Australian Water Recycling
Centre of Excellence

Discussion Paper

Theme 2:

Risk Management and Validation

March 2010

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1 Introduction

Water recycling is increasing in Australia with the water used for a range of purposes from irrigation, use in dual reticulation schemes, use in industries and potentially to augment drinking water supplies. A major obstacle to the implementation of high-end reuse, such as indirect potable reuse has been the acceptability of the risk associated with the intended form of reuse by practitioners, regulators and the general community. Community issues and economics are discussed in Theme 4 Social and Economic Challenges. This theme considers the information needs to enable quantitative and/or qualitative risk assessment and a means to use that information to apply the relevant elements of the Australian Water Quality Framework.

The document is intended to serve as a basis for discussions of research needs that are both researcher and water industry driven and are relevant to the full spectrum of water recycling applications. Included are four topics that broadly follow the information needs required to assess and manage risk to human health and the environment from water quality hazards associated with the return of reclaimed water to the water cycle. Reclaimed water in the context of the research strategy is described as water that has previously been used (for example reclaimed from sewage), reuse of grey and/or black water and potentially other sources as well such as stormwater. Each topic is organised into subsections covering key issues and challenges, known gaps in the knowledge and examples of recently completed and ongoing research.

2 Background

The major capital cities of Australia are currently facing long-term water supply issues. The ability of water authorities to build new dams is limited, demand management has a limited ability to accommodate future water demands and the current droughts have reduced yields from catchments. Other pressures on water supplies arise from population growth, increased uncertainty about rainfall and a changing culture towards resource management. These factors are forcing an examination and adoption of alternative water systems. The use of water conserving strategies such as water recycling and rainwater tanks are likely to become more common. In order to provide a resilient water supply in the future, systems will need to be based on alternative water cycle management practices that are sustainable from economic, environmental, health and social aspects.

Towards this goal, an understanding of the processes underpinning the provision of safe and affordable water is required. Much of the discussion in this theme involves issues related to water availability, water quality and protection of public health. This links strongly to governance in the use of water, community perceptions (see Theme 4 Social and Economic Challenges) and environmental conditions that impact on the sustainability of recycled water schemes (see Theme 2 Sustainability of Water Recycling Programs). Underpinning this is the technology that, by necessity, must form the platform from which the other issues are addressed (see Theme 1 Technology Efficiency and Integration).

Historically, water resources management has focussed on supplying water for human activities, with an intrinsic assumption that technological solutions would keep pace with steadily rising demands for water and progressively more stringent water quality requirements. However in recent times this notion has been challenged. This is accompanied by a growing awareness that humans are impacting on the planet that supports them and that 'sustainability' is desirable for society, can make economic sense and can help protect the environment that we rely on to survive.

Sustainability can be applied to a range of human activities and to society as a whole. The goal of sustainable water resource management is to meet water needs reliably and equitably by designing integrated and resilient systems, optimising water use efficiency and making continuous efforts towards preservation and restoration of natural ecosystems.

The protection of public health is a key requirement when evaluating potential reuse options. Towards this, risk assessment is being increasingly applied in priority setting through evaluating human and ecological exposure and/or effects in response to exposure to waterborne contaminants, both chemical and microbiological. Risk assessment is based on the assumption of adequate and reliable data being available and skilled personnel to apply it. 'Risk' is defined as the probability of the occurrence of an adverse effect on human health or the environment. This is in contrast to 'hazard', which is defined as the source of the potential harm and is independent of occurrence. Risk can arise from a number of chemical, biological and physical contaminants in water.

Risk analysis refers to the broader process based on three components, risk assessment, risk management, and risk communication. The frameworks for risk assessment of chemicals and pathogens are similar, however the measurements are quite different due to varying amounts of knowledge between the two groups. Pathogen risk is described in term of Disability Adjusted Life Years (DALYs) whereas for chemicals a different risk metric is used such as a probability of occurrence of an adverse health effect over a life time of exposure to individual chemicals, be it through contact or through consumption. While this approach is currently the best we have it is limited because it defines chemical risk as the sum of each individual chemical and ignores the potential for interaction between chemicals which can occur as mixtures in the environment.

Quantitative risk assessment depends on the ability of the assessor to build a logical case and also to communicate the risk. Communication has an implicit role in confidence building with an audience comfortable that the information is founded on truth. Thus research that demonstrates that there are solid scientific principles to contaminant behaviour and effects contributes to risk assessment. This may be as simple as demonstrating that something is being done in order to build public confidence.

3 Research Strategy

A significant investment into appropriate technologies is required in order to provide safe water to consumers and it should accompanied by robust and fail-proof risk management. This requires all of the elements of the risk management framework as outlined in the Australian Drinking Water Guidelines and adopted also in the Australian Guidelines for Water Recycling. In order to manage schemes safely it is also important to understand the hazards and how to manage them within an appropriate regulatory and institutional framework. This theme addresses this challenge with four broad research topics presented in a discussion paper authored by acknowledged experts in the field.

The research topic headings are

1. Toxicology and chemistry
2. Pathogens
3. Risk assessment and communication
4. Policy and Practice.

3.1 Toxicology and chemistry

3.1.1 Key issues and challenges

Managing water sustainably and safely requires using water of the right quality for the intended use, usually referred to as "fit-for-use". The quality of water varies depending on its source (storm water, captured rainwater, grey or black water) and the level of treatment required. One key challenge is to determine the tolerable/threshold water quality for a given reuse purpose, for example garden watering, toilet flushing, laundry or commercial use and use in drinking water supplies.

Central to this challenge is assessing the probable degree of exposure to chemicals via different routes (direct ingestion, incidental exposure to aerosols etc) associated with different patterns of water use. Combined, these three factors determine the level of health risk and consequently the cost associated with ensuring safety. The key issues and challenges arise predominantly from incomplete characterisation of the diversity and variability of chemical substances in source waters and chemical substances that may be formed during treatment or distribution of water. Complete molecular identification of all chemical substances, regardless of concentration or toxicology, is neither a necessity nor a realistic ambition. However, much progress can be made in understanding what chemical species present the most significant human health and ecotoxicological risk, and in characterising the magnitude and nature of the risk. Ideally, this characterisation should be of a quantitative nature and include a comprehensive analysis of all associated uncertainties (Khan, 2010).

The diversity of low-concentration chemical substances that may potentially be present in recycled water indicates the need to manage chemical contaminants safely in a manner that does not require full chemical characterisation at a molecular level. Approaches that are likely to advance the achievement of this goal include:

- the identification of a manageable list of priority substances for focussed attention,
- characterisation of unit treatment process performance for specific types or categories of chemicals,
- the establishment of effective indicator chemicals and surrogate measures for monitoring treatment barrier performance, and
- direct toxicological analysis of water samples

3.1.2 Known gaps in the knowledge base

1. Many different chemicals plus transformation products
Source waters to municipal water recycling plants are highly complex and practically any stable chemical that is in use in society has the potential to be present at least intermittently and with the potential to remain in treated water at concentrations that could impact on environmental health. In addition to these, other chemical substances may be formed or added during water treatment processes (eg. disinfectants, disinfection by-products, coagulants) or formed as a result of biological activity in the water (eg. cyanobacterial and algal toxins). All of these chemicals have the potential to undergo chemical or biochemical transformations during water treatment, storage and distribution. The intermittent and final products of these transformation processes are generally poorly characterised for the vast majority of chemical substances.

2. Mixture toxicity
In complex water samples the interaction of individual chemical components may lead to greater toxicity than would be predicted based on their individual toxicity. The significance of this mixture toxicity is currently unclear both from a scientific and a regulatory sense.

3. Low concentrations, long-term exposure and safety assessment

Chemical toxicity is generally evaluated using comparatively short-term exposures to high concentrations on laboratory animals, and there is uncertainty in extrapolating these results to long-term (lifetime) exposures to low concentrations possibly present in water. This leads to conservative approaches used to account for uncertainty but result in guideline values much lower than are probably necessary. Alternative methods for toxicity testing need to be evaluated.

4. Variable exposure as a consequence of 'hazardous events'

Most risk assessments for recycled water are undertaken assuming log-removals, percentage removals, or chemical concentrations that are applicable when a water recycling scheme is functioning under normal operating conditions. However, Australian guidelines require the consideration of potential 'hazardous events' to properly assess, and manage risk. This approach is hindered by knowledge-gaps regarding the 'consequences' of hazardous events in terms of how they affect (or change) exposure to toxic chemical (and microbial) substances.

3.1.3 Recently Completed and Ongoing Research

The following are examples of recently completed and ongoing research. It is acknowledged that other significant research may be or is occurring elsewhere.

1. Purified Recycled Water reliability and safety project, Theme: Closing the loop. 'Urban Water Security Research Alliance' *Funded under the Qld Dept. of Premier and Cabinet and research partners CSIRO, University of Qld, Griffith University and CSIRO Water for a Healthy Country Flagship.* Status: current.

2. **"**Development of an ecotoxicity toolbox to evaluate water quality for recycling**"** Toxicity toolbox project (development/validation of screening assays of relevance to wastewater recycling for IPR and for discharge to aquatic environments): WA Dept of Water, WQRA, Griffith University, AWQC and UNSW (http://www.nwc.gov.au/www/html/494-development-of-an-ecotoxicity-toolbox-to-evaluate-water-quality-for-recycling.asp?intSiteID=1) *Funded under the Raising National Program of the NWC and Water Quality Research Australia (WQRA) and partners.* Status:current.

3. "A national approach to risk assessment, risk communication and management of chemical hazards from recycled water – progress" **:** Development and validation of an *in vitro* bioassay battery for human health risk assessment, management and communication of chemical hazards from recycled water projects. (http://www.nwc.gov.au/www/html/505-national-risk-assessment-comms-management-chemical-hazards.asp?intSiteID=) *Funded under the Raising National Program of the National Water Commission and partners.* Status: Current.

4. " Recycled water quality – A guide to determining, monitoring and achieving safe concentrations of chemicals in recycled water" EPHC/NRW/NWC (2008) *Report commissioned by the Environment Heritage Protection Agency and Natural Resources and Natural Resources and Water, QLD and the National Water Commission*. Status:Completed 2008

5. "Tools to detect estrogenicity in Environmental Waters " Aim:Comparison and bench-marking of *in vitro* methods to detect EDCs (estrogenicity) in environmental waters. *Global Water Research Coalition, WSAA and CRC Water Quality and Treatment.* (Chapman, H. and Leusch, F., 2006, Leusch et al, 2007). Status: completed 2007

6. "Safety of recycled water for end users determined by a mouse in vivo multigenerational study": Exposure of mice to concentrated recycled water over

several generations. Flinders University, SA, AWQC, WQRA and partners. Status: commenced 2010.

7. 'Quantitative chemical exposure assessment for water recycling schemes' (Khan, S J, 2010). Funded by the Fellowships Program under the National Water Initiative, National Water Commission. NWC WaterLines Series, Report No. 27.

8. '*Assessing the Public Health Impacts of Recycled Water Use'*. Project Partners include The University of Western Australia, The University of New South Wales, The Western Australian Department of Health, CSIRO, South Australian Department of Health, The Western Australian Water Corporation, and the Chemistry Centre WA. Co-funded by the WA Department of Water and the Premier's Water Foundation. Premier's Water Foundation Grant # 017 05. Status: Final stages.

3.1.4 Future Research Needs

1. Many different chemicals plus transformation products

- **Pesticides**: Further research in the improved characterisation of insecticides / herbicides / insect repellent content in the feedwater to the water reclamation plants (WRPs). What is the fate of these components in the WRPs? Is it of concern?
- **Endocrine disrupting compounds (EDCs)**: Endocrine disrupting compounds warrant specific attention due to their observed impacts on aquatic species and other wildlife at relatively low exposure levels. Valuable research could include improved characterisation of endocrine active substances including estrogens, androgens, thyroid, glucocorticoid hormones or hormone mimics in recycled water, treatment process performance, and relative exposure to sources to improve the understanding of the significance of exposure via recycled water.
- **Cyanobacterial and algal toxins**: Cyanobacterial and algal cell numbers of are often orders of magnitude higher in nutrient-rich wastewaters than in freshwaters, and often different species occur there. There are examples of such species that have been shown to be toxic *in vivo* but for which a toxic agent has not been identified (e.g. Synechocystis). Studies to access the occurrence of toxic cyanobacteria in municipal wastewater treatment settlement ponds and the further development of rapid toxicity-based screening methods for detection of the relevant cyanotoxins are warranted.
- **Disinfection by-products (DBPs)**: There are a number of disinfection byproducts (DBPs) which appear, in some cases, to be a more significant problem for recycled waters treated by advanced treatment processes than for conventional water supplies treated by conventional processes. Examples include the formation of nitrosamines (eg. NDMA) during chloramination and the formation of aldehydes, epoxides and bromate from ozonation processes. Investigation into the potential suite of DBPs that may be formed by the advanced oxidation processes such as Peroxide/UV is also required..
- **Transformation products of identified and emerging micropollutants**: During biological and chemical treatment processes (as well as in the environment, storage and distribution) chemical contaminants are continuously transformed from one molecular species to another. Most current analytical methods only target the original parent compounds and will not detect molecules that have undergone even a minor chemical transformation. A systematic approach to understanding risk associated with transformation products is required.
- **Emerging groups of chemicals of concern / nanoparticles**: New groups of chemicals are continuously identified as trace contaminants of concern in recycled water supplies. Much recent interest has been focused on perfluorochemicals (eg. PFOA and

PFOS) and nanoparticles, but the ability to quickly respond to new concerns will be the key requirement.

2. Mixture toxicity

- Interaction of chemicals in the toxicokinetic[1] phase: There is a known potential to lead to synergistic and antagonistic effects.
- Concentration additive and response additive characteristics of mixtures
- Quality criteria or guideline values for groups of chemicals with common mode of action – mixture indicators/ sum indicators

3. Low concentrations, long-term exposure and safety assessment

- **Guidelines:** There is a considerable lack of relevant toxicology data upon which to base guideline development for a great number of potential contaminants in wastewater. Improved coordination and consistence between the ADWG and AGWR is required.
- **Intelligent testing strategy (ITS) to be adapted from chemical risk assessment to water quality assessment, including read across and predictive models:** Much could be achieved (at relatively low cost) by use of adequately validated *in vitro* methods. Such studies could be used to prioritise more definitive *in vivo* studies where necessary. Also, what role for new techniques such as proteomics[2] and toxicogenomics[3]?
- **Meaningful interpretation of *in vitro* bioassay response - human health risk assessment and use in guidelines:** Development of toxicity screening assays that are acceptable to regulatory authorities as adequate models for public health risk assessment. Toxicity screening assays need to be validated against known *in vivo* physiological/toxic processes. We are still at the stage of isolating individual biochemical processes, be it receptor binding, enzyme inhibition, DNA structural alterations, in our *in vitro* models without a means to quantitatively translate effects seen into the *in vivo* risk assessment. The development of *in vitro* systems is advancing rapidly (microarray, PCR-based gene expression screens, antibody- and LC-MS-based protein induction screens) but real money needs to be spent in quantitatively validating the outcomes against actual disease processes *in vivo*. Much is already happening in the medical area. We need to better coordinate that effort and identify the gaps that the water industry needs to specifically address.
- *In vivo* testing on recycled water may need to be undertaken, in line with overseas precedent but with more appropriate procedures and giving consideration to the basis – fish and/or rodents
- Bioaccumulation of chemicals in food and other plants and the impact of long term use of recycled water on soil structure and chemistry.

4. Variable exposure as a consequence of 'hazardous events'

- On-line (real-time) monitoring, as addressed in Theme 1
- Improved characterisation of unit operation treatment performance for key classes of chemicals, including key indicator compounds for treatment performance assessment: investigation of indicator chemicals and their use for validating and monitoring process performance for treatment processes such as reverse osmosis and advanced oxidation.
- Analysis of hazardous events in terms of chemical risk: including improved characterisation of 'likelihood' and 'consequences' in terms of impact of chemical exposure to people.

[1] **Toxcokinetics** is the description of what rate a chemical will enter the body and what happens to it once it is in the body.
[2] **Proteomics** is the large-scale study of proteins, particularly their structures and functions
[3] **Toxicogenomics** is a field of science that deals with the collection, interpretation, and storage of information about gene and protein activity within particular cell or tissue of an organism in response to toxic substances

- Implementation and "quantification" of barriers to control risk
- Analysis of source control options as a means of managing risk to both final water quality involved in the treatment, as addressed in Theme 1

3.2 Pathogens

3.2.1 Key issues and challenges

Knowledge of the occurrence and concentrations of pathogens in recycled water is critical in determining exposure and assessing the potential risk of potable water reuse. Relying on indicator organisms for a risk assessment is not adequate in this situation, where public scrutiny and perception of risk is inflated. However, when routine monitoring (daily or weekly) is required, the measuring of all possible microbial constituents of water is impossible, impractical and non-economical. Thus tests for surrogate (or indicator) organisms are used to estimate the presence of pathogens. Traditionally bacterial indicators have been used to assess the effectiveness of the treatment systems in inactivating microorganisms. These indicators are abundant in the intestine of warm-blooded animals and their presence in water indicates faecal pollution and the potential presence of enteric pathogens. For improved management of water quality and mitigation of public health risk, it is imperative to provide sufficient information on the presence or concentrations of these indicators and the presence of potential pathogens. Furthermore, there are some gaps in our knowledge as to what pathogens may remain in various qualities of reclaimed water that can be produced, and what health risks they may impose on end users.

It has been stated that microbial indicators and the criteria used for safety of drinking water are not totally adequate for evaluating the risk of an unexpected outbreak of disease (McQuaig *et al.* 2006). Therefore new indicators and rapid techniques and reporting systems are required (NHMRC 2003). The uptake of molecular genetic methods for determining water quality has been seriously constrained due to methodology in terms of reliability of assay validation and sample preparation, particularly recovery methods and the presence of inhibiting substances (Lemarchand *et al.* 2004; Call 2005; Gilbride *et al.* 2006)}. The key issues and gaps in knowledge described below attempt to address these constraints.

3.2.2 Known gaps in knowledge base

With respect to the risk analysis of pathogens there is an accepted need to improve the use of indicator organisms currently in use as a water quality monitoring tool. The difficulty in doing this is that we need a global consensus on which methods will replace the culture based indicator approach. Each group of organisms have specific research needs to allow this change to occur.

Gaps in knowledge include:

- Efficacy (in terms of pathogen reduction for example) for individual water treatment train processes
- The ability for different jurisdictions to accept log reduction values across regions for individual (proven/validated) treatment trains
- The potential for zoonosis is not well understood. Understanding of whether there are animal pathogens present in the reclaimed water that could present a risk to humans through contact in whatever the adopted form of water recycling**.** Concentrations of pathogens and indicators in raw sewage are poorly defined yet form the basis of the Recycled Water Guidelines. Better definition of pathogen loading in raw sewage accounting for seasonality and weather conditions is required including the development of a national database**.**
- **Im**proved quantitative methods for pathogens, in particular for the three model organisms in the guidelines i.e. *Campylobacter*, rotavirus and *Cryptosporidium*.

- Better correlation between indicator and surrogate organisms and pathogens through treatment processes.

(i) **Parasitic protozoans** *Cryptosporidium* oocyst monitoring methods need improvement in the following areas:

- Improved recovery of oocysts from samples
- Improvement in methods for detecting whether oocysts are viable and/or infectious, particularly when oocyst numbers in the sample are low.
- Identification of appropriate indicator organisms for C & G
- How comparable are data obtained from different laboratories?

(ii) **Virus** culture methods need further work in the following areas:

- Improvement and standardisation of the method for virus recovery.
- Identification of appropriate virus type for use in validation of removal performance of individual process units in a water reclamation plant
- How comparable are data obtained from different laboratories?

(iii) **Bacterial** pathogens including some strains of pathogenic *Escherichia coli* are often more resistant to treatment and survive longer in the environment than the measured indicator organisms and other target organism listed in guidelines such as Enterococci. Therefore we need to extend the repertoire of bacteria used to monitor water quality beyond those already listed in current guidelines (Natural Resource Management Ministerial Council *et al.* 2007). This also includes improved methods for recovery, viability and infectivity.

(iv) **Cyanobacterial** toxins
Toxic cyanobacteria can grow in water storages that receive recycled water. Current initial assessment of toxicity is based primarily on microscopic counts of toxic cyanobacterial cells. Such counts have a high level of inaccuracy and consider all potentially toxic cyanobacteria as being toxin producers. In many cases the toxin genes may not be present, or if present, may not be producing toxin. Development of methods giving a rapid assessment of "as near real time as possible" toxicity is important. A number of such methods are beginning to appear on the market but need to be integrated into a coherent package which will produce data which is acceptable to health regulators and the water industry.

(v) Helminths, fungi, yeast and prions

- Bacteria, viruses, helminths and protozoa are all addressed in the current guidelines. Methods are required to cover all potential pathogenic microorganisms, therefore better methods to validate the removal of helminths, fungi and yeast are also required. Some fungi and yeast are known to be opportunistic pathogens
- Little is known of the potential for prions to enter Australian waters and also if they were present, what is the best method of removal?

(vi) **Disinfection** guidelines and regimes have been based on largely surface and ground waters used for potable purposes. New disinfection studies are need to:

- Determine the appropriate Ct values to be used for water qualities lower than surface/ground water i.e. how applicable are the USEPA disinfection guidelines which were developed for potable water? What are the appropriate organisms to be used to calculate the CT dose?

3.2.3 Recently completed and ongoing research

Molecular methods for the detection of pathogens in water is an area of research that several groups around the globe addressing as a means of improving the reliability of results reported.(Lemarchand *et al.* 2004; Call 2005; Farnleitner *et al.* 2005; Bosch *et al.* 2008; Brettar and Hofle 2008; Lee *et al.* 2008).

Melbourne Water has disinfection studies underway looking into the different Ct values required for different water qualities using ozone, chloramines and free chlorine. However this work is not extensive and requires more input and will need to be extended to new pathogens used for validation as the industry moves away from the reliance on traditional indicator organisms.

3.2.4 Future research needs:

The future research needs in risk assessment of pathogens in recycled water are very much focused on improving methods with quantifiable recovery techniques, ensuring adequate and appropriate internal controls in molecular methods are applied and standardised, more rapid techniques using a molecular genetic approach, or to determine if this is the best approach for future pathogen measurements

Future research could explore and validate the current myriad of molecular genetic techniques, including Mass Spectroscopy –quadropole Time of flight (MS-qTOF), quantitative PCR, multiplex assays, DNA/RNA microarrays in an attempt to come up with a standard methodology, which may include a set of laboratory based standards to allow choice in which methods are most appropriate for specific analytical requirements.

As there is a growing practice for validation of individual process units that make up recycled water treatment plants, there is a need to clearly identify the most appropriate microbiological organism to be used noting that some are more resistant than others to the chemical oxidation/disinfection steps.

Current applications of Quantitative Microbial Risk Assessment (QMRA) are highly conservative due to the lack of sound data on the type of pathogen present in a water source, the effectiveness of treatment processes and the removal in natural systems. An infective dose for reference pathogens is also not known to a large extent, which calls for many conservative assumptions to be made in the analysis. The success of investigations into the above listed research gaps will provide the tools to address these gaps and build our knowledge of pathogens in water. A larger data base of this information will greatly improve QMRA leading to better management options of alternative and recycled water.

Research needs identified by industry partners include

- Improved techniques for quantifying pathogens and their viability and infectivity in water with a risk management approach
- Improved analytical detection methods for quantification of actual pathogens – working towards real-time monitoring of pathogens or surrogates using genetic or metabolic markers
- Which pathogens should be measured and/or monitored, and therefore regulated – are new indicators for pathogens in recycled water produced for high end uses such as industrial or potable reuse required?
- Source tracking of pathogens for protecting catchments and assessing the actual human health risk
- Alternate treatment technologies – determine the efficacy of new or existing treatment technologies

- Reliable/appropriate indicators of pathogens to demonstrate safety of recycled water in real time to improve response time.
- Emerging new or opportunistic pathogens

3.3 Risk assessment and communication

3.3.1 Key issues and challenges:

Perhaps the greatest challenge faced by stakeholders in water recycling programs is to develop strategies for effective stakeholder engagement over the perceived health and aesthetic risks. In order to address concerns over the safety of any water recycling scheme, the system operator(s) and the regulator(s) must be able to address the following three key issues:

1. That there is adequate knowledge of the nature of the microbiological and chemical hazards which may be present in the influent waste water streams;
2. That the multi-barrier system proposed for the scheme is capable of removing all of these hazards, all of the time; and
3. That appropriate risk management plans have been developed and validated to ensure that equipment failure or human error will not compromise the efficiency of the scheme, and if such an event does occur, that appropriate control measures will be promptly activated to insulate the problem and prevent environmental degradation or, in the case of potable reuse, contamination of a potable water supply.

Research shows that public confidence can be seriously diminished if authorities (e.g. policy makers and water managers) are perceived as incompetent or biased. It is therefore vital that policy makers and water managers are shown to have a good communication process (both with each other and with scientists). As with the science to policy interface, stronger links should be established between policy and practice to improve communication and build public confidence. Both policy makers and managers should take into account the experience of stakeholders and there is a need to develop communication strategies and techniques to address specific issues raised by diverse stakeholder groups. Establishing and maintaining stronger links between researchers and policy makers will be necessary to bridge the science-policy gap and to provide assurance to the public that policy decisions are informed by the best available science.

3.3.2 Known gaps in knowledge base:

- The risk management in place for recycled water destined for high end uses such as industrial process water or potable reuse applications tends to be more stringent, costly and complex than that for drinking water. Does the cost of RW risk management outweigh the risk?
- Exposure estimates are inexact and there is a lack of information for new end uses.
- Use of worst case basis and conditions for validating each unit operation in a treatment train separately leads to a high level of conservatism in design and increased treatment costs. Current requirements are costly, resource-intensive and require a high level of knowledge
- Establishing a feedback loop between science and policy. Scientists and policy makers need to look past their different values and objectives so that they understand each other before trying to communicate risk to the public.
- Scientists need to provide policy makers with the right tools for handling scientific uncertainty and provide better access to scientific information.
- Improved coordination between policies and regulations that govern recycled water.
- Improved transparency and evaluation.

3.3.3 Recently completed and ongoing research:

Relevant overseas research:
Holmes,J. and Clark,R. (2008) Enhancing the use of science in environmental policy-making and regulation, *Environmental Science & Policy*, 11 (8), 702-711.
Several of the research projects in the Water Quality Research Australia portfolio are conducted within a risk assessment framework, for example a project under the Raising National Standards program of the NWC "A national approach to risk assessment, risk communication and management of chemical hazards from recycled water ".
Part of this project involves a year-long scoping study to establish a baseline measure of current science to policy practices in Australia: "Enhancing risk communication between scientists, policy-makers and managers of recycled water in Australia" – Smart Water Research Centre. The results of the scoping study will provide a starting point for identifying key issues within science-policy-practice in Australia and provide a basis for more in-depth follow up research.

3.3.4 Future research needs:

Improving communication between industry professionals

- The role of interpreters in facilitating interactions between researchers and policy makers and in providing a balanced overview on scientific knowledge relating to policy issues.
- Improving access to information and expertise for policy makers and how to increase stakeholder involvement in policy and practice.
- Improving coordination between policies and regulations that govern recycled water.
- Assessment of practicality for smaller/poorer communities and possible two-tiered system or establishment of 'standardised' treatment options

Risk Allocation

- The Australian Guidelines for Water Recycling (AGWR) gives a process for managing risk from catchment to tap however allocation of responsibilities and liability (water utility versus user) is unclear. A guidance document is needed to outline the considerations in managing recycled water schemes.

Practical implementation of the AGWR

- There is some disparity between understanding the risk management approach outlined by the Australian Guidelines for Water Recycling and the requirements for delivering this. A guidance document and sessions to help the industry manage recycled water quality risk in practice would be beneficial. There is not a common understanding of risk management across the industry.

Monitoring and risk

- Methods for estimating exposures for both established and new end uses, leading to an expanded database of exposure information
- Establishment of methods for determining of the minimum log removal for a whole treatment train that is not overly conservative
- Assessment of various statistical methods for the analysis of such data and a recommendation on which is the most appropriate for determining minimum log reduction.

Knowledge management and a consistent approach

- Recognition that there is a lot of 'science' out there, and that the knowledge used by policy makers doesn't always come from within (i.e. within the company, the State or even Australia)
- Creating 'fit for purpose' water treatment technologies, instead of 'over the top' water treatment processes (i.e. specifying 10 log reduction when only 5 are needed).

- Consistent national policy frameworks for water treatment (e.g. inconsistency with decentralised treatment technologies from state to state)
- Ensuring good linkages between science policy makers, science practitioners and end users (i.e. adopters)

Irrigation schemes

- An assessment of the risk posed to recycled water quality, from the use of open on-site storages is required, including the development of a consistent risk assessment and management approach.
- There needs to be better quantification of health risk from irrigation using recycled water. Further work needs to be done and/or consolidated to determine what controls are effective. Is a 1 *E. coli* / 100 mL median target appropriate? What is the basis for this target? This target can impact on the commercial viability of irrigation schemes.

3.4 Policy and Practice

3.4.1 Key issues and challenges

Risk issues relevant to the provision of safe, reliable and affordable water, including various uses of recycled water, are best managed with the appropriate involvement of four key groups of stakeholders.

- firstly, the water professionals who plan and operate water systems, noting that water utilities comprise several professions such as operations engineers and financial managers;
- secondly, the policy and regulatory decision-makers, noting that their organisational backgrounds are likely to involve different perspectives and interests;
- thirdly, the independent science researchers, whether in universities or consultancy firms, noting that scientists sometimes disagree strongly about matters of risk and safety; and
- fourthly, the diverse consumers and users of water for different purposes, including domestic, industrial and agricultural.
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These groups typically have different perspectives (see Garvin 2001; Steel et al 2004). Their different viewpoints and needs for information/support should be recognised in developing a comprehensive risk management approach that warrants the trust and confidence of all stakeholders. Some integrative approaches have already been adopted through the setting of national standards and guidelines, though there are many specific issues where further work is needed.

Given the known history of distrust and misinformation concerning water reuse, it is necessary to build improved relationships across these stakeholders as a basis for improved understanding and alignment. Water reuse is an area of policy and practice where it is crucially important to promote and maintain widespread confidence and stakeholder trust in organizational expertise. Trust can break down where decision-makers and advisors are seen to be less than fully competent and rigorously objective in protecting public safety (on trust in organizations, see Hardin 2004; Kramer & Tyler 1996). Confidence is necessary both in relation to the professionalism of water management and their scientific advisors (technical expertise), and also in relation to the quality and transparency of regulatory arrangements (good governance).

Water reuse opportunities are constantly changing as science and technology offer improved ways to capture, purify and distribute reclaimed water at specified standards for different purposes and at a variety of spatial scales. Innovation is a vital feature of the industry, consistent with the overarching requirements for safe, affordable and sustainable supply. The precautionary principle needs to be applied with an eye to the differing uses and contexts for recycled water, and there will be ongoing legitimate debate about how to define these boundaries, and where accountability lies for breaches of standards. Technical innovations will require refinement and adjustments in the assessment and approval processes, especially as decentralised solutions come to occupy more attention alongside large system and grid solutions.

The foundation for developing a robust and transparent system of quality control that warrants trust and confidence is high-quality science, clear identification and communication of risk, together with the identification and communication of best-practice responses. The core risk issues necessarily focus on quality control, as managed by water professionals through ongoing scientific monitoring and technical intervention, to ensure standards of safety and reliability are met.

Institutional arrangements for assessing risk and responding to new challenges play a large role in shaping the overall effectiveness of water reuse supply opportunities. For example, the policy and regulatory systems might not keep up with the insights emerging from R & D and from professional best-practice, thereby diminishing the problem-solving capacities of the overall system. Institutional deficiencies may include (a) poor flows of information; (b) poor linkages between these stakeholder sectors; (c) poor alignment between science, policy and practice; and (d) lack of an integrated strategic framework under which water reuse clearly contributes to broader goals of sustainable water resource management (cf Dovers 2005).

3.4.2 Known gaps in knowledge base

In contrast with the increasing amount of research about *community and household attitudes* to water reuse there is little research concerning the attitudes of other stakeholder groups – science, industry, policy-makers and professional practice – concerning the cost/benefits and the risk of utilising recycled water for specific purposes at various scales.

Filling this research gap would allow better understanding of the current extent of shared knowledge about water reuse in Australia, and the extent of shared perspectives regarding possible future uses of recycled water. This research would provide a foundation for designing educational material, forums, and other activities as noted below. Within the industry stakeholder grouping, there is little known about the particular characteristics of early adopters (e.g. those in manufacturing, construction, mining or property development who seek to use innovation for commercial advantage in their business practices) as against those who resist the opportunities to pursue water-efficiency and best-practice approaches to water-related sustainability.

Secondly, there is little known about how scientific findings can be most effectively communicated, accessed, and taken up in the 'managerial' sectors of water policy and planning, water regulation, and water operations management. There is a massive amount of research and information available but little is effectively communicated and accessed. Even between scientists themselves, there is a range of views about the proper role of science in seeking to inform policy either directly or indirectly (Steel et al, 2004). The majority of applied scientists do seek to influence the policy and practice domains, but find it difficult to disseminate their work in ways most conducive to achieving this desired influence (Holmes & Clark 2008; Pannell & Roberts 2009). Among potential users of scientific research among policy and regulation managers, there are political, organisational and cultural obstacles to accessing and making use of the findings.

Thirdly, the adequacy of regulatory regimes remains to be assessed. The regulatory regimes need to address different products and scales. Innovation often occurs in pilot schemes, whose capacity to up-scale is unknown. Given that much relevant work is occurring internationally, these gaps in knowledge are further exacerbated. It is not clear whether a single integrated approach to risk analysis and management is possible, unless with a wide range of contextual variations. To the extent that risk management may inherently involve divergent perspectives, consideration may need to be given to methods for reconciling differences, e.g. through collective processes for reaching agreement on key information, priorities, and decision-making criteria. Recently completed and ongoing research

Recent research has demonstrated that different stakeholder groups, including regulators, researchers and managers, have varied perceptions of risk and varied expectations regarding the likely level of consensus on water reuse issues (e.g. Baggett, Jeffrey & Jefferson 2006). The implications of this diversity need to be further explored, as noted above.

Water professionals and water utility managers already build risk management into their standard operating procedures, as is clearly required by safety standards for the supply of water for specific purposes. System features such as process design and optimisation, asset management and compliance monitoring are adopted within a broader context of business and environmental risk management (Pollard 2008). Water system managers, like other professionals, are moving from a risk-response framework towards a risk-preparedness and prevention framework, given the unacceptable consequences of error and disruption. The implications of these new approaches for government policy and for water users remain to be explored, including the scale at which risk is best identified and accountabilities managed.

3.4.3 Future research needs

This paper seeks to identify key areas of research focus that should be given high priority, in order to improve the knowledge base supporting water resource innovation including water reuse.

To the extent that water sustainability policy directs attention to improving the safe uptake of reused water, an important dimension of this challenge is to assess and where necessary improve the 'fit' between regulatory contexts and safe forms of water reuse innovation.

Another area for future research is the economic dimension of water reuse innovation, especially the cost-benefit of different supply scenarios with different technical and spatial scales. Clarification of economic issues will need to take account of legal liability issues, development approval regimes, and property rights issues concerning the processing of waste streams. Across these issue areas, higher levels of government may need to provide enabling legislation and financial incentives to facilitate the introduction of sensible innovations. It is also important to ensure that a reasonable degree of regulatory consistency applies across the nation, while at the same time allowing for pilot schemes and other innovation.

There is little research about the most effective methods for sharing knowledge among the stakeholder groups. The need for knowledge-sharing is well established in related fields of natural resource management and public health (e.g. Bosch, Ross & Beeton 2003; Schaefer & Bielak 2006; WHO 2009).

An educational website or 'one stop shop' for information about water reuse is highly desirable. In addition to displaying core information on current technical standards and regulatory requirements, such a site could contain information about trends in the uptake of water reuse, and detailed information about the experience of various water authorities in developing water reuse for different purposes, and at a variety of scales, and in a variety of regions and cities in Australia and overseas. Such a website might also contain links to research findings nationally and internationally and be linked to an Interpretive Centre as part of an overall education and communication initiative, as discussed in Theme 3's Discussion Paper.

A wide range of professionals require this information; they need accurate information about how to plan, manage and operate a water reuse scheme safely. Relevant groups include planners, consultants, government agencies, academic researchers, industrial users, and the general public. Professional provision of reliable information should benefit water users, decision-makers and managers in the water industry in an era of increased regulation and keen public interest in water issues, nationally and internationally.

4 SUMMARY AND CONCLUSIONS

Safe provision of water requires technological solutions, good science and effective risk management and needs to be sustainable. Water safety actions need to be underpinned by evidence based guidelines, effective and efficient application and a consideration of all sources. In addition the broader community (including water industry professionals, government representatives as well as consumers of water) stakeholders need to have confidence in emerging supplies. This requires an understanding of public health and environmental costs and benefits. As we are now in an era of rapid change we need better data, science knowledge and public understanding as well as quality water governance processes.

Topics 1 & 2 of this theme address the myriad of challenges facing the technical aspects of water quality and safety including chemical and microbiological water quality assessment. We are in a period of diversification of sources. Water recycling is just one of a range of diverse sources and while it does present a significant contribution towards water scarcity, it also raised some fairly significant challenges. Topic 3 & 4 strives to bring all of this together by identifying and managing barriers to implementation. The policy environment surrounding water recycling in Australia is complex with the agencies responsible for approving recycling systems differing dependant on state and local government jurisdiction (Power 2009). Most states have their own legislation, and sometimes multiple Acts, covering areas which include building, licensing, environmental protection and more recently public health. Additionally most states either have or are currently developing guidance documents and codes of practice relating to water recycling (Power 2009).

5 LINKAGES

Contributors to white paper

Contributions have been received from a number of sources. All contributors and authors (in bold) are acknowledged as are informal inputs from various discussions on these topics.

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GHD, Warren Traves
Veolia Australia, Yvan Poussade
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Water Secure, Dr Cedric Robillot, Annalie Roux
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South East Water Limited, Greg Ryan, Michele Carson, Shaun Cox
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www.australianwaterrecycling.com.au

The Australian Water Recycling Centre of Excellence has developed four discussion papers and is seeking industry and research practitioner feedback on these papers to inform development of the Centre's Strategic Research Plan.
Copies of the discussion papers can be requested via the Centre's website at www.australianwaterrecycling.com.au or by contacting the Centre at enquiries@australianwaterrecycling.com.au

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