of disease attributable to all pathogens for which the reference is representative. Estimating disease burdens attributable to the reference pathogen is likely to approximate the total disease burden from all pathogens in the same group and for that exposure route. The following reference pathogens are recommended by WHO (2004):

- Rotavirus (as a reference for viral waterborne pathogens);
- *Escherichia coli* O157 (as a reference for bacterial waterborne pathogens); and
- *Cryptosporidium parvum* (as a reference for protozoan waterborne pathogens).

The selection of rotavirus as the viral reference pathogen is reasonable since infection is relatively common and important, where it causes, for example, approximately 50% of hospitalizations for gastroenteritis in the under fives in Australia (Carlin *et al* 1998). Norovirus is probably more common among adults (Hellard *et al* 2002) and would be a suitable alternative reference.

The bacterial reference pathogen *E. coli* O157 was proposed by WHO (2004) because of its symptom severity: the probability of severe illness and death from infection by *E. coli* O157 is much higher than for many other bacterial gastrointestinal pathogens. However, its use in QHRA models is problematic because there are no human feeding trials (the trials were undertaken on rabbits) leading to good dose-response models for *E. coli* O157. Therefore, the bacterial pathogen *Shigella dysenteriae* was selected to provide the dose-response model for infection for *E. coli* O157. Furthermore, any enterotoxigenic *E. coli* (ETEC) could be considered a similar pathogen and, therefore, "ETEC" was selected as the reference bacterial pathogen. This reference hazard, due to its high specific infectivity and symptom severity, can be considered to represent the broad group of bacterial pathogens. *Campylobacter jejuni* would be a suitable alternative (e.g. WHO 2004) but is both less infectious and has less severe symptoms than the model ETEC applied here.

The selection of *Cryptosporidium parvum* as the protozoan reference pathogen is reasonable. It is an established and relatively common cause of waterborne disease outbreaks (Lee *et al* 2002) and for the purposes of risk modeling can be assumed to be more infectious than alternatives such as *Entamoeba coli* or *Giardia lamblia* (Teunis *et al* 2002; Messner *et al* 2001). In addition, a good dose-response model based on a total of five separate human feeding trials is available (Teunis *et al* 2002, Messner *et al* 2001, Teunis unpublished). *C. parvum* is assumed to be representative of both the established and most commonly isolated cryptosporidial oocysts from human stools: *C. parvum* and *C. hominis*.

It is acknowledged that the significance of recycled water as a transmission route for each of these pathogens is not established in all contexts, although each has been shown to be strongly related to waterborne transmission and is present in sewage. Furthermore, it is not certain whether or not other pathogens are more significant than the chosen references in terms of recycled water transmission and potential disease burden. However, it is likely that estimating disease burdens using these reference pathogens as model pathogens for the purposes of the QMRA will provide an acceptable estimate of total disease burden due to gastrointestinal pathogens arising from exposure to the recycled water.

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6.2.3 Exposure assessment

6.2.3.1 Overview

The purpose of the exposure assessment is to estimate the dose of hazards consumed and contacted by the fire fighters. There are two steps involved in exposure assessment:

- Define the hazard concentration in the water used for fire fighting at the point of delivery; and
- Define the volume of water consumed.

The first component is the most important as it is required to determine both relative and actual risk. This is because the volume factors do not vary between water sources. For example, whatever type of water is used for fire-fighting the fire fighters would be expected to be exposed to the same volumes of water by the same exposure routes.

The general description of the exposure assessment was as follows:

- Estimate hazard concentration in water used for fire-fighting;
- Estimate the volumes of water consumed; and
- Multiply the volumes by the hazard concentration to provide the input to the dose-response component.

6.2.3.2 Pathogen concentrations

To define enteric pathogen concentrations as inputs to the QMRA part of the model, frequency distributions were fitted to observed microbial count data from Australian recycled water treatment systems (unpublished). Holding shape parameters constant, scale parameters were modified to fit guideline values such that the desired cumulative density functions of the distributions had the properties consistent with the guidelines:

- Observed microbial count data provided a best-supported estimate of the way that pathogen concentrations were distributed and varied in recycled effluent. The parameters of the distributions were determined by iteratively maximizing the likelihood that the observed data were derived from the modelled underlying distribution. The following principles were applied in fitting distributions:
  - Only distributions that are plausible were considered – the Poisson and negative binomial for discrete variables (El-Sharwaari *et al* 1981, Haas and Heller 1988, Haas and Rose 1996 and Gale 1996) substituted with the gamma distribution to simplify modelling where applicable as well as the normal and lognormal for continuous variables such as volumes consumed or where drawn from other studies (Rose *et al* 1996 and Tanaka *et al* 1998); and
  - The probability distribution of the likelihood value was observed in 2-D (Poisson) or 3-D (all other distributions) space (Figure 1) for a range of parameter values around the optimum to check that the optimal fit calculated was not a false optimum and then checked in 2-D space (Figure 2).
- Appropriate quantiles were selected as interpretations for the guideline values for various classes of recycled water or surface water as follows:
  - Fitted distributions were modified to maintain the same shape parameter but to provide a modified scale parameter to yield the selected quantiles. This involved down-shifting distributions through maximum likelihood fitting;
  - Quantiles for "maximum" values were taken to be 95^{th} percentiles for the viral and protozoan pathogen classes at their guideline values and 50^{th} percentiles were applied for the bacterial pathogen class to correspond to "median" values.
- Distributions were defined based on observed data as follows:
  - The distribution of viruses was defined for cultivable adenovirus in sewage. Data used to determine the shape parameters for the model were unpublished Australian sewage monitoring data ("Australian data") from secondary treated effluent. The Australian data were compared with recent published first world sewage monitoring data from NZ (Green and Lewis 1999, Simpson *et al* 2003) and US (Tanaka *et al* 1998). Only cultivable virus concentrations were used to represent infectious loads. Recent reports describe higher concentrations when nucleic acids have been sought (Le Cann *et al* 2004, Hot *et al* 2003) although older reports have not (Egglestone *et al* 1999, Divizia *et al* 1998). However, Schvoerer *et al* (2001) noted that genome:pfu ratios for viruses in sewage were variable but typically between 10^1 and 6×10^5 depending on the specific virus and cell line used. This was thought to be not due to free nucleic acid but due to non-infectious virus loads (Schvoerer *et al* 2001), a hypothesis supported by the numbers of viral particles observed through immunofluorescence (Kukavica-Ibrulj *et al* 2003) or electron microscopic (Griffin *et al* 2003) observations. Datasets were reasonably consistent with respect to reported actual viral concentrations with the exception of some NZ data from Simpson *et al* (2003) where, for a brief period, higher-level

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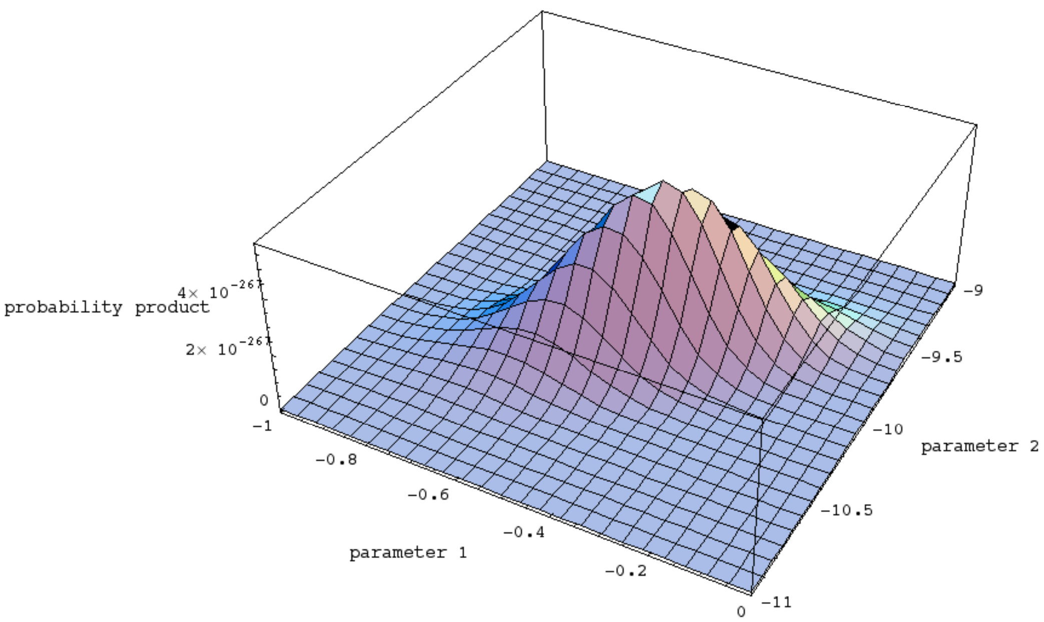
peaks in viral concentration were observed, presumably during a community disease outbreak; and

- The distribution of protozoa was defined for observed *Cryptosporidium* oocyst datasets for sewage. Data used to determine the shape parameters for the model were unpublished Australian sewage monitoring data ("Australian data") from secondary treated effluent corrected for recovery and confirmed. The Australian data were compared with recent first world sewage monitoring data from Italy (Bonadonna *et al* 2002) and the UK (Robertson *et al* 2000, 1999) and found to be reasonably consistent. No reduction was simulated for loss of infectivity to allow for the reduction in going from observed values to infectious concentrations – this is a conservative assumption; and
- The distribution of bacteria was defined for observed indicator *E. coli* datasets for sewage. Data used to determine the shape parameters for the model were unpublished Australian sewage monitoring data ("Australian data") from secondary treated effluent. The ratio of indicator *E. coli* to pathogenic *E. coli* was derived from that for indicator *E. coli* to cultivable *Salmonella* spp from the same unpublished Australian sewage monitoring dataset at 2.5 x10^5:1.

Figure 1 Illustration of the 3-D examination of the fit of observed pathogen data to the modelled distribution



6. Quantitative risk assessment modelling
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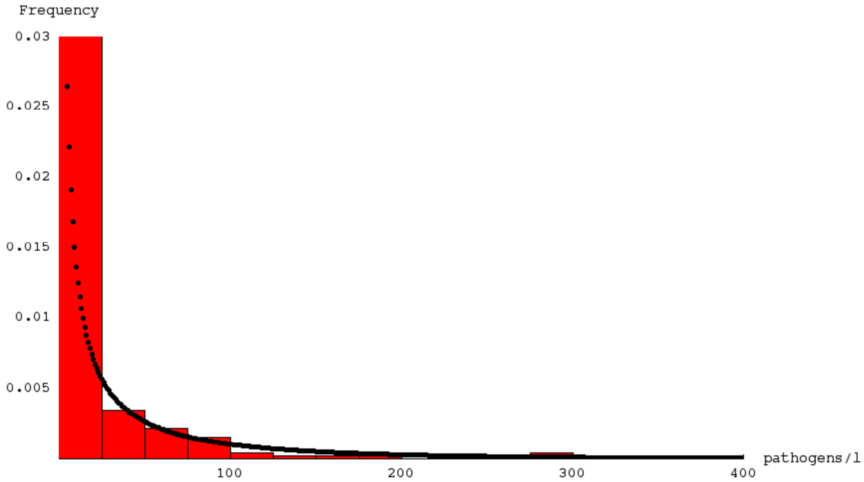
Figure 2 Illustration of the 2-D examination of the fit of observed pathogen data to the modelled distribution



6.2.3.3 Volume of water consumed

The volume of water consumed was determined through consultation with firefighters from the NSW Fire Brigade. Their assumptions appeared reasonable when compared to those used in risk assessments relating to recreational exposure to water and accidental ingestion of recycled water through irrigation (Rose *et al* 1996, Tanaka *et al* 1998) and were therefore applied unmodified:

- A lognormal distribution was fitted to the exposure ballpark estimates provided by the fire fighters. This had a median value of 2 ml and percentiles as shown in Table 5 and illustrated in Figure 3.

For pathogens, exposure was calculated as being the product of the hazard concentration distribution multiplied by the volume-consumed distribution using a Monte Carlo simulation (Figure 4).

Table 5 Illustration of the basis for the “volume consumed” distribution

Mode of accidental ingestion	Exposure estimates of fire fighters		Exposure prediction of model	
	Proportion of fire fighters	Volume consumed	Proportion of fire fighters	Volume consumed
Drink a glassful	0.1% (1 in 1,000)	100 ml	0.1% (99.9th percentile)	100.0 ml
Swallow a mouthful or gulp	2% (1 in 50)	25 ml	2% (98th percentile)	26.9 ml
Take a sip	10% (1 in 10)	10 ml	10% (90th percentile)	10.1 ml
Direct spray in mouth	100% (all)	1 ml	70% (30th percentile)	1.0 ml
Swallow spray drift			99% (1st percentile)	0.1 ml

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Continued

Figure 3. Illustration of the simulated distribution of volumes consumed by fire fighters (note the log scale on the x-axis)

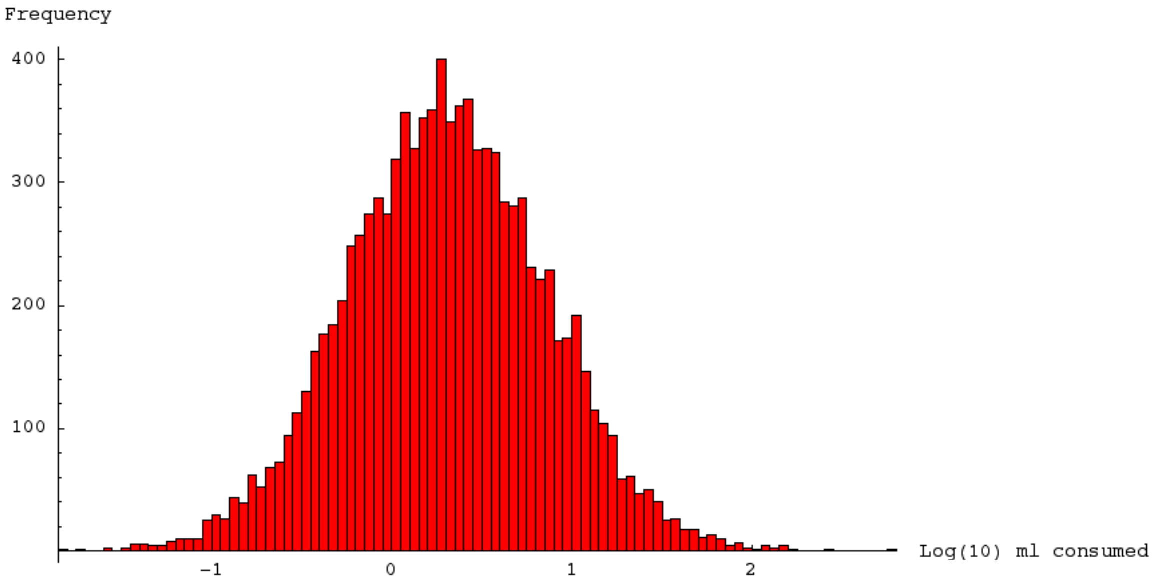
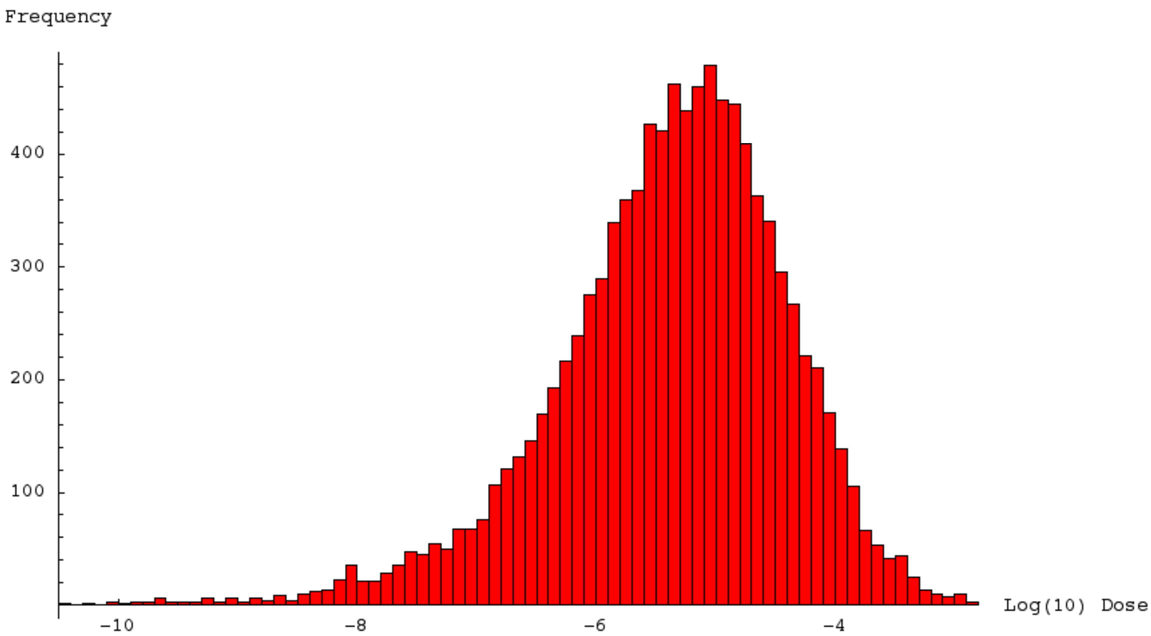


Figure 4 Illustration of the simulated dose of pathogens consumed by fire fighters (note the log scale on the x-axis)



6.2.4 Dose response assessment

Dose response assessment involves predicting the probability of an adverse health-related outcome from an estimated dose of a hazardous agent. Unlike the previously discussed variables the dose response models for the infection endpoint were not allowed to vary and best-supported point estimates were used as follows:

- For rotavirus the beta-Poisson model of Gerba *et al* (1996) was applied in which $r_{inf} = 1-(1+d/b)^a$ where r_{inf} is probability of infection, d is dose, a = 0.26 and b = 0.42 leading to a $r_{inf}1$ (probability of infection for a dose of one virion) of 0.27 and an ID_{50} (dose leading to a probability of infection of 50%) of 6;
- For ETEC the *S. dysenteriae* Weibull-gamma model of Holcomb *et al* (2001) was applied in which $r_{inf} = 1-(1+d^c/b)^{-e}$ where r_{inf} is probability of infection, d is dose, c = 1.08, b = 22.50 and e = 0.25 leading to a $r_{inf}1$ of 0.01 and an ID_{50} of 219; and
- For *C. parvum* the exponential model of Messner *et al* (2001) was applied where $r_{inf} = 1-e^{-d/k}$ where d is dose. Reflecting the fact that sewage contains largely human-derived pathogens, the most infectious of the three strains (Tamu) of *C. parvum* tested at that time was selected with the k parameter proposed by Messner *et al* (2001) being applied whereby k = 16.45 leading to $r_{inf}1$ of 0.059 and an ID_{50} of 12.

6.2.4.1 Disease burden for pathogens

As for the dose response, the DALY estimates were not allowed to vary and point best-supported estimates were used. The annual incidence of infection was the input to the DALY calculation. The assumptions and approach of Havelaar and Melse (2003) have been applied but some modifications have been made in the light of Australian disease burden analysis (Humans Services 1999a, b):

- Disease burden estimates for rotavirus were as described by Havelaar and Mesle (2003) for the developed world except that the duration of mild diarrhoea was reduced from 7 to 3 days based on local data (Human Services 1999a). Background immunity to rotavirus was assumed to be 94% (WHO 2004) and of those not immune and infected there was assumed to be an 88% probability of illness given infection, of which 97.5% develop mild diarrhoea with duration of 3 days (Human Services 1999a), severity weight of 0.1 and 2.5% develop severe diarrhoea with a severity weight of 0.23 and a duration of 7 days, and a probability of death given severe diarrhoea of 0.015% with life years lost from death reduced from 80 to 50 since fire fighters were assumed to be aged 30 on average. The resulting estimated average disease burden per infection was 5.8×10^{-5} DALYs;
- Disease burden estimates for *Cryptosporidium* were as described by Havelaar and Mesle (2003) for the developed world except that the probability of death was increased from 1/100,000 to 1/10,000 as suggested by Havelaar and Mesle (2003) based on the cited analysis of Hunter and Syed. This gives a 71% probability of illness given infection, duration of 7 days, severity weight of 0.067, probability of death given illness of 0.01% and, differing from Havelaar and Mesle (2003) life years lost from death of 50 years, assuming fire fighters are on average 30 years of age. The resulting estimated average disease burden per infection was 4.5×10^{-3} DALYs;
- Disease burden estimates for ETEC were based on Havelaar and Melse (2003). No background immunity was assumed. As described by Havelaar and Melse (2003) the probability of illness given infection was 0.9 and illness resulted in either watery or bloody diarrhoea with a respective probability of 0.53 and 0.47 and respective severity weights of 0.067 and 0.39 and respective durations of 3.4 and 5.6 days. The probability of death given diarrhoea was 0.027% and, differing from Havelaar and Melse (2003), life years lost from death was 25, assuming fire fighters are aged 30 on average but that the older fire fighters would be more likely to suffer mortality. As described by Havelaar and Melse (2003) the probability of HUS given illness was 2.5% and HUS had a severity weight of 0.93 and duration of 21 days with a probability of death given HUS of 0.04. Life years lost due to death from HUS were assumed to be 25. As described by Havelaar and Melse (2003) the probability of ESRD given HUS was 0.1 and ESRD had a probability of death given ESRD being 0.252. Differing from Havelaar and Melse (2003), and based on the assumption that fire fighters were on average aged 30, life years lost due to death from ESRD was set at 25. The resulting estimated average disease burden per infection was 0.066 DALYs.

For the purposes of reporting, the DALY score per infection was multiplied by the probability of infection and final risk estimates reported in DALYs per fire fighting event per firefighter.

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6.2.5 Risk characterisation

6.2.5.1 Comparison with reference levels of risk

The reference level of risk of 1 in one million (10^{-6}) DALYs per person per year, and the alternative of 1 in 10,000 per person per year (10^{-4}) was not exceeded where the risk distribution for a single fire fighting event and for a single fire fighter per year was simulated using the best-supported assumptions applied in the base model. Results are given in Table 6 (infection) and Table 7 (DALYs) which illustrates the results both for single pathogens and all three pathogens combined. An example of the model output is given in Figure 5 for infection probabilities. The assumptions were briefly:

- One fire fighting event per fire fighter using the recycled water;
- Lognormally distributed volume consumed per fire fight with median 2 ml and 99.9%ile 100 ml;
- Gamma distributed median 0.15/50 l (rotavirus) and 0.03/50 l (*Cryptosporidium*) based on 95%ile 1 organism/50 l to fit Australian Class A guidelines and gamma distributed median ETEC concentration 0.02/50 l derived from ratio correction from fitted *E. coli* indicator data scaled to a median concentration of 10/100 ml;
- The dose response estimates identified above whereby the probability of infection with one organism and ID 50s were for rotavirus 27% and 6 respectively, for *Cryptosporidium* 6% and 12 respectively and for ETEC 1% and 219 respectively; and
- DALY estimates were determined as described above with DALYs per infection being 5.8 x 10^{-5} (rotavirus), 4.5 x 10^{-3} (*Cryptosporidium*) and 0.066 (ETEC).

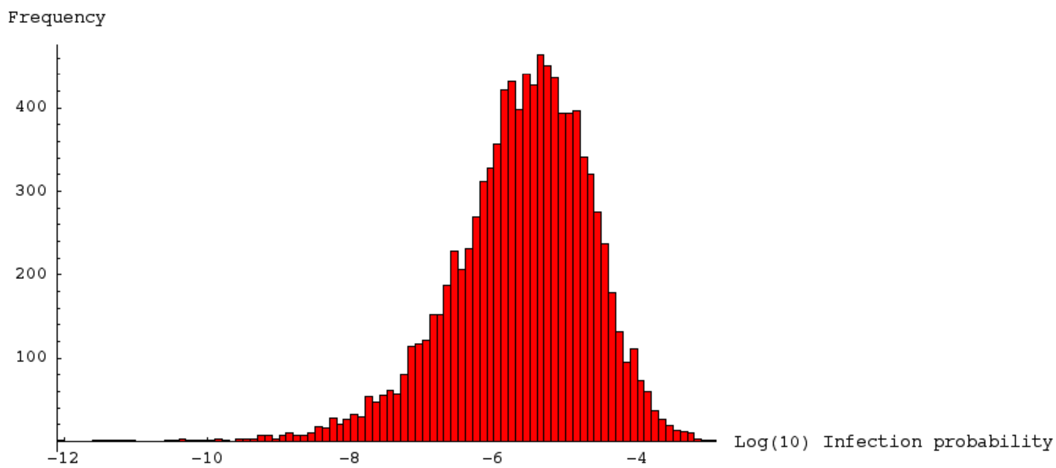
Table 6 Summary of base model infection probabilities (10,000 iterations)

Hazard	Median risk	95%ile risk
Rotavirus	3.4 x 10^{-6}	5.9 x 10^{-5}
Cryptosporidium	6.1 x 10^{-8}	5.1 x 10^{-6}
ETEC	6.4 x 10^{-8}	5.3 x 10^{-6}
Combined	4.3 x 10^{-6}	6.2 x 10^{-5}

Table 7 Summary of base model DALY scores (10,000 iterations)

Hazard	Median DALYs	95%ile DALYs
Rotavirus	1.8 x 10^{-10}	3.4 x 10^{-9}
Cryptosporidium	3.0 x 10^{-10}	2.6 x 10^{-8}
ETEC	1.7 x 10^{-10}	7.6 x 10^{-9}
Combined	2.1 x 10^{-9}	3.3 x 10^{-8}

Figure 5 Illustration of the simulated probability of infection for fire fighters using Australian Class A Recycled Water



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6.2.6 Sensitivity Analysis

6.2.6.1 Discrete changes to assumptions

6.2.6.1.1 Maximal infectivity pathogens

The dose response models assume that the infectious pathogens are not 100% efficient at eliciting an infection in a susceptible host. Instead, "best fitting" dose response models are derived from observed human feeding trial data (Figure 6). To test the importance of this assumption, the total risk of infection and total DALY disease burden estimates were compared for the "best-fitting" and "worst-case" models. The results are shown in Table 8 and indicate that even with worst-case dose response models the median risks are less than the reference levels for both endpoints modelled and the 95%ile risks are just on the reference levels.

6.2.6.1.2 Class B effluent

The Australian Class B guideline provides *E. coli* indicator values that are one order of magnitude higher than for Class A. No specific values are provided for viral and protozoan pathogens. For the purposes of modelling and sensitivity analysis, all pathogen concentrations were assumed to be 10-fold higher in the Class B effluent than the levels derived for Class A. The results in Table 9 show that the median risks would be below the reference levels of risk and the 95%ile risks are only just above the reference level of risk for infection but still below this reference level for the DALY endpoint.

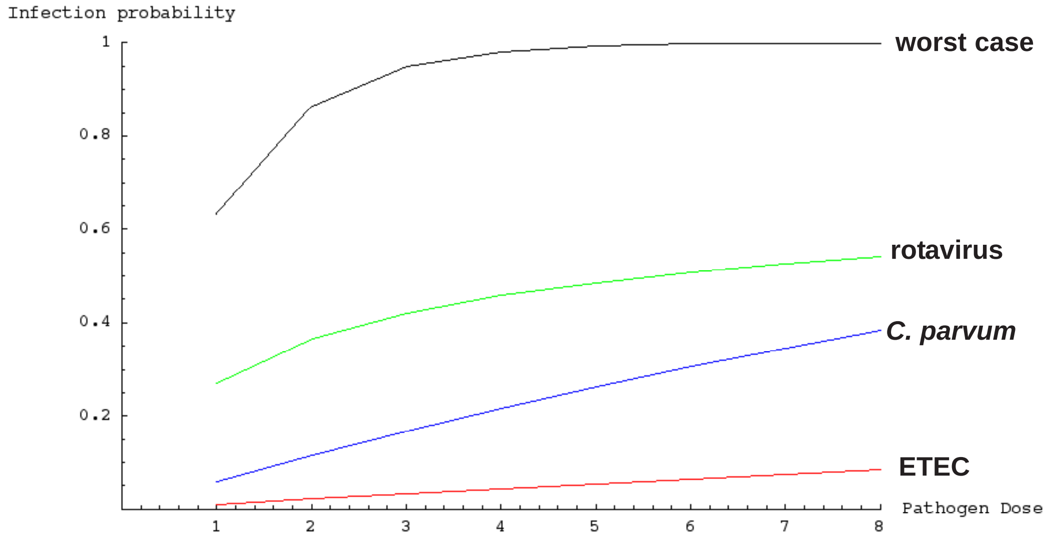
Table 8 Comparison of risks estimated using best fitting with worst-case dose response relationships (10,000 iterations)

Hazard	Median	95%ile
Combined infection risk (base model)	4.3×10^{-6}	6.2×10^{-5}
Combined infection risk (worst case dose response)	1.7×10^{-5} (4-fold increase)	1.8×10^{-4} (3-fold increase)
Combined DALYs (base model)	2.1×10^{-9}	3.3×10^{-8}
Combined DALYs (worst case dose response)	1.0×10^{-7} (48-fold increase)	1.8×10^{-6} (55-fold increase)

Table 9 Comparison of Australian Class A and a possible Class B quality (10,000 iterations)

Hazard	Median	95%ile
Combined infection risk (base model)	4.3×10^{-6}	6.2×10^{-5}
Combined infection risk (Class B)	4.3×10^{-5} (10-fold increase)	6.2×10^{-4} (10-fold increase)
Combined DALYs (base model)	2.1×10^{-9}	3.3×10^{-8}
Combined DALYs (Class B)	2.1×10^{-8} (10-fold increase)	3.3×10^{-7} (10-fold increase)

Figure 6 Comparison of the relevant (low) portion of the dose response relationships applied in the base case model with the worst case. From bottom to top relationships shown are ETEC, *C. parvum*, rotavirus and worst case.



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6.2.6.1.3 HAV DALYs

Since risks from viruses dominated the estimated disease burden, risks from an alternative reference organism were assessed compared to those for rotavirus: hepatitis A virus (HAV). The same dose response model was assumed as for rotavirus but the DALY per infection for HAV was applied and assumed to be 0.128 (as per Havelaar and Melse but assuming a 50% symptomatic infection rate). This is very much higher than for rotavirus, primarily due to the much higher death rate in adults for HAV (0.3% to 3%) versus rotavirus (0.015%) and the lower assumed immunity for HAV (50%) versus rotavirus (94%). In addition, the concentration of HAV was assumed to be tenfold lower than the guideline value in recognition of the low prevalence of HAV in Australia. Infectious HAV levels were likely to be much lower in sewage than the assumed levels of infectious rotavirus or the measured levels of cultivable enteroviruses that are used to define treatment requirements and validate recycled water quality performance. The results in Table 10 show that the median and 95%ile risks are less than the reference DALY guideline. If the HAV concentration was assumed to equal that of the guideline value, the 95%ile individual and combined disease burdens (but not the medians) do just exceed the reference value (7.5×10^{-6}) although this is considered an unrealistic assumption for the case of Australian recycled water.

Table 10 Comparison of the use of HAV and rotavirus DALY scores (10,000 iterations)

Hazard	Median	95%ile
Virus DALY (base rotavirus model)	1.8×10^{-10}	3.4×10^{-9}
Virus DALY (HAV model)	4.0×10^{-8} (222-fold increase)	8.1×10^{-7} (238-fold increase)
Combined DALYs (base model)	2.1×10^{-9}	3.3×10^{-8}
Combined DALYs (HAV DALY)	4.9×10^{-8} (23-fold increase)	7.7×10^{-7} (23-fold increase)

6.2.6.2 Continuous changes to assumptions

6.2.6.2.1 Multiple fire fighting events

In practice, fire fighters fight multiple fires in any one year. However, the chances of the same fire fighter attending a fire in the same suburb more than once are limited. Recycled water for fire fighting is likely to be limited to a handful of suburbs within any major city and the number of fires in such suburbs is likely to be limited. Nonetheless, the change in the risk profile for a fire fighter assuming that between one and 20 (considered an upper limit) fire fighting events are attended with recycled water per year is shown in Table 11 and Figure 7. This illustrates that even if more than 20 fires are fought in any one year, the risks do not exceed the reference level of risk for DALYs and only just exceed the reference level of risk for infection probability. The reference 10^{-6} per person per year DALY level is not attained for the 95th percentile DALY risk until an unrealistic 70 fires per year (gives 1.0×10^{-6} DALYs) are assumed to be fought per fire fighter with recycled water.

Table 11 Relationship between number of fires fought per year and annual combined infection risk and combined DALYs (10,000 iterations)

Number of fires	Median infection risk	95%ile infection risk	Median DALYs	95%ile DALYs
1 (base model)	4.3×10^{-6}	6.2×10^{-5}	2.1×10^{-9}	3.3×10^{-8}
2	1.4×10^{-5}	1.2×10^{-4}	6.8×10^{-9}	6.2×10^{-8}
5	4.9×10^{-5}	2.3×10^{-4}	2.5×10^{-8}	1.3×10^{-7}
10	1.2×10^{-4}	3.9×10^{-4}	6.0×10^{-8}	2.2×10^{-7}
20	2.6×10^{-4}	6.8×10^{-4}	1.4×10^{-7}	3.7×10^{-7}

6.2.6.2.2 Volume consumed

The volume assumed to be consumed by fire fighters could be debated, although in this study the fire brigade provided the figures. Nonetheless, a table and plot showing the relationship between stepwise increases in the assumptions driving the volume consumed distribution and the median and 95th percentile risks is given in Table 12 and Figure 8. This illustrates that even if the distribution representing the volume consumed is increased 16-fold, the risks do not exceed the reference level of risk for DALYs although they do exceed the reference level of risk for infection probability for 95th percentile, but not the median. The reference 10^{-6} DALY level is not attained for the 95th percentile DALY risk until an unrealistic 60 ml (median) and 480 ml (95th percentile) of water (gives 1.0 x 10^{-6} DALYs) is assumed to be consumed per fire fighting event per fire fighter with recycled water.

6.3 Conclusion

The QMRA indicated that the best-supported estimates of the 95th percentile health risks in DALYs due to enteric pathogens when fighting a fire with recycled water complying with Australian Class A recycled water guidelines, as interpreted herein, were less than the current benchmark reference level of risk, (10^{-6} per person per year), applied by the WHO (2004) for drinking water. The same reference level is expected to be adopted by the NHMRC for the revised Australian national recycled water guidelines.

The conclusions relating to Australian Class B effluent are less clear since pathogen targets are not specified. However, the sensitivity analysis suggested that a ten-fold increase in pathogen concentrations in going from Australian Class A to Class B, consistent with the difference in the *E. coli* guideline values, would still lead to 95th percentile DALY estimates below the reference values.

Importantly, the key conclusions were stable to varying the assumptions during the sensitivity analysis. For example, for Australian Class A recycled water, the 95th percentile DALY risk estimate did not reach the reference level of 1 x 10^{-6} per person per year until unrealistic assumptions were applied, such as assuming $\geq$70 fires were fought per year with Australian Class A recycled water per fire fighter, the volume consumed per fire fighter per fire was 60 ml (median) and 480 ml (95th percentile), an increased severity of disease burden (hepatitis A virus unadjusted for concentration) or that all pathogens had the maximal dose response infectivity.

6.4 Recommendation

Fire fighting with Australian Class A, and a reasonable interpretation of Class B, recycled water can be considered to represent an acceptable health risk.

6. Quantitative risk assessment modelling
Continued

Table 12 Relationship between assumed volume consumed per fire and combined infection risk and combined DALYs (10,000 iterations)

Median [95%ile] volume consumed	Median infection risk	95%ile infection risk	Median DALYs	95%ile DALYs
2 [16] (base model)	4.3×10^{-6}	6.2×10^{-5}	2.1×10^{-9}	3.3×10^{-8}
4 [32]	8.6×10^{-6}	1.2×10^{-4}	4.2×10^{-9}	6.9×10^{-8}
8 [64]	1.7×10^{-5}	2.4×10^{-4}	8.9×10^{-9}	1.4×10^{-7}
16 [128]	3.4×10^{-5}	5.1×10^{-4}	1.8×10^{-8}	2.8×10^{-7}
32 [256]	6.9×10^{-5}	1.0×10^{-3}	3.6×10^{-8}	5.4×10^{-7}

Figure 7 Relationship between number of fires fought per year and annual combined infection risk (A) and combined DALYs (B) for median (s) and 95%ile (l) values (10,000 iterations). Note that the reference risk level is used as the denominator of the plotted values such that a y-axis value of 1 equates to the relevant reference level of risk.

A Relationship between number of fires fought per year and annual combined infection risk

B Combined DALYs

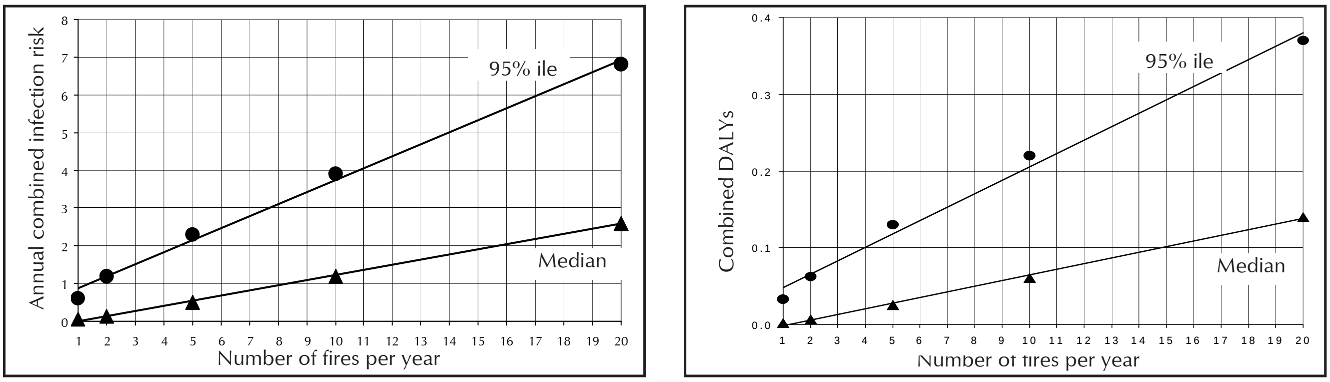
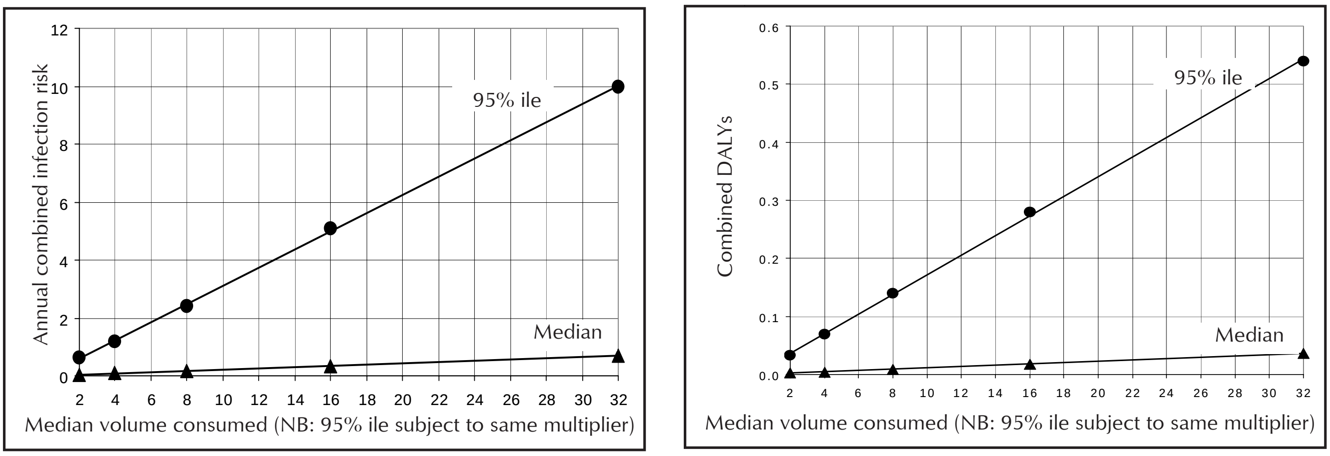


Figure 8 Relationship between assumed volume (ml) consumed per fire and combined infection risk (A) and combined DALYs (B) for median (s) and 95%ile (l) values (10,000 iterations). Median volumes are shown with the 95%ile being subject to the same multipliers (not shown). Note that the reference risk level is used as the denominator of the plotted values such that a y-axis value of 1 equates to the relevant reference level of risk.

A Relationship between assumed volume consumed per fire and combined infection risk

B Combined DALYs



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7. References and Endnotes
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7.3 Endnotes

[1] See for example Vic EPA (2003) Use of recycled water – guidelines for environmental management which specifically state the usefulness of HACCP as a framework for recycled water management and the draft Qld EPA (to be issued in 2004) guidelines which advocate the need for a Recycled Water Safety Plan, the latter being consistent with the World Health Organizations's approach for drinking water management i.e. Water Safety Plan.

WATER SERVICES ASSOCIATION
of Australia

MELBOURNE OFFICE
469 LATROBE STREET, MELBOURNE 3000
VICTORIA AUSTRALIA
TEL: 03 9606 0678. FAX: 03 9606 0376
EMAIL info@wsaa.asn.au

SYDNEY OFFICE
321 PITT STREET, SYDNEY, NSW
PO BOX A812, SYDNEY SOUTH, NSW, 1235
TEL: 02 9283 0725. FAX: 02 9283 0799
EMAIL: david.cox@wsaa.asn.au

INTERNET HOMEPAGE http://www.wsaa.asn.au