Department of Water
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PREMIER'S WATER FOUNDATION

ASSESSING THE PUBLIC HEALTH IMPACTS OF RECYCLED WATER USE
Interim report 1

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ACKNOWLEDGEMENTS

This work was funded by the Premier's Water Foundation Grant to The University of Western Australia. The report represents a collaborative effort between research participants from The University of Western Australia, The University of New South Wales, The Western Australian Department of Health, CSIRO, The South Australian Department of Health, The Western Australian Water Corporation, and the Chemistry Centre WA.

We would also like to thank all the participants in the workshops for their invaluable contributions.

DISCLAIMER

The views expressed are not necessarily the views of the Government of Western Australia, nor the Premier's Water Foundation.

EXECUTIVE SUMMARY

This is an Interim Report for the WA Premier's Water Foundation project #017 05 "Assessing the public health impacts of recycled water use". This project is designed to evaluate the safety of existing and proposed recycled water use in communities of Western Australia (WA) using a public health-based risk assessment; and by March 2010 to have finalised a set of Targeted End User Protocols (TEPs) for water sampling and modelling of health risks for specific applications of recycled water.

The Report is divided into the following main sections

Summary of project achievements

Since the commencement of the project in 2007, a critique of existing guidelines in relation to WA water recycling schemes has been conducted, including an assessment of the relevant benefits and hazards with respect to water recycling activities in Western Australia (WA), drawing on the existing and proposed frameworks established by the National Water Recycling Guidelines (2005) and the Draft WA Water Recycling Guidelines (2006). As a result of this process, the project leaders have identified key knowledge gaps and defined modelling scenarios for the project, based on the areas of most urgent need and greatest uncertainty for WA recycled water projects (see below).

Two workshops have been conducted, pertaining to: (i) evaluating methods for Quantitative Risk Assessment (QRA) and epidemiological analysis and to set the basis for providing socially relevant risk assessments on recycled water proposals; (ii) defining community perceptions of recycled water. Summary documents of the Workshop presentations and principal conclusions were developed and circulated to all members of the research team and external reviewers.

Critique and identification of knowledge gaps in assessing safety of recycled water

To date, our analyses have highlighted the following shortfalls in the available literature and guidelines on recycled water:

- *There is little development of systematic approaches for assessing and prioritising chemical toxicants that may potentially found in recycled water:* There are insufficient safety projections for many emerging chemicals, include endocrine disrupting chemicals (EDCs), pharmaceuticals, new disinfection by-products (e.g. nitrosodimethylamine — NDMA), and complex mixtures.
- *Risk inference is often confined to only a few simplistic endpoints:* The range of potential health effects explored is limited, and few analyses attempt to explore consequences of long-term contact with recycled water.
- *Combined analysis of toxicological and epidemiological evidence is usually absent or incomplete:* Evidence from multiple sources may be required to determine health effects, such as whether an agent that is toxic at high doses exerts a health effect at low doses, or whether it is plausible to extrapolate the effect of other related compounds. These weight-of-evidence conclusions about public health hazards posed by exposure to recycled water have either not been performed or have been undertaken at a qualitative level only.

- *Existing evaluations fail to predict possible health end-points for a range of water applications (e.g. for irrigation; horticulture; consumption etc).*
- *The methods currently used do not plausibly manage uncertainty in evaluating system efficiency and possibilities of failure*
- *There is failure to develop protocols that are interpretable by end-users but also allow flexibility in modelling*

Integrated risk assessments for assessing recycled water use
With respect to water recycling, health risk assessment components include consideration of:

- Pathogen exposure
- Chemical exposure
- System reliability / hazardous events analysis

Such assessments are undertaken for a number of reasons, including prediction of the burden of waterborne disease in the community in both outbreak and non-outbreak conditions and setting target reference pathogen/chemical levels for recycled water supplies that will equate to tolerable levels of illness within populations exposed to that water. At present, the most widely used and validated model in Australia is Quantitative Microbial Risk Assessment (QMRA), a mathematical risk assessment model that can accurately predict the risk associated with exposure to reference pathogens in the key pathogen groups (bacteria, viruses and protozoa) in source waters. Although the traditional approach has related to estimates of some "tolerable risk", this fails to consider the varying severity of outcomes associated with different hazards (for example, the differences between mild diarrhoea, cancer and death as outcomes). This shortcoming can be overcome by measuring severity in terms of disability adjusted life years (DALYs), which have been used extensively by agencies such as the World Health Organization (WHO).

Traditional estimations of risks to human health from exposure to chemicals are based upon extrapolations of animal exposure toxicological data, which is then used to determine safe levels of chemical contaminants in drinking waters. 'Dose-response' relationships can be determined from these data to determine safe levels of specific chemical contaminants in drinking waters.

Screening health risk assessments are useful for undertaking a preliminary assessment of the chemicals of concern in recycled water. Potential health impacts are calculated using risk quotients in which measured concentrations are compared against benchmark values. Chemicals are then classified into one of three tiers dependant upon the level of regulatory and toxicity data available.

Framework for targeted end-user protocols (TEPs) for recycled water use
The key conclusions from the project have been integrated and will be used in the development of *targeted end-user protocols (TEPs)*. The development and publication of TEPs is being applied to all major contexts in which recycling occurs (e.g. residential, industrial/ occupational, and recreational applications) to identify the degree of differential risk - if any - posed by these modes of contact with recycled water. Where appropriate, the system approach outlined in the Drinking Water Guidelines and Recycled Water Guidelines will be incorporated into this approach. The targeted end-user protocols are classified into a number of ***evaluation nodes***

that lead to ***decision nodes*** designed to guide management. This project will advance the traditional, semi-qualitative methods for assessing the safety of water contaminants by using Bayesian approaches to estimate parameters. Depending upon the activity of the agent or the state of knowledge on toxicological effect, probabilistic analysis with WinBUGS will involve determination of the range of plausible risk estimates using Monte Carlo simulations. This process will permit estimation of additional lifetime disease burden at an average intake over a set duration of time, with appropriate interval estimates.

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1. Review of Project Objectives

This project is designed to evaluate the safety of existing and proposed recycled water use in communities of Western Australia (WA) using a public health-based risk assessment; and by March 2010 have finalised a set of Targeted End User Protocols (TEPs) for water sampling and modelling of health risks for specific applications of recycled water.

In achieving the objectives for treated wastewater recycling established by the State Water Strategy for Western Australia, it is critical to consider the public health implications - and interrelated community perceptions - of recycling projects. In all forms of recycled water use (industrial recycling, grey water, rainwater, third-pipe water, agricultural recycling etc.) the "big unknown" remains the correct quantification of health risks. Any recycling scheme is unlikely to be successful without the community's acceptance, and it is essential to achieve a higher degree of epidemiological and quantitative risk assessment (QRA) integration to guide decisions on adequate and safe use of all potential applications of recycled water, such as in commercial and residential subdivisions, schools, sports facilities, and horticultural irrigation.

This project has been specifically designed to address the following issues:

(a) identifying and filling the gaps in the current and future application of recycled water guidelines in Western Australia;
(b) guiding State management decisions to convert a greater number of facilities and vegetated areas to irrigation with recycled water;
(c) to develop a risk framework for adequate interpretation of community concerns related to use of recycled water;
(d) providing WA communities with a public health-based safety analysis to address community concerns regarding safety of recycled water use.

2. Summary of achievements to 09/2008

2.1. Critique of existing research and guidelines for recycled water schemes / Identification of knowledge gaps and planning of risk modelling scenarios

A critique of key themes was undertaken from a review of available literature, assessment of Australian recycling water guidelines, key informant discussions and the Workshops. The critique and identification of knowledge gaps is covered in more detail in **Section 3 and 4**. Each of the titles below will be used as a major section heading for the final project document and will guide the structure of sections of the handbook produced from this Project.

Based on our exploration of the literature and expert consultation, a range of information gaps relating to recycled water and assessment of safety from its utilisation have already been identified. In broad terms, UWA is focussing on the evaluation of chemicals of concern and the UNSW team is assessing the microbiological risks to elucidate where the literature is incomplete.

2.2. Agency approvals for participation

The following agencies have given approval to access recycling schemes and/or identified schemes that are relevant for research within this PWF research project:

Water Corporation - Mark Nener

- Busselton – woodlot/golf course
- Kwinana – reclamation plant
- Albany – tree farm
- Broome – golf course
- Esperance – ovals/golf course
- Pinjarra – industry

Department of Health – Neil McGuinness (now Richard Theobald)

Recycling schemes in the following areas:

- Kalgoorlie/Boulder
- Northam
- Esperance
- Broome
- Karratha/Roebourne

Local Governments

- Shire of Broome – Danielle Rippin
- City of Kalgoorlie-Boulder – Alex Wiese
- Shire of Northam – Phillip Steven
- Town of Port Hedland – Darryal Eastwell

2.3. Workshop 1: Methods for assessment of recycled water proposals

The workshop **Evaluating methods for quantitative risk assessment (QRA) and epidemiological analysis** was conducted over 3-4 December 2007.

The attendees were:

Phil Weinstein – UWA
Angus Cook – UWA
Clemencia Rodriguez – UWA
Brian Devine – UWA
Richard Lugg – DoH
Neil McGuinness – DoH
Richard Theobald – DoH
David Roser – UNSW
Stuart Khan – UNSW
Peter Taylor – Chemistry Centre WA
Nick Ashbolt – USEPA (1 hour Skype conference on 4th Dec)

(Apologies from Jim Dodds – DoH, David Cunliffe – SA Health)

The purpose of the workshop was **to identify knowledge gaps and define risks from recycled water to intended and unintended end users within the risk modelling approach.**

The main issues discussed pertained to:

- risk of viable pathogens or their toxins not being completely removed in the treatment process, thereby causing an excess burden of infectious disease;
- risk of 'chemicals of concern' (such as organic compounds; heavy metals; pharmaceutical by-products etc) not being removed in the treatment process, thereby causing toxicological effects (e.g. endocrine disruptors, which have been linked to infertility and cancers in animal models)

The main problems arise in inferring risk, particularly for long-term contact with recycled water. One of the principal objectives of this project is to assign some risk estimate and predict possible health end-points for a range of water applications. This seeks to include:

(a) in urban and rural communities;
(b) in occupational sites (e.g. agricultural/ mining sites);
(c) in recreational areas, including sports grounds;
(d) in schools/childcare centres;
(e) in the development of new residential or commercial subdivisions;
(f) unintended/illegal uses and contacts with the recycled water stream

Suggestions for sites to evaluate in Western Australia include sites in metropolitan Perth, as well as regional centres where recycled water is already in use (such as Northam, Karratha, Esperance, Broome, and Kalgoorlie).

The presentation accompanying the Workshop sessions appears in **Annexes 1-4.**

Major conclusions are included below in **Section 3 and 4**.

2.4. Workshop 2: Risk analysis and community perceptions of recycled water; Presentation of workshop results

The workshop **Evaluating community perceptions of recycled water** was conducted over 11-12 March 2008.

The attendees were:

Phil Weinstein – UWA
Angus Cook – UWA
Clemencia Rodriguez – UWA
Brian Devine – UWA
Jim Dodds – DoH
Richard Lugg – DoH
Richard Theobald – DoH
Anne Bennett – DoH
Zoe Leviston – CSIRO
Alison Browne – CSIRO
Michael Burton – UWA
Fiona Gibson – UWA
Dan Rigby – UWA
Mark Nener – Water Corporation
Liz Petrow – Water Corporation

(Apology: Neil McGuinness – GHD; Leah Rheinberger – Water Corporation)

The purpose of the workshop was to

(i) identify factors contributing to public acceptance to the use of recycled water;
(ii) assess the impact of such perceptions on the PWF project on safety of recycled water in Western Australia.

Powerpoint presentations by Angus Cook 'Evaluating Community Perceptions of Recycled Water' were copied and provided to participants. The presentation appears in **Annexe 5.** A discussion paper *'Information from research on people's perception that may be considered for factoring into risk assessment/risk communication of alternative water supplies'* was prepared for the workshop by June Marks, a social science researcher at Flinders' University in Adelaide and provided to participants. The document is included in **Annexe 6.**

Major conclusions are included in **Section 3 and 4**.

2.5. PhD projects

It was intended that PhD students would be recruited in the project under joint supervision by UWA / WA Department of Health (under Weinstein/McGuinness) and CSIRO (under Toze) to research the following themes:

- *Development of health risk assessment methodologies to address recycled water needs in Western Australia*
- *Persistence of microbiological and chemical contaminants in differing recycled water systems.*

Advertisements calling for two PhD students for the PWF Project were placed in the following:

- School of Population Health Postgraduate Scholarship in Life and Physical Sciences and Postgraduate Scholarship in Medicine and Dentistry on 13 June 2007,
- Joint Academic Scholarship online Network on 13 June 2007,
- Uniview News June 2007,
- Australian newspaper 4 July 2007, and
- FindAPhD.com 26 July 2007.

The advertisements attracted 18 persons expressing an interest in undertaking research in the two areas indicated. All were considered suitable and advised to apply through the normal process with the University for a PhD scholarship. Unfortunately those that did apply were not successful in gaining a PhD placement.

We have developed an alternative plan for completion of the work as follows:

- part-time employment of postgraduate Public Health students to assist with literature review and analysis
- statistical assistance from Professor Kerrie Mengersen at the School of Mathematical Sciences at Queensland University of Technology

These strategies will ensure that the project milestones are completed by the agreed dates.

2.6. Review of other project criteria

Status of future deliverables

As of 09/2008, it is anticipated that all future Deliverables for this project (apart from those mentioned above pertaining to recruitment of PhD students) will be achievable. It is expected that the timeframe and resources available are appropriate for the completion of the remaining tasks and no revisions are requested at this time.

Identification of risks to project

As of 09/2008, the major potential risks as described in the original Work plan have not arisen and thus it is not foreseen that the completion of the project will be impeded. No additional risks related to this project have been identified at this time.

Budget/Resources

As of 09/2008, the budget and resources related to this project are sufficient to allow completion of the project as planned.

3. Critique and identification of knowledge gaps in assessing safety of recycled water

3.1. Functions of water recycling schemes

(i) Background

The National Water Quality Management Strategy – Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1), defines recycled water as "*Water generated from sewage, greywater or stormwater systems and treated to a standard that is appropriate for its intended use".* The primary sources and contributory waste streams to recycled water are thus: (i) *greywater* sourced from kitchen, laundry and bathroom drains; (ii) *sewage effluent* collected from all internal household drains (therefore containing high concentrations of faecal material/urinary metabolites passed through toilets) as well as wastes from industrial and commercial premises; (iii) *stormwater* from rain draining into the stormwater system from roofs (rainwater), roads, footpaths and other ground surfaces.

The process of recycling water for human consumption can be analogised to a path with several barriers. In the context of the widely employed HACCP approach, there are a number of key control steps for producing an effluent, which (depending on the end uses) will be of sufficient quality that it poses no unacceptable risk to human health, food sources (e.g. crops and livestock) or the environment. The first control step is the adequate pre-treatment of effluent (such as using filtration and reverse osmosis) to ensure that selected disinfection processes work efficiently. The second control step is to ensure that the actual disinfection produces an effluent meeting the required quality standards (Asano, 1998).

The current best available technology for recycling projects is the use of ultrafiltration or microfiltration as pre-treatment for reverse osmosis. Secondary effluent from conventional wastewater treatment plants is treated by MF, which is a low-pressure membrane with a pore size of 0.01 µm. MF can remove most of the fine suspended solids, bacteria, *Cryptosporidium, Giardia*, some viruses and protozoan cysts (van der Graaf, 1999; OCWD and OCSD, 2004; Lazarova, 1999; Beverly, 2001). After MF the water passes through the RO, a high-pressure process that forces water through the molecular matrix of a RO membrane. This membrane separates out minerals and other pollutants, including salts, heavy metals, viruses, and pesticides (Beverly, 2001; Lacy, 2005).

Although MF and RO are reliable and robust barriers, they will not provide a 100% rejection of potential contaminants that may be present in the recycled water. Thus, the implementation of different steps in the treatment (also called the *multiple barriers treatment*) has been implemented as a public health precautionary principle to ensure the continued reliability of the treatment process. The reliability of the treatment system is assured because the failure in one process component must not compromise the quality and the safety of the distributed water to the community. Additional barriers outside the advance treatment process include dilution and natural degradation of the recycled water in the water body followed by drinking water treatment before distribution to the community.

Disinfection of the recycled water is the most important part of the treatment process to protect public health, and is usually the final step in the treatment process. The level of disinfection required depends on the intended final use of the recycled water and the likely level of human contact. Disinfection of recycled water is achieved using a variety of methods, including: chemical (e.g. chlorination, ozonation); physical (e.g. ultraviolet radiation); biological (for example, detention lagoons).

The various treatment stages and their removal capabilities are summarised in **Table 3.1.1** (Landcom, 2006):

Table 3.1.1 Treatment technologies and their pollutant removal abilities

Table 5. Overview of treatment technologies and their pollutant removal abilities[4]

	Suspended solids (TSS)	Biodegradable organics (BOD removal)	Nutrients: nitrogen	Nutrients: phosphorus[5]	Salts	Pathogens
Biological processes	Yes	Yes	Yes	Limited	No	Limited
Natural systems	Yes	Yes	Yes	Yes	No	Good
Recirculating media filter	Yes	Yes	Yes	Limited	No	Limited
Media filtration	Yes	Function of size	Limited	Limited	No	Limited
Membrane filtration	Yes	Function of size	Function of size	Function of size	Reverse osmosis only	Function of size
Membrane bioreactor	Yes	Yes	Function of size	Function of size	No	Function of size
Subsurface flow wetland	Yes	Yes	Yes	Yes	No	Good[6]
Disinfection	No	No	No	No	No	Yes

(Landcom, 2006)

The efficacy of various treatment methods for microbes has been summarised are summarised in **Table 3.1.2** (Toze, 2006):

Table 3.1.2 Examples of maximum and minimum log reduction via different treatment processes

Treatment	Faecal coliforms	Enteric viruses	Phage	*C. parvum*	*Giardia*	Helminths
Secondary	2.5	5	1.6–6.6			
Ponds			0.11–0.39	1	1.6	1.7–3
Chlorination	3		0.1–2.5	0.1		
O3	2–3	3.5–6	2–6			
UV	2–3.5		4–6			
Membrane filtration	7		>6	6–7	6	

(Toze, 2006)

(ii) Key issues relevant to current project

- Currently schemes must manage a highly contaminated water source, and advanced water treatment is required to efficiently remove microbial and chemical contaminants.
- Water safety plans based on barrier controls, as appropriate, are essential elements.
- The modern systems provide a very high degree of removal for many chemical contaminants.
- The difference between expected performance and potential failures (with its associated risks of catastrophic contamination) is significant, and accordingly the concept of 'risks' in this situation is driven by 'hazardous events'. A hazardous event may be the weakest link in a water safety plan.
- The impact of environmental processes on pathogen and chemical decay remains uncertain, and the efficiency of these natural removal processes must be assessed in greater detail before their levels of contaminant removal may be estimated.
- It is recommended that an open audit system is developed and a process for reviewing results. These must be available and accessible to government agencies.

3.2. Existing recycled water guidelines

(i) Background

Different regions using recycled water have developed various approaches to ensure health and environmental protection. In the US, there are no federal regulations governing recycled water and criteria are developed at the state level. Therefore, states operating recycled water projects, such as California, Washington, Arizona and Florida, have developed various guidelines. Criteria among states are generally similar and tend to be conservative with an emphasis on maintaining protection of public health (Crook, 2005). In California, for example, groundwater recharge of potable aquifers requires secondary treatment, filtration, disinfection, and advanced wastewater treatment. Water quality goals include: pH 6.5-8.5; turbidity less than 2 nephelometric turbidity units; no detectable faecal coliform; less than 1 mg/L chlorine residual, total organic carbon (TOC) less than 1.0 mg/L; and compliance with all drinking water standards (CDHS, 2002). In Florida, recycled water projects have to meet primary and secondary drinking water standards, TOC less than 3.0 mg/L, total organic halides less than 0.2 mg/L, and total nitrogen less than 10.0 mg/L (Crook, 2005; Florida DEP).

Recycled water guidelines are based on both monitoring requirements and performance standards (Ivahnenko, 2004). The California Department of Human Services (DHS) released the first draft criteria for indirect potable reuse via groundwater recharge in 2001. These guidelines are considered the most developed so far and include monitoring requirements related to nitrogen compounds, unregulated emerging chemical contaminants (such as endocrine disruptors and pharmaceuticals), and TOC limits (Crook, 2002). The groundwater recharge reuse draft was released in January 2007, and the DHS is continually updating the guidelines as more information is available. In 2007 the DHS published a report related to technologies that have been recognised as being accepted for compliance with treatment requirements of the California Recycled Water Criteria (CDHS, 2007).

RO is required for all injection projects and the minimum retention time in the aquifers is set at 12 months.

In relation to guidelines for recycled water, several approaches using a risk management framework have been developed as a measure of reducing contaminants in the final product, and therefore providing a minimum level of risk, including Best Available Technology (BAT) (Paustenbach, 1995), the Life Cycle Analysis (LCA) and the Hazard Analysis and Critical Control Points (HACCP) (Miller, 2005, WHO, 2003). The HACCP concept was originally developed for risk management decisions involving health and safety in food and pharmaceuticals (FAO/UNCHS/UNEP, 1998; Kirby, 2003; U.S. FDA, 1997) and has recently been introduced to drinking water (Miller, 2005) and recycled water (Dewettinck, 2001; Westrell, 2004; WHO, 2003). The HACCP approach was used in the Australian Drinking Water Guidelines (NHMRC and NRMMC, 2004) and in the National Guidelines for Water Recycling Phase 1 (EPHC & NRMMC, 2005). These later guidelines include a risk management framework and specific guidance on managing the health risks associated with the use of recycled water for all applications other than potable use. The guidelines are intended to provide a unified approach across Australia, and applications will be included in the second phase which is currently being developed.

(ii) Key issues relevant to current project

- The system approach outlined in the Drinking Water Guidelines and Recycled Water Guidelines will be relevant in this project particularly for regional areas. We may need a different protocol for small systems.
- With the release of the National water recycling guidelines, it is important that Western Australia does not depart from the guidelines unless there is a good reason to do so. A critical review to identify gaps and relevance to Western Australia essential. Researchers also need to consider where guidelines may not be specific to Western Australian situation and develop protocols for these areas.
- It is critical to show different technologies and how they vary from each other e.g. what barriers or processes are included and what are excluded.
- Development of 'scenarios' is an important approach to be developed for this project and may include 'exclusions' of what should not be done in a given situation. We must also to consider how far "down the track" do scenarios need to explore e.g. mosquito issues around treatment sites.
- We must indicate exposure pathways and likely health impacts and what the 'uncertainty' factors are.
- Operational matters are considered the weakness in any system and will need to be adequately addressed in any guidelines.
- Proper management systems are of critical importance and should be highlighted in the report.

3.3. General issues in recycled water monitoring

(i) Background

It is accepted that advanced treatment methods can produce recycled water in compliance with drinking water standard and guidelines. Although this compliance is fundamental for the public health protection, it is not necessarily sufficient to guarantee the safety of the recycled water. Wastewater comprises several contaminants from different sources including domestic, industrial and agricultural discharges. As a consequence, monitoring of emerging and non-regulated contaminants present or suspected to be present in wastewaters needs to be implemented to demonstrate that the concentrations of these contaminants, if present after the treatment, do not pose any additional health risk.

Many recycled water projects now implement monitoring programs to evaluate the treatment efficiency in rejecting organic contaminants, including endocrine disruptors, pharmaceuticals and personal care products and other unregulated compounds. Antibiotics are of special interest because of growing concerns over antimicrobial resistance in human medicine. Disinfection by-products may be generated during the treatment and some of them can be stable, polar and toxic, such as N-nitrosamines and trihalomethanes. Their formation should be avoided or their removal must be ensured in any potable reuse project. Endocrine disruptors (particularly those with an estrogenic effect) produce adverse effects in fish and other species at low concentrations. Within the framework of the precautionary principle, the reliability of treatment methods in removing such compounds needs to be demonstrated for the protection of human health.

New monitoring approaches are required to ensure adequate health protection for a number of reasons: (i) several unregulated chemicals of concern are not routinely included in monitoring programs; (ii) many emerging chemicals of demonstrated or suspected health concern have not as yet standard analytical methods; (iii) some current analytical methods have detection limits above the toxic effects concentrations; and (iv) the possibility of other unknown toxic chemicals in the recycled water. On-line biomonitoring systems have been developed in recent years to evaluate potential health impacts without using concentrates of recycled water by using behavioural and/or physiological stress responses of organisms exposed *in situ* (Gerhardt, 2006). Biomonitoring provides additional assurance that untested or not yet detected chemicals of concern would not go undetected. Biomarkers for endocrine, developmental, and potential reproductive effects in aquatic organisms exposed to recycled water are under development and seem to be a promising area (Schlenk, 2006).

Potential human health effects of previously untested contaminants may necessitate additional regulations. It is fundamental to establish whether these emerging contaminants of concern may pose an additional risk to human health at the concentrations currently reported in recycled water. In order to address the potential effects of organic micropollutants in recycled water, the Western Australia trial project developed a three-tiered approach to systematically evaluate the measured concentrations of contaminants in recycled water against benchmark values. The benchmark values are: (1) drinking water guidelines for regulated chemicals, (2) reference doses or slope factors for unregulated contaminants with toxicological information and (3) the value derived from the threshold of toxicological concern model for unregulated contaminants with limited or no toxicological information (Rodriguez, 2007). This screening approach may help regulators to identify contaminants that require further health risk assessment or need for more toxicological studies. It may also help to communicate the study findings in an effective manner to the community.

(ii) Key issues relevant to current project

Monitoring of recycled water treatment

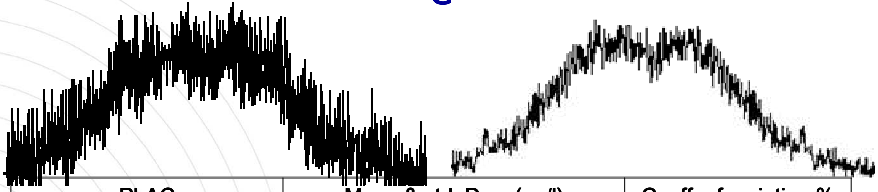
- Monitoring theory and practice is certainly not ideal at this time
- End point testing is the last verification point of the system; however control points are the most important to ensure that the reduction of pathogens or chemicals to safe levels has been achieved.
- It is critical to ensure that any low-level treatment failures must not continue. It is unsure how this is achieved based on current monitoring recommendations
- In any recycled water monitoring system, we need to distinguish between:
  - Routine monitoring vs. hazard investigation v. auditing by regulator
  - Direct "chemicals of concern" monitoring vs. surrogates vs. system performance indicators
  - Tracking and tracing
  - Assessment of baseline performance of a system vs. performance under a hazardous event condition.
  - Monitoring "tailor made" to management requirements.

Variability of treatment effectiveness under normal operation

- In general, a wider range of quantitative descriptions are required. One option is to describe concentrations as probability functions e.g. using Monte Carlo models.
- Individual process performance data can be used to access performance of overall system. This is necessary when contaminants fall below analytical detection limits. Such analysis allows for extrapolation for estimation of probability that treatment goals would be exceeded.
- Sources of variability in processing systems must be considered:
  - Source water quality
    - i. Daily [see **Figure 3.3.1]**
    - ii. Diurnal [see **Figure 3.3.2**]
    - iii. Weather impacts
    - iv. Long-term changes
  - Treatment performance
    - i. Normal variability
    - ii. Gradual change e.g. membrane aging or fouling
    - iii. Hazardous events

Figure 3.3.1. "Normal" variability from grab samples

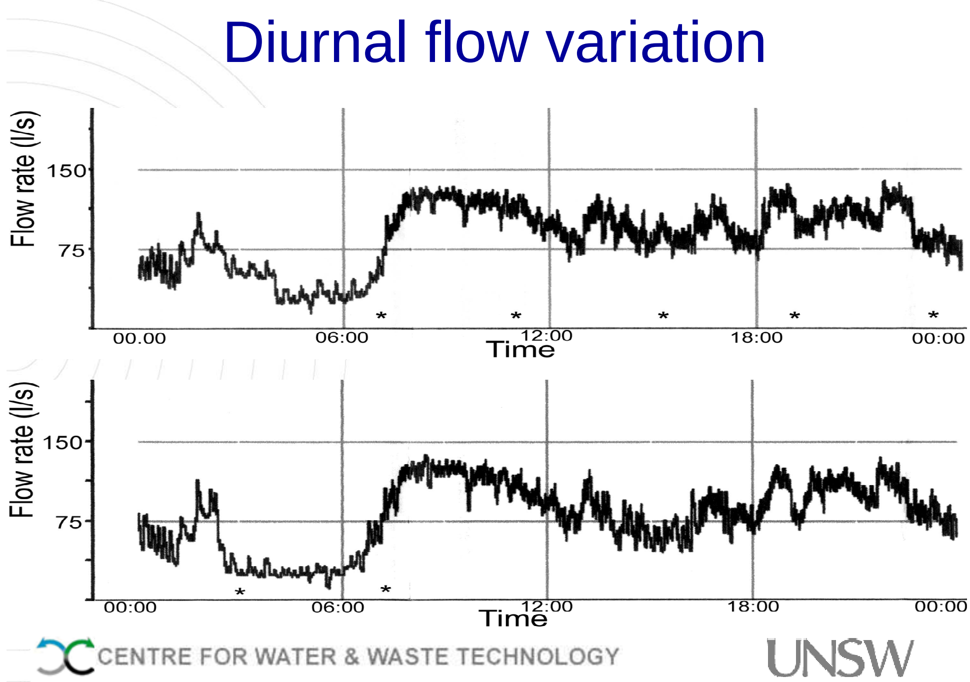
Variation among "grab-samples"



PhAC	Mean & std. Dev. (µg/l)	Coeff. of variation %
Salicylic acid	8.9 ± 0.23	3
Ibuprofen	2.3 ± 0.23	10
Paracetamol	148 ± 17	12
Metronidazole	0.43 ± 0.17	40
Gemfibrozil	1.5 ± 0.06	4
Naproxen	3.8 ± 0.31	8
Methadone	0.06 ± 0.03	50
Ketoprofen	0.13 ± 0.01	8
Phenytoin	0.18 ± 0.04	22
Carbamazepine	0.26 ± 0.04	15
Morphine	0.52 ± 0.11	21

CENTRE FOR WATER & WASTE TECHNOLOGY Khan (2003) UNSW

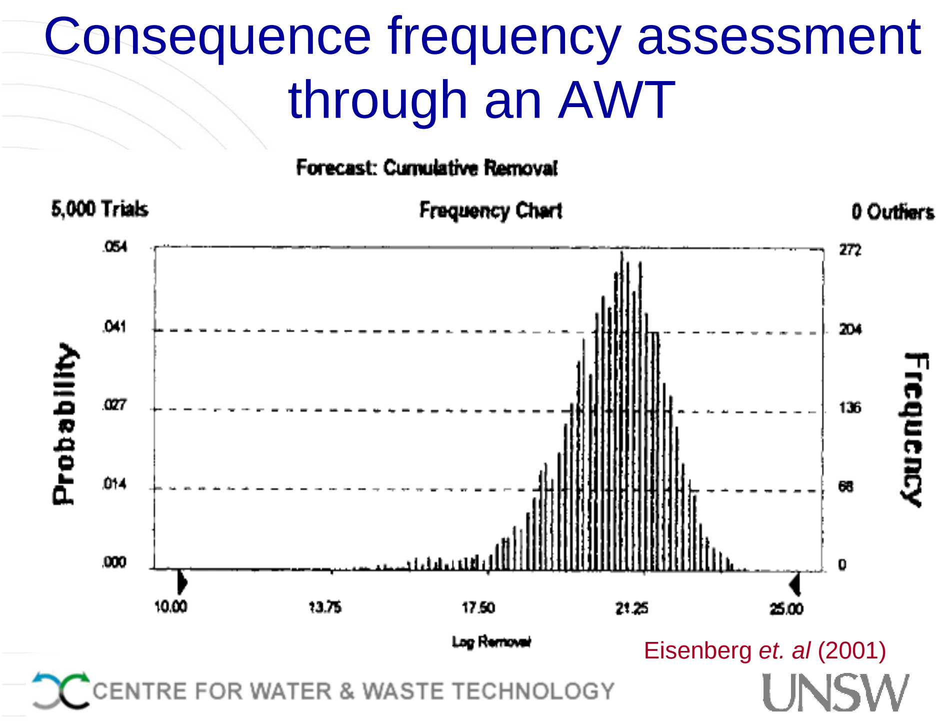
Figure 3.3.2. Diurnal variation in flow rates



Evaluation of recycled water safety using integrated models/ Consequence frequency assessment

- To estimate removal of contaminant through a treatment system, concentrations at each stage of treatment may be described as a conditional probability distribution function. A PDF of plant effluent may be expressed as a multiple integral (one integral for each unit process). However, the multiple integral is often difficult or impossible to process. An example is provided in **Figure 3.3.3.**
- A common alternative is Monte Carlo simulation [see below]

Figure 3.3.3. Example of consequence treatment assessment



Monte Carlo simulations

- Monte Carlo simulations achieve the following:
  - Fit distributions of removal of constituent across each treatment unit
  - Sample each distribution repeatedly
  - Compute final concentration for each set of random samples
  - May represent plant performance in probabilistic manner
  - Explicitly acknowledges uncertainty and variability of the underlying data

Critical components analysis

- This form of analysis is conducted as follows:
  - Identify mechanical components with most immediate impacts on effluent quality should failure occur
  - List all components in facility
  - Categorise:
    - i. By treatment unit
    - ii. Components
    - iii. Subcomponent
  - Collect data for all planned and unplanned maintenance events

– Aggregate data
– Compute performance statistic for treatment units and components: expected frequency of failures. An example is provided in **Figure 3.3.4.**

Figure 3.3.4. Example of critical components analysis

Plant performance statistics for mechanical reliability

Treatment unit	Number of maint. Events[1]	Number of unplanned events[2]	ETBF (days)[3]	Operating availability[4]
Headworks	16	13	26	0.9953
Primary	36	28	41	0.9985
Secondary	82	40	9	0.9757
Tertiary	30	27	13	0.9994
UV	1	1	212	0.9991
Reverse Osmosis	55	35	10	0.9990

[1]Number of times repairs were made including scheduled maintenance on components within the given unit.
[2]Number of times repairs were made due to component failure within the unit.
[3]Expected time between failure somewhere in unit process, based on chi-square distribution.
[4]Fraction of the study period that all components in the unit were operating.

Eisenberg *et. al* (2001)

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

<u>Monitoring hazardous events</u>

- This is defined as an incident or situation that can lead to exposure to a hazard. Examples include:
  – Treatment failure or underperformance
  – Variable production of disinfection by-products
  – Dual reticulation cross-connection
- To assess such events fully, we often require detailed long-term performance data.
- We need to define the nature of potential hazardous events, that is:
  – How poorly may a process perform?
  – When is it likely to occur?
  – How long may underperformance or failure persist?

3.4. Microbial contaminants

(i) Background

One of the major health risks in recycled water relate to the pathogens capable of causing enteric illness, which are at particularly high levels in sewage. Numbers of individual pathogens will vary depending on rates of illness in the humans and animals contributing faecal waste. The disease burden (e.g. excess cases of gastrointestinal disease) relates to the type of microbial pathogens.

Advance treatment (MF/RO) achieves very efficient removal of pathogens and several projects reported excellent microbial log reduction performance with non-detection of bacteria, protozoa and even viruses in the RO effluent. Viruses are the biological contaminants of major concern in recycled water, not only because of the large numbers present in wastewater but also their smaller size (range from 0.01 to 0.1 microns). Because pathogenic viruses have the potential to cause disease outbreaks from short-term exposures, they are a high public health priority. Despite the fact that MF alone produced a 1.9 log removal of MS2 bacteriophage (Jolis, 1996) and ultrafiltration can provide 4 log removal (Beverly, 2001), MS2 has been detected in the RO permeate as a result of gaps or pores in membrane structure (Hu, 2003). In addition, variable log removals has been reported with variable influent concentrations of MS2 (Hu, 2003) and the MS2 sensitivity to the ultraviolet (UV) light was not constant (Jolis, 1996). These issues are complicated by difficulties in isolation the virus and the cost of the analysis. Therefore, projects considering recycling need to perform appropriate challenge tests for viruses to ensure the treatment efficiently remove these contaminants.

Suitable reference pathogens to assess water quality are those that present a worst case combination of:

- high occurrence
- high concentration in water to be recycled
- high pathogenicity
- low removal in treatment
- long survival in the environment.

The acceptable limits for microbial contaminants in recycled water have been defined in a number of reports, such as **Table 3.4.1.** (Salgot, 2006):

Figure 3.4.1. Microbial limits in recycled wastewater

Overview of the compiled and estimated microbiological limits for reclaimed wastewater reuse I (bacteria)

Use	Total bacteria (cfu/mL)	Faecal coliforms[a] (cfu/100 mL)	*Clostridium perfringens* (cfu/mL)	*Legionella* (cfu/100 mL)	Enterococci (cfu/100 mL)	*Salmonella* (cfu/mL)
I	<1,000–<10,000	Abs	Abs–20	<100	Abs	Abs–1,000
II	<1,000	<20–<1,000	Abs–10	—	<1,000	Abs–1,000
III	<10,000	Abs–<1,000	<1	<100	<20	Abs–1,000
IV	<10,000–<100,000	Abs–<10,000	<10	Abs	<1,000	<1
V	<100,000	Abs–<10,000	<100	—	<10,000	<0.1
VI	<10,000	<200–<10,000	<1	—	<20	Abs–1,000
VII	<10,000	Abs–<10,000	<10	Abs–<100	<1,000	<1

[a]or *E. coli*. cfu = colony forming units; Abs = absent.

Overview of the compiled and estimated microbiological limits for reclaimed wastewater reuse II (not bacteria)

Use	Enteroviruses (pfu/L)	Coliphages (pfu/L)	*Cryptosporidium* and *Giardia* (cyst/50 mL)	Nematode eggs (eggs/L)	*T. saginata* (egg/L)	*T. solium* (egg/L)
I	Abs–10	<1	<1	<1–10	—	—
II	Abs–10	<1	<1	<1	—	—
III	<1–<100	<1,000	<10	<1	—	—
IV	—	—	—	<1	—	—
V	—	—	—	<1	<1	<1
VI	<100	<1,000	<10	<1	—	—
VII	<1–0.04	—	—	<1	—	—

pfu = plaque forming units; Abs = absent.

The indicator organisms selected for recycled water are as follows (summarised in **Table 3.4.2.** below; National Water Quality Management Strategy, 2006).

Figure 3.4.2. Pathogen indicators in recycled wastewater

Type/organism	Usually/theoretically employed as	On research	Observations
Total coliforms	Bacterial indicator		Not widely used
Faecal coliforms/ *E. coli*	Faecal indicator	Faster methods	Most used method, despite the problems and discussions
Bacteriophage	Faecal indicator	Most suitable one	Somatic, F-specific and *Bacteroides fragilis* HSP40 and RYC2056 phages
Bacterial count	Indicator for aerobic, heterotrophic bacteria	Amount of DNA/RNA	Recovery of not more than 10%
Nematode eggs	Nematode and helminth indicator	Better concentration methods. Viability	Recovery of not more than 70%
Giardia lamblia	Direct detection of cysts	Better concentration and detection methods. Viability	In wastewater, false positives can be found in high numbers
Cryptosporidium parvum	Direct detection of oocysts	Better concentration and detection methods. Viability	In wastewater, false positives can be found in high numbers

(National Water Quality Management Strategy, 2006).

(ii) Key issues relevant to current project

- It is critical to develop a list of organisms, apart from the indicator organisms already identified in the national guidelines, which will be relevant for sampling purposes (e.g. noroviruses). However, local considerations will need to taken into account e.g. hookworm in north of the State. Indicator organisms are very important in low-level treatment systems but must still be considered in higher treatment systems.
- The role of emerging organisms must be considered, including ExPEC (extraintestinal pathogenic E.coli). Prions are considered too difficult for modelling.
- Any State specific document should address: indicator organisms; significance of *Pseudomonas, Legionella* and *Naegleria spp.* as applicable to WA guidelines; and organisms for future consideration e.g. prions and cyanobacteria.
- A further literature review required on indicators of "biological activity" e.g. proteins, bacterial lipopolysaccharides. Faecal sterols significant for major events but limited value for small events or where low levels are recorded.
- There is growing concern with opportunistic pathogens growing in pipes/garden hoses which may be subject to hot conditions and resultant impact from spraying or aerosols.

3.5. Chemicals of concern

(i) Background

There is an increasing requirement for the inclusion of chemical parameters in guidelines or regulations concerning reuse of reclaimed wastewater. Risk estimates also vary with the particular water application (e.g. for irrigation; horticulture; consumption etc). Many toxic chemicals only have an observable effect only after long-term exposure (e.g. over months or years). The range of chemical agents is extensive and has to be considered in relation to the source, treatment process and intended use of the treated water. Assessment of chemical contaminants needs to include chemicals of concern (COC) with and without maximum contaminant levels (MCL) in drinking water, as well as TICs (tentatively identified compounds, which may not be individually measured but are subject to management e.g. through reduction of total organic carbon and nitrates).

Most inorganic chemicals are not considered to be problematic due to high rejection proportions, and either non-detection or very low concentrations in the RO permeate (OCWD, 2004; City of San Diego, 2005). While organic chemicals of high molecular weight are effectively rejected by the MF/RO treatment, organic chemicals of low molecular weight (less than 500 Dalton) have been detected in the RO permeate (Drewes, 2002). In the studies conducted so far, high percentages of organic contaminant removal are commonly reported. RO can remove up to 95% of hormones (Huang, 2001), and more than 95% of all tested analytes including 16 pharmaceuticals and 3 personal care products (Kim, 2007). In general, membranes are able to reject most of the endocrine disruptors, pharmaceuticals and personal care products, with the exception of lower molecular weight unchanged compounds (Snyder, 2003; Agenson, 2003). Incomplete rejection of certain pesticides, disinfection by-products, endocrine disrupting compounds, and pharmaceutically active compounds has been reported during full- and pilot-scale high-pressure membrane applications (Bellona, 2004).

A major group of contaminants of concern are *endocrine disrupting chemicals* (such as pesticides, PCBs, and synthetic human and animal steroid hormones), which induce biological effects at very low concentrations and may be poorly removed by conventional water treatment processes. Sewage treatment processes, including secondary treatment, substantially reduce concentrations of endocrine disrupting chemicals. For many chemicals of concern, such as endocrine disrupting chemicals and pharmaceutically active compounds, in general very low concentrations are detected in recycled water with very low potential doses. Thus, it is likely that there is minimal potential human health impact from many such agents, even taking into account lifetime projected doses.

A number of problems arise in inferring risk, particularly for long-term contact with recycled water. Risk estimates may be complex because:

- although an aggregate exposure may be inferred, inter-individual differences exist between uptake and metabolisms of agents
- at low levels of exposure, the epidemiological estimation of actual risk to exposed humans may be inaccurate because of insufficient statistical power to detect health outcome and the presence of confounders (e.g. smoking)
- modelling complex mixtures and exposures to multiple agents is often challenging
- setting exposure limits in water may disregard the fact that individuals come into contact with agents from other pathways and sources
- the periodicity of exposure may be important, yet dose rates are often represented just as average dose rates or cumulative dose

Indicators of biological activity/end-point toxicity of recycled water, including:

- ***In vitro* indicators** used to evaluate endpoints, such as genetic damage (e.g. micronucleus test); disturbances in enzymatic or cellular functioning
- ***In vivo* indicators** e.g. animal testing for carcinogenesis; hormonal effects (oestrogenicity, etc); fetotoxicity; other subchronic effects
- **indicators of environmental activity** e.g. estrogenic effects on aquatic organisms in water catchments

Assessment of chemical is increasingly making use of functional toxicology screens that allow an assessment of the degree to which a single compound or multiple compounds might exhibit some other functional activity (e.g. 'dioxin-like' or oestrogenic activity). Toxic equivalency factors (TEFs)/ relative potency factors (RPFs) may be used to estimate potencies for single compounds or mixtures.

It remains uncertain which of these is the optimal bioassay (or combination of bioassays) to use. In the environmental context, a relevant project called "*Development of an Ecotoxicity Toolbox to Evaluate Water Quality for Recycling*" is being conducted by WA Department of Water, Water Corporation, CRC WQT, UNSW (CWWT) and Curtin University. Another project of relevance is "*A national approach to risk assessment, risk communication and management of chemical hazards from recycled water*" coordinated by CRC WQT / WQRA, UNSW (CWWT), EnTox, Australian Water Quality Centre (SA Water), Melbourne Water, Sydney Water, ACTEW (ACT), United Water.

(ii) Key issues relevant to current project

- It is essential to compile a list of chemicals which are removed: adequately, poorly etc to show the effectiveness of the membrane system and indicate if treatment process is working. Therefore, a specific list of chemicals for monitoring will be essential as opposed to the potential list of chemicals. The rationale for eliminating any chemicals from the list must be described.
- Surrogates and indicators will be addressed in the Australian National Guidelines. It is also important to undertake a comparison of US models to Western Australia guidelines and significance of the numbers derived from various models.
- A screening risk assessment is considered a very important tool in determining risk from chemicals. Key chemical indicators will be available from research by Clemencia Rodriguez.
- The current list of chemicals may not be valid in five years time, therefore some risk modelling will be necessary to provide to government agencies.
- It is critical to clarify the acute and chronic effects of chemicals.
- This project should address the matter of bioassays and in particular two projects underway (e.g. Water Corporation and CRC WQRA), as well as a review of overseas research.

3.6. Applications of risk assessment to recycled water

(i) Background

[NB: Refer to **Section 4** for a detailed description of risk assessment approaches.]

Assessment of risk is undertaken in relation to recycled water supplies for a number of reasons (Hunter, 2003), including:

- to predict the burden of waterborne disease in the community in both outbreak and non-outbreak conditions;
- to assist in setting target reference pathogen levels for recycled water supplies that will equate to tolerable levels of illness within populations exposed to that water;
- to identify the most cost effective method to reduce pathogen related health risks to those exposed to recycled water;
- to assist in determining the optimum balance in terms of pathogen kill versus the formation of disinfection by-products (DBPs);
- to provide a conceptual framework for consumers, organizations, regulators and industry to understand the nature and risk to, and from, recycled water and how those risks can be managed.

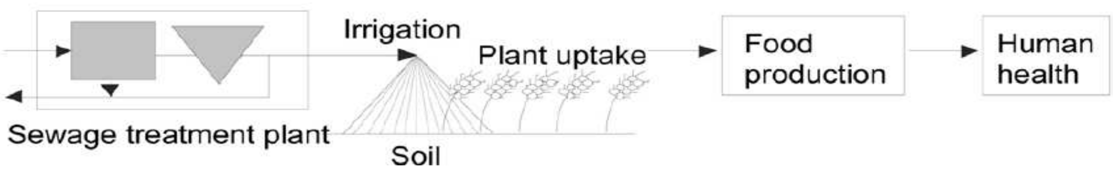
With respect to water recycling, health risk assessment components include consideration of:

- Chemical exposure
- Pathogen exposure
- System reliability / hazardous events analysis

Measurements of biological and chemical concentrations have been modelled in an attempt to provide a valid exposure measure for individuals that may be in contact with the recycled water process. The pathways for contact may sometimes arise from a number of potential pathways. For example, in the irrigation of agricultural land with reclaimed wastewater, four major anticipated pathways of exposure are shown in Table 2. This is does not include additional exposure routes which may be significant for people working directly with the irrigation scheme (**Figure 3.6.1.**; Salgot, 2006):

Figure 3.6.1. Possible pathways of exposure for chemicals in recycled water in an agricultural setting

Pathway	Scenario
Reclaimed water irrigation → soil → plant uptake → food production → human toxicity	Ingestion of food plants cultivated on land irrigated with reclaimed water
Reclaimed water irrigation → soil → plant uptake → animal uptake → human toxicity	Ingestion of meat/animal products from animals pasture on land irrigated with reclaimed water
Reclaimed water irrigation → soil → vadoze zone → groundwater → human toxicity	Ingestion of drinking water produced from groundwater polluted by reclaimed water
Reclaimed water irrigation → atmosphere → human toxicity	Inhalation of volatile contaminants during irrigation process



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The Department of Health and Ageing and En Health Council (2004) note that risk assessments may not always provide a compelling or definitive outcome. Some specific criticisms of the approach are as follows:

- Default values and assumptions are not always realistic, which could lead to risks being seriously overstated or understated if the default values are too conservative or insufficiently conservative respectively;
- Interactions between agents (such as synergist and antagonist effects) may not be adequately accounted for;
- Using default values and assumptions may become too rigid so that circumstance specific data are not utilised;
- The target population to whom the data is applied is often poorly defined, (i.e. often assumed to be a healthy "Western" target population);
- The uncertainties of risk assessment are often not adequately described, point estimates are often used with no real recognition of uncertainty;
- For chemicals of concern, the main emphasis is on cancer risk, at the potential neglect of other adverse health effects such as reproductive and developmental outcomes;
- There may be insufficient information to perform credible risk assessments;
- Risk assessment can be perceived to be tailored to provided a predetermined outcome;
- Often excessive emphasis is given to the process of the risk assessment rather than the content;
- The risk assessment process can be seen by the public and interest groups as a "whitewash";
- Risk assessment can be seen as a method of justifying the continuation or increase of potentially harmful activities.

(ii) Key issues relevant to current project

- It is important to define the difference between 'Qualitative' and 'Quantitative' risk assessments.
- In The National Water Quality Management Strategy – Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1), The tolerable DALYs risk of 10^{-6} that has been set assumes an increased lifetime cancer risk of 1 in 1 00 000 and an increased annual risk of diarrhoeal disease of 1 in 1000. Although DALYs are being used as the predominant health measure, it is important to consider their limitations.
- Risk assessment is not absolute and will needs to be looked at historically and be relevant to the situation.
- A problem with epidemiological studies is that they will not always identify a problem. However, long term data from epidemiological studies are very useful.

3.7. Resource needs for assessing recycled water safety

(i) Background

There is some uncertainty around the expertise, time, and money available within government agencies and affiliated organisations for assessing risks of recycled water use. For example, currently it is difficult to interpret and compare the treatment efficiency to remove emerging contaminants. Analytical methods are at the research stage for measuring many of these contaminants. Therefore, more research is needed not only to identify other potential contaminants of concern in recycled water, but also in the development of validated methods and the implementation of harmonized analytical methods.

Such analytical methods for emerging contaminants and other unregulated contaminants will: (i) facilitate the risk assessment and regulatory process by providing better quality data, (ii) provide comparative information about contaminant fate and removal during the treatment barriers and (iii) assist the analysis of different treatment options to remove contaminants. In future years, it is expected that progress will be made in the validation and standardization of chemical analysis and biomonitoring techniques for recycled water relating to emerging pollutants.

Regulators allowing recycling projects need to implement well-coordinated public health surveillance systems to document and possibly provide early warning of any adverse health events associated with the ingestion of recycled water. Surveillance systems must be jointly planned and operated by health departments, water utilities and other interested stakeholders. Key individuals in each agency need to be appointed to coordinate planning and rehearse emergency procedures. The surveillance plan, its purpose, the monitoring results, and the system process performance should be open to the public and interested stakeholders.

In addition to the health surveillance program, the national research capacity needs to be enhanced to implement a monitoring program that provides an early warning system of potential health impacts from newly detected or emerging contaminants. In order for this monitoring system to be effective, a multi-institutional effort is required for the documentation and monitoring of all major chemical wastewater inputs from household, commercial, agricultural and industrial sources. Pre-established risk mitigation measures also need to be in place.

(ii) Key issues relevant to current project

- There is some uncertainty around the expertise, time, and money available within government agencies and affiliated organisations for assessing risks of recycled water use
- Resource implications particularly for health agencies are a very real issue and must be highlighted in any recycled water assessment.
- Economic analysis is an important consideration with any scheme and should be presented in any recycled water assessment.
- Resource issues for laboratories in regard to chemical analyses are not considered an issue whereas microbiological analyses are considered a resource issue in Western Australia.

- Software offers much promise for facilitating assessments, access to information such as data tables efficiently, comparing the risks, providing initial assessments of specific site risks. However, such systems need to have experts to construct, operate and maintain and this takes resources. There is a long history of "dead" pilot software – the ideas seem sound but the implementation is poor.
- The most useful end-products for a risk assessment were identified as:
  - A flexible software package to asses risk in different scenarios
  - A system for providing external advice on new schemes
  - An applied form of the guidelines

3.8. Public acceptance of recycled water projects

(i) Background

Although communities have been readily accepting recycled water for non-drinking purposes such as irrigation of parks, they are less likely to accept the use of recycled water as a drinking water source. Emotions, or the 'yuck' factor play a huge part in people's acceptance. This perception occurs despite the fact that current treatment technologies can achieve recycled water that meets drinking water standards. Important progress has occurred during the last decade to identify factors of success or failure in the implementation of recycling projects (Hartley, 2006; WERF, 2000; WRF, 2004). In terms of risk perception, communities have significant concerns regarding the potential health impacts of industrial, agricultural and household chemicals in recycled water entering their potable water supply (Rodriguez, 2007). Five aspects were identified by the Water Environment Foundation for building and maintaining community support in recycling projects: (1) "managing information for all stakeholders; (2) maintaining individual motivation and demonstrating organizational commitment; (3) promoting communication and public dialogue; (4) ensuring a fair and sound decision-making process and outcome; and (5) building and maintaining trust" (Hartley, 2006). Promoting communication and public dialogue, building and maintaining trust have also been identified as key aspects in other studies (Marks, 2003; Holliman, 2004; Po, 2005).

Effective communication between the community, key stakeholders and the project proponent is crucial to achieve community support. All recycled water projects need to be accompanied by public education to demonstrate that the current technology is adequate to protect human health, and a communication program to assure the public that contaminants present in wastewater can be effectively and reliable removed. The experience in the US indicated that community understanding and acceptance may need several years, but that such a process is fundamental for a successful implementation of recycled water projects. More social research is needed to understand the psychological factors related to; perception of risk, motivations, attitudes, beliefs and behaviour in the use of recycled water to supplement existing water supplies.

(ii) Key issues relevant to current project

<u>Overview of public perception issues and recycled water use in Australia</u>

- The public may need to be assured with a health risk assessment method, rather than just a description of monitoring. The public will want to know what level of health surveillance is occurring with each system and that the system is working and being managed correctly.

- A Western Australian survey indicated that 'public health' and 'trust' were the most significant factors in accepting recycled water schemes, and water 'contaminants' were a common concern.
- System failure is the greatest concern of the public over technical issues when addressing trust issue.
- We must also establish confidence that the management system which reports to the community is effective.
- Trust in regional areas may be greater due to their historic use and general acceptance of recycled water as compared to city areas which have had no or little exposure to such schemes.
- It is widely acknowledged that we have a valuable resource in recycled water and that is not given a sufficient profile in community discussions i.e. take 'above radar approach' in presenting to the public, rather than looking at the less relevant detail.
- It is important to factor in the energy savings of the different systems and convey to the public.
- It is unclear what the purpose is in treating recycled water to a high level and then not making appropriate use of it. The public should be aware of all alternatives and options available and the economics of proposals.
- Need to communicate to the public both from a marketing and science point of view.
- There is a lack of health promotion messages to improve 'public trust'.
- It is critical to consider the types of applications, treatment processes and health risks should a system break down or fail. It is important to define the real infrastructures issues applicable to health and what is the risk arising from the quality of water for the various uses.
- We need for a 'Framework' on how all the parts of a system works; monitoring details; auditing program and failure response plan which the community is aware of. This must include a feedback component to show that agencies complied with the framework. We also need a contingency plan for diverting the water in cases of plant failure. It may be appropriate to develop suitable graphics of the systems to enable the public to understand how each one works etc.
- Not all experts have accepted that use of a natural buffer (e.g. groundwater aquifer) was a means of improving or reducing the 'risk' factor.

<u>Actual or perceived risks</u>

- It is essential to consider people's attitude to risk: there is a contrast between risks they elect to take themselves. We need to compare being forced to use recycled water versus volunteering to accept.
- Any recycled water project will need to clearly articulate 'health risks' given there are other competing agendas with recycled water issues.
- The health risk, dependent on the treatment process and how the system is managed, is the greater concern to the public in its perceptions on the use of recycled water.
- It is important to provide a modelling framework that will give a high degree of flexibility in considering possible risks, and allows stakeholders to test the assumptions of and scenarios established by the model.
- It is essential to develop a 'health framework' to the show public what the issues are and link with a health risk approach and real health concerns.

- We need to identify those chemicals which are seen by the public as having the element of 'uncertainty', and provide the available research evidence to enable the public to understand the 'risk' factor for such chemicals.
- The public has some difficultly in understanding terms such as 'low risk', 'probability' and 'uncertainty'. It is important to communicate these terms in public forums.
- In setting a 'health guideline', it often assumed by the public that if the water meets the guideline value then it is 'safe' or 'presents no health risk'.
- It is important to have community discussion early in the process and to involve external experts e.g. universities, etc to enable all issues to be fully presented and discussed.
- We need to demonstrate to the various communities what are the 'acceptable risks' and the management options based on the exposure pathways for the types of systems used.
- Risk perception may vary between small and large schemes and concerns with smaller scheme failures, monitoring and management procedures. It is important to differentiate between small and large systems the level of control required for each system.
- Health agencies have an important role and must have competent staff particularly in regard assessment and auditing recycling schemes.
- We may require multiple communication steps to address the various issues that will arise for different applications.

4. Approaches to an integrated risk assessment for recycled water

4.1. Overview of risk assessment models for recycled water

Definitions and evaluation of risk

Risk is defined by (The National Water Quality Management Strategy – Australian Guidelines for Water Recycling: Managing Health and Environmental Risks: Phase 1) as *"The likelihood of a hazard causing harm in exposed populations in a specified time frame, including the magnitude of that harm"*. The methods for assessing risks arising from recycled water include:

- *Epidemiological investigations.*
- *Qualitative risk assessment (with risk ranking).*
- *Quantitative Microbial Risk Assessment (QMRA).*

These approaches are summarised in **Table 4.1.1 (Bartram, 2001)**

Table 4.1.1. Frameworks for assessing risk from water contaminants

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

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

Epidemiological analysis

Most epidemiological data for waterborne disease are provided from outbreak investigations which provide valuable data for the assessment of risk. An example is the Namibia direct potable recycled water scheme, one of the most widely studied recycled water schemes in the world today. Isaacson (1988) conducted a population based study on the consumption of recycled water in Namibia and did not observe an increased risk of gastrointestinal illness.

Hunter et al (2003) note that outbreak investigations may provide useful information regarding which failures in the water supply and distribution chain lead to risks to public health, such as the Milwaukee *Cryptosporidium sp.* outbreak in 1993. Outbreak investigations will also provide information on non-water exposure pathways that could be related to the outbreak pathogen. However, Andersson (2001) argue that outbreak data are somewhat limited in that they do not provide any context as to what proportion of the burden of disease has been contributed via sporadic spread from the water route. Nor is it clearly established that the factors that are responsible for the failure leading to outbreaks are the same as those for the sporadic disease occurrence.

The most common types of epidemiological study that have been used in risk assessments of waterborne disease are indicated in **Table 4.1.2.**

Table 4.1.2. Common epidemiological study types

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

(Adapted from Hunter et al., 2003)

Other types of epidemiological analysis include dynamic risk assessment models, which include the possibility of person-to-person transmission of pathogens. Individuals may be classified as susceptible, carriers, diseased, post-infection and immune, and may move between these states. The differences in incidence may be estimated using a Classification and Regression Tree (CART) to determine which parameters affect disease rates (WERF, 2004). The CART approach has also been used to classify outputs into low and high incidence. Parameters of importance include: the dose of the pathogen/toxicant, exposure intensity, dose-response parameters and the duration of infection (all of these vary depending on the pathogen) or contact with toxicant. Various conditions will be modelled to determine their subsequent risk:

- pattern of exposure
- population exposed
- sensitive populations
- (for infectious diseases) proportions with asymptomatic illness
- proportion with acute symptomatology
- proportion detected using surveillance mechanisms
- proportion confirmed using laboratory investigations
- outcomes: death; chronic illness; hospitalisations; work days lost

The evidence from epidemiological studies – such as those using cohort and case-control designs – may be formally evaluated using meta-analyses. The object of the analysis may be (i) to determine whether an agent is a carcinogen; (ii) to determine whether an agent that is carcinogenic at high doses exerts a health effect at low doses; (iii) to extrapolate the effect of other related compounds, such as using toxicity equivalence factor (TEF). For cohort studies, this will usually take the form of an excess relative risk model, in which the parameter β represents the excess relative risk per unit of exposure.

For a linear risk model:

$$\lambda_{jk} = \lambda_{j0}[1+\beta_{xk}]$$

where

λ_{jk} = rate of disease for the number of person years, for a given exposure level k and level of covariates j

λ_{j0} = the background rate for non-exposure level 0 and level of covariates j

β_{xk} = represents the excess relative risk per unit of exposure at a given mean level of exposure x (for a given exposure level k)

This relationship can be expressed in a more flexible form as generalised linear models (GLMs), in which an appropriate distribution (e.g. Poisson) and link function is used. Additive, interactive and multiplicative models can be used to determine the excess risk or relative risk. The nature of the model and the shape of the dose-response curve are usually guided by Armitage-Doll multistage equations/pharmacokinetic modelling.

<u>Qualitative risk assessment (with risk ranking)</u>

Examples of qualitative risk assessment (with risk ranking) for recycled water risks are indicated in **Table 4.1.3.** (National Water Quality Management Strategy, 2006).

Table 4.1.3. Qualitative measures of recycled water risk

Table 4.5 Qualitative measures of likelihood

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

Table 4.6 Qualitative measures of consequence or impact

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

Table 4.7 Qualitative risk estimation

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

(National Water Quality Management Strategy, 2006)

4.2. Application of risk frameworks for waterborne disease

<u>Overview</u>

Evaluation of the health risks of water contamination often uses some form of risk assessment. Most models are based upon the principles of:

- *Hazard assessment*
- *Exposure assessment*
- *Dose-response analysis*
- *Risk characterisation*

The usual model of choice in Australia is Quantitative Microbial Risk Assessment (QMRA). QMRA is a mathematical risk assessment model that can accurately predict the risk associated with exposure to reference pathogens in the key pathogen groups (bacteria, viruses and protozoa) in source waters (Havelaar, 2003). Past authorities have noted the improved sensitivity of QMRA compared to epidemiological studies, particularly to estimate risks associated with specific pathogens and specific exposure pathways (including in a recycled water context) (World Health Organisation, 2006). QMRA assessments are typically easier and less expensive to perform than epidemiological studies, not requiring extensively large study groups or follow up periods, nor are they subject to the influences of confounding and bias.

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

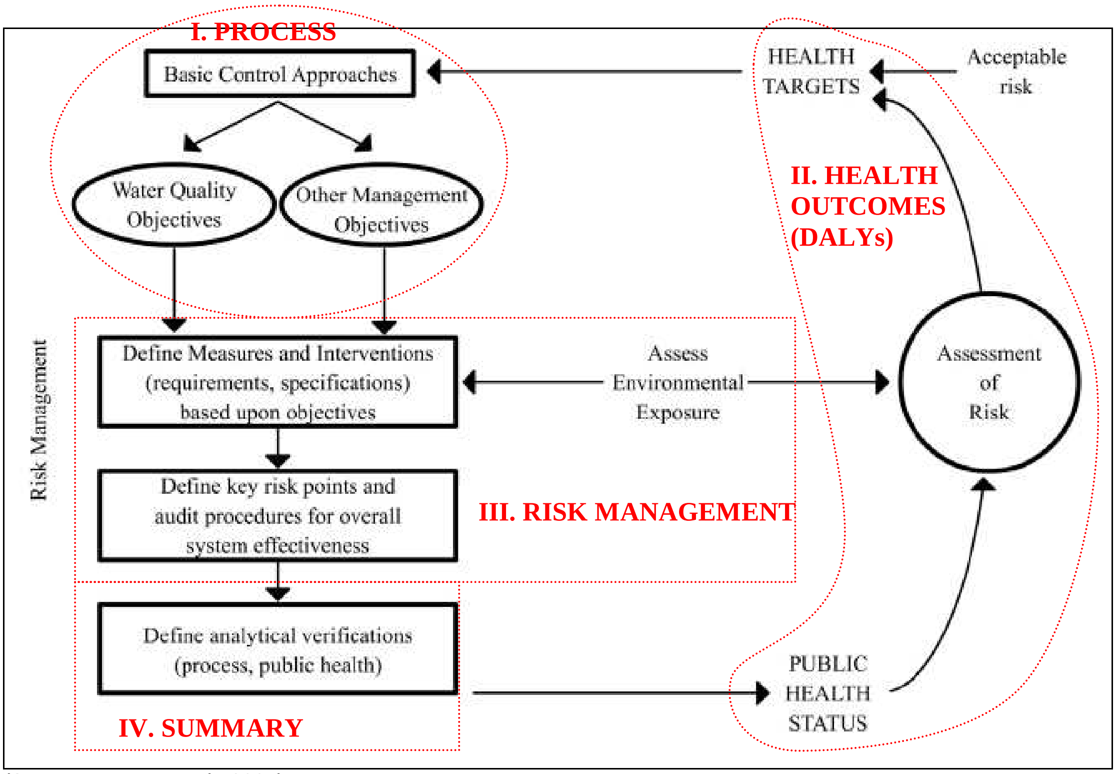
<u>The Stockholm Framework</u>

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

The Stockholm Framework involves the assessment of health risks prior to the setting of health targets, the development of guideline values with defining basic control or management systems and then evaluating the impact of these approaches on public health (World Health Organisation, 2006). The World Health Organisation (2006) notes that the framework can accommodate local social, cultural, economic and environmental circumstances that may contribute to potential confounding exposures, such as foodborne pathogens as well as traditional water and sanitation exposure routes. Intrinsically, this facilitates the management of infectious diseases in an integrated holistic manner, incorporating other diseases and exposure routes (World Health Organisation, 2006). Key elements and considerations of the Stockholm Framework are indicated in **Figure 4.2.1.**

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

Figure 4.2.1. – Stockholm Framework



(Source: Bartram et al., 2001)

Applying the Stockholm Framework to recycled water

As applied to recycled water exposure, assessment of health risks within the Stockholm Framework is an iterative process that considers the environmental conditions - including the currency and integrity of available data on such conditions - within which recycled water systems are operating (Bartram, 2001). Underpinning the risk assessment for such waters are data input tools such as epidemiological evidence, communicable disease investigations, microbial risk assessment studies and studies of environmental behaviour of microbes that could be extrapolated to the human population setting (Bartram, 2001).

The current Australian model incorporates many of these concepts, particularly the utilisation of quantitative microbial risk assessment (QMRA) to determine the likelihood of illness or infection associated with recycled water exposure and the production of DALYs to convert these likelihoods into burdens of disease (Natural Resource Management Ministerial Council, 2006). The DALY approach to assessing public health outcomes to allow risk management decisions to be prioritised is largely equivalent to the model that has been adopted in both phases of the *Australian Guidelines for Water Recycling (2006 and 2007).*

Tolerable (Acceptable) Risk

Previously, the concept of tolerable or "acceptable" risk has been defined as maximum levels of infection or disease in the community. Hunter (2001) elucidate criteria for determining as to whether a particular risk is deemed to be acceptable. They argue that a risk is acceptable if it complies with the following:

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

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

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

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

DALYs = YLL (years of life lost) + YLD (years lived with a disability or illness)

YLL is defined as years of life lost to a fatal condition (Murray, 1997), while YLD is defined as years lost to disability with nonfatal conditions, injuries and diseases (Guerrant, 2002).

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

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

In the context of water contaminants, the 'acceptable' risk approach in its most basic form fails to consider or identify the potential severity or sequelae associated with different hazards such as the differences between – for example - mild diarrhoea, typhoid, haemolytic uraemic syndrome and cancer (Natural Resource Management Ministerial Council *,* 2006). DALYs overcome this shortcoming by providing a metric for severity in terms of cumulative consideration of years lived with the disease or disability and years of life lost. WHO has determined that for water-related exposures, a disease burden of 1×10^{-6} DALYs (called 1 micro-DALY) per person per year (from a chemical or pathogen source transmitted via drinking water) is a tolerable risk (WHO, 2003). The level of health burden is equal to a mild case of diarrhoea with a low mortality rate (1 in 100 000) with an annual incidence risk of disease of 1 in 1000, which equates to 1 in 10 over an average lifetime (WHO, 1996; Havelaar, 2003). Comparatively, the US Environmental Protection Agency (US EPA) sets tolerable risk level using risk of infection rather than the manifestation of the disease (Aertgeerts, 2003). For example for *Giardia intestinalis* infection, the US EPA sets a tolerable risk of less than 1 in 10 000 people per year (10^{-4}) risk from drinking water. Haas (1999) has described this as too low, given the rates of gastrointestinal disease in the general population.

In Australia, *The National Water Quality Management Strategy – Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1)* has set the target value of 10^{-6} DALYs (=1 μDALY) that, if exceeded, is a potentially unacceptable risk. The extent of exceedance of DALYs or guideline values (in the case of chemicals) for recycled water and the frequency of those exceedances can be used to estimate risk as outlined in the *Australian Guidelines for Water Recycling Augmentation of Drinking Water Supplies 2007*.*

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* Examples of DALY Calculations: An Australian example from the National Water Quality Management Strategy – Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) for rotavirus infection is as follows:

- mild diarrhoea (severity of illness weighting 0.1) lasting 3 days in 97.5% of cases;

DALYs in the development of Health Based Targets

Once the tolerable risk has been established health based targets can be set for the key chemical and microbial hazard parameters. This enables a recycled water scheme (operating, for example, under Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1)), to achieve the tolerable risk of 10^{-6} DALYs per person per year. The establishment of these key chemical and microbial parameters, usually in the form of guideline values for chemicals and performance targets for microbial hazards, underpin the development of risk management plans for recycled water schemes (Natural Resource Management Ministerial Council, 2006).

Performance targets determine the required level of hazard reduction by measures such as treatment processes and on-site controls (reducing both hazards and exposure) (Natural Resource Management Ministerial Council , 2006). The removal targets will of course be largely dependant upon the hazard concentration in the source water, particularly with reference to specific reference pathogens (eg *Campylobacter jejuni* for bacteria; rotavirus for viruses; and *Cryptosporidium parvum* for protozoa). The *Australian Guidelines for Water Recycling* sets log reduction targets for these reference pathogens, to ensure that end use water is fit for purpose as is illustrated in **Table 4.2.1.** Viral, protozoal and bacterial log reduction targets assume a known quantity of reference pathogens in the influent water.

Establishing DALYs for chemical hazards in recycled water is an emerging area. Assessment has usually relied on the chemical risks attributed to genotoxic carcinogens being measured in terms of an increased attributable cancer risk over a lifetime (Havelaar, 2003). The current Australian Drinking Water Guidelines (ADWG) (2004) sets target values for chemical parameters based upon on the highest dose that causes no observable adverse effects (NOAEL), validated from long term animal studies (Natural Resource Management Ministerial Council , 2007). The World Health Organisation (WHO) also calculate a guideline value for genotoxic carcinogens (defined as there is there no threshold concentration below which there is zero risk) to equate to a one additional cancer per 100,000 people lifetime consumption risk (discussed in Bartrom, 2001)

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

Thus DALY per case =(0.1x3/365x0.975)+(0.23x7/365x0.025)+(1x80x0.00015)
=0.0008+0001+0.012
=0.013

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

DALY per case = (0.067x7/365)
= 0.0013

Table 4.2.1. Health based target table for reference pathogens (recycled water)

Log reduction targets (V, P, B)[a]	Indicative treatment process	Log reductions achievable by treatment (V, P, B)	On-site preventive measures	Exposure reduction[b]	Water quality objectives[c]
Use — Dual reticulation, toilet flushing, washing machines, garden use					
6.5 5.0 5.0	Advanced treatment required, such as: • secondary, coagulation, filtration and disinfection • secondary, membrane filtration, UV light	6.5 5.0 5.0	Strengthened cross-connection controls required including ongoing education of householders and plumbers		• To be determined on case-by-case basis depending on technologies • Could include turbidity criteria for filtration, disinfectant Ct or dose (UV) • *E. coli* <1 per 100 mL
Use — Dual reticulation — outdoor use only *or* indoor use only					
6.0 4.5 5.0	Advanced treatment required; for example: • secondary, coagulation, filtration and disinfection • secondary, membrane filtration, UV light	6.0 4.5 5.0	Strengthened cross-connection controls required, including ongoing education of householders and plumbers		• To be determined on case-by-case basis depending on technologies • Could include turbidity criteria for filtration, disinfectant Ct or dose (UV) • *E. coli* <1 per 100 mL
Municipal use — open spaces, sports grounds, golf courses, dust suppression, etc *or* unrestricted access and application					
5.0 3.5 4.0	Advanced treatment required; for example: • secondary, coagulation, filtration and disinfection • secondary, membrane filtration, UV light	5.0 3.5 4.0	No specific measures		• To be determined on case-by-case basis depending on technologies • Could include turbidity criteria for filtration, disinfectant Ct or dose (UV) • *E. coli* <1 per 100 mL

(Source: Natural Resource Management Ministerial Council, 2006)

Limitations of DALYs - Sensitivity and Robustness

Existing guidelines use disability adjusted life years (DALYs) to convert the likelihood of infection or illness into burdens of disease. As noted, for infective agents, the consensus suggests a tolerable risk of 1 x 10^{-6} DALYs to adjust for both risk of infection and anticipated severity of infection. However, using QMRA criteria for against such as viruses would require removal to levels below that measurable by most laboratories. Therefore, for Class A indirect potable schemes, a compromise requirement has suggested a suitable log reduction (7-log reduction for influent or 5 log removal after secondary treatment). Because of the diversity of pathogens potentially present in recycled water, the guidelines recommend use of "reference pathogens" instead (such as *Campylobacter* for bacteria, rotavirus and adenovirus for viruses, and *Cryptosporidium parvum* for protozoa and helminths) The provided dose responses for microbes have a moderate problem compared to drinking water in that the DALYs relate to drinking and not inhalation or (less or a problem) dermal entry.

The sensitivity of DALYs is critically dependant upon the amount and integrity of epidemiological data that is provided. Population based data on waterborne illnesses is often not always representative of the entire population, as in the 1993 outbreak in Milwaukee, USA where four deaths occurred in a non-immunocompromised population of approximately 400,000, due to *Cryptosporidium parvum* infection (Havelaar, 2000). Estimation of disease burden has been trialled in the Netherlands due to infection with *Campylobacter* spp (Havelaar , 2000). They concluded that the sensitivity of the total disease burden estimate is quite high and primarily related to the YLD component, due to the low incidence of new cases (Havelaar, 2003).Comparatively, case-fatality rates in developing countries could be expected to be higher due to other contributory factors such as malnutrition, lack of rapid public health interventions and a generally poor background health status of the community.

There is no clear identifiable mechanism within the DALY metric calculation to deal with uncertainties that may be associated with these estimates. Another specific example of the limitation of DALYs inadequately addressing susceptible populations relates to immunocompromised persons, such as persons with HIV/AIDS. Infection with *C.parvum* in individuals with AIDS leads to gastroenteritis in virtually all cases (Havelaar, 2003). This is particularly problematic in regions such as the African nations where large proportions of the population are HIV-positive and would not be considered as minor population subgroups, as they would in Western countries. In other populations, there is also the possibility that a degree of immunity or relative resistance could be afforded due to numerous previous cases of infection with the water pathogens.

Pruss (2002) comment on the significant contribution of infectious diarrhoea to the global burden of disease (GBD) from factors relating to water, sanitation and hygiene, based upon exposure data only given that it can also be commonly transmitted via other vehicles. The authors note that it is difficult to quantify the disease burden due to water, sanitation and hygiene, due to:

a) many interrelated causes involved with the transmission of water-related diseases;

c) lack of information on the risk factor-disease relationship.

<u>Use of alternative data sources and methodologies to estimate DALYs</u>

Utilisation of other data sources for little known pathogens and chemicals through other techniques, such as the use of biomarkers and bio-indicators of exposure, is an emerging area that will ultimately impact on recycled water health risk assessment processes. For example, where recycled water production involves a disinfection process, there is inevitably the production of low molecular weight disinfection by-products (DBPs), with the most notable internationally being NDMA or N-nitrosodimethylamine. The US EPA classifies NDMA as a substance that could be reasonably anticipated to be a human carcinogen with a designated risk level of (1ng/L) and a notification level of 10 ng/L (CDHS, 2007). This is an example, given such low public health action levels, of where molecular epidemiology/biomarker analysis would be particularly relevant to capture the initial exposure (albeit potentially very small) to the NDMA and the associated changes that may occur at the cellular level, prior to a clinically diagnosed disease state occurring.

Other authors (Tourlousse, 2007) refer to predictive model of virulence for all classes of drinking water contaminants (i.e. bacteria, virus and protozoa) called Virulence Factor Activity Relationships (VFAR). VFAR is focussed on prioritising these pathogens based upon using comparative genomics, relevant descriptors of human health and taking into account environment-related factors such as water conditions, water treatment and distribution parameters and competition from other micro-organisms.

4.3. Characterisation of water sources in risk assessment

Source analysis and management is pivotal to the success of any indirect potable recycled water scheme, particularly where there are significant industrial, commercial and hospital waste streams entering the treatment train. The Natural Resource Management Ministerial Council ,.,(2007) note the significant influence that industrial waste discharges to sewers can have on the overall integrity of a recycled water system. This is a view that is also shared internationally by the United States Environmental Protection Authority in their "Guidelines for Water Reuse, September 2004".

Western Australia is distinctive in that the three major treatment plants in the Metropolitan Area receive quite specific wastewater streams as indicated on the following map **(Figure 4.3.1.).** The Subiaco Wastewater Treatment Plant (SWWTP) receives domestic wastewater as well as the majority of the wastewater streams from the major tertiary hospitals in the Perth Metropolitan Area. Accordingly this wastewater treatment plant processes significant levels of pharmaceutically active compounds as other hospital trade waste streams. The SWWTP has a design capacity of 350,000 effective persons and treats approximately 61.4(ML/day) of treated wastewater via an advanced secondary treatment process dissolved air flotation thickening (DAFT) (Water Corporation 2006).

The Beenyup Wastewater Treatment Plant (BWWTP) processes domestic wastewater steams with an ultimate design capacity of 1.1 million effective persons and can treat up to 200ML/day of treated wastewater via advanced secondary treatment, incorporated activated sludge with biological nutrient removal (Water Corporation 2007). The BWWTP is the site for the groundwater replenishment trial that is to be commenced in Perth in 2009. It is proposed that 1.5ML/day of wastewater will be passed through ultra-filtration/reverse osmosis with advanced oxidation (if required) prior to injection into the Wanneroo Member of the Leederville confined drinking water aquifer. Analysis of the behaviour of the injected treated wastewater in the aquifer will be undertaken as well as characterization studies of the treated wastewater itself, an assessment of the hazard reduction effectiveness of the respective treatment train components as well as community acceptance studies into using recycled water as a water source.

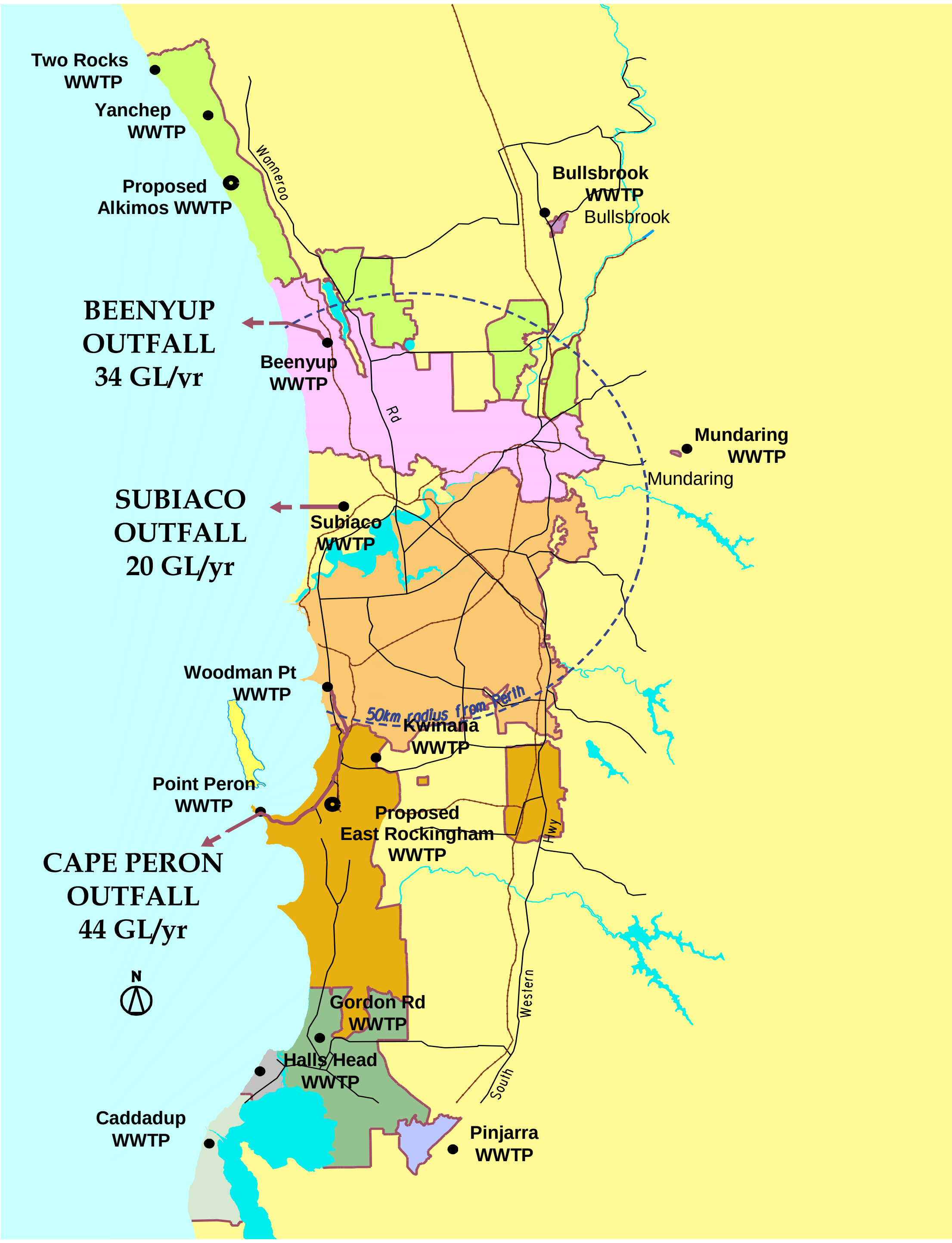
The Woodman Point Wastewater Treatment Plant (WPWWTP) receives and processes domestic wastewater streams and the majority of Metropolitan Perth's industry and trade wastewater sources. According to P Wilmott on 15 January 2008, approximately 7% of the total wastewater inputs to the WPWWTP is made up of industrial flows. These originate from three main sources, namely:

- Large scale food manufacturers (dairies, meat processors and abattoirs, and beverages producers);
- Commercial laundry operations;
- Metal finishers and geochemical laboratories.

This is compared to 6.5% industrial wastewater total flow into SWWTP and 2.5% into BWWTP, from relatively inert commercial and industrial sources such as general retail, restaurants, cafes with a couple of large food processors for SWWTP from the Osborne Park Industrial Area.

P Wilmott confirmed on 15 January 2008 that the Water Corporation operates an extensive source control program for the main metropolitan wastewater treatment plants in Western Australia.

Figure 4.3.1. Source water analysis in Perth



(Turner 2007)

Other WWTPs within Australia typically have a more homogeneous input of wastewater streams which impact markedly on the level and type of Health Risk Assessment that is undertaken for recycled water schemes that may be attached to the respective plants. Source control programs exist widely, primarily in the form of trade waste policies and guidelines such as those implemented by Sydney Water, respective Municipality run schemes (such as the Glenorchy Council Scheme in Tasmania), and governance through the respective States Environmental Regulators licensed and prohibited discharge to sewer mechanisms.

4.4. Microbial risk assessment for recycled water 1: Hazard Identification

Haas ,. (1999) identifies a series of key steps in the hazard identification process as follows:

- Identification of the micro-organism as a cause of human illness associated with proof using Koch's postulates, which demonstrate that the agent is found and is the cause of specific types of disease and when transmitted causes a similar disease in the person newly exposed.
- Development of diagnostic tools that identify the symptoms, the infection and more specifically, the micro-organism in host specimens (e.g., sputum, stools, blood).
- Understanding of the disease process from exposure to infection to the pathology, disease and potentially death.
- Identification of possible transmission routes.
- Assessment of virulence factors and components of the micro-organism and its life cycle that aid in understanding transmission and the disease process.
- Use of the diagnostic tools to evaluate the incidence and prevalence of disease in populations (endemic risks) and for investigation of outbreaks (epidemic risks).
- Development of models (usually animal models) to study the disease process and approaches for treatment.
- Evaluation of the role of the host immune system in combating the infection and the possible development of vaccines for prevention.
- Epidemiological studies associated with various exposures

This analysis must account for the phenomenon of secondary transmission of the pathogenic organism, whereby an infected individual can infect further people, who have had no direct contact with the recycled water source. This has been well documented for noroviruses, for periods of up to 48 hours post recovery, which are discussed further below as potential significant waterborne viral pathogens (Haas ,. 1999).

Quantitative Microbial Risk Assessment (QMRA) is the application of risk assessment principles to estimates the outcomes form planned or actual exposure to pathogenic micro-organisms (Haas, 1999). The theoretical basis for QRA/QMRA is reasonably well established. Both Phase I and Phase II of *The National Water Quality Management Strategy – Australian Guidelines for Water Recycling* indicate QMRA as the preferred method for assessing microbial risks associated with recycled water supplies and the key components of a QMRA Framework are described here.

Reference pathogens for recycled water

Westrell (2004) comments on key inclusion criteria for reference pathogens in QMRA models as follows:

- The major types of organisms should be represented (i.e. bacteria, viruses and protozoans);
- The organisms should be occurring in the population;
- They should have a documented record of being involved in waterborne disease outbreaks or constitute a hazard;
- Particularly persistent organisms should be included;
- Organisms with low infectious doses should be included;
- Organisms with serious symptoms and potential sequelae should be represented;
- The organism and its occurrence should be sufficiently well described in peer reviewed scientific literature.

In view of these recommendations, the following reference pathogens, from key groups (bacteria, viruses, protozoa) have been established as follows for recycled water both in Australia (Natural Resource Management Ministerial Council*,* 2006) and internationally:

- Bacteria (*Campylobacter jejuni)*
- Viruses (Rotavirus / adenovirus)[†]
- Protozoa (*Cryptosporidium parvum)*

The justification and limitations of these reference organisms will now be reviewed.

Selection of bacterial reference pathogens

Thermophilic *Campylobacter spp.* (commonly *C. jejuni*) is a common cause of gastroenteritis. In developing countries, frequent exposure to *Campylobacter spp.* induces significant immunity, and milder and asymptomatic cases are more common. Accordingly, this may limit the indicative ability of this organism in these particular settings to some extent as a reference pathogen for bacterial loadings in recycled water exposure. *Campylobacter spp.* related diarrhoea in developed countries can be particularly problematic for highly susceptible populations such as the elderly, the immuno-compromised and young children. Ashbolt (2004) proposes that *Campylobacter spp.* and *V.cholerae* are the most important enteric bacteria for developing nations. Data from the United States suggest that approximately 1 of every 10,000 cases of clinical campylobacteriosis dies and several complications have been reported including the acute immune disease Guillain-Barre Syndrome (GBS) and reactive arthritis (ReA) (Ashbolt, 2004).

Selection of protozoal reference pathogens

Cryptosporidium parvum is widely recognised as being associated with outbreaks of water related gastroenteritis in immuno-compromised individuals infected with the organism, gastroenteritis consistently develops and death may result (Havelaar, 2003). *Cryptosporidium* is a relatively difficult organism to isolate from recycled water samples and relatively large samples are involved, often up to 50L which then require filtration. Currently Nationally Accredited Testing is not able to be performed

[†] In Australia, the indicator chosen for viruses is an amalgam of rotavirus and adenovirus, using dose-response data for rotaviruses and occurrence data for adenovirus.

in Western Australia for *Cryptosporidium* in water samples, which in itself is problematic as the nearest accredited testing facility is located in South Australia, so issues of transport cost, logistics and the sample integrity itself being compromised arise.

<u>Selection of viral reference pathogens</u>
Rotaviruses are the single most important agents of severe viral diarrhoeal illness in infants and young children worldwide. Rotaviruses tend to display a seasonal pattern of infection in temperate climates, with epidemic peaks occurring in the cooler months. Four serotypes of human rotavirus exist, although serotype 1 is the main cause epidemic rotavirus diarrhoea in temperate climates. The virus is particular threatening to susceptible populations such as the elderly, the immuno-compromised and children under 24 months. Worldwide, rotavirus infection has been estimated to have caused 35-40% of hospital admissions for diarrhoeal disease in patients under 2 years of age). Occurrence of rotavirus diarrhoea in developed countries is also high, but relative mortality rates are low. In 1994 the number of cases of rotavirus in the US was estimated at over 1 million in the 1-4 year old age group, with 150 deaths and a case-fatality rate of 0.015% (Havelaar, 2003).

The hepatitis A virus is another potentially waterborne viral micro-organism that is distributed worldwide and is often associated with geographic areas of low socioeconomic status. Common-source outbreaks have been associated with contaminated water directly or indirectly, such as from undercooked molluscs harvested from contaminated water. An example of this transmission occurred at Wallace Lake in New South Wales where failing on-site effluent disposal systems contaminated commercial shellfish harvesting farms with the Hepatitis A Virus. Post infection immunity is thought to be life-long. An inactivated vaccine is available and is part of the routine childhood immunisation schedule in Western Australia. Hepatitis A in the United States has the highest incidence in young adults and children (Haas, 1999).

Norovirus is one of the two genera of the human caliciviruses (the other being *Sapovirus)(*Westrell, 2004). Noroviruses affect all age groups globally and are considered to be the most common cause of gastroenteritis in Western countries in terms of the numbers of outbreaks and persons affected (Koopmans, 2004). Andersson (2001) reported that the number of reported waterborne outbreaks with norovirus is increasing internationally.

A range of other water related pathogens can cause chronic and severe symptoms and sequelae in a limited number of infected individuals, including:

- Diabetes, associated with the Coxsackie B4 virus;
- Myocarditis associated with echovirus and Coxsackievirus
- Respiratory illness and central nervous system disorder associated with Coxsackievirus
- Haemolytic uraemic syndrome, associated with haemorrhagic *Escherichia coli*
- Reactive arthritis, associated with *Salmonella spp*

<u>Selection of appropriate indicator pathogens</u>

The limitations of singular reference pathogens have been discussed previously, particularly where multiple potential sources of the pathogen (outside the waterborne pathway). For example, *Cryptosporidium* has also been implicated in food-borne outbreaks and its use a reference pathogen for water exposure may introduce a confounding effect. Rotavirus has been isolated from respiratory secretions which would also introduce an additional potential mode of transmission for this reference viral pathogen. Rotavirus also has the ability to persist for extended periods on human skin and inanimate surfaces.

The route of exposure is a key consideration when selecting appropriate reference pathogens for recycled water exposure and disease causation risk assessment models. Many waterborne pathogens have varied disease-causing potential based upon their route of human exposure such as:

- *Naegleria sp.,* associated with aerosol exposure
- *Pseudomonas sp*., associated with skin exposure
- Campylobacter, associated with direct ingestion of contaminated food.

The Stockholm Framework advocates selecting reference pathogens that are representative of susceptible subpopulations and notes that more than one reference pathogen is often required (Bartram, 2001). The indicator organisms that have been chosen for the Australian Guidelines may not be completely representative for all population groups. In particular populations, significant transmission of these pathogens could arise from other sources and potentially confound the results, such as developing nations where, for example, *Campylobacter* from food borne sources causes more cases of diarrhoea than food borne S*almonella*. In Western Australia particularly in the Northwest Region, helminths are a major concern in recycled water systems and it has been argued that this group should be included as a reference pathogen.

4.5. Microbial risk assessment for recycled water 2: Exposure assessment/ Dose-response assessment

As noted, the dose-response assessment in QMRA is directed towards the mathematical characterisation of the relationship between the average pathogen dose received and the likelihood of infection or disease in the exposed population (Haas, 1999). Two main models exist of infection process for QMRA, the *exponential model* and the *beta-Poisson model.* The exponential model is the simplest dose response model and assumes that the distribution of organisms between doses is random and that each organism has an independent and identical survival probability to initiate infection (Haas, 1999). The model is illustrated below:

Exponential Model

$$\text{Probability}_{\text{infection}} = 1 - \exp(-rD)$$

where

D = pathogen dose

r = fraction of pathogens that survives to produce an infection

The beta-Poisson model takes into account variability in the pathogen-host survival probability (r). Such variability can be due to diversity in human responses, a range of pathogen competence or both. The model is illustrated below as follows:

Beta-Poisson Model

$\text{Probability}_{\text{infection}} = 1 - (1+(D/ID_{50}))^{-\alpha}$
where
D = pathogen dose
α & ID =parameters of the beta-distribution used to describe variability in survival.

(Haas et al., 1999)

The two primary sources of relevant information for dose response models are *human feeding trials* and *outbreak data*. Human feeding trials are controlled experiments where "volunteers" are administered doses of different pathogen concentrations (Petterson, 2006). The number of volunteers who exhibit a response that indicates an infection are then recorded for incorporation into the respective QMRA dose-response model. However, a number of important uncertainties exist with these studies (Petterson, 2006; Teunis, 2000): (i) uncertainty regarding the absolute number of viable particles in the dose. This will be dependant upon the source of the inoculum and the individual pathogen, as there will be uncertainty about how many particles were actually infectious at the point of consumption; (ii) the actual strain of the micro-organisms contained within the inoculum. The sourcing of pathogens for feeding trails is largely driven by practical and logistical issues in terms of what organism is available for use. In some circumstances the strain of organism administered varies quite markedly from that cases infection in humans. One example is where *Cryptosporidium parvum* is used, when in fact most human infections are believed to be caused by *Cryptosporidium hominis;* (iii) the representativeness of volunteers. For obvious ethical considerations, feeding trials are only carried out on healthy adults whose immune response may not be representative of the entire community.

In recent times, information from outbreaks of enteric illness have also been used to estimated dose-response parameters (Teunis, 2005; Teunis, 2004). Data from a real outbreak will demonstrate an actual response to human pathogens, without constraints and adjustments required for a controlled study (i.e. the pathogens are native to the systems and the exposed population are a true sample form the susceptible population). However, uncertainties also exist in relation to these types of data, including: (i) estimating the dose. There is an incubation period between the pathogen is ingested and when the response (illness) occurs, and this time lag makes it difficult for the source material to be readily identified for direct analysis. If it is available, it may no longer be representative of the organism density at the time of exposure (due to either inactivation or growth); (ii) illness rather than infection is generally the endpoint. In controlled feeding trails, blood serum can be analysed on daily intervals following exposures to identify whether infection has occurred. For a real outbreak there is a reliance on the reporting of symptoms of infection (illness), which is only a proportion of the total infected population.

Once a set of dose-response data has been provided (often from the sources defined above), the best fitting parameters of a dose- response relationship can be computed via standard maximum likelihood techniques, as in **Table 4.5.1.** The method has been widely used for human viruses, bacteria and protozoan reference organisms (including rotavirus, enteroviruses *Campylobacter sp. and Cryptosporidium parvum*). According to Kang ,., (2000) confidence limits can then be estimated for these parameters which will allow extrapolation of results to low-dose studies (i.e. animal to human study extrapolation).

4.5.1. Dose-response relationships for reference pathogens

Organism type	Distribution	Model	Parameters
Enteric virus (rotavirus)	Beta-Poisson	$P_{inf} = 1-(1+d/ß)^{-\alpha}$	$\alpha = 0.253$ $ß = 0.426$
Bacterium (*Campylobacter jejuni*)	Beta-Poisson		$\alpha = 0.145$ $ß = 7.58$
Protozoan (*Cryptosporidium parvum*)	Exponential	$P_{inf} = 1-\exp(-rd)$	$r = 0.059$

α and r are parameters describing probability of infection; d = dose; ß = median infective dose (N_{50}) ÷ ($2^{1/\alpha}$–1);
P_{inf} = probability of infection
Model parameters are as described in Table 9.15 from Haas et al (1999), except for *Cryptosporidium*, where the data of Messner et al (2001) have been used.

(Source: Natural Resource Management Ministerial Council*,* 2006)

4.6. Microbial risk assessment for recycled water 3: Risk Characterisation

In the context of water contaminants, risk characterization integrates the results of dose response and exposure assessment into a "risk statement" that includes quantitative estimates of risk. Relevant outcomes made on the basis of the risk assessment (Haas, 1999) may include:

- Expected risk of infection to a "typical person";
- Expected number of illnesses in a community;
- Upper confidence limit for the expected number of illnesses;
- Upper confidence limit for illness in a "highly exposed person"
- Maximum number of illnesses existing in a community at any one time.

Within the organisational structure of a water treatment, key elements of risk characterisation have been summarised as follows:

- Determination of quantitative estimate of risk;
- Description of uncertainty;
- Presentation of the risk estimate;
- Communication of the results of the risk analysis to the key managers/ stakeholders

The Natural Resource Management Ministerial Council , (2006), also refers to magnitude of risk in terms of recycled water being assessed on two levels being: *maximum risk:* risk in the absence of preventative measures; and *residual risk:* risk that remains after consideration of existing preventative measures. High priority risks can be identified by considering the maximum risk which enables appropriate preventative strategies to be developed, performance targets to be calculated and planning for preventative measure or barrier failure. Residual risk provides an indication of the safety and sustainability of a recycled water scheme and the requirement for additional preventative measures (Natural Resource Management Ministerial Council, 2006).

4.7. QMRA applications and limitations

International application of QMRA to recycled water schemes

As previously mentioned, QMRA has been widely validated for a number of reference pathogens and is internationally accepted as the indirect microbial risk management tool of choice for both drinking and non drinking waters. An *,.,* (2007) refer to the use of the Beta Poisson Model to determine the microbial risk of *E.coli* ingestion for framers and neighbouring children from rice paddy fields irrigated with recycled water in South Korea. The study indicated that risks were calculated to be 10^{-4} to 10^{-8} , which were comparable with the surface water irrigation supply risks. Children were at the greatest risk of infection (An *,.,* 2007). QMRA has also been used to define children as a population at high risk from infection by waterborne pathogens based on growing body of international evidence (Nwachuku and Gerba, 2004).

Petterson ,. (2001) undertook a screening risk assessment utilising QMRA to assess microbial risks from viruses associated with the consumption of lettuces spray irrigated with secondary treated municipal effluent from Wastewater Treatment Plants in California. The study assessed the impact of two main factors on the risk of infection being: (i) probability density for the occurrence of human enteroviruses in irrigation water; (ii) estimated die-off rates for viruses on the lettuce crops. Previous QMRA investigations have used directly assayed enteric virus data, although for these investigations a database of enterovirus concentrations was compiled for a range of exposure settings, including golf course irrigation, salad crop irrigation, recreational swimming and managed aquifer recharge. The QMRA Model found that the estimate of risk from consuming lettuces irrigated with secondary treated was more sensitive to virus decay rate than variation in the initial virus probability density function (Petterson, 2001; Petterson, 2007).

Limitations of QMRA analysis

A number of constraints in QMRA estimates have been defined. Depending on the experimental data provided, single hit models (such as the Beta Poisson Model) can often lead to gross overestimates of risk at relatively low doses of reference pathogens. These models may thus be considered an approximation whose validity is not widely known (Teunis, 2000). This is particularly problematic where reliance is placed upon relatively small data sets, with the production of likelihood-based confidence intervals that can potentially have significant error margins. Some exact models have a maximum risk curve, which limits the upper confidence limit of the dose-response relationship due to the fact that risk cannot exceed the probability of exposure. However, this property is not present with the Beta Poisson Model and may limit its suitability for uncertainty analysis and for risk assessment of pathogens with unknown properties (Teunis, 2000).

Peterson ,. (2001) note that the most important constraint to undertaking exposure analysis for QMRA is lack of quantitative data on pathogens in waters and their relative reduction at each stage of the treatment train. A rare example is the analysis by Zmirou-Navier ,. (2006), who cross-validated the dose-response data for *Giardia* *sp.* as a waterborne infectious disease risk (using an Exponential QMRA Model) and found that it was consistent with epidemiological data.

4.8. Chemical risk assessments for recycled water

As with pathogens, risk assessment of chemicals of concern is composed of four elements: hazard/problem identification, hazard/problem assessment, risk characterisation and risk management. In brief, hazard identification defines properties of chemicals, such as physical state and its potential for bioaccumulation and toxicity. Hazard assessment assesses the distribution of contaminants in the environment (soil, water, air) and in biological tissues. Risk characterisation evaluates the potential negative effects and probability of effects occurring.

Chemical hazards in recycled water consist of a variety naturally occurring, synthetic, organic and inorganic species (Khan, 2007). The key classes of the chemicals that are potentially found in recycled water are diverse, and include:

- inorganic chemicals;
- nutrients;
- pesticides;
- conventional water treatment chemicals, disinfection by-products and advanced oxidation by-products;
- industrial chemicals;
- household and garden chemicals;
- surfactants;
- flame retardants;
- human and veterinary pharmaceutical products;
- personal-care products;
- natural hormones;
- general organic chemicals – aliphatics, chlorobenzenes, monocyclic hydrocarbons, nitrosamines, organotins, phenols, phthalates, plasticizers, polychlorinated biphenyl (PCBs), polycyclic aromatic hydrocarbons (PAHs), sterols and stanols.

<u>Indicator chemicals</u>

An emerging area is the use of surrogate operational measures and indicator chemicals to determine the presence of in particular trace organic and unregulated organic compounds in recycled water. Indicator chemicals have similar physical and chemical properties to the low molecular weight compounds for which they are typically acting as a measure. They must also have similar rates of occurrence and persistence in the environment to be considered as appropriate indicator measures of actual chemicals that may be found in recycled water (Dickenson, 2008).

Indicator chemicals have been identified relative to the efficiency of respective treatment train technologies to remove trace organic and unregulated low molecular weight organic compounds from source water. The treatment train technologies that have used to assess these indicator chemicals are:

- Biodegradation (soil- aquifer treatment) e.g. MAR;
- Chemical oxidation (ozone, advanced oxidation, chlorine and chloramine);
- Ultraviolet light disinfection (low-medium level radiation);
- Adsorption (activated carbon filters); and

- Physical separation (nanofiltration/reverse osmosis and submerged microfiltration/ultrafiltration).

They are then broadly classified into three removal efficiency categories:

- Good removal (>75%);
- Moderate removal (30%<x<75%);
- Poor removal (<30%).

This classification approach was verified by a nanofiltration membrane experiment (Dickenson, 2008), whereby indicator rejection percentages corresponded with the anticipated membrane treatment bin for the trace organic compounds.

<u>Surrogate Measures</u>
Surrogate parameters have also been proposed, whereby "bulk parameters" can be assessed to determine the removal wastewater-derived chemical contaminants of concern. The use of surrogates can be cost-effective: for example, conducting an analysis for total organic carbon (TOC) is generally cheaper and often simpler than that required for many of the lower molecular weight organic compounds (Dickenson, 2008).

Research on the use of surrogate measures for assessing efficiency of wastewater derived contaminants of concern is limited. However, the following surrogate measures are generally accepted as being representative of the effectiveness of the relevant treatment processes:

Surrogate Measure	**Treatment System Performance Prediction**
TOC, BDOC, hydrophilic DOC, colour, COD, BOD, UV, fluorescence, molecular weight, adsorption analysis, TOC, TOI	Used to characterize effluent organic matter.
Nitrogen, Phosphorus, alkalinity	Used to determine whether wastewater is amenable to biological treatment.

4.9. Exposure assessment/ Toxicological evaluation of chemicals of concern

Traditional estimations of risks to human health from exposure to chemicals are based upon extrapolations of animal exposure toxicological data, which is then used to determine safe levels of chemical contaminants in drinking waters. 'Dose-response' relationships can thus be determined to determine safe levels of specific chemical contaminants in drinking waters. Although this approach has proven to be successful for drinking water derived from pristine sources, it does not adequately consider the potential contributions to the drinking water system that may arise from the addition of recycled water or other non-traditional water sources (Khan, 2007).

Toxicity of chemicals to an organism is normally defined in terms of dose-response relationships. When the target organisms are humans, dose-response relationships may be derived from data obtained in epidemiological investigations, extrapolations from animal studies, or toxicity assays on mammalian or bacterial cells. Epidemiological data can provide the most realistic cause-effect relationships, but are only available for a very limited number of chemicals. Credible and substantial international research and standards exist to regulate the hazards posed from a variety of chemicals that have existing regulatory or guideline values and are commonly found in recycled water sources. In Australia, the most commonly used standard is the Australian Drinking Water Guideline (2004). Other chemicals exist in recycled water that may have no guideline or regulatory value but credible toxicological information, whereas other chemicals have no guideline or regulatory value nor toxicological information available.

The dose-response relationships for chemicals of concern have been categorised in a number of ways. These include classification into;

- '*genotoxic' or 'threshold' group* (e.g. using the TD_{50} or tumorigenic 50% dose for cancers) versus *'non-genotoxic' group* (using the NOEL/Uncertainty factor approach e.g. EU, UK, WHO and drinking water guidelines).
- *low dose linear* versus *non-linear models* (e.g. USEPA).
- the *threshold of toxicological concern* (TTC) that refers to the establishment of a human threshold value below which there would be no appreciable risk to humans based on intakes (in µg per person per day). Dose-response relationships, once established, may then be used to derive an acceptable daily intake (ADI) for each specific chemical, with an appropriate safety factor.

Advanced methods that may be particularly applicable to this context include:

- *Low-dose extrapolation* may be determined using *one-hit, multistage* or *multi-hit* models to determine the virtual safe dose. These models require an extrapolation term of the form:

$$\mathbf{P = a \times BW^b}$$

where

P = potency of a chemical in a given species
a = constant relating to the potency of the chemical in a given species
BW = body weight of the species
b = empirically determined scaling constant

- *Structure activity relationships (SAR)* in which the effect of a toxicant if inferred based on its chemical structure. Structure-activity relationships can be used to extend the range of plausible inference and extrapolation within and across chemical classes. In the assessment of possible chemical activities, molecular epidemiology and the presentation of plausible ranges of risk for populations and sensitive individuals within those populations are emphasized.
- Xenobiotics may also be evaluated using methods such as *functional toxicology screens*. These screens are comprised of cells transfected with a functional gene (e.g. oncogene) along with a 'reporter' gene. These *in vitro* screens allow an assessment of the degree to which a single compound or multiple compounds might exhibit 'dioxin-like' or oestrogenic activity or some other functional activity.
- *Physiologically-based pharmacokinetic (PBPK) and toxicokinetic models* are increasingly being used for the conduct of high dose to low dose and interspecies extrapolations required in cancer risk assessment. One

common toxicokinetic model includes terms for distribution to four compartments - well-perfused tissues, poorly refused tissues, fat and the liver – and metabolism in the liver and/or kidneys (e.g. for TCDD or 'dioxin').

Screening health risk assessments are useful for undertaking a preliminary assessment of the chemicals of concern in recycled water. Potential health impacts are calculated using risk quotients in which measured concentrations are compared against benchmark values Rodriguez *,.;* (2007). Chemicals are then classified into one of three tiers dependant upon the level of regulatory and toxicity data available, as follows:

Three Tier Approach (Rodriguez ,. 2007)

Tier 1 – Chemicals with Regulatory Guidelines
For these chemicals the risk quotient (RQ) of measured concentration to the maximum contaminant level is calculated. The relevant Regulatory Guidelines that are applied to calculate the RQ (in order of priority) are:

- Australian Drinking Water Guidelines (NHMRC and NRMMC 2004);
- World Health Organization (WHO 2004);
- US Environmental Protection Agency (US EPA 2006); and
- California Code of regulations – Title 22 – (California Office of Administrative Law 2006).

Tier 2 – Unregulated Chemicals with Available Toxicity Information
For these chemicals health-based advisory values for non-carcinogenic and risk specific doses are used. Reference doses, acceptable daily intakes or tolerable daily intakes are used non-carcinogenic chemicals with the slope factor used carcinogenic chemicals to calculate safe levels of consumption of drinking water over an entire lifetime.

The International Agency for Research on Cancer (IARC) monographs and the US EPA Integrated Risk Information System (IRIS) are used for cancer classification in order of priority. Compounds determined not to be carcinogenic (Group 3) in the IARC classification system are treated as non-carcinogens. Compounds classified as "possible carcinogens" by the IARC (Group 2B) have an uncertainty factor of 10 included in the benchmark values

For non-cancer health outcomes an adult consumption rate of 2L/day of membrane filtration/reverse osmosis (MF/RO) water is assumed with a typical body weight of 70kg and a 70 year lifespan. It also assumes a relative source contribution from recycled water to diet of 20%, excluded other potential intake sources such as air and food.

Tier 3 Unregulated Chemicals without Available Toxicity Information
In recycled water the threshold of toxicological concern (TTC) is used to determine safe chemical concentrations, below which there would no significant risk to human health (Kroes ,. 2004 ; Kroes ,. 2005) This threshold is established from a statistical analysis of available toxicological data. Each of the individual unregulated chemicals is then allocated into one of the three Cramer classes – low, medium or high toxicity, based primarily upon its chemical structure.

Limitations of chemical risk assessment
The 'traditional' chemical risk assessment involves (i) identifying known chemicals of concern; (ii) considering toxicity (dose-response); (iii) considering exposure; (iv)

setting limits within safe concentrations. However, this approach is often insufficient for some water reuse schemes, with new exposure pathways arising from non-traditional sources. Exposure assessment are traditionally undertaken for "normal" or "expected" conditions only, with or without variability analysis. There is a complex mixture of chemicals that are poorly defined and highly variable. With respect to hazard identification, it remains unclear which chemicals/ endpoints to select. Dose response-assessment are often conducted for specific chemicals, but some argue should instead encompass the entire effluent mixture. Risk characterisation and management are often oriented to managing the exposure to hazards identified under "expected" conditions.

As with microbial contaminants, acceptable levels of chemical parameters will be dependant on the proposed reuse applications for the water and, in many cases, site-specific factors such as the degree of dilution with water from other sources. Risks to human health from chemicals is variable, with some imparting acutely toxic effects and others resulting in chronic health risks and sequelae from often lifetime exposure to relatively low levels of a particular chemical (Khan, 2007). The long latency period of disorders, such as cancer, caused by some environmental toxicants limits the accuracy of these estimates.

The issue of indicator chemicals is highly relevant at present, as the draft Australian Guidelines for Water Recycling: Managing Health and Environmental Risks Augmentation of Drinking Water Supplies (2008), currently require exhaustive sampling, particularly in the pharmaceutically active compounds (PhACs) group. This sampling requirement tends to conflict with local research work that has been undertaken in Western Australia by the Premiers Collaborative Research Project (PCRP). The PCRP has identified that sampling for targeted structurally similar compounds in the PhAC groups would be sufficient rather than all of the compounds in the respective PhAC groups.

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5. Framework for Targeted End-user protocols

The targeted end-user protocols are classified into a number of **evaluation nodes** that lead to **decision nodes.**

This project will advance the traditional, semi-qualitative methods for assessing the safety of water contaminants by using Bayesian approaches to estimate parameters. Depending upon the activity of the agent or the state of knowledge on toxicological effect, probabilistic analysis with WinBUGS will involve determination of the range of plausible risk estimates using Monte Carlo simulations. This process will permit estimation of additional lifetime disease burden at an average intake over a set duration of time, with appropriate interval estimates.

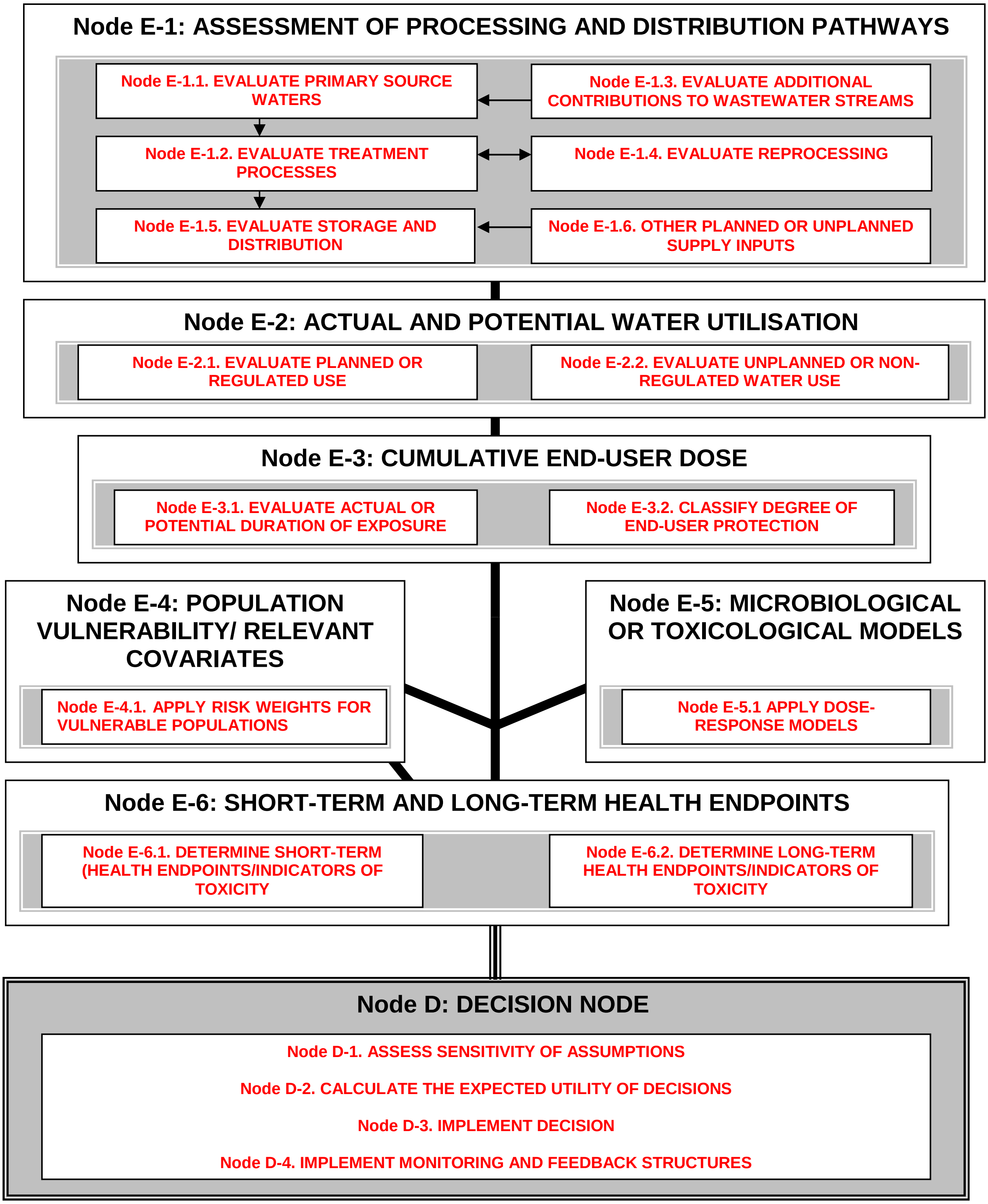
Monte Carlo analysis performs particularly well in the following situations: (i) the quantity of data is small. For many estimates of exposure, Bayesian models require less data than empirical models; (ii) flexibility of Bayesian hierarchical modelling which permitting the declaration of parameters which are related but not necessarily equal.; (iii) Bayesian models more successfully incorporate absence of data from analytical from low contaminant levels (i.e. shortcomings from the limitations of detection; LOD).

It is proposed to use a Bayesian network to combine the various pathways components and data sources illustrated in *Figure 5.1*. Monte Carlo testing is a simulation-based method for the assessment of evidence for the support of different hypotheses by generating a large number of sample values from the joint posterior distribution for the hyperparameters and dose–response parameters. Once the model has been constructed and posterior distribution tested (usually using simulation), the fit of model will be assessed. Sensitivity analyses are used to consider how much posterior inferences change when other probability models are used (such as those that differ in priors, sampling distribution, or in what information is included). In particular, consistency of the model in relation to the data will be assessed (posterior predictive checking).

For example, in estimating population intakes of contaminants in recycled water, probabilistic models based on resampling empirical data will be used to estimate the intake distribution by combining, in a large number of iterations, the consumption and body weight of a randomly selected consumer with randomly selected concentration values from the monitoring data. Sampling errors in the consumption and concentration data generate uncertainty corresponding to each percentile estimate. Bayesian estimates for this uncertainty can be obtained by calculating the selected percentiles in many intake distributions, each based on several Monte Carlo iterations. A common output would be the 50th and 95th percentiles of sampling distribution, which would be include uncertainties.

The framework for the targeted end-user protocols are defined below in Figure 5.1. The fields and information boxes are not yet complete, but the components of the Evaluation Node E-1 and the Decision Node have been included to indicate the order of analysis and general appearance.

Figure 5.1. Overview of evaluation and decision nodes for recycled water exposures and health endpoints



EVALUATION NODE E-1: ASSESSMENT OF PROCESSING AND DISTRIBUTION PATHWAYS*

***Example only**

NODE E-1.1 EVALUATE PRIMARY SOURCE WATERS

BACKGROUND

The source water may be derived from a number of contributory streams:

- Original potable water source
- Municipal wastes (excreta, detergents, antiseptics, washings, etc)
- Stormwater influx
- Industrial discharges
- Treatment processes
- Biochemical production during storage or distribution

Such waters may contain the following:

Pathogenic organisms or their by-products

Human microbial pathogens found in water are often enteric in origin. Enteric pathogens enter the environment in the faeces of infected hosts and can enter water either directly through defecation into water, contamination with sewage effluent or from run-off from soil and other land surfaces.

Full analysis of each pathogen is limited by cost and technical constants on rapid identification of the organism. However, sampling and inferences about concentrations of pathogens may be problematic given their highly variable distribution in water supplies. Optimal reference pathogens that have been suggested by various authors include:

- **Bacteria:** such as *Campylobacter, Shigella, Salmonella. E. coli* O157:H7
- **Viruses:** such as noroviruses, rotaviruses, adenoviruses, enteroviruses, Coxsackieviruses)
- **Protozoa:** (e.g. Giardia, Cryptosporidium)
- **Helminths** e.g. cestodes such as *Taenia* spp., and nematodes, such as *Ascaris lumbricoides*

Chemical toxicants

Chemical toxicants that may potentially found in effluent include:

- **Pharmaceuticals and their metabolites**
- **Personal care products (PPCPs)**: e.g. benzophenone, musk ketone, galaxolide and triclosan
- **Disinfection by-products**: e.g. trihalomethanes, HAAs, HANs, furanones
- **Nitrates and nitrogen-based by-products:** e.g. nitrosodimethylamine — NDMA
- **Heavy metals and metalloids:** e.g. As, Cd, Cr, Cu, Hg, Ni, Pb, Zn and Fe
- **Pesticides and other agricultural chemicals:** e.g. atrazine, organophosphates (including fenitrothion), organochlorines (including dieldrin, heptachlor and DDT), synthetic auxins (2,4,5-T and 2,4-D)
- **Detergents, disinfectants and other cleaning agents**
- **Hydrocarbons,** including Total petroleum hydrocarbons (TPH)/ Polycyclic aromatic hydrocarbons (PAH)
- **Food components and additives/Caffeine**
- **Other domestic, industrial and agricultural compounds I: Organic** including phthalates**/** phenols (e.g. bisphenolA, nonylphenol and nonylphenol polyethoxylate)/ polybrominated diphenyl ethers (PBDE)/ Polychlorinated biphenyls (PCBs) / Volatile organic compounds (VOCs), including benzenes, toluenes
- **Other domestic, industrial and agricultural compounds II: Inorganic**
- **Radionuclides**
- **Chemical mixtures**

Radioactive species

In some circumstances, high concentrations of radioactive products (radionuclides) may potentially be found in effluent.

→ PRIORITISE MICROBIAL CONTAMINANTS IN PRIMARY SOURCE WATERS

Example of data	Example of estimation procedure	Example of output
Counts/levels of microbial indicators/reference pathogens in source water constituents entering treatment plant	Mixture models	Estimates of median and 97.5% centile microbial concentrations

→ PRIORITISE CHEMICAL CONTAMINANTS IN PRIMARY SOURCE WATERS

Example of data	Example of estimation procedure	Example of output
Concentrations of chemical indicators/ representative chemicals of concern in source water constituents entering treatment plant	Mixture models	Estimates of median and 97.5% centile chemical concentrations

◎ NODE E-1.2 EVALUATE TREATMENT PROCESS

⌧ BACKGROUND

The processes to be evaluated include those for <u>primary treatment</u> (the initial screening and sedimentation to remove gross and settleable solids), <u>secondary treatment</u> (this is the minimum standard required for most agricultural and municipal recycled water schemes and usually involves low rate stabilisation processes, such as facultative lagoons or biological/mechanical treatment such as biofiltration, trickling filter, intermittently decanted extended aeration or activated sludge plants;) and <u>tertiary treatment</u> (treatment of recycled water beyond the secondary biological stage, usually with removal of a high percentage of suspended solids and/or nutrients through additional filtration processes, such as membrane filtration followed by disinfection).

Treatment effectiveness may be influenced by design features such as:

- bed depth, hydraulic flows and media characteristics for dual-media filtration
- pore size of membranes (e.g. microfiltration versus ultrafiltration)
- disinfectant doses and detention times
- detention times in lagoons and wetlands.

To assess the variability of treatment effectiveness under normal operation, various indicators of treatment efficiency may be selected, including 'targeted' testing in the treatment train. Nanofiltration/Reverse osmosis systems provide the maximum log-reduction and are often preferred where direct human exposure is likely to be significant.

Examples of removal efficiencies are provided in the Australian recycled water guidelines:

Table 3.4 Indicative log removals of enteric pathogens and indicator organisms

	Indicative log reductions[a]							
Treatment	*Escherichia coli*	Bacterial pathogens (including *Campylobacter*)	Viruses (including adenoviruses, rotaviruses and enteroviruses)	Phage	*Giardia*	*Cryptosporidium*	*Clostridium perfringens*	Helminths
Primary treatment	0–0.5	0–0.5	0–0.1	N/A	0.5–1.0	0–0.5	0–0.5	0–2.0
Secondary treatment	1.0–3.0	1.0–3.0	0.5–2.0	0.5–2.5	0.5–1.5	0.5–1.0	0.5–1.0	0–2.0
Dual media filtration with coagulation	0–1.0	0–1.0	0.5–3.0	1.0–4.0	1.0–3.0	1.5–2.5	0–1.0	2.0–3.0
Membrane filtration	3.5–>6.0	3.5–>6.0	2.5–>6.0	3–>6.0	>6.0	>6.0	>6.0	>6.0
Reverse osmosis	>6.0	>6.0	>6.0	>6.0	>6.0	>6.0	>6.0	>6.0
Lagoon storage	1.0–5.0	1.0–5.0	1.0–4.0	1.0–4.0	3.0–4.0	1.0–3.5	N/A	1.5–>3.0
Chlorination	2.0–6.0	2.0–6.0	1.0–3.0	0–2.5	0.5–1.5	0–0.5	1.0–2.0	0–1.0
Ozonation	2.0–6.0	2.0–6.0	3.0–6.0	2.0–6.0	N/A	N/A	0–0.5	N/A
UV light	2.0–>4.0	2.0–>4.0	>1.0 adenovirus >3.0 enterovirus, hepatitis A	3.0–6.0	>3.0	>3.0	N/A	N/A
Wetlands — surface flow	1.5–2.5	1.0	N/A	1.5–2.0	0.5–1.5	0.5–1.0	1.5	0–2.0
Wetlands — subsurface flow	0.5–3.0	1.0–3.0	N/A	1.5–2.0	1.5–2.0	0.5–1.0	1.0–3.0	N/A

N/A = not available; UV = ultraviolet

a Reductions depend on specific features of the process, including detention times, pore size, filter depths, disinfectant

Sources: WHO (1989), Rose et al (1996, 2001), NRC (1998), Bitton (1999), USEPA (1999, 2003, 2004), Mara and Horan (2003).

(Source: Natural Resource Management Ministerial Council ,, 2006)

Other indicators of treatment/disinfection efficiency include:

- **Turbidity**
- **Biochemical oxygen demand (BOD)**
- **Suspended Solids**
- **pH**

- **Chlorine residuals**
- **Ammonia**
- **Phosphates**

For chemicals of concern, priorities include pharmaceutically active compounds (PhAC) and endocrine disrupting compounds (EDC). PhACs and EDCs originate either from industrial or domestic sources and thus can be detected in a wide range of recycled waters although they tend to be present at very low concentrations (usually in the range of ng/L).

→ PRIORITISE MICROBIAL CONTAMINANTS POST TREATMENT PHASES

Example of data	Example of estimation procedure	Example of output
- Log removal data for specified pathogens - Challenge testing of various operational components of the system with safe biological surrogates (phages)	Meta-analysis of log-removal efficiencies for treatment phases	Range of performance criteria for removal of microbes

→ PRIORITISE CHEMICAL CONTAMINANTS POST TREATMENT PHASES

Example of data	Example of estimation procedure	Example of output
- % removal of specified micropollutants - Challenge testing of various operational components of the system with safe chemical indicators	Meta-analysis of %-removal efficiencies for treatment phases	Range of performance criteria for removal of chemicals of concern

◎ NODE E-1.3 EVALUATE ADDITIONAL CONTRIBUTIONS TO WASTEWATER STREAMS

⌧ BACKGROUND

Other sources of water may intentionally or unintentionally enter the treatment stream. Microbial pathogens may exist in other supplies or catchment environments, depending upon factors such as sunlight, temperature, oxygen, organic carbon concentration and competition from other microorganisms. The levels of chemicals of concern, such as persistent organic pollutants, in additional supplies must be assessed to estimate levels entering recycled water streams.

→ PRIORITISE MICROBIAL CONTAMINANTS IN ADDITIONAL WASTEWATER STREAMS

Example of data	Example of estimation procedure	Example of output
Counts/levels of indicator pathogens in other source water flows e.g. stormwater inputs	Mixture models	Estimates of median and 97.5% centile microbial concentrations

→ PRIORITISE CHEMICAL CONTAMINANTS IN ADDITIONAL WASTEWATER STREAMS

Example of data	Example of estimation procedure	Example of output
Concentrations of indicator chemicals in other source water flows e.g. stormwater inputs	Mixture models	Estimates of median and 97.5% centile chemical concentrations

◎ NODE E-1.4 EVALUATE REPROCESSING

⌧ BACKGROUND

Additional disinfection of the recycled water is the most important part of the reprocessing and depends on the intended final use of the recycled water and the likely level of human contact. Disinfection of recycled water is achieved using a variety of methods, including: *chemical* (e.g. chlorination, ozonation); *physical* (e.g. ultraviolet radiation, microfiltration); *biological* (for example, detention lagoons).

→ PRIORITISE MICROBIAL CONTAMINANTS FOLLOWING REPROCESSING

Example of data	Example of estimation procedure	Example of output
Counts/levels of indicator pathogens before and after reprocessing events	Meta-analysis of log-removal efficiencies for reprocessing	Range of performance criteria for removal of microbes

→ PRIORITISE CHEMICAL CONTAMINANTS FOLLOWING REPROCESSING

Example of data	Example of estimation procedure	Example of output
Concentrations of indicator chemicals before and after reprocessing events	Meta-analysis of %-removal efficiencies for reprocessing	Range of performance criteria for removal of chemical of concern

◎ NODE E-1.5 EVALUATE STORAGE AND DISTRIBUTION

⌧ BACKGROUND

Primary aspects of waterway storage and distribution which will be used to inform human health outcomes include the hydrodynamics of aquifers in relation to surrounding geomorphologies, effluent inflow management, draw-off rates and levels, temperature destratification and abstraction sites.

→ PRIORITISE MICROBIAL CONTAMINANTS IN DISTRIBUTION PATHWAY

Example of data	Example of estimation procedure	Example of output
Counts/levels of indicator pathogens in storage reservoirs or during augmentation; Multistage pathogen sampling of recycled water at point of supply	Time-dependent models for correlated data	Rates of decay or microbial growth

→ PRIORITISE CHEMICAL CONTAMINANTS IN DISTRIBUTION PATHWAY

Example of data	Example of estimation procedure	Example of output
Concentrations of indicator chemicals in storage reservoirs or during augmentation; Multistage chemical sampling of recycled water at point of supply	Time-dependent models for correlated data	Rates of chemical degradation or formation

◎ NODE E-1.6 EVALUATE OTHER PLANNED OR UNPLANNED SUPPLY INPUTS

⌧ BACKGROUND

Sources of information for this evaluation include:

- employee knowledge
- hydrological records and stormwater flows
- inspections and field audits
- land-use surveys and catchment maps (stormwater)
- maps (of sewerage system, stormwater system)
- records from local authorities (e.g. locations of on-site systems, animal feedlots, sewage treatment plants), and records of trade waste programs (sewage)
- research and investigative monitoring
- resource maps and reports from natural resource management agencies (e.g. for soils, vegetation, geology, groundwater)
- sanitary surveys (stormwater) and surveys of industrial inputs into sewerage systems

→ PRIORITISE MICROBIAL CONTAMINANTS IN UNPLANNED SUPPLIES

Example of data	Example of estimation procedure	Example of output
Counts/levels of microbial parameters in non-regulated streams e.g. river/dam supplies	Hierarchical models	Median and 97.5% centile values of microbial contributions

→ PRIORITISE CHEMICAL CONTAMINANTS IN UNPLANNED SUPPLIES

Example of data	Example of estimation procedure	Example of output
Concentrations of chemical parameters in non-regulated streams e.g. river/dam supplies	Hierarchical models	Median and 97.5% centile values of chemical contributions

RECYCLED WATER DECISION NODE*

***Example only**

◎ NODE D-1. ASSESS SENSITIVITY OF ASSUMPTIONS

⌦ BACKGROUND

This analysis is based on **the conditional distribution of relevant parameters and outcomes, given information observed as a result of an earlier decision (Gelman, 2004).** These models permit optimisation of decisions and acknowledgement of uncertainties.

The first step is to identify all possible decisions *d* and outcomes *x*. In this context, a plausible outcome would be DALYs, although outcomes may have multiple attributes (e.g. may want to include dollar costs) and be expressed as vectors.

◎ NODE D-2. CALCULATE THE EXPECTED UTILITY OF DECISIONS

⌦ BACKGROUND

The next stages are:

- to determine the probability distribution of *x* for each decision option *d*; in Bayesian terms, this equates to determining the conditional posterior distribution, *p(x|d)*

-a utility function U(x) mapping outcomes onto real numbers must be defined: e.g. may be a simple continuous representation of x e.g. years of life saved; costs – or may be represented by multiple attributes e.g. DALYs.

- an expected utility E(U(x)|d) is calculated as a function of the decision d, and the decision with the highest utility is selected. In this context, a decision tree is formed, in which a sequence of 2 or more decisions might be taken and the expected utility must be calculated at each decision point.

◎ NODE D-3. IMPLEMENT DECISION

⌦ BACKGROUND

The final format of the data will constitute an algorithm to determine the management decisions for the recycled water pathway. The management option at each decision node will be one of the following:

➩ **I. NO ACTION**

➩ **II. URGENT RE-TESTING AND REVIEW**

➩ **III. MONITORING AT INCREASED SAMPLING FREQUENCY AND REVIEW**

➩ **IV. ADDRESS NON-FUNCTIONING OR SUBOPTIMAL COMPONENTS IN WATER RECYCLING PROCESS**

◎ NODE D-4. IMPLEMENT MONITORING AND FEEDBACK STRUCTURES

6. Planning for the next stages

This project will apply the models and targeted end-user protocols (TEPs) - with their evaluation of recycled water using the integrated public health/quantitative risk assessment (QRA) - for schemes in metropolitan Perth, as well as focusing on needs of regional centres where recycled water in already in use (such as Northam, Broome and Kalgoorlie).

These include:

- *systems in new urban residential developments*– reason for prioritisation: many opportunities for potential exposures to large populations; installation of untried or little documented technologies
- *agricultural applications* – reason for prioritisation: potential for indirect routes of human exposure via uptake by plants or livestock
- *small-scale schemes in rural towns* – reason for prioritisation: limited opportunity for installing highly advanced water treatment processes or systems for monitoring treatment effectiveness
- *systems in tropical areas* – reason for prioritisation: nature of pathogens in source waters and possibility of pathogen regrowth in warmer temperatures

In each setting, the analysis will identify:

- which contaminants are of a higher risk and are therefore a priority for attention; and
- which water recycling strategies are deserving of full implementation on the grounds of reasonably demonstrated safety. This will include recycled water schemes which may have potential impacts likely to compromise water sources (e.g. groundwater, which are particularly difficult to remediate once damaged).

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8. Annexes 1-6

ANNEXE 1

Session notes of P.W.F Workshop

Angus Cook, David Roser, Stuart Khan

Premier's Water Foundation Grant
ASSESSING THE PUBLIC HEALTH IMPACTS OF RECYCLED WATER USE

EVALUATING METHODS FOR QUANTITATIVE RISK ASSESSMENT (QRA) AND EPIDEMIOLOGICAL ANALYSIS

DECEMBER 2007

Department of Water
Government of Western Australia

PREMIER'S WATER FOUNDATION

AGENDA

Mon am
- OVERVIEW
- WORKSHOP THEME I. IDENTIFICATION OF KNOWLEDGE GAPS

Mon pm
- WORKSHOP THEME II. IMPLEMENTATION OF RECYCLED WATER PROGRAMS
- WORKSHOP THEME III. DEFINING RISKS TO INTENDED AND UNINTENDED END-USERS

Tues am
- WORKSHOP THEME IV. DECISION SUPPORT
- WORKSHOP THEME V. RESOURCE NEEDS
- SUMMARY AND REVIEW

OVERVIEW

In achieving the objectives for treated wastewater use established by 'A State Water Strategy for Western Australia (2003)'

→ critical to consider the **public health implications of recycled water projects.**

In all forms of recycled water use, the "big unknown" remains the correct quantification of health risks.

- Any recycled water scheme is unlikely to be successful without the community's acceptance
- Essential to achieve a higher degree of epidemiological and quantitative risk assessment (QRA) integration to guide decisions on adequate and safe use of all potential applications of recycled water

A key component of the success of the project in this State is the evaluation of recycled water schemes in urban and rural Western Australia

This seeks to include:

(a) in urban and rural communities;
(b) in occupational sites (e.g. agricultural/ mining sites);
(c) in recreational areas, including sports grounds;
(d) in schools/childcare centres;
(e) in the development of new residential or commercial subdivisions;
(f) unintended uses and contacts with the recycled water stream

Suggestions have included sites in metropolitan Perth, as well as regional centres where recycled water is already in use (such as Northam, Karratha, Broome, and Kalgoorlie).

This project does NOT currently include:

In this project, we will not explicitly include these issues for logistical reasons

- Environmental issues/effects *per se* e.g. impacts on aquatic species
- Effects on agricultural crop/pasture growth *per se* e.g. effects of recycled water used for irrigation on salinity, phosphorous, nitrogen
- Stormwater
- Rainwater
- The Brian Devine "Greywater for Every WA Home" ™ system
- Water from desalination

We may however in the future seek to apply our methods to these other water uses in separate 'add-on' projects

OBJECTIVES OF THE CURRENT P.W.F. PROJECT

(a) identifying and filling the gaps in the current and future application of recycled water guidelines in Western Australia;
(b) guiding State management decisions to convert a greater number of facilities and vegetated areas to irrigation with recycled water;
(c) to develop a risk framework for adequate interpretation of community concerns related to use of recycled water;
(d) providing WA communities with a public health-based safety analysis to address community concerns regarding safety of recycled water use.

Table 1
Factors contributing to the degree of public acceptance of water reuse

US public acceptance of water reuse seems to be higher when [2–5]:

- Degree of human contact is minimal
- Protection of public health is clear
- Protection of the environment is a clear benefit of the reuse
- Promotion of water conservation is a clear benefit of the reuse
- Cost of treatment and distribution technologies and systems is reasonable
- Perception of wastewater as the source of reclaimed water is minimal
- Awareness of water supply problems in the community is high
- Role of reclaimed water in overall water supply scheme is clear
- Perception of the quality of reclaimed water is high
- Confidence in local management of public utilities and technologies is high

Hartley, 2006

Generic experiences from undertaking/being involved in water reuse risk assessment

- Guideline selection.
- Data management
- Defining the scale of the risk assessment and the end point.
- Selecting the input data for modeling risk (initial concentrations, barrier effects, dose response)
- How much can you use the literature and when do you need to collect specific site data?
- Respective roles of qualitative v. quantitative risk assessment.
- Point estimation / Monte Carlo simulations
- Risk scenario selection and construction
- Relationship of risk estimates to decision processes
- Is it acceptable to have a high risk to small populations under rare situations?
- Inclusion in the assessment of other related risks (from factors other than recycled water)
- Hazardous event modeling
- Assessment 'standards' applied to old schemes v. new schemes

(Discussion led by D. Roser and S. Khan)

WORKSHOP THEME I.

IDENTIFICATION OF KNOWLEDGE GAPS

The main issues pertain to:

- **risk of viable pathogens or their toxins not being completely removed in the treatment process, thereby causing an excess burden of infectious disease**
- **risk of 'chemicals of concern'** (such as organic compounds; heavy metals; pharmaceutical by-products etc) **not being removed in the treatment process, thereby causing toxicological effects** (e.g. endocrine disruptors, which have been linked to infertility and cancers in animal models)

The main problems arise in inferring risk, particularly for long-term contact with recycled water.

One of the principal objectives of this project is to assign some risk estimate and predict possible health end-points for a range of water applications (e.g. for irrigation; horticulture; consumption etc).

QUESTIONS FOR THE PANEL

Q. For each of the following contaminants/ contaminant groups, what is the optimal evidence-base that should be used to assess risk? [i.e. for a given contaminant, what information and analysis is required for you to determine likely risks to the end-users?]

Q. In the worst-case scenario, what are the health implications of human contact with this contaminant/ contaminant group?

Q. Is additional information or analysis needed for you to determine the safety of this contaminant/ contaminant group?

A. Microbial hazards

Table 2.1 Microorganisms of concern in raw sewage

Pathogen type	Example	Illness
Bacteria	*Salmonella*	Gastroenteritis, reactive arthritis
	Campylobacter	Gastroenteritis, Guillain–Barré syndrome
	Pathogenic *Escherichia coli*	Gastroenteritis, hemolytic uremic syndrome
	Shigella	Dysentery
	Yersinia	Gastroenteritis, septicemia
	Vibrio cholerae	Cholera
	Atypical *Mycobacteria*	Respiratory illness (hypersensitivity pneumonitis)
	Legionella spp	Respiratory illness (pneumonia, Pontiac fever)
	Staphylococcus aureus	Skin, eye, ear infections, septicaemia
	Pseudomonas aeruginosa	Skin, eye, ear infections
	Helicobacter pylori (?)	Peptic ulcers
Viruses	Enterovirus	Gastroenteritis, respiratory illness, nervous disorders, myocarditis
	Adenovirus	Gastroenteritis, respiratory illness, eye infections
	Rotavirus	Gastroenteritis
	Norovirus	Gastroenteritis
	Hepatitis A	Infectious hepatitis
	Calicivirus	Gastroenteritis
	Astrovirus	Gastroenteritis
	Coronavirus	Gastroenteritis
Protozoa	*Cryptosporidium*	Gastroenteritis
	Giardia	Gastroenteritis
	Naegleria fowleri	Amoebic meningitis
	Entamoeba histolytica	Amoebic dysentery
Helminths	*Taenia* (*T. saginata*)	Tapeworm (beef measles)
	Ascaris	Roundworm
	Trichuris	Whipworm

Source: Adapted from Feachem et al (1983), Geldreich (1990), NRC (1998), Bitton (1999)

Additional microbial hazards

- **Prions**
- **Microbial By-products**
  e.g. algal / cyanobacterial toxins

B. Chemical hazards

Chemical toxicants that may potentially found in effluent include:

- **Pharmaceuticals and their metabolites**
- **Personal care products (PPCPs):** e.g. benzophenone, musk ketone, galaxolide and triclosan
- **Disinfection by-products:** e.g. trihalomethanes, HAAs, HANs, furanones
- **Nitrates and nitrogen-based by-products:** e.g. nitrosodimethylamine — NDMA
- **Heavy metals and metalloids:** e.g. As, Cd, Cr, Cu, Hg, Ni, Pb, Zn and Fe
- **Pesticides and other agricultural chemicals:** e.g. atrazine, organophosphates (including fenitrothion), organochlorines (including dieldrin, heptachlor and DDT), synthetic auxins (2,4,5-T and 2,4-D)
- **Detergents, disinfectants and other cleaning agents**
- **Hydrocarbons,** including Total petroleum hydrocarbons (TPH)/ Polycyclic aromatic hydrocarbons (PAH)
- **Food components and additives/Caffeine**
- **Other domestic, industrial and agricultural compounds I: Organic** including phthalates/ phenols (e.g. bisphenolA, nonylphenol and nonylphenol polyethoxylate)/ polybrominated diphenyl ethers (PBDE)/ Polychlorinated biphenyls (PCBs) / Volatile organic compounds (VOCs), including benzenes, toluenes
- **Other domestic, industrial and agricultural compounds II: Inorganic**
- **Radionuclides**
- **Chemical mixtures**

From an analytical perspective, the contaminant classifications may be summarised in *Table 1*.

CLASS	ANALYTICAL CATEGORY	ANALYTICAL IMPLICATIONS	EXAMPLE
MICROBIOLOGICAL CONTAMINANTS [PATHOGENS AND/OR THEIR BY-PRODUCTS]	Relevant dose and health endpoint well-defined	Quantitative microbial risk assessment applicable/ Suitable log reduction	Campylobacter
	Relevant dose and health endpoint poorly defined but plausible comparative models available	Modified quantitative microbial risk assessment/suitable log reduction may be applicable if information on appropriate comparative organisms available	Some enteric viruses
	Relevant dose and health endpoint poorly defined and few/no comparative models available	Current methods of inference inadequate	Prions
CHEMICAL CONTAMINANTS [CHEMICALS OF CONCERN]	Relevant dose and health endpoint well-defined	Toxicological / epidemiological models adequate	Many common heavy metals
	Relevant dose and health endpoint poorly defined but plausible comparative models available	Modified toxicological / epidemiological models partially adequate if information on appropriate analogues available	Endocrine disruptors
	Relevant dose and health endpoint poorly defined and few/no comparative models available	Current methods of inference inadequate	NDMA [N-Nitroso-dimethylamine]

Rumsfeld's Postulates - known knowns and unknown unknowns

(Discussion led by S. Khan / D. Roser)

WORKSHOP THEME II.

IMPLEMENTATION OF RECYCLED WATER PROGRAMS

Understanding water treatment performance variability

(Discussion led by S. Khan / D. Roser)

QUESTIONS FOR THE PANEL

Q. Which of the following parameters are or may be particularly informative with regard to recycled water quality?

Q. Which of the following parameters are NOT or are UNLIKELY to be particularly informative with regard to recycled water quality?

Water quality indicators/ bulk parameters

Additional indicators of water quality and treatment process integrity include:

- **Turbidity**
- **Biochemical oxygen demand (BOD)**
- **Suspended Solids**
- **pH**
- **Chlorine residuals**
- **Ammonia**
- **Temperature**

Indicator organisms are used to detect the presence of faecal contamination, including:
- **Thermotolerant coliforms**
- **Coliphages**
- **Clostridial spores**
- ***Pseudomonas***
- **Aeromonads**

Indicator contaminants are used to detect the presence of faecal contamination, including:
- **Faecal sterols**

Other indicators of biological activity, including:
- **Proteins**
- **Phospholipids**
- **Bacterial lipopolysaccharides (LPSs)**

Toxicity testing

Other indicators of biological activity/end-point toxicity of recycled water, including:
- ***In vitro*** e.g. genetic damage; disturbances in enzymatic or cellular functioning
- ***In vivo*** e.g. animal testing for carcinogenesis; fetotoxicty; other subchronic effects
- **Environmental activity** e.g. estrogenic effects on aquatic organisms in water catchments

Other indicators of treatment efficiency, including 'targeted' testing in the treatment train for:
- Log removal data for specified pathogens
- % removal of specified micropollutants

AND/OR

challenge testing of various operational components of the system with safe surrogates (phages / chemicals)

Other relevant predictors of water quality

Additional predictors of water quality may include the nature of the source waters:
- **Residential**
- **Industrial**
- **Meat and poultry processing sites (e.g. abattoirs)**
- **Clinical / hospital**

QUESTIONS FOR THE PANEL

Q. What safety issues arise in water recycling schemes at different scales and in different contexts e.g. large water utilities versus small schemes; industrial versus residential?

Q. What role do health and other government agencies have in assessing safety issues in this full range of recycling schemes?

Q. What safety issues can be transferred from other projects, what can be derived from the guidelines, what has to be done *de novo?*

Q. How can the end-users be best informed of safety issues in differing schemes?

WORKSHOP THEME III.

DEFINING RISKS TO INTENDED AND UNINTENDED END-USERS

QUESTIONS FOR THE PANEL

Q. What do you see as the risks to intended users in each of the following categories?

Q. Could unintended use/accidental contact arise in the following categories, and what would be the risks to individuals as a consequence?

Q. How do we optimise safety for these intended and (if relevant) unintended users?

INDIVIDUAL-LEVEL, DOMESTIC USE

INDIVIDUAL-LEVEL, DOMESTIC USE (1)

i. For indoor potable domestic use in urban and rural communities

ii. For indoor non-potable domestic use in urban and rural communities

iii. For outdoor non-potable domestic use in urban and rural communities

INDUSTRIAL / COMMERCIAL USE

INDUSTRIAL/COMMERCIAL USE (1)

Sub-category I: Potential impingement on human food supplies

iv. For commercial purposes potentially impacting on food supply (e.g. sites or activities relating to agriculture, horticulture, cropping, etc)

Sub-category II: (For processes not included in subcategory I) Potential worker exposure possible

v. For open system commercial purposes (e.g. with external application of water relating to silviculture, cultivation of turf, mineral extraction, etc)

Sub-category III: (For processes not included in subcategory I or II) No potential worker exposure

vi. For closed system commercial purposes (e.g. use of water within internal industrial processes, etc)

MUNICIPAL USE

MUNICIPAL USE (1)

Sub-category I: Uncontrolled access

vii. Use in uncontrolled municipal or other public areas, including parks, gardens and sports grounds, schools/childcare centres

Sub-category II: Controlled/restricted access

viii. Use in controlled municipal or other public areas

Sub-category III: Mixed access

ix. Other in which use may be controlled or uncontrolled depending on the context e.g. fire fighting

WORKSHOP THEME IV.

DECISION SUPPORT

NSW Case example by David Roser and Stuart Khan

A possible 'exposure/risk structure' of recycled water that is being considered for this project is along these lines:

REFER TO HANDOUT

- The final format of the data will constitute an algorithm to determine the management decisions for the recycled water pathway.
- The management option at each decision point will be one of the following.

⇨ I. NO ACTION

⇨ II. URGENT RE-TESTING AND REVIEW

⇨ III. MONITORING AT INCREASED SAMPLING FREQUENCY AND REVIEW

⇨ IV. ADDRESS NON-FUNCTIONING OR SUBOPTIMAL COMPONENTS IN WATER RECYCLING PROCESS

QUESTIONS FOR THE PANEL

Q. What do you see as the key decision points in the safe provision of recycled water to users? [possibly with reference to the pathways described earlier]

Q. Who do you see as responsible for these decisions?

Q. What monitoring information is needed to support these decisions?

Q. How do/should we evaluate the effectiveness of the decisions that have been made?

Q. How do/should we manage hazardous events which are rare and/or there are no data for?

WORKSHOP THEME V.

RESOURCE NEEDS

Staff and facilities

There is some uncertainty around the expertise, time, and money available within government agencies and affiliated organisations for assessing risks of recycled water use

Software

- Software offers much promise for facilitating assessments, access to information such as data tables efficiently, comparing the risks , providing initial assessments of specific site risks
- Such systems need to have experts to construct, operate and maintain and this takes resources.
- There is a long history of dead pilot software – the ideas seem sound but the implementation is poor.

Monitoring costs 1: Costs of chemical analyses [Salgot, 2006]

Cost calculation and proposed monitoring frequency of physicochemical and chemical quality parameters

Parameter	Example indicators	Measuring frequency	Costs	Importance for chemical cat. (Table 5)
Physico-chemical	pH, EC, turbidity, TSS, colour	+++	Very low	1–4
	Sodium absorption ratio (SAR), UV 254	++		1–4
Organic sum parameters	COD (TOC, DOC), BOD, DO, AOX	+++	Low–medium	1–4
		++		1–4
Nutrients, minerals	Total-N, NH_4^+-N, Total-P, NO_3^-	+++	Low	1–4
	SO_4^{2-}, CN^-, F^-, Cl^-	++	Low	1–4
Residual chlorine	Cl_2 (if chlorination)	+++	Low	1, 2, 4
	Disinfection products/by-products (e.g., NDMA)	+	Very high	1, 3
(Heavy) metals	As, Cd, Cr(III,VI), Hg, Pb, B, Al, Be, Ba, Co, Cu,	++	Medium	1, 2, 3
	Fe, Li, Mn, Mo, Ni, Se, Sn, Th, V, Zn	+	Medium	1, 2
Organic micro-pollutants	Surfactants	++	Medium	1, 2
	Mineral oil	++	Medium	1, 2
	Pesticides (e.g., Diuron; 2,4-D)	+	High	1–3
	Complex-forming substances (e.g., EDTA)	+	High	1–3
	Chloride solvents (if AOX > limit, e.g., TCE)	+	High	1, 2
	Aldehyde	+	Medium	1, 2
	Aromatic organic solvents (e.g., benzene)	+	High	1, 2
	PAHs (e.g., benzo(a)pyrene)	+	High	1, 2
	Phenols	+	Medium	1, 2
	Pharmaceuticals (e.g., carbamazepine, x-ray contrast media, sulfamethoxazole), endocrine disruptors (E-Screen)	+	Very high	1–3

Frequency: +++, permanently–weekly; ++, monthly– once per year; +, once per 1–5 years.
Costs per analysis: very high, >€200; high, €60–200; medium, €20–60; low, €6–20; very low, <€6.

Monitoring costs 2: Costs of microbial analyses [Salgot, 2006]

Table 6
Cost calculation of microbiological analysis

Parameter	Cost	Important for microbial category (Table 5)
Legionella	High	I, III–V
E. coli and similar	Very low	I–VII
Enterococci (*Salmonella*)	Low	I–VII
Nematode eggs	Medium	I–VII
Taenia	Medium	V
Giardia and *Cryptosporidium*	High	I–III, VI
Bacteriophage	Low	I–III, VI
Enterovirus	High	I–III, VI–VII

Costs per analysis: Very high, > €200; high, €60–200; medium, €20–60; low, €6–20 €; very low, <€6.

QUESTIONS FOR THE PANEL

Q. Are health departments properly set up/resourced (expertise, time, money) for assessing risks of recycled water use?

Q. Are the State's laboratory resources sufficient for the optimal monitoring process for recycled water?

Q. What would be the preferred form in which these risk assessment were completed? IE in-house software; externally supported analyses; expert analyses

SUMMARY AND REVIEW

QUESTIONS FOR THE PANEL

END-PRODUCTS

Which of the following products from this project will ne most useful to you:

- Software sausage machine – either standard issue risk assessment or specialist modelling
- System for generically applying QRA to classify recycled systems broadly into 'safe', intermediate', 'unsafe'
- A desktop, locality-based model that accounts for scale in terms of assessment e.g. large volume systems (>1000 kl/day) receive full quantitative assessment; smaller volume systems receive generic assessment
- Education package
- Database of key references
- Monitoring and audit scheme
- Start-up criteria for new projects e.g. as list of qualitative and quantitative checkboxes
- List of case applications
- List of recommendations for additional DoH/State resources for a dedicated recycled water unit
- Cross-links for the above with existing or proposed guidelines

ANNEXE 2

Rumsfeld's Postulates –
Known knowns and unknown unknowns

Stuart Khan
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UNSW

Rumsfeld's Postulates – Known knowns and unknown unknowns

Stuart Khan
Centre for Water & Waste Technology (CWWT)
University of New South Wales

CENTRE FOR WATER & WASTE TECHNOLOGY

Health risks assessment components

- Chemical exposure
- Pathogen exposure
- System reliability / hazardous events analysis

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Chemical contaminants

- All chemicals (potentially) in source water (municipal sewage)
- May have come from:
  - Original potable water source
  - Municipal wastes (excreta, detergents, antiseptics, washings, etc)
  - Stormwater influx
  - Industrial discharges
  - Treatment processes
  - Biochemical production during storage or distribution

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

What is acceptable quality?

- Accepted benchmarks:
  - Acute chemical risks: HQ<1
  - Chronic chemical risks: cancer risk < 10^{-6}
  - No such bench marks for others such as EDCs
- Common US approach for IPR:
  - Reclaimed water of equal or better quality than traditional source water
- Alternative approach:
  - DALYs as used for pathogens (still require benchmarks)

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

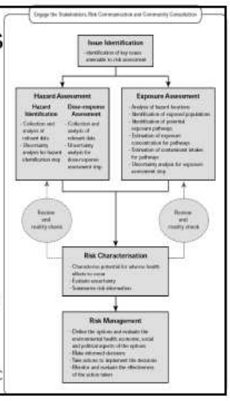
Defining quality objectives

- Traditional approach:
  - Identify known chemicals of concern
  - Consider toxicity (dose-response)
  - Consider exposure
  - Set limits within safe concentrations
- Insufficient for some water reuse schemes
  - New exposures pathways to non-traditional sources
  - Complex mixture of chemicals
    - Poorly defined
    - Highly variable

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

EnHealth Guidelines

- enHealth Council (2002)
- *"Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards"*
- Provide framework for public health risk assessment



CENTRE FOR WATER & WASTE TECHNC

Typical risk characterisation calculations

Risk from ingestion and inhalation exposures to carcinogenic contaminants in water:

$$\text{Risk (R)} = \frac{C \times [(EF_r \times IFW_{adj} \text{ x } CSF_o) + (EF_r \times VF_w \text{ x } InhF_{adj} \text{ x } CSF_i)]}{AT_c \text{ x } 1000 \mu g/mg}$$

Hazard quotients from ingestion and inhalation exposures to noncarcinogenic contaminants in water:

$$\text{Hazard Quotient (HQ)} = \frac{C \times EF_r \times ED_r \, [(\frac{IRW_a}{RfD_o}) + (\frac{VF_w \text{ x } IRA_a}{RfD_i})]}{BW_a \times AT_n \times 1000 \mu g/mg}$$

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Rumsfeld's Postulates

- Known knowns
  - Chemicals we know we know
- Known unknowns
  - Chemicals we know we don't know
- Unknown unknowns
  - Chemicals we don't know we don't know
- Unknown knowns?
  - Chemicals we don't know we know

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Alternative risk characterisation

- Can not identify ALL chemicals
- Can identify toxicological endpoints
  - Can be quantified by *in vitro* or *in vivo* assays
    - Ames test,
    - sister chromatid exchange assays,
    - micronucleus test
    - 6-thioguanine resistance assay
    - induction of adenomas
    - hormonal effects (estrogenicity, etc)
    - other toxic effects
    - bioaccumulation

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…but which assays?

- "Development of an Ecotoxicity Toolbox to Evaluate Water Quality for Recycling"
  - WA Department of Water
    - Water Corporation
    - CRC WQT
    - UNSW (CWWT)
    - Curtin University
- "A national approach to risk assessment, risk communication and management of chemical hazards from recycled water"
  - CRC WQT / WQRA
    - UNSW (CWWT)
    - EnTox
    - Australian Water Quality Centre (SA Water)
    - Melbourne Water, Sydney Water, ACTEW (ACT), United Water

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Variability of treatment effectiveness under normal operation

- Quantitative descriptions required
- Describe concentrations as probability functions
- Monte Carlo models may be necessary
- Analogous to QMRA
- Individual process performance data used to access performance of overall system
  - Necessary for contaminants below analytical detection limits
  - Allow for extrapolation for estimation of probability that treatment goals would be exceeded

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Typical chemical risk assessment

- Hazard identification
  - which chemicals/ endpoints?
- Dose response assessment
  - For specific chemicals or 'whole effluent mix'
- Exposure assessment
  - Traditionally undertaken for "normal" or "expected" conditions only
  - With or without variability analysis
- Risk characterisation
- Risk management
  - Manage exposure of hazards identified under "expected" conditions

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Extreme example of hazardous events

- Chernobyl
  - Hazard identification
    - Radioactive substances
  - Dose-response assessment
    - Acute and chronic effects
  - Exposure assessment
    - How much is released from the plant during operation?
    - Transport and fate
    - Exposure pathways (oral, inhalation, etc)
  - Risk characterisation

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Water recycling schemes

- Highly contaminated water source
- Advanced water treatment
- Very high degree of removal for many chemical contaminants
  - For many chemicals >3 Log_{10} removal expected
  - Difference between expected performance and potential failures is significant
  - 'Risks' driven by 'hazardous events'

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Water recycling hazardous events

- An incident or situation that can lead to exposure to a hazard
  - Examples:
    - Treatment failure or underperformance
    - Variable production of disinfection byproducts
    - Dual reticulation cross-connection

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

New National Guidelines

- Phase 1: non-potable uses (2006)
- Phase 2: potable uses (2008)
- Requires serious consideration of chemical hazards
- Requires consideration of hazardous events
- Risk management framework
  - Hazard identification
  - Risk assessment
  - Preventative measures

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Risk in terms of hazardous events

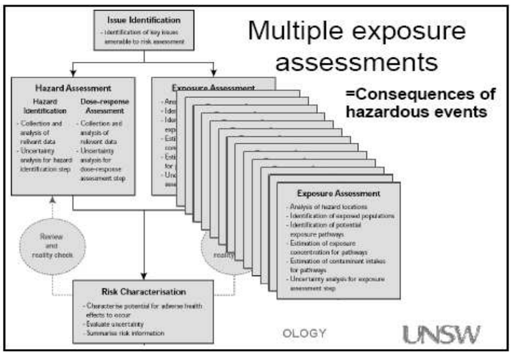
- Risk
  - Likelihood of identified hazards causing harm
    - in exposed populations or receiving environments
    - in a specified timeframe
    - including the severity of the consequences
  - Characterised as
    - Low
    - Moderate
    - High
    - Very High

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Hazardous events

- Each hazardous event associated with unique set of
  - Likelihoods
  - Consequences
    - Hazard exposures (chemical concentrations, etc)
    - Acute hazard quotients
    - Chronic risk factors
- Represents an additional dimension to (enHealth) risk assessment

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW


Multiple exposure assessments
=Consequences of hazardous events
Issue Identification
- Identification of key issues amenable to risk assessment
Hazard Assessment
Hazard Identification
- Collection and analysis of relevant data
- Uncertainty analysis for hazard identification step
Dose-response Assessment
- Collection and analysis of relevant data
- Uncertainty analysis for dose-response assessment step
Exposure Assessment
- Analysis of hazard locations
- Identification of exposed populations
- Identification of potential exposure pathways
- Estimation of exposure concentration for pathways
- Estimation of contaminant intakes for pathways
- Uncertainty analysis for exposure assessment step
Review and reality check
Risk Characterisation
- Characterise potential for adverse health effects to occur
- Evaluate uncertainty
- Summarise risk information
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Current gaps in hazardous events data
• Detailed long-term performance data
– Advanced treatment processes
– DBP production variability
• Nature of potential hazardous events
– How poorly may a process perform?
– When is it likely to occur?
– How long may underperformance or failure persist?
• Likelihood and consequences!
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ANNEXE 3

Experiences from Quantifying Microbial and Chemical Risks

D. J. Roser, S. Khan, N. J. Ashbolt

UNSW

Experiences from Quantifying Microbial and Chemical Risks

David Roser, Stuart Khan, Nick Ashbolt

The 'Devil in the Details'

Generic Experience Sources

- Water reuse risk assessment- Replacement Flows
- EU MicroRisk – operational implementation of QMRA theory to drinking water supplies
- Feedlot Waste Risk Assessment and Management – especially exposure assessment
- SCA Risk assessment planning
- NHMRC 2005 Rec guideline implementation

Guideline Selection

- Water Reuse Guidelines –
- But Also:
  - Recreation Guidelines
  - EnHealth Impact Assessment Guidelines
  - EnHealth Risk Assessment Guidelines
  - Drinking Water Guidelines Principles
    - Water Safety Planning (Davidson et al)
    - Hazard identification and (Qualitative) Risk Assessment in Water supplies (CRCWQT/Nadebaum/Hrudey)

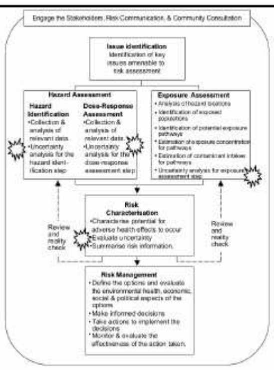
Standard format for Regulators

- During Replacement Flows Project DOH requested complete reformat as a result of assessor change
- Format requested was standard EnHealth HRA Heading Setup
- This is a good logical format worth consistent with Recycled Guidelines
- But its implementation led to identification of data gaps! (Good and Bad)

Health Risk Assessment

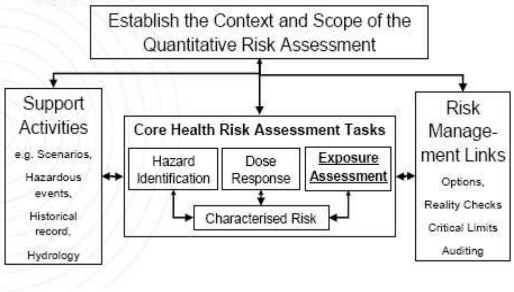
- Use scheme to systematise work
- Data mining + gap filling (CWWT work)
- Requires:
  - Hazard assessment (research lit review)
  - Dose response (literature)
  - Exposure Pathway Assessment (Initial provides basis for research program)

'Uncertainty'



Health Risk Assessment Task Groups

!!!Not just motherhood statements but a workable system to link assessment/research to management outcomes!!!



Data Management

- Large Volumes of Data Collected
- Range of baseline and hazardous even scenarios to explore (permutations + combinations also known as the complexity problem)
- Large number of assumptions and sub models (concept of meta model) to be documented
- Special Case of SCADA data – much promise but no system (data rich, information poor)
- Data interpretation – e.g. dose response curves have much uncertainty - parameter variability, relevance of bioassays to disease

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Uncertainty Identification

- Variability v. Uncertainty in data
- Data Gaps (other pathogens and especially chemicals)
- Impossible to quantify total risk because of poor data on many rare catastrophic events
- 'Rumsfelds Postulates
  - unknown unknowns = prions
  - unknown knowns = climate change + evolution effects – *P. aeruginosa* example
  - known unknowns = prion
- *Documentation is well suited to generating fear irrespective of risks – political football and suggests a lack of clarity demanded of decision makers*

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Defining the Scale of a Risk Assessment and Its Endpoint

- Risk assessments are necessarily open ended and decision on where to stop assessment is necessarily a value judgement
- Execution of HRAs leads to iterative learning and gap identification for better and worse
- DOH kept coming back wanting more as they grew to understand the system
- A useful model is EPAA, EIA and EIS implementation experience – consider the size of this 'industry'

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Adaptation of HRA to the Commercial Environment

- Expectation is that many HRAs would be done by commercial companies? Or by government?
- When is a qualitative assessment enough?
- Commercial companies need certainty for budgeting?
- Companies are time constrained and may not be able to fill the real knowledge gaps
- Replacement water project led to a quadruple resource need and double budget in practice
- Potential for unrealistic expectations on part of commission organisations, water companies, local government etc.
- *The trouble is the inexorable logic in the assessment process drives information gap filling*

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Are health departments properly set up/resourced

- Expertise
  - state health units seem to have *ca* 5 operational people (in the 10s nationally – molecular/analysts could be trained but different specialist view the world differently)
- Dedicated unit/structure???
- Time
  - time poor is the bane of the current era;
  - management demands ever increasing quality and attention to detail while providing less resources
  - Flexibility
- Philosophically (goes to competing drivers)
  - Resource allocation heavily based on emotion rather than statistics
  - Environmental v. Human Health
  - Victoria and between state differences in guideline application
  - Easy to say No! where there is any risk
  - People v. the environment as the priority (Deep Ecology)
  - Collignon and first principles (science plus emotion plus hidden agendas??)
  - Risk management v. risk assessment divide
- Consider financial resources needed for Environmental Assessments

CENTRE FOR WATER & WASTE TECHNOLOGY UNSW

Selecting the input data for barrier modeling of risk

- Initial concentrations
- Model contaminants
- Barrier effects
- Environmental fate and transport
- Treatment processes and malfunctions
- Dose response – can alter the output risk greatly
- Exposure doses
- Selected populations

Options can be many, varied, suspect, limited in detail and contradictory

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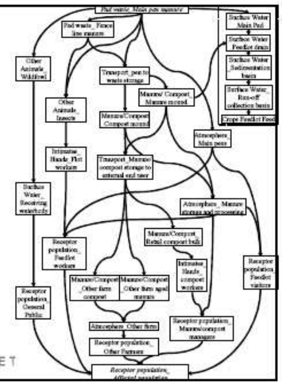
Literature v. Site specific data

- How much can you use the literature and when do you need to collect specific site data?
- Generic assumptions in guidelines good enough v. Need for site specific.
- Desktop Assessment First is often Feasible
- But **Exposure Pathway Assessment** may identify many data gaps

Exposure Pathway Complexity (feedlot example)



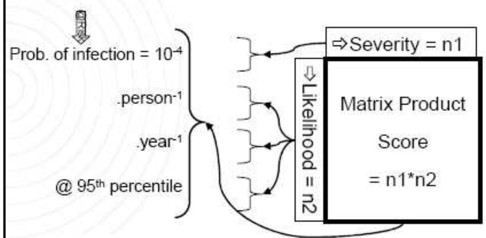
Exposure Pathway Screening

- Identify hazards
- Identify compartment classes and specific compartments where they might be found
- Identify between compartment links where transfer might occur e.g. water to atmosphere
- Identify start compartment and end receptor population
- Assess qualitative 'risk potential' posed by transfer between compartments if it occurs
  - Likelihood of transfer = frequency
  - Impact potential (load, proximity to humans, perceptions)
  - Identify low priority transfers (e.g. covered by other, feedback etc.)
  - Set transfer concern threshold (>5)
- Compile information in database
- Using database query engine compile all possible pathways
- Calculate the aggregate risk score of each path
- Filter paths based on filtering low priority transfers and risk score
- Compile list of high priority paths and score compartments and transfers

Some Aspects of Quantitative Assessment

- Respective roles of qualitative v. quantitative risk assessment.
  - (qualitative ratings are scientifically unsatisfying and open to perceptions of bias)
- When is point estimation enough, when do you need to Monte Carlo simulations.
- If Monte Carlo – then which statistic
  - 95th percentile v. Average v. median
- Risk scenarios selection and construction.

QMRA (Decision Analysis) / Qualitative Risk Assessment (Decision Intuition)



Relationship of risk estimates to decision processes.

- Do risk estimates become the new de facto compliance target?
- Do they stand apart and the decision is based on weighing qualitatively all factors?
- Put another way how prescriptive do you want to be?

Dowie (2005) - Bayesian Decision Analysis

Is high risk to small population under rare situations acceptable?

- If hazardous event has catastrophic impact risk is automatically high (biosolids assessment)
- High risks are associated with unlikely hazardous events
- RF hypothetical example - Risk from drinking raw river water over a lifetime
- New Zealand Example – where to you put resources – more efficient in the city

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Inclusion in the assessment of other related risks

- Do you add the risks from factors other than recycled water or assess in isolation?
- Logistics Issue encountered with Replacement Flows project where scope of project kept expanding
  - Drinking, recreation, vegetables, shellfish
  - Aerosols, spraying of fields, other sources

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Hazardous event modeling

- Can throw up scenarios that are very worrying
- How realistic they are is unclear.
- What constitutes being overcautious
- How to express, how to respond?

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Assessment 'standards' applied to old schemes v. new schemes.

- Address all at once
- Address at upgrade or expansion time
- Replacement Flows - water from STPs was already acting as 'environmental flows in the river and was being used for indirect potable recycling thanks to the 'Magic Mile'

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SEVEN THORNY ISSUES

and some other stuff

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1. Grey Water Recycling especially for single dwellings

- We propose excluding this issue for logistical reasons but whatever guidelines are developed should at least be consistent with the likely management of such externalities in the future
- This issue will likely come back because of its high public profile
- Possible approach might be to class recycled projects on volume treated, population exposed basis using the volume as analogous to likelihood and population analogous to severity.

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2. Uniqueness

- Every project is unique
- What can be transferred from other projects,
- What can be obtained directly from the guidelines?
- What work has to be done *de novo?*
- What issues should operational guidelines prescribe and what should be left to the assessor?

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3. Monitoring /Critical limits/Auditing (these are a sample)

- Compliance v. Targeted monitoring
- Traditional analysis based compliance monitoring is:
  - very expensive and
  - only gives warning after a problem is detected which can be weeks or months
- Monitoring of or for hazardous events
  - Risks are much more a concern at such time;
  - The Change point problem
- Proactive(=applied research) v. Reactive monitoring

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4. Planning instruments

- Do require Water Safety plans as part of the process?
- At what level of risk or recycling scale do you trigger recycling guidelines (workshop?)
- Integration with general land and water planning
- Adaptive Environmental Management and Planning
- Drinking water

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5. Planning system theory

- The current model is known as the scientific or rational management method
- The system can fail at times
- The system is currently failing e.g.:
  - it does not have a good response to ad hoc grey water recycling which is taking place anyway
  - 'unintentional' indirect potable reuse
- There are alternative planning theories from the Environment literature but unclear how applicable to Health context.

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6. Software, DSS and electronic support

- Software offers much promise for:
  - facilitating assessments,
  - access to information such as data tables efficiently,
  - comparing the risks ,
  - providing initial assessments of specific site risks
- There are several types of software:
  - Specialized tools such as Hydrus – a groundwater modelling tool
  - More generic risk assessment and estimation such as @Risk programs
  - Expert systems which could be based on rules and database
- Such systems need to have experts to construct, operate and maintain and this takes resources.
- Research is first step after which there is development and marketing and training which require traditionally 10 times additional resources
- There is a long history of dead pilot software – ideas seem sound but implementation is poor.

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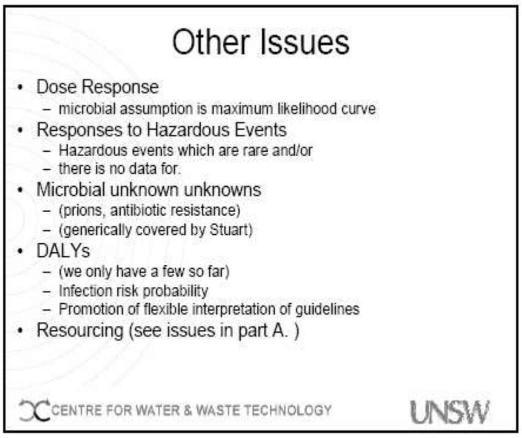
Other Issues
• Dose Response
– microbial assumption is maximum likelihood curve
• Responses to Hazardous Events
– Hazardous events which are rare and/or
– there is no data for.
• Microbial unknown unknowns
– (prions, antibiotic resistance)
– (generically covered by Stuart)
• DALYs
– (we only have a few so far)
– Infection risk probability
– Promotion of flexible interpretation of guidelines
• Resourcing (see issues in part A.)
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END OF NEW STUFF
• PWF seminar 1 about the system
• Water Reuse Conference presentation
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ANNEXE 4

Understanding water treatment performance variability

Stuart Khan
Centre for Water & Waste Technology (CWWT)
University of New South Wales

UNSW

Understanding water treatment performance variability

Stuart Khan
Centre for Water & Waste Technology (CWWT)
University of New South Wales

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Sources of variability

- Source water quality
  - Diurnal
  - Daily
  - Weather impacts
  - Long-term changes
- Treatment performance
  - Normal variability
  - Gradual change
    - Eg. Membrane aging or fouling
  - Hazardous events

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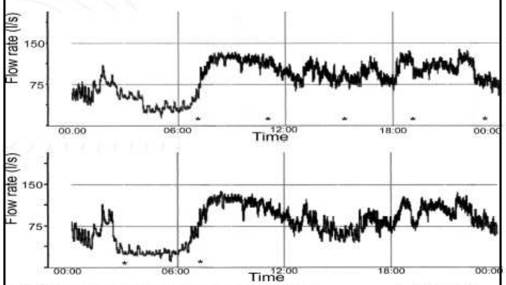
Variation among "grab-samples"

PhAC	Mean & std. Dev. (µg/l)	Coeff. of variation %
Salicylic acid	8.9 ± 0.23	3
Ibuprofen	2.3 ± 0.23	10
Paracetamol	148 ± 17	12
Metronidazole	0.43 ± 0.17	40
Gemfibrozil	1.5 ± 0.06	4
Naproxen	3.8 ± 0.31	8
Methadone	0.06 ± 0.03	50
Ketoprofen	0.13 ± 0.01	8
Phenytoin	0.18 ± 0.04	22
Carbamazepine	0.26 ± 0.04	15
Morphine	0.52 ± 0.11	21

CENTRE FOR WATER & WASTE TECHNOLOGY Khan (2003) UNSW

Diurnal flow variation



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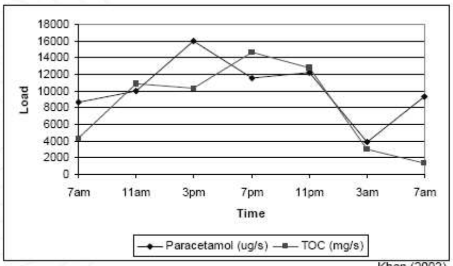
Diurnal load variations



Khan (2003)

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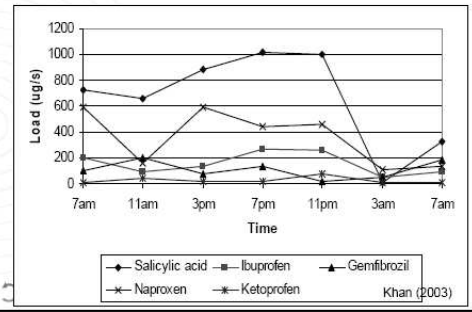
Diurnal load variations



Khan (2003)

Mean concentrations (µg/L) from 5 consecutive 24-hour composites

PhAC	Raw influent	Primary effluent	Secondary effluent
Salicylic acid	13 ± 3.3	6.1 ± 1.4	0.38 ± 0.13
Ibuprofen	2.7 ± 0.35	2.3 ± 0.34	0.22 ± 0.15
Paracetamol	104 ± 1.8	28 ± 3.5	0.39 ± 0.23
Gemfibrozil	1.5 ± 0.19	1.3 ± 0.08	0.25 ± 0.03
Naproxen	6.5 ± 0.42	5.5 ± 0.73	0.35 ± 0.12
Ketoprofen	0.90 ± 0.08	1.0 ± 0.18	0.59 ± 0.05
Morphine	0.26 ± 0.11	0.19 ± 0.02	0.02 ± 0.00

Khan (2003)

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Rejection by NF/RO membranes

- Different membranes designed for different purposes
  - MWCO
  - Reliance on electrostatic repulsion
- Retention decreases as pore size decreases
  - NF 90 > NF 270 >> TFC-SR2
- Retention is dependant on solute physicochemical characteristics

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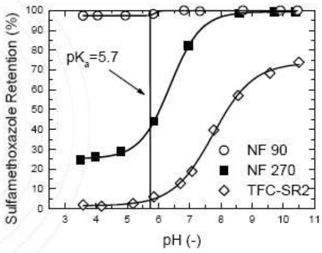
Effects of solution pH



Nghiem & Khan (2007)

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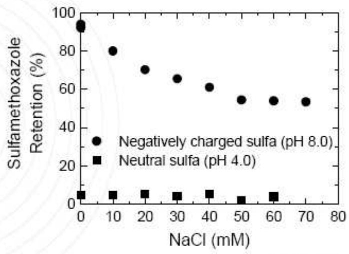
Effects of ionic strength



Nghiem & Khan (2007)

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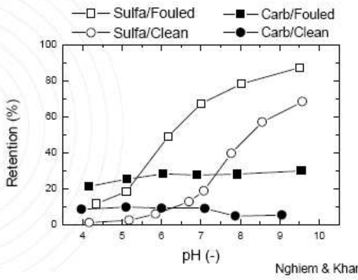
Effects of membrane fouling



Nghiem & Khan (2007)

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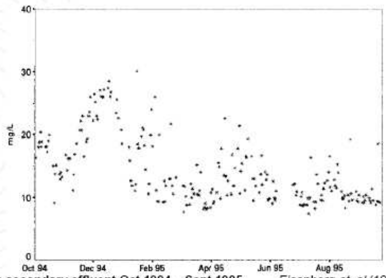
Time series plot for TOC



TOC in secondary effluent Oct 1994 – Sept 1995 Eisenberg *et. al* (1998)

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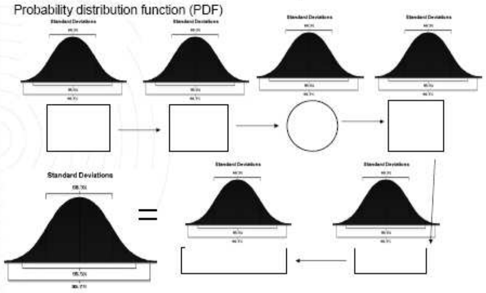
Cumulative probability distributions

Probability distribution function (PDF)



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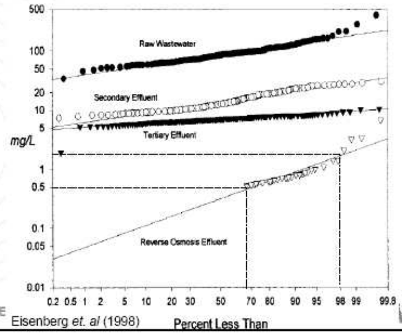
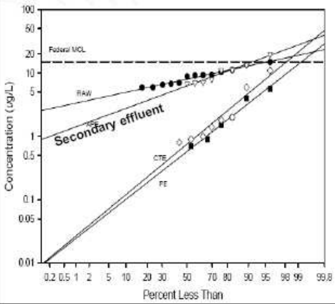
Lognormal probability plot for TOC



Eisenberg *et. al* (1998)

Lognormal probability plots for lead



Eisenberg *et. al* (1998)

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Consequence frequency assessment

- To estimate removal of contaminant through a treatment system
  - Concentrations at each stage of treatment may be described as a conditional PDF
  - PDF of plant effluent may be expressed as a multiple integral
    - (one integral for each unit process)
  - However, the multiple integral is often difficult or impossible to process
  - A common alternative is Monte Carlo simulation

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Monte Carlo simulation

- Fit distributions of removal of constituent across each treatment unit
- Sample each distribution repeatedly
- Compute final concentration for each set of random samples
- May represent plant performance in probabilistic manner
  - Explicitly acknowledges
    - Uncertainty
    - Variability of the underlying data

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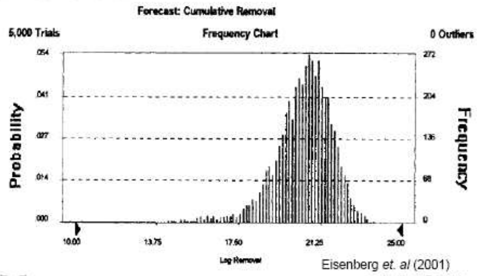
Consequence frequency assessment through an AWT



Eisenberg *et. al* (2001)

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Probability of treatment failures

- Critical components analysis
  - Identify mechanical components with most immediate impacts on effluent quality should failure occur
    - List all components in facility
    - Categorise:
      - By treatment unit
      - Components
      - Subcomponent
    - Collect data for all planned and unplanned maintenance events
    - Aggregate data
    - Compute performance statistic for treatment units and components: expected frequency of failures

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Plant performance statistics for mechanical reliability

Treatment unit	Number of maint. Events[1]	Number of unplanned events[2]	ETBF (days)[3]	Operating availability[4]
Headworks	16	13	26	0.9953
Primary	36	28	41	0.9985
Secondary	82	40	9	0.9757
Tertiary	30	27	13	0.9994
UV	1	1	212	0.9991
Reverse Osmosis	55	35	10	0.9990

[1]Number of times repairs were made including scheduled maintenance on components within the given unit.
[2]Number of times repairs were made due to component failure within the unit.
[3]Expected time between failure somewhere in unit process, based on chi-square distribution.
[4]Fraction of the study period that all components in the unit were operating.

Eisenberg *et. al* (2001)

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ANNEXE 5

Evaluating Community Perceptions Of Recycled Water: Workshop Presentation

Dr Angus Cook
School of Population Health
The University of Western Australia

Premier's Water Foundation Grant

ASSESSING THE PUBLIC HEALTH IMPACTS OF RECYCLED WATER USE

EVALUATING COMMUNITY PERCEPTIONS OF RECYCLED WATER

11-12 MARCH 2008

Department of Water
Government of Western Australia

PREMIER'S WATER FOUNDATION

AGENDA

Tues am
- OVERVIEW
- WORKSHOP THEME I. FACTORS CONTRIBUTING TO PUBLIC ACCEPTANCE OF WATER REUSE

Tues pm
- WORKSHOP THEME II. THE SCOPE OF RECYCLED WATER PROGRAMS
- WORKSHOP THEME III. IDENTIFYING CONTAMINANTS OF PUBLIC CONCERN; MANAGING UNCERTAINTY I.
- WORKSHOP THEME IV. THE ROLE OF WATER UTILITIES, GOVERNMENT DEPARTMENTS AND OTHER AGENCIES

Wed am
- WORKSHOP THEME V. INFORMATION SHARING; MANAGING UNCERTAINTY II.
- WORKSHOP THEME VI. RESOURCE NEEDS
- SUMMARY AND REVIEW

OVERVIEW

This project is designed to:

- evaluate the safety of existing and proposed recycled water use in communities of Western Australia (WA) using a public health-based risk assessment;
- by February 2010, have finalised a set of Targeted End User Protocols (TEPs) for water sampling and modelling of health risks for specific applications of recycled water

Research team:

Within WA
- University of Western Australia (Professor Philip Weinstein, Dr Angus Cook, Mr Brian Devine, Ms Kimberley Chisholm, Dr Clemencia Rodriguez)
- Department of Health (Drs Richard Lugg, Richard Theobald and Neil McGuinness)
- CSIRO (led by Dr Simon Toze within the Urban and Industrial Water Theme)
- Chemistry Centre (including Dr Neil Rothnie and Dr Peter Taylor)
- Water Corporation of WA (including Mark Nener and Leah Delfs, Re-use Program, Water Corporation)

Interstate
- Centre for Water and Waste Technology, Sydney (Professor Nicholas Ashbolt; Dr David Roser)
- Department of Health, Adelaide (Dr David Cunliffe, Principal Water Quality Adviser)

In achieving the objectives for treated wastewater use established by 'A State Water Strategy for Western Australia (2003)'

→critical to consider the **public health implications of recycled water projects.**

In all forms of recycled water use, the "big unknown" remains the correct quantification of health risks.

The main issues pertain to:

- risk of viable pathogens or their toxins not being completely removed in the treatment process, thereby causing an excess burden of infectious disease
- risk of 'chemicals of concern' (such as organic compounds; heavy metals; pharmaceutical by-products etc) not being removed in the treatment process, thereby causing toxicological effects (e.g. endocrine disruptors, which have been linked to infertility and cancers in animal models)

The main problems arise in inferring risk, particularly for long-term contact with recycled water.

One of the principal objectives of this project is to assign some risk estimate and predict possible health end-points for a range of water applications (e.g. for irrigation; horticulture; consumption etc).

- Any recycled water scheme is unlikely to be successful without the community's acceptance
- Essential to achieve a higher degree of epidemiological and quantitative risk assessment (QRA) integration to guide decisions on adequate and safe use of all potential applications of recycled water

A key component of the success of the project in this State is the evaluation of recycled water schemes in urban and rural Western Australia

This seeks to include:

(a) in urban and rural communities;
(b) in occupational sites (e.g. agricultural/ mining sites);
(c) in recreational areas, including sports grounds;
(d) in schools/childcare centres;
(e) in the development of new residential or commercial subdivisions;
(f) unintended uses and contacts with the recycled water stream

Suggestions have included sites in metropolitan Perth, as well as regional centres where recycled water is already in use (such as Northam, Karratha, Broome, and Kalgoorlie).

OBJECTIVES OF THE CURRENT P.W.F. PROJECT

(a) identifying and filling the gaps in the current and future application of recycled water guidelines in Western Australia;
(b) guiding State management decisions to convert a greater number of facilities and vegetated areas to irrigation with recycled water;
(c) to develop a risk framework for adequate interpretation of community concerns related to use of recycled water;
(d) providing WA communities with a <u>public health-based safety analysis to address community concerns</u> regarding safety of recycled water use.

This project does NOT currently include:

In this project, we will <u>not</u> explicitly include these issues for logistical reasons

- Environmental issues/effects *per se* e.g. impacts on aquatic species
- Effects on agricultural crop/pasture growth *per se* e.g. effects of recycled water used for irrigation on salinity, phosphorous, nitrogen
- Stormwater
- Rainwater
- Greywater
- Water from desalination

We may however in the future seek to apply our methods to these other water uses in separate 'add-on' projects

KEY OBJECTIVE OF WORKSHOP

The key objective of this workshop is to contribute **to collectively defining community perceptions of recycled water**,

in order to **assist the eventual successful transference of the scientific innovations of this study accounting for community understandings and expectations from recycled water schemes.**

Summary of survey results by June Marks, Flinders University

National telephone survey conducted in the summer of 2004-2005 of households in seven capital cities (n=2504, approx 357 each city) that had experienced water restrictions in the previous summer

Indirect Potable Reuse

Indirect Potable Reuse: Reasons for hesitation or concern

	Health risk	Trust factors	Source	Water quality	Cost	Other	
National (n=[illegible])	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100%
Perth (n=[illegible])	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100%

Examples of specified concerns in the Perth sample include:

Health Risk – only two elaborated:

- How it is going to affect my kidney – I will be on tablets all the time
- Skin allergies – reactions to chemicals

Trust Factors – 30 described the issues, including:

Standards
- Chemical load
- Chemicals used in the treatment
- Health standards
- Quality of the treatment
- The purity of the water for straight drinking
- Want to know more information – how they got it to that stage

Compliance
- As long as they treat it properly so you don't get sick
- The treatment carried out efficiently
- Failure of the machinery and human incompetency
- Failure in the system – if not safe medical and health are primary concern
- Water quality, bugs, microbes, other problems
- Would want to be sure that the tertiary treatment plant was operating properly and that it was operating to EPA guidelines

Accountability
- Can't trust government – don't trust them
- I don't have enough knowledge to see whether it is good enough – I would need more proof
- Not familiar with the concepts
- Until I know more I wouldn't be comfortable using it

Source – most were precoded, representative comments are:
- Germs
- Bacteria
- Chemicals, smell
- It doesn't appeal to me the recycled water
- Not the same – it is what you call dirty water – wouldn't do it
- Psychological – its not a good image drinking effluent treated or not treated – doesn't fit in with our image as Australians as civilized people

Water Quality – all but 4 were precoded
- Chemicals
- Taste
- Taste and health
- Taste and hygiene

Domestic water recycling for non potable uses

- Respondents considered water sourced from sewage effluent treated to a standard that would be suitable for garden watering (irrigation systems and hand watering), car washing, toilet flushing, washing machine and hand washing of clothes. There was some reluctance in recycling water for use in the laundry

- **Health risk**
  - There's a possibility of wiping mouth or splashing on skin or inadvertently drinking it
  - Health effects in the future - you don't know what it's going to do
  - [To make it] Not accessible for children
  - Just the difference between water for irrigation and water that comes out of the tap - children may be able to access the recycled water especially if it was not suitable for drinking - in terms of the cleanliness of the water
  - Discolouration and health risks
  - Unsure of chemicals in the water
  - Not safe for foodstuff
  - Infection

- Reasons for hesitation or concern for one or more of these uses can be compared to the national data:

Non potable domestic water recycling: Reasons for hesitation or concern

	Trust factors	Health risk	Water quality	Water source	Cost	Other	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100%
Perth [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100%

- Perth's response almost mirrors the national population. There is slightly less concern for health risks and around 5% more concern for the water source than the national data.

"It should not be overlooked, however, that there is strong public support for a range of alternative sources and uses of water…

Well targeted and well timed information and transparency may well be all that is required to implement most of these initiatives."

WORKSHOP THEME I.

FACTORS CONTRIBUTING TO PUBLIC ACCEPTANCE OF WATER REUSE

Table 1
Factors contributing to the degree of public acceptance of water reuse

US public acceptance of water reuse seems to be higher when [2–5]:

- Degree of human contact is minimal
- Protection of public health is clear
- Protection of the environment is a clear benefit of the reuse
- Promotion of water conservation is a clear benefit of the reuse
- Cost of treatment and distribution technologies and systems is reasonable
- Perception of wastewater as the source of reclaimed water is minimal
- Awareness of water supply problems in the community is high
- Role of reclaimed water in overall water supply scheme is clear
- Perception of the quality of reclaimed water is high
- Confidence in local management of public utilities and technologies is high

Hartley, 2006

QUESTIONS FOR THE PANEL

Q. What are the primary community and individual factors that impact on acceptance of water reuse?

WORKSHOP THEME II.

THE SCOPE OF RECYCLED WATER PROGRAMS

QUESTIONS FOR THE PANEL

Q. Is there a difference with regard to safety issues arising in water recycling schemes at different scales and in different contexts e.g. large water utilities versus small schemes; industrial versus residential?

QUESTIONS FOR THE PANEL

Q. What do you see as the actual or perceived risks to intended users in each of the following categories?

Q. Could unintended use/accidental contact arise in the following categories, and what would be the actual or perceived risks to individuals as a consequence?

INDIVIDUAL-LEVEL, DOMESTIC USE

INDIVIDUAL-LEVEL, DOMESTIC USE (1)

i. For indoor potable domestic use in urban and rural communities

ii. For indoor non-potable domestic use in urban and rural communities

iii. For outdoor non-potable domestic use in urban and rural communities

INDUSTRIAL / COMMERCIAL USE

INDUSTRIAL/COMMERCIAL USE (1)

Sub-category I: Potential impingement on human food supplies

iv. For commercial purposes potentially impacting on food supply (e.g. sites or activities relating to agriculture, horticulture, cropping, etc)

Sub-category II: (For processes not included in subcategory I) Potential worker exposure possible

v. For open system commercial purposes (e.g. with external application of water relating to silviculture, cultivation of turf, mineral extraction, etc)

Sub-category III: (For processes not included in subcategory I or II) No potential worker exposure

vi. For closed system commercial purposes (e.g. use of water within internal industrial processes, etc)

MUNICIPAL USE

MUNICIPAL USE (1)

Sub-category I: Uncontrolled access

vii. Use in uncontrolled municipal or other public areas, including parks, gardens and sports grounds, schools/childcare centres

Sub-category II: Controlled/restricted access

viii. Use in controlled municipal or other public areas

Sub-category III: Mixed access

ix. Other in which use may be controlled or uncontrolled depending on the context e.g. fire fighting

WORKSHOP THEME III.

IDENTIFYING CONTAMINANTS OF PUBLIC CONCERN; MANAGING UNCERTAINTY I

QUESTIONS FOR THE PANEL

Q. Which of the following are or are likely to be of major concern to the public?

A. Microbial hazards

Table 3.1 Microorganisms of concern in raw sewage

Pathogen type	Examples	Illness
Bacteria	*Salmonella*	Gastroenteritis, reactive arthritis
	Campylobacter	Gastroenteritis, Guillain–Barré syndrome
	Pathogenic *Escherichia coli*	Gastroenteritis, haemolytic uraemic syndrome
	Shigella	Dysentery
	Yersinia	Gastroenteritis, septicaemia
	Vibrio cholerae	Cholera
	Atypical *Mycobacteria*	Respiratory illness (hypersensitivity pneumonitis)
	Legionella spp	Respiratory illness (pneumonia, Pontiac fever)
	Staphylococcus aureus	Skin, eye, ear infections, septicaemia
	Pseudomonas aeruginosa	Skin, eye, ear infections
	Helicobacter pylori (?)	Peptic ulcers
Viruses	Enterovirus	Gastroenteritis, respiratory illness, nervous disorders, myocarditis
	Adenovirus	Gastroenteritis, respiratory illness, eye infections
	Rotavirus	Gastroenteritis
	Norovirus	Gastroenteritis
	Hepatitis A	Infectious hepatitis
	Calicivirus	Gastroenteritis
	Astrovirus	Gastroenteritis
	Coronavirus	Gastroenteritis
Protozoa	*Cryptosporidium*	Gastroenteritis
	Giardia	Gastroenteritis
	Naegleria fowleri	Amoebic meningitis
	Entamoeba histolytica	Amoebic dysentery
Helminths	*Taenia* (*T. saginata*)	Tapeworm (beef measles)
	Ascaris	Roundworm
	Trichuris	Whipworm

Source: Adapted from Feachem et al (1983); Geldreich (1990); NRC (1998); Bitton (1999)

B. Chemical hazards

Chemical toxicants that may potentially found in effluent include:

- Pharmaceuticals and their metabolites
- Personal care products (PPCPs): e.g. benzophenone, musk ketone, galaxolide and triclosan
- Disinfection by-products: e.g. trihalomethanes, HAAs, HANs, furanones
- Nitrates and nitrogen-based by-products: e.g. nitrosodimethylamine — NDMA
- Heavy metals and metalloids: e.g. As, Cd, Cr, Cu, Hg, Ni, Pb, Zn and Fe
- Pesticides and other agricultural chemicals: e.g. atrazine, organophosphates (including fenitrothion), organochlorines (including dieldrin, heptachlor and DDT), synthetic auxins (2,4,5-T and 2,4-D)
- Detergents, disinfectants and other cleaning agents
- Hydrocarbons, including Total petroleum hydrocarbons (TPH)/ Polycyclic aromatic hydrocarbons (PAH)
- Food components and additives/Caffeine
- Other domestic, industrial and agricultural compounds I: Organic including phthalates/ phenols (e.g. bisphenolA, nonylphenol and nonylphenol polyethoxylate)/ polybrominated diphenyl ethers (PBDE)/ Polychlorinated biphenyls (PCBs) / Volatile organic compounds (VOCs), including benzenes, toluenes
- Other domestic, industrial and agricultural compounds II: Inorganic
- Radionuclides
- Chemical mixtures

From an analytical perspective, the contaminant classifications may be summarised in *Table 1*.

CLASS	ANALYTICAL CATEGORY	ANALYTICAL IMPLICATIONS	EXAMPLE
MICROBIOLOGICAL CONTAMINANTS (PATHOGENS AND/OR THEIR BY-PRODUCTS)	Relevant dose and health endpoint well-defined	Quantitative microbial risk assessment applicable/ Suitable log reduction	Campylobacter
	Relevant dose and health endpoint poorly defined but plausible comparative models available	Modified quantitative microbial risk assessment/suitable log reduction may be applicable / information on appropriate comparative organisms available	Some enteric viruses
	Relevant dose and health endpoint poorly defined and no/weak comparative models available	Current methods of inference inadequate	Prions
CHEMICAL CONTAMINANTS (CHEMICALS OF CONCERN)	Relevant dose and health endpoint well-defined	Toxicological / epidemiological models adequate	Many common heavy metals
	Relevant dose and health endpoint poorly defined but plausible comparative models available	Modified toxicological / epidemiological models partially adequate / information on appropriate analogues available	Endocrine disruptors
	Relevant dose and health endpoint poorly defined and no/weak comparative models available	Current methods of inference inadequate	NDMA (N-Nitroso-dimethylamine)

WORKSHOP THEME IV.

THE ROLE OF WATER UTILITIES, GOVERNMENT DEPARTMENTS AND OTHER AGENCIES

QUESTIONS FOR THE PANEL

Q. What do you see as the key steps in ensuring the safe provision of recycled water to users?

Q. Who do you see as responsible for these decisions?

Q. What information is needed to support these decisions?

Q. How do/should we evaluate the effectiveness of the decisions that have been made?

Q. How do/should we manage hazardous events which are rare and/or there are no data for?

WORKSHOP THEME V.

INFORMATION SHARING; MANAGING UNCERTAINTY II

QUESTIONS FOR THE PANEL

Q. How can the end-users be best informed of safety issues in differing schemes?

Q. How do we best mange uncertainty about recycling schemes?

WORKSHOP THEME VI.

RESOURCE NEEDS

Staff and facilities

There is some uncertainty around the expertise, time, and money available within government agencies and affiliated organisations for assessing and communicating risks of recycled water use

QUESTIONS FOR THE PANEL

Q. Are water utilities, government departments and other agencies properly set up/resourced (expertise, time, money) for assessing and communicating risks of recycled water use?

Q. What (if any) other resources are needed?

ANNEXE 6

Submission for WA Premier's Water Foundation Workshop "Evaluating Community Perceptions Of Recycled Water"

Dr June Marks
Interwater Pty Ltd

WA Premier's Water Foundation

Submission for discussion at the 2nd Workshop to be held in Perth, 11-12 March 2008

Information from research on people's perceptions that may be considered for factoring into risk assessment/risk communication of alternative water supplies

Background

These findings are drawn from a national telephone survey conducted in the summer of 2004-2005 of households in seven capital cities (n=2504, approx 357 each city) that had experienced water restrictions in the previous summer. See the attached summary of the questions and responses to a range of alternative sources of water.

After considering willingness to use a different source of water for a particular application, those respondents who stated they were willing without hesitation, or were not willing, were asked the main reason for this.

Most comments were brief and aligned with pre-coded responses such as "water quality", "the water source", "cost", "don't trust the technology", "don't trust the managers", "have to be convinced it's safe", "health risk". Others were recorded verbatim for post-coding. All comments were finally coded into five distinct categories.

Health risk, Water source, and Water quality were applied when the clarity and brevity of the response simply stated these terms, e.g. because of the cost; or, the health risk. The category Trust Factors was applied when uncertainty was expressed, or guarantees required for safety, or assurances of water quality, or that no harmful chemicals would be used. The miscellaneous Other category embraces concerns for the environment, that there are alternatives, there are concerns outside the proposed use, or that the initiative is not necessary.

Reasons for hesitation or concern

The following Table 1 summarises all the reasons given by respondents (national data) who expressed some hesitation or concern. These provide a comparator to the Perth responses for some of these applications. Each of the options are explained in more detail below together with comments drawn from the Perth sample, which are typical of those for other cities.

Table 1 Coded reasons for hesitation or concern (7 capital cities, 2005; percent)

	Non potable recycling				Potable uses			
	Domestic	Greywater	Retrofit	Stormwater	Rain/recycl	IPR	Desalination	5 Options
n=	1861	155	136	55	84	2012	1172	1719
Cost	2.4	49.2	45.7	16.8	28.6	1.0	14.2	4.1
Health risk	25.3	19.1	23.5	59.4	19.3	33.4	11.6	38.3
Water source	14.4	3.7	3.1	6.8	8.0	23.0	9.0	23.5
Trust factors	28.4	19.1	14.1	5.1	10.6	24.4	23.1	13.5
Water quality	24.7	4.6	11.4	9.8	30.6	14.7	17.7	16.8

Other	4.8	4.2	2.2	2.2	3.0	3.5	24.4	3.9
Total	100	100	100	100	100	100	100.0	100

Domestic water recycling for non potable uses

Respondents considered water sourced from sewage effluent treated to a standard that would be suitable for garden watering (irrigation systems and hand watering), car washing, toilet flushing, washing machine and hand washing of clothes. There was some reluctance in recycling water for use in the laundry (see attachment, Table A2).

Reasons for hesitation or concern for one or more of these uses can be compared to the national data:

Table 2 Non potable domestic water recycling: Reasons for hesitation or concern

	Trust factors	Health risk	Water quality	Water source	Cost	Other	
National (n=1861)	28.4	25.3	24.7	14.4	2.4	4.8	100%
Perth (n=266)	27.8	21.1	24.1	19.2	3.8	4.1	100%

Perth's response almost mirrors the national population. There is slightly less concern for health risks and around 5% more concern for the water source than the national data.

In the Perth sample, only 11 comments referred to **Cost**. Other responses are summarised below.

Trust factors

Has to be done correctly
Want to know more about the reclaimed water before using it
Possibility for mistake or manmade error - could be fatal
Need to know the processes that make it clean
Would depend upon the level they reprocess it to. In Australia they don't often process it to tertiary level - would want it to be to that level
As long as the technology was up to par
Staining and discolouration - question the filtering process
Depends on what they did to treat it
The chemicals in the water can eat through the paint of the car - the question is the treatment of the water and if the water is treated properly, i.e make sure there is no smell, no bacteria, etc.
I would like to be sure that they are using the correct technology
Need to know more about it
Odours and germs. I would want more qualification and information
Splatter everywhere and it will get all over the place - requires reassurance
As far as I know it has been done in other parts in the world- just make sure it is safe.
Test it regularly
Safe - no bacteria
It has to meet the safety standards - what safety level?
Have to be convinced its safe (40)*
How the water is to be recycled
Do not trust the managers (one only)*
Do not trust the technology (8)*
* comment aligned with a pre-coded response

Water Quality Four comments refer specifically to the laundry application, and the fifth listed below is also concerned about effects on washing the car, as is the last comment:

Staining or damaging clothes or even the washing machine over time
May spoil the machine after buying it
Staining of clothes
Stains – I've seen it before
Some of the detergents in the water that may damage the car - don't want to damage the machine because of the method of treating recycled water - because of the contents of recycled water
Effect it might have on the car
Water quality (no elaboration, 61)

Another wants to know how the quality of the water compares with "non-grey water" – meaning non recycled water (often referred to by the general public and the media as "grey water"). And fourteen refer to chemicals or the chemical load of the water.

Health risk

There's a possibility of wiping mouth or splashing on skin or inadvertently drinking it
Health effects in the future - you don't know what it's going to do
[To make it] Not accessible for children
Just the difference between water for irrigation and water that comes out of the tap - children may be able to access the recycled water especially if it was not suitable for drinking - in terms of the cleanliness of the water
Discolouration and health risks
Unsure of chemicals in the water
Not safe for foodstuff
Infection
Health risk (47)

Source – 27 matched precoded "source", other comments include:

Smell, stains and hygiene
Smell (3)
Cleanliness of the water
Cleanliness of the water – if the water is clean enough
Sewage source (7)
Hygiene (2)
Bacteria (2)
Germs (3)
Depends where it comes from
It is used water – don't think it is right
Does not feel right (4)
Unclean (13)
My concern is that it is not pure enough - not as pure as if we get rainwater and the dam is full and then filtered through. It is just not the same love.

Other

For personal use must be treated properly - for irrigation I don't care
Outdoor uses only
Another eight specified drinking was to be avoided, e.g.:
To preserve freshwater for drinking and use recycled for others
Fine except would not like to drink it - the thought of where it has come from

Five alternative options

In the initial phase of the survey, people were given the open ended question on why they hesitated or were concerned after considering each option. However, due to time constraints, this had to be withdrawn with one question only being asked at the end of the series – greywater, recycled (reclaimed) water for garden only, rainwater and recycled water, stormwater for garden and toilet, and stormwater for drinking (five options).
The following can be reported from the initial national sub-set – where 572 respondents across the 7 cities were given the opportunity to comment after each option.

Greywater (Option 1)
This refers to onsite greywater systems (water from shower, bathroom and laundry). The national results show that Cost is the main concern (half of the 155 who commented), followed by Health Risk and Trust Factors. Only 19 of these respondents were from the Perth sample so the national findings (Table 1, n=155) are a better representation of the spread of public opinion.

Comments in the Perth sample concentrated on **Cost** (9 of 19).

Three cited **Health Risk**, one elaborating:
Wary of what could happen

Source (2)
The smell
The smell of the water

Trust (2)
I have doubts about how safe and healthy the water is
More information – ill informed

Water Quality (3)
My wife's concern is whether it was clean enough
Quality of the water
Quality of the water - germs

Recycled water for the garden (Option 2)
Respondents were asked how willing they would be to recycle water if it was delivered to their homes for outdoor uses only such as garden watering. As shown in Table 1 (n=136), Cost was the most concern, followed by Health Risk.

Of the 18 from Perth, the predominant concerns were also for Cost (half), Health Risk (5). Others commented:

Source

Germs and odours
Quality of water - could have anything in it

Trust

Don't know what they used to purify it
If the pipes were above ground to fix - if the council would take all responsibility over the cost of maintenance and repairs.

Rainwater and recycled water (Option 3)

A scenario was put to respondents whereby if they were in the market for a new home and rainwater was supplied for most indoor uses and recycled water for toilet flushing and garden watering, would they be willing to buy into the development. In the national sample (Table 1. n=84), Water Quality, Cost and Health Risk were of most concern.

Only eight in the Perth sub-sample commented: Health Risk (4), Cost (1), Trust Factors (3) – two saying:

Depends on what they used to purify the water
Reliability would be a concern

Stormwater for toilet flushing and garden watering (Option 4)

Only 55 in the initial sample commented in the national data with Health Risk being the main concern. There were five comments from Perth: Health risk (2), Source (2) "germs"; and one for Trust Factors:

Make sure the water is reliable – that the water resource does not interfere with nature

All five options: Stormwater for all domestic uses, including drinking, and the other four options above

This section reports reasons given for hesitating or being concerned for any of the five options, the fifth being the use of stormwater for all household purposes including drinking. Table 3 summarises the national and Perth coded results.

Table 3 Five options: Reasons for hesitation or concern

	Health Risk	Water source	Water quality	Trust factors	Cost	Other	
National (n=1719)	38.3	25.5	16.8	13.5	4.1	3.9	100%
Perth (n=241)	31.1	22.8	19.5	17.4	5.8	3.3	100%

The summary shows that the same order is held in the Perth sample as for the national data, with slightly less concern about Health Risk and more opportunities suggested for building trust (Trust Factors). Most comments aligned with precoding.

Health Risk – only two elaborated:

Skin allergies, reactions to chemicals
Healthwise, wouldn't know if you could use it safely

Water Source – most matched precoding, 13 described this further, such as:

It is just dirty water – I wouldn't have it
Sounds yukky to drink
Storm water I have little concern. I'm concerned about reclaimed water because of its nature - where it comes from and how it's been treated
Storm water has pollution and chemicals that couldn't be treated properly

Trust Factors – all articulated their concern, for example:

As long as it was processed properly to make sure that it was safe
To be sure it is being monitored regularly by an independent body
The treatment process it goes through to end up with its rating at the end
Treatment plants worry me in that they will be poorly managed
Concerned about end quality and cleanliness of the treated recycled water and the chemicals to do that
Faith in the authority concerned
Have to see the practicalities of each treatment and use
It has to be treated properly because the individual source has its qualities and problems, depending on the system volumes
The amount of trace elements and chemicals contained in the treated water

Water quality – 11 gave descriptive comments, for example:

The taste and smell
Quality of the reclaimed water
Pollutant free
Chemicals

Other – 8 comments, such as:

For everything but drinking and cooking otherwise OK
In Perth, the drinking water tastes the best, we don't have to give it up
Not for drinking
Not sure about personal consumption
Only for outdoor uses but not for indoors

Desalinated Seawater

It was explained that desalination removes the salt and has been an expensive option that uses a lot of energy, but is becoming more economical. The results for Perth compared to the national findings are set out in Table 4.

Table 4 Desalination: Reasons for hesitation or concern

	Enviro, other	Trust factors	Water quality	Cost	Health risk	Source	
National (n=1172)	24.4	23.1	17.7	14.2	11.6	9.0	100%
Perth (n=144)	29.9	20.1	13.2	13.2	15.3	8.3	100%

For the first time, the environmental impact is voiced by national and Perth respondents. Trust factors are also important and source is of the least concern.

Environment and Other – most were pre-coded, 11 described this further, for example:

Don't agree with desalination process - extra salt goes back into sea - I don't like the idea

Dragging of water out of the sea – doesn't seem right - what about the quality of life of sea creatures

Firstly, I don't know where they are dumping the excess water and, secondly, where they are dumping the excess salt

It produces too many gases and is not good for environment- left over salt and energy required

No concern with the end product but am concerned with the energy use in the end product and the salt level in the sea

Use it anywhere else but the tap – a lot of companies discharge their waste into the sea

Trust Factors – all but one described these concerns, such as:

If it is clean enough to drink and if it is able to be used on the gardens without ill effects Main concern is that if it goes wrong it won't be clean enough to use it

Drinking side of it is a concern

Safety -will be happy to use anything that is recycled as long as someone can show me that it is safe and give me that information

As long as it is perfectly safe and adequately tested and proved to be safe

Don't know how they can removed the salt from the water

Would have to try first and see if I like it

Water Quality

The smell and taste

Taste and cleanliness

Fresh and free from chemicals

Health Risk – four described this:

Health effects – concern about purity

Health and safety reasons

Health risks and chemicals

That it would be harmful to drink. I would be happy to use it for anything except drinking and cooking

Source – all gave reasons other than 'source':

Don't like the idea of drinking sea water

I've heard everything flows into the ocean

Source and how it is going to be delivered

Germs

Hygiene

Purity of the water

Bacteria and smell

That it would be harmful to drink. I would be happy to use it for anything except drinking and cooking

Indirect Potable Reuse

Respondents were then told that recycled water could also be treated to drinking water quality ... "it can then be mixed with traditional sources, such as water collected in reservoirs, and then treated and piped in the usual way to the whole city or town" . They were asked first about their willingness to use water mixed with recycled water, treated to drinking water quality, for all their household needs. This question was followed up with how confident they would be to use the water for showering, cooking and drinking. The results are given in the Attachment, in Tables A9 and A10. Set out below are the reasons for hesitation or concern of the Perth respondents, compared to the national results (Table 5).

Table 5 Indirect Potable Reuse: Reasons for hesitation or concern

	Health risk	Trust factors	Source	Water quality	Cost	Other	
National (n=2012)	33.4	24.4	23.0	14.7	1.0	3.5	100%
Perth (n=274)	30.3	27.4	23.4	14.2	1.5	3.3	100%

The ranking of reasons emerges is similar for both samples, the most important being Health Risk, followed by Trust and Source. It will be appreciated that reasons given under Trust Factors for any of the alternative sources and uses can be further coded into Standards, Compliance or Accountability, as illustrated in the listing below. Standards covers comments that query the final water quality, testing, the need to be convinced, proof that it works. Compliance relates to those asking whether the process will continually meet the standards set, methods of treatment, possibility of human error, contamination, and the need for monitoring and maintenance. Accountability groups those simply stating they need more information, those that want guarantees of safety, the need to see how the water is processed, and those who express distrust in government or private providers.

Examples of specified concerns in the Perth sample include:

Health Risk – only two elaborated:

How it is going to affect my kidney - I will be on tablets all the time
Skin allergies - reactions to chemicals

Trust Factors – 30 described the issues, including:

Standards
Chemical load
Chemicals used in the treatment
Health standards
Quality of the treatment
The purity of the water for straight drinking
Want to know more information - how they got it to that stage

Compliance
As long as they treat it properly so you don't get sick
The treatment carried out efficiently
Failure of the machinery and human incompetency
Failure in the system - if not safe medical and health are primary concern
Water quality, bugs, microbes, other problems
Would want to be sure that the tertiary treatment plant was operating properly and that it was operating to EPA guidelines

Accountability
Can't trust government – don't trust them
I don't have enough knowledge to see whether it is good enough - I would need more proof
Not familiar with the concepts
Until I know more I wouldn't be comfortable using it

Source – most were precoded, representative comments are:
Germs
Bacteria
Chemicals, smell
It doesn't appeal to me the recycled water
Not the same - it is what you call dirty water – wouldn't do it
Psychological - its not a good image drinking effluent treated or not treated – doesn't fit in with our image as Australians as civilized people

Water Quality – all but 4 were precoded
Chemicals
Taste
Taste and health
Taste and hygiene

Conclusion

This report on the explanations given by respondents for hesitation or concern about various sources of water and their use confirms that health risk is generally one of the main issues for the public. However, few define this response in detail. More information can be gleaned from the Water Quality and Source categories. Additionally, the comments grouped under Trust Factors include specific types of knowledge and information that are needed to allay concerns. These speak to the areas that are addressed in the National Guidelines, which are summarised here as Standards, Compliance and Accountability. One way of using this qualitative data may therefore involve aligning the various concerns (under all categories) against the appropriate 'solutions' detailed in the Guidelines. This may in turn throw some light on how some of these concerns may be addressed.

It should not be overlooked, however, that there is strong public support for a range of alternative sources and uses of water, as tabled in the Attachment. Well targeted and well timed information and transparency may well be all that is required to implement most of these initiatives.

Attachment

National and City responses (2005) to a range of uses for alternative sources of water

Table A1 Percentages in favour of public uses of recycled water

	National	Adelaide	Brisbane	Canberra	Hobart	Melbourne	Perth	Sydney
Flushing toilets	95.4	94.9	93.3	96.6	89.6	95.4	95.5	96.9
Commercial laundry	78.9	81.4	74.9	82.4	74.0	80.5	75.3	79.7
Golf, parks, gardens	96.9	97.8	98.6	97.2	94.7	96.4	95.8	96.9
School yards, play fields	88.1	90.7	89.4	90.7	86.4	88.6	86.0	86.9
Dairy, beef, sheep pasture	77.6	82.3	83.2	84.1	80.5	74.8	79.2	75.0
Vegetable, fruit crops	70.5	76.1	72.1	73.1	74.4	69.3	73.3	68.0
Vineyards	76.7	83.2	79.5	80.5	79.4	72.5	78.6	76.2

Table A2 Domestic uses (percent)

	National	Adelaide	Brisbane	Canberra	Hobart	Melbourne	Perth	Sydney
Toilet flushing								
Without hesitation	78.4	76.7	74.1	87.0	73.8	77.9	78.1	80.8
Some qualifications	19.0	21.1	23.4	10.8	22.8	19.3	19.0	16.9
Garden irrigation								
Without hesitation	81.5	81.7	84.2	86.2	80.3	79.6	81.4	81.7
Some qualifications	15.3	14.9	13.6	11.8	16.3	17.6	12.1	15.2
Hand watering								
Without hesitation	80.5	80.2	85.5	86.2	79.8	77.7	78.8	81.0
Some qualifications	15.1	14.8	11.6	11.9	16.3	18.0	12.0	15.4
Car washing								
Without hesitation	78.2	76.2	76.2	81.4	71.2	73.7	68.6	77.7
Some qualifications	14.3	13.3	13.9	12.0	14.9	15.2	12.8	12.9
Washing machine								
Without hesitation	39.0	37.9	35.2	45.0	39.1	38.1	37.9	41.4
Some qualifications	34.8	36.5	33.8	35.8	28.0	39.5	32.9	31.8
Hand washing clothes								
Without hesitation	35.1	32.5	31.0	39.4	33.1	34.1	38.2	37.2
Some qualifications	33.0	37.0	35.2	37.1	28.6	36.9	27.8	29.3

Table A3 Willingness to use greywater for non potable uses (percent)

	Adelaide	Brisbane	Canberra	Hobart	Melbourne	Perth	Sydney
n=	358	354	354	355	351	357	357
Without hesitation	67.6	58.5	70.1	60.3	53.0	65.0	63.0
Some qualifications	29.6	37.0	26.8	35.8	37.3	28.3	35.0

Not willing	2.8	4.5	3.1	3.9	9.7	6.7	2.0
Total percentage	100	100	100	100	100	100	100

The National result for Table 3 is: Without hesitation 60.3, With some qualifications 34.5%.

Table A4 Willingness to use recycled water for garden irrigation, retrofitted to existing residential properties from a regional treatment plant (percent)

	Adelaide	Brisbane	Canberra	Hobart	Melbourne	Perth	Sydney
n=	357	354	354	354	349	350	353
Without hesitation	69.2	66.7	75.1	69.5	55.0	74.3	65.4
Some qualifications	26.9	29.7	22.0	26.8	37.2	20.0	30.9
Not willing	3.9	3.7	2.8	3.7	7.7	5.7	3.7
Total percentage	100	100	100	100	100	100	100

The National percentages for Table 4: Without hesitation 64.3, Some qualifications 30.7%.

Table A5 Willingness to buy into a housing development featuring recycled water for toilet flushing, garden watering and rainwater for all other applications (percent)

	Adelaide	Brisbane	Canberra	Hobart	Melbourne	Perth	Sydney
n=	355	350	356	355	349	356	352
Without hesitation	76.6	80.0	78.9	75.8	75.1	80.6	75.9
Some qualifications	20.6	16.3	18.8	21.1	22.9	14.9	20.5
Not willing	2.8	3.7	2.2	3.1	2.0	4.5	3.7
Total percentage	100	100	100	100	100	100	100

National percentages - Without hesitation 76.8, Some qualifications 20.0%

Table A6 Willingness to use treated stormwater for toilet flushing and garden watering (percent)

	Adelaide	Brisbane	Canberra	Hobart	Melbourne	Perth	Sydney
n=	358	356	357	358	351	356	358
Without hesitation	88.8	83.1	88.0	82.7	80.3	85.4	86.0
Some qualifications	8.7	13.5	10.1	12.0	14.5	10.1	12.3
Not willing	2.5	3.4	2.0	5.3	5.1	4.5	1.7

Total percentage	100	100	100	100	100	100	100

National results – Without hesitation 84.2, Some qualifications 12.5%.

Table A7 Willingness to use drinking water quality stormwater for all household uses (percent)

	Adelaide	Brisbane	Canberra	Hobart	Melbourne	Perth	Sydney
n=	355	358	352	352	350	358	352
Without hesitation	24.8	25.1	30.1	17.3	26.0	26.0	26.4
Some qualifications	52.4	48.9	53.1	49.7	45.4	54.2	48.0
Not willing	22.8	26.0	16.8	33.0	28.6	19.8	25.6
Total percentage	100	100	100	100	100	100	100

National result – Without hesitation 25.8, Some qualifications 48.6%

Table A8 Willingness to use water from desalinated seawater (percent)

	Adelaide	Brisbane	Canberra	Hobart	Melbourne	Perth	Sydney
n=	355	355	350	352	353	355	353
Without hesitation	57.2	60.0	54.6	43.2	43.3	58.9	52.1
Some qualifications	36.3	33.0	36.3	48.9	45.9	34.1	40.8
Not willing	6.5	7.0	9.1	8.0	10.8	7.0	7.1
Total percentage	100	100	100	100	100	100	100

National result – Without hesitation 51.8, Some qualifications 40.0%.

Table A9 Willingness to use water from an IPR system (percent)

	Adelaide	Brisbane	Canberra	Hobart	Melbourne	Perth	Sydney
n=	356	354	353	354	348	357	353
Without hesitation	25.3	23.2	25.5	21.2	19.8	25.2	22.7
Some qualifications	52.8	50.3	51.8	53.4	52.3	50.7	50.1
Not willing	21.9	26.6	22.7	25.4	27.9	24.1	27.2
Total percentage	100	100	100	100	100	100	100

National result for Table 10 – Without hesitation 22.5, With some qualifications 51.2%.

Table A10 Confidence to use water from an IPR system (great plus moderate confidence)

	Adelaide	Brisbane	Canberra	Hobart	Melbourne	Perth	Sydney
n=	357	356	355	356	351	356	358
Showering	78.4	76.1	85.1	75.8	74.6	76.4	76.0
Cooking	55.3	55.3	66.4	53.0	51.1	58.3	53.9
Drinking	43.8	42.3	55.6	41.9	37.3	48.2	41.7

National results for Table 11 – Showering 76.1; Cooking 54.3, and for drinking 41.8%.