

Urban Water Security Research Alliance

5 years of
Urban Water Research in
South East Queensland
2007-2012

Urban Water Security Research Alliance

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National Research
FLAGSHIPS
Water for a Healthy Country



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Introduction from the Chairman

The Urban Water Security Research Alliance (the Alliance) was a unique, \$50 million collaborative research partnership between CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland, funded over five years by the Queensland Government.

Formed in 2007, at the height of the Millennium Drought, the Alliance conducted multi-disciplinary research that aimed to address some of South East Queensland's (SEQ) emerging urban water issues, with a focus on water security and recycling.

Alliance research framework

Once the drought began to break in 2009-2010, SEQ's water management challenges changed significantly. The Alliance responded by realigning its research program to look more closely at three areas:

- Reducing water grid demand.
- Ensuring water quality.
- Planning for efficiency and sustainability.

A growing population and healthy economy will ensure SEQ faces increasing pressure on its water resources in coming years. While the precise nature of future rainfall change remains uncertain, predicted climate change is likely to bring more extreme flood and drought events, which will add to the challenges to water security created by urban growth.

There is good agreement that both temperature and evaporation will increase in coming years, bringing more frequent, deeper droughts that take longer to break. Under this scenario, exploiting alternative water supplies, reducing water demand and lowering evaporation losses from reservoirs will become more important to SEQ water planners and managers. That means the Alliance's research findings will be even more relevant.

Demand for water is growing around the world but, in many places, supplies are increasingly precarious. Thus, the Alliance's SEQ-based research will also be useful to water planners and managers who seek new ways to collect and supply potable water in any urban environment.

This synthesis report gives the reader an informed snapshot of the Alliance's entire program, representing the research and findings generated by five years of collaboration by the Alliance partners. The complete collection of Alliance Technical Reports, journal papers, fact sheets and other resources is available at www.urbanwateralliance.org.au

Water will always be fundamental to our quality of life, to economic growth and to the environment, no matter whether there is plenty or whether it is in short supply. The need to keep improving urban water management will not go away, and the Urban Water Security Research Alliance has contributed valuable new knowledge to this goal.

I commend our *"Five Years of Urban Water Research in South East Queensland – 2007-2012"* to you.



Chris Davis
Chairman

Director's Overview

Over the past five years it has been a privilege to lead the Alliance urban water research agenda on behalf of the Queensland Government, CSIRO, Griffith University and The University of Queensland.

The support of those organisations, and in particular the professional and personal support provided by their representatives on the Alliance Management Board and Research Advisory Committee, provided the engine that kept the research machine running.

The program brought an unparalleled capability and capacity in urban water research and development to SEQ, incorporating many years of world-class research expertise. Our task was to address Queensland's current urban water challenges and anticipate future risks, assumptions and uncertainties facing SEQ's water supply strategy.

Our research sought to help optimise management of a diverse SEQ water supply portfolio that, at that time, included reservoirs, the Tugun desalination plant and recycled water. The Alliance also researched smaller, decentralised water systems including rainwater tanks and stormwater.

In March 2010, after the Millennium Drought broke, we realigned the research program to focus on issues that are fundamental to the region's long-term water security, including:

- Alternative supplies such as rainwater and stormwater, water use efficiency and demand management.
- Water quality management and the risks to human health posed by alternative source waters.
- Integrated urban water planning and management.

In the final year of the Alliance, we worked hard to transfer the knowledge, skills and capacity we had gained into

Government agencies and water utilities. For example, we organised more than 20 targeted engagement events with water managers, policy officers and scientists in industry, government and academia.

Each year from 2009 we staged a two-day Science Forum to share knowledge with our research peers from other organisations, publishing the papers each time in a comprehensive compendium.

Overall, during the life of the Alliance, our researchers published 109 technical reports, more than 50 journal articles and delivered 11 papers to international and national conferences based on their work in SEQ.

It is gratifying to note that all 22 Alliance projects were delivered on time and within budget, despite the realignment of research effort after the Millennium Drought ended.

Over the life of the Alliance, a total of \$23.46 million cash has been invested in the research projects - \$23.12 million from the Queensland Government and around \$0.34 million from interest on the Alliance Trust Account (see full Financial Report on page 31). The State's investment was matched with \$25.23 million of in-kind contributions from the research partners: CSIRO, Griffith University and The University of Queensland - a total investment of \$48.69 million in research projects. In addition, the Alliance Partners invested approximately \$3.76 million in the Administration of the Alliance, for a total investment of approximately \$52.45 million over the five years.

I am proud to report that this research delivered a range of outputs that are already proving to be influential, both within Australia and overseas. Across its whole portfolio, the Urban Water Security Research Alliance's research findings represent a healthy return on the Alliance partners' investment in urban water security.



About the Alliance

Powerful Partners Invest in Urban Water Research

The Urban Water Security Research Alliance (the Alliance), a partnership between the Queensland Government, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Griffith University and The University of Queensland, was established in 2007 to address South East Queensland's (SEQ) urban water issues.

The timing was significant. The nation was at the peak of the Millennium Drought. SEQ's water security was vulnerable, with the capacity of the region's main water storages having dropped to below 17% in August 2007. So the need to learn more about how to conserve water and source alternative water supplies was paramount.

The State Government was so concerned about the deteriorating water supply that it invested \$7 billion in new drought secure infrastructure, including the SEQ Water Grid, the Western Corridor Recycled Water Project, the Tugun Desalination Plant and new dams and weirs.

Fortunately for everyone, heavy rainfall throughout 2009-2010 filled the region's dams. The end of the drought also signalled a change in research direction for the Alliance.

Initially established for five years to research water supply and recycling, after the drought broke a review of the Alliance saw its focus move to alternative sources such as rainwater and stormwater, reducing water grid demand, ensuring the quality of our diverse water sources, and integrated urban water planning and management.

With \$50 million invested in cash or in-kind over five years to 30 June 2012, the partners' combined strengths brought an unparalleled intensity of focus to SEQ's water research.

The research investment created 36 new full-time research positions across the Alliance partners, including six PhD students. These researchers represented a range of

disciplines including chemistry, engineering, hydrology, climatology, microbiology, ecotoxicology and sociology in an unprecedented multidisciplinary approach to researching urban water challenges.

In its time, the Alliance was the largest urban water research program in Australia. Consequently, we generated an extensive body of research.

Some of our work is already helping to improve Queensland's water management. Other project findings offer water-security options to drought-stricken urban communities nationally and around the world.

The Alliance research findings support real outcomes in urban water management, and will continue to do so.

Collaborative Science

A key feature of the Alliance was the development of strong collaborative partnerships across the research partners. This ensured that the best researchers in the group were identified and allocated to specific projects in a "best for project" approach.

Collaboration helped stretch the Alliance's research capacity, delivering more significant outcomes than each organisation could achieve in isolation, and thereby increasing the overall return on this investment in sound, practical science.

The research would not have been possible without the direct support and collaboration of the water industry and local governments, such as Queensland Urban Utilities, Unitywater, Seqwater, Gold Coast City Council and the Moreton Bay Regional Council. The research results have been presented and well received nationally and internationally and has help foster strong national and international linkages which have provided a springboard for future research opportunities.

The Alliance also collaborated nationally with other research organisations and water industry stakeholders such as the Australian Water Recycling Centre of Excellence, Water Quality Research Australia, the Water Services Association of Australia, and Cooperative Research Centres.

The Alliance was also a leading member of the Australian Water Research and Development Coalition, formed in recognition of the benefits of coordination across research organisations in the urban water sector.

Research Highlights

Source Control

- The Alliance found six SEQ hospitals contributed 1–9% of the total pharmaceutical load at the corresponding sewerage treatment plant. Hospital effluent is therefore not likely to represent a risk to humans at this level.
- At least 85% of the pharmaceutical loads in wastewater originate from households and would reach a sewerage treatment plant, even if hospital effluents were treated separately.
- The Alliance developed a prototype sensor system to provide critical wastewater quality data and real-time online event detection, which is being extended into a co-ordinated event detection system in the wastewater network.

Pathogens in Reservoirs

- Dams are an effective treatment barrier for the removal of pathogens and trace organics, even after major flooding.
- Natural processes remove 90% of most pathogens found in reservoirs within days.

Stormwater Harvesting

- Human contaminants in stormwater are high and there

is evidence of sewer overflows during storm events, particularly in older suburbs.

- Health-risk assessments indicate that captured stormwater should undergo treatment prior to use, even for non-potable purposes.

Rainwater Tank Management

- In homes fitted with rainwater tanks, rainwater supplied on average about 33% of the water used on the property each year – an annual saving of about \$150 per household.
- 71% of tanks sampled in SEQ did not meet Australian Drinking Water Guidelines due to the presence of *Escherichia coli* (*E. coli*).
- Birds, possums and other small mammals are a major source of pathogens in rainwater tanks in SEQ. This limits options to expand rainwater use inside the home, eg, for drinking and showering.

Advanced Water Treatment

- Changing the dosing point and contact time of chloramine in advanced water treatment plants reduces disinfection by-product formation below guideline levels. This change may also reduce operating and treatment costs.
- Non-membrane technology can produce high quality, fit-for-purpose recycled water more economically than reverse osmosis, with lower greenhouse gas (GHG) emissions and no brine waste stream. For example, combining ozonation and Biological Activated Carbon (BAC) filtration in treated wastewater effluent significantly reduces organic matter, organic micropollutants and disinfection by-products (DBPs).
- Bioanalysis has demonstrated that the quality of purified recycled water (PRW) produced at the advanced water treatment plants in SEQ is at least as good as drinking water.

Total Water Cycle Management

- Life Cycle Analysis showed that applying Water Sensitive Urban Design to both new and existing developments provides greater water savings and the lowest overall nutrient discharges. However, these options are also more costly.
- The Alliance analysed and compiled a compendium of externalities associated with seven water supply options – stormwater harvesting, rainwater tanks, centralised wastewater recycling, dams, desalination, groundwater and greywater reuse.
- A new method to evaluate water supply options was developed, which applies extended cost effectiveness analysis including water-supply and pollution-abatement costs.

The Water-Energy Nexus

- Adopting water-efficient technologies can markedly reduce energy consumption. Installing a solar hot water system and connecting the clothes washing machine and dishwasher to this hot water source is currently the most energy-effective technical measure.
- Behavioural changes, such as less time in the shower, have the potential to reduce household water-related energy and GHG emissions by 50% or more.
- Correct pump sizing and informed selection of other components in residential rainwater tank pump systems ensure domestic rainwater delivers a smaller energy footprint than desalination and recycled water.

Climate Variability and Future Water Security in SEQ

- Each year, evaporation takes more water out of SEQ storage systems than the amount supplied through the reticulation network, with about 300 gigalitres per year (GL/yr) lost from SEQ dams alone.
- The Alliance's finer-scaled climate modelling shows good agreement on increased temperature and

evaporation into the future, with increased frequency and duration of drought.

- Modelling of dam yields based on the finer-scaled climate model data indicates that, in future years, SEQ can expect to experience reduced inflows to dams and more time between dam-filling rain events.

Knowledge Transfer

- Alliance researchers published 109 technical reports, more than 50 journal articles and delivered 11 papers to international and national conferences based on their work in SEQ.
- Each year from 2009 the Alliance held a two-day science forum to share knowledge with our research peers, publishing the papers each time in a comprehensive compendium.
- In 2011-2012 the Alliance staged more than 20 workshops and other engagement events with water managers, policy officers and scientists in industry, government and academia.
- The Alliance's website www.urbanwateralliance.org.au holds all our technical reports, journal articles, papers and other publications. The website will be managed until 2017.
- The Alliance's research partners (CSIRO, Griffith University and The University of Queensland) are storing our data sets on their servers. In a final collaborative effort, the Alliance and the Australian National Data Service are developing metadata descriptions that will help stakeholders discover the stored data sets.

Testimonials – Our Researchers and Stakeholders

The strength of the Alliance wasn't just about the amount of funding we received. It was more than that, with research topics that addressed both current needs and the future directions of urban water management.

As a result, the Alliance really helped us focus on some well-targeted research that's already having impact within SEQ, nationally and internationally.

Dr Simon Toze
Research Team Leader
CSIRO Water for a Healthy Country Flagship

The Alliance's climate change findings are very important for South East Queensland's water security.

Our finer-scaled climate modelling shows a consistent increase in temperature and evaporation into the future. Feeding this change into a Brisbane hydrological model shows an increased frequency and duration of drought and more time between dam-filling rain events.

Dr Wenju Cai
Senior Principal Research Scientist
CSIRO Ocean Climate Prediction Program

The Alliance was a highly effective collaboration that resulted in the one of the largest collections of urban water research publications I have seen. It has made a truly remarkable contribution to urban water research.

Alliance funding enabled Griffith University scientists to acquire in-depth knowledge of intelligent water metering systems. We forged links with industry and universities around the world and Australia is now a leading player in the field.

Associate Professor Rodney Stewart
Director
Centre for Infrastructure Engineering and Management
Griffith University

The Alliance administrators did an excellent job, keeping this diverse research program on track in the face of sometimes challenging circumstances.

Their constant networking through personal visits, teleconferences, workshops and other communication ensured the partners' business managers were always informed about how the program was running – and even about the science, which was well beyond the call of duty!

Mr Vince Lalor
(then) Deputy Group Resource Manager, Finance
Griffith University

The Alliance built an excellent capacity for urban water research that will continue having an impact for many years to come. In particular, it gave many young researchers like myself the opportunity to become experts in the field, recognised nationally and internationally.

Dr Julien Reungoat
Research Fellow, Advanced Water Management Centre
The University of Queensland

I was invited to be a reference panel member and/or State Government project champion on a number of Alliance research projects. This gave my agency, Queensland Health, the opportunity to influence those projects' directions and outcomes.

The Alliance ticked all the boxes for me: high quality research, focused on my agency's needs, delivered in a timely fashion. Plus, the Alliance ran like a well-oiled machine. It has been a privilege to be involved with the Alliance.

Dr Greg Jackson
Director, Water Quality Unit
Environmental Health Branch – Queensland Health

In 2011, I was proud to receive a prestigious four-year Australian Research Council Future Fellowship, awarded to mid-career researchers who have successfully undertaken collaborative interdisciplinary research.

The Alliance enabled me to move my career in this direction and I became a visiting scientist at CSIRO, working with various State government agencies on cutting-edge research that brought together social science and other disciplines to address urban water issues.

The Future Fellowship allows me to continue to pursue urban water research questions that we began to address in the Alliance, which has made all of this possible for me.

Dr Kelly Fielding
Senior Researcher and ARC Future Fellow
Institute for Social Science Research
The University of Queensland

A "co-production" approach was taken by UWSRA – a collaborative approach which provided more scientific freedom but still delivered what is required by research users. Research was undertaken by non-government: at The University of Queensland, Griffith University or CSIRO, both in Queensland and interstate as well as a small component undertaken by experts based in the then Department of Environment and Resource Management's Environment and Natural Resource Sciences Division, which had skills not available from the three research partners. Each project also had a stakeholder group including government and industry representatives to help frame and direct the research outputs. This collaborative approach produced research with a strong outcomes focus. It also allowed the fine-tuning of the research program, during the life of the Alliance, when the research drivers changed due to the drought breaking in 2009.

The Alliance also held annual forums for its researchers and key stakeholders, the users of its research outputs, which provided forums both for knowledge transfer and as annual meeting places for valuable policy and research interactions. These approaches made the Alliance a good model for science delivery of complex water problems.

Mr Craig Walton
Policy Advisor
Urban Water Management
(Former) Department of Environment and Resource Management

The Alliance has contributed substantially to our knowledge of water and its good management.

Mr Neil Palmer
Chief Executive Officer
National Centre of Excellence in Desalination Australia

Before the Alliance there was a real problem for water planners – we struggled to know what the demand for potable water would be in the long term after the implementation of various water saving initiatives. By the time the Millennium Drought broke, there were so many big questions being asked that needed answers.

We now have a better understanding of the costs and benefits of the wide range of water management solutions available to us, whereas previously we were too focused on short-term financial analysis. The Alliance gave us better tools to understand whole-of-life cycle costs, including social and environmental metrics.

Mr Andrew Sloan
Principal Engineer, Water Cycle Planning
Unitywater

Testimonials – Our Partners

CSIRO

As an Alliance partner the CSIRO Water for a Healthy Country Flagship has been proud to help advance knowledge to guide urban water supply and management. The Alliance research supports the delivery of real outcomes that benefit urban communities, not just in South East Queensland, but nationally and internationally.

Many of the projects focused on water management during droughts and these findings will improve system management in future drought sequences. Additionally, the enduring legacy of increased water use efficiency will help to underpin sustainable water use in the region.

Dr Bill Young
Director
CSIRO Water for a Healthy Country Flagship

Griffith University

The Alliance brought together three leading water research institutions – Griffith University, The University of Queensland and CSIRO – with funding by the Queensland Government.

This powerful partnership created many opportunities for scientists, water managers and policy officers to collaborate in what became a flexible, multi-disciplinary endeavour. On their own, none of the partner organisations could have delivered the Alliance's thematic body of research findings.

Mr Larry Little
Chief Executive Officer
Smart Water Research Facility – Griffith University

The University of Queensland

The Alliance brought together some of the best scientific minds in Australia from a range of disciplines including chemistry, engineering, hydrology, climatology, microbiology, ecotoxicology and sociology.

This comprehensive and collaborative approach to researching urban water management allowed questions to be addressed with a range and depth well beyond the usual technical reports commissioned by the water sector.

Mr Ian Harris
Director
Research Partnerships Office – University of Queensland

Queensland Government

The Urban Water Security Research Alliance has given Queensland a wealth of water research insights and outputs that will be very valuable in the years to come, especially when drought inevitably returns to challenge conventional water supply options for South East Queensland's rapidly expanding population.

Mr Philip Reed
Director-General
Department of Science,
Information Technology,
Innovation and the Arts

Mr Jon Black
Director-General
Department of Energy
and Water Supply

Our Research

When the Alliance was established in 2007, the research had a clear focus on water security and recycling. The initial research program included ten projects aiming to ensure the reliability and safety of recycled water systems and building the scientific knowledge and community confidence in the health and safety of the water supply system.

By 2009, our dynamic research program had grown to 14 projects in response to the rapidly changing operating environment. Four new projects addressed emerging water industry issues, including residential water end use and disinfection by-product formation potential in the drinking water and recycled water systems.

After the drought broke in 2010, there was a dramatic change in SEQ's water security situation. In response, the Alliance consulted with the water industry and government to realign its research program to focus more on reducing water grid demand, the nature and level of risk to human health of our diverse water sources, and integrated urban water planning and management for longer-term efficiency and sustainability.

In this section of the synthesis report, we present a snapshot of the Alliance's 22 research projects (see page 26 for full project listing), discussing what we did, reporting what we found, and identifying future challenges in this important area of research.

Source Control – Hospitals

The Alliance's early research on PRW examined potential sources of contaminants in sewage systems (such as from hospital wastes), removal of contaminants by the sewage treatment plants and the fate of contaminants such as pathogens in storages.

In 2007, the Queensland Water Commission's Expert Panel considered hospital wastewater to be the greatest knowledge gap as, until now, no one could declare that

hospitals were not a significant risk to human health in the production of PRW.

Hospital wastewater is normally discharged directly to sewers, without pre-treatment. Despite mostly being only a small fraction of the total wastewater volume in the influent of a sewage treatment plant (STP), hospital wastewater is often suspected of being a major source of pharmaceutical residues in municipal wastewater and, as such, in need of treatment prior to discharge.

Antibiotics are heavily used in hospitals and often blamed for the transfer of resistant bacteria. The increasing prevalence of antibiotic resistant and multi-antibiotic resistant bacteria is of great concern to health professionals.

What we did

The Alliance investigated the contribution of six SEQ hospitals to the loads of 589 pharmaceuticals in municipal wastewater.

Annual pharmaceutical consumption audit data was collected and compared with pharmaceutical consumption by the general population. The aim was to predict the contribution of a hospital to the loads of pharmaceutical in the influent to the corresponding STP.

A prioritisation tool, based on actual pharmaceutical consumption data from the six hospitals, was developed to identify those pharmaceutical compounds for which hospitals would be a major contributor and to evaluate the potential risk for human health.

To confirm the outcomes and validate this consumption-based approach, the Alliance sampled wastewater from a 296-bed hospital and the influent to the corresponding STP, which served 75,000 people.

What we found

Overall, the six hospitals were found to contribute from only

1-9% of the total pharmaceutical load at the corresponding STP. Audit data of pharmaceutical consumption showed that SEQ hospitals contribute less than 6% of the total mass of active pharmaceutical ingredients consumed in a catchment. This confirms they have only a limited impact on municipal wastewater, and are unlikely to represent a risk to humans at that level.

Alliance researchers found that, for up to 84% of the 589 pharmaceuticals investigated, the contribution from SEQ hospitals was likely to be less than 15%. At least 85% of the loads originate from households and would reach the corresponding STP even if hospital effluents were treated separately.

Reducing pharmaceutical loads in municipal wastewater through onsite treatment of effluent from these hospitals would therefore be of limited benefit.

The research also examined more closely the relative contribution of 123 compounds used only within hospitals. However, many drugs administered at the hospital are more likely to be excreted at home rather than in the hospital, suggesting that the contributions of hospitals for this type of drugs are greatly overestimated.

Of the 123 compounds investigated, only nine remained at a high enough concentration in the STP influent to be of potential concern. Concentrations of pharmaceuticals in raw wastewater are expected to be significantly reduced after conventional wastewater treatment and advanced water treatment.

Therefore, these hospital-specific compounds are unlikely to be present in STP effluents at levels representing a risk to humans. However, they warrant more detailed investigation including environmental and human toxicity, biodegradation and treatment or source control options.

Critically, this project developed a sound methodology that can be applied anywhere to assess the relative contribution of a hospital to the pharmaceutical load in municipal wastewater.

Future challenges

The Alliance also investigated the presence of antibiotic resistant bacteria in hospital wastewater and whether these

are also found in the STP influent. However, more research is needed to establish the relative contribution of a hospital to antibiotic resistant bacteria in comparison to wastewater from the general community.

Wastewater Source Control

Traditionally, wastewater management has focused on managing disposal while meeting environmental discharge targets. In this scenario, potable water quality was viewed more or less independently of the quality of wastewaters.

However, with the increasing use of recycled water, wastewater is now seen as an important alternative source water, especially in drought conditions.

Effective wastewater source control and management are crucial to mitigate potential risks at the earliest stage. Source water characterisation and effective control of inputs are essential for safeguarding the recycled water infrastructure, quality of the recycled water, and ultimately public health.

Current wastewater monitoring practices rely on lab-based analysis of discrete samples due to the lack of an effective continuous online wastewater monitoring system. Many off-the-shelf systems perform well in laboratory environments with clean water, but wastewater quality is highly variable as well as physically and chemically problematic. These problems have contributed to the previous failure of other online systems.

As a result of the Alliance's work, online, real-time monitoring of wastewater quality is now possible.

What we did

The Alliance developed a prototype Water Quality Information Acquisition System (WQIAS) for wastewater environments to provide critical wastewater quality data and real-time, online event detection. The WQIAS is capable of acquiring real-time water quality data and functions reliably over the long-term in wastewater environments, without the need for maintenance.

The WQIAS includes:

- a specially designed sensing platform to host all required sensors, integrated control electronics and the interface to an on-board computing system; and
- system control software and event detection mathematical models, “married” with the new electronic control hardware.

What we found

The fully functioning prototype sensing system was installed at the inlet and outlet of the Bundamba Wastewater Treatment Plant (WWTP) in SEQ to validate the system through a long-term, on-site trial.

The trial demonstrated the applicability and reliability of WQIAS for online wastewater quality event detection in real-time.

Future challenges

The prototype is now being extended into a co-ordinated event detection system in the wastewater network to help identify excursions from normal wastewater quality.

Such a system could provide a powerful tool for source control, including monitoring the illegal dumping of materials to the sewerage system. This can provide an early warning system for WWTPs, helping to safeguard operations and improve risk management.

With further work, this system could be adapted for on-line, real time water quality monitoring in other parts of the water cycle and grid, for example in the drinking water distribution system.

Wastewater Treatment

The production of safe and sustainable PRW relies on the effectiveness of a number of treatment barriers. One such barrier is WWTPs, which treat raw sewage to a suitable quality effluent.

By international standards, most WWTPs in Australia's major cities are modern. They are designed to maximise

carbon and nutrient removal, but much less is known about their ability to remove other key contaminants such as microbial pathogens and trace organic chemicals.

What we did

The Alliance team investigated the efficiency of three SEQ WWTPs in removing microbial pathogens, and biological and trace chemical contaminants.

Over an 18-month period, raw sewage and secondary treated effluent was sampled and tested for selected bacterial indicators and pathogens. An additional four months of intensive sampling also included analysis for *Cryptosporidium* oocysts and enteric viruses.

What we found

The Alliance's research demonstrated that the three WWTPs tested were very efficient in removing faecal indicator bacteria, enteric microbial pathogens and organic compounds such as pharmaceutical and personal care products.

Indeed, the WWTPs removed more than 90% of most organic compounds and reduced pathogen numbers by more than 99%. These removal rates were generally higher than those found in studies undertaken at WWTPs in other Australian states, and were higher than the removal rates cited in the *Australian Guidelines for Water Recycling*.

The efficiency of the removal of microbial pathogens by SEQ WWTPs has implications for the reuse of the treated wastewater. Specifically, secondary treated effluent possibly has a lower inherent health risk from microbial pathogens than may be assumed if only the guideline values are used.

These results should give water authorities confidence in SEQ's WWTPs as an effective treatment barrier in the production of recycled water.

Future challenges

While the Alliance's research shows that SEQ WWTPs are very effective in removing microbial pathogens and indicator bacteria, there remain a series of questions and issues that require further investigation.

Due to the nature and scope of the study, the number of samples taken for the analysis of some pathogens was limited, particularly for *Cryptosporidium* and the enteric viruses. Extending the research over 24 months would provide a larger data set to increase accuracy of, and confidence in, the results.

Scope should also be given to the detection and removal of a wider range of viruses and *Giardia* cysts in WWTPs. There are often more *Giardia* cysts in wastewater than *Cryptosporidium* oocysts, even though *Giardia* cysts are considered to be less environmentally stable.

The viruses detected in this study were all DNA viruses, which are easier to detect in raw and treated effluent with the methods used in this research. However, several RNA viruses, notably norovirus and rotavirus, can create major disease burdens in communities.

It would also be highly valuable to determine the extent to which SEQ WWTPs can remove these RNA viruses and *Giardia* cysts from SEQ WWTPs.

Advanced Water Treatment – Non-Membrane Technology

Most advanced water recycling plants in Australia use membrane technology, specifically Micro Filtration and Reverse Osmosis (MF/RO), to produce high quality water. Membrane technology also uses a lot of energy and produces a highly saline by-product.

However, there are potentially less complex and less costly treatment processes, such as ozone and BAC, that are not so widely used yet are also highly effective treatment processes.

In SEQ, for example, the South Caboolture and Landsborough WWTPs are already producing recycled water to a very high standard without using membranes.

BAC filtration has been used for many years in drinking water treatment, typically after ozonation, to remove natural organic matter (NOM) and pesticides. Ozonation typically leads to the formation of products that are more degradable than the parent compounds, increasing the efficiency of the BAC filters.

Although it seems to have great potential for the removal of organic contaminants from treated effluents, there has been little investigation of the combination of ozonation and BAC filtration for water reclamation and reuse.

What we did

To investigate the effectiveness of alternative treatment technologies and provide guidance on their use, the Alliance research team assessed the ability of three WWTPs to produce high-quality treated water by applying BAC filtration after ozonation.

Also, to assess the treatment efficiency of biofiltration, pilot-scale biofiltration columns were set up at the South Caboolture Recycled Water Treatment Plant.

The research team also sought to understand and optimise BAC technologies for advanced treatment of secondary effluents.

What we found

The research demonstrated that the combination of ozonation and BAC filtration is effective in reducing effluent organic matter, organic micropollutants and DBPs in treated wastewater effluent.

This process can remove 90% of trace organic micropollutants. It can also reduce non-specific and specific toxicity as measured by bioanalytical tools, reducing non-specific toxicity by up to 70%, and estrogenicity by 90%.

The ozone dose and the empty bed contact time are key parameters controlling the process effectiveness.

Non-membrane technologies can produce high quality, fit-for-purpose recycled water more economically than RO, with lower GHG emissions and no brine waste stream. They can also be integrated in a multiple barrier treatment train to produce water suitable for indirect potable reuse.

BAC filtration without prior ozonation is also capable of significantly improving the quality of the WWTP effluent and is therefore suggested as a simple and cheap option for upgrading WWTPs to reduce the environmental impact of treated effluent discharge.

Future challenges

Our project is of significant value as it supports the application of a much simpler technology than MF/RO when generating fit-for-purpose recycled water.

Further research is needed to better understand the parameters influencing the performance of BAC filters and to provide information for the design of full scale units.

Nonetheless, the Alliance's findings will be applicable to a number of WWTPs nationally that would benefit from upgrades to produce higher quality recycled water.

Natural Barriers in Water Treatment

Raw drinking water storages are exposed to multiple sources of microbial pathogens and trace organic contaminants which, if allowed to contaminate drinking water, constitute a significant health risk.

The potential sources of these contaminants include small sewage treatment plants that serve regional towns and runoff from agricultural land.

While water treatment plants are a highly effective treatment barrier in producing high quality drinking water, natural storage systems such as reservoirs and streams also significantly reduce pathogen and chemical contaminants. To date, however, natural storage has been used only as a passive control mechanism.

What we did

To determine how effectively reservoirs and receiving water bodies reduce contaminants, the Alliance researched the behaviour and fate of microbial pathogens and selected trace organics under different climatic and seasonal conditions.

In collaboration with Seqwater and the University of California, Berkeley, this project focused on how selected enteric pathogens and trace organic compounds decayed in selected SEQ reservoirs and associated waterways.

Central to our work was assessing the attenuation of pathogens at different depths of the reservoir, with different light inputs, and at a range of water temperature, chemistry and biological parameters. Similar experiments were also conducted in the mid-Brisbane River.

The project team also sampled three SEQ catchments to determine if the source of these microorganisms was human or animal by comparing genetic variations in faecal indicator bacteria.

We also examined the health risks associated with exposure to the pathogens generated by different recreational activities permitted in reservoirs.

In 2011, major flooding in SEQ presented the opportunity to investigate removal rates for selected pathogens in Wivenhoe Dam, before and after major floods. The project also investigated the decay of trace chemical contaminants in Wivenhoe Dam and the mid-Brisbane River.

What we found

Overall, the results indicate that reservoirs in SEQ have a valuable treatment capability and remove contaminants, particularly pathogens, under a range of climatic and environmental conditions.

Dams are an effective treatment barrier for the removal of pathogens and trace organics. We found that natural processes removed 90% of most pathogens in a matter of days. Even after extreme events such as major flooding, reservoirs still acted as active treatment barriers.

Microbial source tracking results indicated that animals, most likely cows, birds and kangaroos, were the greatest source of *Escherichia coli* (*E. coli*). Human input was less, but still constituted a human health risk.

In another finding, Alliance researchers identified the potential to combine pathogen and chemical decay data with hydrodynamic models, helping to increase the accuracy of risk assessments in reservoirs.

Future challenges

This work will help guide the design of suitable processes for water treatment, stormwater reuse and catchment

management. The major issue identified was the contamination contributed by the catchments and the need for better catchment management.

Further research is required with Seqwater on a proof-of-concept to incorporate pathogen and trace chemical removal data into the complex hydrodynamic model of Wivenhoe Dam.

In combination with data on sources and loads of contaminants provided by microbial source tracking, the ability to manage the reservoir could be significantly enhanced. This will be particularly important for assessing changes in health risk levels under different climatic events and/or exposure scenarios.

Water Treatment – Disinfection By-Products

Naturally occurring organic matter found in untreated water reacts with disinfectants to form DBPs. The presence of DBPs in drinking water is of concern, as some of these by-products have been linked to potential negative health effects.

The SEQ Water Grid draws on water from a number of different sources, including dams, groundwater and the Tugun desalination plant, each with a different background water chemistry and quality.

In future, PRW is also likely to provide an important additional water supply option when the combined capacity in the drinking water dams drops below 40% in times of drought.

Different parts of the Water Grid use either chlorine or chloramine disinfection regimes. This complexity creates the potential for DBPs to form when the treated waters are mixed, and makes it hard to forecast DBP formation potential in the grid.

Coagulation is undertaken as a standard aspect of water treatment to effectively remove dissolved natural organic carbon and nitrogen. However, coagulation alone does not always reduce DBP formation potential due to poor removal of halides and the more reactive NOM fraction.

Understanding DBP formation in the mix of treated water sources and disinfection strategies is important for decisions about future water treatment strategies in the SEQ Water Grid, and can only increase confidence in the water supply.

What we did

The Alliance research focused on identifying:

- the emerging and regulated DBPs most relevant in SEQ, considering it has two separate disinfection regimes;
- DBP formation potential from blending drinking water of different qualities from different sources and using different disinfectants in the grid; and
- the components of NOM not removed by enhanced coagulation and strategies to remove NOM or halides to minimise the formation of DBPs.

What we found

Alliance researchers found that DBP levels in SEQ drinking water were well within the Australian guidelines and are unlikely to be a concern in current water treatment plant operations when chloramination is used.

Compared to chlorine, monochloramine generally resulted in lower concentrations of DBPs. However, the formation of some DBPs was increased when chloramines were used before chlorine disinfection in comparison to the use of chlorine alone. Therefore, the conversion of chloramines to chlorine via breakpoint chlorination is not recommended for those source waters with a high risk of DBP formation.

The study at the two conversion stations in the SEQ Water Grid showed that all regulated DBPs were within the Australian Drinking Water Guidelines for all sampling events, even during the breakpoint chlorination trials.

The Alliance research identified Silver Impregnated Activated Carbon in conjunction with enhanced coagulation as the best strategy to remove both dissolved organic carbon (DOC) and bromide from source waters.

The potential formation of DBPs at advanced water treatment plants was also investigated. Importantly, we found that changing the dosing point and contact time

of chloramine reduced DBPs below guideline levels, and suggest that adopting these procedures may reduce operating and treatment costs.

Overall, Alliance researchers developed a strong understanding of DBP formation, which has lowered the cost of disinfecting potable and recycled water, and reduced public health risks.

Future challenges

The potential effects that combining water from a variety of sources and treatment trains will have on water quality needs further investigation to help maintain confidence in the system.

It is important that more research be done into the increased formation potential of emerging DBPs, such as haloacetonitriles and chloral hydrate, after breakpoint chlorination.

It would also be beneficial to find out how DBP formation might be mitigated through plant operational changes or treatment improvements, in particular, where a change in disinfection strategy is under consideration.

Climate and Evaporation Loss

Drought, high rainfall and floods are natural for life in SEQ. The Alliance looked at whether climate change had played a role in recent extreme weather events, and at what the region's climate might be like in the future. We also investigated the impact of climate variability and climate change on the region's future water supplies.

Evaporation from water storages represents another threat to SEQ's water security. Each year, evaporation takes more water out of SEQ storage systems than the amount supplied through the reticulation network, with about 300 GL/yr lost from SEQ dams alone. Developing innovative techniques to reduce evaporation clearly offers many long-term benefits.

What we did

In the past, water strategy in SEQ was informed by data from large-scale global climate models with a resolution of several hundred kilometres (km). Our research team completed 13 experiments at a finer-scale resolution of 15 km, using eight global models to more confidently assess the impact of multi-decadal climate variability and climate change on water supply.

In 2011-2012, the project team undertook two further downscaling experiments at the super-fine resolution of 8 km, to compare results to the 15 km experiments and assess whether significant additional benefits could be gained from climate modelling at this very fine scale.

The Alliance also researched promising evaporation reduction technologies for large water storages. Several monolayers and surface films were assessed in wave-tank and field studies for their evaporation reduction potential, resilience to wind and wave action, and potential impacts on water quality.

What we found

Alliance research showed that the rainfall fluctuations experienced in SEQ, ranging from the depth of the Millennium Drought in 2007 to severe flooding in 2011, can be accounted for by multidecadal variability in the Pacific Ocean and its link with the El Niño-Southern Oscillation. However, in the longer term the magnitude of such events may increase with climate change.

Although the nature of future rainfall change remains uncertain, downscaling of the Global Climate Models shows good agreement on increased temperature and evaporation in years to come. These increases are likely to bring more frequent, longer-lasting and deeper droughts that will take longer to break.

The finer scale climate models are being used to help assess future dam yields. They indicate that longer-term climate variability and change will reduce inflows to SEQ dams and also lengthen the periods between dam-filling rainfall events.

Under this scenario, the State would once more need to prioritise the security of alternative water supplies, as well as trying to reduce both regional demand and evaporation losses from reservoirs.

The Alliance research identified surface films and monolayers as promising evaporation reduction technologies for large water storages. Innovative techniques were also developed to accurately measure evaporation losses over large bodies of water and for applying monolayers according to prevailing weather conditions with a “smart” autonomous monolayer application system.

The Alliance’s research has greatly improved our understanding of how climate change and evaporation loss can affect water supply, with data incorporated into the State’s analysis of supply and demand. The outcomes of this research have important implications for future water resource security and will enable the State to revise the SEQ Water Strategy based on more detailed climate information.

Future challenges

Further downscaling experiments on the International Panel on Climate Change’s updated global models would provide even more up-to-date climate projections for use in planning. More work using the 8 km downscaling experiments would also provide more robust results.

The modelling could also be usefully applied to analyse the implications of extreme floods for water managers, which this project didn’t focus on as the Alliance was chiefly formed to investigate responses to extreme drought.

While initial wave tank experiments with monolayers were promising, field trials of monolayers were less successful and warrant further investigation. Nonetheless, new monolayer products currently under development by the Cooperative Research Centre for Polymers have the potential to significantly reduce evaporation on SEQ dams.

The results of the Alliance’s research into climate and evaporation will continue to be valued by stakeholders across a range of sectors, particularly anyone who is planning for Queensland’s future needs and looking at exceptional climate events.

Rainwater Tanks

Urban rainwater and stormwater are among the most promising untapped sources of water in SEQ, as in other parts of the developed world. Such water has high potential to replace significant volumes of grid water for a range of non-potable end uses such as irrigation and toilet flushing.

All new houses built in SEQ since January 2007 are expected to save 70 kilolitres (kL) of potable mains water each year. One of the recommended measures to achieve this target is through the installation of a rainwater tank, which needs to be internally plumbed to toilet cistern(s), the cold water washing machine tap and at least one external tap.

It is estimated that more than 300,000 rainwater tanks have been installed in SEQ homes over the last five years. However, there is evidence to suggest that home owner maintenance of tank systems is minimal.

The design, installation, operation and maintenance of the rainwater tank systems all affect the efficiency and cost-effectiveness of rainwater tanks.

What we did

The Alliance research focused on:

- conducting a number of analyses to validate the mains water savings being achieved through internally plumbed rainwater tanks. Water use was compared between SEQ households with and without plumbed rainwater tanks and against regional water usage;
- an onsite inspection of the physical characteristics of 200 SEQ household rainwater systems to determine the impact of factors such as connected roof area and effective tank size on the usage and performance of the rainwater systems;
- a monitoring study of 20 households with rainwater tanks using real-time water demand data to quantify the volumetric reliability (the ratio of the rainwater usage to the total household water demand) and to establish the total peak hour water demand met by rainwater;
- the overall impact on energy consumed of a number of rainwater system variables (eg, pump size, header

tanks, pressure vessels and infrastructure pipe size) to determine the potential to increase the energy efficiency of rainwater tank systems for a single storey dwelling;

- the potential health risks associated with the use of water from rainwater tanks; and
- strategies and interventions to promote rainwater tank maintenance.

What we found

Rainwater tanks supplied on average about one third of water used in SEQ residential properties in 2009-10, a saving of about \$150 per household at current grid water prices. On-site assessments show that, on average, 28% of morning peak demand is met by tank water, with usage typically driven by toilet flushing and clothes washing.

We also found that 40% of tank systems did not have the required roof area connected to the tank. The research indicates that increasing the area of roof catchment connected to the rainwater tank is the most important physical installation factor to improve the yield from rainwater tank systems.

The most commonly used rainwater tank pumps are efficient for high-flow applications, such as watering the garden. However, they often operate in their low efficiency range for low-flow applications for end uses such as toilet flushing and the washing machine. Properly sized pressure vessels have the potential to reduce energy consumption while maintaining suitable pressure and flow for appliances.

Analysis showed that 71% of tanks sampled in SEQ did not meet Australian Drinking Water Guidelines due to the presence of *E. coli*. Some samples were also found to be positive for other pathogens, reinforcing government recommendations on tank water consumption. The high prevalence of pathogens in possum and bird faecal samples suggested these animal species were the most likely source of faecal contamination in rainwater tanks.

Research into the effect of sunlight and temperature on pathogen survival on the roof, in gutters and tanks showed that direct sunlight on a roof completely deactivated faecal indicator bacteria in a matter of hours and less than a day in clean gutters.

Research into householder attitudes and behaviours towards tank maintenance highlighted that a focus on awareness and education campaigns would encourage residents to maintain their own tanks.

Future challenges

The Alliance’s multi-disciplinary research has increased the understanding of the need for better rainwater tank design, installation and management, and highlighted areas where further investigation may help deliver the greatest benefits.

Further research should focus on the optimal design, energy efficiency and cost-effectiveness of both individual and communal rainwater tanks as a reliable alternative source of water.

Very little is known about the existing condition of tanks across SEQ, their likely lifespan and how this may be affected by maintenance. Programs aimed at enhancing owner awareness and improved tank operation and maintenance would help secure longer-term benefits.

Further research on the potential health risk associated with exposure to rainwater will help inform guidelines for appropriate treatment and the potential for wider use of rainwater, for example in showers.

Stormwater Harvesting

SEQ urban runoff ranges from 245 to 750 GL/yr, with an average of 470 GL/yr, compared with current unrestricted urban water consumption across the region of about 450 GL/yr.

Stormwater appears to have enormous potential as an alternative water source for dual reticulation in greenfield developments. If it is to be considered viable and reliable, research into the impact of stormwater harvesting on urban creek ecosystem health and on potential health risks is essential.

What we did

The Alliance researchers studied these needs through two main projects – one focusing on eco-hydrology, the other on stormwater quality.

- Stormwater Management Models (SWMM) were developed for 12 catchments in SEQ. A case study was undertaken to simulate the impacts of increasing urban development and implementation of the SEQ frequent flow management objectives (FFMOs), which are designed to mitigate the increase in frequency and magnitude of flows associated with increased impervious areas from the urbanisation of catchments;
- we explored the macroinvertebrate population of three sites with different levels of urbanisation to identify the factors leading to poor urban creek instream health; and
- through a collaboration with the Cities as Water Supply Catchments program led by Monash University, we examined the quality of stormwater, in terms of pathogens and chemical contaminants, and potential health risks associated with using stormwater for various end uses.

What we found

Urbanisation increases the mean flow, the frequency of high flow events and the total number of days at high flow in local waterways. Higher impervious areas also result in decreasing frequency of low flow spells, but increases in the total duration of those spells.

While flow itself may be partially responsible by directly dislodging macroinvertebrates, its impact on sediment delivery to the stream through increased erosion may also change habitat quality and therefore availability. Harvesting stormwater to meet the FFMOs established in the SEQ Regional Plan presents an opportunity to achieve environmental benefits in creeks and/or to reduce existing impacts.

Preliminary findings from stormwater analysis showed *E. coli* and enterococci were found at levels that exceeded the recreational water quality guidelines. Human contaminants in stormwater are high, with evidence of sewer leakage and overflows during storm events, particularly in older suburbs. Health risk assessments indicate that captured stormwater should undergo some degree of treatment prior to use for non-potable purposes.

Future challenges

Our research will help developers and local authorities achieve the objectives of the SEQ Regional Plan, which aims to maintain streams as close as possible (in hydrological terms) to pre-urban or reference conditions.

The effectiveness of different technologies and strategies, such as bioretention basins, to detain and delay the release of harvested flows is worth further investigation.

Further research also needs to investigate how stormwater can be cost-effectively captured, stored, treated (for pathogens and other health risks) for fit-for-purpose supply to end-users in a manner that does not adversely impact environmental flows.

Household Water Use

Householders' water conservation attitudes and behaviour can be influenced by the provision of appropriate information on water end use, demand management and water conservation strategies. Knowledge gained on how, why and when householders use water inside the home provides better information for developing water conservation initiatives.

What we did

The Alliance research focused on:

- residential water end-use in 250 households in SEQ across a range of seasons, linked to social research, to examine household water use, conservation behaviour and the effectiveness of demand-management strategies; and
- the link between water-efficient technologies and lowering energy use and GHG emissions. The diurnal pattern and average day peaks in water use were also investigated.

What we found

Average total water consumption in SEQ during winter 2011 was 144.9 litres per person per day (L/p/d), well below the Permanent Water Conservation Measures target of

200 L/p/d. Shower (34%), clothes washer (22%), tap (17%) and toilet (17%) comprised the bulk of SEQ domestic water consumption in winter 2011, with irrigation making up less than 5% of average total use.

Water wise initiatives, such as switching from top loading to front loading washing machines and installing high-efficiency showerheads, provide significant water, energy and cost savings. For example, a water-efficient shower head reduces water use by about 37% and energy consumption by about 63%. These findings have implications for water distribution infrastructure and the potential to reduce costs by considering smaller diameter or deferred distribution infrastructure.

Households that were provided general information on how to conserve water showed the fastest change in water use behaviour. However, they also demonstrated a "rebound effect", with their water use slowly returning to levels similar to those recorded prior to the study. In contrast, the households that received specific information on their water end use had a more gradual but longer-lasting reduction of water use behaviour.

Future challenges

Making people aware of their water end-use and what others are doing to reduce water consumption strongly influences long-term changes to their own water use. However, questions remain as to whether water conservation can be maintained outside of times of drought and how the approach can be rolled out across a larger number of households.

More research is needed to better understand any rebound of external water use to previous high levels before the introduction of water restrictions during the drought.

Total Water Cycle Management

Total Water Cycle Management (TWCM) planning aims to consider all elements of the water cycle so that water can be delivered in ways that minimise costs while maximising social and environmental benefits.

The *South East Queensland Regional Plan 2009–2031* requires SEQ local governments to start implementing TWCM plans by July 2012. This project was established to fill the knowledge gap on methods to evaluate and compare the costs, benefits, impacts and trade-offs of various alternative water source options.

Because the urban water cycle interacts with so many variables – the different sources and characteristics of water, nutrient flows, energy and GHG emissions – there are many repercussions for water cycle management.

Externalities are impacts that are not directly taken into account in day-to-day decisions, such as the costs and benefits to the environment and community of alternative water supply strategies. Failure to factor externalities into project planning can have significant impacts on preferred options and may lead to the misallocation of resources and increased damage to the natural environment.

Improved information about likely external effects therefore helps water managers understand the likely broader impacts over time. Nonetheless, it is rare to see full adoption of private and external costs and benefits into economic decision-making.

This research project asked how local TWCM planning processes can account for the highly integrated nature of SEQ's water supply grid. Second, it sought to identify how the TWCM planning process can account for externalities that urban water system planners working in a localised context may not be aware of.

In coming decades, GHG emissions are expected to rise faster than population growth, and more than double for water and wastewater services. Traditional estimates of GHG emissions for the water and wastewater sector have focused on energy use for centralised services. However, there is little information available about diffuse emissions from wastewater systems and reservoirs — potentially the largest sources of GHG emissions for the sector. Clouding the long-term picture, alternative sources of water such as rainwater tanks, recycled water and desalination currently have greater energy intensity than traditional sources.

What we did

An integrated research project was undertaken in collaboration with the Queensland Water Commission, Seqwater, the Healthy Waterways Partnership and local governments to develop a range of enhanced analytical methods, incorporating:

- costing pollution mitigation;
- energy consumption;
- life cycle assessment (LCA);
- methods for quantifying decentralised systems' impacts on water quantity and quality at a regional scale;
- ways to consider uncertainty and reliability in multi-objective decision-making; and
- trade-off analysis.

In addition, extensive measurements of methane emissions were undertaken at two dams in SEQ to reduce uncertainty and determine the benefits of GHG mitigation.

What we found

A LCA of the Gold Coast water system showed that, although they are more expensive, water servicing options that apply Water Sensitive Urban Design principles to both new and existing developments, including non-potable reuse of wastewater and stormwater, provide greater water savings and lowest overall nutrient discharges.

LCA was also used to analyse urban wastewater recycling systems and three scenarios were considered in the Caboolture TWCM planning study undertaken by the Moreton Bay Regional Council (MBRC). The results demonstrated how this approach could lead to different conclusions compared to the generic estimates for infrastructure operations that are more frequently adopted in SEQ planning studies.

A method was developed to use extended cost effectiveness analysis for water supply option evaluation, including the cost for water supply and the cost of abatement of pollution from the water supply option. The draft TWCM Plan for MBRC was also used as the case study.

A compendium of externality effects and their monetary values was compiled for different water supply options

including stormwater harvesting, rainwater tanks and wastewater recycling to strengthen assessments of sustainable water management options and to inform decision-making.

Methane bubble fluxes occurring over a relatively small proportion of a reservoir were found to account for the majority of each reservoir's emission. In Little Nerang Dam, 80% of the total flux was emitted from 10% of the reservoir's surface area. Methane fluxes were orders of magnitude greater at the upstream ends of the arms of the dam that receive fresh inputs of sediment and detritus direct from the catchment.

Previous research has shown that the most common method used to calculate total grid water savings from rainwater tanks at a city/regional scale tends to overestimate the total water savings for the region due to the spatial variability of tank and residential water use characteristics. Alliance researchers developed an improved method to overcome this problem.

The results also show that ignoring the spatial variability of tank and residential water use characteristics can overestimate the aggregated water savings from rainwater tanks by up to 14%, and underestimate the aggregated overflow from rainwater tanks by up to 30%.

Future challenges

Many aspects of this project would benefit from longer-term research.

One challenge in planning is that there is no clear way to choose which water supply technology (or mix of technologies) to use to reduce mains water demand while at the same time maximising benefits to the community and environment. Further research is needed into novel methods for undertaking Multi Criteria Decision Analysis, such as the application of Bayesian Networks and Subjective Logic, in a way that incorporates uncertainty and information reliability into decision-making.

Further research is needed to better understand uncertainties in diffuse emissions from reservoirs and wastewater systems. These large uncertainties present significant opportunities for mitigation.

Household Energy and Water Use

Household energy use is as important as household water use, so the Alliance researched how much energy householders use and where they use it when consuming water.

Household water use comprises a substantial component of water-related energy consumption. Australia's households are major consumers of water-related energy, accounting for around 30% of the water-related energy use and contributing about 9% of Australia's GHG emissions from cities.

What we did

The project team examined energy and water use in one household in Brisbane to develop a systematic method to understand water-related energy in a household and the implications for other household types.

What we found

The study found that water-related energy use accounts for approximately 59% of total energy use at home (not including transport). The major contributing uses are hot water use for the shower, bath, clothes washing machines and dishwashers and energy costs comprised a significant proportion of the cost of internal services involving water.

Behavioural changes, such as less time in the shower, have the potential to reduce household water-related energy and carbon dioxide (CO₂) emissions by 50% or more. Not only are these changes effective, they are low cost and have flow-on cost savings for water, wastewater and energy infrastructure or installations. They can also be applied immediately and independently.

The installation of technical improvements, such as a solar hot water system combined with the connection of clothes washing machines and dishwashers to a hot water source, could lead to a reduction of about 70% in water-related energy and about 25% in CO₂ emissions in the individual household studied. Significant reductions in both energy demand and peak water demand can also be achieved by using various water-efficient fixtures and appliances, such as water-efficient shower heads and clothes washers.

This research provides a valuable insight into strategies to reduce residential energy use.

Future challenges

Many aspects of this project would benefit from longer-term research. The work on household energy use is being extended to analyse the different types of households in a city, thus providing a developed model that can be applied to a whole city. It could also help give information to households and water utilities seeking to save water and energy costs simultaneously.

Another obvious area for improvement is to ensure energy-efficient installation of the 800,000 new rainwater tanks planned for SEQ over the next 50 years, which, if installed and operated at the lower ranges of energy use, could save large amounts of energy over time.

Water Smart Cities

The notion of Water Smart Cities has developed in recent times, in response to the increasing size of urban populations.

Accordingly, with significant population growth in SEQ in recent years, Alliance stakeholders consistently identified the need for cities and towns to become much smarter about water use. This project, which scoped a framework and future research needs for moving to Water Smart Cities, was chiefly driven by that perceived need.

However, agreement on assessment criteria for "water-sensitive" or "sustainable" cities and their water systems is no easy task. While the Australian water sector has taken a strong international leadership role in this regard, there remains significant uncertainty regarding "best" approaches.

Lack of agreed assessment criteria leaves planners with relatively few solid metrics against which to plan. There is a need to improve the quantification of sustainability principles and of how cities as a whole are performing, along with their component water systems.

The objective of the project was to provide a "legacy" for future research to design cityscapes that integrate water planning and policy with overall urban policy and design.

What we did

The Alliance initially reviewed national and international literature, then conducted workshops with colleagues from across Australia and government stakeholders to identify what should change to achieve water smart cities and towns. The Alliance also examined Queensland policy and planning around water strategies.

What we found

The Alliance developed a conceptual framework focusing on factors which would make the most impact. Critical factors included the need for:

- clearly defined urban development objectives;
- development of a broader context for the role of water in urban environments;
- a multi-scale approach with a clear definition of system boundaries;
- differentiation between cities and towns with a range of bio-physical and socio-economic contexts;
- differentiation around a range of water uses; and
- outcome-oriented measurement tools.

Future challenges

The Alliance identified a range of future actions that could be taken, including informing and engaging the public as a possible “quick win”. Within Queensland, we identified regional planning instruments and reporting mechanisms critical to the development of water smart cities.

More challenging strategies for change include creating a clearer link between costs and services, and developing more effective State planning policies. It would also be useful to identify and value the costs and benefits of smarter water policies in new urban developments.

The project team recommends setting up a Planning Support System for Water Smart Tropical and Sub-Tropical Cities and Towns as a vehicle for future research outputs.

Institutional Factors

The water crisis in 2006-07 provided a catalyst for the State Government to undertake significant and far-reaching regulatory and institutional reform in SEQ.

Our research, completed at the end of 2010, looked at the key factors and relationships needed to build effective, long-term institutional arrangements to strategically and sustainably manage SEQ’s water.

What we did

Researchers sought to answer the following questions:

- What were the main stages in the evolution of water planning, policy and responsibilities in SEQ since the late 1970s?
- What were the professional, managerial and scientific knowledge bases that underpinned water planning, policy and delivery from the late 1970s?
- Has policy effectively shaped residential and corporate water use?
- What institutional conditions facilitate knowledge production and sharing for integrated water planning?

Another Alliance project examined the development of water recycling in SEQ. This study drew on public policy documents, regulatory documents, internal reports, media reports and a number of interviews with key people connected with this story.

What we found

The Alliance found that SEQ’s water governance and management was dynamic, complex and interconnected and that regulatory reform is sometimes out of step with technological innovation, as demonstrated by the inability of local authorities to initiate water recycling schemes in the decade before the Millennium Drought.

In managing the complicated dynamics of institutional change, communication and knowledge-sharing proved to be just as critical as structures and protocols. The researchers also emphasised the importance of “boundary” organisations – such as the Healthy Waterways Partnership – in helping to transfer knowledge across organisational boundaries.

Preliminary findings from an ongoing PhD research project still supported by the Alliance suggest the Government’s demand-management policy had a significant influence on declines in the average water use by individual SEQ households and corporations. Both groups were influenced by regulatory approaches (eg, water restrictions targeting outdoor water use, Water Efficiency Management Plans,

mandatory water efficiency measures) and incentive approaches (eg, State and local government rebates, the Target 140 media campaign in SEQ).

The Alliance’s study into the development of water recycling in SEQ imparted some important lessons, in relation to the regulatory context for technical innovation in water management, the complexities of multi-level governance, the interplay between professional expertise and public confidence in water safety, and the need for leadership.

Another Alliance project highlighted and described some of the complex links between water, energy and climate. In considering future options for water security, the energy requirements and climatic impacts of each solution-option must be taken into account. Similarly, approaches that consider energy security but which do not simultaneously account for water or climate variability are not likely to be sustainable. Historically, policy and decision-making has not actively scrutinised the key connections between these linked systems (although there are signs that this is gradually changing).

Future challenges

In the face of climate extremes, increasing populations, changing governments and evolving institutions, the business of managing water supply and demand will remain dynamic. Thus, the ability to continually update, transfer and integrate knowledge across water institutions remains a key challenge for long-term problem-solving around the world.

The Alliance demonstrated that the Integrated Water Resource Management framework can be used in practical ways to form a risk-based management approach capable of incorporating the contemporary challenges of the water, energy and climate-change nexus.

With greater attention being paid to “resilience”, ie, practices that emphasise adaptation and learning, these approaches will need to draw not only on market mechanisms (including appropriate pricing) but also on non-market measures such as standards, regulation, consultation, education, and research and development programs.

Human Factors

The human element in complex socio-technical systems has gained increasing importance in the study and application of risk and safety management.

Many industries, including aviation, nuclear power and healthcare, now recognise the need to integrate human factors research and principles into their overall risk management schemes. Surprisingly, there has been little research into the essential service of bulk water storage, treatment and distribution.

The SEQ Water Grid has undergone sweeping changes in recent years, including the introduction of new technologies and changes in the ownership of large assets.

What we did

The first phase of this research was a basic overview of human factor issues in the area. The second phase focused on control room operations in the context of changing roles, responsibilities and asset ownership in the water sector.

What we found

Our research has provided an encouraging initial assessment, however, a number of issues were identified as needing attention to achieve best practice.

The recent amalgamation of water grid assets created confronting compatibility and consistency issues in bulk water distribution. Operators are acutely aware of shortcomings and have developed strategies and work-arounds to cope with inadequacies in infrastructure and work practices.

The Alliance found that technological changes to support operator activities are improving performance but further technological advances would enhance integration across the grid.

In the long term, the water industry would benefit from viewing the human element in the system as an integral contributor to safety, reliability and efficiency.

Future challenges

The research identified the need to improve aspects of control-room design and work practices to bring the SEQ Water Grid in line with best practice and reduce the risk of human error.

Future research should include processes and procedures for abnormal situations, and reviews of previous accidents and incidents using retrospective task analysis methodologies.

The Research Program and Project Leaders

Purified Recycled Water	Project Leader: Dr Simon Toze, CSIRO
With the initial focus of the Alliance on PRW and perceived risks associated with recycling water, the PRW project researched the safety and sustainability of the seven-barrier PRW treatment scheme. In 2010, this project was restructured and split into three projects dealing with <i>Hospital Wastewater</i> , <i>Bioassays and Risk Communication</i> , and <i>Pathogens and Trace Contaminants in Dams</i> .	
Life Cycle Analysis and Integrated Modelling	Project Leader: Dr Shiroma Maheepala, CSIRO
This project focused on the life cycle analysis of water supply scenarios and models and tools to enable the adoption of Integrated Urban Water Management (IUWM). In 2010, this project was restructured to focus on <i>Evaluation Methods for Evidence-Based Total Water Cycle Planning</i> .	
Institutional Change for Water Management	Project Leader: Professor Brian Head, UQ
This project, completed in 2010, looked at the key factors and relationships necessary for building effective long-term institutional arrangements to manage SEQ's water strategically and sustainably.	
NDMA Formation Potential	Project Leader: Dr Maria José Farré, UQ
This contestable funded project researched NDMA formation potential in wastewater treatment plant effluent and advanced water treatment for the production of recycled water.	
DBP Formation and Minimisation in Drinking Water	Project Leader: Dr Glen Shaw, GU
This contestable funded project was established to address the gap in information regarding disinfection by-product formation in potable water treatment in SEQ using chlorination or chloramination.	
Stormwater Harvesting and Ecohydrology	Project Leader: Dr Brian McIntosh, International WaterCentre / CSIRO
This project researched the innovative capture and storage of stormwater for additional water supply in SEQ and the impact of harvesting stormwater on creek and ecosystem health.	
Decentralised Systems	Project Leader: Dr Ashok Sharma, CSIRO
This project aimed to validate the contribution rainwater tanks can make to water savings targets in SEQ. It also researched tank maintenance approaches and energy costs associated with tanks and decentralised wastewater treatment.	
Demand Management and Communication Research	Project Leader: Dr John Gardner, CSIRO
This project researched household water conserving behaviour with demand management interventions.	
Residential Water End Use Study	Project Leader: Dr Rodney Stewart, GU
This project quantified residential water end uses and the impact of urban water demand management strategies in SEQ.	
Hospital Wastewater	Project Leader: Dr Kristell Le Corre, UQ
This project aimed to quantify the relative contribution of hospital wastewater to sewage treatment plants.	
Pathogens and Trace Contaminants in Dams	Project Leader: Dr Simon Toze, CSIRO
This project investigated pathogen and trace contaminant attenuation within reservoirs and developed source tracking methods.	
Bioassays and Risk Communication	Project Leader: Dr Beate Escher, UQ
This project further developed the scientific, technical and communication basis for implementation of bioanalytical tools in Queensland's water quality monitoring programs.	

Health Risk Assessment of Local Source Waters	Project Leader: Dr Simon Toze, CSIRO
This project identified pathogens in rainwater and stormwater in SEQ and quantified the associated health risks.	
Enhanced Treatment	Project Leader: Dr Julien Reungoat, UQ
The project researched the effectiveness of biological activated carbon in non MF/RO treatment of fit-for-purpose recycled water.	
Assessment of Regulated and Emerging Disinfection By-Products in SEQ Drinking Water	Project Leaders: Dr Maria José Farré, UQ Dr Nicole Knight, GU
This project assessed emerging and regulated DBP formation potential from blending water from different sources and using different disinfectant regimes in the grid and strategies to remove NOM or halides to minimise the formation of DBPs.	
Climate and Water	Project Leader: Dr Wenju Cai, CSIRO
This project assessed and quantified the impact of climate variability and change on water supply over the SEQ region.	
PRW in the Lockyer Valley	Project Leader: Dr Leif Wolf, CSIRO
This project researched the implications of using PRW as an adjunct to groundwater for irrigation in the Lockyer Valley.	
Evaluation Methods for Evidence-Based Total Water Cycle Planning	Project Leader: Dr Shiroma Maheepala, CSIRO
This project developed improved analytical methods and tools for quantitative assessment and decision-making for the development of total water cycle management plans.	
Water Quality Monitoring Technology and Information Collection System	Project Leader: Professor Huijun Zhao, GU
This project developed a proof-of-concept prototype online, real-time monitoring system to identify sudden changes in the water matrix at a wastewater treatment plant at Bundamba in SEQ.	
Evaporation Loss	Project Leader: Professor Stewart Burn, CSIRO
This project analysed technology to reduce evaporative losses from large SEQ dams and completed detailed field analysis and trials of the effectiveness of monolayers on a large farm dam.	
Water Smart Cities	Project Leader: Dr Sharon Biermann, CSIRO
This project scoped a framework for moving to Water Smart cities.	
Human Factors in Urban Water System Safety	Project Leader: Professor Brian Head, UQ
This project scoped human elements in risk management and quality control systems in the context of the introduction of new technologies and changes in the ownership of large assets in the water sector.	
Electrochemical Treatment of Problematic Water Recycling Waste Streams (ARC Linkage Project)	Project Leader: Dr Jelena Radjenovic, UQ
The Alliance provided financial support for this Australian Research Council Linkage project. Electrochemical oxidation and reduction is an emerging area of science, with particular application for the treatment of problematic waste streams such as reverse osmosis concentrate, produced in advanced water treatment and the treatment of water extracted in coal seam gas production.	

Governance

Management Board

Over the five years of the Alliance, the key role of the Management Board was to: establish the strategic priorities of the Alliance; approve the annual research program and budget; and oversee the effective delivery of the research program. The Board met four times a year to review progress with implementation of the Alliance research program. The Board also held joint strategic planning workshops with the Research Advisory Committee on a yearly basis to consider the strategic direction for the research projects to ensure product delivery was in line with priorities.

Management Board membership comprised an independent chair, two representatives for both Queensland Government and CSIRO, and one representative for both Griffith University and The University of Queensland.

Members of the Management Board for 2007-2012 were:

Independent Chair



Chris Davis (2007-2012)

Chris brought a wealth of experience to the Alliance after 15 years as CEO of the Australian Water Association. His in-depth knowledge and passion of the urban water industry and its research issues and challenges have been invaluable to the Alliance, as have his strong linkages with industry stakeholders.

Government (two members)



Judith Jenson
(Sept 2012 – Dec 2012)
Replaced Karen Waldman
General Manager
Liaison Office,
Department of Energy
and Water Supply

Karen Waldman
(July 2010 – Sept 2012)
Replaced Dan Spiller
Chief Executive Officer
Queensland Water
Commission

Dan Spiller
(July 2009 – June 2010)
Replaced Barry Dennien
Director of Operations
SEQ Water Grid
Manager
(Former Acting
Executive Director,
Queensland Water
Commission)

Barry Dennien
(2007 – June 2009)
Chief Executive Officer
SEQ Water Grid
Manager
(Former Executive
Director of Regional
Planning and Policy,
Queensland Water
Commission)

Christine Williams
(July 2009 – Dec 2012)
Replaced Brian Vandersee
Assistant Director-General
Science Delivery,
Department of Science,
Information Technology,
Innovation and the Arts

Brian Vandersee
(2007 – retired July 2009)
Executive Director
Natural Resource
Sciences, Former
Department of Natural
Resources and Water

CSIRO
(two members)



Alan Gregory
(2007-2012)
Research Theme Leader
Urban Water, CSIRO

Scott Keyworth
(2007-2012)
Manager, Research
Adoption
Water for a Healthy Country
National Research Flagship,
CSIRO

The University of Queensland
(one member)



Ian Harris
(Feb 2012 – Dec 2012)
Replaced John Mott
Director

Research Partnerships,
The University of Queensland

John Mott
(2007 – retired Feb 2012)
Strategic Research
Coordinator

The University of Queensland

Griffith University
(one member)



Larry Little (2007-2012)
Chief Executive Officer
Smart Water Research Facility
Griffith University

Research Advisory Committee

The Research Advisory Committee (RAC) provided advice to the Management Board on the annual research program and budget, including review of knowledge gaps, progress, milestones and implementation of Alliance research activities and adoption of research findings. It conducted periodic reviews of Alliance research project activities and made recommendations about the direction, content and details of future activities.

Members of RAC for 2007-2012 were:

Independent Chair



Professor Paul Greenfield,
AO (2007-2012)
Former Vice-Chancellor
The University of Queensland

Independent (three members)

Adjunct Professor Mark Pascoe (2008-2012)
Deputy Chair
Chief Executive
International WaterCentre

Mr Ian Law (2007-2012)
Principal, IBL Solutions
Adjunct Professor, The University of Queensland

Associate Professor Rebekah Brown (2007-2012)
Program Leader, National Urban Water
Governance Program
Monash University

CSIRO (one member)

Mr Alan Gregory (2007-2012)
Research Theme Leader, Urban Water
CSIRO

Government (two members)

Mr Ted Gardner (2007-2012)
Principal Scientist
Former Department of Environment and Resource
Management

Mr Tad Bagdon (2010-2012) Replaced Dan Spiller
Acting General Manager
Regional Planning and Policy, Queensland Water
Commission

Mr Dan Spiller (2009-2010)
A/Principal Executive Director
Queensland Water Commission

Griffith University (one member)

Associate Professor Heather Chapman (2009-2012)
Replaced Joe Lee
Program Leader, Health and Environment
Smart Water Research Centre

Professor Joe Lee (2007-2009)
Deputy Director
Australian Rivers Institute

The University of Queensland (one member)

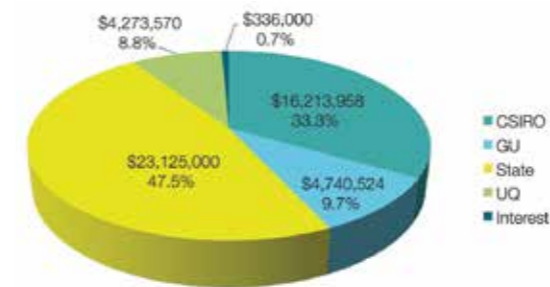
Professor Jurg Keller (2007-2012)
Director
Advanced Water Management Centre

Financial Summary – 2007-2012

Research Program

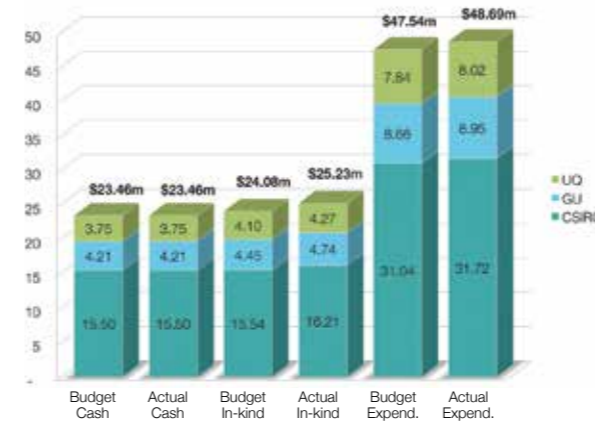
Over the life of the Alliance a total of \$23.46 million cash has been invested in the research projects - \$23.12 million directly from the Queensland Government and around \$0.34 million from interest earned on the Alliance Trust Account. This cash investment has been matched with \$25.23 million of in-kind contributions from the project partners – CSIRO, The University of Queensland and Griffith University – bringing the collective whole-of-life investment across the 22 research projects to \$48.69 million.

On a whole-of-life basis, the Alliance partners' cash and in-kind contributions to the research program were: Queensland Government \$23.125 million (47.5%), CSIRO \$16.214 million (33.3%), Griffith University \$4.741 million (9.7%), The University of Queensland \$4.274 million (8.8%), with around \$0.336 million (0.7%) from interest.



Whole-of-life cash and in-kind contributions to the Research Program.

On a whole-of-life basis, total cash and in-kind expenditure on the research program was: CSIRO \$31.719 million (65.15%), Griffith University \$8.950 million (18.38%), The University of Queensland \$8.020 million (16.47%).



Whole-of-life budgeted and actual cash and in-kind Research Program expenditure.

	State	CSIRO	UQ	GU	Total (\$)
Opening Balance	–	–	–	–	1,120,984.70
Receipts	–	–	–	–	Nil
Disbursements	–	698,227.00	51,250.00	40,500.00	789,977.00
Interest	–	–	–	–	11,015.46
Closing Balance					342,023.16

Administration Program

The total cost of administration for the Alliance on a whole-of-life basis to 30 June 2012 was \$3,191,380 with a further \$573,441 planned for the 2012/13 financial year, giving an estimated total spend of \$3,764,821.

The Administration Program was funded in accordance with each partners' participating interest in the Alliance (State – 50%, CSIRO – 32.60%, Griffith University – 9.14%, The University of Queensland – 8.26%), as represented in the chart below.

The anticipated minor administration overspend of around \$14.8k will be funded by excess Trust Account interest not required for research purposes.



Contribution by the Alliance Partners to the Administration Program.

Alliance Trust Account

The opening balance of the Alliance Trust Account for the 2012-13 financial year was \$1,120,984.70 and was \$342,023.16 as at 30 November 2012 (see table below). All research payments have now been made from the Trust Account. The only remaining cost until completion of the Alliance is the final administration payment of around \$337,291, which should leave the Trust Account with a balance of approximately \$4,732 depending on any additional interest earned in the interim.

Over the life of the Alliance, the closing balance of \$342,023.16 comprises:

- total receipts from all partners of \$26,875,000.03;
- total interest received of \$353,637.12; and
- total disbursements to research partners of \$26,886,613.99.

Data Discovery

Over the five-year life of the Alliance, the Partners in the Alliance have invested in and provided some \$50 million in research information, data and results.

The Alliance has collaborated with the Australian National Data Service (ANDS) and the Queensland Cyber Infrastructure Foundation (QCIF) to ensure key Alliance research data and reports are discoverable for key stakeholders and researchers nationally beyond the life of the Alliance. Metadata describing the Alliance research data and information will be exposed in Research Data Australia (RDA), the ANDS national metadata repository. The Alliance data collection can be accessed through <http://researchdata.ands.org.au/urban-water-security-research-alliance-collection>

The research data and reports are stored by the relevant Research Partner (CSIRO, The University of Queensland and Griffith University) on their secure storage facilities, with metadata describing those data ensuring discoverability through the RDA. Access to key data sets is also being provided, with access restrictions and licences where appropriate.

Technical Reports and Publications

- The Alliance's website <http://www.urbanwateralliance.org.au/> holds all our technical reports, journal articles, papers, annual reports and other publications. The website will be managed until 2017.
- All the published Technical Reports and Science Forum Books have ISSN status and are lodged with the National Library. The Queensland State Library also holds a collection of these reports (including our Annual Reports).
- CSIRO has developed a new repository, *ePublish*, for all their publications. Alliance Technical Reports containing CSIRO authors are included in this repository.

The records for newer reports will contain a URL to link to a pdf of the report. The older reports listed in the repository will only contain a link to the pdf of the report on the Alliance website. More information on the CSIRO repository can be found on: <https://publications.csiro.au/rpr/home>

- Both UQ and GU have similar repositories for publications with either a lead author or co-author from the two universities. The UQ facility is called *eSpace*. The GU facility is called *Griffith Research Online*. More information on the UQ and GU repositories can be found on: <http://espace.library.uq.edu.au/> and <http://www98.griffith.edu.au/dspace/>, respectively.

Research Data

- CSIRO is building a research data service with a *Data Access Portal* (DAP) to provide access to published data by CSIRO across a range of disciplines. The DAP has metadata provisions to describe and cite the data, upload data and set access restrictions. Metadata entered on the DAP is discoverable through RDA. Further information on the DAP is available from <http://data.csiro.au>
- GU research data is stored on the *Research Data Repository*, with the associated metadata being harvested to the RDA through the *Griffith Research Hub*. Further information on the Research Hub is available from <http://research-hub.griffith.edu.au/>. Further information on the data repository is available from <http://equella.rcs.griffith.edu.au/research/logon.do/>
- Similar research data storage and metadata facilities are currently being built at UQ. In the meantime, the data and metadata will be stored on a research development box (ReDBox) facility until the data can be transferred to the new storage facilities later in 2013.

Glossary

ANDS	Australian National Data Service
BAC	biological activated carbon
CO₂	carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAP	data access portal
DBP	disinfection by-product
DOC	dissolved organic carbon
FFMO	frequent flow management objective
GHG	greenhouse gas
GL/yr	gigalitres per year
GU	Griffith University
kL	kilolitres
km	kilometres
LCA	life cycle analysis
MBRC	Moreton Bay Regional Council
MF	micro filtration
NOM	natural organic matter
PRW	purified recycled water
QCIF	Queensland Cyber Infrastructure Foundation
RDA	Research Data Australia
ReDBox	research development box
RO	reverse osmosis
SEQ	South East Queensland
STP	sewage treatment plant
SWMM	stormwater management models
TWCM	total water cycle management
UQ	The University of Queensland
WQIAS	Water Quality Information Acquisition System
WWTP	wastewater treatment plant



RECYCLED CONTENT



FOREST MANAGEMENT



ENVIRONMENTAL
MANAGEMENT SYSTEMS



BLEACHING PROCESS