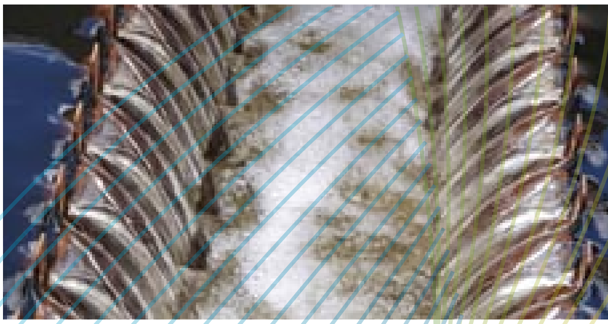
Australian Water Recycling
Centre of Excellence

Strategic Research Plan



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Australian Water Recycling Centre of Excellence

Australian Government
Water for the Future

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A list of organisations and individuals who contributed to the Strategic Research Plan development is provided in Appendix A.

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Glossary of Terms

ADWG	Australian Drinking Water Guidelines
AWA	Australian Water Association
AWRCE	Australian Water Recycling Centre of Excellence
AGWR	Australian Guidelines for Water Recycling
AQUAREC	Name of a joint Australian/European project on *Integrated Concepts for Reuse of Upgraded Wastewater*
AUSLCI	Australian Life Cycle Inventory
DAFF	Dissolved Air Floatation and Filtration
DBP	Disinfection By-product
DPR	Direct Potable Reuse
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
EDC's	Endocrine Disrupting Compounds
EPA	Environmental Protection Authority
GHG	Greenhouse Gas
HACCP	Hazard Analysis and Critical Control Point
ITS	Intelligent Testing Strategy
IPR	Indirect Potable Reuse
IWA	International Water Association
KWR	Watercycle Research Institute, The Netherlands
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LRV	Log Removal Value (1 Log removal = 90% removal)
MF	Micro-filtration
NCED	National Centre of Excellence in Desalination
NF	Nano-filtration
NWC	National Water Commission
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulphonate
PUB	Public Utilities Board
RAC	Research Advisory Committee
Reclaimed Water	*Water of a quality that is suitable for recycling for a particular point of use*
RO	Reverse Osmosis
SRP	Strategic Research Plan
SOPA	Sydney Olympic Park Authority
UV	Ultraviolet
UNEP SETAC	United Nations Environment Programme & Society of Environmental Toxicology & Chemistry
UWSRA	Urban Water Security Research Alliance
WQRA	Water Quality Research Australia
WSAA	Water Services Association of Australia
Water Recycling	*The beneficial use of reclaimed water for communities, industries and the environment*
WWTP	Wastewater Treatment Plant

Executive Summary

Securing Australia's water future requires a diversity of water sources to ensure the country is prepared for future droughts and changing population patterns. Water recycling has a substantive and important contribution to make in securing future water supplies and in improving the health of the nation's waterways. Ongoing scientific, social and technical studies are required to maximise this contribution through developing water recycling opportunities that are environmentally, socially and economically sustainable.

The Australian Water Recycling Centre of Excellence (AWRCE) was launched in March 2010 and will receive $20 million from the Federal Government to establish a national research program in water recycling.

The Centre's Strategic Research Plan (SRP) has been developed in stages – starting with the production of Discussion Papers on four Research Themes in time for the Centre's launch in March 2010. These Papers summarised gaps in current day research in each of the Theme areas and identified a wide range of research topics of potential relevance to the water recycling industry in Australia.

Subsequent discussion with utilities, regulators, private companies and researchers in metropolitan and regional areas identified four Goals that the industry believed the Centre could contribute to achieving, and which would enhance efficiency, expansion and acceptance of water recycling in Australia:

- Goal 1. The social/ economic/ environmental value of water recycling is demonstrated and enhanced;
- Goal 2. A national validation framework for water recycling is established;
- Goal 3. Reclaimed water is seen as an acceptable 'alternative water' for augmenting drinking water supplies; and
- Goal 4. A national knowledge, training and education program for water recycling is established.

The SRP outlines the status of water recycling development overseas and in Australia, recognises the challenges associated with the continuing development of water recycling, and outlines how the research topics and goals will guide the Centre's investment portfolio to help meet these challenges.

Contributions from industry and research organisations will help deliver the research agenda. There is a focus on having projects and outcomes that are supported by industry are clearly measurable, and that contribute to the achievement of the goals over the next three to five years.

The first call for proposals to address Priority Research Themes and help deliver on the Centre goals will be made shortly after the release of this plan. This SRP will be reviewed annually and made available on the Centre's website.

1. Introduction

1.1 Objectives of the Centre

The Australian Government's objectives for the Centre are for it to help secure Australia's water supply by:

- Providing leadership in accelerating ground-breaking research on energy efficient water recycling technology for water supply being developed in Australia, including:
  - Investigating ways of optimising and adapting water recycling technology for use in Australia's unique circumstances;
  - Expanding on research into the use of water recycling technology in rural and regional areas; and
  - Researching ways of efficiently and affordably reducing the carbon footprint of water recycling facilities and technologies;
- Providing facilities to researchers and industry to support the development of new technologies and practices including pilot test facilities;
- Commercialising the resultant new water recycling technologies, including patenting and promoting the uptake of new or improved water recycling technologies both within Australia and internationally;
- Utilising and developing the research and industry skills base, including but not limited to providing high quality postgraduate and post doctoral research opportunities and training; and
- Promoting increased public acceptance of alternate water sources and their opportunities for use in the context of a 'fit for purpose' water use strategy.

Vision of the Centre

The Vision for the Centre, adopted by the Board and foundation participants is:

"The Centre is recognised as a world leader in research and promotion of sustainable water recycling."

1.2 Why Water Recycling?

Water Recycling offers many benefits, including:

- Reclaimed water can replace drinking water for many uses, with the reclaimed water having a quality that is 'fit for purpose'. The uses can range from park and playing field irrigation, environmental flows, domestic non-potable use, industrial use and potable use;
- Reclaimed water can replace raw 'untreated' water (such as river water) for irrigation of crops, pastures, vineyards, vegetables etc. again with a quality that is 'fit for purpose';
- Reclaimed water can be used to create new business opportunities as it is a guaranteed supply of water; for example, it can be used as process water for industries or as irrigation water for land that was previously not irrigated due to a lack of water.
- Reclaimed water can, under certain circumstances, benefit the environment by reducing wastewater discharges

It is for these reasons that there has been a dramatic increase in the uptake of water recycling both overseas and within Australia (discussed in Section 2 below). There are also, however, impediments and challenges that will have to be addressed to continue to grow water recycling around the world – as are discussed in Section 3 below.

1.3 Structure of the Strategic Research Plan

The SRP contains five main sections as follows:

Section 2: Status of Water Recycling - Internationally and within Australia

Section 3: Development of the SRP and Centre Goals

Section 4: Priority Research Themes

Section 5: Aligning Research Topics and Goals

Section 6: Research Linkages – National & International.

The Priority Research Themes identified in Section 4 have been selected with the Centre's goals in mind; some may be major initiatives in their own right while others may be smaller steps that when amalgamated will achieve one or more of the Centre goals.

The SRP will be available on the Centre's website and reviewed at least annually.

2. Status of Water Recycling – Internationally and within Australia

2.1 Status of Water Recycling Overseas

Water is recycled extensively in countries around the world. The nature of the recycling and associated treatment strategies varies, however, according to local drivers which are essentially very similar to those pertaining to Australia.

This section presents a brief summary of water recycling overseas with the aim being to highlight that many of the research topics identified in this report are relevant to overseas applications as well. It becomes important therefore to ensure that there is close contact maintained, and in some cases research activities shared with, overseas associations and research entities.

2.1.1 Global Recycling Perspectives

Water recycling is almost universal. The global installed capacity of water reuse plants is around 50, 000 ML/day, a little more than half of which has been treated to the tertiary level (suspended particles have been removed and the water has been disinfected).[1] Actual output from water reuse plants has been estimated at about 60% of capacity.

Annual expenditure on building water reuse projects is currently in the region of US$2.4 billion. This is expected to rise to US$8.4 billion in 2016[2] as communities look to reinforce and diversify their supply strategies.

The EU's AQUAREC project in 2006 identified over 3,300 water reclamation projects across the world.[3] Japan had the largest number of reuse projects (1800), followed by the USA (800), Australia (450) and the EU (230).

In Japan, most projects involved urban recycling. By contrast, projects in the USA and EU were relatively evenly split between urban and agricultural projects with a smaller number of industrial and mixed-use projects. Most EU projects were in southern Europe, predominantly in Spain.

1. http://www.globalwaterintel.com/press-releases/ accessed 17 May 2010

2. ibid

3. http://www.aquarec.org/ AQUAREC Final Report (2006), p35, accessed 17 May 2010

2.1.2 Examples of Water Recycling Around the World

North America

Water recycling practices vary widely across North America. In Canada, recycling is generally limited to small-scale operations. In the USA, states with water supply limitations – notably California, Florida, Arizona and Texas – have practiced water recycling extensively for many years and it is accepted as an integral part of water resource strategies. Some states have specifically defined regimes for water quality requirements and treatment processes for different reuse applications, while others are focused on alternatives to surface water discharge.[4]

California is one of the most prominent examples of water recycling in the United States. Orange County near Los Angeles is, in some ways, the "home" of potable recycling due to the quantum of research work published on the subject of potable reuse. The original "Water Factory 21" built in the 1970s was the first to apply the reverse osmosis (RO) process for the recycling of a high quality reclaimed water. The original project has been followed by a number of successor projects of increasing size. Now known as the Orange County Groundwater Replenishment System, the project currently has a capacity of 265 ML/day.

Until recently, the primary objective of the recycling program was to help sustain the region's aquifers which were under threat of seawater intrusion. More recently, with the commissioning of new plants, the recycling projects are intended to make a positive direct contribution to groundwater resources.

Other well-known reuse projects in the United States include the Upper Occoquan system in Virginia, the Scottsdale Water Campus in Arizona and the Hueco Bolson Recharge Project in El Paso, Texas.

Latin America

There are examples of water recycling in Latin America, but the scope is limited in many areas because of the absence of a wastewater treatment plant (WWTP). One of the biggest recycling projects is in Amezquital Valley, Mexico, where 83 000 hectares are irrigated with raw wastewater.

Europe

Most of the water recycling projects in Europe are located along the coastlines and on the islands in the southern, semi-arid countries (especially Spain) and in the highly urbanized areas of northern and central Europe. In 2000, the European Community issued a Framework Directive (2000/60/EC) that encourages sustainable management of resources, including water recycling.

In Spain, water recycling is rapidly expanding. In excess of 300 water recycling systems have been identified, and in 2008 this represented a volume of about 447 GL/year. Of this, 71% was used for agriculture, 17.7% for environmental flows, 7% for recreation, 4% in urban areas, and 0.3% for industry.

Barcelona is home to the largest water recycling plant in Europe that aims at agricultural irrigation, but also aquifer recharge for preventing seawater intrusion, and delta irrigation. Notably, the 2008 survey estimated that only 61% of the recycled water systems operating in 2007 had water treatment processes that were suitable for the application. About 11% of the systems used desalination (RO or electro dialysis reversal, mostly located on the Canary Islands).

Although less common than in Spain, there are a number of significant recycling projects in France. In Sainte Maxime, Sperone and Pornic, water is recycled via tertiary treatments for the irrigation of urban green spaces, golf courses and protection of bathing waters. Near Clermontferrand, 700ha are irrigated from recycled water. In Brittany, zero nuisance piggeries using membrane bioreactors are being developed in order to recycle flush waters and prevent nitrates from polluting drinking water supplies.

4. Crook, J (2004), Innovative Applications in Water Reuse: Ten Case Studies, WateReuse Association, Virginia

In Wulpen, Belgium, recycled water is added to groundwater to prevent salt water intrusion in drinking water supplies. Water is treated to drinking water standards before being released to the groundwater system. About 45% of the total drinking water demand in the local distribution area is met using recycled water.

The Langford Recycling Scheme in Essex, United Kingdom, commenced operation in 1997. Flow in the Chelmer River is augmented by the discharge of treated wastewater, supplementing the supply to a reservoir. The combined flow is taken from the river at Langford, near Maldon, where it is treated and used in the local drinking water supply. The supply serves a population of about 100,000.

Other significant examples of water recycling applications in Europe include two of its capital cities: Berlin and London. In Berlin, drinking water is produced from an aquifer that is recharged by riverbank filtration (55%), natural recharge (30%) and artificial recharge (15%). Lakes used for riverbank filtration receive between 14% and 28% of Berlin's tertiary treated waters, making this effectively an indirect potable reuse (IPR) scheme. In London, Thames Water is currently running a five year research program for the potential implementation of planned IPR in South East England.

Middle East

The Middle East is characterized by a very arid climate with minimal rainfall. Groundwater supplies are typically limited or saline, and many countries have turned to seawater desalination as a primary source of drinking water. Israel, the UAE, Qatar, Kuwait and Bahrain are predominantly dependent on desalination for drinking water.

This also creates a significant driver for water recycling. Desalination is expensive, so water recycling has become prevalent across the region. Reclaimed water is commonly used for irrigation of landscaping, delivering significant social value in an arid climate while some is used for district cooling systems, although this is less common. Typically, the supply of reclaimed water is over-subscribed and there is a shortage in many communities.

Israel achieves more than 90% recycling of all reclaimed water [5], mainly in agriculture. Egypt also has a very active recycling program for agricultural application.

Asia

Although not as well-publicised in Asia, there are numerous formal and informal recycling schemes in place. For example, it is estimated that up to 35% of effluent from WWTP's in India is recycled for agricultural use.

Singapore is a widely recognized leader in recycled water. The nation has limited natural water resources of its own and has historically been very dependent on the supply of water from Malaysia to meet its water needs. Over the past decade, Singapore has been very active in developing its own supplies to reduce its dependence on Malaysia. As a result, it has constructed a number of projects including seawater desalination plants and advanced water reclamation plants.

Known as NEWater, the reclaimed water is reticulated to industrial users where high quality water is required, and since 2003 some of the water is released back to the nation's reservoirs to augment the island republic's drinking water supplies.

5. "Water Reuse and Recycling: Status and Forecast", presentation given to Western States Water Council Legal and Water Quality Committees by Richard Atwater, President WateReuse Association on 16 July 2009

Africa

The AQUAREC survey published in 2006 identified fewer than 10 water recycling projects in Africa. However, these include one of the more significant projects at Windhoek in Namibia. Windhoek has been successfully using recycling water for drinking purposes since 1968. Recycling can now provide 35% of the City's water supply needs. Significantly, this is done *directly* rather than *indirectly* via aquifer recharge or release to a surface storage. This is the only known significant example of direct potable reuse (DPR) and thus is well-known in the international arena.

2.2 Status of Water Recycling in Australia

In Australia, a range of urban and regional water recycling projects have been built to extend the communities initial investment in the infrastructure to collect and treat wastewater. Although implementation of the projects commenced slowly, growth in water recycling has been almost exponential in the last 20 years as a result of a change in how water is valued by the community, planning to accommodate population growth, and as a means of ensuring that growth can continue in areas where local fresh water supplies cannot cater for current or future demands.

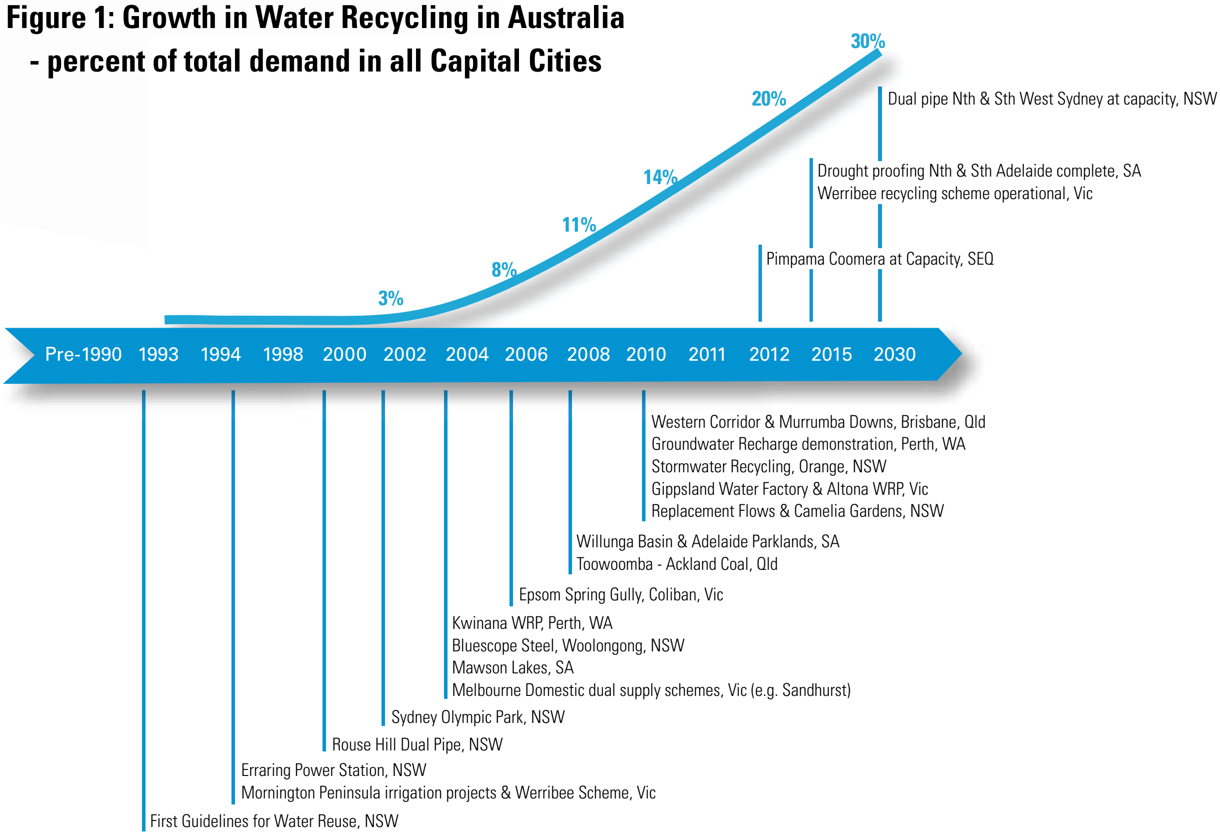
From the late 1970's to the early 1990's, water recycling was promoted in Australia as an alternative to the discharge of wastewater into receiving waters. As the level of treatment required for discharge to the environment increased, it was recognised that it would be beneficial to use this water resource for the irrigation of crops, pasture and public gardens as well as in the maintenance of sporting fields and recreational areas. By the mid 1990's the first recycled water scheme to supply water directly to industry was commissioned at the Erraring power station, while the release and development of land for new residential developments in NSW and Victoria included provisions for a third pipe to deliver water from a centralised recycling facility to individual domiciles for outdoor use and toilet flushing. From 2002, which was the start of almost seven years of drought in eastern Australia, the effects of population growth coupled with less predictable and declining yield from dams and reservoirs have accelerated the development of water recycling schemes.

During this period the motivation has been to develop schemes that offset the need to supply water from the potable distribution system. The result has been an increase in schemes supplying the petrochemical, building material and paper industries and third pipe schemes for both suburban Greenfield developments as well as new urban in-fill developments. In addition, recycling schemes were implemented to offset the release of surface water stored in dams and impoundments to maintain environmental flows in rivers and recharge aquifers. Finally, as the surface water supplies in NSW and South East Queensland approached dramatically low levels, the planned augmentation of surface water supplies with water from water recycling schemes was proposed, but not implemented in Goulburn and Toowoomba, and built, but as yet only operated to supply industrial uses, in Brisbane.

A time line covering the development of recycling projects in Australia is presented in Figure 1 over page, showing a dramatic growth in water recycling since 2004.[6 7 8]

6. http://www.atse.org.au/index.php?sectionid=597 Radcliffe, J. C. (2004), Water Recycling in Australia
7. Radcliffe, J. C. (2010), Evolution of water recycling in Australian cities since 2003, Water Science & Technology
8. http://www.waterforlife.nsw.gov.au/about/plan Waterforlife, Metropolitan Water Plan, NSW Government

**Figure 1: Growth in Water Recycling in Australia
- percent of total demand in all Capital Cities**



The remainder of the section contains a summary of the features of the main types of regional and urban recycling schemes including the scale and types of technology typically employed, with details for iconic projects constructed in urban and regional Australia.

2.2.1 Agricultural, Horticultural and Viticultural applications

The earliest water recycling projects in Australia delivered water for land application via irrigation systems. These schemes are common in regional Australia where wastewater is diverted for irrigation of turf growing, woodlots and pastures. The form of treatment provided at the WWTP in regional projects includes oxidation ditches, intermittently decanted extended aeration and lagoons. The probability of public contact at the point of application is low, consequently minimal or no additional treatment is provided after the wastewater treatment system. The main technical criteria for monitoring of these schemes was based on recording the water salinity and sodium adsorption ratio to ensure that prolonged irrigation did not exacerbate soil sodicity problems.

Extension of these schemes to supply horticultural operations where there is the potential for the finished product to be consumed raw requires the addition of a disinfection system usually preceded by a step to lower the suspended solids content. The largest scheme of this type in Australia is located near Bolivar in the Northern Adelaide Plains. The scheme has a capacity of up to 24 GL per annum and processes secondary treated wastewater using dissolved air floatation and filtration (DAFF). The water is delivered to a network of 100 km of distribution pipe to a range of horticulture operations in the Virginia triangle. Similar schemes developed by the Willunga Basin Water Company divert water from the Christies Beach WWTP for irrigating 2500 ha of vineyards. The sustainable production of high value products from viticulture and horticulture operations can be used to justify the cost of developing the extensive distribution network.

2.2.2 Third Pipe or Dual Supply Systems

Dual supply recycling refers to projects that supply water to individual domiciles or businesses for outdoors use, such as landscape irrigation and car washing as well as indoor use in toilet flushing. Water is delivered from the water recycling plant through a separate pipe (often referred to as the 'third pipe') that crosses the property boundary (the other two pipes deliver water from the potable system and collect wastewater). Plumbing codes for dual pipe schemes are designed to allow ready identification of the third pipe and prevent cross connection with the potable supply.

The level of treatment provided for dual supply schemes is based on managing the risks associated with a high probability of human contact with the water. The first step following the oxidation and settling of the wastewater to remove bulk suspended solids is additional treatment to reduce the level of suspended solids and improve the clarity of the wastewater.

The types of treatment used include dual media filtration, cloth filtration, DAFF and membrane filtration using a micro-porous ultra-filter or micro-filter. In some cases the membrane separation step is combined with the biological treatment stage in a membrane bioreactor. Removing suspended solids and improving the clarity of the water improves the performance of the disinfection process and ensures that the water can be reticulated and used without clogging nozzles and fittings. Disinfection can be achieved using ozonation, ultraviolet (UV) irradiation and chlorination. Water reticulated through the third pipe contains residual chlorine to prevent regrowth of microorganisms in the pipes and storages.

Dual supply schemes are mostly operated from a centralised WWTP. Centralised schemes enjoy advantages of economy of scale and co-location of wastewater treatment and water recycling operations in the one facility. The disadvantage of this approach is transport of the product water from the centralised plant back to the individual domiciles or businesses that will use the water. The alternative is based on a decentralised approach where the feedwater to the recycling plant is sourced close to where the product water will be consumed. Decentralised water recycling schemes represent a small but growing number of dual supply schemes.

Decentralised schemes can source water from either a large sewer main located close to where the product water will be used or from wastewater generated on-site. In NSW, examples of decentralised schemes that source water from main sewers are the Kogarah Golf Course in Southern Sydney and the Pennant Hills Golf Club in North West Sydney.

The decentralised schemes that source water for single domiciles or strata titled buildings have been developed in many cities and urban areas. In some cases black water (combined toilet, bathroom laundry and kitchen waste water), grey water (segregated bathroom and laundry wastewater) or yellow water (waste from urinals) is collected, treated and recycled on site. Examples of these schemes include Council House Two (CH2) and the Department of Human Services in Lonsdale St Melbourne, Sydney Water Head office in Parramatta, Sydney and the GAP house in Brisbane.

The first urban Australian dual supply system was built in Rouse Hill, NSW in 1991, to service a development with an ultimate capacity of 35,000 people. The plant has been modified several times and provides treatment using membrane and media filtration and disinfection using ozonation and chlorine. A dual supply system was built as part of the precinct constructed for the 2000 Olympic Games and managed by the Sydney Olympic Park Authority (SOPA). The dual supply system supplies the water features and toilet amenities in the precinct as well as the original athlete's village and new residences now known as the suburb of Newington. Wastewater is collected and treated through a sequencing batch reactor followed by microfiltration, RO and chlorination. The system also allows for the treatment of stormwater collected on the site.

The inclusion of RO has allowed SOPA to gain permission to use the water in the air-conditioning and laundry systems. Similar schemes are being commissioned or are in the planning stages as part of the Western Sydney Recycled Water Initiative to supply 160,000 new homes to be built in new suburbs in Sydney's North West and South West by 2015 that will account for 12% of Sydney's water needs. In Victoria, dual pipe systems supply residents in Sandhurst, Aurora and Bendigo. It is anticipated that in the next 25 years more than 50,000 Melbourne homes will be supplied with water via a dual pipe recycling systems located at both the Western Treatment Plant at Werribee and the Eastern Treatment Plant at Carrum.

In South Australia, the suburb of Mawson Lakes is supplied with a mixture of water via dual pipe scheme from the Bolivar water recycling plant and stormwater collected from the City of Salisbury. Water from the Bolivar recycling plant is processed using DAFF and chlorination while the storm water is treated through constructed wetlands. In South Adelaide, homes at Seaford Meadows will be supplied with water following the upgrade of the Christies Beach WWTP using a combination of an immersed membrane bioreactor and an Integrated Fixed-film Activated Sludge system followed by UV disinfection.

Examples of dual-reticulation schemes in Queensland include the South Caboolture and the more recent Pimpama-Coomera schemes – both supplying reclaimed water to adjacent communities.

2.2.3 Industrial

Water recycling projects supplying large industrial customers have become common where WWTP's are located near industrial precincts. The delivery of water from these schemes is used to replace potable or surface water used by the industry, and the reclaimed water is normally delivered via a third pipe directly into a tank that is used for all but potable applications on the industrial site.

These uses often include fire fighting, evaporative cooling and steam production. Exposure through the fire fighting system and use in the high pressure boilers predicate high levels of disinfection and removal of dissolved salts. Typical treatment systems for these applications, post wastewater treatment, consist of membrane filtration followed by RO and chlorination.

Most recycling projects serving industrial customers are located in metropolitan areas; however, both the initial and possibly the most complex projects are located in regional Australia. The first major industrial water recycling project was commissioned in 1994 and supplies the Eraring power station in the Hunter Valley in NSW with reclaimed water. A more complex project is the Gippsland Water Factory that was commissioned in early 2010 and involves the development of a wastewater collection system for three towns and a large paper mill plus treatment through Australia's largest membrane bioreactor followed by treatment with RO.

Water recycling projects in urban centres in Queensland include the Luggage Point water recycling project supplying BP Bulwer Island Clean Fuels facility developed by Brisbane City Council in 2000 and the Western Corridor Recycled Water scheme supplying water to two power stations in Brisbane. A similar project was built at the Murrumba Downs WWTP using membrane filtration and RO to supply water to the Amcor carton board factory at Petrie.

In NSW the Wollongong Water Recycling project supplying Blue Scope Steel was developed by Sydney Water in 2002, while in Perth the Kwinana water recycling project supplies BP and High Smelt with up to 17 ML/d. Similar schemes operating in Victoria include the delivery of 2 ML/d of water from South East Water's Somers WWTP to BlueScope, the delivery of 4 ML/d from City West Water's Altona WWTP to the plastics manufacturer Qenos and the proposed delivery of 2 ML/d from Barwon Water's Northern Treatment Plant to the Shell Refinery near Geelong.

2.2.4 Environmental Flows

Water produced from recycled water projects can be used to restore flow in rivers and recharge aquifers. In these applications the use of water from recycling plant can reduce the need to release surface water stored in impoundments to maintain environmental flows or maintain production rates from aquifers that are in danger of being overdrawn. In NSW, the Western Sydney Replacement Flows project will use membrane filtration followed by RO to produce water with a low nitrogen content that can be reintroduced in to the Hawkesbury-Nepean system. Wastewater will be sourced from biological nutrient removal plants located at St Marys, Quakers Hill and Penrith. The high-quality recycled water from this plant will be pumped at 8ML/d back to Penrith for discharge into the Hawkesbury-Nepean River, below Penrith Weir. A similar scheme is currently under consideration for the Yarra River in Victoria.

2.2.5 Potable Water Augmentation

The recent drought has put the planned recycling for augmentation of potable supplies on the agenda of communities in both urban and regional Australia. Replenishment of surface waters or groundwater using water from a water recycling plant is referred to as IPR. Under an IPR scheme the water will eventually be used for drinking water, however it will be supplied indirectly through the source water storage and will receive additional treatment in a water treatment plant prior to distribution.

The alternative to IPR is DPR where the water is blended into the drinking water being supplied to the consumer through the distribution system without any additional treatment. IPR has been considered for regional communities in Goulburn, NSW, the ACT and Toowoomba, Queensland. The need for the IPR project in Goulburn was obviated by the NSW's government decision to construct a water transfer pipeline, while the IPR project for the ACT did not proceed past the planning study. In the case of Toowoomba, however, the project moved through the planning phase and attracted support from the Australian Government for $22.9m of the $67.8m total project cost, subject to community support in a referendum. However, the community voted 61% to 38% against the project and the IPR project was abandoned.

The only IPR project that has been built in Australia to date is the Western Corridor Recycled Water Scheme in South East Queensland that produces drinking quality water suitable for release into Wivenhoe dam, Brisbane's principal water storage. The scheme consists of three advanced water treatment plants located at Bundamba, Gibson Island and Luggage Point which draw feedwater from six nutrient removal WWTP's. Each of the three water recycling plants incorporate microfiltration (MF) and RO followed by an advanced oxidation system using UV light and hydrogen peroxide to remove specific disinfection by-products and non-specific low molecular weight organics.

The residual brine stream from the Bundamba advanced water treatment plant is nitrified and denitrified to reduce nitrogen concentrations before discharge into the Brisbane River that flows to Moreton Bay. The project has a production capacity of 232 ML/d and more than 200km of interconnecting and product water delivery pipelines. The project was delivered using five fast track alliances over a two year period when the dam levels ranged from 17 to 30%. However, significant rains in early 2008 raised dam levels to over 40%, which combined with a perceived reduction in public support for IPR prior to the November 2008 election resulted in the introduction of policy by the State Government not to augment drinking water supplies until dam levels fall below 40%. The Scheme is currently operating at reduced capacity supplying reclaimed water to two major power stations.

In Western Australia, Water Corporation is operating a demonstration project investigating the feasibility of reclaiming water from the Beenyup WWTP using membrane filtration, RO and UV disinfection prior to injection into the Leederville aquifer. If successful a full-scale facility could provide an additional 1.5GL/a supply to the aquifers supplying Perth's drinking water.

2.2.6 Potable Water Augmentation with Stormwater

Stormwater harvesting is finding increasing application in Australia – and in particular, in South Australia where most applications are for irrigation of parklands and agricultural areas. In one instance, at Mawson Lakes in Adelaide, captured stormwater is blended with effluent from the Bolivar WWTP and used for irrigation and toilet flushing within the adjacent residential area.

The city of Orange in NSW has recently commissioned a potable water augmentation scheme with stormwater captured from its Blackmans Swamp Creek catchment which yields some 1,300 ML/a of additional water to the City's water supply. It is currently planning another such scheme for its Ploughmans Creek catchment.

Yarra Valley Water in Victoria has recently commenced the planning for a 'stormwater to potable reuse' scheme in its area of operation.

2.2.7 Regulations for Water Recycling

The first guidelines developed for water recycling projects were generally influenced by land based recycling applications. The approach was based on principles developed for point source discharge and set targets for water quality that was to be monitored at the point of application.

The guidelines were somewhat prescriptive on the type of treatment with the extent of treatment increasing with increasing probability of public contact. Examples of this approach were described in the National Water Quality Management Strategy Guidelines and the NSW Guidelines for Urban and Residential Use of Reclaimed Water. Similar guidelines issued by the Environmental Protection Agency (EPA) covering dual pipe reticulation schemes are in operation in Victoria, while the department of Natural Resources and Water developed a regulatory framework for Queensland.

The guidelines have now been superseded at the national level by the AGWR (Australian Guidelines for Water Recycling) which are based on a risk management framework which is consistent with the approach taken in the Australian Drinking Water Guidelines (ADWG). The motivation for the development of these guidelines was to provide greater flexibility for different treatment systems and reduce the burden and cost associated with end point monitoring. The intent was to provide a framework that would enable the development and management of recycled water in the urban domestic environment rather than being mainly oriented to land application.

There are currently no regulations or guidelines in Australia covering the use of stormwater as potable water supplement.

3. Development of the Strategic Research Plan and Centre Goals

3.1 Water Recycling Challenges

In the last 20 years there has been considerable progress in expanding the scope and capacity of water recycling in Australia. There are, however, some challenges to the continued development and expansion of water recycling applications, and it is important that they are identified and addressed in order for the full potential of water recycling to be realised.

Examples of such challenges include the current institutional capacity to deliver operate and manage the schemes, poor understanding of the cost benefits of water recycling, the lack of a national data-base (or warehouse) of water recycling schemes in Australia, variable application of national guidelines, uniform and reliable analytical capacity, social and political issues and concerns.

In preparing the SRP the Centre has recognised these challenges, and others, and developed a number of research themes and goals to help address them.

3.2 Developing the Plan

The Objectives outlined in Section 1.1 above and the impediments and challenges outlined in Section 3.1 have been considered during the development of the Centre's four Research Themes:

Theme 1: Technology, Efficiency and Integration;

Theme 2: Water Quality and Scheme Validation;

Theme 3: Social, Economic and Institutional Challenges;

Theme 4: Sustainability in Water Recycling.

Discussion Papers on each of these Research Themes were released at the Centre's launch on 24th March, 2010 made available through the Centre's website (www.australianwaterrecycling.com.au) and discussed at workshops held around Australia in late May 2010.[9]

The production of each Discussion Paper was co-ordinated by a member of the Research Advisory Committee (RAC) who in turn sought input from researchers, utilities, regulators and consultants in the water industry in Australia and in some cases, overseas.

Responses to the Discussion Papers, and discussions during a series of National workshops in metropolitan and regional centres, were the basis for the identification of a broad range of research needs to inform the development of this SRP.

In addition to identifying the research gaps, the Centre also sought to establish industry priorities for enhancing water recycling efficiency, expansion and acceptance in Australia. Feedback on the discussion papers and during the National workshop tour resulted in the Centre identifying a number of operational goals to which the Centre could contribute through its investment program. As with the research themes above, the goals are intended to apply to all water recycling end uses, and are intended to be relevant to metropolitan, rural and regional applications of water recycling in Australia.

This SRP will guide investment in projects that address the research needs and achieve the goals identified below

3.3 Centre Goals

The Commonwealth Government objectives for the Centre are relatively broad and unbounded, and the Centre has identified that delivery on these objectives will benefit from a set of goals to focus the Centre's activities over the first three - five years. The goals will focus research investment, guide the Centre's business planning, and provide a focus for stakeholder engagement by the Centre.

During the development of the SRP, the CEO and Chair of the RAC undertook a national tour to seek feedback on priorities for water recycling investment. These discussions identified desired outcome areas where industry believed that Centre investment could leverage significant improvements in water recycling practice in Australia. These outcome areas, which may be progressing at a state or territory scale, but for which there is little national uniformity, have been refined into goals and are outlined over page:

9. A summary of those utilities, regulators, universities, private companies and individuals who commented on the Discussion Papers and who provided additional feedback following the national workshops in May 2010 is presented in Appendix A.

Goal 1. **The social/ economic/ environmental value of water recycling is demonstrated and enhanced** – this would include projects to demonstrate and promote water recycling as a high value (social/economic/ environmental) option to secure future water needs, including research with a focus on optimising water recycling for purposes including environmental, industrial and agricultural end uses.

Goal 2. **A national validation framework for water recycling is established** – this would include projects to support a national validation framework for water recycling schemes and the research to support regulator and industry confidence in regional and metropolitan implementation.

Goal 3. **Reclaimed water is seen as an acceptable 'alternative water' for augmenting drinking water supplies** – this would include projects that demonstrate water recycling as a viable option, including research into communication and other challenges associated with water recycling for potable use.

Goal 4. **A national knowledge, training and education program for water recycling is established** – this would include projects to consolidate recycled water knowledge and activities in Australia, with research that supports student and postdoctoral appointees and provides opportunities to capture and relay the industry learning's that are rapidly being developed at the jurisdictional level.

4. Priority Research Topics

This Section outlines the Priority Research Topics in each of the four Research Theme areas that are considered relevant to achieving an increased acceptance of water recycling. It draws on the contents of the discussion papers as well as subsequent feedback from the water industry.

4.1 Theme 1: Technology, Efficiency and Integration

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 of a quality from a wastewater stream that is superior to that of a 'clean water'. At the same time, it has been recognised that not all water end-uses need the high quality standard of drinking water, increasing the potential for use of lower water qualities in certain end-uses.

Water recycling technologies therefore sit between the drinking and wastewater 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. It is therefore critically important that these "new" water treatment technologies work most efficiently for the end-uses for which they are designed, and that they integrate optimally into that space between the clean and the dirty water streams.

The Priority Research Topics identified for this Theme are:

- Management of salt and saline effluents in water recycling
- Improving on-line monitoring of water qualities at all stages of water recycling processes (source control to RO permeate)
- Optimisation of existing process technologies and trains
- Optimal integration of water sources, users and technologies to achieve most suitable outcomes with least impacts
- Novel innovative technologies for water recycling

4.1.1 Management of Salt and Saline Effluents in Water Recycling

Salinity levels in our waters and wastewaters are causing increasing concern and much effort is expended in either managing salt levels through discharge controls or through removing the salt during treatment. The latter gives rise to saline discharges that have their own unique management problems. Research projects under this Topic could be:

- Development and demonstration of high recovery water systems e.g. Accelerated Seeded Precipitation, novel recycling and targeted precipitation processes, membrane distillation and/or alternative methods for increased water recoveries on water recycling streams;
- An understanding of membrane scaling and degradation processes and the catalytic effect of inorganic ions in these processes, leading to economic optimisation strategies;
- Development of biofouling control strategies that do not have a residual oxidant and minimise by-product formation;
- Removal of monovalent salts from wastewater via electrodialysis with monovalent selective membranes to improve the Sodium Adsorption Ratio. This could improve the water quality of wastewaters being used for agricultural purposes and also for industrial water recycling;
- Understanding the treatment of classes of industrial effluent to encourage wider industrial water reuse;
- Brine treatment processes that remove organics and metals of concern. There is the potential to combine this with value adding processes (e.g. algae growth) as well;
- 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 (e.g. mining industry), where the mixture of inorganic compounds affects the kinetics of precipitation of the major scalant (e.g. sulphate may interfere with carbonate precipitation etc).

4.1.2 Improving On-line Monitoring at All Stages of Water Recycling Processes (Source Control to Product Water)

With the advent of risk management and in particular the principle of hazard analysis and critical control point (HACCP), there has been increasing attention paid to on-line monitoring and the role it has in optimizing the control of treatment plant performance. To further develop the scope of on-line monitoring, research projects under this Theme could be:

- The future research in this area needs to be closely coordinated with the current ongoing activities in this field, which are considerable. Despite the current existing activities, there is significant scope to further expand on these projects, as well as follow alternative approaches to achieve the desired outcome. Most of the current projects are 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 environment in which the sensors must operate;
- A particular need exists in developing direct performance measurements for various treatment processes, particularly membrane processes. A high sensitivity (>3 log), on-line or at least rapid "integrity" measurement for nano-filtration (NF) and RO membranes would be highly valuable as a "critical control point" measurement in the HACCP context;
- 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 key focus of the research would need to be the concentration/ measurement of the very low levels of these pathogens in many water sources, even recycled water, particularly after extensive treatment;

- A novel range of contaminants to be monitored regularly and rapidly are the micro pollutants 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 analysis processes and need pre-concentration steps, hence will be very difficult to measure in-situ or even on-line. While indicator or surrogate measurements such as on-line total organic carbon, 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;
- For cost-efficient monitoring of those contaminant that are not accessible to on-line monitoring, sampling techniques, such as passive sampling techniques, must be developed and established that allow an instantaneous response to alerts and/or the taking of random control samples. A continuous passive sampling strategy could be developed to collect an archive of samples that are only tested if required;
- 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.

4.1.3 Optimisation of Existing Process Technologies and Trains

There are now many different treatment technologies and trains in operation in water recycling schemes in Australia and operational experience has highlighted many areas in which there appears to be scope to optimise not only materials and energy consumption but also how best to integrate the engineered systems with natural systems.

- 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 chemical consumption or development of "green" chemicals with minimum environmental impact (recycled minerals, biodegradable products);
- Development of more effective 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 and control of the processes by which disinfection by-products are generated during the production of recycled water when different raw water qualities are used;
- Establish an indicator for disinfection by-product formation when alternative disinfectants to chlorine are used;
- Establish a better understanding of the performance of natural systems on the removal of pathogens and target compounds of concern leading to a more appropriate integration of engineered systems with natural systems.

4.1.4 Optimal Integration of Water Sources, Users and Technologies to Achieve Most Suitable Outcomes with Least Impacts

Historically, water reclamation plants have just been 'added' to a WWTP in order to produce a high quality of water that can be recycled for a particular use or uses. Little attention is paid to the overall system to ensure that the outcomes of the scheme are achieved with the least impacts. Research projects under this Theme could be the following and it will be noted that they also all have relevance to Research Theme 4 which covers Sustainability in Water Recycling:

- Compilation of a detailed, comprehensive, geo-referenced chemical inventory of substances that are likely/possible 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 the Water Services Association of Australia (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;
- Evaluate more effective 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 storage (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, low-energy, low- chemical usage 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.

4.1.5 Novel Innovative Technologies for Water Recycling

The research needs in this area are highly diverse and specific for the applications in particular situations. This research area should also investigate the use of emerging new technologies in related fields (such as drinking water treatment) and evaluate their adaptation to water recycling. It should also build on the rapid advances in the areas of material sciences and biotechnology and focus on their application in water recycling technologies, both current and novel ones.

No particular research directions or topic are raised in this area, but more generic research ideas and proposals may be called for. This will likely create opportunities to apply and adapt existing expertise and technology developments from different research or application fields to water recycling applications.

4.2 Theme 2: Water Quality and Scheme Validation

A challenge to achieving wide-scale uptake of water recycling, and particularly with high quality reuse schemes such as potable reuse, has been defining and agreeing (amongst practitioners, regulators and the general community) the acceptability of the risk associated with the intended form of reuse. In addition, industry validation of such schemes has often been a complex and costly exercise.

Theme 2 addresses research needs associated with water quality, risk and validation for water recycling, with nine topics outlined below:

- Chemicals and transformation products
- Mixture toxicity
- Low concentrations, long-term exposure and safety assessment
- Variable exposure as a consequence of 'hazardous events'
- Pathogens – selection, measurement and validation
- Risk allocation
- Practical implementation of the AGWR
- Monitoring and risk
- Knowledge management and a consistent approach to implementation

Issues relating to each of these Priority Research Topics are identified below.

4.2.1 Chemicals and Transformation Products

The difficulty in assessing the magnitude of the risk posed by chemical contamination of reclaimed water stems from the fact that there is typically not an individual chemical or group of organic micro pollutants dominating the risk but rather many different chemicals with a wide range of physicochemical properties and toxicological features, which may have cumulative mixture effects even at the very low concentrations at which they occur. These chemicals can be classified in several categories: (1) naturally occurring compounds such as cyanobacterial and algal toxins, (2) man-made organic chemicals, including pesticides, industrial chemicals, pharmaceuticals and personal care products etc., and (3) chemicals that are produced during the water treatment process. The latter group includes disinfection by-products produced from natural precursors as well as transformation and degradation products of organic micro pollutants introduced with the waste stream.

Priority Research Themes may include:

- Endocrine Disrupting Compounds (EDC's) as they may have adverse impacts at very low exposure levels;
- Transformation products of identified and emerging micro pollutants: As most current analytical methods only target the original parent compounds a systematic approach to understanding risk associated with transformation products is required. Effect-directed analysis and fractionation could be a tool to address this topic. Research is also required to improve understanding and control disinfection by-product (DBP) formation in recycled waters as well as on their impact. It would also be advisable to develop bioanalytical techniques targeted at disinfection by-products for a risk-based assessment of their mixture effect;
- DBP's as they are newly formed during advanced oxidation processes and conventional chlorination and chloramination from benign precursors such as natural organic matter (but also from micro pollutants);
- 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 (e.g. perfluorooctanoic acid - PFOA and perfluorooctane sulphonate - PFOS) and nanoparticles, but the ability to quickly respond to new concerns will be the key requirement.

4.2.2 Mixture Toxicity

Individual chemicals present in reclaimed water generally do not reach levels of concern but since there can be a plethora of chemicals present in the water, their mixture effect might be of relevance and might trigger adverse effects. While mixture effects can, in principle, be assessed by bioanalytical tools, there remain knowledge gaps such as:

- Concentration additive and response additive characteristics of mixtures , including potential for synergism and antagonism; and
- Quality criteria or guideline values for groups of chemicals with common mode of action – mixture indicators/ sum indicators.

4.2.3 Low Concentrations, Long-term Exposure and Safety Assessment

An intelligent testing strategy (ITS) needs to be developed for water recycling. ITS methods usually follow a tiered approach with computational and screening methods in lower tiers and more elaborate testing only in higher tiers if found to be necessary. Much could be achieved (at relatively low cost) by use of adequately validated *in vitro* methods. Also, the role that new techniques such as proteomics and toxicogenomics could play in risk assessment could be evaluated.

Meaningful interpretation of in vitro bioassay response: Development of toxicity screening assays that are acceptable to regulatory authorities as adequate models for public health risk assessment need to be developed and existing assays need to be validated.

4.2.4 Variable Exposure as a Consequence of 'Hazardous Events'

A greater understanding is required of the impact of variable exposure of micro pollutants and micro-organisms.

Research in this area could include:

- Improved characterisation of unit operation treatment performance for key classes of chemicals and micro-organisms, including key indicator compounds for treatment performance assessment:
- 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;
- Implementation and "validation" of barriers to control the risk posed by these temporal fluctuations in key quality parameters.

4.2.5 Pathogens – Selection, Measurement and Validation

The priority research needs in risk assessment of pathogens in reclaimed water are very much focused on improving methods of analysis with quantifiable recovery techniques, ensuring adequate and appropriate internal controls and standardised, more rapid techniques using a molecular genetic approach. In addition, a greater understanding of pathogen survival through a treatment train comprising multiple process barriers is required.

Research in this area could 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 in the removal of pathogens;
- Potential synergism of consecutive treatment processes in terms of removal of pathogens and the impact it might have on overall log removal values (LRV) for different treatment trains;
- Investigate alternatives to the current method of treatment process LRV validation that relies on the most resistant organism for each unit process in the treatment train;
- Reliable/appropriate indicators of pathogens to demonstrate safety of recycled water in real time to improve response time;
- Emerging new or opportunistic pathogens.

4.2.6 Risk Allocation

The AGWR give 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.

4.2.7 Practical Implementation of the AGWR

There is some disparity between understanding the risk management approach outlined by the AGWR and the requirements for delivering this. Guidance to help the industry manage recycled water quality risk in practice would be beneficial as there is no current common understanding of risk management across the industry.

4.2.8 Monitoring and Risk

There is currently limited data available with which to measure acute risks and as a result practitioners and regulators often resort to overly-conservative designs. Items which could assist in achieving more confidence in the risk assessment and monitoring aspect of any water recycling scheme, particularly those for high-end uses, would be:

- 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.

4.2.9 Knowledge Management and a Consistent Approach to Implementation

A lack of clear understanding over the implementation of the AGWR as well as the lack of useful and relevant data mentioned in Section 4.13 above has led to an inconsistent approach to the establishment of treatment trains for water recycling applications. Items that could be addressed under this section include:

- Creating 'fit for purpose' water treatment trains, instead of 'over the top' water treatment trains (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).

4.3 Theme 3: Social, Institutional and Economic Challenges

Research Topics in this Theme area are described as: Prioritised Investment in alternate water supply portfolios; Decision Support in policy design and implementation; and Implementation and Evaluation to ensure community and industry acceptance coupled with ongoing monitoring and water reform assessment.

The research topics are interdependent and while they represent tractable research components, they should not be considered in isolation; for example data and analyses from both the Prioritised Investment and Implementation and Evaluation phases provide critical inputs to Decision Support by way of economic analysis, design updates, performance and analytical feedback and identifying points of probable failure.

Issues relating to each of these Priority Research Topics are identified below.

4.3.1 Prioritised Investment (Economics of Water Recycling)

- Establishing a national economic database resource on the direct and indirect (lifecycle) costs of water recycling for various types and scale of schemes;
- Establish rapid and comprehensive methods to estimate the relative cost effectiveness of recycling relative to other water supply investment options when the full range of community wide environmental, social and economic direct / indirect costs and benefits are considered;
- Determine whether a more comprehensive portfolio analysis improves the assessment capacity of urban water planners when evaluating the mix of demand and supply side investment options available. More specifically, consideration of flexibility aspects, including:
  - Investment sequencing;
  - The value of preserving the option to delay irreversible investments; and
  - The value of securing the option to implement timely and effective contingency plans in the event of extreme water shortages (i.e. drought insurance).
- Linked to Theme 4, undertake an holistic systems based evaluation of the future economics of water, energy and nutrient recovery from wastewater, taking into account local, city and regional scale environmental and economic costs and benefits (e.g. fertilizer industry, energy and resource offsets, food security drivers, constraints to urban development from nutrient discharges, reduced wastewater treatment energy use and greenhouse gas (GHG) emissions, emissions trading, impacts on existing wastewater networks etc.).

4.3.2 Decision Support (Institutions and Governance)

Public Confidence in Water Governance and Institutions

- Analysis of the institutional basis of public confidence in water and recycled water management, including the drivers and barriers related to institutional adaptive capacity and improved performance, as perceived by customers, regulators and industry practitioners;
- Closely related to the social research objectives, assess the mechanisms associated with public participation, transparency and accountability in infrastructure decision making, particularly how these institutional processes affect public trust in water recycling outcomes.

Adequacy of Policy and Institutional Capacity to Foster the Development of Innovative Water Recycling

- Review the fit of current service delivery, risk management, regulatory and institutional arrangements to emerging forms of water harvesting and recycling, particularly at the decentralised scale;
- Analysis of the benefits and constraints of current cost recovery, economic incentive and pricing

structures across the range of recycled water service provision alternatives, in context of the multiple environmental and social benefits that may be realised from their implementation compared to more traditional water services;

- Undertake an evaluation of how current urban water environmental and economic regulatory regimes and institutional inertia support or constrain the development of water recycling and alternative supplies, and identify potential governance enhancements that could enhance the development of sustainable alternative water supplies;
- Understanding the conditions for information transfer and institutional coordination at the appropriate scale of implementation (household, organisational, or policy level) is required to build institutional capacity for innovation. Managing the boundaries between science and decision making, and between regulators, producers and consumers, is necessary to provide a means of addressing these coordination challenges. Research priorities include:
  - Exploring the current capacity for institutional integration via boundary organisations (research organisations, urban development organisations, stakeholder groups, etc) to facilitate the communication and translation of emerging information about water recycling in a strategic manner, i.e. the development of communities of practice across institutional boundaries;
  - Exploring and understanding information integration via multi-level analysis to match available knowledge with decisions, purposes and responsibilities at the level of households, organisations and policy.

4.3.3 Implementation and Evaluation (Social Research into Water Recycling)

Community Engagement and Communication

- Establish a program of experimental research to test the effectiveness of different methods and modes of communicating about water recycling to the public. This should include:
  - A Science Communication driven process to focus on external drivers to decision making as it impacts on water recycling. This dialogue should be conducted within the context of the entire water cycle;
  - Assessing the baseline level of knowledge about water recycling in a total water cycle context. This should assess beyond the community understanding of recycled water as a consumable product (including the perceived risks) and explore understanding about the broader environmental and community benefits of recycling;
  - Exploring how the different states of water supply security and shortages can influence community perceptions of risk and corresponding willingness to accept recycling alternatives;
  - Understanding the role that "water" education and increasing knowledge plays in influencing community perceptions about recycling, particularly potable recycling. To this should be added the impacts of opinions of leaders or champions on the overall decision making process;
  - The role that language, terminology, images and definitions related to water recycling play in shaping community perceptions and acceptance responses;
  - The communication about water quality risks "microconstituants/emerging pollutants of concern" and the relative risks associated with these potential contaminants in all water supplies;
  - Testing approaches to effectively communicate about the technologies and science applied in producing and delivering manufactured water supplies and how risk management approaches are designed into these systems and management structures;
  - Understanding how best to involve the community in shaping the treatment facilities for a particular

- end use rather than simply adding additional 'barriers' to a train in the often misguided attempt to 'force an increased confidence level' through more treatment steps;
    - Exploration of the effects of common anomalies and confusing signals within water management on community perceptions e.g. planned vs. unplanned recycling, two guidelines for drinking water, water quality vs. its history, and how changing these messages can change perceptions and positive community engagement.
- Identify and design guidance for community engagement strategies that draw the valuable insights from previous social psychology research on how to minimise critical engagement risks, analysed in reference to the observations from previous unsuccessful project implementation;
- Undertake research into the method by which the media receives and reports information and opinions surrounding the development of alternative water sources, how it shapes community perceptions about water recycling and how the water industry can engage the media more effectively in promoting open and constructive dialogue within the community.

Decentralised Water Recycling

- Profiling community perceptions, acceptance and expectations for multi dwelling residential decentralised recycling systems in high rise buildings, cluster developments or local recycling schemes;
- Evaluate options and preferences for how these services might be delivered, priced and maintained to meet these expectations and overcome any negative perceptions.

Water Industry Culture

- Linked to the issue of communication and engagement, researching the various industry perspectives about water recycling to identify where there are significant cultural and communication anomalies within the industry itself that require some national consensus in order to provide a unified view to the community. For example, two sets of guidelines for drinking water; emphasis on the source of water rather than the quality; the mixed messages community receives from the insistence upon environmental barriers; the distinction between 'planned' and 'unplanned' potable recycling;
- Facilitating a national industry dialogue about these issues that would enable an exchange of ideas and discussion on the attitudes and views of various 'public and private decision-makers and experts' in order to resolve some of the anomalies.

4.4 Theme 4: Sustainability in Water Recycling

The sustainability theme is based on a suite of knowledge management and targeted technology initiatives. Knowledge management could involve lifecycle analysis (LCA) methods for water recycling while targeted technology could focus on the implementation of technologies, techniques or strategies designed to:

- Reduce energy requirements and expand water recycling in inland Australia through judicious management of dissolved salts in the water cycle.
- Achieve simultaneous recovery of water nutrients and energy.
- Reduce the consumption of chemicals and consumables associated with the water recycling process.

4.4.1 Knowledge Management

Supporting the AUSLCI Database Initiative

This work could involve generating information that can be used in LCA to evaluate water recycling schemes. The Discussion Paper on Sustainability identified three key data sets that require information specific to water recycling projects: consumables, infrastructure and geographical/demographic.

Collaboration with the Ecoinvent Database

Ecoinvent is an operational lifecycle inventory (LCI) database with approximately 4000 discrete inputs. Research could involve the development of a process model for a water recycling project operating in an urban or regional centre and the use of the Ecoinvent data base to assess the consequences of changing nutrient pathways through the water system.

Development of Improved Impact Assessment Methods

Irrigation projects using recycled water in either urban or regional situations can result in changes in soil salinity profiles and the movement of nutrients in catchments. An inland water recycling project could be assessed in order to gauge the movement of nutrients and salts in the water catchment, noting that this work would compliment studies underway by the CSIRO and the UNEP SETAC Life cycle initiative.

Development of Standard Technology Units for use in LCA

Standard technology units or parametised inventories for the treatment processes and networks currently used in water recycling schemes could be developed. Sydney Water has developed a carbon estimator tool for infrastructure which could seed the development of more comprehensive LCA based technology tool that can be extended to water recycling systems.

Use of LCA to Compare Sustainability of Decentralised and Centralised Systems

LCA (focussing on the operational rather than construction phase) could be used to compare the sustainability index of various centralised and decentralised water and wastewater systems for urban developments. An important subsidiary study area could be to advance the rationale to weight the relative impact (e.g. resource depletion, greenhouse gas emissions, energy use, eutrophication, ecotoxicology) of the mid point assessment criteria used in LCA.

Economies of Scale in Water Recycling Systems

This research area seeks to identify the impact of scale on the per capita (connection) cost of providing alternative water services and whether all the components of these services are characterised by economies of scale. The understanding of the economies of scale to the total system is important for planning new infrastructure.

Quantifying the Impact of Small-scale Systems at City/Regional Scales

Frequently, the assumption is made that the performance outcomes of a single decentralised system can be scaled linearly to predict the performance of such systems at city and/or regional scale. Decentralised systems can be either household scale systems such as rainwater tanks or cluster scale recycled, rainwater and stormwater use systems. City/regional scale performance outcomes are required to assess the impact of decentralised systems on supply/demand balance assessment and whole-of-system scale water quality assessment. Some preliminary work undertaken by the CSIRO indicated that when large numbers of household scale systems (e.g. rainwater tanks) are lumped with factors such as roof area and occupancy, set to average values, the performance outcomes at city and/or regional scale can generate biased and overestimated results for annual supply from such systems. Building on the current work, this research area could investigate how small scale recycling, rainwater and stormwater harvesting systems can be scaled up to city and/or regional scale performance assessment, to feed into regional scale supply/demand assessment; water quality assessment in receiving water bodies; and energy and greenhouse gas assessment.

4.4.2 Targeted Technology Projects to Reduce Carbon Footprint in Water Recycling

Integration of Nutrient Recovery into High Grade Water Recycling Projects

Recovery of phosphate at centralised WWTP's is seen as economically unviable because of low phosphate levels compared with decentralised systems. However, the recent growth in membrane based water recycling projects, where RO is used to produce high quality water has resulted in the production of liquid waste streams with high concentrations of phosphate which may improve the viability of this approach.

Adaptation of Caustic and Cleaning Chemical Recycling Techniques from the Dairy Industry to the Water Recycling Industry

There is an opportunity to adapt strategies from the dairy industry for recycling cleaning chemicals and to develop an alliance between end users and manufacturers to handle the waste generated from Australian water recycling plants.

5. Aligning Research Topics and Goals

The SRP identifies a range of research topics and four industry relevant goals that the Centre is committed to helping achieve. The Centre will seek proposals from industry and research organisations that are designed to address the research gaps and help deliver on the goals.

The Centre's RAC is responsible for specifying proposal criteria, evaluating submissions and recommending projects to the Board. In fulfilling these responsibilities, the RAC will seek to ensure that proposals are aligned with the SRP and that research topics are structured and prioritised to help achieve the Centre's goals.

The following tables align the Priority Research Topics presented in Section 4 with the four Centre goals and provide an indication of how the research gaps and goals may relate. These tables do not prescribe how projects should address the goals and proponents will be required to demonstrate how their project proposals will integrate a range of research topics to help achieve the Centre's goals.

Topic	Goal 1: The social/ economic/ environmental value of water recycling is demonstrated
4.1.1	Management of salts and saline effluents in water recycling
4.1.3	Optimisation of existing process technologies and trains
4.1.4	Optimal integration of water sources, users and technologies
4.1.5	Novel innovative technologies for water recycling
4.2.1	Chemicals and transformation products
4.2.2	Mixture toxicity
4.2.3	Low concentrations, long-term exposure and safety assessment
4.2.9	Knowledge management and a consistent approach to implementation
4.3.1	Economics of water recycling
4.3.2	Institutions and governance
4.3.3	Social research into water recycling
4.4.1	Knowledge management & life cycle assessment implementation
4.4.2	Targeted technology projects to reduce carbon footprint in water recycling

Topic	Goal 2: A national validation framework for water recycling is established
4.1.2	Improve on-line monitoring at all stages of water recycling processes
4.2.1	Chemicals and transformation products
4.2.2	Mixture Toxicity
4.2.3	Low concentrations, long-term exposure and safety assessment
4.2.4	Variable exposure as a consequence of 'hazardous events'
4.2.5	Pathogens – selection, measurement and validation
4.2.7	Practical implementation of the AGWR
4.2.8	Monitoring and risk
4.2.9	Knowledge management and a consistent approach to implementation

Topic	Goal 3: Water recycling for drinking water supply is seen as an acceptable 'alternative water'
4.1.2	Improve on-line monitoring at all stages of water recycling processes
4.1.3	Optimisation of existing process technologies and trains
4.1.4	Optimal integration of water sources, users and technologies
4.2.3	Low concentrations, long-term exposure and safety assessment
4.2.4	Variable exposure as a consequence of 'hazardous events'
4.2.5	Pathogens – selection, measurement and validation
4.2.6	Risk allocation
4.2.8	Monitoring and risk
4.2.9	Knowledge management and a consistent approach to implementation
4.3.1	Economics of water recycling
4.3.2	Institutions and Governance
4.3.3	Social research into water recycling

Topic	Goal 4: A national knowledge, training and education program for water recycling is established
4.1.4	Optimal integration of water sources, users and technologies
4.1.5	Novel innovative technologies for water recycling
4.2.6	Risk allocation
4.2.7	Practical implementation of the AGWR
4.2.9	Knowledge management and a consistent approach to implementation
4.3.1	Economics of water recycling
4.3.2	Institutions and Governance
4.3.3	Social research into water recycling
4.4.1	Knowledge management & life cycle assessment implementation
4.4.2	Targeted technology projects to reduce carbon footprint in water recycling

The RAC recognises that industry and research organisations may require support to develop the appropriate suite of research projects to optimise goal delivery. To this end, in addition to seeking proposals on specific research topics, the RAC may also use Expressions of Interest, invited workshops and targeted partnerships with industry associations to continue to refine and guide the Centre's research investment, and to broker improved project proposals for the Centre's consideration.

Examples of potential approaches the RAC may use to assist delivery of Goals 2 and 3 are identified in Figures 2 and 3 in Appendix B.

The first call for proposals to address Priority Research Themes and help deliver on the Centre goals will be made shortly after the release of this plan. Proposal calls will be made principally through the Centre's website at www.australianwaterrecycling.com.au.

6. Research Linkages – National & International

Research linkages will, when appropriate, be developed with both national and international agencies with the aim of minimising duplication of research effort and maximising research output through collaboration on research programs and projects.

Examples of water research fund managers and research agencies with which the Centre is interested in having discussions include:

- Nationally:

  NCED, NWC, WSAA, AWA, WQRA, UWSRA, Victorian Smart Water Fund, Local Government Associations
- Internationally:

  Singapore's Public Utility Board (PUB), Orange County Water District, WateReuse Research Foundation, EAWAG, KWR, Global Water Research Coalition, IWA Specialist Group on Water Reuse

Appendix A: Providers of Feedback

The following table summarises those organisations and people who provided feedback direct to the Centre.

Melbourne Water	CSIRO
Sydney Water	GHD
Water Corporation	University of Victoria, Melbourne
Gold Coast Water	Dr Kaye Power, NSW Health
Government of Western Australia, Dept. of Water	Nanda Altavilla, NSW Health
Wide Bay Water, Queensland	Prof Judy Motion & Prof Catherine Lumby
Cynthia Mitchell, UTS	Gary Bickford, Nestis Consulting
Damien Batstone, UQ	Jonathan Francis, Orange City Council
Tim Grant, RMIT	Shane Morgan, CH2M HILL
David Roser, UNSW	Lauren Engel, Caltex Australia
Stuart Khan, UNSW	Kate Vinot, Veolia Water
Helen Stratton, Griffith University	Prof Brian Priestley, ACTRA
Fred Leusch, Griffith University	National Recycled Water Regulators Forum

Feedback was also received through the workshops held in Canberra, Adelaide, Brisbane, Perth, Sydney, Melbourne and Orange in late May 2010 where there were over 150 attendees and presentations were made by

Canberra:

Kirilly Dickson	ACTEW
Bruce Gray	DEWHA
Paul Smith	NWC
Robert Lenon	Dept. Innovation Industry Science Research

Adelaide:

Dr David Cunliffe	South Australia Dept. of Health
Chris Marles	SA Water

Sydney:

Peter Denis	Hunter Water
Adam Lovell	WSAA
Lauren Engel	Caltex Australia
Kaye Power	NSW Dept. of Health

Orange:

Chris Devitt	Orange City Council
Jon Francis	Orange City Council
Stuart McLeod	Dubbo City Council
Martin Haege	Geolyse Pty Ltd

Brisbane:

Kelvin O'Halloran	Wide Bay Water
Mike Taylor	SEQ Water
Martin Done	Unity Water
Greg Jackson	Queensland Dept. of Health
Anita Packwood	Dept. Environment & Resource Management

Perth:

Rob Hammond	Dept. of Water
Chris Higgs & Palenque Blair	Water Corporation
Wayne Schaffer	GHD
Nanette Schapel	DEC
Richard Theobald	Western Australia Dept. of Health

Melbourne:

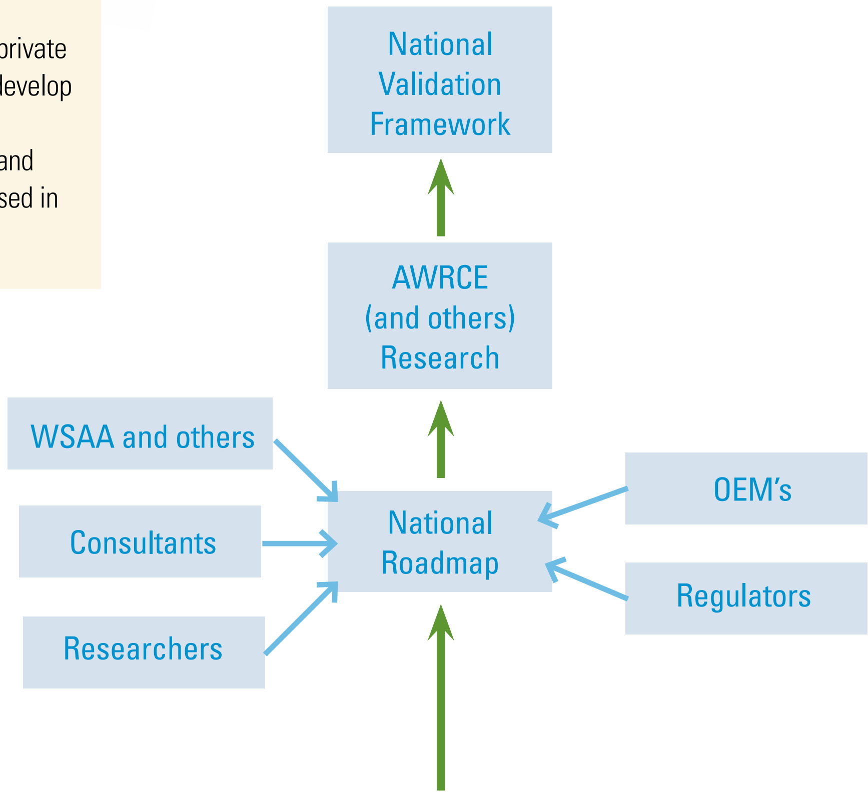
Dr. Judy Blackbeard	Melbourne Water
Dr. Greg Ryan	South East Water
Dr. Darhma Darhmabalan	Coliban Water
Suzie Sarkis	Victoria Dept. of Health
Phillip Johnstone	Dept. Sustainability and Environment

Appendix B: Potential Delivery Strategies for Goals 2 and 3.

Figure 2: Goal 2- A National Validation Framework for Water Recycling is Established

Output

Work with utilities, regulators, private companies and researchers to develop a national roadmap that clearly defines the gaps in knowledge and practice that need to be addressed in order to achieve the Goal.



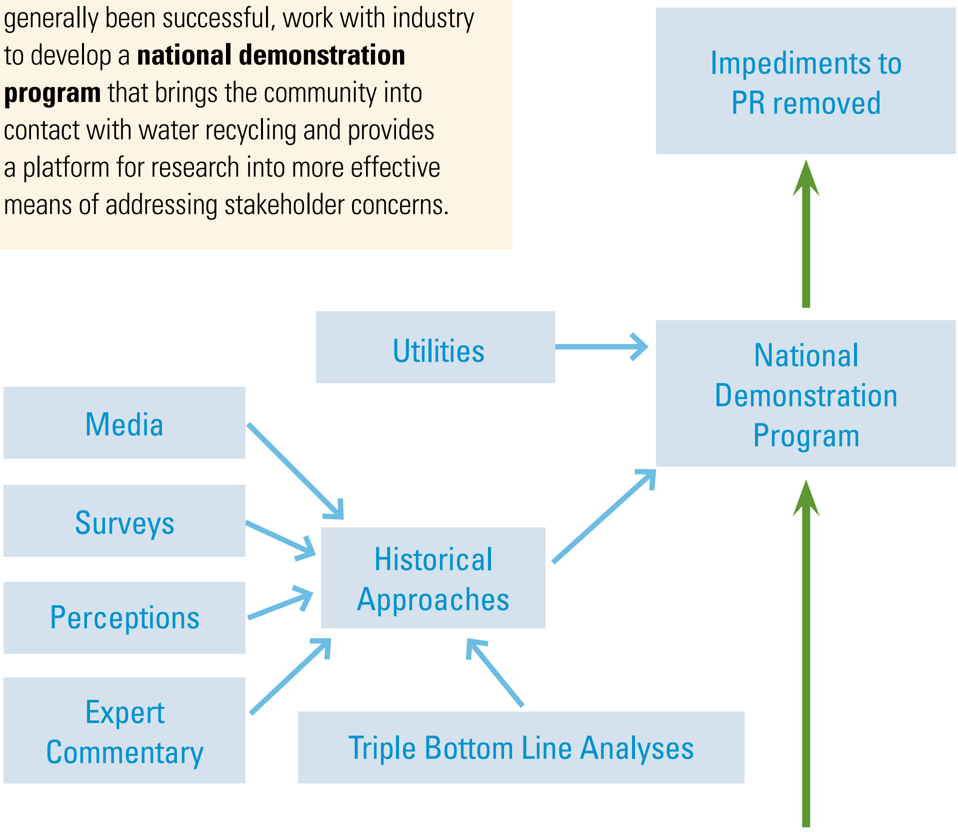
Potential Issues to Consider

- Surrogates – microbial and chemicals
- Influence of synergies in treatment train on overall LRVs
- Removal through different technologies and treatment trains
- Monitoring techniques – on-line & passive
- Interpretation of National Guidelines
- Cost impacts of over design
- Validation/revalidation
- Database & knowledge management
- Technology accreditation
- Social, environmental & economic issues
- Laboratory validation
- Methods of analysis

Figure 3: Goal 3 - Reclaimed Water is viewed as acceptable 'Alternative Water' for augmenting Drinking Water supplies

Output

Recognising that historical efforts to achieve acceptance of potable reuse (PR) have not generally been successful, work with industry to develop a **national demonstration program** that brings the community into contact with water recycling and provides a platform for research into more effective means of addressing stakeholder concerns.



Potential Issues to Consider

- Stakeholder engagement
- Media liaison/communication
- Science communication to both community and institutions
- Lessons learned from other industries
- Professional and political barriers
- Development of trust
- Countering misconceptions
- Transparency of carbon and energy footprint
- Operational reliability
- Social cost benefit analysis
- Actual costs
- Impacts of maturity of society

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