Australian Water Recycling Centre of Excellence

Discussion Paper

Theme 1:
Technology, Efficiency and Integration

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1 Introduction

This document outlines the conceptual framework and research needs in the area of water recycling technologies with a particular focus on the process efficiencies and integration. These have been identified from a range of inputs from industry participants and researchers and serve as a basis for the development of this particular Theme in the Strategic Research Plan of the Australian Centre of Excellence in Water Recycling.

2 Background

The century-old concept in urban and rural (not agricultural) water system design has been to maintain a strict separation of clean water (drinking water) and “dirty water” (wastewater) to ensure minimal human health risks due to pathogens and other contaminants crossing from the dirty to the clean water stream. Over the years, the treatment technologies in both streams have improved considerably, to the point where it is now technically feasible to create water quality from the wastewater stream that is at least comparable to the clean water quality. At the same time, it has been recognised that not all water uses need the high quality standard of drinking water, hence increasing the potential for use of lower water qualities in certain situations.

Water recycling technologies therefore sit in between the two streams, as they are (typically) using wastewater as a source and generating a water quality that can be used to either replace drinking water in certain applications or even augment drinking water supplies. Therefore, it is critically important that these “new” water treatment technologies work most efficiently for the purposes that they are employed, and that they integrate optimally into that space between the clean and the dirty water streams.

The following research topics aim to capture the most commonly raised aspects in relation to water recycling technologies, and they have been grouped to address particularly the efficiency or the integration objectives.

3 Research Strategy

3.1 Management of salt and saline effluents in water recycling

3.1.1 Key issues & challenges

While the treatment of saline wastewaters has been successfully practiced for many years, there are still challenges for this technology, particularly in water stressed environments and in the current trend where communities look to implement greater levels of water recycling.
For instance, salinity in the Western Treatment Plant (WTP) wastewater in Melbourne, Victoria has limited its suitability for use in recycling schemes. It is currently used for irrigation

purposes in the Werribee Irrigation District (WID) but it limits the types of crops that can be grown and the profitability of farmers. Additionally, it has slowed the use of recycled water from WTP in 3rd pipe systems as it is not generally regarded as being suitable for irrigation of gardens. A large salt reduction plant was investigated but the cost and brine disposal concerns have hindered development. There is now a commitment to a small desalination plant to service new estates in the Werribee district, and brine will be discharged with the treated wastewater effluent (still to be approved). However, a further expansion of the recycling scheme at WTP is likely to find hurdles because of brine disposal concerns and the discharge of concentrated brines containing complex mixtures of organic compounds and nutrients into sensitive receiving waters. Similar concerns have seen the need to treat the brine concentrate in Bundamba, Queensland, and in California [11, 12, 13].

For in-land communities the disposal of brine usually requires evaporation ponds although, in some instances, the more expensive mechanical evaporation and crystallisation option has been considered. This is a large issue for coal seam gas water, where beneficial use of the treated water and recovered salt is expected.

Treatment of saline wastewaters also presents some unique fouling issues for desalination processes, with high levels of phosphate and organic compounds. Calcium phosphate precipitation can limit water recoveries in desalination systems and it is not effectively managed with anti-scalants [10]. Silica may also limit recovery in some waters, such as coal seam gas waters, and while not specific to recycling of wastewater streams it can still present as an issue in these systems. There are also a wide range of complex inorganic mixtures in wastewater streams within the minerals industry, where recycling of water would be of benefit to their profitability

Additionally specific organic contaminants, particularly from industrial wastewaters, can present productivity issues for recycling plants [9]. Techniques to identify such issues and knowledge regarding the likely compounds responsible for such fouling outcomes may be beneficial for industrial water recyclers as well as municipal water recycling plants.
While costs involved in desalination processes generally preclude the use of the treated water in agriculture, selective removal of monovalent ions to improve the sodium adsorption ratio and allow recycling of nutrients such as phosphate may provide advantages for intensive horticulture. Other applications would likely be found if such a process could be developed.

3.1.2 Known gaps in knowledge base (Australian & International)

1. Understanding of the kinetics and thermodynamics of calcium phosphate precipitation and scaling. The many potential phases of calcium phosphate complexes have made a detailed understanding of these precipitation processes in real water situations difficult.
2. Better control of RO processes to reduce scaling and the requirement for chemical cleaning – use of sensors to predict the on-set of scaling.
3. Understanding of the cost of membrane degradation so that optimisation of the operations with regard to membrane replacement can occur. Particularly in the area of catalysis of degradation processes with inorganic ions (see also section 3.3 below).
4. Techniques to achieve higher water recoveries through RO processes. Some progress has been made and predicted costings for Accelerated Seeded Precipitation (ASP) process have suggested that it might be cost neutral (ie. increased capital and operating offset by decreased brine management expenses).
5. Understanding the impacts of wastewater brines on local ecologies – will be specific for each site.

6. Improved brine treatment systems to remove trace organic compounds and metals of concern.
7. How to improve the economics of brine management via value addition e.g. salt production, growth of algae for biofuels or other valuable products?
8. Separation of monovalent and divalent ions for improved water qualities and/or nutrient recovery eg. phosphate recovery.
9. Understanding of industrial recycling approaches that can be utilised for specific classes of waters e.g. high surfactant concentration wastewaters, recovery of water in minerals streams.

3.1.3 Recently completed & ongoing research

1. Accelerated seeded precipitation (ASP) desalination of wastewaters to increase water recovery through RO systems. There may also be potential to recovery of $CaHPO_4$ for use as a fertiliser. There is a current Smart Water project on this topic in Victoria (Victoria University, GWMWater, United Utilities Australia, UNSW, UCLA).
2. Development and use of an on-line scale meter to control RO processes (UCLA). Another type of scale sensor is in development in Singapore – Tony Fane.
3. Alternating the direction of flow through the RO pressure vessels to limit scaling and reduce or eliminate the need for chemical cleaning – UCLA, Ben Gurion University
4. Use of membrane distillation to increase water recovery though RO systems treating saline wastewaters (likely to be similar projects in the National Centre of Excellence for Desalination on brackish waters). Current challenges in need of research are membrane fouling and performance in increasingly saline waters, i.e. scaling issues – VU, GWMWater, WQRA
5. Membrane distillation treatment of industrial wastewaters – VU, WQRA,
6. Study on the effectiveness of anti-scalants in fouling prevention – WQRA/WRF, UNSW, VU, UCLA
7. Membrane degradation studies - VU, UNSW, UQ (all working separately).
8. Improved electrodialysis membranes for lower operating costs – UQ (Nano-functional materials group).
9. Brine treatment studies in California and Queensland – [11, 12, 13]
10. Increased evaporation rates in brine ponds using Wind Assisted Intensive Evaporation (WAIV). Orica has a demonstration site near Geelong, and there is a Smart Water fund proposal to provide a greater scientific understanding of this demonstration (Orica, VU). Also work in Israel at Ben Gurion University.
11. Smart Water decision support framework for encouraging use of recycled water in industry – VU.

3.1.4 Future research needs

1. Development and demonstration of high recovery water systems e.g. ASP, membrane distillation and/or alternative methods for increased water recoveries on streams such as coal seam gas water, etc.
2. An understanding of membrane degradation processes and the catalytic effect of inorganic ions, leading to economic optimisation strategies.
3. Development of biofouling control strategies that do not have a residual oxidant.
4. Removal of monovalent salts from wastewater via electrodialysis with monovalent selective membranes to improve the Sodium Adsorption Ratio (SAR). This could

improve the water quality of wastewaters being used for agricultural purposes and also for industrial water recycling.

5. Understanding the treatment of classes of industrial effluent to encourage wider industrial water reuse.
6. Brine treatment processes that remove organics and metals of concern. There is the potential to combine this with value adding processes (eg. algae growth) as well.
7. Improved understanding of the kinetics and thermodynamics of calcium phosphate precipitation and scaling, leading to better control strategies. This could also be extended to other wastewater streams (eg. mining industry), where the mixture of inorganic compounds affects the kinetics of precipitation of the major scalant (i.e. sulfate may interfere with carbonate precipitation etc).

3.2 Improving on-line monitoring of water qualities at all stages of water recycling processes (source control to RO permeate)

3.2.1 Key issues & challenges

The HACCP concept requires the establishment of "Critical Control Points" after each treatment process where a key parameter that is indicative of the treatment performance can be monitored ideally on-line (or at least frequently and rapidly). While this is reasonably well achievable in certain processes (e.g. microfiltration via turbidity meters or particle counters, UV systems via direct UV energy transmission measurements, effluent ammonium in BNR process), it is more challenging in others (e.g. source control in sewers, RO performance due to limited reduction of the available on-line indicator measurements, conductivity and TOC, compared to the actual pathogen removal). Additionally, to ensure the required water quality is delivered to households in areas with dual reticulation systems, an on-line measurement could be valuable to detect and rectify possible cross-connections with the recycled water supply.

Furthermore, most of these measurements are mainly looking at indicator compounds, rather than at the actual pollutants. While this may be adequate in many situations, particularly the very high removal efficiencies required for microbial contaminants (viruses, bacteria, protozoa) often exceed the achievable reduction measurements for the indicator compounds. For example, RO membranes only get typically a 1.5 – 2 log reduction credit for the microbial contaminants since this is the reduction achieved for the indicator measurements (conductivity or TOC), while the actual microbial contaminant rejection is likely much higher. There is currently a clear lack of adequate surrogates for pathogens that could be used for on-line or at least frequent and rapid measurements.

Due to the lack of direct pathogen on-line measurements, the removal requirements for the indicator compounds are often overly conservative since they are based on the maximally expected ratio of pathogens to indicator organisms in the source water, while the actual ratio might be considerably lower (and hence the required log removal might be lower as well). If the directly relevant compounds (i.e. the pathogens) could be measured, a lower safety margin could be required.

In systems where lower water qualities are required, a different problem arises. Even though less stringent water quality requirements apply, the relevant regulatory standards still need to be achieved continuously. The on-line measurement of these (elevated) levels of contaminants poses different challenges, particularly also in relation to long-term stability of the measurements.

Finally, not all contaminants of concern are in the source water, a number may be produced in the treatment process itself. Of particular relevance in this regard are the disinfection by-products (DBPs), which include a wide range of chemicals potentially generated in chemical treatment/disinfection processes. Many of these are of particular concern (see following section) and should therefore be monitored regularly or ideally on-line as well. Very limited capabilities exist at present to have on-line measurements of these compounds.

3.2.2 Known gaps in knowledge base (Australian & International)

The major gaps in this area are in a range of applications and pollutant measurements. These are summarised in the following:

- In-sewer on-line measurements of relevant pollutants for source control
- Measurements of pollutant removal capacities of biological wastewater treatment systems (which pollutants, how to measure?)
- High-sensitivity (>3 log) measurements for RO treatment steps
- In-line (household level) evaluation of drinking water quality in areas with dual reticulation systems to detect possible cross contaminations.
- Detection of key contaminant levels in lower quality recycled water streams
- On-line detection and measurement of disinfection by-products (at least in a reasonable robust and affordable way).
- Overall improved stability, robustness and self-diagnosis/calibration capabilities of on-line measurements to minimise false readings.
- No direct measurements of pathogens possible unless very time-consuming and expensive lab-based methods are used. These are not transferrable to plant operations.

3.2.3 Recently completed & ongoing research

Several projects are underway or have been completed recently trying to address some of these gaps. The following list provides an overview, although other projects may also be underway.

- A project in the SEQ Urban Water Security Research Alliance is underway to collect on-line measurements of a number of parameters (pH, Temp, conductivity, DO, turbidity) to determine possible unexpected discharges into the sewers. The main challenge in this regard is to determine the relevance of these measurements for actual contaminants of concern, such as heavy metals, non-degradable or toxic organics, volatile organic carbon etc.
- On-line sulfide measurements using the S::CAN UV/Vis spectroscopic measurements has been established as part of a recently completed ARC Linkage project at UQ, in collaboration with DCM Pty Ltd. This requires a pH measurement in parallel, but is able to determine soluble sulfide measurements in the range of 1-20 mg/L (as S). Again, while this measure is highly relevant for sewer corrosion and odour purposes, its importance for source control of critical contaminants is limited.
- Detection of cross-contamination of Class A recycled water in drinking water supplies is the focus of a project undertaken at UNSW (Rita Henderson) in conjunction with WQRA and an ARC Linkage Project. The main approach is to use fluorescence spectrophotometry to distinguish key characteristics of the recycled and the drinking water.
- WaterSecure has recently initiated an investigation of possible options for an improved measurement for RO permeate to increase the possible log-reduction credit achievable for the process.
- Several projects locally and internationally are looking at the overall sensor stability and in-situ calibration and self-diagnosis. A promising approach based on artificial intelligence has been investigated by Shoshana Fogelman (PhD at Griffith University,

now continuing at UQ). Similarly, research particularly on sensor fault detection and self-diagnosis has been underway since several years at the ModelEAU research group (Peter Vanrolleghem, Quebec University, Canada).

3.2.4 Future research needs

The future research in this area needs to be closely coordinated with the current ongoing activities as outlined above (plus others not listed). Despite the current ongoing activities, there is significant scope to further expand on these projects, as well as follow alternative approaches to achieve the desired outcome. Most of these projects are currently aiming at the detection of particular contaminants or characteristics from the water, but additionally also more generic research needs to be undertaken to particularly address the robustness, reliability and stability of these measurements. Given the very challenging environments that many of these sensors have to be working in, this aspect is often the most critical in actually achieving a practically useful and valuable outcome.

A major limitation in terms of pathogen removal is the lack of direct and rapid measurements of the pathogens in the water. While DNA-based methods have been advocated for some time, they are still far from applicable in the extremely dilute situations encountered in water recycling processes. Nevertheless, such a direct measurement technique would be of major value to the water industry worldwide.

A novel range of contaminants to be monitored on-line (ideally) are the micropollutants and disinfection by-products. The main challenges in this regard are the wide range of compounds to be considered, and the typically very low concentrations at which they need to be measured (typically µg/L or even ng/L level). Many of these even challenge the current off-line analysis processes and need pre-concentration steps, hence will be very difficult to measure on-line. While indicator or surrogate measurements such as on-line TOC, fluorescence or UV absorption may be used, they are far broader and not at all specific for the actual contaminants that may be of relevance to human or environmental health.

Additionally, the purpose of and required action from such measurements needs to be carefully evaluated in particular situations. The direct actions taken on the basis of these measurements need to be well considered and implemented to achieve effective and relevant control as is required under the HACCP concept.

3.3 Optimisation of existing process technologies and trains

3.3.1 Key issues & challenges

Water recycling is a reality in Australia and elsewhere in the world and has been for decades. In Australia alone, wastewaters have been effectively treated and reused for a broad range of applications including recreational reuse, parkland irrigation, crop irrigation, aquifer recharge, industrial reuse and more recently schemes are been developed for indirect potable reuse (Australian Academy of Technological Sciences and Engineering, 2004, Radcliffe, 2009).

Based on that simple observation, one can claim that the current state of technology developments is adequate for successfully treating and reusing wastewaters and meeting various requirements in terms of water quality, including drinking water quality standards. In addition to biological wastewater treatment, current technologies implemented for water recycling mainly rely on two major techniques that can be used independently or in combination: separation (through coagulation, flotation, sedimentation, granular media filtration or membrane filtration) and oxidation/disinfection (chlorination, chloramination, ozonation, UV light irradiation, H_2O_2/UV advanced oxidation). While very effective in removing target contaminants such as pathogens, salt or even pharmaceutical and endocrine disruptor compounds, these technologies come with some major drawbacks. Some of the main challenges faced by current technologies implemented for water recycling can be listed as follows:

a. Costs for capital investments can be significant, especially for advanced water recycling technologies in comparison with conventional wastewater treatment or water supply methods, even if increased competition between technology providers has already led to a significant reduction in capital costs in the past two decades. That also means that long-term asset management planning is required.
b. A lot of these engineered processes have high energy and chemical demands that result in high operation costs and environmental footprints. Membrane systems in particular rely too much on high levels of chemicals dosed continuously for maintaining the performance or occasionally for restoring the performance (fouling control strategy). This high chemical dosage can also result in an increased rate of chemical damage to the membrane itself.
c. Separation processes generate either solids (sludge) or liquid (concentrate) waste streams that require extra management to be disposed off, often in a way that has no benefits but can generate even additional costs.
d. Disinfection and oxidation processes generate transformation products (more commonly known as disinfection by-products) that can be potentially harmful for the environment (ecotoxicology) or human health.
e. Demonstrating permanent and long-term performance of these systems requires careful monitoring, which can be a limiting factor either because of the lack of sensitivity of online monitoring equipment or the cost and time needed for extensive water quality monitoring.

Some of these challenges are discussed in more details elsewhere in this theme (e.g. online monitoring, concentrate management) or in other themes (e.g. environmental footprint) and are not further discussed in this section.

3.3.2 Known gaps in knowledge base (Australian & International)

In spite of many efforts in reducing the energy and chemical consumption of membrane separation systems, these technologies still come at high operation and maintenance costs. The pre-treatment currently applied may not be the most suitable for fouling minimization or long term asset life. The tools for online monitoring of water fouling propensities are not optimal, nor are the characterization techniques used for membrane autopsies. Generally biofouling mechanisms are not well understood.

While chlorinated disinfection by-products have been well studied in drinking water applications, there is still little known about their formation from alternative disinfection techniques (monochloramine, ozonation, hydrogen peroxide/UV advanced oxidation) in matrices as complex and varied as wastewaters. It has been shown that these alternative disinfectants can generate different disinfection by-products compared to those generated by chlorine (Richardson, 2009). However, regulated DBPs have been historically selected as indicators of DBPs formed when disinfecting water with chlorine (Richardson et al. 2007). Therefore, regulated DBPs (derived from chlorination) are unlikely to be an appropriate or comprehensive indicator of the presence of DBPs in recycled water when other disinfectants are used. The challenge is to be able to find suitable indicators for alternative (to chlorination) disinfection strategies.

Finally, performances of natural systems (large reservoirs, rivers, aquifers) in removing target contaminants such as pathogens, herbicides and pesticides, pharmaceuticals and other trace organic compounds, are still not completely understood and probably underestimated which leads to either fully engineering water recycling systems or the over engineering of hybrid (engineered/natural) systems.

3.3.3 Recently completed & ongoing research

The need for conducting research on water recycling quality and technologies has been recognised in the USA for some time already and organisations such as the Water and Environment Research Foundation (WERF, USA) or the WaterReuse Foundation (WRF, USA) are managing a substantial research portfolio in this area (www.WERF.org, http://www.watereuse.org/foundation).

In Australia, several initiatives have been launched more recently to address this subject. Water Quality Research Australia (WQRA, Australia) has significant research work initiated in water recycling (WQRA, Annual Report 2008-2009). Several other research entities have also recently started research programs dedicated to water recycling. Just to limit the list to the current members of the Australian Water Recycling Centre of Excellence, the CSIRO (Urban Water: Recycling and Diversified Supply Stream), the University of Queensland (Advanced Water Management Centre), and the University of New South Wales (Water Research Centre, UNESCO Centre for Membrane Science and Technology) all have ongoing research projects more or less directly relevant to this theme and topic.

3.3.4 Future research needs

In spite of all these efforts, the issues discussed previously remain challenges met only partially by the water industry and restraints for state or local governments in further promoting and developing water recycling schemes in Australia. These challenges are even further highlighted by the growing awareness of environmental constraints such as green-house gases emissions and the rapid worldwide depletion of minerals and fossil fuels.

Therefore the research needs that we can clearly identify in order to optimize current technologies for water recycling are:

- Reduction of energy consumption primarily on advanced water recycling schemes, through the development of new materials, technologies or process configurations to improve currently used technologies.
- Reduction of chemicals consumption or development of “green” chemicals with minimum environmental impact (recycled minerals, biodegradable products…)
- Development of better membrane fouling characterization techniques and online water fouling indicators for a better understanding of low- and high-pressure membrane fouling mechanisms.
- Identification of best pre-treatment practices (including biological wastewater treatment) for membrane applications.
- Identification of the most suitable disinfection strategies and technologies depending on the initial water quality, target pathogen inactivation and formation of disinfection by-products.
- Understanding of the processes by which disinfection by-products are generated during the production of recycled water when different raw water qualities are used.
- Find an indicator for disinfection by-product formation when alternative disinfectants to chlorine are used.
- Better understanding of the performance of natural systems on the removal of pathogens and target compounds of concern and better integration of engineered systems with natural systems.

3.4 Optimal integration of water sources, users and technologies to achieve most suitable outcomes with least impacts

3.4.1 Key issues & challenges.

Occurrence, fate and effect of many compounds in alternative water sources (e.g. wastewater, urban stormwater) are unknown. It is an enormous task to analytically quantify them in water samples, assess the treatment efficiency of existing/novel technologies and determine safe levels for the intended end use (fit for purpose). While the occurrence of some compounds is almost ubiquitous some others are highly variable in space and time. The challenge is to find an economic approach to 'know' which pollutants are present in the source water (predictive characterization based on audit data, or with enhanced chemical analyses and bioassays) in order to define the most appropriate way to deal with them (treat, source control, ban of a substance). Both public sewer systems and urban catchments are "open systems" and are difficult to protect from any unwanted/illegal discharges.

Advanced treatment processes (oxidation, adsorption, membrane filtration) have proven to be effective for the removal of wastewater pollutants. However, these techniques are often energy intensive and might not always be necessary or the most appropriate depending on the use of the recycled water. There is a need to develop "fit for purpose" treatment trains to reduce as much as possible the impact of recycling schemes. Particularly for smaller and remote applications, the reliability and robustness of the treatment train (particularly with minimal operational supervision/maintenance) may be the most important feature to achieve a successful implementation. There are opportunities to develop new treatment concepts such as biological activated carbon filtration without pre-ozonation. Alternative treatment trains also need to consider the integration of (engineered) natural systems. Natural systems include for example lakes, rivers and aquifers; engineered natural systems are for instance riverbank filtration, managed aquifer recharge and constructed wetlands. Integration of these systems may also have particular benefits for the public acceptability of the water recycling process.

3.4.2 Known gaps in knowledge base (Australian & International)

<u>Source control:</u>
Currently, the source control is generally undertaken only as part of the trade waste control systems that each major utility has for their industrial and commercial customers. While potentially very effective, most of this information is commercially sensitive and not accessible publicly or even for regulators. Furthermore, each utility has their own approach in dealing with their trade waste customers, including their own limits and risk assessment procedures.

Beside the trade waste controls, there are very limited control mechanisms for discharges to sewers. Potentially relevant discharges can originate from hospitals and other health care facilities, from household dumping of chemicals (legal or illegal), and existing or emerging chemicals of concern such as detergents, personal care products, pharmaceuticals, novel materials (e.g. nano-materials) etc.

Particular knowledge gaps and needs in relation to source control include:

- Comprehensive, consistent and accessible chemical inventory (data sharing, commercially sensitive, although Europe has made a start with REACH "**R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances")
- Geo-referenced trade waste data base for chemicals likely to enter public sewers (with or without pre-treatment).

- Accepted categorization (risk assessment) for unregulated compounds (e.g. formal integration of expert knowledge and QSAR (quantitative structure-activity relationships)).
- Reliable and sensitive monitoring concepts and techniques (legal and illegal discharges) that can deal with complex and variable matrices (see also on-line monitoring topic).
- Occurrence and fate of novel materials such as engineered nanomaterials.

<u>Treatment processes and overall recycling schemes:</u>
Depending on the local situation, water recycling schemes might be decentralized, smaller-scale installations or more large-scale systems. They may even use different water qualities such as in sewer mining operation, gray water recycling or effluent from a wastewater treatment plant. The particular treatment processes needed to achieve the required water quality will depend on a number of factors beside the actual water quality requirements. Non-potable recycling often uses ponds or reservoirs for intermediate storage, which might create additional pollution (algae etc.) but might also have further treatment effects (e.g. UV disinfection, retention time for degradation.). Additionally, the remaining organics in such waters will support microbial growth in pipes and storages, potentially leading to water quality deterioration and associated effects (e.g. odours).

The following issues are considered as significant knowledge gaps in this area:

- Biofilm growth and associated effects in non-potable recycling schemes (eg. purple pipes).
- Effect of microbial processes in covered or underground (e.g. aquifers) recycled water storages
- Control of algae in open recycled water storages
- Post-storage or in-line disinfection and re-treatment options (e.g. at outlet of reservoirs)
- Fate of pollutants and pathogens in (engineered) natural systems
- Performance, robustness and optimization of engineered natural systems
- Integration of (engineered) natural systems in treatment trains: where, why, how?
- Validation of emergent technologies and innovative process trains.

3.4.3 Recently completed & ongoing research

<u>Source control</u>
Numerous scientific studies have been carried covering effluents of various industries and attract ongoing research interests to better understand mass fluxes and to optimize treatment of industrial wastewater either for internal reuse or as pre-treatment to allow discharge to public sewers (paper and pulp, metal plating, petrochemical, textile and tannery, chemicals and pharmaceuticals, dairy producer, laundries, abattoirs etc.). Although hospitals and households are not pharmaceutical industries, the investigation of the corresponding wastewaters showed the following: national consumption data for pharmaceutically active compounds used by the general public and site specific audit data for a particular hospital proved to be reliable to realistically predict mass fluxes in the catchment of a sewage treatment and advanced water treatment plant (Ort et al. 2010, Weissbrodt et al. 2009). The success needs to be attributed to three aspects: a) the presumably large inter personal variation of consumption of different pharmaceuticals is compensated with the size of the catchment; an average consumption calculated from national data is representative. b) Hospital specific audit data was available to estimate the load from a point source. c) The applied sampling scheme to collect wastewater samples accounted for the high dynamics in the sewers and provided representative average samples.

Additionally, extensive trade waste controls and investigations have been undertaken by various utilities, however, very little of this information is accessible outside of these utilities.

There do not seem to be coherent trade waste assessment protocols used in different cities, further reducing the comparison between different locations. In some cases, even on-line monitoring of major trade waste discharges is undertaken by the utility, however, the information is currently not used for operational optimisation of sewers or wastewater treatment processes.

Treatment Processes and overall recycling schemes
In recent years, significant knowledge as been gained on the fate of wastewater pollutants in classical (biological) and advanced (oxidation, adsorption, membrane filtration) treatment processes. The main emphasis has been on the treatment performance, but limited efforts on the storage and piping aspects of recycling schemes. While the PRW-quality water has been studied substantially (e.g. Western Corridor Recycled Water Scheme in SEQueensland, the NEWater Scheme in Singapore and the GWRS in Orange County, US), the main challenges in this regard are with lower quality recycled waters. Gold Coast Water has undertaken some studies, which have identified the potential for regrowth both in pipes and also in storages (particularly open ponds). Limited if any studies seemed to have been done on the re-treatment or in-line disinfection processes in such schemes.

Furthermore, research has mostly focussed on assessing and optimising existing processes for tertiary wastewater treatment. There is also still a gap regarding the fate of pollutants and the regrowth potential in (engineered) natural systems. Monitoring of real systems has been undertaken in various part of the world and results have shown that (engineered) natural systems (such as bank filtration, aquifer storages, infiltration basins) are capable of mitigating pollutant loads and environmental impact. However, these results can be hardly generalised as they very much depend on the quality of the water source and site specific conditions.

3.4.4 Future research needs

- Compile a detailed, comprehensive, geo-referenced chemical inventory of substances that are likely to end up in public sewers (from the production to the intended application in households or offices). It is recommended to do this in close collaboration with trade waste officers and in coordination with WSAA and its members.
- Categorize the unregulated substances depending on degradability with conventional treatment steps, removal in advanced treatment systems, persistence and expected negative effect in the environment or on public health.
- Assess the potential of online measuring technologies and real-time data processing to identify unusual discharge events. It could serve as an early warning system for compounds that cannot be removed or damage treatment facilities (e.g. flammable or explosive substances).
- Evaluate more effective (maybe also higher energy demanding) treatment technologies to treat high strength, low volume industrial wastewater prior to on-site recycling or discharge to sewers.
- Investigate the microbial processes and their effect on water quality in non-potable recycled water during transport and storages (both closed and open storages).
- Develop effective algal growth controls and treatment processes for removal of algae from recycled water streams.
- Develop innovative combinations of engineered and natural treatment processes adapted to secondary treated wastewater quality to achieve efficient, low-maintenance and robust treatment trains.
- Investigate the fate of organic and microbial pollutants in (engineered) natural systems and determine strategies for optimization and validation of such processes.

3.5 Novel innovative technologies for water recycling

3.5.1 Key issues & challenges

Given the relatively recent development of water recycling as a widespread additional water supply, there are ongoing developments of innovative technologies underway. Additionally, the emergence of novel materials (e.g. nano-composite materials) and processes (like electrochemical oxidation/reduction) offer new opportunities to expand the range of technologies currently available for water recycling.

Of particular interest are novel, low-energy and/or highly selective membranes to reduce energy demands and possibly improve water recoveries, while minimising by-product generation (e.g. brine streams). Similarly, membrane distillation processes (using polymer or novel ceramic materials) can increase water recoveries and reduce brine streams, while using low-grade heat.

Also novel adsorption processes, possibly using nano-particles, may be emerging with high selectivity for particular pollutants. There are also novel UV or even visible light-sensitive nano-compounds that could be used for advanced oxidation processes, e.g. using sunlight. They could possibly also be incorporated into membrane processes to minimise fouling on the surface of the membranes. The same effect might be achieved by conductive coatings on the membranes and the use of electric potentials to provide oxidative or reductive conditions at the membrane surface. If and how these processes could be used in water recycling applications needs to be evaluated.

Additionally, novel “treatment” options could be considered that are derived or adapted from other sectors of the water industry. Possibly algal ponds could be used to “treat” brine water from inland RO operations (e.g. from coal seam gas water production). While the actual “treatment” will mainly be based on evaporation of the water and collection of the salt (in the end), these brine ponds can be used for beneficial purposes to either create algae for anaerobic digestion, extraction of lipids for biodiesel production or even direct production of more valuable products (e.g. beta-carotene).

3.5.2 Known gaps in knowledge base (Australian & International)

The main knowledge gaps in this field are related to the specific characteristics of these novel materials for water recycling applications. In many cases, the materials may not be specifically produced for (recycled) water applications, but could be adapted for such purposes.

3.5.3 Recently completed & ongoing research

Incorporation of carbon nanotubes and related nanomaterials in membranes has been investigated for some time already. Much of this research is done in the research labs of the major membrane manufacturers, and hence not publicly available.

Significant work is underway worldwide on UV or visible light based advanced oxidation processes based on novel nanocomposites (doped semiconductors), also at the ARC Centre for Functional Nanomaterials at UQ. Initial results are encouraging but there are still substantial further developments of both the material and the implementation necessary.

Similarly, the coating of membranes (or other surfaces) with nanomaterials or conductive surfaces to control biofouling has been proposed in the past, but only limited research seems to have been undertaken so far.

Research on algal production has been rapidly intensifying worldwide in recent years based on the projection that this is a promising route for biofuel production in future. Most of this work is either concentrated on photo-bioreactors or open pond platforms, the latter being a possible option to incorporate in a water recycling scheme. Beside the water, these processes require nutrients and CO_2 supply, hence need to be incorporated into an overall resource recovery process, possibly focused on carbon sequestration. Such a situation may be feasible in the coal seam methane production areas in inland Queensland and NSW. Beside the (salty) water, there are also substantial CO_2 sources available (gas engines for power production and compressors), as well as agricultural sources of nutrients (manure, agro-industry by-products). The nutrients could eventually be returned to the land via the biosolids application (after anaerobic digestion), hence would be a genuine resource recovery operation.

3.5.4 Future research needs

The research needs in this area are highly diverse and specific for the various applications noted above. One consideration is that in this particular topic specific research directions are not specified, but more generic research ideas and proposals could be called for. This will likely create some unforeseen opportunities to apply and adapt existing expertise in a completely different field to water recycling applications.

4 Summary and Conclusions

In the area of Technology Efficiency and Integration, a wide range of challenges have been identified and grouped in five topic areas. While there is some overlap between certain topics, this overview clearly shows that there are many possible research gaps existing in this theme and it will be necessary to clearly prioritise the research topics to be focused on. It is also critical to identify existing research activities in these priority areas and potentially collaborate closely with these partners, or maybe concentrate the efforts on other topics where limited or no research activities are currently ongoing.

5 Linkages

Linkages with existing groups;

Research Topic 1.

VU, NCED, UNSW, CSIRO

Research Topic 2

UNSW, UQ, VU, WaterSecure, Veolia Water

Research Topic 3

Veolia Water, UQ, VU, UNSW, GHD

Research Topic 4

UQ, Veolia Water, GHD

Research Topic 5

Monash, UNSW, UQ, VU, CSIRO

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- Veolia Water Australia
- Victoria University

- University of NSW
- University of Queensland
- CSIRO
- GHD

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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.
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