

# Urban Water Security Research Alliance

## Science Forum and Stakeholder Engagement

*Building Linkages, Collaboration and Science Quality*

28-29 September 2010

Brisbane, Queensland

## Program and Abstracts



The Urban Water Security Research Alliance (UWSRA) is a \$50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South-East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South-East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

For more information about the:

UWSRA - visit <http://www.urbanwateralliance.org.au/>

Queensland Government - visit <http://www.qld.gov.au/>

Water for a Healthy Country Flagship - visit [www.csiro.au/org/HealthyCountry.html](http://www.csiro.au/org/HealthyCountry.html)

The University of Queensland - visit <http://www.uq.edu.au/>

Griffith University - visit <http://www.griffith.edu.au/>

Enquiries should be addressed to:

The Urban Water Security Research Alliance  
PO Box 15087  
CITY EAST QLD 4002

Ph: 07-3247 3005; Fax: 07- 3405 3556

Email: [Sharon.Wakem@qwc.qld.gov.au](mailto:Sharon.Wakem@qwc.qld.gov.au)

Begbie, D.K. and Wakem, S.L. (eds) (2010), *Science Forum and Stakeholder Engagement: Building Linkages, Collaboration and Science Quality*, Urban Water Security Research Alliance, 28-29 September, Brisbane, Queensland.

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## Welcome from the Chair

Water is fundamental to our quality of life, economic growth and the environment. The **Urban Water Security Research Alliance (UWSRA)** is a \$50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance was formed to address Australia's South East Queensland's (SEQ) emerging urban water issues with a focus on water security and recycling. With its booming economy and growing population, SEQ faces increasing pressure on its water resources, compounded by the impact of climate variability and climate change.

The Alliance is the largest regionally focused urban water research program in Australia. The program brings new research capacity to SEQ tailored to tackling existing and anticipated future issues to inform the implementation of the SEQ Water Strategy.

### Alliance Research Framework

Since October 2007 when the Alliance was formed, the water situation for SEQ has changed dramatically. The Alliance has responded accordingly to realign its research program, with a greater focus on reducing water grid demand, ensuring the quality of our diverse water sources and planning for efficiency and sustainability.

Research for the Alliance will be delivered under three research themes:

1. Reducing Water Grid Demand
2. Water Source Quality
3. Total Water Cycle Planning and Management to Enhance Sustainability and Efficiency

### Research Program Objectives

- Undertake research into off-Grid supply sources, water use efficiency and demand management behavioural measures to reduce demand on the SEQ Water Grid by about 35 GL per annum in 2026 and defer new infrastructure by up to five years.
- Undertake research to inform water quality management planning, regulation, guidelines and communication on the nature and level of risk to human health from a wide range of source waters within SEQ.
- Undertake integrated urban water planning and management research to transform to a water smart SEQ region and enhance management efficiencies of the SEQ Water Grid and off-grid supplies.

The Alliance research program currently consists of 17 inter-related projects, each managed by one of the research partners (see page 6 for more details).

The Alliance will seek to align research where appropriate with other water research programs such as those of other local SEQ water agencies, The Australian Water Recycling Centre of Excellence, Water Quality Research Australia Limited (WQRA), the Water Services Association of Australia (WSAA) and Cooperative Research Centres (CRCs). In undertaking projects, consideration will be given to the direction, achievements and gaps in current research and alignment with the focus and goals of the Alliance.

The objectives of the Science Forum are to increase awareness of the science emerging across the Alliance and to increase key stakeholders' understanding of the current research findings of our projects. The intended audience includes key stakeholders, external reference panel experts and scientists undertaking urban water research in SEQ.

It is with great pleasure that I welcome you to the Alliance's 2nd Science Forum being held on Tuesday, 28 and Wednesday, 29 September 2010, in Brisbane.



**Chris Davis**  
Chair, Urban Water Security Research Alliance

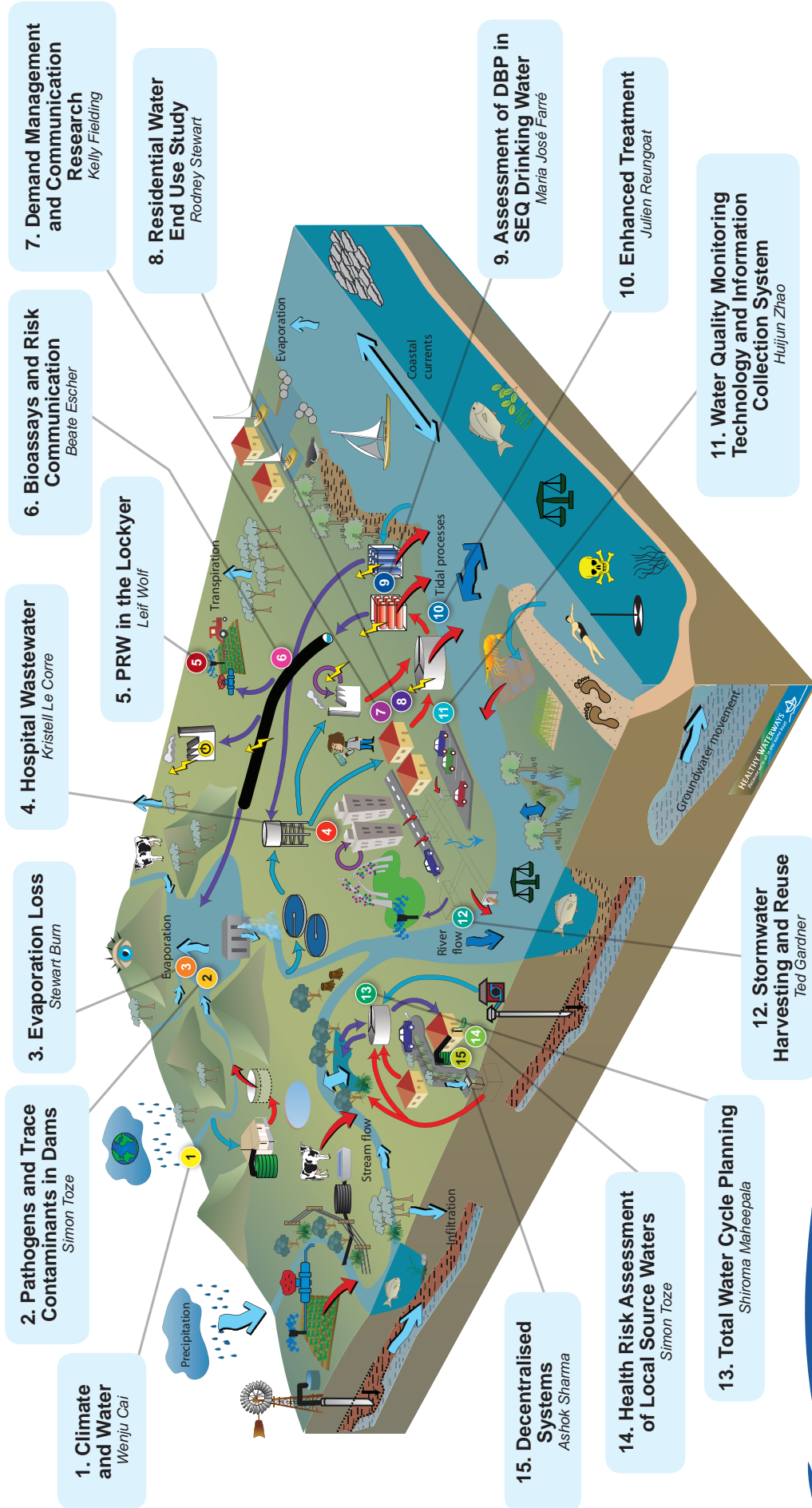
## The Alliance Research Program and Project Leaders

<b>Stormwater Harvesting and Reuse</b>	<i>Project Leader:</i> Mr Ted Gardner, DERM/CSIRO	07-3896 9488 <a href="mailto:Ted.Gardner@derm.qld.gov.au">Ted.Gardner@derm.qld.gov.au</a>
This project researches the innovative capture and storage of stormwater for additional water supply in SEQ. It will also research the impact of harvesting stormwater on creek and ecosystem health.		
<b>Decentralised Systems</b>	<i>Project Leader:</i> Dr Ashok Sharma, CSIRO	03-9252 6151 <a href="mailto:Ashok.Sharma@csiro.au">Ashok.Sharma@csiro.au</a>
This project will validate the contribution rainwater tanks can make to water savings targets in SEQ. It will also focus on energy costs associated with tanks and decentralised wastewater treatment.		
<b>Demand Management and Communication Research</b>	<i>Project Leader:</i> Dr Kelly Fielding, UQ/CSIRO	07-3214 2419 <a href="mailto:Kelly.Fielding@csiro.au">Kelly.Fielding@csiro.au</a>
This project is researching household water conserving behaviour with demand management interventions.		
<b>Residential Water End Use Study</b>	<i>Project Leader:</i> Dr Rodney Stewart, GU	07-5552 8778 <a href="mailto:r.stewart@griffith.edu.au">r.stewart@griffith.edu.au</a>
This project is installing "Smart Meters" in 320 homes in SEQ to quantify the impact of urban water demand management strategies.		
<b>Water Smart Cities</b>	<i>Project Leader:</i> Dr Tony Priestley, GU	03-9252 6514 <a href="mailto:tony.priestley@csiro.au">tony.priestley@csiro.au</a>
This project will scope a framework for moving to Water Smart cities and identify the barriers to adoption of water smart technology.		
<b>Hospital Wastewater</b>	<i>Project Leader:</i> Dr Kristell Le Corre, UQ	07-334 67207 <a href="mailto:k.lecorre@awmc.uq.edu.au">k.lecorre@awmc.uq.edu.au</a>
This project will focus on the relative contribution of hospital wastewater to sewage treatment plants.		
<b>Pathogens and Trace Contaminants in Dams</b>	<i>Project Leader:</i> Dr Simon Toze, CSIRO	07-3214 2698 <a href="mailto:Simon.Toze@csiro.au">Simon.Toze@csiro.au</a>
This project will focus on pathogen and trace contaminant attenuation within reservoirs and developing source tracking methods.		
<b>Bioassays and Risk Communication</b>	<i>Project Leader:</i> Dr Beate Escher, UQ	07-3274 9180 <a href="mailto:b.escher@uq.edu.au">b.escher@uq.edu.au</a>
This project will further develop the scientific, technical and communication basis for implementation of bioanalytical tools in Queensland's water quality monitoring programs.		
<b>Health Risk Assessment of Local Source Waters</b>	<i>Project Leader:</i> Dr Simon Toze, CSIRO	07-3214 2698 <a href="mailto:Simon.Toze@csiro.au">Simon.Toze@csiro.au</a>
This project will research the health risks associated with exposure to rainwater and storm water.		
<b>Enhanced Treatment</b>	<i>Project Leader:</i> Dr Julien Reungoat, UQ	07-3346 3235 <a href="mailto:j.reungoat@awmc.uq.edu.au">j.reungoat@awmc.uq.edu.au</a>
The project will research the effectiveness of biological activated carbon in non MF/RO options to achieve potable water quality.		
<b>Assessment of Regulated and Emerging Disinfection By-Products in SEQ Drinking Water</b>	<i>Project Leader:</i> Dr Maria José Farré Olalla, UQ	07-3346 3233 <a href="mailto:m.farre@awmc.uq.edu.au">m.farre@awmc.uq.edu.au</a>
This project will investigate the presence of emerging and regulated disinfection by-products in different SEQ drinking water sources.		
<b>Climate and Water</b>	<i>Project Leader:</i> Dr Wenju Cai, CSIRO	03-9239 4419 <a href="mailto:Wenju.Cai@csiro.au">Wenju.Cai@csiro.au</a>
This project will assess and quantify the impact of climate variability and change on water supply over the SEQ region.		
<b>PRW in the Lockyer Valley</b>	<i>Project Leader:</i> Dr Leif Wolf, CSIRO	07- 3214 2749 <a href="mailto:Leif.Wolf@csiro.au">Leif.Wolf@csiro.au</a>
This project will research the implications of using PRW as an adjunct to groundwater for irrigation in the Lockyer Valley.		
<b>Total Water Cycle Planning Framework</b>	<i>Project Leader:</i> Dr Shiroma Maheepala, CSIRO	03-9252 6072 <a href="mailto:Shiroma.Maheepala@csiro.au">Shiroma.Maheepala@csiro.au</a>
The project aims to provide the analytical methods and data required to improve the quantitative assessment and decision-making for the development of total water cycle management plans in SEQ.		
<b>Water Quality Monitoring Technology and Information Collection System</b>	<i>Project Leader:</i> Professor Huijun Zhao, GU	07-5552 8261 <a href="mailto:h.zhao@griffith.edu.au">h.zhao@griffith.edu.au</a>
This project has focussed on developing a proof-of-concept prototype on-line, real-time monitoring system to identify sudden changes in the water matrix at a wastewater treatment plant at Bundamba in SEQ.		
<b>Evaporation Loss</b>	<i>Project Leader:</i> Dr Stewart Burn, CSIRO	03-9252 6032 <a href="mailto:Stewart.Burn@csiro.au">Stewart.Burn@csiro.au</a>
This project is analysing technology to reduce evaporative losses from large SEQ dams and is undertaking detailed field analysis of the effectiveness of monolayers on a large farm dam.		
<b>Human Reliability Analysis Techniques</b>	<i>Project Leader:</i> Professor Brian Head, UQ	07-3346 7450 <a href="mailto:Brian.Head@uq.edu.au">Brian.Head@uq.edu.au</a>
This project will scope human elements, eg judgement, decision making, perception, in risk management and quality control systems.		

# Alliance Research Program 2010-2012

Leading water research and knowledge in South East Queensland

Urban Water Security Research Alliance



Conceptual model source:  
Healthy Waterways Partnership

**URBAN WATER SECURITY RESEARCH ALLIANCE**  
**Science and Stakeholder Engagement Forum #2**  
*Building Linkages, Collaboration and Science Quality*

Tuesday, 28 September 2010, 8:30am – 6:00pm  
 Wednesday, 29 September 2010, 8:00am – 4:00pm

Venue: Avro and Bristol Rooms, Royal on the Park, Cnr Alice and Albert Streets, Brisbane

Program

DAY 1 – Tuesday, 28 September		
Time	Session	Presenter
8:30am	<i>Registration and Welcome Coffee</i>	
9:00am	<b>Welcome and Opening Remarks</b>	Chris Davis Chair, UWSRA Management Board <i>Don Begbie, Director, MC</i>
9:15am	<b>Official Opening</b>	Mr Michael Choi, MP, Parliamentary Secretary to the Minister for Natural Resources, Mines and Energy, and Trade
9:30am	<b>Keynote Speaker</b> Towards Fourth Generation Water Infrastructure	Professor Stuart White Director, Institute for Sustainable Futures, University of Technology, Sydney, NSW
10:30am	<i>Morning tea</i>	
11:00am	<b>SESSION 1 - (Chair –Simon Toze)</b> <b>Reducing Water Grid Demand</b>	
	<b>Guest Speaker</b> Yarra Valley Water's Approach to Water Sensitive Communities	Mr Pat McCafferty A/CEO, Yarra Valley Water, Mitcham, Victoria
	Stormwater Research in South East Queensland an UWSRA Perspective	Ted Gardner
12:30pm	<i>Lunch</i>	
1:30pm	Communal Rainwater Harvesting: Monitoring and Validation	Steven Cook
	What Predicts Household Water Use Intentions and Behaviour in SEQ?	Anneliese Spinks
	South East Queensland Residential Water End Use Study: Baseline Results	Cara Beal
3:00pm	<i>Afternoon tea</i>	
3:30pm	<b>POSTER SESSION - (Chair – Rodney Stewart)</b> <b>Presentation of Selected Project Posters</b>	
4:30pm	<p style="text-align: center;"><b>Session Drinks and Networking Opportunity hosted and sponsored by</b></p> <p style="text-align: center;"></p> <p style="text-align: center;"><b>SPONSOR Presentation - Mark Roberts, Sustainability Leader, Water</b></p>	
6:00pm	<b>Close – Day 1</b>	

DAY 2 – Wednesday, 29 September		
Time	Session	Presenter
8:00am	Registration and Welcome Coffee	
8:30am	<b>SESSION 2 - (Chair – Leif Wolf)</b> <b>Water Source Quality</b>	
	<b>Guest Speaker</b> Advanced Wastewater Treatment: Trends in Europe	Dr Adriano Joss EAWAG, the Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland
	Bioanalytical Tools to Evaluate Micropollutants Across the Seven Barriers of the Western Corridor Scheme	Miroslava Macova
	Removal of Pharmaceuticals and Personal Care Products from Secondary Effluents by Ozone/Biological Activated Carbon Plants in Australia	Julien Reungoat
10:15am	Morning tea	
10:45am	Minimising the NDMA Formation during the Production of Purified Recycled Water	Maria Farre Olalla
	Disinfection By-product (DBP) Formation and Minimisation in Drinking Water	Nicole Knight
	Univariate Event Detection for Real-Time Waste Water Treatment Plant Protection	Huijun Zhao
12:15pm	Lunch	
1:15pm	<b>SESSION 3 - (Chair – Ted Gardner)</b> <b>Total Water Cycle Planning and Management to Enhance Sustainability and Efficiency</b>	
	Drought Frequency and Duration Projections for South East Queensland	David Kent
	Urban-Rural Water Exchange with Purified Recycled Water as an Adjunct to Groundwater Resources for Irrigation in the Lockyer Valley	Leif Wolf
	Life Cycle Analysis of the Gold Coast Urban Water Cycle	David de Hass
	Evaluation of Wind and Wave Action on Monolayers and Assessment of their Optical Properties	Peter Schouten
3:15pm	Afternoon tea	
3:45pm	<b>Awards for Best:</b> ➤ Paper ➤ Presentation ➤ Poster	Chris Davis / Don Begbie
3:55pm	<b>Summing Up and Close</b>	Don Begbie / Chris Davis
4:00pm	Close	

## OFFICIAL OPENING SPEAKER



### **Mr Michael Choi, MP**

*Parliamentary Secretary to the Minister for Natural Resources, Water and Energy  
and Minister for Trade, QLD*

Michael Choi was elected to State Parliament in 2001 and is Parliamentary Secretary to the Minister for Natural Resources, Water and Energy and Minister for Trade.

Michael is a professional chartered engineer and has many years experience in project management, design and construction. He is married and has three daughters.

Michael has served as Honorary Ambassador for Brisbane city, fostering ties between Brisbane and Asia Pacific countries, as well as chairing the Sister Cities Committee with the Chinese city of Shenzhen. As president of the Valley Business Association, he helped the Valley business community through the difficult Fitzgerald Inquiry period and was instrumental in creating the safe, vibrant recreational culture enjoyed there today. He is also involved in many professional and community organisations such as the Housing Industry Association, the Small Business Council of Queensland and was a director of Queensland Ballet Inc. Michael's interests are politics, music, scuba diving and watching movies.

## KEYNOTE SPEAKER



### **Professor Stuart White**

*Director, Institute for Sustainable Futures  
University of Technology, Sydney, NSW*

Professor Stuart White is Director of the Institute for Sustainable Futures where he leads a team of researchers who create change towards sustainable futures through independent, project-based research. With over twenty years experience in sustainability research, Professor White's work focuses on achieving sustainability outcomes at least cost for a range of government, industry and community clients across Australia and internationally. This includes both the design and evaluation of programs for improving resource use efficiency and an assessment of their impact. Professor White has written and presented widely on sustainable futures and is a regular commentator on sustainability issues in the media.

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## GUEST SPEAKERS



### **Mr Pat McCafferty**

*A/Chief Executive Officer*

*General Manager, Strategy and Communications, Yarra Valley Water, Mitcham, Victoria*

Pat is a senior executive with over 25 years experience in the water industry. As General Manager, Strategy and Communications, he is responsible for corporate strategy, regulation and planning, marketing, and strategic communications at Yarra Valley Water, the largest water retailer in Melbourne. He is primarily responsible for long term strategic planning, the organisation's regulatory interface, contributing to metropolitan water industry policy and long term planning, and overseeing communications, marketing and water conservation functions.

Prior to his current position, Pat was General Manager, Customer Operations at Yarra Valley Water, where his responsibilities included overseeing customer service for water and wastewater services to a population over 1.5M.

Pat spent six months in the USA in 2002 on secondment to a Californian water utility, advising on strategic planning and learning about California's approach to water conservation.

In 2007 Pat was Chair of an Expert Group advising the Federal Government on communications and billing practices in the water sector to support water conservation, as part of the National Water Initiative.

Pat holds a Bachelor of Business degree from RMIT and an Executive MBA from Monash University. He is also a graduate of Leadership Victoria's Williamson Community Leadership Program.



### **Dr Adriano Joss**

*EAWAG, the Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland and*

*Visiting Academic, Advanced Water Management Centre, The University of Queensland*

Dr Adriano Joss is a Research Associate in the Process Engineering Division of EAWAG, the Swiss Federal Institute of Aquatic Science and Technology, based at Duebendorf, Switzerland. He has just commenced a 12 month sabbatical to take up a position of Visiting Academic with the Advanced Water Management Centre at The University of Queensland. He is married and has two children. He speaks fluent German, Italian, English and French.

Adriano's major research areas cover modelling and design of biological wastewater treatment; description and modelling of fate of micro-pollutants in municipal wastewater treatment; application of membrane technology for activated sludge treatment; nitrogen removal with combined nitrification/anammox; and N<sub>2</sub>O emission from wastewater treatment. He has written and published extensively on these issues.

Adriano's other professional activities have included various commissions for the planning of the renewal of the WWTP (Uerikon, Wädenswil, Herisau, Flawil, Brugg-Windisch) and a member of the Swiss Water Association, active in the commission for advanced training of professionals. He is also a Member of the International Water Association (IWA), London and a Member of the European Membrane Society (EMS), Toulouse.



# Abstracts – Podium Presentations

# Communal Rainwater Harvesting: Monitoring and Validation

Cook, S.<sup>1</sup>, Chong, M.<sup>2</sup>, Sharma A.<sup>1</sup>, Gardner, T.<sup>2</sup> and Chowdhury, R.<sup>2</sup>

<sup>1</sup> CSIRO Land and Water, 37 Graham Road, Highett, Victoria

<sup>2</sup> CSIRO Land and Water, 120 Meiers Road, Indooroopilly, Queensland

## Summary

Decentralised water sources are an important part of the strategy to secure urban water services for South East Queensland (SEQ) by reducing pressure on grid water supply. This paper details a study into the feasibility of communal rainwater tanks in achieving the mandatory water saving targets, and what are the energy use implications for moving to this alternative water source. Two case study developments, with communal rainwater systems, are being monitored and modelled to validate system performance under different operating conditions. The preliminary results from the monitoring show that rainwater systems can be designed to meet significant portion of internal water demand for both residential and commercial buildings.

## Keywords

Communal rainwater, decentralised water systems, water-energy nexus, water balance.

## Background

Rainwater tanks have been identified in the *South East Queensland Water Strategy* as a key element in securing sustainable levels of urban water services for SEQ (Queensland Government, 2009). All new detached dwellings are now mandated to achieve 70 kL in annual reduction in demand for grid water supplies; for townhouses the requirement is to reduce demand for grid water by 42 kL. Part 4.2 of the Queensland Development Code (QDC) stipulates that internally plumbed rainwater tanks are one option to achieve the water saving target. Other options include: communal rainwater tanks, stormwater harvesting, dual reticulation recycled water schemes, and the treatment and reuse of greywater. The QDC also specifies performance criteria and acceptable solutions for alternative water sources in commercial buildings (MP 4.3). This research project has been initiated to understand the feasibility of achieving water savings targets specified under the QDC through communal rainwater tanks and any energy penalty associated with these systems.

Two case study developments with communal rainwater systems were selected for monitoring and validation: Capo di Monte and Green Square North Tower. Capo di Monte (CDM) is a 46 dwelling residential development at Mt Tamborine on the outskirts of the Gold Coast. CDM is self sufficient for water and wastewater services. Potable water demand (drinking, cooking, bathroom and laundry) is met by rainwater harvested from roof runoff, which is treated and stored communally, and then reticulated to residences. Top-up is available from a bore. Recycled wastewater is used to meet non-potable demand (toilet flushing and irrigation). The other case study development is Green Square North Tower (GSNT), which is a 12 storey commercial building in Brisbane's central business district that is certified under the voluntary Green Building Council of Australia's environmental rating system as six Green Stars. Roof runoff is directed to an 80 kL basement storage tank, before being pumped to two smaller roof-top tanks (40 kL and 27 kL), which in turn are gravity fed for toilet flushing and landscape irrigation. Roof runoff is also supplemented by cooling tower blowdown water, fire-fighting test water and air conditioner condensate.

For each of the case studies, extensive monitoring systems have been set up to capture energy and flow data from the rainwater systems. Manual meters are used to validate electronic data-logging. We have also undertaken water balance and hydraulic modelling to complement field measurements that explored the optimal performance of communal rainwater systems under different operating assumptions.

## Results

### Capo di Monte

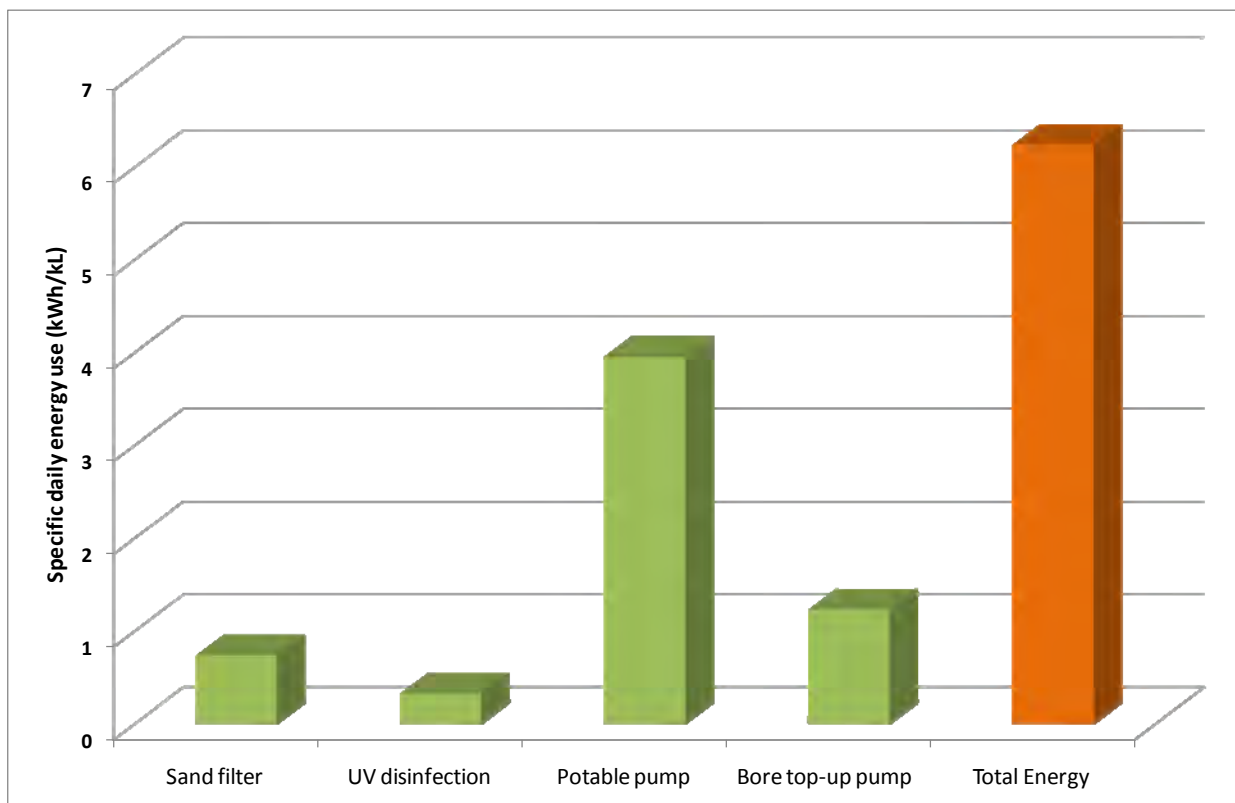
Table 1 presents a summary of monitoring data for CDM for the period December 2009 to June 2010. The total water use at CDM of 2,326 kL is equivalent to a daily per person use of 178 litres of which 76 litres is treated rainwater used exclusively internally and 102 litres used for garden watering and toilet flushing. Over the monitoring period, bore water top-up was needed to meet less than 20 per cent of drinking water demand. This is due to the six month monitoring period experiencing high rainfall over the summer months. The low reliance on bore water was validated with water balance modelling, using 30 years of historical rainfall data, which showed that even given seasonal and yearly fluctuations in rainfall the CDM system would only have limited reliance on bore water top-up. Table 1 also shows the estimated yearly values for water flows, which are extrapolated on the basis of the six months of monitoring data. This shows that the rainwater system provides an estimated 42 kL per household (hh) per year compared with an estimated total potable demand of 51 kL/hh/year (including bore water top-up). The recycled

wastewater system supplied 63 kL/hh/year for non-potable use. Comparison of CDM with the QDC target of 70 kL/hh/year needs to consider that under MP4.2 of the code alternative sources can only be used for toilet flushing and laundry demand.

**Table 1.** Summary of Capo di Monte communal rainwater system monitoring data.

Source	Total water use for period 07/12/2009 to 03/06/2010 (kL)		Daily water use for period (kL/day)	Estimated yearly water use per household (kL/hh/year)
Total household water use	2,326		13.3	105.5
Potable rainwater system	1,001		5.3	42.2
Non-potable recycled water system	1,325		8	63.3
Bore water top-up for hh purposes	Top-up to Potable Rainwater system	203	1.1	8.7
	Top-up to Non- potable recycled water system	41	0.2	1.8
Recycled water for Irrigation (public open spaces)	137		0.8	6

Figure 1 shows the specific daily energy use for the various elements of the CDM communal rainwater system, with total daily energy use of 6.2 kWh/kL. The highest specific energy is associated with the potable pump (3.9 kWh/kL), which may be a result of the pump being an on demand system where any use in the system will trigger pumping. This is likely to result in high transient energy consumption on pump start-up and will be explored further in this research. In comparison, Kenway *et al.* (2008) reported that the average energy associated with centralised potable water supply for Brisbane was 0.7 kWh/kL.



**Figure 1.** Specific energy – Capo di Monte communal rainwater system.

## Green Square North Tower

Results from GSNT are only preliminary at this stage, as there were problems in commissioning the automatic energy and water meters. However, manual readings have been used to initially characterise the rainwater system. This shows that landscape irrigation demand is negligible ( $<0.1$  kL/day), while demand for toilet flushing is 8.2 kL/day. Roof runoff is not sufficient to satisfy demand for toilet flushing with tank top-up required from municipal water mains. Header tanks supply the outlets (toilets and irrigation of planter boxes) by gravity, eliminating the need for pressure pumps or vessels. The specific energy of the rainwater supply from the basement tanks was 0.6 kWh/kL.

## Significance and Future Work

This research is validating the performance of communal rainwater tanks as an option to achieve the mandatory 70 kL/hh/year water saving required for new separate dwellings in SEQ. The monitoring study will assist in exploring the reliability of these systems in delivering the water savings and also any associated energy penalty when compared to grid water supply. Water balance and hydraulic modelling combined with field measurements will give us a better understanding of the optimal performance of the communal rainwater system in satisfying demand under different operating assumptions.

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# What Predicts Household Water Use Intentions and Behaviour in SEQ?

Spinks, A.<sup>1</sup>, Fielding, K.<sup>1,2</sup>, Russell, S.<sup>3</sup>, Mankad, A.<sup>1</sup> and Price J.<sup>1</sup>

<sup>1</sup> CSIRO Ecosystem Sciences, Queensland Biosciences Precinct, St Lucia, Queensland

<sup>2</sup> Institute of Social Sciences Research, The University of Queensland, St Lucia, Queensland

<sup>3</sup> School of Business, Griffith University, Nathan, Queensland

## Summary

This paper describes the key predictors of householders' intentions to engage in everyday water saving actions and to install water efficient appliances, and provides recommendations of ways that these factors may be influenced.

## Keywords

Household water conservation, psycho-social determinants, socio-demographic determinants.

## Background

Long term strategies are needed to ensure that future demand for residential water does not exceed the available supply. The success of interventions targeting water conservation is dependent, however, on the social and behavioural aspects of household water use. There is a need to understand how people use water, and how sustainable levels of water use can be achieved and maintained in the long-term. The Demand Management and Communication Research project addresses these issues.

The research involved a quantitative survey of free standing owner-occupied households from the South East Queensland (SEQ) community. The survey identified psychosocial and socio-demographic drivers of residential water use, using an expanded Theory of Planned Behaviour (TPB) as the overarching theoretical framework (Ajzen, 1991) (see Figure 1). The expanded TPB model was used to identify the predictors of two different types of household water conservation behaviours: 1) *curtailment* behaviours, which referred to everyday water saving actions (eg, taking shorter showers, turning tap off while brushing teeth); and 2) *efficiency* behaviours, which referred to one-off installations of water efficient appliances (eg, water efficient washing machines, rainwater tanks; Gardner and Stern, 1996).

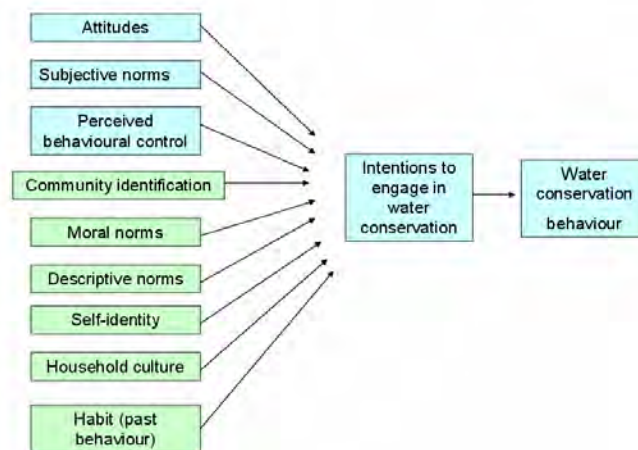


Figure 1. Expanded Theory of Planned Behaviour Model.

## Methods

The study was conducted within four local government areas (LGAs) in the SEQ region: Brisbane, Gold Coast, Ipswich and Sunshine Coast. Participants were owner occupiers of free-standing dwellings in the target regions and were recruited via a commercial list supplier ( $n = 1,381$ ) or through an online research panel ( $n = 603$ ). Targeted households were connected to the central water supply and had an individual water meter attached to their premises. Participants completed The Household Water Use Survey (paper or online version), which consisted of 27 multi-item questions which were designed to elicit information about participants' household water use and conservation, as well as standard demographic and household composition data. In the analyses, variables were assessed based on the expanded TPB model and responses were distinguished as *curtailment* and *efficiency* water saving behaviours, with associated attitudes and intentions.

## Results

Results showed that regional and demographic factors played a role in water efficiency intentions. Age, income, education, household size, cultural background, perceptions of water use, and psychosocial and behavioural measures varied across the four regions and between groups of participants. Younger respondents were less likely to demonstrate positive attitudes, perceived less support to engage in water saving behaviours, and felt less morally obliged to save water than their older counterparts. Females were more likely to feel a moral obligation to conserve water and reported higher self-efficacy in relation to water saving behaviours. Females also reported higher intentions to engage in both curtailment and efficiency behaviours around the home, as did people within the lower income and education categories. Respondents in the lower income and education categories also reported engaging in past curtailment actions more often than other groups of participants. Interestingly, households in the top two income categories were less likely to have installed grey water systems in their homes. However, there was a linear relationship between household income and past installation of water-wise washing machines.

Linear regression models were performed to test how well the expanded TPB variables were able to predict intentions to carry out curtailment and efficiency related behaviours, whilst controlling for demographic and household characteristics. Consistent with past research framed by the TPB (Armitage and Conner, 2001; Conner and Armitage, 1998), the analyses showed that stronger overall intentions to engage in water conservation practices - both everyday actions and installation of efficient devices - were associated with more positive attitudes to these actions, a greater sense of personal obligation, and a greater sense of self-efficacy. Looking specifically at everyday water saving practices, it was clear that a sense of personal moral obligation to conserve water around the home was the strongest determinant of curtailment intentions. Household culture of water conservation was also an important determinant of respondents' intentions to engage in everyday water saving practices. In terms of overall water *efficiency* intentions, feeling a sense of personal moral obligation to save water was again the strongest predictor of efficiency intentions. Stronger overall efficiency intentions were also associated with a greater sense that others in the community had installed efficiency devices (ie, descriptive norms) and identification with the SEQ community. These findings suggest that water efficiency intentions are, in part, influenced by householders' connection with the larger community and their observations of what others in the community are doing.

The results also highlighted the important influence of water conserving habits on future intentions - both overall and specific (cf. Conner and Armitage, 1998). Specific water conserving habits were significant predictors of overall curtailment and efficiency intentions. Water conserving habits were also the strongest predictor of future intentions to engage in specific water curtailment actions (eg, checking and fixing leaking taps, taking shorter showers). The only other consistent predictor was self-identity, with householders with stronger identities as water conservers also stronger efficiency intenders. This finding is consistent with identity theory (Stryker, 1968; 1980), which explains the processes underlying why individuals adopt shared attitudes with groups to which they feel they belong. The findings are also consistent with past research demonstrating that self-identity is an important addition to the TPB (eg, Conner and Armitage, 1998). In terms of predictors of intentions to install specific water efficient appliances, the most consistent predictors across the different appliances were moral norms and self-efficacy.

## Significance and Impact

Taken together, these results suggest avenues for motivating householders' willingness to engage in water conservation practices. Feeling a sense of personal moral obligation to conserve water is an important determinant of overall water curtailment and efficiency intentions and intentions to install specific water efficiency devices. Messages that highlight the link between individual actions and the collective outcome and those that emphasise the responsibility of all citizens to address the issue of water conservation may help to develop this sense of moral obligation. Creating a culture of water conservation, within the household and within the broader community, may promote willingness to engage in water conserving actions. Providing procedural information or rebates and incentives (eg, for installing water efficient appliances) may help to develop householders' confidence and efficacy. Further, providing prompts at the point of water use or developing implementation intentions, such as a written plan of when, where, and how to enact particular behaviours may help to do this. Once people acquire an identity as a water conserver, they are likely to pursue actions that are congruent with that identity.

## Future Work

Future analyses will be performed to test whether householders' intentions to save water predict their future water use behaviour. Additionally, a number of interventions will be tested to establish their effectiveness at maintaining efficient water use among households in SEQ.

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# South East Queensland Residential Water End Use Study: Baseline Results

Beal, C., Stewart, R.A., Huang, A., Talebpour, R., Rey, E. and Maitland, J.  
Smart Water Research Centre, Griffith University, Southport, Queensland

## Summary

This paper provides residential water end uses for a sample of 250 households located in South East Queensland (SEQ). Specifically, end use analysis was undertaken for a two week period in winter 2010. A mixed method approach was used, combining high resolution water meters, remote data transfer loggers, household water appliance audits and a self-reported household water use diary. Generally, for most regions, total household water use was lower than reported in other Australian end use studies. Moreover, as per prior recent studies, shower and clothes washer end uses had the highest per capita consumption. Irrigation end use was low due to the season as well as changed behavior towards outdoor water use in SEQ instilled during the drought period. Future analysis will correlate end use data with socio-demographic factors, household appliance stock and diurnal trends.

## Keywords

Trace analysis, end use, water efficiency, demand management, smart meters, data capture.

## Introduction

Despite the successful and ongoing water conservation outcomes in SEQ, the demand management approach to reduce water consumption necessitated a 'reactionary' approach rather than a proactive approach. This highlighted the need for more detailed information on how potable water is proportioned in households and how this may change both spatially and temporally across SEQ. In Australia, there have been only a few end use studies using a combination of metering technology, household surveys and end use software. End uses of water in residential households include showers, clothes washers, toilets, taps, dishwashers, baths and irrigation (Mayer and DeOreo 1999). Advances in methods for data capture, transfer, storage and analysis have improved the resolution of water volume data and made transfer and collection of data substantially more time efficient. Factors that influence end use consumption include demographics of the household, water appliances and residential attitudes and behaviours. Bathroom (toilet, shower) and laundry activities generally place the greatest demand on potable water with a combined daily usage averaging around 95 L per person (Loh and Coghlan 2003, Roberts 2005, Willis *et al.* 2009). The primary aim of the greater study was to quantify and characterise mains water end uses in a sample of 300+ residential dwellings located within SEQ in different seasonal periods. This paper reports on the baseline end use analysis conducted in winter 2010.

## Methods

A mixed method approach was used, combining high resolution water meters, remote data transfer loggers, household water appliance audits and a self-reported household water use diary (Figure 1).



Figure 1. Schematic flow of process for acquisition, capture, transfer and analysis of water flow data.

Existing standard water meters were replaced with high resolution meters that are capable of providing 0.014 L/pulse outputs in five second intervals to wireless data loggers. Received data was extracted from the database and disaggregated into all end use events associated with the sampled residential households. A stock appliance survey on the study sample was also conducted to document each household's water fixture/appliance inventory as well as to qualify how householders interact with such stock. Each household was also asked to fill out a water diary where as many internal and external water use events as possible were recorded over a seven day period. The logged water flow data was analysed by Trace Wizard® software (Aquacraft 2010). The sub-sample for the SEQ End Use Study

(SEQEUS) project was generated from the Demand Management component of the larger Systematic Social Analysis (SSA) study, which involved the completion of a questionnaire for over 1,500 homes across SEQ. From this pool, a smaller sub-sample of homes in each of the four regions, namely, Gold Coast, Brisbane, Ipswich and Sunshine Coast, consented to the SEQEUS project.

## Results

The results suggest that residential water consumption was generally lower than previous reports for SEQ (eg, Queensland Water Commission (QWC) weekly estimates) and other Australian end use studies (eg, Roberts 2005; Willis *et al.* 2009). An average total water consumption of 371 L/household/day was recorded during the period of analysis. This represented a per capita average of 145 L/p/d. In comparison, the QWC reported average per capita water use of 154 L/p/d for the period of analysis. The Queensland Water Commission's permanent water conservation measures have a target per capita daily water consumption of 200 L/p/d which exceeded average per capita water usage measured in this study.

The bulk of the end uses were contributed by shower 43 L/p/d (29%), clothes washer 31 L/p/d (21%) and general tap use 27.5 L/p/d (19%). Irrigation made up less than around 5% of average total consumption, which is much less than a decade earlier (Loh and Coghlan 2003). Although larger families used the greatest share of water, they were also usually more water efficient on a per capita basis. Bath use was more predominant for families with young children and tended to reduce these households per capita shower use. Overall, bath use made up less than 2% of total use providing evidence that showering is now preferred for the majority of households. Shower water use for fixtures with low flow shower heads had a substantial impact on reducing shower volumes. Families with young children had the greatest frequency of tap usage and typically used higher volumes for clothes washing. Conversely, clothes washing was usually lower for elderly households but toilet usage was over-represented in this demographic compared to other family types.

The stock surveys undertaken for each home revealed a variety of water star rating machines with a clear trend for higher star rating machines to use less water. This provides further evidence that monetary incentives such as government rebates for purchasing high efficiency (AAA+ or 3 star+) appliances can be economically worthwhile and a successful demand management strategy. The attitudes and water use behaviours of people have generally moved toward a more conservative approach to water use. Interestingly, despite 44% of the survey respondents self-identifying as 'high' water users, they consumed an average of 23 L/p/d less than the self-identified 'low' water users (155 L/p/d).

## Conclusions

The low water consumption reported for this study confirms the anecdotal and government reporting of a shift in general water consumption post drought in SEQ. This may be partly a result of the prolonged water restrictions that have created a behavioural shift in SEQ consumers. Given that the sample was across four regions of varying levels of water restrictions in the recent past (eg, severe for Brisbane and Ipswich, more relaxed for the Gold and Sunshine Coasts) the observed trend of generally lower water consumption is likely to be representative across SEQ. This will be confirmed in future research linking end use data with consumer attitudinal data. Water end use data is useful for developing, validating and refining urban water policy. Moreover, end use data correlated with demographic data (eg, income, age, gender and family composition), land use data and household appliance stock data can inform government and water business demand management policy, water rebate program effectiveness and householders' response to changed water policy.

## Future Work

End use analysis will also be completed for other seasons (eg, summer 2010/11) where more detailed analysis and discussion will cover comparative assessments between clustered samples based on demographics, households with different fixture/appliance star ratings, water end use diurnal patterns, analysis of leakage volumes and leak typology patterns, and comparisons of water end uses before and after a range of interventions instigated through the SSA Demand Management project.

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# Bioanalytical Tools to Evaluate Micropollutants across the Seven Barriers of the Indirect Potable Reuse Scheme

Macova, M.<sup>1</sup>, Escher, B.<sup>1</sup>, Mueller, J.<sup>1</sup> and Toze, S.<sup>2</sup>

<sup>1</sup> National Research Centre for Environmental Toxicology (Entox), The University of Queensland, Coopers Plains, Queensland

<sup>2</sup> CSIRO Water for a Healthy Country, Queensland Biosciences Precinct, St Lucia, Queensland

## Summary

We evaluated the use of a range of bioanalytical tools for monitoring micropollutants across the seven barriers of the indirect potable reuse scheme and to assess the efficacy of different treatment barriers. Overall, the toxicity of the samples across the seven barriers ranged in the same order of magnitude as seen during previous studies in wastewater and advanced water treatment plants and reservoirs. Barrier 2 treatment (wastewater treatment plant) reduced the responses in all selected bioassays. Further decrease in toxic effects in the water was observed after microfiltration, reverse osmosis and advanced oxidation (Barrier 3-5) to the level typically falling below the detection limit of the assay or not significantly different from the blank.

## Keywords

Bioanalysis, micropollutants, toxicity, water recycling, indirect potable reuse.

## Introduction

The potable water recycling scheme consists of seven treatment barriers: 1 – source control, 2 – wastewater treatment plant (WWTP), 3 – microfiltration, 4 – reverse osmosis, 5 – advanced oxidation (combining hydrogen peroxide and UV irradiation), 6 – natural environment and 7 – water treatment plant. The water produced meets potable standards, but is not currently used for drinking water supply. Therefore the resulting purified recycled water is not piped to Lake Wivenhoe - the potable water reservoir. Water at all stages of this process is subject to quality monitoring to assess the efficacy of the treatment barriers and to ensure the water meets health and safety requirements. Toxicity testing may provide complementary information to chemical analysis on the sum of micropollutants present during water treatment. Therefore, a bioanalytical “mode of action” test battery, developed or optimised at Entox in collaboration with colleagues from the Swiss Federal Institute of Aquatic Science and Technology, has been included in water recycling projects to support water quality assessment. Bioanalytical techniques have been selected to target the groups of chemicals of particular relevance for human and environmental health including genotoxicity, endocrine activity, neurotoxicity, dioxin-like activity and non-specific cell toxicity (Macova *et al.*, 2010).

In this study, we focus on the applicability of selected bioanalysis in the monitoring of the micropollutants across all seven treatment barriers, to ensure that the limitations and strengths of bioanalytical tools are understood.

## Material and Methods

Grab samples were collected at 21 sites across the seven barriers: Oxley Creek WWTP (Barriers 1 and 2); microfiltration, reverse osmosis and advanced oxidation at Bundamba advanced water treatment plant (AWTP), Bundamba offtake, Lowood and Caboonbah Pipeline (Barriers 3 to 5); Power station lake, Wivenhoe dam and mid-Brisbane river representing the natural environment (Barrier 6); and Mt. Crosby WTP and the drinking water distribution system (Barrier 7). Sampling was complemented by two types of bottled water to compare the quality of PRW and by procedural blank (MilliQ water processed the same way as the samples) to assess any effect associated with the extraction process or with the solvent.

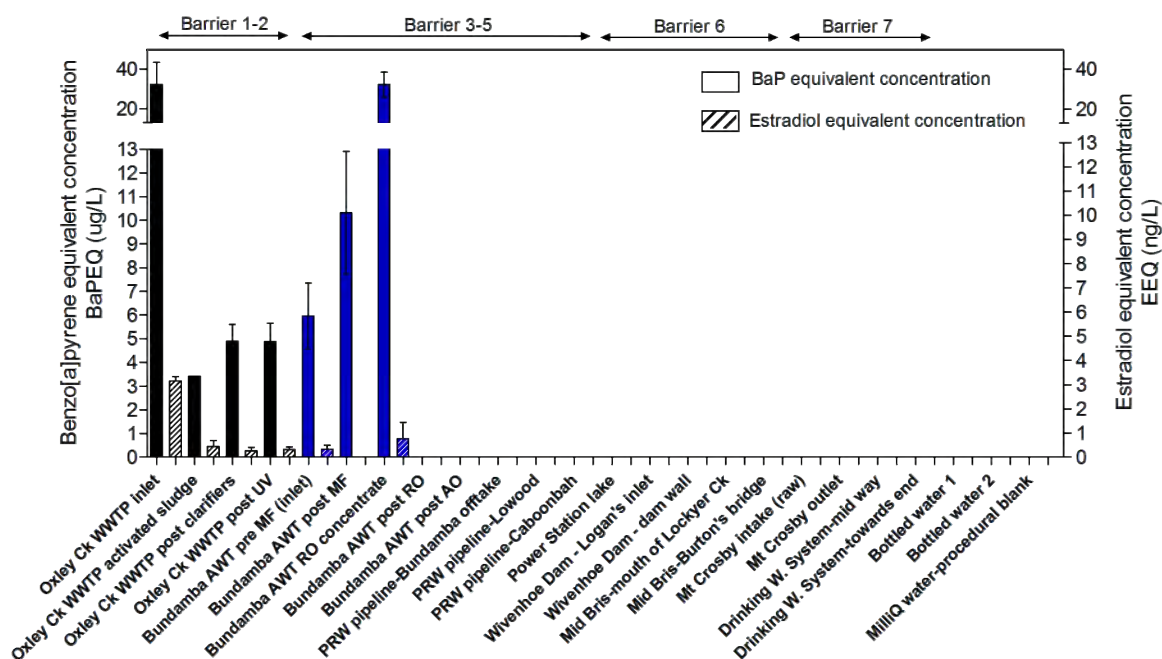
The aqueous samples were enriched using solid-phase extraction and tested in six selected bioassays to cover representative endpoints from the three categories of modes of toxic action, non-specific, specific and reactive toxicity. The non-specific baseline toxicity, representing the integrative effect of all micropollutants and low molecular-weight organic molecules in the sample, was assessed with the bioluminescence inhibition test using the marine bacterium *Vibrio fischeri*. The umuC assay, with and without prior metabolic activation, was chosen to represent an important aspect of reactive toxicity and targeted chlorinated byproducts, aromatic amines and PAHs. Groups of chemicals with specific modes of toxic action were targeted with four additional bioassays: E-SCREEN (which targets estrogens and estrogenic industrial chemicals); AhR-CAFLUX (which targets polychlorinated dibenzodioxins/furans, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs)); neurotoxicity (organophosphates and carbamate insecticides); and phytotoxicity (triazine herbicides and phenylurea).

## Results and Discussion

Results of all six assays are reported in toxic equivalent concentrations (TEQ) using a corresponding reference compound representing the group of targeted chemicals. TEQ is the concentration of a reference compound required to elicit the same response in a given assay as the mixture of micropollutants present in the sample.

Baseline toxicity of the samples was decreased by 94% after treatment in Oxley Creek WWTP (Barrier 2) (Figure 1). Microfiltration (Barrier 3) did not significantly alter the baseline toxicity. Further reduction in the baseline toxicity was observed after reverse osmosis and advanced oxidation at Bundamba AWT (Barrier 4-5) to 2% and 0.5% of the original activity, respectively. Apart from the Mt. Crosby outlet sample, the baseline toxicity of samples collected after Barrier 5 were not significantly different from the blank. The observed increased baseline toxicity of the Mt. Crosby outlet sample was reproducible in a second sampling campaign but the level is of no concern as the levels are below effect levels modeled for this endpoint under the assumption that all chemical concentrations are present below their drinking water guideline values.

The genotoxicity was decreased below detection limit after Barrier 4. The benzo[a]pyrene equivalent concentrations for genotoxicity after metabolic activation are depicted in Figure 1. The corresponding values for the assay performed without metabolic activation are very similar. All four endpoints for specific modes of toxic action showed a similar response pattern. In all cases, the micropollutant burden was significantly decreased post Barrier 2 (to a different extent) and further reduced after reverse osmosis treatment (Barrier 4) and advanced oxidation (Barrier 5). The effects in Barrier 6, 7 and in drinking water were very low for many endpoints, typically falling below the detection limit. As an example, estrogenic effect, expressed as estradiol equivalent concentration (EEQ), is depicted in Figure 1.



**Figure 1.** Genotoxicity after metabolic activation expressed as benzo[a]pyrene equivalent concentration and estrogenicity expressed as estradiol equivalent concentration of the samples across the seven barriers of the Western Corridor Recycled Water Scheme. Data represent the average of two replicates. Bars indicate the standard deviation. (Missing bars represent data below detection limit of the assay: 0.01 ng/L of EEQ and 0.81 µg/L of BaPEQ.)

## Conclusion

The toxicity of samples was reduced across the seven treatment barriers in all six selected bioassays. Each bioassay showed a differentiated picture representative for a different group of chemicals and their mixture effect. Detection limits of the bioassays, comparable to or lower than the quantification limits of the routine chemical analysis, allowed monitoring of the presence and removal of micropollutants post Barrier 2. The results obtained by bioanalytical tools were reproducible, robust and consistent with previous studies assessing the effectiveness of the wastewater and advanced water treatment plants. The results of this study indicate that bioanalytical results expressed as TEQ provide valuable complementary information to identify potential issues or to predict potential exposure/risks of micropollutants to humans or the environment. In the next two years of the project on bioanalytical tools, we plan to further validate and expand the test battery and put a particular focus on developing an effective communication strategy.

The authors acknowledge the collaboration with Seqwater, WaterSecure, Veolia Water, Brisbane Water and Ipswich Water (now both part of Queensland Urban Utilities) for providing access to facilities and water samples for this study.

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# Removal of Pharmaceuticals and Personal Care Products from Secondary Effluents by Ozone/Biological Activated Carbon Plants in Australia

Reungoat, J., Rattier, M., Gernjak, W. and Keller, J.

Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

## Summary

This research compares the removal of pharmaceuticals and personal care products (PPCPs) in wastewater reclamation plants combining ozonation and biological activated carbon (BAC). The results confirm that ozone/BAC treatments are very effective for PPCPs removal, indeed over 90% concentration reduction was observed for most of the detected compounds. Ozone dose and empty bed contact time in the BAC are key operating parameters influencing the removal of PPCPs.

## Keywords

Pharmaceuticals and personal care products, ozonation, biological activated carbon, advanced treatment, wastewater treatment plant effluent.

## Introduction

With the ever increasing pressure of the population on natural resources and the threat of climate change consequences, wastewater reclamation for indirect potable reuse has become of growing interest to secure water supply. To date, many of the large reclamation schemes operating in the world rely on the combination of microfiltration and reverse osmosis (MF/RO) to provide a physical barrier to biological and chemical hazards. The major drawback of this technology is that it produces a concentrate waste stream equivalent to about 15% of the treated volume, limiting the recovery efficiency of the process to 85%. Moreover, this stream has high salt and other compounds concentrations which make it very difficult to discharge in water bodies other than the open sea to avoid major impacts on the environments. Thus, alternatives to MF/RO have to be developed to promote indirect potable reuse for inland locations and treatments based on the combination of ozonation and biological activated carbon (BAC) could be used. Pharmaceuticals and personal care products are a major concern when considering indirect potable reuse. It is therefore of paramount importance to investigate their fate in proposed alternative treatment trains. Previous work on a full scale reclamation plant showed that the combination of ozonation and BAC was responsible almost totally for the removal of PPCPs and toxicity observed along the treatment train (Macova *et al.*, 2010; Reungoat *et al.*, 2010). These two treatment stages together removed most of the targeted PPCPs by more than 90%, whereas other pre- and post-treatment showed poor removal. This study investigates the fate of PPCPs in full-scale advanced treatment plants using ozonation and BAC in Australia and compares the performance of the plants based on water quality and operational parameters.

## Material and Methods

The two reclamation plants studied treat effluents from biological nutrient removal wastewater treatment plants (WWTP). Samples were collected before and after ozonation as well as after the BAC. Reclamation plant A (RP A) has a capacity of 40,000 equivalent people (8,000 m<sup>3</sup> d<sup>-1</sup>) and consists of: denitrification, pre-ozonation; coagulation-flocculation; dissolved air flotation-filtration; main ozonation; BAC; and post-ozonation. Two sets of 24 hours composite samples were collected on consecutive weeks. Reclamation plant B (RP B) has a capacity of 10,000 equivalent people (2,500 m<sup>3</sup> d<sup>-1</sup>) and consists of: sand filtration, ozonation; BAC; and UV disinfection. Three sets of grab samples were collected on non consecutive days. Bulk parameters (temperature, pH, conductivity, dissolved oxygen) as well as nutrients concentrations (dissolved organic carbon (DOC), ammonia, nitrite, nitrate and phosphate) were determined for each sample. A wide range of PPCPs and some pesticides were quantified by LC-MS/MS after a 200 fold concentration step using solid phase extraction.

## Results

The quality of the water before ozonation was very similar in both plants, DOC were 7.2±0.3 and 6.1±0.4 mg L<sup>-1</sup> in RP A and RP B respectively. In RP A, 24 compounds (among 34 targeted) were detected with an average concentration above their limit of quantification (LOQ, in the ng L<sup>-1</sup> range). Average concentrations ranged from 0.5 ng L<sup>-1</sup> (chloramphenicol) to 1,418 ng L<sup>-1</sup> (tramadol). In RP B, 38 compounds (among 44 targeted) were above their LOQ, average concentrations ranged from 0.3 ng L<sup>-1</sup> (metolachlor) to 1,078 ng L<sup>-1</sup> (tramadol). For any given compound, average concentrations were similar in both plants. Removal efficiencies after the ozonation and BAC stages were calculated for selected compounds and compared between the plants (Figure 1).

In RP A, the removal of the 22 selected compounds by ozonation was very good: concentrations decreased by more than 80% for 20 compounds and caffeine and DEET were removed by 61 and 64% respectively. The BAC stage improved the removal of most compounds, particularly the ones that were less affected by the ozonation stage, achieving a total removal of more than 80% for all compounds and more than 94% for 19 of them.

In RP B, the removal of the 34 selected compounds by the ozonation stage ranged from 13 to more than 99%. For compounds that were selected in both plants, lower removals were observed in RP B compared to RP A. This is due to the almost three times lower ozone dose employed in RP B ( $0.26 \text{ mg}_{\text{O}_3} \text{ mg}_{\text{DOC}}^{-1}$ ) compared to RP A ( $0.7 \text{ mg}_{\text{O}_3} \text{ mg}_{\text{DOC}}^{-1}$ ). Ozone dose is a key parameter controlling micropollutant removal in ozonation processes. The BAC stage also further reduced the concentration of most compounds in RP B, achieving total removals from 40 to more than 99%; 12 compounds were removed by more than 90%. When comparing both BACs for selected compounds with similar concentrations after ozonation, RP A showed similar or higher removals compared to RP B. The removal of DOC was also higher in RP A (26%) compared to RP B (17%) as was the oxygen consumption ( $5.4$  and  $2.5 \text{ mg L}^{-1}$  respectively). The BAC in RP A has an empty bed contact time (EBCT) twice as long as RP B (18 and 9 minutes respectively), which allows further degradation of organic matter and micropollutants.

Final concentrations of the targeted compounds after ozone/BAC treatment were very low in both plants, below  $50 \text{ ng L}^{-1}$  and  $170 \text{ ng L}^{-1}$  for RP A and RP B respectively, which is several orders of magnitude below the Australian guidelines values for indirect potable reuse. For the compounds detected in both plants, final concentrations were lower in RP A compared to RP B.

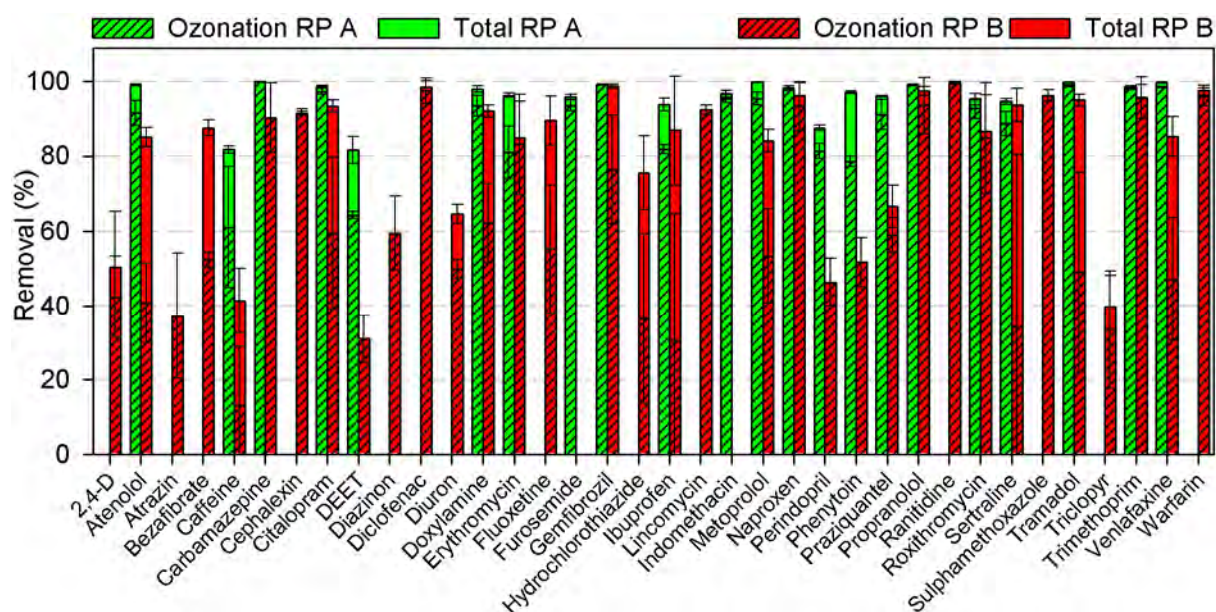


Figure 1. Removal of selected PPCPs and pesticides in RP A and RP B.

## Conclusions

These results confirm that advanced treatment of WWTP effluents using ozone/BAC is very effective in the removal of PPCPs. The comparison of two plants showed that ozone dose and EBCT in BAC are key operating parameters influencing PPCPs removal.

## Future Work

A third reclamation plant using ozonation and BAC will be sampled and the results will be compared with RP A and RP B. This is expected to confirm the above conclusions and possibly identify additional key operational or water quality parameters influencing PPCP removal. At the same time, samples have been collected for bioanalysis. Bioanalytical tools are complementary to chemical analysis and can bring further information on water quality and treatment performance. Results obtained with bioanalysis will be compared to chemical analysis.

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# Minimising the NDMA Formation during the Production of Purified Recycled Water

Farré, M.<sup>1</sup>, Döderer, K.<sup>1</sup>, Hearn, L.<sup>2</sup>, Holling, N.<sup>3</sup>, Mueller, J.<sup>2</sup>, Keller, J.<sup>1</sup>, Poussade, Y.<sup>4,5</sup>, Robillot, C.<sup>5</sup> and Gernjak, W.<sup>1</sup>

<sup>1</sup> Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

<sup>2</sup> National Research Centre of Environmental Toxicology (ENTOX), The University of Queensland, Coopers Plain, Queensland

<sup>3</sup> Queensland Health Forensic and Scientific Services (QHFSS), Organics Laboratory, Coopers Plain, Queensland

<sup>4</sup> Veolia Water Australia, PO Box 10819, Adelaide St Post Office, Queensland 4000

<sup>5</sup> WaterSecure, Level 2, 95 North Quay, Brisbane, Queensland

## Summary

The formation of N-nitrosodimethylamine (NDMA) is of major concern among wastewater recycling utilities practicing disinfection with chloramines. This paper investigates the fate of NDMA and NDMA precursors during the production of Purified Recycled Water (PRW). Results show that while only 10% of NDMA is rejected by the Reverse Osmosis (RO) membranes, this system is able to eliminate more than 98.5% of NDMA precursors. The Advanced Oxidation Process (AOP) used at AWTPs is proven very effective in destroying NDMA that is not rejected by the RO membranes. However, results from this research also show that the formation of this compound can be minimised by controlling the contact time between the wastewater effluent and the disinfectant before the RO membranes because of the slow kinetics of NDMA formation. This strategy has been implemented at Bundamba AWTP (Queensland, Australia) where NDMA concentrations have been reduced by a factor of 20 before the AOP.

## Keywords

Chloramination, disinfection by-product, N-nitrosodimethylamine, reverse osmosis membrane, water recycling.

## Introduction

One of the most concerning disinfection by-products (DBP) that has been found in water utilities when disinfecting wastewater by means of chloramination is N-nitrosodimethylamine (NDMA). The US Environmental Protection Agency (US EPA) classifies NDMA as “B2 carcinogen - reasonably anticipated to be a human carcinogen” and a 10<sup>-6</sup> cancer risk level in drinking water at 0.7 ng/L has been determined (EPA 2001). Moreover, Public Health Regulations in Queensland require that NDMA concentrations in recycled water to augment a supply of drinking water are no more than 10 ng/L (QPC 2005). In the SEQ context, NDMA was found at medium to high ng/L levels before the AOP during the commissioning phase of Bundamba AWTP (Poussade, Roux *et al.* 2009). This was not the case for Luggage Point AWTP where values of NDMA across the plant were always lower than the 10 ng/L guideline value. Although the AOP used at Bundamba AWTP was proven to be very effective in destroying NDMA, the need for understanding and managing NDMA formation to minimise the risks of presence of nitrosamines in the environment and drinking water supply emerged. As a result of this knowledge gap, two projects to carry out applied research on NDMA formation and management in PRW were independently funded at the Advanced Water Management Centre (UQ). A two-year project funded by the Urban Water Security Research Alliance (UWSRA) focused on the NDMA formation potential (FP) in source water for PRW. A second project funded by The University of Queensland, Veolia Water Australia and WaterSecure, focused on the understanding of the fate of NDMA and NDMA precursors across the different barriers of an AWTP in order to better identify and reduce the concentration of NDMA and its precursors during the PRW production treatment train. This paper presents the results of these two projects generated in a joint effort of the AWMC, EnTox, Veolia Water Australia, WaterSecure and the UWSRA.

## Results

NDMA formation potential is a measure of the maximum NDMA concentration that can be obtained as a result of an extreme disinfection of the water with chloramines. The first aim of that project was to identify source streams and operating conditions with increased NDMA FP in SEQ. To this aim, the systematic analysis of the NDMA FP from a number of source waters was performed. Results obtained showed that the NDMA FP of the evaluated effluents ranged between 350 and 1,020 ng/L, showing remarkable differences among individual WWTPs. The actual concentration of NDMA in those effluents was normally lower than 5 ng/L and never higher than 25 ng/L. When trying to relate chemical parameters with NDMA FP it was found that ammonium concentration of the secondary effluent could not be used to predict the formation of NDMA in the disinfection process since high values of NDMA precursors were observed in the presence of high and low concentration of ammonia. However, a weak correlation between dissolved organic nitrogen (DON) and non purgeable organic carbon (NPOC) and NDMA FP was observed ( $R^2 = 0.4$  for both parameters) that could be used to roughly estimate the NDMA FP from these parameters. It was observed that more than 98.5% of NDMA precursors were effectively removed by RO membranes and no major

changes in relation to the NDMA precursor concentration were experienced during the rest of the treatment train (except coagulation for Bundamba AWTP). The high removal of NDMA precursors by RO membranes drastically reduced any potential for reformation of NDMA in the RO permeate even if chloramines were present (or added) there or later during drinking water treatment and distribution. To complement these findings, the NDMA formation potential of different size fractionations of secondary effluents was performed. It was observed that more than 75% of NDMA precursors were found in the fraction smaller than 1,000 Da, among them, 50% were less 500 Da.

On the other hand, only 10% of the NDMA that was formed before the RO membranes was rejected by the RO membrane at Bundamba AWTP. Thus, based on the poor NDMA rejection in comparison to the high rejection for NDMA precursors, the minimisation of NDMA formation before RO membranes was identified as a key point to overcome the problem of high NDMA concentrations in the RO permeate as observed during the commissioning phase of Bundamba AWTP. Therefore, the operational parameters that influence the kinetics of formation of NDMA were investigated at bench scale. It was observed that the disinfection of secondary effluents with pre-formed monochloramine generated significantly less NDMA than monochloramine formed in-line in the treatment train. Following this strategy, the generation of dichloramine, the main chloramine species related to the NDMA formation, was minimised. NDMA formation increased with the disinfectant dose applied. However, the contact time between disinfectant and wastewater was the most important parameter to consider when the minimisation of NDMA formation was required. From those results, it was concluded that a contact time lower than six hours was an acceptable value to keep NDMA formation below the regulation limit when the chloramine dose was lower than 10 mg/L Cl<sub>2</sub>, independently of the disinfection strategy.

## Conclusions and Impact

- The NDMA formation potential (FP) of secondary effluent as source waters for Purified Recycled Water (PRW) in SEQ was studied in order to evaluate the presence of NDMA precursors. Results obtained showed concentrations between 350 and 1,020 ng/L for NDMA FP, showing remarkable differences among single WWTPs.
- While only 10% of NDMA was rejected by Reverse Osmosis (RO) membranes at Bundamba AWTP, more than 98.5 % of NDMA precursors were effectively removed by this system at both Bundamba and Luggage Point AWTPs. No major changes in relation to the NDMA precursor concentration were experienced during the rest of the treatment train (apart from the coagulation step at Bundamba AWTP).
- The disinfection of secondary effluents with pre-formed monochloramine generates significantly less NDMA than monochloramine formed in-line in the treatment train. Following this strategy, the formation of dichloramine, the main chloramine species related to the NDMA formation, is minimised.
- The contact time between disinfectant and wastewater is an important parameter to consider when the minimisation of NDMA formation is required during the production of high quality recycled water. From the results presented in that work, it can be concluded that a contact time lower than 6 hours is an acceptable value to keep NDMA formation below the regulation limit when chloramine dose is lower than 10 mg/L Cl<sub>2</sub> independently of the disinfection strategy.

The findings of this research were successfully implemented at Bundamba AWTP (Queensland, Australia) resulting in the formation of NDMA during the production of high quality recycled water being reduced by a factor of 20 before the AOP.

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# Disinfection By-Product (DBP) Formation and Minimisation in Drinking Water

Knight, N.<sup>1</sup>, Watson, K.<sup>1</sup>, Farré, M. J.<sup>2</sup> and Shaw, G.<sup>1</sup>

<sup>1</sup> Smart Water Research Centre, Griffith University, Southport, Queensland

<sup>2</sup> Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

## Summary

This project investigates which disinfection practices are most suitable for treatment of South East Queensland's (SEQ) water for potable use, in terms of disinfection by-product (DBP) minimisation. The research presented here examines the factors affecting *N*-nitrosodimethylamine (NDMA) formation as well as trihalomethane (THM) formation and speciation. We investigate the NDMA and THM formation potential of a number of SEQ source waters, as well as actual NDMA and THM concentrations occurring at SEQ water treatment plants and at the point of supply.

## Keywords

NDMA, DBPs, enhanced coagulation, formation potential, brominated trihalomethanes.

## Introduction

The current Australian Drinking Water Guideline value for total THMs (tTHMs) is 250 µg/L. While chloroform is often the most prevalent of all the THMs, its brominated or iodinated counterparts can also be formed upon disinfection under circumstances when these halides are present in the source water, often arising from salt water intrusion (Richardson *et al.* 2007). The Australian context has potential for regions with increased Br-THM and I-THM concentrations, due to the high salinity and low rainfall of many catchments, and the recent movement into desalinated water as an alternative water source.

The 2010 revision of the Australian Drinking Water Guidelines calls for the introduction of a guideline concentration for NDMA in potable water. The value in the draft guidelines is 100 ng/L, which is equal to the World Health Organisation's suggested guideline value (National Health and Medical Research Council 2010). NDMA is classified as a "probable human carcinogen" by the USEPA (USEPA 1987). The presence of NDMA in certain foods, beverages and other consumer products (for example; processed meats and beer) has been known for some time (Jakszyn and Gonzalez 2006) and it has also been identified as a contaminant in groundwater (from rocket fuel). However, more recently it has been identified as a disinfection by-product occurring in both wastewater and drinking water, arising primarily from chloramination, although it can also come about in chlorinated waters which contain an appropriate source of amine precursors (World Health Organisation 2006).

Natural organic matter (NOM) encompasses a significant portion of NDMA precursors, however, this does not account for the total NDMA potentially formed by chloramination (Gerecke and Sedlak 2003). Further sources of NDMA precursors may arise from organic polymeric coagulants such as polyDADMAC, which may be used in the water treatment process (Wilczak *et al.* 2003).

The aim of this study is to measure NDMA and THM formation potentials for a number of current and perspective SEQ drinking water sources, and to investigate advanced oxidation and enhanced coagulation strategies in terms of their effect on NDMA and THM formation during water treatment.

## Results

NDMA and THM formation potential experiments were undertaken using source waters from a number of SEQ WTPs, as well as directly from Logan River, Teviot Brook and Mary River. NDMA formation potentials were consistently quite low (5 – 21 ng/L) from chloramination of raw waters, and not detected (< 5 ng/L) in chlorinated raw waters. THM formation potentials were consistently below the Australian Drinking Water Guideline of 250 µg/L, however levels were higher for chlorinated waters than for chloraminated waters.

A general analysis of THM concentrations present in a large number of Queensland source waters was also undertaken, using data collected in 2007-2008. This THM survey identified a number of interesting trends including: the prevalence of highly brominated THMs in chlorinated bore waters; consistent compliance with guideline values for THMs in chloraminated waters; and failure to comply with Australian Drinking Water Guidelines for THMs in a number of chlorinated waters. THMs are predictably low in chloraminated water supplies, and occur over a wide concentration range in chlorinated waters.

NDMA does not appear to be a contaminant currently occurring in significant concentrations in SEQ drinking water. NDMA was not detected (< 5 ng/L) in any of the finished waters examined, either at the WTP or at the point of supply. Low levels of NDMA (< 20 ng/L) were, however, detected in a number of SEQ wastewater effluents.

In addition to the above, Advanced Oxidation and Enhanced Coagulation procedures were assessed in relation to their impact on DBP formation. Ozone or UV/H<sub>2</sub>O<sub>2</sub> pre-treatment was found to be effective in producing water with very low THM concentrations upon chlorination, although bromate formation was found to occur in significant concentrations in high bromide source waters upon ozonation. UV irradiation was found to be an excellent method for NDMA degradation in NDMA spiked source waters, and H<sub>2</sub>O<sub>2</sub> was not required for this to be achieved.

Enhanced coagulation using Alum, ferric chloride or polyDADMAC was found to be ineffective in removing DBP precursors, irrespective of the low DOC and DON able to be attained with this treatment. In fact, coagulation with polyDADMAC gave rise to a greatly increased NDMA formation potential, and all three coagulants led to an increased tTHM formation potential when using high bromine source waters, due to the high concentration of Br-THMs formed. The quaternary amine anion exchanger, polyDADMAC, was found to contain NDMA precursors and produced significant concentrations of NDMA upon chloramination, however NDMA was not formed at a detectable level by this material upon chlorination.

## Conclusions

NDMA was not found in any potable water samples taken during the one year of this study. This is not to imply that the study was comprehensive in monitoring the entirety of the distribution system, but certainly, treated water leaving the WTPs consistently had NDMA <5 ng/L. NDMA formation potentials were consistently < 22 ng/L, suggesting finished waters from SEQ WTPs are unlikely to require additional treatment to adhere to the proposed Australian Drinking Water Guideline value of 100 ng/L for NDMA. NDMA formation potentials were found to be lowered by longer free-chlorine contact times prior to the addition of ammonia, however, THM formation potential experiments confirmed that, in general, chlorination forms higher concentrations of THMs than chloramination.

Photolysis experiments found that UV irradiation at a dose similar to that used for disinfection (UV dose of up to 60 mJ/cm<sup>2</sup>) was effective in reducing existing NDMA concentrations in raw water. Therefore, UV disinfection would be expected to be sufficient to remove low levels of NDMA present as a contaminant in potable water sources. THMs were not able to be destroyed by either UV radiation or UV in conjunction with H<sub>2</sub>O<sub>2</sub>. However, application of advanced treatment (UV or UV/H<sub>2</sub>O<sub>2</sub>) to raw waters prior to disinfection was very effective in removing THM precursors, and subsequent THM formation was low. Pre-treatment by advanced oxidation may be an excellent means of reducing tTHM levels in regions with particular difficulties minimising these compounds.

Enhanced coagulation enabled a notable decrease in the DOC and DON of Teviot Brook source waters, however, the NDMA formation potential of the treated water remained constant with and without coagulation, except when coagulating with polyDADMAC, in which case the NDMA formation potential was dramatically increased upon chloramination. The high bromide waters of Teviot Brook all exhibited an increased tTHM formation potential from enhanced coagulation/chlorination despite having significantly lower DOC. This arose as a consequence of DOC and bromide competing for chlorine, therefore, lower DOC waters gave rise to higher Br-THMs. When bromide levels are sufficiently high, enhanced coagulation will lead to an increase in tTHM concentration upon chlorination.

## Future Work

Future work will focus on investigating novel strategies for bromide and iodide removal from raw waters using silver-impregnated organic carbons and MIEX resin, toward lowering brominated and iodinated DBP concentrations in finished waters. In addition, the characterisation and targeted removal of organic material that is not amenable to removal by traditional enhanced coagulation techniques will be studied.

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# Univariate Event Detection for Real-Time WWTP Protection

O'Halloran, R.<sup>1</sup>, Toscas, P.<sup>2</sup>, Winnel, M.<sup>2</sup>, and Zhao, H.<sup>3</sup>

<sup>1</sup> CSIRO Land and Water, Clayton South, Victoria

<sup>2</sup> CSIRO Mathematics Informatics and Statistics, Clayton South, Victoria

<sup>3</sup> Griffith School of Environment, Gold Coast Campus, Griffith University, Gold Coast, Queensland

## Summary

We have developed real-time software that can detect significant discharge events in online sewage monitoring data collected from the Bundamba WWTP. The methodology emulates the approach used when a trained human observer evaluates the data, and is remarkably tolerant of short-term noise transients that often cause false alarms. The univariate method analyses data from each sensor separately and when combined with empirical and statistical rules provides real-time alerts to enable protection of wastewater treatment plants. Further optimisation is in progress to embed the software in the next version of our event detection hardware.

## Keywords

Event detection, online monitoring, wastewater analysis.

## Introduction

The online wastewater event detection system installed at the Bundamba WWTP features a series of robust physicochemical sensors that collect data related to the quality of the wastewater matrix. The system is designed to detect exceptional conditions ('events') that indicate a major contaminant load has been discharged to sewer which could potentially upset the treatment plant and adversely impact the treated effluent. The event detection system must be able to define 'normal' variations in the online sensor data, and then construct a reference baseline against which sensor data can be compared.

The univariate approach developed assesses data from each sensor separately, and is designed to mimic the procedure used by experienced human observers. To implement this empirical approach on an automated system, we have developed real-time software to calculate a reference baseline, and appropriate statistical tests are then used to detect significant events.

There are two stages to the univariate method:

- Stage 1 – the reference baseline is estimated for each variable separately.
- Stage 2 – a univariate statistical test is applied to each variable to determine if the readings are anomalous relative to the baseline.

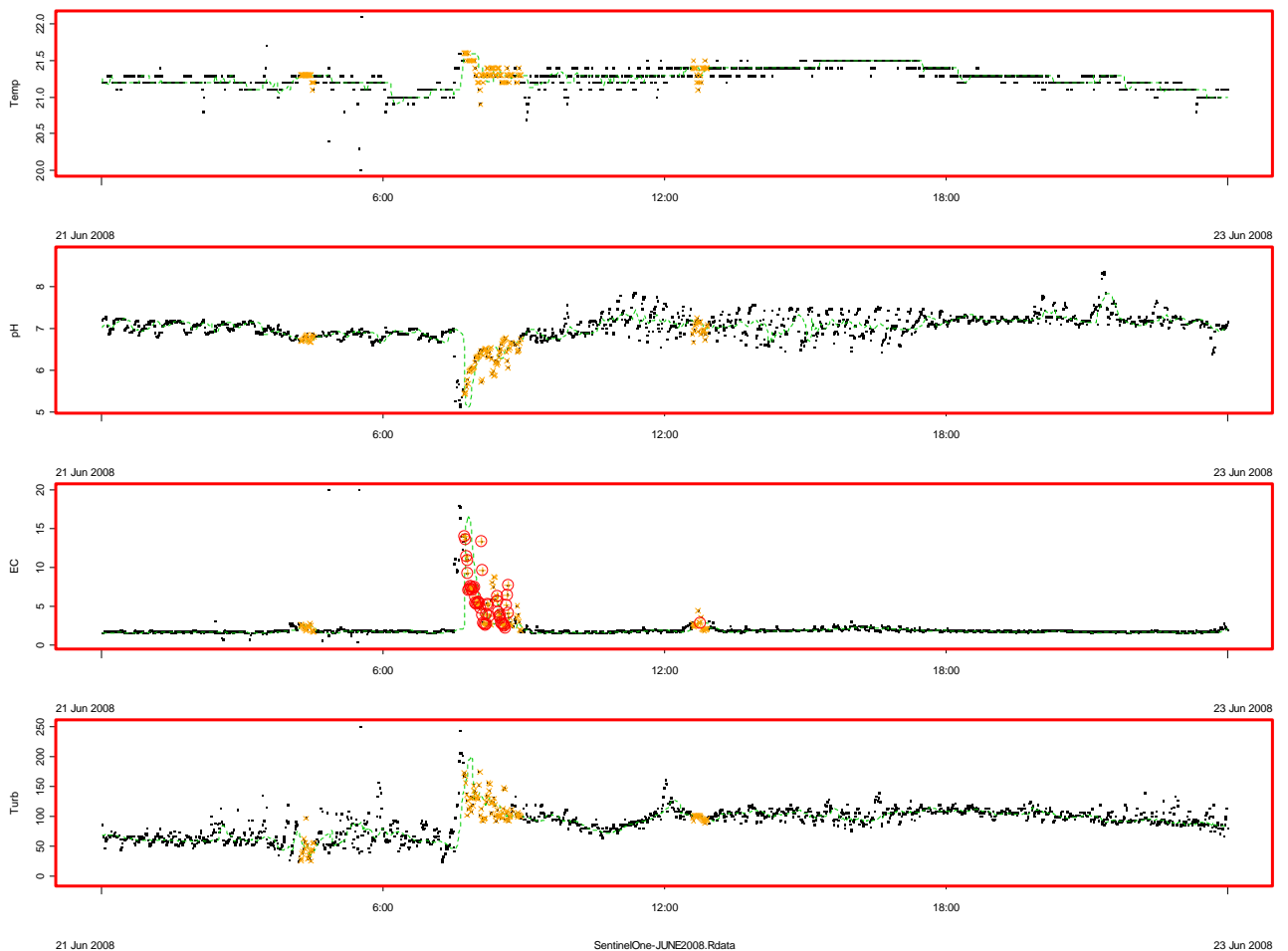
## Results

### Stage 1 – Baseline Estimation

The first task is to construct a reference baseline that accurately reflects the underlying trend in the time-series data. The sewage monitoring data collected from Bundamba exhibits a great deal of short term measurement noise that can cause problems by triggering multiple false alarms in the event detection routine. We have developed a method to remove this noise from the baseline, while at the same time preserving larger events that may represent potential threats to the treatment system.

### Stage 2 – Univariate Event Detection

Different wastewater treatment plants may measure one or more parameters, so a test statistic is needed that can identify a change in a single variable that is significant enough to be considered an event by itself. Once it is determined that there is a possible event, rule-based testing is then applied (Figure 1) to determine whether the event should be classified as an alert (ie, the data is unusual) or an event (ie, the data is extremely unusual or likely to harm the treatment plant).



**Figure 1.** An irregular industrial discharge event. Black dots: original sensing signals; Green lines: reference-baseline; Amber X and red O symbols: alerts and event warnings, respectively.

Classification of an alert is done by comparing samples to the 90% confidence interval calculated from the previous two days data. To upgrade this alert to an alarm, the data needs to continue either above or below the baseline and be outside the previous two days 99% confidence interval.

A further set of boundary conditions based on safe operating limits for the parameters are also used to determine if an alarm is flagged. If a variable is observed to exceed this boundary during a possible event situation then an event is automatically flagged.

## Conclusions

We report here the development of a method to estimate a robust baseline for online wastewater monitoring data. The objective was to closely match the baseline interpolated by a trained observer. The results presented demonstrate that the robust baseline successfully discriminates against single outliers and clusters of short-term measurement noise, and provides a reliable reference baseline for event detection. Some preliminary examples of event detection are also presented, and show that industrial discharges (indicated by parameters such as pH, turbidity and conductivity) can be successfully detected and categorised as alerts (unusual data) or alarms (probably harmful events). The technique also successfully dealt with long duration events such as catchment overflow following heavy rain. Further optimisation is being done at present to embed the software in the next version of our event detection hardware.

# Drought Frequency and Duration Projections for SEQ

Kent, D., Nguyen, K., and Cai, W.

Centre for Australian Weather and Climate Research, CSIRO Marine and Atmospheric Research, Aspendale, Victoria

## Summary

High-resolution dynamical downscaling of 21<sup>st</sup> Century climate projections for South East Queensland (SEQ) provides data suitable to assess the regional implications for water resources. An analysis of a water-balance based drought index for six downscale runs based on the output of five global circulation models suggests that drought duration is going to increase dramatically over the next century compared to the late 20<sup>th</sup> Century.

## Keywords

Drought, Palmer Drought Severity Index, South East Queensland, regional projections.

## Introduction

High-resolution dynamical downscaling of 21<sup>st</sup> Century climate projections for SEQ provides data suitable to assess the regional implications for water resources. In particular, it is possible to examine how the key drivers of drought - precipitation, temperature and evapotranspiration - might evolve in a modified climate. Using a water-balance model based drought index, this study assesses how two important drought characteristics (ie, frequency and duration) that have significant implications for both urban water supply and demand, will change over the 21<sup>st</sup> Century.

## Results

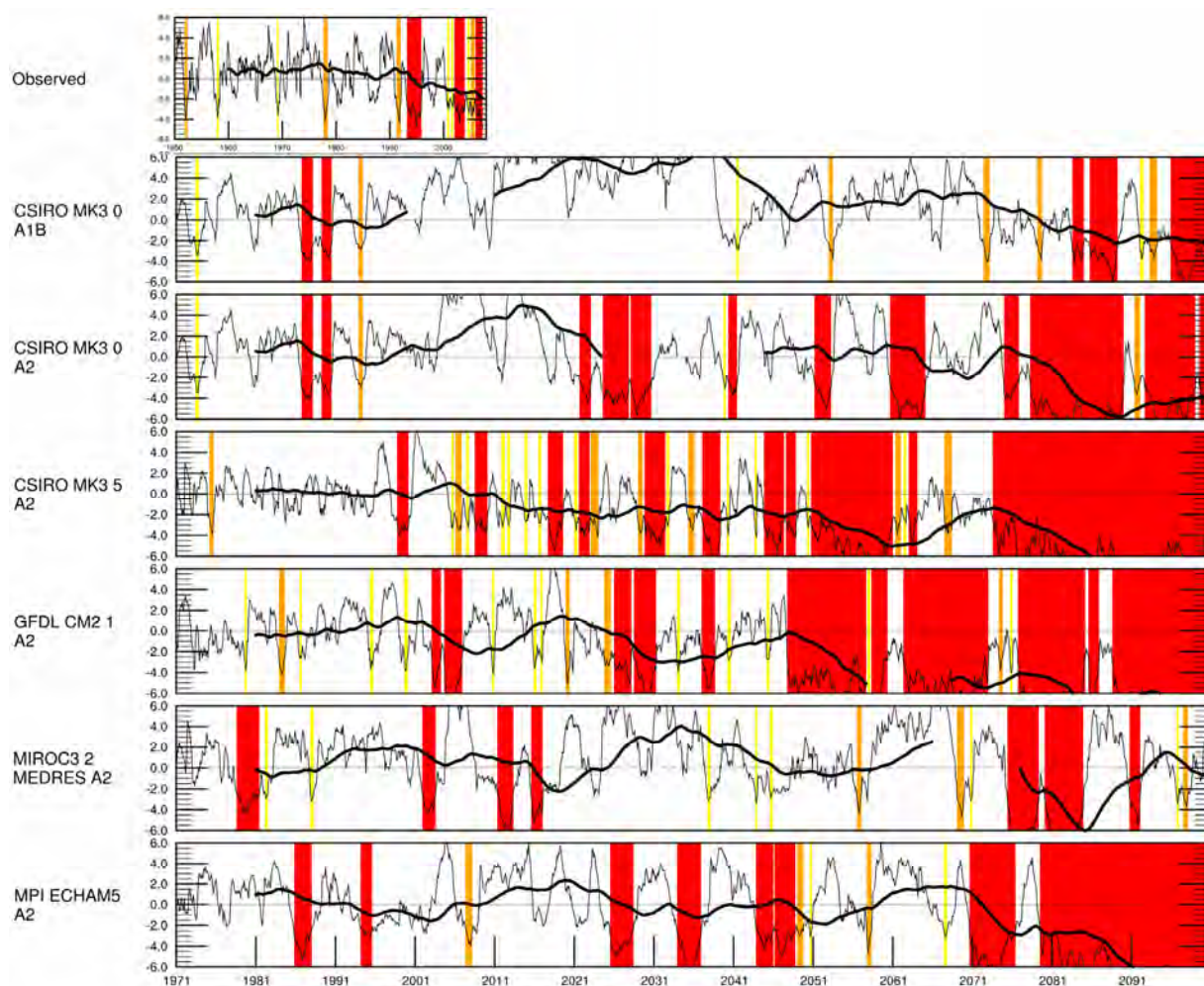
To assess the projected changes in drought frequency and duration, the Palmer (1965) indices are calculated for each dynamically downscaled model. The monthly mean is produced for the Moreton catchment and these time-series are analysed for changes. The analysis is similar to that of Soulé (1992) where drought events are identified as periods when the index falls below a threshold for a defined period of time. Six different types of drought events are considered using a combination of two indices and three minimum event durations (3, 6 and 12 months). The indices used are the Palmer Drought Severity Index (PDSI), which assess meteorological drought, and the Palmer Hydrological Drought Index (PHDI), which describes hydrological drought, both calibrated based on the 1971-2000 period. The thresholds used are -2.00 and -2.25 respectively, corresponding to a moderate to severe drought.

**Table 1.** The mean drought event duration (D, months) and number of drought events (#) for each model for 40-year periods centred on the given years. The minimum drought event length is three months using the PHDI. Bold numbers indicate the greatest value for each model.

Model	1990		2010		2030		2050		2070	
	D	#	D	#	D	#	D	#	D	#
OBSERVED	11.8	8								
CSIRO-MK3.0 A1B	10.8	5	8.5	2	4	1	5	2	<b>16.2</b>	<b>5</b>
CSIRO-MK3.0 A2	10.8	4	24	4	19.5	<b>6</b>	21	5	<b>60.3</b>	4
CSIRO-MK3.5 A2	9.7	6	9.4	14	11.3	<b>18</b>	20.3	14	<b>31.8</b>	4
GFDL CM2.1 A2	6.6	12	10.2	<b>14</b>	12.8	8	44	4	<b>59.9</b>	7
MIROC3.2 MEDRES A2	15.8	4	20.3	3	10.4	5	6.5	<b>6</b>	<b>22.7</b>	<b>6</b>
MPI/ECHAM5 A2	17.7	3	20.7	3	23.3	6	16.7	<b>7</b>	<b>27</b>	3

Figure 1 shows the monthly time series of the PHDI (light stroke) for each member of the downscaled ensemble along with its decadal mean (bold stroke). Periods of drought 3-5 months long are highlighted in yellow, 6-11 months in orange and greater than 12 months in red. The top panel shows the 1950 – 2007 observed PHDI. The long sequence of drought events in the early 21<sup>st</sup> Century are clearly shown, however, the downscaled model results appear to underestimate the drought events compared to the observations for the same period. There is significant variability between models but an increase in the frequency and duration of drought events later in the 21<sup>st</sup> Century. As expected, this result is nearly identical using the PDSI (not shown) which really only differs from the PHDI in the amount of time it takes to exit a dry period. Table 1 presents similar information with the number and mean length of drought events occurring across forty-year periods for each of the six model realisations shown. The non-uniform distribution of events with a very small population makes the analysis of such statistics difficult. However, most of the models show consistent increases in drought duration over time and the greatest mean duration occurring in the last 40-year period for all models. Longer droughts, averaging at around 12 months around 1990 compared to 36 months around 2070 have significant implications for the period of time over which water storages will not be

refilled. Drought frequency has a weaker signal over time but Figure 1 demonstrates that over the later 21<sup>st</sup> Century frequency becomes far less useful as a drought diagnostic as the percentage of time spent in drought rapidly approaches 100, and there are less drought breaks to identify the next drought.



**Figure 1.** Monthly PHDI for the observed period (top panel, note different time axis to lower 6 plots) and each model realisation. Decadal mean shown in bold. Periods below threshold of -2.25 for 3 – 5 months highlighted in yellow, 6 – 11 months in orange and greater than 12 months in red.

## Conclusions

The PHDI, driven by downscaled time-series of rainfall, temperature and evaporation, shows a trend toward longer drought periods over the 21<sup>st</sup> Century in the Brisbane region. This has significant implications for urban water supply in the region as prolonged drought, of similar or longer duration than that experienced over the last 10 years, severely impacts on the ability of water storages to meet demand.

## Future Work

As the Palmer indices are based on a simple water-balance model driven by the monthly precipitation, temperature and potential evaporation produced by the downscaling model, it is possible to examine what is driving the increased drought frequency and duration described above. In each realisation it appears that long-term trends in average temperature and the associated trend in potential evaporation primarily drives the change in drought characteristics, not a change in mean monthly rainfall. This requires further examination as well as does the spatial distribution of such changes in drought characteristics across SEQ.

## Acknowledgements

PDSI code used for the calculations downloaded from the University of Nebraska – Lincoln, <http://greenleaf.unl.edu/downloads/>.

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# Urban-Rural Water Exchange with Purified Recycled Water as an Adjunct to Groundwater Resources for Irrigation in the Lockyer Valley

Wolf, L.<sup>1</sup>, Cresswell, R.<sup>1</sup>, Rassam, D.<sup>1</sup>, Ellis, T.<sup>1</sup>, Toze, S.<sup>1</sup>, Foley, J.<sup>2</sup>, Robinson, B.<sup>2</sup>, Silburn, M.<sup>2</sup>, Bleakley, A.<sup>3</sup>, Arunakumaren, J.<sup>4</sup>, Evans, P.<sup>4</sup>, Hawke, A.<sup>5</sup> and Cox, M.<sup>5</sup>

<sup>1</sup> CSIRO Land and Water, Indooroopilly, Queensland

<sup>2</sup> Department of Environment and Resource Management, Toowoomba, Queensland

<sup>3</sup> Department of Environment and Resource Management, Water Services South East, Gatton, Queensland

<sup>4</sup> RPS Consultant, Fortitude Valley, Queensland

<sup>5</sup> Queensland University of Technology, Brisbane, Queensland

## Summary

A significant amount (ca. 15-25 GL/a) of Purified Recycled Water (PRW) from urban areas is foreseen as augmentation of the depleted groundwater resources of the Lockyer Valley (approx 80km west of Brisbane). The research project uses field investigations, lab trials and modelling techniques to address four key management challenges: (i) how to quantify benefits for individual users from the augmentation of a natural common pool resource; (ii) how to minimise impacts of applying different quality water on the Lockyer soils, to creeks and on aquifer materials; (iii) how to minimise mobilisation of salts in the unsaturated and saturated zones as a result of increased deep drainage; and (iv) is there potential for direct aquifer recharge using injection wells?

## Keywords

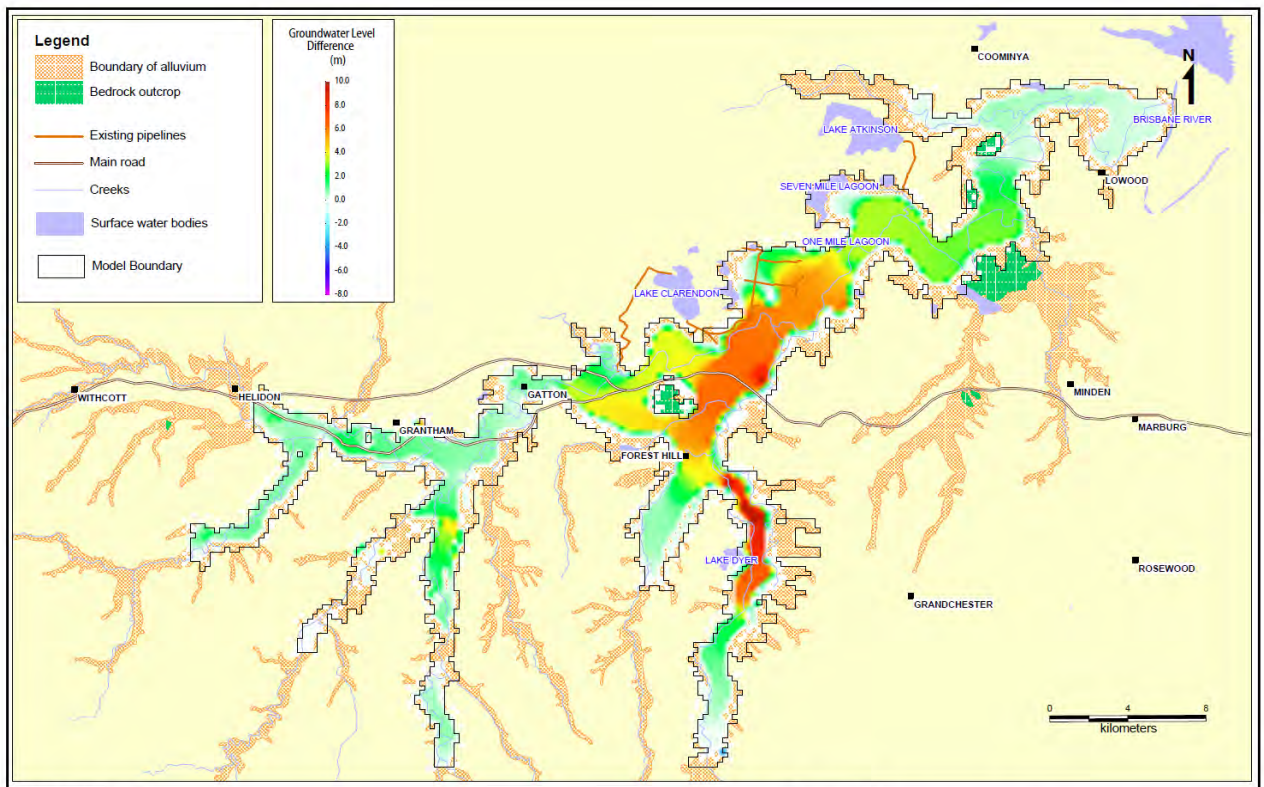
Indirect reuse, common pool resources, groundwater, surface-groundwater interaction, desalinated water.

## Introduction

With a maximum combined production capacity of 232 million litres of purified recycled water (PRW) a day, the South East Queensland (SEQ) Water Grid operates the third largest recycled water scheme in the world and the largest in the southern hemisphere. The additional water volumes are critical to provide supply security during drought conditions, but are underutilised in wet periods. The option to supply a significant amount (ca. 15-25 GL/a) of PRW to augment the depleted groundwater resources of the Lockyer Valley (approx. 80km west of Brisbane) is currently explored in detail by government agencies and the SEQ Water Grid Manager. Historically in the 1980s, estimated annual groundwater withdrawal in the Lockyer Valley has been on average 46,500 ML, while groundwater storage in the alluvial aquifers is estimated at a safe annual yield of only 27,000 ML (DPI 1994, Sarkera *et al*, 2009). The import of additional water is thus required to sustain the farming practice in its current extent. In order to avoid costly infrastructure for a distributed network of piped supply to farm gates, the concept of PRW discharge into local reservoirs and creeks is being considered as a means of augmenting a common resource. The supply of PRW to agricultural communities appears to be a straightforward concept, especially considering the excellent water quality, but closer scrutiny revealed the four major management challenges already listed in the summary above.

## Results

All four aspects constitute a research project funded through the Urban Water Security Research Alliance, South East Queensland. The suitable approach identified to address the common pool allocation problem is to define sustainable yields and volumetric water entitlements for the base case without PRW, then defining any additional water abstraction by individual users as being enabled through the artificial resource augmentation (PRW importation). A 3-D visualisation hydrogeological model was developed (Groundwater Visualisation System (GVS)) to integrate existing bore data and define the configuration of the alluvial aquifer system and its component volumes. Available numerical groundwater models (MODFLOW SURFACT) were updated and critically assessed, and this highlighted the spatial heterogeneity of model sensitivities (Fig. 1). The additional deep drainage from PRW application was modelled using a combination of the HOWLEAKY/APSIM model to predict likely deep drainage below the root zone, with these results fed into the HYDRUS model then run for the main soil and crop types of the region. Within a sensitivity study, salt travel times across a 20m unsaturated zone were modelled between seven years and 371 years. The time lag between irrigation pulses and groundwater recharge pulses was found to vary between 150 days and 16 years, depending on subsoil hydraulic characteristics and existing moisture content. It can thus be concluded that no direct response of deep drainage rates to today's weather conditions can be expected. Models are currently being verified through a number of deep soil cores to 20m, providing soil chloride-depth profiles for chloride mass balance analysis. The response of clay minerals in soils and creek bed sediments to the changing electrolyte concentrations was examined using column and batch tests.



**Figure 1.** Differences in groundwater levels compared to the base case after a 10 year simulation period and an assumed 20% decrease in well abstractions. The figure shows the spatially distributed model sensitivity to uncertainty in input data (eg, lack of metering).

## Conclusions and Significance

The research project has demonstrated that the supply scenario currently favored by the grid operators requires a reliable characterisation of the water resources status and the sustainable yield for the base case before PRW can be introduced into the Lockyer Valley. It was recommended to progress the metering programs for water use in the Lockyer with high priority. The existing models and quantification were updated but found to require a refinement before they can be developed into an operational management tool for common pool resource augmentation quantifying the expected benefits. Unsaturated zone modeling work showed that the contribution of deep drainage under irrigated agriculture is likely to exceed previous estimates. The viability of the 3-D GVS was demonstrated and the system is able to support public participation and understanding of the subsurface resource management. A preliminary risk assessment of direct PRW injection via wells was performed along the requirements of Australian Water Recycling Guidelines, indicating comparatively low risk and likely feasibility. Supply of high purity recycled water from urban areas to agricultural areas currently has a high priority since the demand for recycled water is dependent on drought conditions, which results in a potential of the SEQ water grid to supply water to agriculture in normal years. Thus the recharge of common pool groundwater resources, which are characterised by their ability to also sustain elongated drought periods without PRW addition, is an attractive concept to improve overall system efficiency.

## Future Work

For the future, a joint effort with the Department of Environment and Resource Management and the Queensland Water Commission is planned to upgrade the available models for sustainable yields estimation and to develop a management methodology for the common pool resource augmentation. CSIRO will explore the adaptation of methods used in the Murray-Darling Basin and sustainable yields projects to the situation in the Lockyer Valley. The project will extend the deep soil coring activities to document changes in soil salinity over the last 12 years and utilise this data to validate models for salt transport triggered by additional irrigation with PRW. Work on changes of soil hydraulic properties caused by the response of clay minerals to the different electrical conductivity and sodium adsorption ratios of the new irrigation water will be concluded. Using the numerical groundwater models, positions and injection rates for aquifer storage and recovery will be evaluated.

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# Life Cycle Analysis of the Gold Coast Urban Water Cycle

Lane, J.<sup>1</sup>, de Haas, D.<sup>1,3</sup> and Lant, P.<sup>2</sup>

<sup>1</sup> Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

<sup>2</sup> School of Chemical Engineering, The University of Queensland, St Lucia, Queensland

<sup>3</sup> GHD, GPO Box 668, Brisbane, Queensland 4001

## Summary

The Life Cycle Assessment (LCA) methodology was used to quantitatively assess the environmental burdens associated with urban water supply and wastewater systems. The Gold Coast area was used as an indicative example of both the traditional infrastructure approaches and the future water supply approaches being considered under the SEQ Water Strategy. These two infrastructure mixes were compared across a range of environmental indicators.

The wastewater system was found to be the biggest contributor to the environmental burden of the urban water cycle. The main sources of impact, and key opportunities for impact reduction, were identified. The results also suggest that future social pressures for environmental mitigation by the urban water sector are likely to be spread across a greater range of issues than is currently the case. While this case study has been completed, it has highlighted important research needs that could help guide water system planning towards environmentally optimal outcomes.

## Keywords

Life Cycle Assessment, environmental burden, infrastructure scenarios, tradeoffs.

## Background

In response to rapid population growth and recent challenges such as drought, a range of non-traditional water supply and wastewater infrastructure options are being implemented or considered in South East Queensland (SEQ). The objective of this research was to quantitatively consider the environmental burdens associated with these responses. To do this, quantitative LCA was applied to two infrastructure scenarios. Average per capita water demand was assumed to be the same across both scenarios, so as to specifically investigate the change in infrastructure mix.

The 'Traditional' scenario was based on the water supply and wastewater infrastructure in operation at the Gold Coast for the 2007/08 period. Water supply was from conventionally treated dam water, supplemented with a small number of household rainwater tanks. Urban sewage was treated to secondary standard (with a relatively high degree of nutrient removal) and disinfected (UV or chlorine). 20% of the wastewater was reused by irrigation of public spaces (eg, golf courses), with the remainder being discharged to the sea. Biosolids disposal was by dewatering and disposal to beneficial use in broad-acre agriculture.

For the 'Future' scenario, the existing dam water supply was augmented by: a 125 ML/d seawater desalination plant; one advanced wastewater treatment plant (54 ML/d) providing product water for indirect potable reuse (IPR) via a local dam; another advanced wastewater treatment plant supplying Class A+ water to ~5% of the households; and rainwater tanks installed with all (~350,000) new households. The number of additional households included in the 'Future' scenario was set such that total demand for mains water equalled the total supply capacity for the above infrastructure set. To service these additional households, the sewage treatment capacity was expanded with a (weighted) mix of the plants in the 'Traditional' scenario, together with the new STP at Pimpama (commissioned 2008-9) and the advanced wastewater recycling plants described above. Demand for secondary wastewater recycling (public open space irrigation) was assumed to grow in proportion to total wastewater throughput.

The modelling required a substantial amount of inventory (inputs and outputs) data to be collated. Significant effort was directed at collecting actual operating data for the centralised infrastructure, using data specific to the Gold Coast in most cases. Estimates for fugitive greenhouse gas emissions and wastewater/biosolids micropollutants were based on mass balances and the latest research in these areas. Rainwater tank data was based on a mix of literature sources and yield modelling. Uncertainty distributions were generated for the operational data, so as to assess the significance of the large uncertainty associated with certain key parameters. Construction inventories used a mix of Gold Coast and literature data.

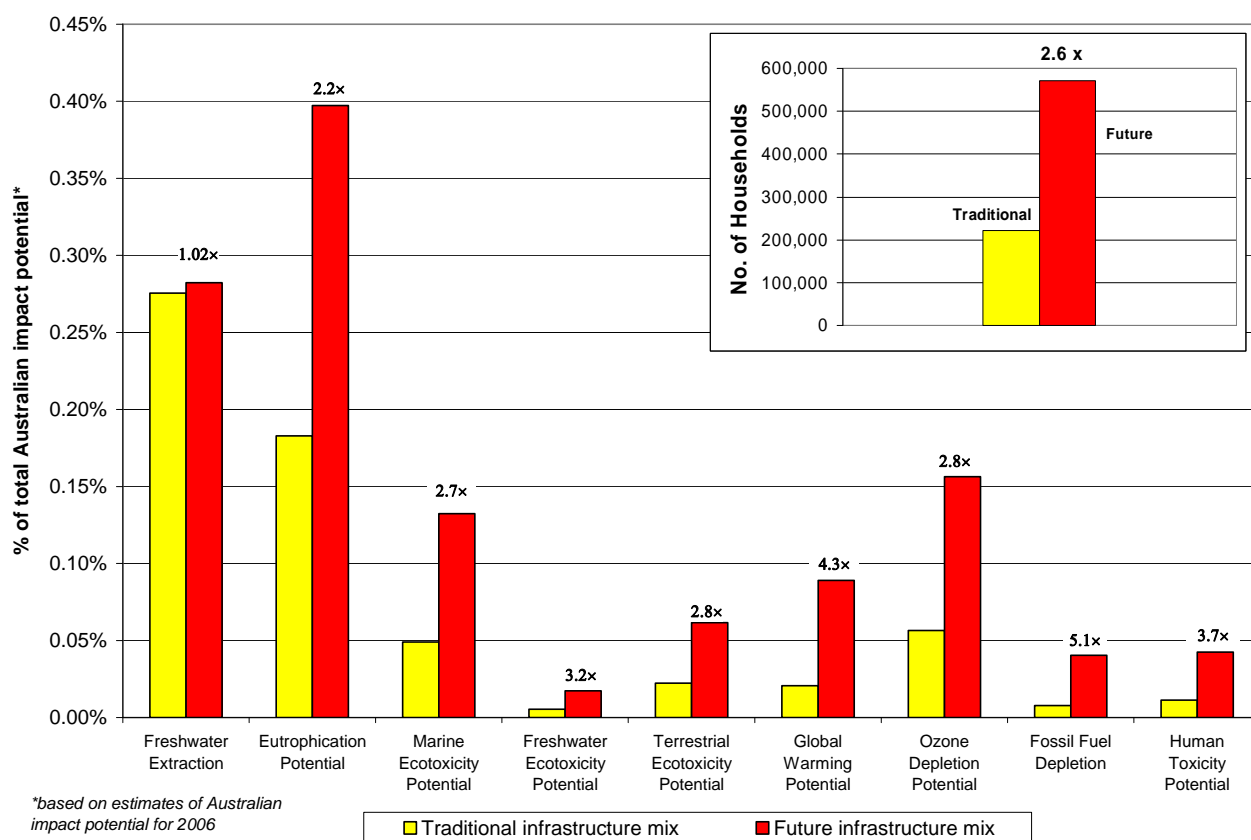
The inventory data was then analysed using a range of linear impact models (*Freshwater Extraction, Eutrophication Potential, Global Warming Potential, Ozone Depletion Potential, Fossil Fuel Depletion, Ecotoxicity Potential, Human Toxicity Potential*) consistent with the midpoint impact approach frequently used in LCA studies. Midpoint indicators act as proxies for the potential of environmental impact, but do not attempt to predict the actual damage that might occur.

## Findings

The results show that wastewater management (collection, treatment and discharges) dominates the environmental impacts from the urban water system in both the 'Traditional' and 'Future' scenarios. The largest impacts are from power use, fugitive gaseous emissions, wastewater discharge to waterways, and disposal of biosolids to land. There are also a raft of notable but indirect impacts due to power generation, chemicals manufacture, and transport. This study highlighted specifically that fugitive nitrous oxide emissions have the potential to contribute not only to global warming but also very significantly to ozone depletion, which is an emerging scientific issue and one that has received almost no attention in the popular press to date.

These results suggest that the current environmental regulations surrounding eutrophication and biosolids disposal (as examples) are justified. However further research, plus the development and use of local fate and impact models (for nutrients and metals), would improve confidence in the use of LCA models to compare alternative options for urban water planning. Uncertainties over metals toxicity, particularly under Australian conditions in agriculture, remain high and deserve further research. Moreover, the current debate in Australia over emissions trading and mandatory reporting of greenhouse gas emissions for Scope 1 (direct including fugitives) and Scope 2 (power) seems justified in the context of water utilities seeking to minimise their environmental impact. Urban water systems are therefore likely to come under increasing scrutiny in regards to emissions not only as dissolved nutrients and solids wastes (eg, biosolids) but through power use and fugitive greenhouse gas emissions.

This study demonstrated the strength of LCA when comparing alternative options such as for water supply. In our 'Future' scenario, the contributions from water supply (through desalination, water recycling and rainwater tanks) were clearly greater in a number of impact categories than were the contributions from water supply (predominantly from dams) in the 'Traditional' scenario. These alternative water supply options are more energy-intensive and thus worsen global environmental impacts through greenhouse gas emissions, fossil fuel depletion, and indirect pathways for ecotoxicity potential. Figure 1 shows that the 'Future' scenario increases the *Global Warming Potential* and *Fossil Fuel Depletion* impacts by 4.2-fold and 5.1-fold respectively. This is substantially greater than the 2.6-fold increase in the total number of households serviced under the 'Future' scenario.



**Figure 1:** Example of LCA midpoint impact results for the scenarios in this study, benchmarked against an estimate of the total Australian impact potential for 2006.

However, there are tradeoffs involved. *Freshwater Extraction* did not increase despite the large increase in population served, thereby avoiding the risk of attendant environmental impacts. *Eutrophication Potential* increased by only 2.1-fold, due to the benefits of more advanced treatment and nutrient removal for the modelled water recycling treatment systems. *Marine Ecotoxicity Potential* increased in roughly the same proportion as population served. The benefits of increased wastewater recycling (and therefore reduced marine discharge) were offset by the increased indirect effects (from higher power use) and higher chlorine discharges from surplus Class A+ water discharged from Pimpama treatment plant (a somewhat unique feature). *Freshwater Ecotoxicity Potential* increased by 3.2-fold, driven by the cumulative effects of micropollutants (predominantly metals, mostly at or near detection limits) in the LCA models. Organic micropollutants made only a minor contribution to all the toxicity results. These results call into question the application in LCA of toxicity effects for discrete micropollutants in an additive manner. A more realistic approach<sup>1</sup> might be to apply 'whole effluent' aquatic organism toxicity test data for discharged streams from water/ wastewater treatment; however further research would be required to collect appropriate data and apply these in LCA.

The LCA models predicted that *Human Toxicity Potential* was strongly linked to the manufacture of pipeline materials. Further consideration is required as to whether there is a case for factoring this into materials selection choices. This was the only impact category where construction impacts were the major contributor.

## Significance of the Research

This study demonstrates the strengths and weaknesses of LCA as a planning tool to assist decision makers when comparing alternatives or developing strategies. Its strengths lie in the rigour of quantitative assessments, based on inventories of operational and construction data and the consolidation of these into an interpretative tool that readily allows options to be compared on a relative or normalised basis. The challenges lie in the large amounts of data required, the sheer complexity and diversity of impact models which underpin the assessments, and the difficulty of ensuring that these models are appropriately calibrated when local impacts dominate the results.

Nevertheless, we conclude that continued effort into the research, use and application of LCA as an interpretative and decision-support tool has a place in the water industry. With the increased trend toward manufacture of freshwater from alternative supplies (seawater or recycled wastewater), increased focus by governments and regulators on impacts that are either directly or indirectly production-related (eg, global warming, ozone or resource depletion, and ecotoxicity) can be expected. This study illustrates that these environmental impacts are the trade-offs incurred from the historical planning and regulatory paradigms for urban water systems, that have focussed primarily on freshwater supply and local waterway health (by minimising eutrophication). The results also demonstrate that the more recent focus on greenhouse gas management is not an adequate proxy for the range of environmental issues that might challenge the urban water sector into the future.

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# Evaluation of Wind and Wave Action on Monolayers and Assessment of their Optical Properties

Schouten, P., Palada, C. and Lemckert, C.

School of Engineering, Griffith University, Parklands Drive, Gold Coast, Queensland

## Summary

Drought coupled with excess water wastage continues to be a serious issue facing the global population. As a result, many different products have been developed to reduce water loss. Chemical monolayers are one such example. The influence of waves and wind on the overall effectiveness of monolayers and their ability to reduce evaporation has not been completely quantified. Consequently, it is necessary to derive a relationship connecting wave and wind conditions to monolayer performance. The research discussed in this abstract has begun to solve this issue by implementing a testing regime using a wave tank located in an atmospheric controlled room (constant temperature and capable of simulating wind on the water surface). Preliminary results have found that the simultaneous application of wave action and wind interference does have a quantifiable negative effect on monolayer performance and can seriously limit the usability of monolayers in even moderately mild conditions. Further testing has shown that monolayers can absorb and reflect incoming ultraviolet (UV) radiation and as a result have a measurable impact upon the underwater ecosystem. These particular optical properties are being utilised in order to develop a monolayer visualisation technique.

## Keywords

Monolayer, evaporation, wind, waves, ultraviolet.

## Introduction

Several technologies have been developed to reduce losses in water storages. Some of these technologies have included shade sails, wind breaks, surface covers, along with more complicated destratification and mixing systems. However, all of these particular evaporation reduction mechanisms have disadvantages that greatly reduce or even prohibit their use. Some of these disadvantages are that they are expensive and difficult to install and maintain, pose a threat to the health of local environments and the successful propagation of ecosystems and they can ruin the usability and aesthetic appeal of publically accessible water basins. However, over the past fifty years several cost-effective and easily deployed chemical films and monolayers have been produced and deployed by a range of end users from the agricultural, commercial and government sectors. Monolayers consist of long chain molecules that contain one hydrophilic end and one hydrophobic end. This enables the monolayer to anchor itself on top of a water surface and rapidly disperse and reassemble in a closely packed regime usually only a few nanometres thick. This traps a high percentage of water vapour beneath it. The successful application of monolayers is dependent on local atmospheric, environmental and water quality conditions. They are sensitive to direct wind and wave action and are also affected by biological degradation caused by interactions with a wide variety of microbes on the water surface.

The influence of wind and waves on the overall effectiveness of monolayers and their ability to reduce evaporation rates has not yet been addressed. Wind and wave action and the combination of the two have the potential to break up and stretch out a monolayer film over time. This has a greatly negative impact by reducing their thickness and regrouping ability and hence their water trapping value. The combination of both wind and wave action on the applicability and effectiveness of monolayers has not been analysed. As a result, it is necessary to derive relationships connecting wind and wave conditions to monolayer performance. Also, very little is known about how monolayers influence the distribution of solar radiation, specifically the biologically damaging UVB waveband, above and below the water surface. Therefore, the effect that monolayers have on the solar energy budget in and around a water body should be quantified to gauge how local ecosystems may be affected by their application.

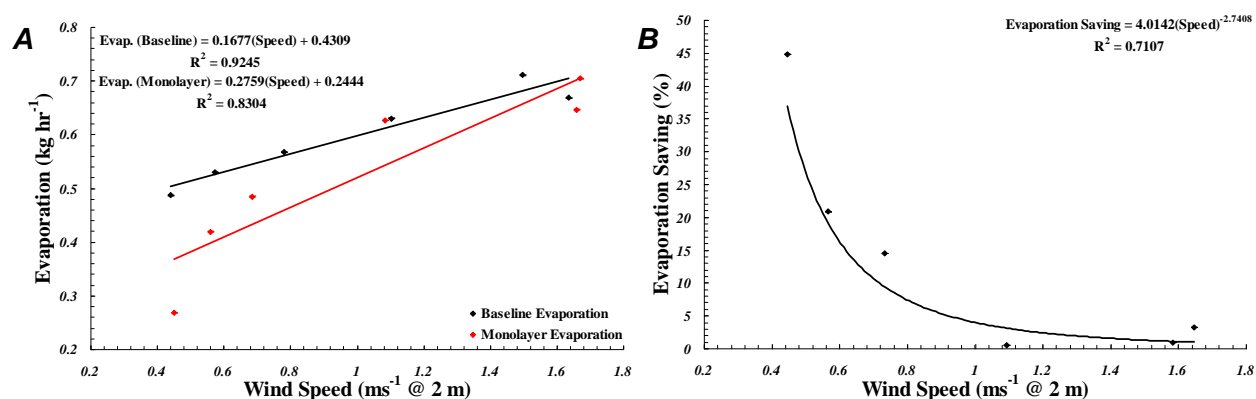
## Methods

To maintain consistent temperatures throughout each experiment a temperature stabilised enclosure was built around a wave flume (15m x 0.46m x 0.85m). Air conditioning was provided by two split cycle systems. A programmable wave paddle was inserted inside the wave tank so that sinusoidal waves could be produced over an experimental time interval of 48 hours. Controlled winds were delivered via a wind blower unit to the surface of the water in the same direction of propagation as the waves. After application of a standard monolayer (octadecanol suspension:  $\text{CH}_3(\text{CH}_2)_{16}\text{CH}_2\text{OH}$ ), evaporation rates were measured over regular time intervals by using a pulse distance sensor. Conditions such as humidity, air temperature and water temperature were monitored for each trial. Also investigated in a separate tank was the underwater distribution of artificial UVB radiation underneath a variety of commonly used chemical films/monolayers including octadecanol suspension, silicon film and a calcium hydroxide/cetyl alcohol/stearyl alcohol mix. The UV measurement instrument employed was an immersion effect corrected IL1,400 meter ('A' Series, International Light, Newburyport, MA). A waterproof detector (SUD240, International Light) with

a spectral response in the UV running from 265 nm to 332 nm was attached to the meter. This detector was combined with a UVB filter (UVB1 phototherapy filter, International Light). In this arrangement the IL1,400 broadband meter gave a response only to the UVB.

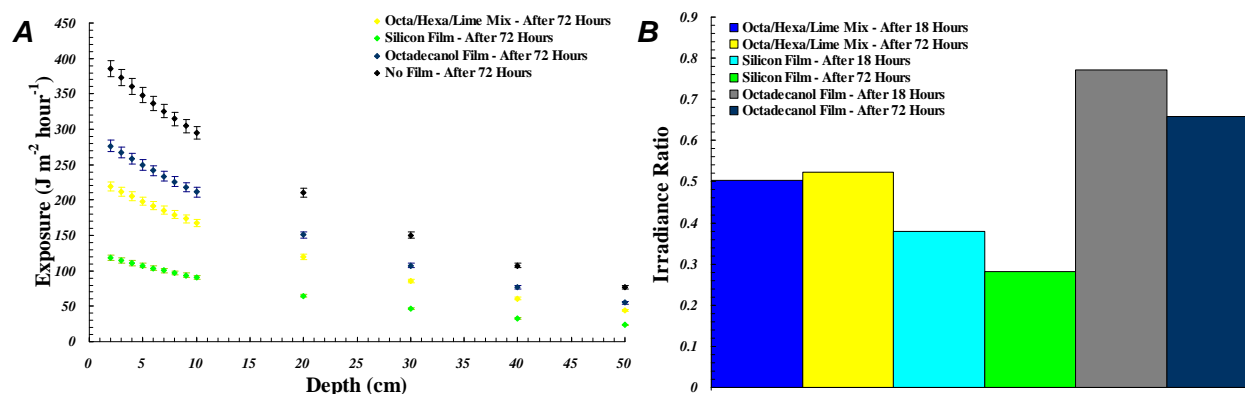
## Results

The evaporation rates measured with and without octadecanol for wind speeds from  $0.4 \text{ ms}^{-1}$  to  $1.7 \text{ ms}^{-1}$  with a simultaneous sinusoidal wave pattern ( $T = 6\text{s}$  and  $h = 2\text{cm}$ ) are displayed in Figure 1(A). The percentage evaporation savings calculated for octadecanol with increasing wind speed are displayed in Figure 1(B).



**Figure 1.** (A) Evaporation measurements with and without octadecanol on the water surface for low wind speeds combined with a simple sinusoidal wave pattern ( $h = 2\text{cm}$  and  $T = 6\text{s}$ ) after 48 hours. (B) Percentage evaporation savings calculated for octadecanol with increasing wind speed combined with a sinusoidal wave pattern ( $h = 2\text{cm}$  and  $T = 6\text{s}$ ).

The underwater distribution of artificial UVB radiation underneath a variety of commonly used chemical films/monolayers is shown in Figure 2(A). The ratio between underwater UVB measured beneath the chemical films/monolayers and in-air UVB after 18 and 72 hours is displayed in Figure 2(B).



**Figure 2.** (A) Modelled artificial UVB (298 nm to 320 nm) exposure water column depth profiles for three commonly employed evaporation reducing films (after 72 hours exposure time). Clean tap water was used for this investigation. (B) Irradiance ratios calculated between underwater UVB measured 1 cm beneath the chemical films/monolayers and in-air UVB measured after 18 and 72 hour exposure intervals.

## Conclusions and Impact

From Figure 1(A), it can be seen that the effectiveness of the octadecanol suspension monolayer approaches a threshold at a wind speed between  $1 \text{ ms}^{-1}$  and  $1.6 \text{ ms}^{-1}$  (at a reference height of 2 m) when subjected simultaneously to moderate sinusoidal wave conditions. From Figure 1(B), it is clear that as wind speeds increase the ability of the octadecanol suspension to block evaporating water decreases rapidly. Consequently, octadecanol may not be effective in real-world water basins as average wind speeds at these locations can be much greater than this threshold. However, they may be useful for use in water storages in indoors environments where the influence of wind speed is negligible. Figure 2(A) shows that chemical films/monolayers when applied to surface water can reduce the penetration of UVB into the water column by a substantial amount. From Figure 2(B), it is clear that each chemical film/monolayer can either absorb or reflect UVB at the water surface by at least 25%. This could have a positive influence on the aquatic ecosystem, as harmful UVB radiation may be prevented from reaching and consequently damaging a variety of organisms. Also, it follows that the component of reflected UV radiation could potentially be used to visually monitor the spread and positioning of the monolayers/chemical films on the water surface.

## Future Work

Further trials will be carried out in the wave flume with different wave heights and periods and wind speeds to build an extensive database to completely quantify the performance of octadecanol and other prototype monolayers under development. A UV camera (UVCorder, Oculus Photonics, United States) will be used to visualise the octadecanol monolayer both beneath and on top of a water surface subjected to a wide range of wind conditions.



# Abstracts - Others

# Pre-Treatment Monitoring of Logan Dam Ecosystem and its Potential Responses to Monolayer Application

**Matveev, V.F.**

CSIRO Land and Water, 120 Meiers Rd, Indooroopilly, Queensland

## Summary

In the highly productive Logan's Dam in South East Queensland (SEQ), characterised by low water transparency and low N:P ratio, total biomass of suspended algae and cyanobacteria (phytoplankton) was strongly correlated with ammonia concentration, suggesting ammonia limitation of their growth. As monolayers are known to reduce volatilisation of ammonia and increase its concentration in lake water, application of monolayers may potentially enhance or trigger blooms of toxic blue-green algae (cyanobacteria), creating a water quality problem. This project is investigating the effects of monolayer on ammonia, cyanobacteria and other components of the ecosystem.

## Keywords

Monolayers, lake ecosystem, cyanobacteria, water quality.

## Introduction

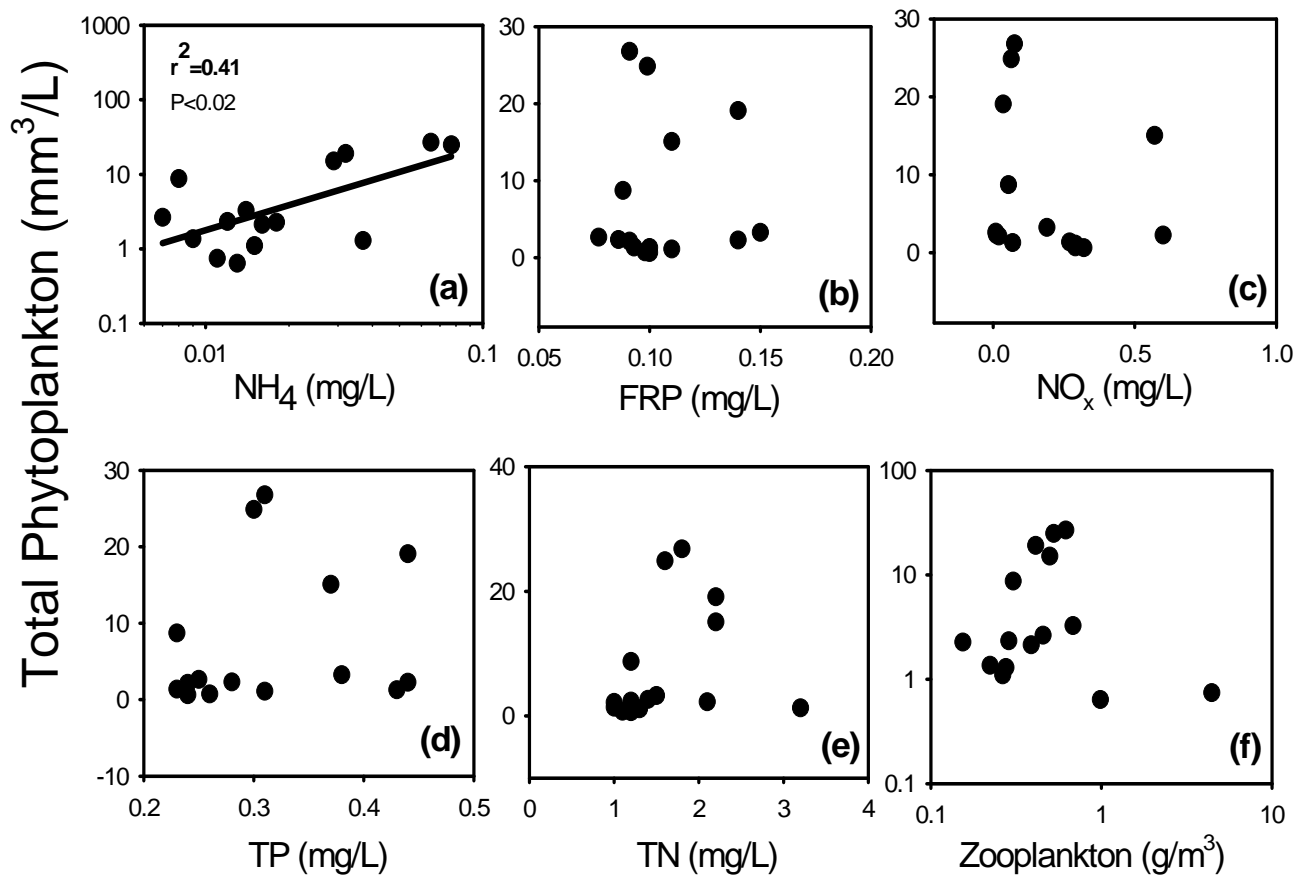
Application of monolayers aimed at reducing evaporation losses may change ecological processes in lakes. Such variables as temperature, oxygen, nutrients, suspended micro-algae/cyanobacteria, planktonic micro-grazers and fish can potentially be affected. As these variables are all terms of "the water quality equation", their monitoring is important for assessing the effects of monolayers on water quality. Natural ecosystem variability complicates the detection of monolayer effects making necessary frequent sampling throughout the year. The present stage of the project is investigating seasonal dynamics of major components of the ecosystem before the application of the monolayer, establishing relationships important for predicting possible outcomes of monolayer application.

## Results

Logan's Dam was found to have very high concentrations of phosphorus, both dissolved and total, and moderate concentrations of nitrogen. This produced a low N:P ratio, known to favor blooms of toxic cyanobacteria. The biomass of one species of noxious cyanobacteria, *Microcystis*, was found to be high and oscillatory in Logan's Dam, often exceeding Queensland Health alert level in summer. In winter cyanobacteria had relatively low concentrations. Measured biomass and mean size of microscopic grazers (zooplankton) remained relatively low throughout the four seasons, suggesting the lack of suppression of cyanobacteria and algae by their natural consumers. The concentration of ammonia in the lake was strongly positively correlated with total phytoplankton biomass, dominated by cyanobacteria. All other species of N and P were not correlated to phytoplankton biomass (Figure 1). This suggested that the concentration of ammonia could be limiting the growth of *Microcystis* - this observation is supported by studies on other lakes. Chlorophyll a concentration, the frequently used measure of primary productivity in lakes, was not correlated with ammonia concentration. Neither it was correlated with total phytoplankton biovolume, indicating that Chl a is a poor predictor of phytoplankton biomass when the phytoplankton community is dominated by cyanobacteria. This was also found in other studies.

## Conclusions

Pre-treatment monitoring of concentrations of nutrients, phytoplankton and micro-grazers in Logan's Dam revealed a high degree of natural seasonal variation. Top-down control of total algae and cyanobacteria by micro-grazers was probably insignificant, while bottom-up control by nutrients was mainly due to ammonia. Logan's Dam is likely to be a nitrogen-limited ecosystem, and the application of the monolayer may increase the concentration of ammonia by reducing its volatilisation, which, in turn, may favor the growth of potentially toxic blue-green algae (*Microcystis*).



**Figure 1.** Correlations between the biovolume of total phytoplankton and concentrations of nutrients or biomass of micro-grazers (zooplankton) in Logan's Dam in 2009-2010. Note that the only significant correlation found was that with the concentration of ammonia. (a) ammonia, (b) filterable reactive phosphorus, (c) oxides of nitrogen, (d) total phosphorus, (e) total nitrogen, (f) zooplankton.

## Future Work

The second, post-treatment stage of this project should establish whether the magnitude of the effects of monolayer on ammonia, toxic cyanobacteria and other components of the ecosystem are significant or not. Densities of phytoplankton and zooplankton, as well as concentrations of nutrients and variation in other physio-chemical parameters will be monitored after the application of a monolayer. Before- and after- time series for all the parameters monitored will be compared.

# An Assessment of Floating Hard Covers on Large Water Storages within South East Queensland

Brook, A., Lemckert, C., and Talbot, L.

Griffith University, School of Engineering, Gold Coast Campus, Gold Coast, Queensland

## Summary

In South East Queensland (SEQ), large water storages or dams are the primary drinking water supply. The volume of water lost through evaporation each year is roughly equivalent to the SEQ water usage. This considerable loss of water indicates that research into innovative techniques for reducing evaporation could prove beneficial as demand increases in SEQ with rapid population growth. At present, physical hard covers have shown the highest evaporation reduction efficiencies. To date, application of the commercially available products has been limited to small agricultural dams. This study will investigate the possible application of floating hard covers on large water storages within SEQ. Using a generic risk framework it will identify those dams with the most potential for hard cover application and outline risks associated with their deployment.

## Keywords

Evaporation reduction, floating hard covers, dam risk assessments.

## Introduction

The loss of water from our dams through evaporation is seen as a significant problem as demand for water increases, reduction in evaporation is seen as a viable alternative to alternate water sources. Reducing evaporation on water storages can be achieved at various levels of efficiency. The main methods currently under investigation are monolayers, physical hard covers and destratification. The National Centre for Engineering in Agriculture (NCEA) undertook a thorough evaluation of the full range of evaporation techniques, identifying floating hard covers as out-performing all other evaporation reduction techniques in terms of efficiency (Howard and Schmidt, 2008).

A floating hard cover is an object that floats on the water surface providing a physical barrier against incoming solar radiation. This reduction in solar radiation decreases surface temperatures and hence evaporation. This technique has claimed to have very high evaporation reduction rates of up to 95% (Craig *et al.* 2005), however there are a number of negative issues relating to the application of floating hard covers. Edmonds 2010, also looked at the water saving benefits hard covers could have, but did not consider any possible negative issues associated with their application. These issues include, high cost, possible water quality issues, and a number of increased risks in relation to dam safety and operation (GHD, 2003). To date, floating hard covers have only been applied and tested on relatively small and confined agricultural dams. The risks associated with their application on large regional water supply dams need to be identified to assess their viability.

This study uses a generic risk framework developed by SMEC consulting (Baldwin, 2010) to assess SEQ water storages to identify those dams with the most potential for hard cover application and outline risks associated with their deployment. The generic risk assessment was developed by SMEC under the guidance of Griffith University with funding support provided by the Urban Water Security Research Alliance (UWSRA). As a base case, Maroon dam was used to develop the risk framework with additional risks being added to include those risks that maybe encountered with other types of dams in the region. For the risk assessment, the commercial available Aquacap and AquaArmour hard cover products were used.

## Methodology

Information on the 25 main dams owned and operated by Seqwater was compiled to make an assessment on which dams would be most suitable for the application. To make a preliminary assessment of whether a dam was suitable for the application of floating hard covers, generic information was obtained on the following areas.

- General Dimensions – The volume and surface area of the dam were found to determine the potential for evaporation reduction and to make judgements on suitable capacity and possible deployment locations.
- Dam specifications – The type of dam wall, spill way and any other structures were found to assess the risks associated with floating hard covers.
- Recreational activities – recreational activities permitted on each dam were investigated to assess the risks floating hard covers may create.

From this preliminary assessment, seven dams were identified as showing potential for the application of floating hard covers. Each dam was critically analysed using the generic risk framework developed by SMEC (Baldwin, 2010). Wind and wave climates were determined using wind data from the Bureau of Meteorology and the Australian Standard Wind Code (AS/NZS 1170.2:2002).

It should be noted that the study was a preliminary investigation only, used to identify areas where further investigation is required to gain a better understanding of specific performance and design issues. Before the implementation of hard covers on any water supply dam is undertaken a full detailed risk assessment should be conducted in conjunction with the dam owners and operators.

## Results

The investigation of the existing Seqwater dams determined that the greatest potential for the evaporation reduction with minimal risk to the dam structures and operation would be best achieved on off-stream storages and indirect supplies to the SEQ water grid. The secondary water supply storages proved to have the most favourable conditions in terms of minimal increases to the existing risk profiles. The seven dams selected as being suitable for the risk analysis were: Bromelton Dam, Enoggera Dam, Ewen Maddock Dam, Gold Creek Dam, Leslie Harrison Dam, Little Nerang Dam, and Poona Dam.

The preliminary risk analysis of the seven dams showed that floating hard covers would be most applicable to unpopulated and non-recreational locations. These two features were identified as imposing the most risk to the public and dam safety.

The wind and wave loadings that could be experienced at the dams were significant in magnitude, with wave heights ranging between 0.5m to 1.1m produced in a one in 100 year wind event depending on fetch lengths. The AquaCap and AquaArmour products have not been tested for such conditions to date.

The major risk associated with increasing the dam safety risk profile was containment of the hard covers. To date, no containment boom has been developed for either product and, as such, the risk of the hard covers escaping from a dam's containment or causing damage to dam structures is in need of future investigation.

## Conclusions

Bromelton, Gold Creek, Little Nerang and Poona dams were identified as being the most feasible for hard cover application. These dams have characteristics that resulted in the least increase in their existing risk profile. However, at this stage this does not mean these dams are suitable for hard cover application. This study has identified that further investigation must be undertaken in a number of areas. A number of the more critical risks were associated with the need for a containment boom that has not yet been developed. Once a suitable containment boom for the floating hard covers has been developed the safety risks associated with deployment of hard covers could be mitigated to an acceptable level. Without the development of containment booms or a suitable anchorage system, application of hard covers on major storages at this time would pose too great a risk. Until further details can be provided it is not recommended that hard covers be deployed on SEQ dams.

## Future Work

It is not recommended that further investigation into hard covers on large water storages be undertaken until a containment boom is developed. Other critical issues in regard to hard cover application such as water quality should be further investigated on smaller water storages that do not pose the same risks to safety.

## Acknowledgements

Griffith University would like to thank the Urban Water Security Research Alliance for their funding assistance for this project.

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# Will Artificial Monolayers Adversely Affect Water Quality? Insights from Twelve Months of Monitoring with No Monolayer

Pittaway, P.

National Centre for Engineering in Agriculture, University of Southern Queensland, West St, Toowoomba, Queensland

## Summary

Evaporative loss from water storages can be reduced by applying an artificial monolayer to the surface, but municipal water managers are concerned about the impact on potable water quality. A study has been undertaken over the last year on a 16 ha irrigation storage in the Lockyer Valley to characterise key water quality parameters prior to the application of an artificial monolayer. Analyses of water sampled every two weeks from the air/water interface and the subsurface have been interpreted in the context of climatic data recorded at the site. Preliminary results indicate that the natural storage dynamics associated with algal blooms, wind and rainfall may have more of an impact on water quality than the application of an artificial monolayer.

## Keywords

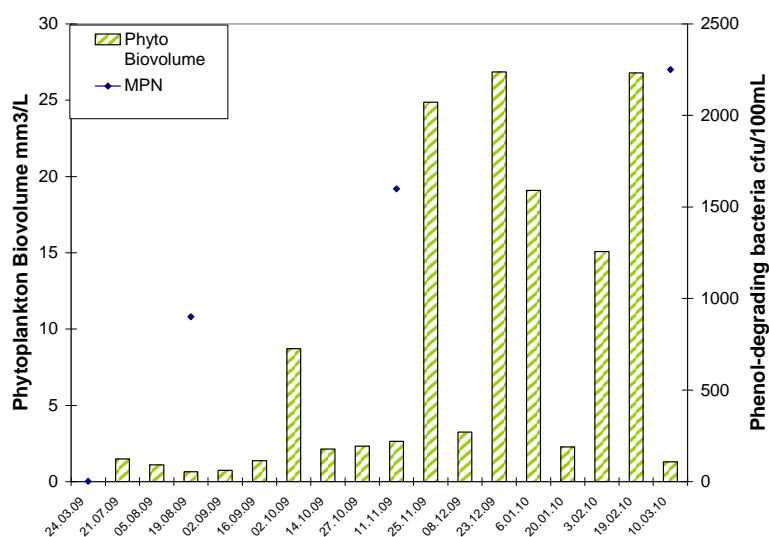
Air-water interface, microlayer, monolayer, water quality.

## Introduction

Freshwater ecologists are concerned that applying an artificial monolayer to a water storage will adversely affect water quality and aquatic ecology (Wiltzius 1967). Artificial monolayers increase the surface pressure at the air/water interface (the microlayer), damping capillary waves and reducing evaporative loss. The surface tension of the water is reduced, surface temperature may increase, and gaseous diffusion may decrease (Gladyshev 2002). From July 2009, microlayer and subsurface water samples (5-10 cm below the microlayer) have been collected every two weeks from Logan's Dam in the Lockyer Valley, within one hour after dawn. The samples were analysed for temperature, pH, conductivity, dissolved oxygen, and absorbance in the ultraviolet range (UV absorbance). The surface pressure of the southeast and northwest shores was measured during each sampling, by applying indicator oils to the microlayer. At four specific times over the year, the biochemical oxygen demand (BOD<sub>5</sub>), chemical oxygen demand (COD), non-ionic surfactants, and the activity of phenol-degrading bacteria (species most likely to degrade aromatic microlayer and artificial monolayer compounds) were monitored to document how key seasonal changes affect the properties of the natural microlayer.

## Logan's Dam Monitoring in the Absence of Monolayer Application

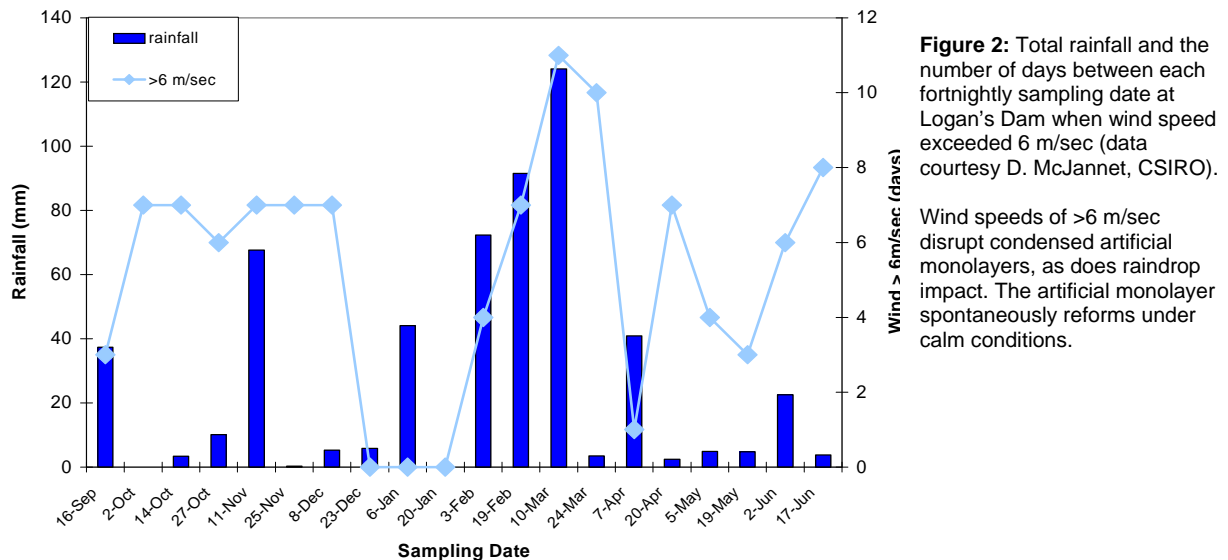
Initially the activity of phenol-degraders was low and the concentration of UV absorbing compounds was high, indicating the potential for high rates of photodegradation. Hydrophobic aromatic compounds derived from tree leaf and bark litter flushed into water storages are usually the main substrate for microlayer bacteria (Norkrans 1980). At Logan's Dam, the concentration of UV absorbing organics changed little over the season, suggesting that they are derived from organic carbon in the black soil. The water catchment is cleared, with pasture grasses the predominant vegetation. However, the population size of phenol-degrading bacteria increased substantially over the seasons, in response to the population dynamics of blue-green algae (Figure 1).



**Figure 1:** Change in the biomass of algae (columns, data courtesy V. Matveev, CSIRO) over time and the seasonal change in the population of phenol-degrading bacteria (diamonds). Results suggest there is a lag phase of several weeks between a blue-green algal bloom and an increase in the population of phenol-degrading bacteria. Storage compounds released from dying algal cells serve as substrate for the phenol-degrading bacteria.

The increase from a low of 13 colony forming units (cfu) to 2,250 cfu per 100 ml was two orders of magnitude greater than the increase recorded during a tank trial, comparing bacterial activity in potable water with and without the application of an artificial monolayer. The monolayer octadecanol was added at a rate of 0.14 kg per ha to the surface of a tank (10 m diameter, 0.8 m deep filled with Toowoomba town water), twice weekly for 2 months. 70 ml of Logan's Dam water sampled from the water column was added to each tank as a microbial inoculant. The population of phenol-degrading bacteria increased from 5 cfu to only 20 cfu per 100 ml over the two months.

Changes in the surface pressure of Logan's Dam were greatest within 2 to 4 m of the shore. The pressure across the centre of the storage was consistently less than 4 mN/m. The peak in surface pressure of 35 mN/m coincided with the decline of a blue-green algal bloom. These results suggest that the frequency of algal blooms may have a greater impact on the activity of heterotrophic bacteria than repeat applications of an artificial monolayer.



**Figure 2:** Total rainfall and the number of days between each fortnightly sampling date at Logan's Dam when wind speed exceeded 6 m/sec (data courtesy D. McJannet, CSIRO). Wind speeds of >6 m/sec disrupt condensed artificial monolayers, as does raindrop impact. The artificial monolayer spontaneously reforms under calm conditions.

Small-scale changes in capillary wave action and the thickness of boundary air and water layers (the microlayer) can affect both gaseous diffusion and thermal convection (Gladyshev 2002). Many surface-active compounds suppress capillary waves calming the water, but only a more limited class of saturated, long-chain compounds are capable of reducing evaporative loss (Barnes 2008). The combination of damping capillary waves and a reduction in evaporative cooling has the greatest potential to increase microlayer temperature and to reduce gaseous exchange. However, larger scale changes induced by wind speeds in excess of 6 m/sec and by rainfall have a far greater impact on these processes (Jones 1992).

On average, wind exceeding 6 m/sec occurred on 6 of the 14 day sampling interval, with the exception of very calm weather during January (Figure 2). Rainfall was recorded during most months, indicating that the persistence of a condensed monolayer increasing surface temperature and reducing gaseous exchange will be limited to days, not weeks. Re-application and re-spreading will restore the condensed monolayer, but the frequency of wind and wave disruption may have a greater impact on microlayer temperature and gaseous diffusion than the presence of the monolayer. Further monitoring after monolayer application commences in August or September 2010 will confirm if the impact of the monolayer on the water quality of the storage exceeds natural seasonal dynamics.

## Preliminary Conclusion

Preliminary monitoring results suggest that the natural seasonal dynamics associated with algal blooms, wind speed and rainfall intensity may have more of an impact on the water quality of Logan's Dam than the application of an artificial monolayer. Monitoring will continue to enable comparisons of temperature and dissolved oxygen differentials for microlayer and subsurface water samples, and seasonal changes in the COD, BOD, phenol-degrading bacteria and non-ionic surfactants before and after the application of a monolayer product.

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# Photodegradation of Australian Freshwater Microlayers and the Implications for Potable Water Management

Stuckey, N.<sup>1</sup>, Pittaway, P.A.<sup>1</sup>, Larsen, K.<sup>2</sup>

<sup>1</sup> National Centre for Engineering in Agriculture, Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, Queensland

<sup>2</sup> Faculty of Sciences, University of Southern Queensland, Toowoomba, Queensland

## Summary

Photodegradation has been known to break down toxic compounds in potable water storages as well as degrading pesticides and herbicides in agricultural water storages. In this study, the concentration and reactivity of humic substances (HS) present in natural microlayers on water storages in South East Queensland (SEQ) was investigated. Microlayer and subsurface samples were taken from eight water storages with dissolved organic carbon (DOC) used to quantify HS concentration. The  $E_2/E_3$  ratio (ratio of absorbance at 250 nm to 365 nm) was used to indicate the molecular weight of DOC compounds, and absorbance at 253.7 nm and the permanganate index were used to compare the reactivity of humified DOC. The concentration of carbonyl compounds in the microlayer was also investigated as carbonyls are considered the most photoreactive functional group present in HS. Preliminary results indicate that the concentration of HS and their chemical reactivity in SEQ water storages are highly variable, reflecting the characteristics of the water catchments.

## Keywords

Photodegradation, microlayer, monolayer, potable water, humic substances.

## Introduction

The photodegradation of freshwater microlayers has both advantages and disadvantages when it comes to implications for potable water management. Firstly the degradation of HS to smaller, more reactive compounds can be detrimental to potable water treatment, as these small molecular weight organic compounds can be toxic (eg, hydrogen peroxide, Scully 1996). However, photodegradation can have a positive effect on potable water treatment. This is evident from the use of UV light as a disinfectant in the treatment of potable water for many years (Legrini *et al.* 1993).

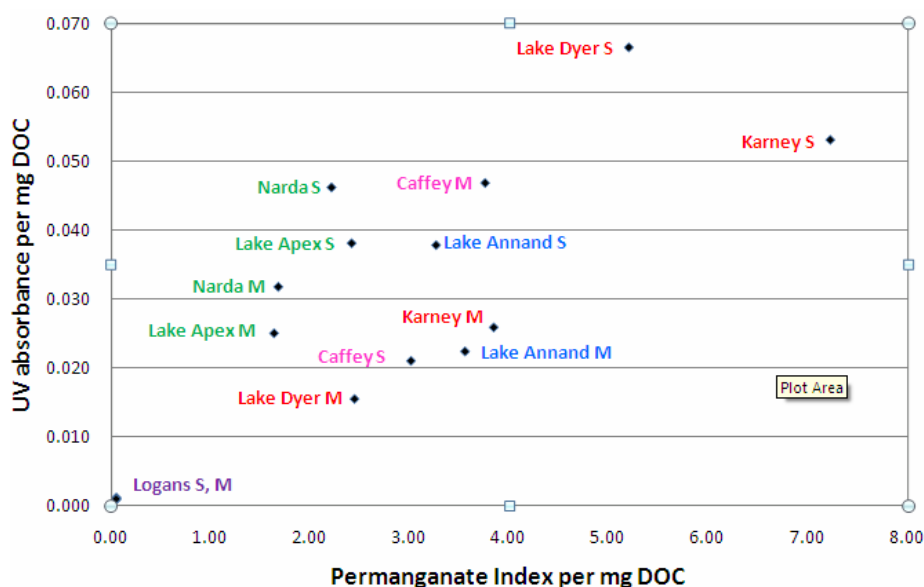
Compounds in freshwater microlayers include naturally occurring and anthropogenic hydrophobic HS, including pesticides and artificial monolayers. Artificial monolayers have been applied to water storages and studied as an evaporation suppression method since the 1950's. However, they have shown varying field performance due to wind and wave action and varying half lives. The variation in half life is due to photo and microbial degradation, natural processes that may be substantially enriched in the microlayer relative to the immediate subsurface water.

The composition of microlayers on freshwater storages in Northern Europe has been studied for decades. Research in Australia is more recent, highlighting differences in microlayer and subsurface water composition associated with vegetation and climate (Pittaway and van den Ancker 2009). The hydrophobic, aromatic compounds concentrating within the microlayer strongly absorb ultraviolet light to produce photoreactive compounds, limiting the half-life of artificial monolayer products. Of the compounds found in the microlayer, those that have a lower molecular weight are considered the most reactive (Hessen and Tranvik 1998).

In this study, the chemical reactivity and rate of photodegradation occurring within natural microlayers was investigated. Microlayer and subsurface water samples from eight storages located within SEQ were sampled in May 2010, with the concentration of DOC quantified using a Total Organic Carbon (TOC) analyser. The  $E_2/E_3$  ratio (absorbance at 250 nm and 365 nm) was used to indicate the molecular weight of aquatic HS. Absorbance at 253.7 nm and the permanganate index was used to quantify the concentration and reactivity of HS in the water samples.

## Results

Results indicate that larger organic molecules derived from wooded catchments absorb UV light more strongly, and are more chemically reactive (higher permanganate index). Smaller molecules derived from a storage constructed on black vertisol soil within a cleared catchment absorbed less UV light, and were relatively unreactive (lower permanganate index). When UV absorbance was plotted against the permanganate index (all data standardised per unit DOC), results for the eight storages tested clustered into five groups (Figure 1), reflecting the attributes of the water catchments (Table 1).



**Figure 1.** Relationship between UV absorbance and permanganate index (both standardised for DOC concentration). Storages with similar results to these two tests and similar relationships between microlayer and subsurface water have been grouped together, as shown by the different colours.

**Table 1.** Summary of results from testing carried out on water storages in SEQ. Colour coding of water storages in this table match those in Figure 1. UV absorbance was carried out at 253.7nm, and molecular size was inferred using the E<sub>2</sub>/E<sub>3</sub> ratio with molecular size inversely proportional to the ratio.

Storage	Micro/ Subs	DOC mg/L	KMn Index / mg TOC	UV absorbance / mg TOC	E <sub>2</sub> /E <sub>3</sub> Ratio	Storage Catchment Attributes
Logan's NW	M	2708	0.04	0.001	4.71	Black soil, grassy, very turbid
	S	2648	0.04	0.001	5.74	
Logan's SE	M	3083	0.04	0.001	5.28	Black soil, grassy, very turbid
	S	2775	0.04	0.001	5.48	
Narda Lagoon	M	41	1.67	0.032	4.05	Woodland, saw mill adjacent
	S	27	2.21	0.046	4.01	
Lake Apex	M	30	1.63	0.025	3.37	Woodland, runoff over grasses terrain
	S	19	2.41	0.038	3.52	
Caffey	M	16	3.84	0.026	3.68	Filled with bore water
	S	11	3.00	0.021	2.79	
Lake Annand	M	14	3.55	0.022	3.07	Runoff primarily from roads
	S	6	3.26	0.038	2.48	
Kearneys Spring	M	6	3.75	0.047	2.49	Parkland, primary inflow from spring
	S	4	5.20	0.067	2.58	
Lake Dyer	M	15	2.44	0.016	3.14	Parkland, primary inflow pumped from creek
	S	3	7.22	0.053	2.47	

## Preliminary Conclusions

Preliminary results indicate that water storages in SEQ differ substantially in the concentration and reactivity of DOC in subsurface and microlayer water samples. Differences in the chemical reactivity of the water samples reflect differences in the vegetation and management of the catchments. Results indicate/show that high molecular weight molecules, such as those derived from terrestrial vegetation, are more reactive than low molecular weight molecules which are derived from black soil.

Currently, an analytical method for the quantification of carbonyls in aqueous solutions is being developed to determine the amount of carbonyls present in a water sample. Controlled photodegradation experiments are being developed to quantify the rate and seasonality of photodegradation occurring in water samples from each of the storages. Results from these studies will be used to compare the resilience of artificial monolayer products to photodegradation, as a function of water quality.

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P.A. Pittaway, T.R. van den Ancker (2009) Microbial and Environmental Implications for use of Monolayers to Reduce Evaporative Loss from Water Storages. Technical Report, NCEA, University of Southern Queensland, Australia.

# Electrochemical Oxidation of Trace Organic Contaminants in Reverse Osmosis Concentrate using Ti/Ru<sub>0.7</sub>Ir<sub>0.3</sub>O<sub>2</sub> Anodes

Radjenovic, J., Bagastyo, A., Mu, Y., Rozendal, R., and Rabaey, K.

Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

## Summary

Electrochemical oxidation has been investigated for the treatment of reverse osmosis concentrate generated in an advanced water treatment plant treating secondary sewage effluent. The efficiency of Ti/Ru<sub>0.7</sub>Ir<sub>0.3</sub>O<sub>2</sub> electrodes for the removal of organic carbon, specific ultra-violet absorbance at 254 nm (SUVA<sub>254</sub>), and trace organic contaminants (pharmaceuticals and pesticides) was evaluated. The removal of organic carbon and SUVA<sub>254</sub> turned out to be dependent on the accumulation of oxidants in the bulk, and possibly on the initial aromaticity of the sample. Considering the trace organics, several compounds were resilient to oxidation even at the highest current densities employed, characterised by the presence of electron withdrawing groups on the aromatic ring. Although they were removed in batch experiments for high specific electrical charge consumed, a drastic increase in baseline toxicity during electro-oxidation was observed in bioluminescence inhibition tests using the marine bacterium *Vibrio fischeri*, suggesting the formation of (poly)halogenated organic by-products.

## Keywords

Electrochemical oxidation, reverse osmosis concentrate, pharmaceuticals, pesticides, LC-MS, Microtox test.

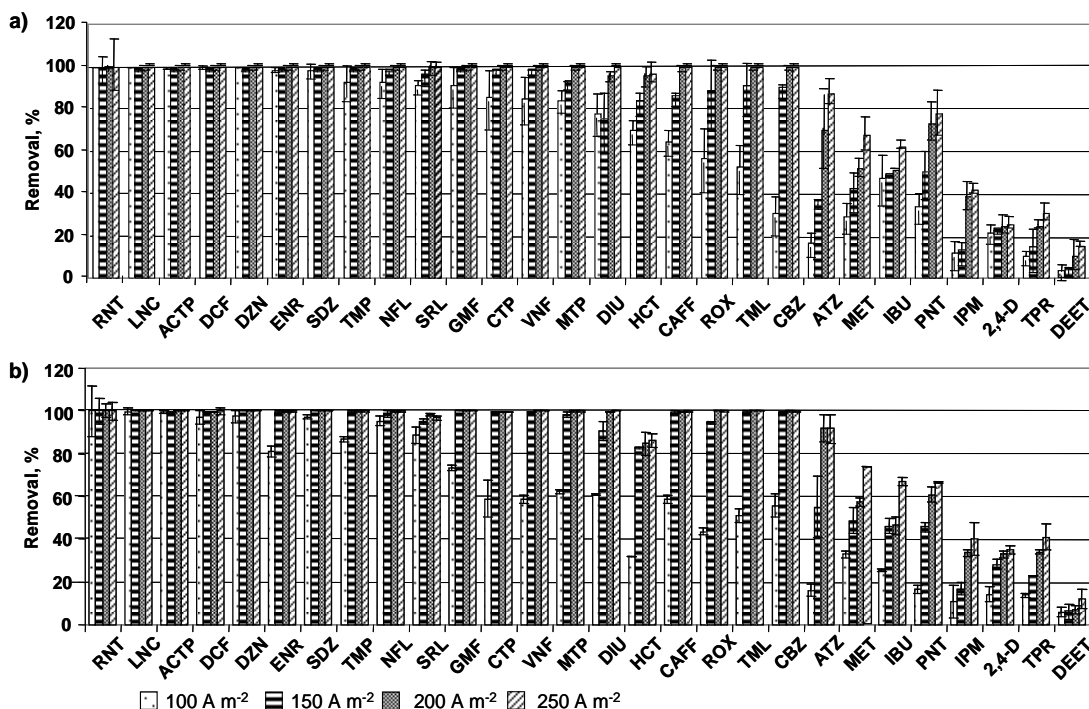
## Introduction

Due to the growing pressure on water resources, the use of treated municipal wastewater for groundwater recharge and indirect potable reuse has increasingly been considered. A number of reuse facilities worldwide currently employ microfiltration (MF) followed by reverse osmosis (RO) membranes for the treatment of sewage effluent prior to the aquifer recharge. Along with the public and regulatory scrutiny, high pressure RO membranes have gained popularity due to their outstanding performance in rejecting the trace organics such as endocrine disruptors, pesticides, pharmaceuticals and others (Bellona *et al.*, 2007; Radjenovic *et al.*, 2008; Snyder *et al.*, 2007). These recalcitrant compounds will be preconcentrated up to seven times in the waste stream (reverse osmosis concentrate, ROC), which normally comprises about 15-25% of the incoming water. This concentrate offers an opportunity for reducing human and ecotoxicological risk by implementing brine treatment prior to environmental discharge.

Electrochemically driven processes are becoming an attractive alternative for the remediation of problematic waste streams. Advantages of electrochemical treatment are efficient control of reaction conditions, no chemicals requirement, simplicity and robustness of operation at ambient temperature and pressure. Notably, mixed metal oxide (MMO) coated electrodes have found widespread environmental applications in recent years for the treatment of pesticide-contaminated water, landfill leachate, organic petroleum wastewater and other hard to treat waste streams (Panizza, 2010). In this study, electrochemical oxidation using titanium electrodes coated with mixed ruthenium and iridium oxides (Ti/Ru<sub>0.7</sub>Ir<sub>0.3</sub>O<sub>2</sub>) was investigated for the treatment of ROC. The process efficiency was evaluated based on the removal of 28 trace organic contaminants (ie, pesticides and pharmaceuticals), selected for their ubiquity in municipal wastewater effluents and brine streams. The target analytes have diverse molecular structures (eg, primary, secondary and tertiary amines, activated aromatic rings, halogen-substituted aromatic rings, heterocyclic rings, carboxylic groups) and physico-chemical properties. Furthermore, baseline toxicity of electrochemically treated ROC was quantified with the bioluminescence inhibition test using the marine bacterium *Vibrio fischeri*.

## Results and Discussion

The experiments were performed galvanostatically in continuous mode with step-wise increase in current density ( $J=1-250 \text{ A m}^{-2}$ ), and in batch mode at  $J=250 \text{ A m}^{-2}$ . The results of each experimental condition are given as the means of triplicate, with their corresponding standard deviations (SDs). In the continuous experiments, two different ROC streams from the Bundamba AWTP were used (ie, ROC collected with one month time in between), marked as ROC-1 and ROC-2, while in batch experiments only ROC-1 was used. While the initial non-purgeable organic carbon (NPOC) and chloride ions content in the two ROCs were similar ( $57 \text{ mg L}^{-1}$  and  $\sim 1.3 \text{ g L}^{-1}$ , respectively), the initial aromaticity expressed as SUVA<sub>254</sub> was higher for the ROC-2 than for the ROC-1 (2.3 and  $1.6 \text{ L mg}^{-1} \text{ m}^{-1}$ , respectively). The two ROCs were spiked with the mix of selected compounds at concentrations in the range of 7.8 (carbamazepine) to  $37.4 \text{ } \mu\text{g L}^{-1}$  (iopromide).



**Figure 1.** Removal of target analytes during anodic oxidation in continuous mode, with stepwise increase in current density ( $J=100$ – $250 \text{ A m}^{-2}$ ) of: a) ROC-1, and b) ROC-2, spiked with a known concentration of trace organic contaminants. RNT-ranitidine, LNC-lincloxylin, ACTP-acetaminophen, DCF-diclofenac, DZN-diazinon, ENR-enrofloxacin, SDZ-sulfadiazine, TMP-trimethoprim, NFL-norfloxacin, SRL-sertraline, GMF-gemfibrozil, CTP-citalopram, VNF-venlafaxine, MTP-metoprolol, DIU-diuron, HCT-hydrochlorothiazide, CAFF-caffeine, ROX-roxithromycin, TML-tramadol, CBZ-carbamazepine, ATZ-atrazine, MET-metolachlor, IBU-ibuprofen, PNT-phenytoin, IPM-iopromide, 2,4-D-2,4-dichlorophenoxyacetic acid, TPR-triclopyr.

Several compounds were readily oxidized already at  $J=100 \text{ A m}^{-2}$  (acetaminophen, diclofenac, diazinon, ranitidine, enrofloxacin, etc). Considering low  $\text{Cl}_2$  evolution overpotential of  $\text{Ti/RuO}_2/\text{IrO}_2$  electrodes, and the affinity of most of these compounds towards chlorine, it can be assumed that they were oxidized by hypochlorous acid (Bedner and MacCrehan, 2006a; Westerhoff *et al.*, 2005; Acero *et al.*, 2008; Dodd *et al.*, 2005). However, for several compounds known to have high affinity for  $\text{Cl}_2$  (eg, caffeine, diuron, metoprolol) (Bedner and MacCrehan, 2006a; Westerhoff *et al.*, 2005; Acero *et al.*, 2008; Chen and Young, 2008; Chamberlain and Adams, 2006; Gould and Richards, 1984; Bedner and MacCrehan, 2006b) lowered oxidation efficiencies were observed. Other compounds for which poor reactivity with chlorine has been previously demonstrated (eg, enrofloxacin, carbamazepine) (Dodd *et al.*, 2005; Huber *et al.*, 2005) are rapidly oxidized. The largely incomplete action of the homogeneous oxidation by chlorine and unexpectedly rapid disappearance of compounds known to be resistant to chlorination suggests that an important role is played by the surface electrochemical reactions. On the other side, compounds that were more persistent to electro-oxidation ( $<20\%$  removal at  $J=100 \text{ A m}^{-2}$ ) were mostly characterised by the decreased electron density at the aromatic ring either due to the presence of electron withdrawing groups such as halogen substituents (eg, 2,4-dichlorophenoxyacetic acid (2,4-D), atrazine, triclopyr and iopromide) and amide groups (eg, N,N-Diethyl-met-atoluamide, DEET). With the increase in current density up to  $250 \text{ A m}^{-2}$  almost complete oxidation of atrazine was achieved ( $>80\%$ ), probably by the chloro-species (Malpass *et al.*, 2006). Also, around 30–40% of 2,4-D, triclopyr and iopromide removal was observed, while DEET could not be oxidized. Therefore, these compounds could be used as surrogates for the estimation of efficiency of electrochemical oxidation. In batch mode experiments at  $J=250 \text{ A m}^{-2}$  these more persistent trace organics were completely oxidized after 23 hours (passed specific electrical charge,  $Q=1.45 \text{ kA h m}^{-3}$ ), except for triclopyr for which the final removal was  $\sim 64\%$ . Thus, these compounds require considerably longer residence times in order for indirect oxidation to occur.

Due to their low overpotential for chlorine evolution,  $\text{RuO}_2/\text{IrO}_2$  electrodes were effectively used for the degradation of pharmaceuticals, pesticides and other organics via indirect electrolysis (Costa *et al.*, 2008; Malpass *et al.*, 2006; Carlesi Jara *et al.*, 2007; Gallard *et al.*, 2004). However, while in-situ generated active chlorine can effectively oxidize many pollutants, the formation of chlorinated by-products could lead to increased wastewater toxicity. The *Vibrio fischeri* bioluminescence assays were performed using the samples enriched by the same solid-phase extraction (SPE) protocol as the one used for the trace analysis, eliminating the majority of matrix components such as salts, particulates and generated oxidants. The baseline toxicity expressing the effects of a mixture of chemicals preconcentrated by SPE increased for the electrochemically treated samples (Escher and Schwarzenbach, 2002). This indicated the generation of chlorinated and possibly brominated by-products. Although the contribution of by-products proceeding from the trace organics and from other organics (eg, halogenated hydrophobic fraction of organic matter) cannot be determined, the increased ecotoxicity of the treated ROC is unquestionable.

## Conclusions

Electrochemical oxidation was investigated for the treatment of brine stream at various current densities. The RuO<sub>2</sub>/IrO<sub>2</sub> anode was capable of oxidizing most of the selected trace contaminants in the two investigated ROC samples. Several compounds were found to be persistent to oxidation, all characterised by the presence of electrophilic substituents at the aromatic ring. Less than 40% of 2,4-D, triclopyr, iopromide and DEET were oxidized at the highest investigated current density (250 A m<sup>-2</sup>) in continuous mode experiments. Although much higher specific electrical charge (Q=1.45 kAh dm<sup>-3</sup>) applied in batch mode experiments was able to remove all target analytes, only up 64% of triclopyr was oxidized. This raises concerns on the potential formation of polyhalogenated by-products during the electrochemical oxidation. As they might be persistent to further degradation and/or require extreme treatment conditions (ie, very high currents, long residence times), the process may not be feasible from an economic perspective. Furthermore, the results of the bioluminescence bioassay highlight that the electrochemical oxidation of ROC will cause transformation of trace organics to their halogenated derivatives.

## Future Work

Future work will be focused on the qualitative analysis of the selected compounds in electrochemical oxidation on RuO<sub>2</sub>/IrO<sub>2</sub> electrodes. Identification of degradation by-products will give insight into the oxidation pathways of the trace organics, and into possible formation of halogenated (eg, chlorinated and brominated) derivatives. Electrochemical reduction will be tested as a post-treatment after the oxidation, as it could provide a solution for the reduction of residual chlorine and possibly other halogenated organics. Activated carbon polishing or an alternative downstream dehalogenation approach will be considered as an alternative for the reduction of toxicity of the electrochemically treated ROC. Finally, other electrode materials will be tested for which different oxidation mechanisms can be expected, leading to different process outcomes in terms of toxicity and by-products generation.

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# The Collapse of Rainfall Teleconnections to Climate Drivers over South East Queensland

van Rensch, P. and Cai, W.

CSIRO Marine and Atmospheric Research, 107-121 Station St., Aspendale, Victoria

## Summary

The rainfall across South East Queensland (SEQ) has been declining over recent decades. Based on current general circulation models it seems unlikely that this is a result of climate change, but due to a breakdown in the La Niña-rainfall relationship in the region. This result opens the question as to what is driving rainfall variability now. Various propositions are brought forward to try and pinpoint the main driver of rainfall in the SEQ region as well as exploring the nature of the breakdown. Rainfall in the region shows a significant relationship with the Southern Annular Mode; however this relationship suffers a similar breakdown as seen in the La Niña case. In conjunction with the breakdown, a decoupling of rainfall with local sea level pressure is observed from about 1980, and there is a decrease in the amount of tropical cyclones, both requiring further investigation.

## Keywords

Rainfall, climate, El Niño, La Niña, Southern Annular Mode, tropical cyclones.

## Introduction

SEQ has seen a decline in rainfall over the last 30 years; placing a significant strain on the local water supply. However, recent flooding over the catchment region has led to water supplies reaching nearly 100% capacity in early 2010. Variability of this magnitude has occurred throughout the rainfall record, and requires further investigation considering the consequences reduced rainfall can have on the region and also considering the potential for it to occur again.

Cai *et al.* (2010) found that the SEQ rainfall decline is unlikely due to climate change. Using an ensemble of twenty four models used by the Intergovernmental Panel on Climate Change they could not reproduce the observed SEQ rainfall decline. Furthermore, targeted experiments with radiative forcing factors such as anthropogenic aerosols and ozone depletion were analysed, but again did not adequately reproduce the observations. Based on these model simulations it seems that climate variability is responsible for the SEQ rainfall decline, although uncertainty exists due to the fact that some key processes associated with SEQ rainfall are not properly represented.

A large scale mode associated with rainfall variability in the SEQ region is El Niño-Southern Oscillation (ENSO). A feature of ENSO is a central Pacific Ocean oscillation between anomalously high (El Niño) and low (La Niña) sea surface temperature in the central Pacific Ocean on annual to inter-annual timescales. The effect of ENSO on SEQ summer rainfall is found to be asymmetric; a more significant teleconnection exists with the La Niña phase of ENSO. During a La Niña, anomalously warm sea surface temperatures are observed closer to the Australian continent, causing the South Pacific convergence zone to shift closer to eastern Australia bringing convective rain-producing systems and the stronger the La Niña event, the more the rainfall produced. El Niño events bring reduced rainfall to SEQ. However, there is not a statistically significant relationship between the magnitude of the El Niño event and the amount of rainfall reduction. That is, stronger El Niño events do not necessarily produce less rainfall.

In recent decades, the La Niña-summer rainfall teleconnection has collapsed with convective systems shifting slightly to the east missing the Australian continent altogether. This is consistent with a change in the Walker circulation and with the fluctuations of the Interdecadal Pacific Oscillation which tends to increase the occurrence of either La Niña or El Niño on multi-decadal timescales. Therefore the question is raised: what, if any, is the main driver of SEQ rainfall variability while ENSO has little effect?

## Findings

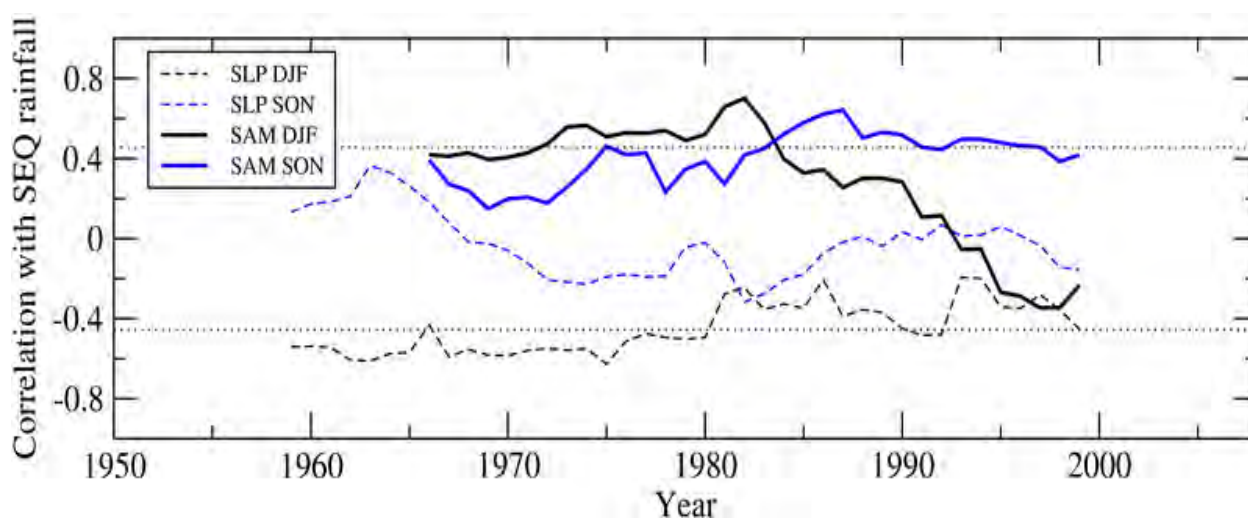
The Pacific Ocean can not explain the current variability of SEQ rainfall, however there are other climate drivers that influence the Australian region, such as the Indian Ocean Dipole (IOD) and the Southern Annular Mode (SAM). The IOD shows little statistical relationship to SEQ rainfall, due to the IOD's pathway of influence missing the SEQ region. Also, during the time of IOD maturity (spring season) the rainfall does not show a notable decline. The SAM is a pressure variation to the south of Australia that influences the strength of the westerly winds in the mid latitudes and is known to effect southern Australian rainfall.

Analysis shows that in summer the SAM-rainfall relationship suffers from the same decay as ENSO in recent decades. A significant correlation is observed from 1950-2008, but this is dominated by a strong teleconnection in the early period (see Figure 1). The latter half of the period shows no relationship. The teleconnection pre-1980 is mainly evident in low rainfall summers, suggesting the SAM was a driver of calmer weather. A significant

relationship is seen in spring, particularly later in the period; however this is a low rainfall season and the observed rainfall decline in SEQ is small in comparison to the overall decline.

The nature of the rainfall trends over the last 60 years do not assist in deducing the cause. The annual trend in rainfall decline of  $3\text{mm yr}^{-1}$  is significant at the 95% confidence level, however when splitting the rainfall into seasons, no individual season appears responsible (no trend is statistically significant). Spring shows almost no trend, with summer being the highest, followed by winter then autumn. The overall small decline throughout the calendar suggests a higher order mechanism is operating to decrease rainfall, such as circulation changes. This is evident when comparing the sea level pressure to rainfall, a slight decoupling is observed in the latter period during summer (see Figure 1).

The rainfall record is littered with years of exceptionally high rainfall, particularly in the early periods. A high degree of these events are due to rainfall associated with tropical cyclones (TCs). The frequency of TC centres propagating within 400km of Brisbane has seen a distinct decline over the period. A total of 34 TCs were detected from 1950-1979, yet from 1980-2006 only 9 were detected. This is a stark difference between the two periods and may also be due to the same mechanism as the reduction of the rainfall response to La Niña, because more TCs typically occur during a La Niña phase in this region (Hastings, 1990).



**Figure 1.** 19-year sliding window correlation of local mean sea level pressure (SLP, dashed lines) and the Southern Annular Mode Index (SAM, solid lines) with SEQ rainfall in summer (DJF, black lines) and spring (SON, blue lines). The dotted lines indicate the 95% confidence level of 0.456 (meaning correlation lines above 0.456 and below -0.456 are statistically significant).

## Conclusions

It is known that prior to 1980 the SEQ rainfall variability was predominantly driven by ENSO, but this connection does not currently operate. If this breakdown was driven by the Interdecadal Pacific Oscillation then it is possible this teleconnection will return. However, there is no known remote climate driver of SEQ rainfall variability that is currently operating. Likewise, the SAM's influence has also decayed in synchronisation with ENSO. It seems the rainfall has decoupled with the general circulation perhaps as a consequence of the ENSO relationship breakdown. This may be manifested through a decline in TC incidence in the area. Therefore other processes should be examined to determine what is driving the SEQ rainfall fluctuations.

## Future Work

Removing the rainfall events associated with TCs from the rainfall record could unveil the true mechanism that is driving smaller rainfall events, and explore the significance of TCs on the ENSO-rainfall relationship. This will also expose what effect the lack of TCs has on rainfall totals, comparable to the situation we are experiencing now. Also an examination of the changes in properties that are increasing TC generation and duration could be undertaken. Considering the importance of large rainfall events (on daily timescales) to the preservation of the water supply, a further examination of the typical processes associated with these events could also be carried out.

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# Quantification of Evaporation from a Water Storage Reservoir: An Inter-Comparison of Scintillometry and Eddy Covariance Methods

McGloin, R.<sup>1</sup>, McGowan, H.<sup>1</sup>, McJannet, D.<sup>2</sup>, Cook, F.<sup>2</sup> and Burn, S.<sup>3</sup>

<sup>1</sup> Climate Research Group, School of Geography, Planning and Environmental Management, The University of Queensland, St Lucia, Queensland

<sup>2</sup> CSIRO Land and Water, 120 Meiers Road, Indooroopilly, Queensland

<sup>3</sup> CSIRO Land and Water, 37 Graham Road, Highett, Victoria

## Summary

Accurate quantification of evaporation from water storage reservoirs presents a significant challenge but is essential for water resource management in water scarce regions, in particular those where rapid growth in demand for water exceeds natural supply. In order to ascertain suitable methods for direct measurements of evaporation, two of the most scientifically advanced evaporation measurement techniques, eddy covariance and scintillometry, have been applied to a small reservoir in South East Queensland, Australia. This paper provides a description of the methodologies required to achieve accurate evaporation measurements using the two techniques and presents a brief comparison of the results so far. These show that the two techniques are producing remarkably similar results with an average evaporation rate of 3.57 mm/day measured by scintillometry compared to 3.56 mm/day measured by eddy covariance over a 10 day period in November 2009.

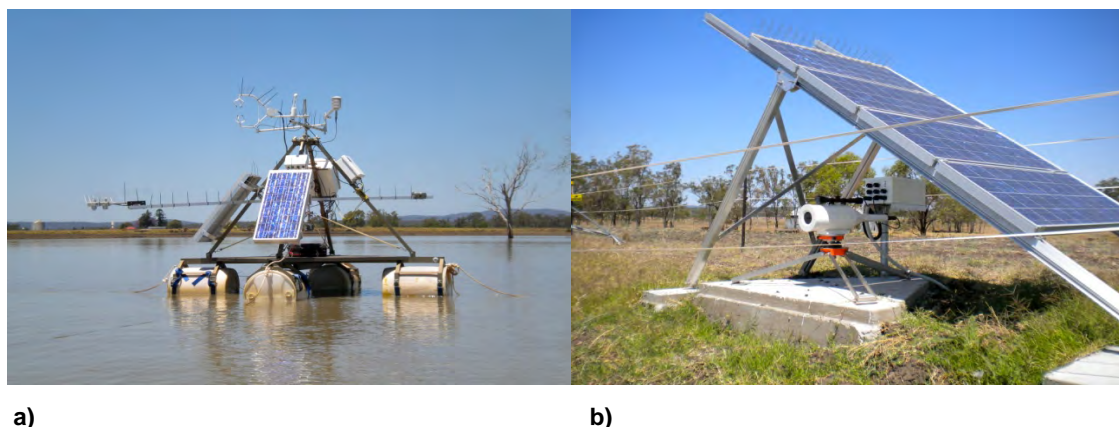
## Keywords

Evaporation, eddy covariance, scintillometry.

## Introduction

According to Craig (2005) the mean rate of evaporation over Australia is greater than 2 m per year and mean rainfall is less than 500 mm per year. “On average 90% of rainfall is directly evaporated back into the atmosphere or used by plants and only 10% runs off to rivers and streams or recharges groundwater aquifers” (National Water Commission 2007, p.2). The estimated value of annual runoff for Australia is just 45 mm, making Australia the world’s driest continent if Antarctica is excluded (National Water Commission 2007). It is clear that water is an extremely precious commodity in Australia and the application and development of water saving measures is of extreme importance. Reliable and representative evaporation rates are essential for predicting water availability and for assessing the effectiveness of evaporation mitigation techniques. The ultimate ambition of this research is to accurately measure the effect of a monolayer in reducing evaporation from an open-water surface; to do this effectively accurate measurements of evaporation are required.

The most common method of direct evaporation measurements is the eddy covariance technique (Figure 1a). This technique involves determination of the latent heat flux using high frequency measurements of vertical wind velocity by a sonic anemometer and the density of water vapour by an infrared gas analyser. Latent heat flux is calculated using the covariance of the turbulent components of vertical wind speed and water vapour density. This must be corrected for density fluctuations associated with rising and descending air parcels, cross contamination of the measured vertical flux by other wind components, high and low frequency attenuation of the flux co-spectrum and horizontal advection, to ensure that the measured flux is equal to the surface flux.

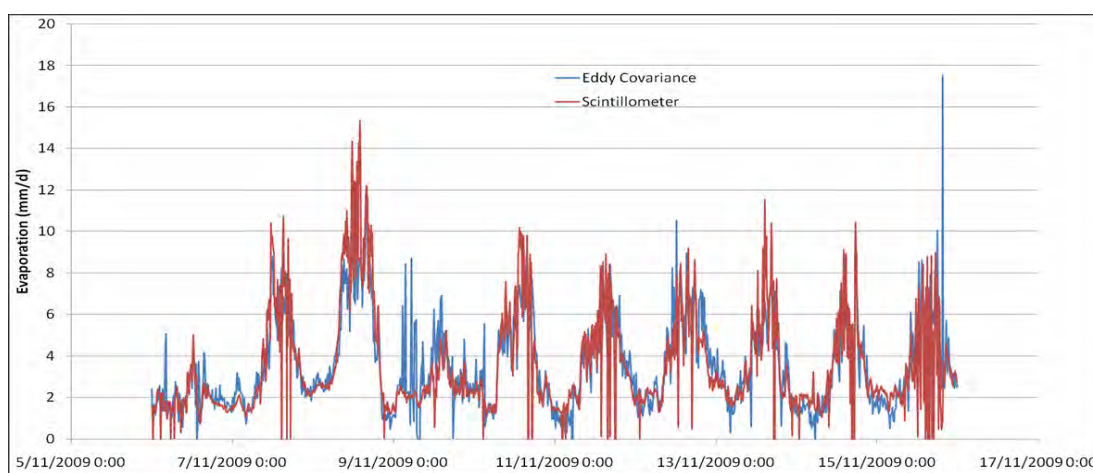


**Figure 1.** (a) eddy covariance apparatus and (b) scintillometer transmitter.

The use of scintillometry for evaluation of latent heat flux over open-water has never been attempted. A scintillometer consists of a transmitter (Figure 1b) and a receiver, a beam of electromagnetic radiation is transmitted to the receiver across a path length ranging from several hundred metres to a few kilometres. The electromagnetic radiation emitted by the transmitter in the direction of the receiver is scattered by the turbulent atmosphere (Meijninger *et al.* 2002). The observed intensity fluctuations (or scintillations) of the electromagnetic signal ( $G_{intA}$ ) are analysed at the receiver, and can be expressed as a structure parameter of the refractive index of air ( $C_n^2$ ) (Meijninger *et al.* 2002). The measured structure parameter of the refractive index of air can be related to structure parameter of temperature and from this, the sensible heat flux can be calculated. In this study the linearised Bowen ratio technique described in Vercauteren *et al.* (2009) is used to then determine evaporation using the sensible heat flux measurements from the scintillometer.

## Results

Results for a ten day period in November 2009, show that the two techniques are producing remarkably similar results. For example, the eddy covariance system measured an average evaporation rate of 3.56 mm/day compared to 3.57 mm/day measured by scintillometry. Figure 2 shows the time series of evaporation measured during the ten day period by the eddy covariance and scintillometer techniques.



**Figure 2.** Time series of evaporation measurements by eddy covariance and scintillometry over a 10 day period in November 2009.

## Conclusions

Results suggest that the method developed in this study for evaluating the latent heat flux over open-water using scintillometry, provides evaporation measurements that are just as accurate as those made by eddy covariance which has generally been regarded as the most accurate evaporation measurement technique. When used together eddy covariance and scintillometry allow for accurate measurements of evaporation from reservoirs not previously achieved.

## Future Work

Future work will involve a more in-depth and long-term comparison of the eddy covariance and scintillometry methods. As well as a comparison of a variety of evaporation models applied to the reservoir, an analysis of the impact of climate variability on lake evaporation in a sub-tropical environment and eddy covariance and scintillometry measurements of the ability of a monolayer to reduce evaporation from the reservoir.

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# Adoption of Decentralised Water Supplies: The Role of Community Perceptions

Tucker, D.<sup>1</sup>, Mankad A.<sup>2</sup>, Tapsuwan, S.<sup>1</sup> and Greenhill, M.<sup>1</sup>

<sup>1</sup> CSIRO Sustainable Ecosystems, Wembley Western Australia

<sup>2</sup> CSIRO Sustainable Ecosystems, Queensland Biosciences Precinct, St Lucia, Queensland

## Summary

The intention of this study was to better understand perceptions of the general community towards adopting decentralised water supply systems. In order to understand both future intentions and actual adoption behaviours in depth, qualitative interviews were undertaken with participants with and without decentralised systems in their homes. The findings of the study point to a need for further research to quantify and potentially predict adoption behaviour on the basis of psycho-social indicators, as well as to further examine the role of geography and location on adoption.

## Keywords

Decentralised water supplies, community perceptions, social psychology.

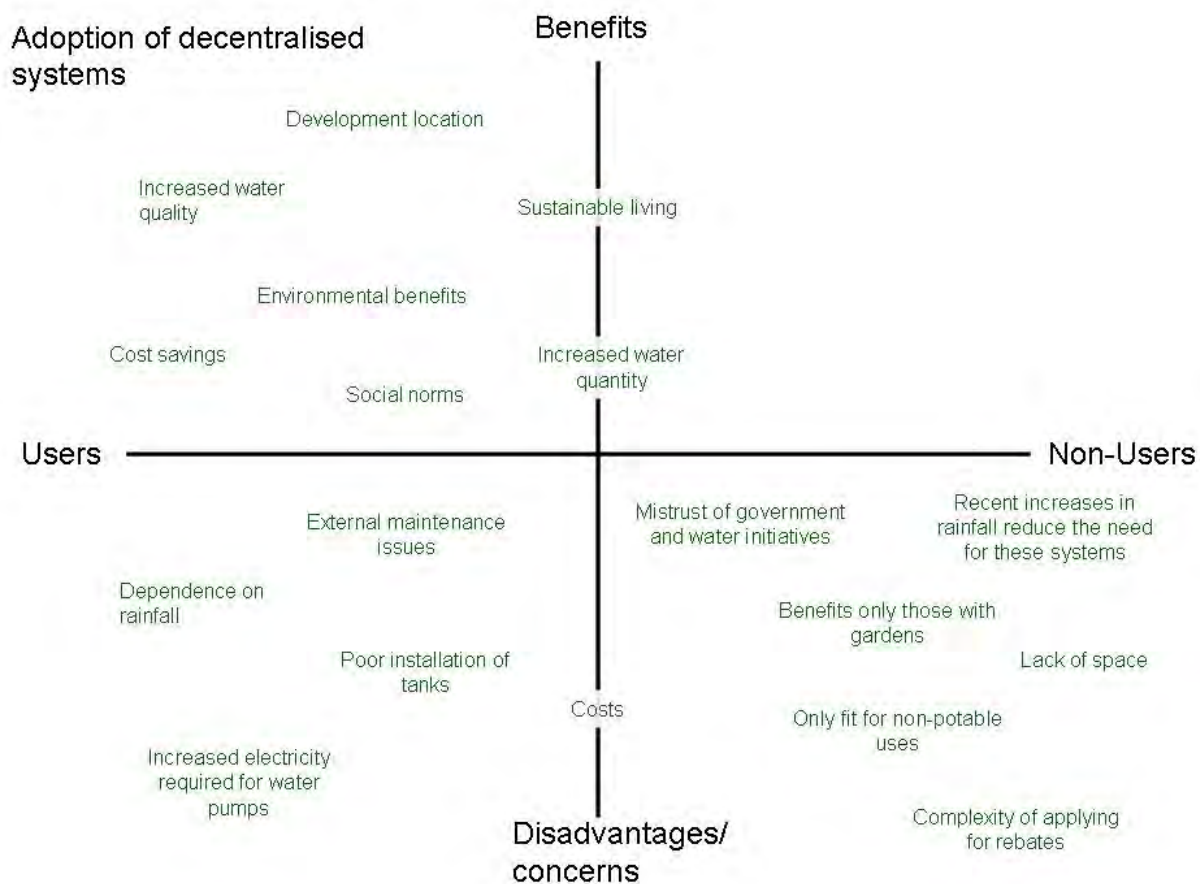
## Introduction

This research was undertaken as a pilot study, aiming to examine the perception of both adopters and non-adopters of decentralised water supply systems in South East Queensland (SEQ), prior to implementing a more extensive survey research design on a broader sample. Decentralised systems, such as rain water tanks and greywater systems, are those that allow households to collect, treat and reuse localised wastewater in areas where high quality water is not required. The key benefit of these systems is to reduce potable water demand, increase fit-for-purpose water use, and reduce wastewater discharge. Decentralised systems are being increasingly viewed as a key water alternative to supplement dwindling water supplies. Past research indicates that community acceptance is very important in the success of new water supply options such as decentralised systems, therefore, this study explores how communities and individuals might attitudinally and behaviourally respond to these systems. In addition, by interviewing residents of communities that have already adopted such systems, factors influencing actual adoption were able to be identified. A qualitative research methodology was utilised, allowing for a meaningful, semi-structured exploration of a broad range of issues and concerns specific to decentralised systems at the household level.

Preliminary research explored the beliefs, knowledge and attitudes of users and non-users of decentralised systems (Mankad, Tucker, Tapsuwan, and Greenhill, 2010). Twenty eight individuals from three locations were interviewed by researchers. Participants comprised of individuals from communities already supplied with decentralised systems (n = 20) and from neighbouring communities with traditional, centralised systems (n = 8). Interviews were recorded and transcribed verbatim; transcripts were subsequently analysed based on emergent and created themes.

## Results

Results indicated both commonalities and differences between adopters (Users) and non-adopters (Non-users). Diagram 1 gives a representation of the themes emerging from the interviews, highlighting the perceived benefits and disadvantages of the systems, and indicating overlap. Both groups indicated that living sustainably was desirable, however, the decision to live sustainably was usually influenced by external factors such as property regulations and finance. Both groups also cited the benefits of having more water around the home, especially with regard to an increase in the quantity of water available to water gardens and lawns. Respondents from the User group in all three locations stated that property location was a major factor influencing the adoption of systems, with environmental benefits of secondary importance. The primary advantage cited by Users was the superior quality of drinking water produced from the rainwater tanks which, unlike potable water from the water grid, was perceived to be free of chemicals such as chlorine and fluoride. Cost savings were also mentioned as another benefit; however, most Users admitted that the true financial benefits of installing a decentralised system would not be realised for some time.



**Figure 1.** Advantages and disadvantages associated with decentralised systems, for both users and non-users.

Users interviewed came from three distinct locations utilising different types of decentralised systems (see Table 1). Concerns with the use of decentralised systems differed for the Users group depending on the type of systems they had installed. The main concerns raised were: increased energy consumption associated with pumping water from rainwater tanks into the house; poor installation of rainwater tanks leading to leakages and back flow; and fluctuating chlorine levels in treated wastewater which impacted on garden health. By all accounts, the experiences Non-users had observed vicariously of decentralised systems were positive, possibly explaining why the present data highlighted such high attitudinal acceptance for decentralised systems among Non-users.

**Table 1.** Decentralised system adoption by study locations.

	Location		
	A	B	C
<b>Types of Decentralised System</b>	Potable water supplied by individual household tanks Non-potable water supplied by community based recycled water treatment plant	Potable water supplied by individual household tanks Non-potable water supplied by individual household grey water systems	Underground rainwater tanks supplied water for toilet flushing, laundry applications and garden irrigation

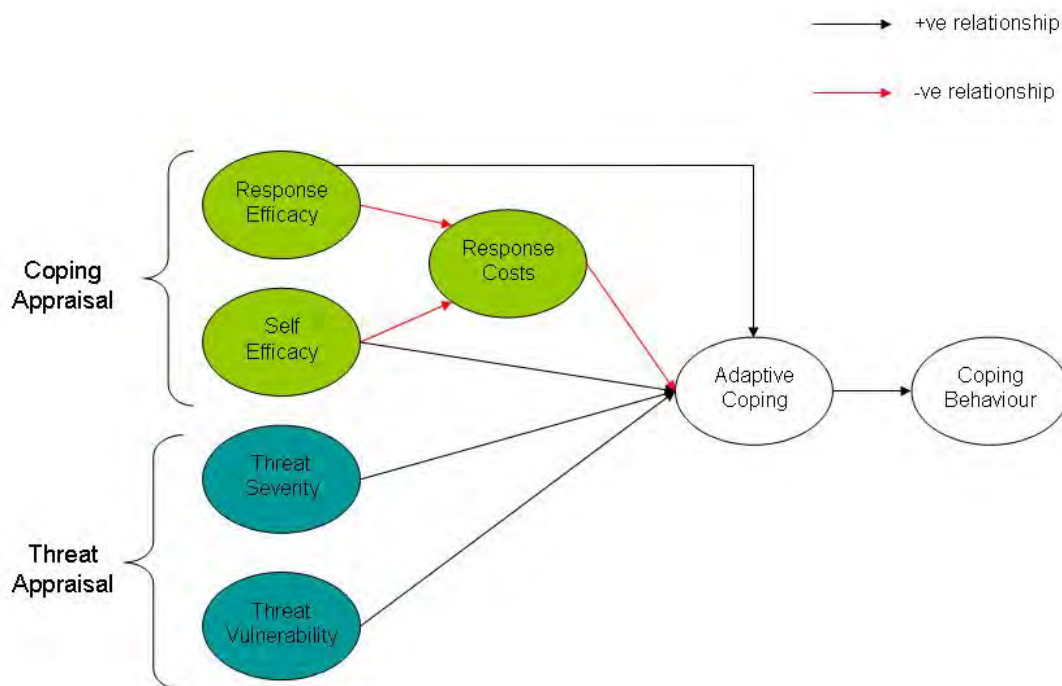
## Conclusions

The results highlight a number of important considerations for moving forward with this research. First, one advantage of the current study over similar studies is the incorporation of people actively engaging in the behaviour of interest. From the comparison of actual (Users) and intended behaviours (Non-users), it becomes evident that there is at least some disparity between the groups.

The mandatory requirement for water savings in new homes has meant that most new homes built since 2007 have installed rainwater tanks. This raises some important questions about whether householders who have mandated tanks interact differently with their tanks than those who have retrofitted the tanks. Theoretically, we would expect people who have made a conscious choice to install a rainwater tank to be much more engaged with the infrastructure because they took part in the decision-making process, whereas, mandated tank owners may feel that the decision is not their own and consequently they have less involvement. There may also be individual differences between people who choose to install tanks (eg, more environmentally aware, care more about their gardens) compared to those who have not chosen. It is important therefore to understand whether there are attitudinal, knowledge, and socio-demographic differences between the two types of tank owners and whether these difference impact on the way they manage their tanks.

## Future Work

It is proposed that future research could focus on theoretically important predictor variables associated with actual and intended behaviours and how one can infer information from models of intended behaviour to guide the prediction of actual behaviour. A combination of interviews and survey work would be undertaken, with the survey aiming for a representative sample of mandated and non-mandated tank owners. Second, given the importance of development location in the adoption of decentralised systems, more research is needed to quantify this effect and assess the degree to which this might be an important consideration for land and water planning in the future. Additionally, with increased water quantity and concerns around costs common to both users and non-users, it is possible that the social psychological theory of Protection Motivation Theory (PMT) might be used to better understand people’s behaviour, and willingness to adopt decentralised systems. PMT, was originally created by Rogers (1975) to help understand people’s behaviours and responses to threatening or stressful situations, and incorporates the measurement of three main factors: threat appraisal, response efficacy and response costs (see Figure 2). Given the common emergent themes, this may be a useful conceptual framework to further understand people’s behaviours around the adoption or non-adoption of decentralised systems.



**Figure 2.** A model of Protection Motivation Theory, adapted from Rogers (1975).

One possibility is to incorporate geospatial data into potential future modelling endeavours, to essentially ‘map out’ current and projected acceptance and adoption behaviours. This will in turn help inform the level of projected urban water demand in new sustainable housing development areas.

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# A Comparison of Different Methods of Impervious Area Estimation

Chowdhury, R.<sup>1</sup>, Hartcher, M.<sup>1</sup>, Gardner, T.<sup>1,2</sup> and Gardiner, R.<sup>2</sup>

<sup>1</sup> CSIRO Land and Water, 120 Meiers Road, Indooroopilly, Queensland

<sup>2</sup> Department of Environment and Resource Management, 80 Meiers Road, Indooroopilly, Queensland

## Summary

Estimation of impervious area is a pre-requisite for hydro-ecological research. Previous studies identified a linear relationship between catchment impervious fraction and stream ecosystem health indicators. Therefore, an accurate estimation of catchment imperviousness is of current interest to urban hydrology researchers. In this study, three methods were compared to estimate the imperviousness of eight catchments located in South East Queensland (SEQ), as part of the Stormwater Harvesting and Reuse Project. The techniques are: (a) manual digitisation of geo-referenced aerial photos; (b) automated image analysis using Erdas IMAGINE and ESRI ArcGIS software; and (c) rainfall runoff depth relationship. For five of the catchments, standard deviations of total impervious area (TIA) percentages are less than 3.6%. For the other three catchments, standard deviation fell between 5% to 8%. The automated image analysis method underestimated results for two catchments. Major constraints of the image processing technique were shading effects and different colours of surfaces, which can be reduced by appropriate selection of signature colours and multiple iterations of a supervised classification. The rainfall–runoff method, which is considered an accurate method from a hydrology perspective, depends on availability of event-based rainfall and runoff data, however a linear relationship was not observed for all catchments. The manual digitisation technique estimated TIA reasonably well, but requires careful selection of sample area for digitisation. Whilst the method requires less GIS skill than image analysis technique, it was time consuming.

## Keywords

Catchment, hydrology, ecosystem, Geographical Information System, aerial photo.

## Background

In hydrological science, the most important surrogate measure of urbanisation is the fraction of impervious surfaces, which includes pavement, roof, paved parking, driveways and other sealed surfaces. Catchment imperviousness increases surface runoff, sediment concentration, associated pollutant discharge and heating of receiving water bodies, and reduces evapo-transpiration and aquifer recharge potential (Han and Burian, 2009). Numerous previous studies have delineated catchment imperviousness as a predictor of stream ecosystem health (Beach, 2003; Walsh *et al*, 2005). Impervious surfaces are either hydraulically connected to stormwater pipe inlets or separated by pervious surfaces. Hydraulically connected indicates runoff follows an entirely sealed pathway prior to entry to stormwater pipes or drains. The hydraulically connected portion of total impervious area (TIA) is known as directly connected impervious area (DCIA). Some recent studies have identified a more defined relationship between DCIA and ecosystem health indicators (Walsh *et al*, 2005). Several recent studies have attempted to estimate DCIA using a high resolution digital elevation model (DEM), multi-spectral satellite image and digital stormwater drainage pipe network database (Han and Burian, 2009; Kunapo *et al*, 2009). However, due to lack of availability of required data and estimation difficulties, TIA is widely accepted as an indicator of urbanisation for hydrologic modelling and hydro-ecological studies.

This study has been conducted as part of the SEQ Stormwater Harvesting and Reuse project. Primary objectives of the project are to: (a) develop relationship between catchment imperviousness, creek hydrology and ecosystem health; and (b) develop biophysical rules for ecologically efficient stormwater harvesting opportunities in SEQ. In this regard, 12 catchments in SEQ have been instrumented for data collection on continuous rainfall, creek flow, and creek water quality. An accurate estimation of TIA is essential for hydrology modelling of these catchments in order to define relationship between hydrology and ecosystem health, and to delineate ecologically sustainable stormwater harvesting practices.

## Methods

Several studies have reported on estimation methods for catchment imperviousness (Lee and Heaney, 2003). All of these methods were based on image analysis technique. In this study, impervious percentages have been estimated for eight urban catchments located in SEQ. Catchment information have been provided in Table 1. Three estimation methods were applied:

**(a) Manual digitisation of geo-referenced aerial photos using the ArcGIS software.** The method involves digitisation of roof, pavement, paved driveway and other sealed areas, such as swimming pool surrounds, for representative sample areas (eight to 10 sample areas) within the catchment boundary. Representative sample areas were selected based on aerial view of dwelling density. A weighted average technique was applied to estimate TIA.

$$TIA(\%) = 100 \frac{\sum (\frac{I_i}{a_i}) A_i}{\sum A_i}$$

Where: *TIA* is total impervious area in percentage; *a<sub>i</sub>* is estimated area for representative sample area *i* (in m<sup>2</sup>); *I<sub>i</sub>* is estimated impervious area for representative sample area *I*; and *A<sub>i</sub>* is part of catchment area (in m<sup>2</sup>) represented by sample area *a<sub>i</sub>*.

**Table 1:** Catchments used for impervious area estimation.

Creek Name	Location in SEQ	Catchment Area (ha)	Land Use
Blunder Creek	Carolina Parade	2176	Mixed <sup>1</sup>
Oxley Creek	Heathwood	46	WSUD <sup>2</sup>
Blunder Creek	Forest Lake	360	WSUD
Lower Yaun Creek	Coomera	142	WSUD
Stable Swamp Creek	Sunnybank	442	Urban
Stable Swamp Creek	Rocklea	2299	Urban
Blunder Creek	Durack	563	Urban
Sheepstation Creek	Parkinson	190	Urban

<sup>1</sup> Combinations of forest, WSUD and urban land use types

<sup>2</sup> Catchment involves water sensitive urban design (WSUD) features such as a wetland and/or pond

**(b) Image analysis using the Erdas IMAGINE and ESRI ArcGIS software.** This automated technique involves conversion of geo-referenced colour aerial photo tiff to native IMAGINE format (.IMG), then creation of mosaics for each catchment area. Development of sample signature sets were then taken for each mosaic with a good representation of surfaces such as different roof colours, road, grass, trees and other key surfaces. An initial supervised classification is run for each mosaic using the respective signature set as training data with further sampling of signatures and a re-run of the classification to correct false positives. Classified .IMG files are converted to ArcGIS GRID format. GRIDs are re-classified into impervious and pervious classes and each GRID clipped to the respective catchment boundary extent. Finally, a comparison was made with digital cadastral data (DCDB) for SEQ to help eliminate large pervious areas, ie, forest, which contain false-positives in the classified outputs.

During the supervised classification process, performance quality was checked with some additional signature class sampling where spectral confusion occurred, such as for different coloured road surfaces and where roof colours were confused with non-impervious areas such as a green roof and green grass. Total impervious area was estimated for each catchment by viewing summary statistics (number of impervious grid cells for reclassified catchment grid) and subtracting number of false positive areas from the digital cadastre comparison.

The major constraints of automated image analysis technique are the shading effects and different colours of roofs. However, while the shading effects cannot easily be corrected, the effects of coloured surface confusion, eg, green roof and forest, can be reduced with careful selection of signature colours and several iterations of the supervised classification. This method requires advanced skill in GIS softwares (ArcGIS and ErDAS IMAGINE).

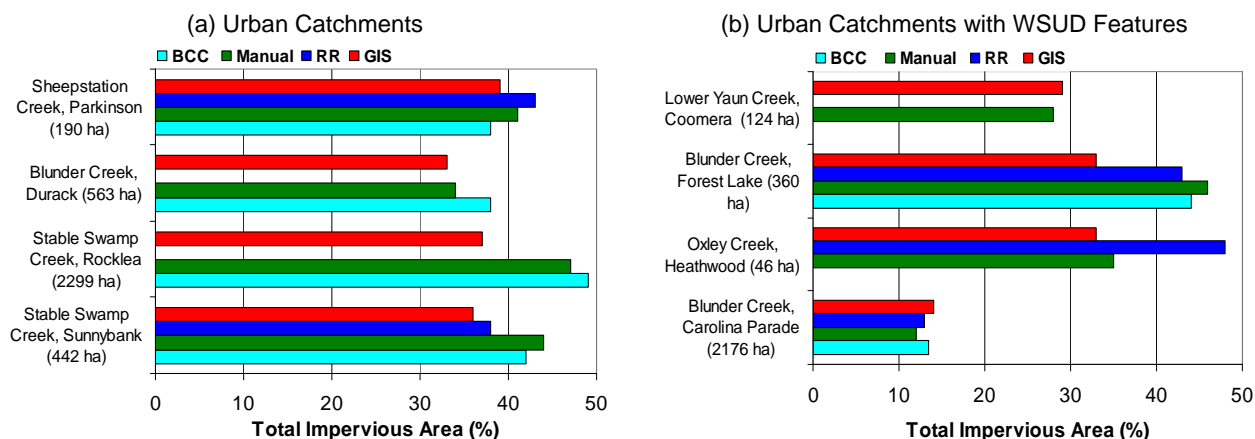
**(c) Rainfall and runoff depth relationship.** The method involves scatter plot and linear regression of rainfall and runoff depth over the catchment (Boyd *et al*, 1993). Ideally for an urban catchment, after initial losses of rainfall, there are three segments of linear relationship. Slopes of these segments represent directly connected impervious area fraction, total impervious area fraction and whole catchment contributing to runoff (1:1 slope). However, easily defined linear relationships are not always observed due to heterogeneous nature of catchment. This method is widely used for catchment calibration.

The major constraint of the rainfall-runoff relationship method is the requirement for a rated gauging station at the catchment outlet.

## Results

Estimated impervious percentages are given in Figure 1. Results are compared with the Brisbane City Council (BCC) GIS data on impervious area. For three catchments (Oxley Creek at Heathwood, Blunder Creek at Forest Lake and Stable Swamp Creek at Rocklea), standard deviations of TIA (%) lie between 5% and 8%. For the Oxley Creek catchment, the rainfall-runoff method overestimated impervious area in comparison to other methods. For Stable Swamp Creek and Blunder Creek catchments, the image analysis technique underestimated results. For the five other catchments, standard deviations of TIA (%) varied from 0.8% to 3.7% indicating reasonably good estimation by all techniques.

The rainfall-runoff relationship method did not provide a linear relationship between rainfall and runoff due to heterogeneous catchment characteristics. Whilst the manual digitisation technique is time consuming, it provides a reasonably good estimation of impervious area. This method requires basic skill on ArcGIS and needs a careful selection of representative sample areas for manual digitisation.



**Figure 1.** Estimated total impervious area for two sets of catchments located in SEQ. Different methods are expressed as Manual (manual digitisation of aerial photo), RR (rainfall-runoff depth relationship) and GIS (automated image analysis technique). BCC indicates Brisbane City Council data. Catchment areas in hectare (ha) are shown for each catchment. For Blunder Creek (Durack), Stable Swamp Creek (Rocklea) and Lower Yuan Creek (Coomera), rainfall-runoff linear relationships were absent. The Lower Yuan Creek is located outside of BCC impervious area data.

## Conclusions

Three different methods of impervious area estimation are reported in this study. Whilst the automated image analysis technique is robust, it underestimated impervious area for two catchments, mainly due to shading effects and the presence of many different roof colours, each having multiple shades due to different sun angles. A careful selection of signature colours and several iterations of a supervised classification may improve the accuracy of results. The method is suitable for any catchment but it requires advanced remote sensing and GIS skills. The rainfall-runoff method was found suitable for urban catchments only. A linear relationship was not observed for some urban catchments with WSUD features. The accuracy of the manual digitisation method depends on selection of representative sample areas. This method gives a reasonably good estimation and it requires only basic GIS skill. However, the method is time consuming. A future improvement by coupling some manual digitising with the automated classification to refine the signature sampling is recommended.

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# Catchment Hydrology Modelling for Stormwater Harvesting Study in SEQ: From Instrumentation to Simulation

Chowdhury, R.<sup>1</sup>, Gardner, T.<sup>1,2</sup>, Gardiner, R.<sup>2</sup>, Chong, M.<sup>1</sup> and Tonks, M.<sup>1,2</sup>

<sup>1</sup> CSIRO Land and Water, Indooroopilly, Queensland

<sup>2</sup> Department of Environment and Resource Management, Indooroopilly, Queensland

## Summary

Hydrology modelling is essential for stream flow simulation and to define hydrologic characteristics of streams. A reliable flow simulation depends on availability of reliable stream flow data and a reliable rainfall runoff model. In this project, considerable effort has been invested in instrumentation of 12 catchments located in South East Queensland (SEQ) in order to obtain continuous rainfall and creek flow data. These catchments represent a diverse range of land use characteristics. Using one year (April 2009 to March 2010) of continuous rainfall and flow data, six catchments have been calibrated and validated at hourly time scale using the Storm Water Management Model (SWMM). The calibrated model was then used to simulate 30 years of creek flow data using historic rainfall data from 1975 to 2005. Simulations were carried out to predict creek hydrologic responses to catchment urbanisation. This was performed by increasing catchment imperviousness. We found that catchment imperviousness increases runoff percentage from 12% at unimpacted condition to 38% at 50% impervious condition. Number of flow events increased from seven events/year to 37 events/year at 50% imperviousness. The one-month to six-month ARI peak flow events were observed to increase significantly with imperviousness. This continuing study will help to identify ecologically sustainable stormwater harvesting practices in SEQ.

## Keywords

Catchment, flow, calibration, simulation, stormwater harvesting.

## Background

Stormwater has recently been acknowledged as a potentially major urban water source. Identification of spatial harvesting opportunities and optimal extraction rules are an active area of research. Previous studies in Australia indicated that catchment urbanisation increases frequency of surface runoff, peak flow and total runoff (Fletcher *et al*, 2007), whilst decreasing creek ecosystem health (Walsh *et al*, 2005). Restoration of urban creeks to their pre-urban flow regime is the key in sustaining their ecosystem health (Kennard *et al*, 2010). Stormwater harvesting can mitigate / prevent degradation of creek ecosystem following urbanisation (Fletcher *et al*, 2007). It can not only supply potable water substitution but also compliance with frequent flow management objectives and peak discharge objectives (Guideline No. 7, DIP, 2009). Therefore, this study selected 12 catchments in SEQ (Table 1) and instrumented them to measure continuous six minute rainfall and stage height. The rainfall and runoff data was then used to calibrate the US EPA model SWMM, which allowed: runoff extrapolation for 30 years (1975 to 2004); exploration of the impact of total impervious area (TIA) on runoff characteristics (runoff percentage, number of events, peak flow and flow duration); and exploration of stormwater harvesting practices on volume yield as well as on runoff characteristics important for creek ecosystem protection.

**Table 1:** Catchments used for instrumentation and hydrology modeling.

Creek Name	Location in SEQ	Area (ha)	Land Use	Impervious (%)	Time of Concentration (hr)
Tingalpa Creek*	Sheldon	2785	Reference <sup>1</sup>	1	8.25
Pimpama River	Kingsholme	415	Reference	1	-
Scrubby Creek*	Karawatha Forest	144	Reference	0	1.40
Upper Yaun Creek	Coomera	362	Reference	3	-
Blunder Creek*	Carolina Parade	2176	Mixed <sup>2</sup>	14	8.85
Oxley Creek*	Heathwood	46	WSUD <sup>3</sup>	37	0.80
Blunder Creek*	Daintree Crescent	360	WSUD	42	2.15
Lower Yaun Creek	Coomera	142	WSUD	29	-
Stable Swamp Creek	Sunnybank	442	Urban	38	-
Stable Swamp Creek	Rocklea	2299	Urban	43	-
Blunder Creek	Durack	563	Urban	33	-
Sheepstation Creek*	Parkinson	190	Urban	39	1.50

<sup>1</sup> Unimpacted or forest catchment; <sup>2</sup> Combinations of reference, WSUD and urban land use types;

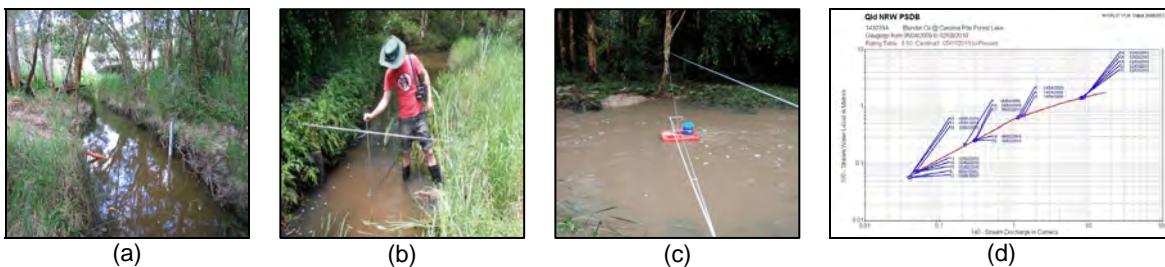
<sup>3</sup> Catchment involves water sensitive urban design (WSUD) features (wetland / pond); \* Calibrated catchments.

Three main themes of the study are:

- Long term simulation of runoff volumes and flow dependent harvesting opportunities for urbanised catchments;
- Identification of flow characteristics that can be related to contemporaneous measures of creek ecosystem responses; and
- Exploring the likely effect of stormwater harvesting practices on achieving frequent flow objectives and more generally protecting creek ecosystem health.

## Catchment Instrumentation and Rating Curve Development

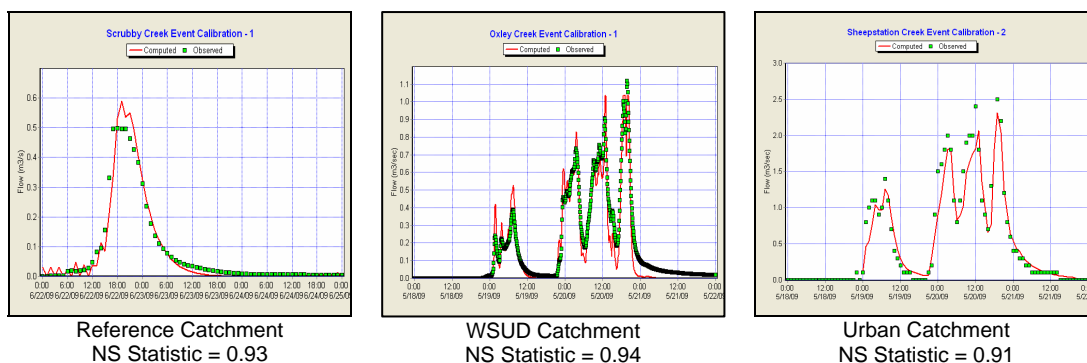
All catchments have been instrumented with a controlled section eg. weirs (less affected by erosion and sedimentation), tipping bucket raingauge (0.2 mm) and pressure transducer with data logger for measuring continuous six minute rainfall and water height data respectively. A gauge board was installed at every site for quality control of pressure transducer water height data. Cross sections of all creeks at the gauging section have been surveyed. Flow rate and depth of water at the creek gauging section have been estimated using a Current Meter and an Acoustic Doppler Current Profiler (mounted in a small boat) for different flow conditions (low, medium and high flow). Rating curves (stage vs discharge relationship) have been developed and validated for all catchments using the HydStra software. This allowed converting continuous water height data into flow rates. A Sonde was also installed in the catchments (three Sondes rotated around 12 catchments) for continuous measure of pH, dissolved oxygen, turbidity and electrical conductivity. Figure 1 shows photographs of catchment and their instrumentation.



**Figure 1.** Selected photographs of catchment instrumentation processes and rating curve development: (a) pressure transducer and gauge board setup; (b) low and medium flow gauging using current meter; (c) high flow gauging using Acoustic Doppler; and (d) a validated rating curve for Blunder Creek at Carolina Parade.

## Catchment Calibration and Validation

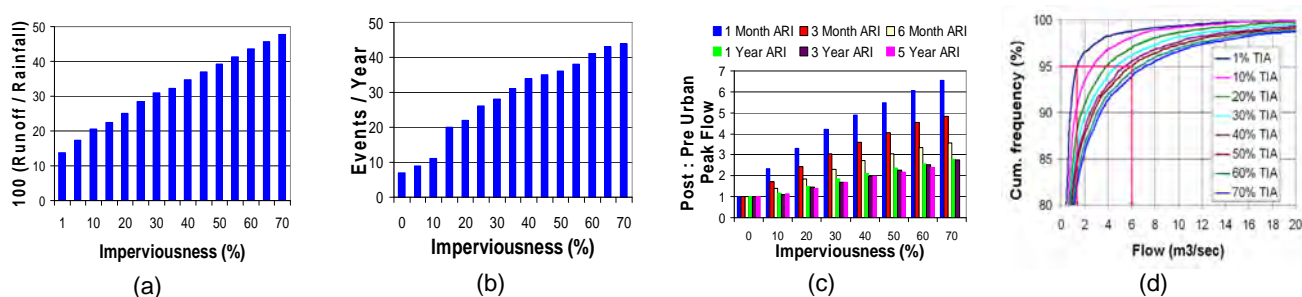
The SWMM model has been used for catchment calibration at an hourly time step. The model has been applied worldwide for all types of stormwater drainage management (Barco *et al*, 2008; Obropta and Kardos, 2007). In this study, six catchments have been calibrated and validated using one year (April 2009 to March 2010) of continuous rainfall and runoff data. Time of concentration for each catchment has been estimated using the Brunby–William method (ARR, 2001). One of the most important catchment parameters is impervious fraction, which has been estimated using image analysis of geo-referenced aerial photos (Chowdhury *et al*, 2010). Model parameters such as catchment slope, characteristic width and creek length were estimated from Digital Elevation Model (25m pixel size) data. Other parameters such as roughness coefficient, soil and aquifer properties were adjusted by comparing predicted and observed runoff of selected storm events. The calibration goodness-of-fit has been estimated using the Nash–Sutcliffe (NS) efficiency statistic. The estimated NS statistics for calibration and validation vary from 0.45 to 0.94; where 1 indicates best and 0 indicates the lowest goodness-of-fit.



**Figure 2:** Selected event calibration results for three contrasting catchments using SWMM.

## Creek Hydrology Simulation

A time series of flow data (usually 20 to 30 years) is essential in order to define creek hydrologic characteristics. This is usually accomplished by using long term rainfall data as an input variable to a calibrated rainfall runoff model. In this study, six minute point rainfall data from 1975 to 2005, collected by the Australian Bureau of Meteorology (BOM), was used for flow simulation. Selected BOM rainfall stations are located within 5 km of catchment outlets, and are reasonably good in representing catchment rainfall patterns. In order to model effects of stormwater harvesting on runoff characteristics and ecosystem response, calibrated unimpacted (reference) catchments are considered to capture the full suite of runoff pathways than do highly urbanised catchments. This is because unimpacted catchments incorporate calibration of sub-surface and base flow components. The two unimpacted catchments (Tingalpa and Scrubby Creek) have been chosen for the more comprehensive hydrology simulation analyses. Urbanisation impacts on creek hydrology were simulated by increasing impervious fractions of reference catchments from 1% to 100%. Hydrologic responses to urbanisation are expressed in terms of: (a) change in runoff percentage; (b) change in number of events per year; (c) change in peak flow for various Average Recurrence Intervals (ARI); and (d) change in cumulative flow distributions. These hydrologic criteria reflect stormwater frequent flow management objectives in SEQ (Guideline No. 7, DIP, 2009). Results indicate that runoff volume increased about three times at 50% impervious condition with respect to their unimpacted condition whilst the annual number of events increased from seven events/year to 37 events/year. The one-month to six-months ARI peak flow events are significantly affected by change of catchment imperviousness, but less so for less frequent events, for example, one-year ARI discharge is only doubled. Simulation results are shown in Figure 3.



**Figure 3.** Simulation results on hydrologic responses to catchment imperviousness based on two calibrated reference catchments, Tingalpa and Scrubby Creek: (a) change of runoff percentage; (b) change in annual number of events; (c) change in peak flow expressed as post : pre urban ratio; (d) change in cumulative distribution of flow.

## Conclusions

Hydrologic modelling and simulation of this study allow quantification of catchment urbanisation effects on the hydrology of receiving streams. Urban creeks experience frequent small events, increased peak flow and runoff volume. Previous studies in Australia observed that catchment imperviousness decrease ecosystem health condition of streams (Walsh *et al.*, 2005) – which are believe to be associated with altered creek hydrology and pollution load conditions. In future, we will develop relationships between creek hydrology and ecosystem health indicators. This will allow investigation of the role of stormwater harvesting in improvement of urban creek ecosystem health and development of ecologically efficient stormwater harvesting rules in SEQ. The next stage of this project will explore stormwater harvesting rules – their effects on harvestable yield and change in hydrological characteristics.

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# Triple Bottom Line Analysis of Water Servicing Options – Identifying and Valuing Externalities as an Input for Decision-Making

Daniels, P, Porter, M, Bodsworth, P. and Coleman, S.

School of Environment, Griffith University, Nathan, Queensland

## Summary

This abstract provides an overview of the most comprehensive compendium of externality effects and valuations available for decision and policy makers concerned with sustainable water management. The compendium has been specifically compiled by the Griffith University team of the Life Cycle Assessment-Integrated Modeling (LCA-IM) Alliance project as a support tool for the option evaluation functions of the project and broader strategic water planning. An overview of the method, structure and scope of the detailed information system is complemented with a proposed non-technical, and simple methodology for applying the results to option evaluation in the South East Queensland (SEQ) context. The compendium provides a comprehensive review of existing research into the identification and economic assessment of externalities pertinent to the adoption of seven different water supply options under consideration in SEQ including: stormwater harvesting, rainwater tanks, centralised wastewater recycling, dams, desalination, groundwater and greywater reuse.

## Keywords

Externalities, economic valuation, cost-benefit analysis, policy, water supply and demand options.

## Introduction

The compendium of water externalities is aimed at providing water managers, scientists, and practitioners with a detailed reference to help incorporate the full range of costs and benefits into option and scenario assessment and decision-making. The focus is upon externalities, or those effects beyond direct financial costs and returns associated with water supply scenarios. Improved identification and information about the likely external effects of alternative water options and the magnitude of their economic impacts can assist in the efficient allocation of resources and the avoidance of unexpected costs later in the project cycle (Siebert, Young and Young 2000). The research has targeted the SEQ context and the results presented have been influenced accordingly. This abstract provides an overview of the content and potential implementation of the water externalities compendium.

## Results

The water externalities compendium has been compiled to provide the background information required to prepare basic externality analyses to supplement and strengthen the assessment of sustainable water management options. The two main sets of data presented to support this process are: (1) the identification of an extensive range of externalities related to water servicing options; and (2) existing economic valuations of these externality effects.

The first major part of the compendium consists of a set of tables listing all the externality effects that have been identified for individual water servicing options in the literature surveyed. Each study option has been analysed to identify externality types and characteristics that are likely to be relevant and significant for that option. The impacts of options are assessed both in general terms and across the various stages of its life cycle. The life cycle and operational phases typically included collection, and sometimes storage, treatment, use and distribution, and decommissioning. The externalities associated with each option were identified by surveying relevant existing research and findings in water-related studies and through technical analysis of the option characteristics and technologies. The individual list of externalities are classified according to an externality type classification reflecting the focus and categories commonly used in related research (for example, greenhouse gas emissions (GHG), nutrients (N) and recreation (R) impacts).

The second major part of the compendium presents an extensive listing of existing economic valuations for the individual externalities identified in the first part of the analysis. The externality valuations are presented in one overall table and, while classified by type, are not distinguished in terms of the water supply options to which they are linked.

The valuations are intended to help guide externality analyses and valuation attempts across a wide range of applications and contexts. However, the focus impacts have been selected on the basis of their relevance for water options under consideration for SEQ. As the foundation for possible ongoing economic assessment, the externality values are first assessed in “average” dollars per biophysical unit terms (for example, an economic cost of \$100 per kg for nitrogen emissions from wastewater recycling). Per unit values are provided on a benefit or costing transfer basis (that is, from other relevant studies), but they can be calculated, with much more time and expense, from primary research or proxy data (based on the study area and context-specific characteristics). Estimates from transfer methods may also be adapted or adjusted on the basis of the unique features and conditions of the study context.

Appropriate monetary unit value ranges, or median, modal or other measures of central tendency, would need to be identified for multiplication by total flow, production or other water supply changes.

**Table 1.** Major externalities and indicative economic valuations for two selected water supply options for SEQ.

(Summary example extract only. The full tables are in much greater detail.)

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (■).

KEY EXTERNALITIES	
<b>RAINWATER TANKS</b>	
<ul style="list-style-type: none"> <li>• Comparatively higher energy usage than reticulated mains water (mostly due to inefficient pump systems). (All Stages (+, ↑, ↓, ■))</li> <li>• Higher greenhouse gas emissions than reticulated water. (All Stages)</li> <li>• Enables gardening and home food production to occur despite drought conditions and water restrictions, leading to amenity and recreational benefits. (Use/Distribution Stages (+, ■))</li> <li>• Decreased fresh water usage, which may defer the need for additional water infrastructure. (Use Stages (+, ↓, ■))</li> <li>• Decreased pressure on drainage infrastructure in flood events. (Collection and Storage Stages (+, ↓, ■))</li> <li>• Potential contamination risk leading to negative health consequences. (Storage and Use Stages (-, ■))</li> <li>• Possible mosquito breeding site if poorly maintained. (Storage Stages (-, ■))</li> <li>• Health and environmental problems stem from the pollutants and wastes associated with the manufacture of the tanks. (Manufacturing Stages (-, ■))</li> <li>• Waste disposal is a source pollution and of potential environmental and health contamination risk. (Disposal Stages (-, ↓, ■))</li> </ul>	<p><b>Main externality types</b> Greenhouse gas emissions (GHG), Health (H), Ecosystem (E)</p> <hr/> <p><b>Valuation Examples (\$AUD 2010)</b></p> <ul style="list-style-type: none"> <li>• GHG: vary from \$5.94 to \$177.43/tonne CO<sub>2</sub></li> <li>• WTP to avoid waterway degradation \$184.73/person/yr (ref 95)</li> <li>• Energy Costs \$19.75/MWh (ref 289)</li> </ul>
<b>WASTEWATER RECYCLING</b>	
<ul style="list-style-type: none"> <li>• Reduced degradation of receiving waters. (Collection and Treatment Stages (+, ↓, ■))</li> <li>• Additional water resource available to drought constrained farmers and other industries. (Collection and Use Stages (+, ■))</li> <li>• Risk of soil contamination. (Use Stages (-, ↓, ■))</li> <li>• Contamination risks and associated health concerns. (Treatment and Use Stages (-, ■))</li> <li>• Risk of cross-contamination and consequent illness. (Use/ Distribution Stages (-, ■))</li> <li>• Low levels of community acceptance for 'high-contact' uses, which may lead to feelings of disempowerment. (Use Stages (-, ■))</li> <li>• Additional nutrients found within recycled water may serve as potential sources of fertiliser for agricultural uses. (Use Stages (+, ■))</li> <li>• Increased capacity for maintenance of 'green spaces' throughout droughts – amenity and recreational benefits. (Use Stages (+, ■))</li> <li>• Disposal of concentrate (a by-product) may lead to environmental degradation and high transport requirements. (Waste Management Stages (-, ↓, ■))</li> </ul>	<p><b>Main externality types</b> Water Quality (WQ), Production (P), Health (H), Non-Use (NU)</p> <hr/> <p><b>Valuation Examples (\$AUD 2010)</b></p> <ul style="list-style-type: none"> <li>• Cost of a visit to emergency room \$488.52 (ref 346)</li> <li>• WTP – -\$70.35/year addition to current water charges for recycled water with high contact uses (ref 218)</li> <li>• \$1073 tonnes/year for annual phosphorus load reduction (ref 302)</li> </ul>

## Conclusions

This research report represents, to the authors' knowledge, the most comprehensive compendium of externality effects and valuations available for decision and policy makers concerned with sustainable water management. The externality, and associated valuation, compendium has been compiled from a review and technical analysis of relevant water options and an extensive survey of existing valuation studies (transfer cost and benefit methods) at national and international levels.

## Future Work

The abstract outlines a methodological procedure for potential consideration and integration of externality impacts into general water management policy processes so that more complete triple bottom line assessments of water supply options can be undertaken in SEQ and other settings. This procedure will be formalised in a forthcoming report from the Griffith University team of the LCA-IM Alliance project team (August 2010).

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# Assessing Potable Water Savings of Rainwater Tanks at a Regional Scale

Maheepala, S.<sup>1</sup>, Loonat, N.<sup>2</sup>, Xu, H.<sup>3</sup>, Mirza, F.<sup>1</sup>, Coultas, E.<sup>1</sup> and Rahilly, M.<sup>1</sup>

<sup>1</sup> CSIRO, PO Box 56, Highett, Victoria

<sup>2</sup> Visiting Student of CSIRO, University of Melbourne, Victoria

<sup>3</sup> Visiting Scientist of CSIRO, Hohai University, Nanjing 210098, China

## Summary

Traditional urban water planning and management practices are now being substituted by the Integrated Urban Water Management approach, which amongst other options employs rainwater tanks as an alternative to secure water supplies in cities. A common approach used by the practitioners to quantify the impact of rainwater tanks on supply and demand balance at either city or regional scale is linear extrapolation of the performance outcomes of a single tank to represent a system with a number of tanks (this is called spatial lumping). However, such an approach has the potential to lose significant dynamics of the rainwater tanks' behaviour and generate biased results. This study examines the effect of spatial lumping of rainwater tanks on regional water supplies using Melbourne-based and Canberra-based data. The method is now being further improved and applied to South East Queensland (SEQ) to assess potable water savings of rainwater tanks on the regional supply and demand balance.

## Keywords

Rainwater tanks, potable water savings, regional scale impacts, spatial lumping.

## Introduction

Rainwater tanks (RWTs) are now being considered as a potential source to secure water supply in most cities in Australia. This is evident from the current urban water management strategies such as the SEQ Water Strategy (Queensland Water Commission 2009) and Think water ACT water (ACT Government 2004). A common approach used by the practitioners to quantify the impact of RWTs spread across a city is linear extrapolation of the performance outcomes of a single tank to represent a system with a large number of tanks (this is called spatial lumping). Mitchell *et al.* (2008) were the pioneers in examining the impacts of spatial lumping on the performance of RWTs. Using a cluster size of 1,000 RWTs, an hourly time step and Melbourne-based data, they found that spatial averaging of multiple RWT system characteristics could systematically predict higher values of volumetric reliability and yield. In particular, they reported 14.2% and 13.1% overestimation of the average annual yield and the volumetric reliability respectively, for 1,000 tanks due to spatial averaging of RWTs.

While Mitchell *et al.* (2008) provided some insights into the effect of spatial lumping of RWTs, they did not examine how the effect of spatial lumping varies with a varying number of RWTs and the impact of this effect on the performance of water supply systems at either regional or city scale. Such knowledge is required for urban water planners to identify supply augmentations and secure water supplies in a timely and efficient manner. Therefore, a study was initiated as part of the Urban Water Security Research Alliance with an aim of developing a methodology for quantifying the performance of household RWTs in terms of their ability to contribute to securing water supply at a regional scale. Melbourne- and Canberra-based data were used to develop the methodology because of timely access to required data and the need for comparison with the results of the Mitchell *et al.* (2008) study. This paper reports the methodology and outcomes of the study and planned activities for the next two years.

## Methodology

The methodology consisted of two key research activities: (1) an assessment of the impact of spatial lumping of RWTs on potable water savings obtained with different sizes of multiple RWT systems (or clusters of houses with RWTs); and (2) an assessment of the impacts of systems with multiple RWTs on water supplies at either city or regional scale. Outcomes of the first activity fed into the second activity. The first activity involved development of two cases. They were called "average case" and "variable case". Both cases consisted of a cluster of houses with RWTs. The average case used average water demand and average values for the parameters of all the RWTs in the cluster. The parameters were tank size, effective roof area, depression storage and roof area loss factor. The variable case used variable values for both water demand and the parameters of the RWTs in the cluster. Variable water demand accounted for the variability in household occupancy and the variability in occupants' behaviour in each household with regard to water use for different end uses such as laundry, tap use and toilet flushing. The average case represented the common practice. The variable case represented an improved method that had the capacity to eliminate the effect of spatial lumping through accounting for the spatial variability of RWT and household water use characteristics.

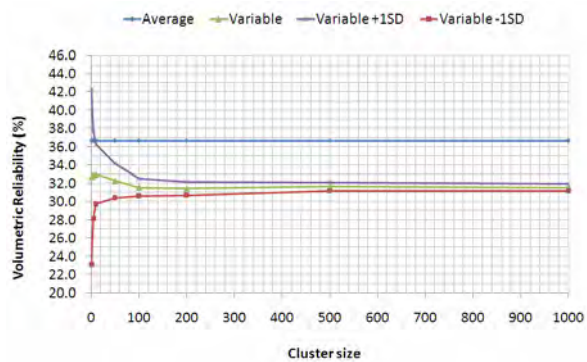
Two measures were used to examine the performance of the two cases: (a) average annual yield, ie, the volume of water supplied by RWTs on an average annual basis over the simulation period; and (b) volumetric reliability, ie, the total volume of water supplied by RWTs divided by the total target demand volume. The rainwater tank model of Mitchell *et al* (2008) and the stochastic household demand generator model of Duncan and Mitchell (2008) were used for simulating the performances of the two cases and generating demand profiles, respectively. The method adopted in the first activity involved generating demand profiles, defining probability distributions for RWT parameters, simulating the behavior of different clusters of RWTs using daily time step and quantifying the impact of spatial lumping on the performance of different clusters of RWTs. The output of the first activity was determining the “optimal RWT cluster size”, of which the performance did not vary with the number of RWTs. Hence the performance of the optimal cluster size can be linearly extrapolated to represent performance of a large number of RWTs in an urban area. The second activity involved representing the regional water system in a suitable simulation model and making changes to the supply system simulation model to represent scaled up RWT supply time series as a node inflow and quantifying the effect of RWTs at the regional scale. Details of the methodology can be found in Xu *et al* (2010) and Loonat (2010). The first activity was undertaken for both Canberra- and Melbourne-based data to examine the effect of different climatic conditions on spatial lumping. The second activity was undertaken only for Canberra-based data because of timely access to required data. For the Melbourne case, rainwater was used for garden watering and toilet flushing, whereas for the Canberra case, rainwater was used for laundry, garden watering and toilet flushing. Input parameters of the RWT model for the average and variable cases are shown in Table 1. For the variable case, RWTs were randomly generated using the probability distributions shown in Table 1. A number of different cluster sizes were considered (5, 10, 50, 100, 200, 500, 1,000 and 2,000) and 50 runs were done for each cluster.

**Table 1.** Details of input parameters used for RWT model simulation.

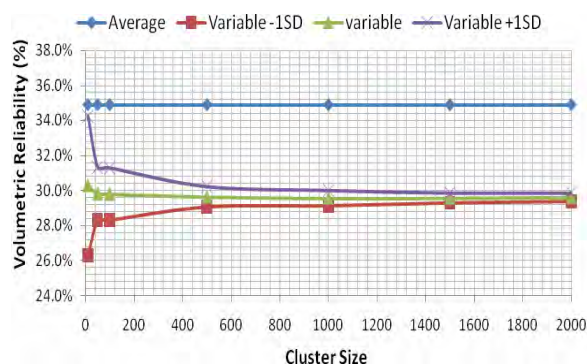
Parameters	Units	Variable Case					Average Case
		Min	Mean	Max	Distribution	Standard Deviation	
Melbourne Case simulation period: 1935 - 1984							
Tank capacity	kL	0.6	3	8	normal	2	3.37
Effective roof area	m <sup>2</sup>	25	100	300	normal	100	132
Depression storage	mm	0	0.5	1.75	normal	0.5	0.63
Roof area loss factor	%	0	15	30	normal	5	15
Occupancy	No.	1	2.6	>= 6			2.6
Canberra case simulation period: 1920 - 2009							
Tank capacity	kL	0.5	5	30	Normal	3	5.41
Effective roof area	m <sup>2</sup>	25	103	300	Normal	100	133.41
Depression storage	mm	0	0.5	1.75	Normal	0.5	0.63
Roof area loss factor	%	0	15	30	Normal	5	14.97
Occupancy	No.	1	2.4	>6			2.4

## Results

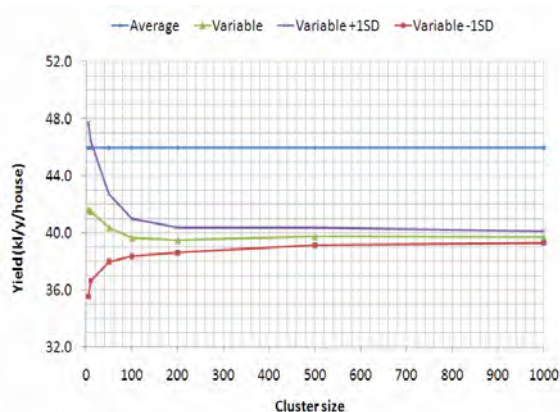
Figures 1, 2, 3 and 4 show the impact of spatial lumping on volumetric reliability and the average annual yield of different cluster sizes of RWTs, for Melbourne and Canberra data. For both cities, spatial lumping has caused an overestimation effect on the performance of RWTs. For Melbourne data, the overestimation of volumetric reliability and the average annual yield were 14% and 13.7% respectively, whereas for Canberra data, 15% and 18% respectively. Results of the Melbourne case are very similar to the results reported in Mitchell *et al* (2008), even though a daily time step was used for simulating the behaviour of RWTs of the current study. This shows the adequacy of using daily time step for simulating the behaviour of RWTs, for tank sizes greater than 0.5 kL. This finding is in agreement with the findings reported in Mitchell (2007) and Mitchell *et al* (2008). Figures 1, 2, 3 and 4 also indicate that both performance measures do not vary much when the cluster size reaches 500 for Melbourne data and 1,000 for Canberra data. It means that for Melbourne data, the performance of a cluster of 500 tanks can be linearly scaled up to represent systems with more than 500 RWTs. Similarly for Canberra data, the optimal cluster of RWTs for linear scaling up of the performance is 1,000 tanks. These results indicate that the amount of overestimation of the RWT performance and the optimal cluster size for linear scaling up depend on such factors as climatic conditions and the spatial variability of RWT and demand characteristics. For example, in Canberra the spatial variability of the tank sizes is higher than that of Melbourne (see Table 1). The REALM model of Canberra, provided by ACTEW (ActewAGL, 2010) was used to simulate the water supply system in Canberra in order to examine the impact of spatial lumping of RWTs on the performance of a regional water supply system. Results indicated that spatial lumping of RWTs had an overestimation effect on Canberra’s water supply, if inflows to Canberra’s surface water reservoirs were reduced by more than 75% of the inflows corresponding to the base case and if the rainwater tanks were used to meet 40% of the average monthly water demand in Canberra. The overestimation was up to: 25% for the system reliability; 4% system yield and 17% for the average storage volumes.



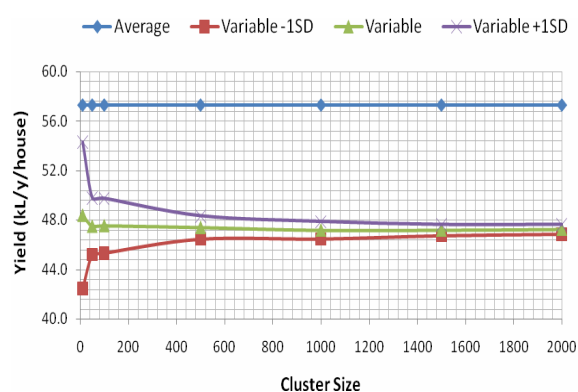
**Figure 1.** Impact of spatial lumping on volumetric reliability for Melbourne data



**Figure 2.** Impact of spatial lumping on volumetric reliability for Canberra data



**Figure 3.** Impact of spatial lumping on average annual yield for Melbourne data



**Figure 4.** Impact of spatial lumping on average annual yield for Canberra data

## Conclusions

This study provides evidence for the need to account for the spatial variability of rainwater tanks when quantifying the impact of rainwater use at city and/or regional scales. The outcomes of the study can be improved by assessing the effect of key assumptions, which include the use of stochastically generated climate data to account for climatic variability, examining the effect of climate change and use of a supply system simulation model that runs on a daily time step to assess the performance of the supply system.

## Future Work

The future work involves refining and applying the methodology to SEQ to quantify the impact of using RWTs to substitute potable water as per Queensland Development Code, ie, potable water savings of 70,000 litres per year for new detached houses, on the performance of SEQ's water supply and demand balance. It is expected that the outcomes of the future work will inform the next update of the SEQ Water Strategy.

## Acknowledgement

We would like to thank: Ross Knee of ACTEW and Jennifer Gilles of ACT Government for providing approval to use the Canberra case study and Tim Purves of ActewAGL and Arifur Rahman of ACT Government for technical advice on the use of Canberra data and REALM model.

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# Methane Emissions from Little Nerang and Hinze Dams

Sherman, B.<sup>1</sup>, Ford, P.<sup>1</sup>, Hall, M.<sup>2</sup> and Udy, J.<sup>3</sup>

<sup>1</sup> CSIRO Land and Water, GPO Box 1666, Canberra, ACT

<sup>2</sup> CSIRO Sustainable Ecosystems, North Ryde, New South Wales

<sup>3</sup> Seqwater, PO Box 15236, City East, Queensland 4002

## Summary

Detailed monitoring of two reservoirs in South East Queensland (SEQ), Little Nerang Dam and Hinze Dam, has revealed some of the highest reservoir methane emission rates reported in the world, 280 and 108 mg-CH<sub>4</sub> m<sup>-2</sup> d<sup>-1</sup>, respectively. The high rates of methane emissions observed at these reservoirs was dominated by the periodic release of methane-containing bubbles, but also included a more steady diffusive flux. Assuming the observed emissions are representative of average annual conditions at these dams and using the assumed water yield for these storages from the SEQ Water Strategy gives a GHG intensity for the combined storages of 0.017 t-CO<sub>2</sub>e per ML. However, this data suggests that the high spatial and temporal variability in GHG emissions could lead to large errors in any extrapolated average value, unless appropriate sampling is undertaken to quantify this variability. High emissions occur in specific small areas (5-10%) of the reservoirs and diffusive flux occurred across the entire reservoir, but was responsible for much lower flux rates on an areal basis. The type of vegetation in the catchment is likely to be an important factor in influencing methane production.

## Keywords

Methane, emissions, reservoir, flux, organic carbon load.

## Introduction

In 2009 a review [1] of the greenhouse gas emissions for the SEQ Water Strategy revealed that reservoir methane emissions were potentially very large for particular reservoirs. Reservoir emissions are not commonly considered when assessing the GHG footprint of urban water supply options. In addition, the review of existing data and methodology identified a knowledge gap for methane emissions and reservoir dynamics in regions with conditions like those in SEQ. Understanding of emission rates and reservoir dynamics also gives insight into the effectiveness of potential management strategies.

## Results

Flux chamber measurements (bubbles plus diffusion) of methane emissions across the water surface at Little Nerang Dam found that emissions exhibit very high spatial (4 to 5,700 m<sup>-2</sup> d<sup>-1</sup>) and temporal variability (factor of 20-40 during an hour at a single site). Due to this high variability, the interpolation of emission is difficult and there is a large error margin in any estimates of areal emission. Based on the current data, it was estimated that Little Nerang Dam produced 280 mg m<sup>-2</sup> d<sup>-1</sup> and Hinze Dam produced 108 mg m<sup>-2</sup> d<sup>-1</sup>. The Little Nerang Dam value is area-weighted using time averages over three field trips from late November 2009 through March 2010 at 11 sites, whereas Hinze Dam is area-weighted using data from 12 sites measured during a single trip in February 2010. The large spatial heterogeneity in the CH<sub>4</sub> flux suggests that simple averaging of rates is not appropriate for these reservoirs and that an accurate estimation of the flux requires mapping zones of similar flux rates. The fate of methane stored in the hypolimnion during seasonal stratification is currently being investigated and may increase the average areal fluxes further. These results rank Little Nerang Dam as having similar flux rates to reservoirs in Brazil and confirm that high CH<sub>4</sub> fluxes occur in SE Qld reservoirs that are comparable to subtropical/tropical reservoirs previously recorded (Table 1).

Such high CH<sub>4</sub> emissions are more often associated with young (<10 years old) dams located in the tropics (eg, Petit Saut). We believe the high values observed at Hinze and Little Nerang Dams are representative of steady state conditions typical of mature reservoirs and reflect the combination of dense vegetation and high rainfall rates that provide high labile organic carbon loads to the dams. The dense vegetation in the catchment coupled with relatively frequent high rainfall events ensures a high load of labile organic carbon reaches the reservoirs where strong stratification and shallow surface mixed layers ensures large areas of anoxic conditions required for methane production to occur.

**Table 1.** Measured methane fluxes at the water surface of reservoirs around the world.

Reservoir	Mean Flux (s.d.) mg-CH <sub>4</sub> m <sup>-2</sup> d <sup>-1</sup>	Reference
<b>Little Nerang Dam</b>	<b>280</b>	<b>This study</b>
<b>Hinze Dam</b>	<b>110</b>	<b>This study</b>
Tasmania (12 reservoirs)	2.3	[9] range 0.1 - 9.0
Western USA (6 reservoirs)	6.2	[10]
British Columbia (8 reservoirs)	42 (67)	[7]
Manitoba/Ontario (4 reservoirs)	12 (211)	[7]
Ontario/Québec (23 reservoirs)	8.8 (12)	[7]
Miranda (Brazil)	154	[8]
Tres Marias (Brazil)	196	[8]
Barra Bonita (Brazil)	21	[8]
Segredo (Brazil)	8.8	[8]
Xingó (Brazil)	40	[8]
Samuel (Brazil)	104	[8]
Tucuruí (Brazil)	109	[8]
Itaipu (Brazil)	11	[8]
Serra da Mesa (Brazil)	113	[8]
Petit Saut (French Guiana)	87 (29)	[9]

Areas with high fluxes were dominated by bubble fluxes. 78% of the total flux at Little Nerang Dam was found to be emitted from just 9% of the surface area, with the highest emissions occurring at the upstream ends of the reservoir where organic matter delivered from the catchment accumulates. Hinze Dam also exhibited high levels of ebullition at the upstream end of the western arm, with fluxes >3,000 mg m<sup>-2</sup> d<sup>-1</sup> observed. However, the eastern arm - which receives water from Little Nerang Dam - did not exhibit unusually high emissions. We believe the reason for this is that, as is the case with both arms of Little Nerang Dam, the western arm of Hinze Dam is the first standing water that receives organic matter from the catchment.

**Table 2.** Methane fluxes and Greenhouse Gas intensity for Little Nerang and Hinze Dams (NOT including seasonal methane storage).

	Surface Area (m <sup>2</sup> )	Mean Flux (mg-CH <sub>4</sub> m <sup>-2</sup> d <sup>-1</sup> )	Annual Flux (t-CO <sub>2</sub> -e/y)	Yield (ML/a) [2] Table 5.1.	GHG Intensity (t CO <sub>2</sub> -e/ML)
<b>Little Nerang Dam</b>	490,000	280	1100	13,640 [11]	0.081
<b>Hinze Dam</b>	9,700,000	110	8100		
<b>Total</b>			9200	550,000	0.017

**Table 3.** Comparison of Water Sector Greenhouse Gas Intensity and Data Sources.

Emission Source	Emission Intensity (tonne CO <sub>2</sub> e/ML)	Interval from Mode	Data Accuracy [3]	Summary of Data Sources
<b>Indirect (energy) for centralised water</b>	0.41 (0.35 pumping; 0.053 treatment)	±15%	Good	SEQ utility surveys [4] and reports for SEQ grid energy performance [5].
<b>Indirect (energy) for desalination</b>	4.5 (0.37 pumping; 4.1 treatment)	±15%	Good	As above but number of plants in the region is small.
<b>Direct GHG emissions from Hinze and Little Nerang Dam (NOT including seasonal methane storage)</b>	0.017		Good	Based upon detailed monitoring undertaken for this project. Little Nerang Dam values are averages over 3 field trips from late November 09 through March 10, whereas Hinze Dam is from a single trip during February 10. The total annual emissions for the two reservoirs is expressed in terms of the annual average contribution to Level of Service yields for the two dams as reported in [2] – Table 5.1. The data appears reliable and uncertainty bounds will be calculated when all data has been collected.

## Conclusions

The research confirms that these two reservoirs in SEQ have very high mean areal rates of methane emissions and that the estimated emissions have a wide margin of error due to the high spatial and temporal variability in the measurements. It is necessary to better resolve both the spatial and temporal variability in order to improve the accuracy of the estimates. The emission estimates presented here are slightly higher than the assumed medium emission scenario in which we estimated reservoir CH<sub>4</sub> emissions (as CO<sub>2</sub>-e) as contributing 30% (0.43 reservoir, 1.0 non-reservoir) of the total global warming potential from all sources associated with the urban water cycle in SEQ [1]. It also significantly increases the scientific understanding of reservoir processes that lead to methane emissions in SEQ. This has implications for other reservoirs in SEQ as well as the development of management measures.

The estimated total CH<sub>4</sub> emission from all SEQ storages will be very sensitive to the assumed emissions from Wivenhoe, Somerset and North Pine Dams as these three storages represent 60% of the total surface area of all SEQ storages when full. The high spatial variability of emissions within both Little Nerang (78% of total emission from 9% of total surface area) and Hinze Dams indicates that it is important to quantify the emissions from the upstream ends of these storages where they are likely to receive higher organic matter loading from their catchments.

The fact that such a large proportion of the flux was emitted from the shallow upper arms of the storages suggests that management actions to reduce or modify these fluxes could be logistically difficult. But this research identifies the areas of the reservoir that need to be focused on if any management actions are going to be considered to reduce methane emissions. One possible management action could be to increase the oxidation of the bottom water in zones with high methane flux. If the anoxic interface could be relocated into the sediments, it is possible that methane oxidising bacteria could reduce the flux before it enters the water column and decrease the amount of methane available to migrate to the surface (through both diffusive and bubble fluxes). Bubble fluxes have been observed to be reduced through hydrostatic effects as the water column deepens. Reservoir management measures that raise the temperature of the hypolimnion (eg, destratification) are likely to increase the methane production rate. Hence, balancing actions that reduce methane generation and increase methane consumption rates will be essential to achieve positive management outcomes.

Given the high emissions for Little Nerang and Hinze Dams and the likely association of these emissions with catchment organic matter supply, it would be beneficial to undertake similar measurements on other SEQ storages with different vegetation and climatic conditions. Such information would provide the foundation for a predictive modelling capability to estimate CH<sub>4</sub> emissions from unmonitored existing storages as well as proposed new storages.

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# Poster - Abstracts

## Influence of Electrode Material on the Electrochemical Oxidation of Reverse Osmosis Concentrates

**Bagastyo, A., Radjenovic, J., Mu, Y., Rozendal, R., Batstone, D. and Rabaey, K.**

Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

Reverse osmosis (RO) membrane technology has been successfully applied around the world for wastewater reuse applications in agriculture, industry, and indirect potable water reuse. However, RO is a physical separation process, and besides the clean water stream (ie, permeate) a reverse osmosis concentrate (ROC) is produced, which usually represents 15-25% of the feed water flow. In this study electrochemical oxidation has been investigated for the treatment of ROC generated during the reclamation of municipal wastewater effluent. During electrochemical oxidation, ROC is sent through an anode compartment, where the anodic electrode exerts a strong oxidative force. This anode is separated from the cathode by a cation exchange membrane, allowing separate anodic ROC oxidation and cathodic reduction. Five electrode materials (ie, titanium coated with IrO<sub>x</sub>, Ru<sub>0.7</sub>Ir<sub>0.3</sub>O<sub>2</sub>, Pt-IrO<sub>2</sub>, PbO<sub>2</sub>, and SnO<sub>2</sub>) have been tested as anodes in laboratory-scale batch mode experiments, using ROC from Bundamba AWTP. The best oxidation performance was observed for Ti/Pt-IrO<sub>2</sub> anodes, followed by the Ti/SnO<sub>2</sub> and Ti/PbO<sub>2</sub> anodes. The effectiveness of the treatment appears to correlate with the formation of oxidants by the anode. As a result, electro-generated chlorine led to the abundant formation of harmful by-products such as trihalomethanes (THMs) and haloacetic acids (HAAs) at Ti/SnO<sub>2</sub> and Ti/Pt-IrO<sub>2</sub> anodes. The highest concentration of HAAs (ie, 2.7 mg L<sup>-1</sup>), was measured for SnO<sub>2</sub> electrode, after 0.55 A h L<sup>-1</sup> of supplied specific electrical charge. Future research will focus on electrochemical reduction as a solution for the dehalogenation of anodically treated ROC.

## Critical Thresholds of Ecological Function and Recovery Associated with Flow Events in Urban Streams

**Leigh, C.<sup>1</sup>, Dunlop, J.<sup>2</sup> and Sheldon, F.<sup>1</sup>**

<sup>1</sup> Australian Rivers Institute, Griffith University, Nathan, Queensland

<sup>2</sup> Department of Environment and Resource Management, Indooroopilly, Queensland

Water flow from impervious (non-porous) surfaces and the direct connection of stormwater outflows has a major effect on stream ecosystems that can lead to sudden pulses of water which may catastrophically dislodge organisms like invertebrates and affect ecological function. Subsequently, dissolved oxygen levels may become critically low. Important to the management of urban streams is the identification of critical thresholds of response. Across 24 sites in the Brisbane region, along a gradient from natural (forested) to highly urbanised (modified), aspects of stream ecosystem health were assessed, with the aim of determining thresholds of impact and providing knowledge critical for the future management and health of stream ecosystems in urban settings. The results suggest upstream impervious area influences stream health. Sites downstream of urbanised catchments tended to have lower canopy cover and dissolved oxygen but to also have greater discharge, conductivity and pH compared with reference and WSUD catchments.

## Purified Recycled Water - Research Outcomes

**Toze, S.<sup>1</sup>, Ort, C.<sup>2</sup>, Kookana, R.<sup>3</sup>, Stratton, H.<sup>4</sup>, Sidhu, J.<sup>1</sup> and Escher, B.<sup>5</sup>**

<sup>1</sup> CSIRO Water for a Healthy Country, Queensland Biosciences Precinct, St Lucia, Queensland

<sup>2</sup> Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

<sup>3</sup> CSIRO Water for a Healthy Country, Waite Campus, Glen Osmond, Adelaide, South Australia

<sup>4</sup> School of Biomolecular and Physical Sciences, Griffith University, Nathan, Queensland

<sup>5</sup> National Research Centre for Environmental Toxicology, University of Qld, Coopers Plains, Queensland

The *Purified Recycled Water* project undertook research on issues relating to the production of PRW. A major focus of the research was studying the impact hospitals have on the level of pharmaceuticals in domestic sewage (Barrier 1); the capacity of wastewater treatment plants to remove pathogens and trace chemicals (Barrier 2); and the removal of pathogens and trace chemicals in reservoirs via natural treatment processes (Barrier 6). The research outcomes demonstrated that: hospitals are most likely contribute less than 10% of pharmaceutical concentrations in sewage; wastewater treatment plants can remove more than 90% of most chemicals and greater than 98% of all the tested enteric micro-organisms; and enteric pathogens and trace organic chemicals do decrease in reservoirs due to biotic and abiotic processes. Other research activities undertaken in the PRW project included examining changes in responses of bioanalytical assays across the 7-Barrier system; the concentration and detection of microbial pathogens; and the detection of existing and novel chemicals in water.

## Pathogens and Trace Chemicals in Dams

**Toze, S.<sup>1</sup>, Kookana, R.<sup>2</sup>, Bartkow, M.<sup>3</sup>, Sedlak, D.<sup>4</sup>, Stratton, H.<sup>5</sup> and Page, D.<sup>2</sup>**

<sup>1</sup> CSIRO Water for a Healthy Country, Queensland Biosciences Precinct, St Lucia, Queensland

<sup>2</sup> CSIRO Water for a Healthy Country, Waite Campus, Glen Osmond, Adelaide, South Australia

<sup>3</sup> Seqwater, Brisbane, Queensland

<sup>4</sup> Department of Civil and Environmental Engineering, University of California, Berkeley, California

<sup>5</sup> School of Biomolecular and Physical Sciences, Griffith University, Nathan, Queensland

The *Pathogens and Chemicals in Dams* project was created to continue with the research undertaken in the PRW project examining the treatment capacity of South East Queensland reservoirs. The project plans to test the notion of *using catchment health as a “generator of good water quality”*; in other words, assigning a level of treatment capacity to the reservoirs and streams. This would improve the capacity to produce a consistent quality of water via a better understanding of what contaminants the treatment plants need to routinely cope with, and what contaminants will be most likely be removed via natural treatment processes in the reservoirs. To achieve this aim, the most important processes in natural systems for the removal of biological and chemical contaminants need to be documented under a range of climatic conditions. This information can then be incorporated into existing and future contaminant fate models to assist the development of improved management options that include natural systems as active treatment barriers.

## The Meteorological Controls on Lake-Atmosphere CO<sub>2</sub> Exchange

**Gray, M. and McGowan, H.**

Climate Research Group, School of Geography, Planning and Environmental Management, The University of Queensland, St Lucia, Queensland

This poster presents results from the first eddy covariance (EC) measurements of carbon dioxide (CO<sub>2</sub>) flux over a terrestrial water body in the Southern Hemisphere. Measurements were made using a pontoon-mounted EC system at Logan’s Dam, a small reservoir in South East Queensland, Australia, from 14 August 2009 to 11 January 2010. The dam was found to be a net source of CO<sub>2</sub> to the atmosphere of the order of 0.63 mg m<sup>-2</sup> day<sup>-1</sup>. This daily flux rate was, in general, less than rates measured by EC over Northern Hemisphere lakes. Total monthly CO<sub>2</sub> flux was found to vary in response to prevailing synoptic weather patterns. While the current phase of the project is complete, there is significant scope for further work including the acquisition of a longer dataset covering annual changes in local to synoptic scale weather. This would allow the influence of a much larger range of meteorological conditions on CO<sub>2</sub> flux to be quantified.

## Validation and Monitoring of Cluster-Scale Wastewater Treatment Technologies

**Chong, M.N.<sup>1</sup>, Gardner, T.<sup>1,3</sup>, Sharma, A.<sup>2</sup>, Cook, S.<sup>2</sup>, Palmer, A.<sup>1</sup> and Carlin, G.<sup>1</sup>**

<sup>1</sup> CSIRO Land and Water, Long Pocket Laboratories, Indooroopilly, Queensland

<sup>2</sup> CSIRO Land and Water, Highett, Victoria

<sup>3</sup> Department of Environment and Resource Management, Indooroopilly, Queensland

This poster presents results from our research into decentralised wastewater treatment plants in the South East Queensland context. The research objectives were focussed on increasing knowledge of decentralised treatment technologies (DTT) in the following areas: system robustness under different operating conditions; energy efficiency; and emissions of fugitive GHGs. We advanced these objectives through a monitoring program which collected continuous data on water quality, flow, and energy consumption for three different types of DTTs. The monitoring sites incorporate a range of wastewater treatment technologies, including: immersed membrane bioreactor (IMB), membrane filtration (MF/RO), biofilm textile filters, zeolite and sand filtration, septic systems, and UV disinfection. To further explore the performance of the IMB, monitoring data has been used to calibrate a biophysical computer model (BIOWIN), to investigate system robustness to shock loads. In addition, detailed instrumentation has allowed the energy consumption of individual components of the DTT plants to be quantified. Future research effort may consider quantifying fugitive GHG fluxes from the DTTs. The research outputs will be integrated into a decision-making framework to guide the selection of appropriate DTT for greenfield developments.

## Fundamental Investigation on Biological Activated Carbon?

Rattier M.<sup>1</sup>, Reungoat J.<sup>1</sup>, Tyson G.<sup>1</sup>, Yang Q.<sup>2</sup>, Gernjak W.<sup>1</sup> and Keller J.<sup>1</sup>

<sup>1</sup> Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

<sup>2</sup> Henan Normal University, College of Life Science, Xinxiang 453007, Peoples Republic of China

It is essential to improve the quality of secondary treated effluents in order to protect the environment, preserve the quality of water sources used for human consumption and provide high quality water for reuse. Biological filtration has a great potential for improving secondary effluent quality with low energy requirement. Whereas the removal of micropollutants from secondary effluents in slow sand filtration, river bank filtration and managed aquifer recharge has been investigated, more research needs to be done on Biological Activated Carbon (BAC) filters.

In addition to activated carbon adsorption, the attached microbial biofilm is capable of breaking down and removing adsorbed substances in a process known as ‘‘biodegradation’’. Biodegradation of organic pollutants occurs in the BAC beds where a large amount of aerobic biomass grows. The carbon type and structure influences the structure of the biofilm, the adsorption and biodegradation mechanisms. This project aims to characterise the BAC media, quantify the performance of BACs, investigate the microbial communities in BACs and elucidate the mechanisms of contaminant removals.

In laboratory conditions, real secondary effluent and BAC filters outlets will be analysed to assess the removal of organic matter and micropollutants, the influences of operational parameters and the roles of simultaneous adsorption and biodegradation in the treatment. Recent microbiological tools will also be used to characterise the microbial communities hosted by the macropores.

## Understanding Water Savings from Mandated Rainwater Tanks in South East Queensland

Mankad, A.<sup>1</sup>, Chong, M.<sup>2</sup>, Gardner, T.<sup>2,3</sup>, Beal, C.<sup>4</sup> and Sharma, A.<sup>5</sup>

<sup>1</sup> CSIRO Sustainable Ecosystems, Queensland Bioscience Precinct, St Lucia, Queensland

<sup>2</sup> CSIRO Land and Water, Long Pocket Laboratories, Indooroopilly, Queensland

<sup>3</sup> Department of Environment and Resource Management, Indooroopilly, Queensland

<sup>4</sup> Smart Water Research Centre, Griffith University, Gold Coast, Queensland

<sup>5</sup> CSIRO Land and Water, Hightett, Victoria

This study helps researchers to develop an understanding of water savings from mandated rainwater tanks in South East Queensland. Household composition, tank size, property area, garden water requirements, and tank set-up were identified as having a major impact on potential water savings from rainwater tanks (Beal, *et al.*, 2010). It was hypothesised that these demographic variables likely contributed to the effectiveness of a household’s ability to achieve the 70kL/household/year water savings target mandated under the revised Queensland Development Code. Telephone surveys were administered to mandated rainwater tank owners (n=2,000) from four local government areas (LGAs): Caboolture, Pine Rivers, Redlands, and Gold Coast. Permission was also obtained from householders, allowing access to their property’s water billing records from 2008 to 2012. This would allow subsequent statistical analyses to determine real mains water savings among mandated tank owners. Knowledge of rainwater tank systems, household applications for rainwater, satisfaction with the quality and quantity of rainwater, and general water beliefs are also investigated in survey, as potential descriptors of household rainwater use.

## Energy Use and Prospective Governance Models for Rainwater Tank Water Supply

Tjandraatmadja, G.<sup>3</sup>, Moglia, M.<sup>3</sup>, Pollard, C.<sup>3</sup>, Gardner, T.<sup>1,2</sup> and Sharma, A.<sup>3</sup>

<sup>1</sup> CSIRO Land and Water, Long Pocket Laboratories, Indooroopilly, Queensland

<sup>2</sup> Department of Environment and Resource Management, Indooroopilly, Queensland

<sup>3</sup> CSIRO Land and Water, Hightett, Victoria

The aim of this study is to understand the energy footprint and future governance needs required for the sustainable operation of mandated rainwater tanks for new dwellings as specified under the Queensland Development Code MP4.2.(2007).

The specific energy use (kWh/kL) of residential rainwater supply systems is affected by the characteristics of each individual rainwater pumping system including pump size and type and supply/distribution accessories (eg, trickle top, pressure vessels, mains switch valve, etc). The various rainwater pump energy studies across the country show highly variable outcomes, which are of limited value for informing the energy-water nexus debate. A controlled

laboratory study is therefore being conducted to understand the reason of this high variability and to investigate optimal rain tank pump system to minimise energy demand.

In addition, given the widespread adoption of rainwater tanks in South East Queensland, a lax tank maintenance regime may have a severely detrimental impact on long-term water reliability of rainwater supply systems and public health. Hence possible governance and management models for domestic rain tanks will also be investigated.

## **Pharmaceutical Audit Data from Hospitals – Are Hospitals a Major Point Source of Pharmaceuticals? For Which Compounds? At Which Locations?**

**Le Corre, K.<sup>1</sup>, Salter, J.<sup>2</sup>, Kateley, D.<sup>2</sup>, Allen, B.<sup>2</sup> and Ort, C.<sup>1</sup>**

<sup>1</sup> Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

<sup>2</sup> Medication Services Queensland, Queensland Health, Herston, Queensland

Determining the contribution of hospitals towards the total pharmaceutical residue load in domestic wastewater is a difficult task. Factors such as access to raw hospital wastewater, obtaining representative samples and the availability of chemical analyses imply certain restrictions: economic sampling campaigns can only be carried out over a short period of time (snapshot) and analytical methods only provide results for a limited number of compounds. To overcome these restrictions and provide an exhaustive understanding of pharmaceutical loads that may originate from hospitals, a detailed evaluation of annual audit data from all hospital in Queensland is performed. The vast database covers 107 public hospitals, includes more than 70,000 entries and 5,000 distinct products; it provides a unique opportunity to identify, quantify, and hence predict specific substances for which hospitals may be a major point source in domestic wastewater.

## **NDMA and Trihalomethane Formation and Minimisation in South East Queensland Drinking Water**

**Watson, K.<sup>1</sup>, Knight, N.<sup>1</sup>, Farré, M. J.<sup>2</sup> and Shaw, G.<sup>1</sup>**

<sup>1</sup> Smart Water Research Centre, Griffith University, Southport, Queensland

<sup>2</sup> Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

This project examined the use of Advanced Treatment using UV/H<sub>2</sub>O<sub>2</sub> and/or photolysis (UV) to determine how these strategies may be utilised for disinfection by-product (DBP) minimisation. The research presented here shows that both NDMA and THM concentrations can be minimised in the finished water (using Teviot Brook source water) by appropriate use of advanced treatment. The *N*-nitrosodimethylamine (NDMA) and trihalomethane (THM) formation potentials of a number of South East Queensland source waters, as well as actual NDMA and THM concentrations occurring at South East Queensland water treatment plants and at the point of supply was also investigated as part of this significant contribution to the overall project on DBP minimisation in drinking water.

## **Health Risk Assessment of Local Source Waters**

**Toze, S.<sup>1</sup>, Sidhu, J.<sup>1</sup>, Ahmed, W.<sup>1</sup>, Hodgers, L.<sup>1</sup> and Page, D.<sup>2</sup>**

<sup>1</sup> CSIRO Water for a Healthy Country, Queensland Biosciences Precinct, St Lucia, Brisbane

<sup>2</sup> CSIRO Water for a Healthy Country, Waite Campus, Glen Osmond, Adelaide

Local water sources such as urban stormwater and roof harvested rainwater are viewed as some of the most likely alternative water sources that can be used in South East Queensland. These water sources have the potential to replace significant volumes of grid water in and around domestic dwellings and industry if used for the most appropriate potable water substitutions. The use of alternative water sources in toilets, cold water washing in washing machines and outdoor irrigation is currently mandated for all new establishments in South East Queensland. However, there are restrictions on further uses within the house, due to uncertainties about the potential health risks associated with these water sources, in particular from pathogens. Research on pathogens in both rainwater and in stormwater will focus on the incidence and type of pathogen most commonly detected. The resulting research outcomes will then be used to test the actual potential health risks for a number of potential exposure pathways via a Quantitative Microbial Risk Assessment. The research conclusions will provide information that will be useful for the formulation of transparent, accurate and valid policies and guidelines for the use of these alternative water sources, including required levels of treatment required, and if necessary, to validate restrictions for some uses.

## Communicating Scientific and Technical Information about Alternative Water Supply Systems

**Green, M.<sup>1</sup>, Fielding, K.<sup>1,2</sup>, Leviston, Z.<sup>1</sup> and Price, J.<sup>1</sup>**

<sup>1</sup> CSIRO Sustainable Ecosystems, Brisbane, Queensland

<sup>2</sup> The University of Queensland, St Lucia, Queensland

What is the role of communication in water management? How do we best package information so that it is meaningful to communities? How do we know if communication efforts have been effective? These are some of the questions that have been investigated via a review of the literature as part of the communications sub-component of the Demand Management and Communication Research project. Previous water management communication strategies are reviewed according to Moser's (2010) key elements of communication which include: goals, audience, framing, messages, messengers, channels and effect. Overall, effective communication is deemed important for the successful implementation of alternative water supply schemes, yet there is little empirical evidence to suggest what exactly this entails and very few examples of evaluation. Engaging the community; appealing to their attitudes, values and beliefs; and empowering them to participate in decision making are all considered essential to the success of communication. To conclude, avenues for future research are suggested.

## Water Quality Event Detection System

**Ganther, W.<sup>1</sup>, Goodman, N.<sup>2</sup>, O'Halloran R.<sup>2</sup>, Toifl, M.<sup>2</sup>, Winnel, M.<sup>3</sup> and Zhao, H.<sup>4</sup>**

<sup>1</sup> CSIRO Materials Science and Engineering, Clayton South, Victoria

<sup>2</sup> CSIRO Land and Water, Clayton South, Victoria

<sup>3</sup> CSIRO Mathematics Informatics and Statistics, Clayton South, Victoria

<sup>4</sup> Griffith School of Environment, Gold Coast Campus, Griffith University, Queensland

Our project is currently developing a fully functioning, real-time event detection system prototype for Barrier 1 of the South East Queensland water grid. It is designed to detect exceptional conditions ('events') that indicate a major contaminant load has been discharged to sewer that could potentially upset the treatment plant and treated effluent. A new generation sensor flow manifold, electronics and control hardware are being built, and the univariate and multivariate mathematical event detection models will be further optimised and embodied in software embedded on the onboard processor. By June 2011, five prototype units will be available for monitoring Barriers 1 (sewage source control) and 2 (WWTP treated effluent quality). The system is intended to form the basis of a real-time event detection network and early warning system. This will further safeguard operation of the water grid, provide a powerful tool for source control/management, and significantly improve risk management practices.

## Assessment of Regulated and Emerging DBPs in SEQ Drinking Water

**Farré, M.<sup>1</sup>, Knight, N.<sup>2</sup>, Watson, K.<sup>2</sup>, Shaw, G.<sup>2</sup>, Leusch, F.<sup>2</sup>, Sadler, R.<sup>2</sup>, Birt, J.<sup>3</sup>, Bartkow, M.<sup>4</sup>, Keller, J.<sup>1</sup>, Gernjak, W.<sup>1</sup> and Burrell, P.<sup>5</sup>**

<sup>1</sup> Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

<sup>2</sup> Smart Water Research Centre (SWRC), Griffith University, South Port, Queensland

<sup>3</sup> Bond University, Queensland

<sup>4</sup> Seqwater, Brisbane, Queensland

<sup>5</sup> SEQ Water Grid Manager, Queensland

As described in the South East Queensland (SEQ) Regional Plan 2009-2031, the purpose of the SEQ Water Strategy is to ensure that water in the region is managed on a sustainable and integrated basis to provide secure and reliable supplies of acceptable quality for all uses for the long term. Public health and safety will not be compromised and the highest water quality standards appropriate to use will always be maintained. Investigating the presence of emerging and regulated disinfection by-products (DBPs) in SEQ drinking water is a key component to guarantee that these statements are achieved.

This poster will present the aims of this two-year research project that has recently started. The key questions of the project are:

- Which emerging and regulated DBPs are of concern in the SEQ context, considering that two separate disinfection regimes (chlorination and chloramination) are utilised in different jurisdictions?
- What are the effects in terms of DBP formation of blending drinking water of different qualities from different sources within the SEQ Water Grid?

- What components of natural organic matter are not removed by enhanced coagulation strategies employed in the SEQ context? Can strategies to remove natural organic matter or halides be successfully applied to minimise the formation of DBPs?

The Key stakeholders of this project are WaterSecure, Seqwater, Office of the Water Supply Regulator, Link Water and Queensland Health. Professor Urs Von Gunten (EAWAG) and Professor Howard Weinberg (UNC) will provide expertise by being members of our reference panel.

## Event-Based Stormwater Quality Measurement: Sampling Methodologies for Urban Catchments

**Chong, M.<sup>1</sup>, Gardner, T.<sup>1,2</sup>, Chowdhury, R.<sup>1</sup>, Ort, C.<sup>3</sup>, Toze, S.<sup>4</sup>, Escher, B.<sup>5</sup>, Gardiner, R.<sup>2</sup>, Tonks, M.<sup>1,2</sup>**

<sup>1</sup> CSIRO Land and Water, Long Pocket Laboratories, Indooroopilly, Queensland

<sup>2</sup> Department of Environment and Resource Management, Indooroopilly, Queensland

<sup>3</sup> Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

<sup>4</sup> CSIRO Land and Water, Queensland Bioscience Precinct, St Lucia, Queensland

<sup>5</sup> National Research Centre for Environmental Toxicology, The University of Queensland, Cooper Plains, Queensland

Stormwater is one of the last major untapped water resources that can be utilised for urban water supply in major Australian cities. In Brisbane alone, the volume of annual stormwater runoff is estimated to be 1.45 times the volume of potable mains water imported from external catchments. To date, end-uses of treated stormwater are mostly for public open space irrigation, but potable substitution in urban developments as well as augmentation of drinking water reservoirs are of increasing interest. The critical issue of stormwater reuse is similar to other recycled water sources, which requires appropriate understanding of the associated health and environmental risks as outlined in the current *Australian Guidelines for Water Recycling (Phase 2) – Stormwater Harvesting and Reuse* and related reports. The intrinsic hazards associated with raw stormwater use include human and zoonotic pathogens and trace organic contaminants (ie, pesticides, pharmaceuticals and personal care products, heavy metals, petroleum derivatives, etc) from point (eg, sewer leakage) and diffuse (eg, car, pesticide application) sources. Whilst there is an abundance of scientific data available for total suspended solids, nutrients and to a lesser extent, heavy metals in stormwater, much less scientific information is available for the occurrence and detection of organic contaminants and pathogens (as opposed to indicator microorganisms).

In this study, we will measure the event mean concentration (EMC) for individual stormwater contaminants in up to three contrasting urban catchments in SEQ (Fitzgibbon, Brisbane CBD and Southbank) over a wide range of runoff events ( $n > 20$ ). This will be compared with data from similar studies in other Australian cities (from the *Cities as Water Supply Catchments* program). Our main focus will be on pathogen detection and quantification (including virus and protozoan), individual trace organic contaminants, and bioanalytical tools as sum parameters for mixture of organic contaminants with a common mode of toxic action. The use of bioassay will provide a screening test for a range of human-health related and environmental endpoints that in turn will guide the focus of (more expensive) confirmatory chemical analyses.

The key challenges in stormwater quality sampling are (1) the high number of samples from the entire storm event which directly translates into high analysis costs; and (2) the volume of sample required to obtain positive results for specific microbial pathogens enumeration (eg,  $\geq 100L$  for *Cryptosporidium*). To resolve these challenges, we have developed a flow-weighted sampling protocol that captures the hydrograph and concentration changes during a storm event and composites them into one sample for subsequent EMC analysis. With the EMC outcomes, a risk assessment can be performed according to the specific end-uses of stormwater, and subsequent fit-for-purpose treatments can be devised to achieve the regulated water quality standard (eg, a defined pathogen log-reduction; acceptable chemical concentration, etc). This study will be one of a few to characterise individual microbial pathogens and chemical contaminants in stormwater, and should facilitate the planning of large-scale stormwater harvesting and potable water substitution projects in Australia.

## SEQ Residential Water End Use Study: Baseline Results

**Beal, C., Stewart, R., Talebpour, R. and Huang, A.**

Smart Water Research Centre and Griffith University School of Engineering, Griffith University, Southport, Queensland

This poster presents residential water end uses for a sample of 250 households located in South East Queensland (SEQ). Data was captured using high resolution water meters and remote data transfer loggers. Household water appliance audits and a self-reported household water use diaries were used in combination with the Trace Wizard software to disaggregate end use data. Generally, total household water use was lower than reported in other recent end use studies with shower and clothes washer end uses having the highest per capita consumption. Irrigation was

low due to the season and changed behaviour instilled during the drought period in SEQ. Water efficient fixtures and appliances were usually effective in reducing consumption. Future analysis will correlate end use data with socio-demographic factors, household appliance stock and diurnal trends.

Other research aligned with this study includes estimating peak demand factors for pipe network models, designing and testing a device for recording water flow at each household fixture, and energy and water end uses of residential hot water systems.

## **Spatial Analysis of Stormwater Harvesting Opportunities in SEQ**

**Laredo, L.<sup>1</sup>, Chowdhury, R.<sup>2</sup>, Gardner, T.<sup>2,3</sup> and Wolf, L.<sup>2</sup>**

<sup>1</sup> CSIRO Ecosystem Sciences, St Lucia, Queensland

<sup>2</sup> CSIRO Land and Water, Indooroopilly, Queensland

<sup>3</sup> Department of Environment and Resource Management, Indooroopilly, Queensland

The challenge for using stormwater includes its capture, storage, appropriate treatment, and supply to end uses at cost effective prices. Major potential end uses include dual reticulation in greenfield urban developments and irrigation of high value public open spaces such as playing fields. The harvestable amount of stormwater depends on many factors such as topography, geology, climatic conditions, drainage practices, environmental flow needs of urban waterways, storage availability, distribution method and end uses. By combining a set of biophysical rules with a range of GIS layers (DEM, easements, aquifers, future urban, HEV freshwater bodies, etc.) it is expected that locations can be ranked on their stormwater harvesting and reuse opportunities. In order to establish an appropriate method of analysis, the Ripley Valley – a future urban growth area in South East Queensland - has been selected as a case study. This area will be developed as a combination of residential, commercial and recreational purposes. Existing biophysical factors of the area include neighbourhoods of varying dwelling density and hence water demand, existing storages, easements and a topographic relief conducive to efficient runoff collection (2% to 10% slope). Initially, this process will identify areas within this catchment which may house storage facilities of appropriate capacity based on runoff accumulation.

## **Quantifying Water-Related Urban Energy Use**

**Kenway, S.J.<sup>1</sup>, Lant, P.<sup>1</sup>, Daniels, P.<sup>2</sup> and Priestley, T.<sup>3</sup>**

<sup>1</sup> Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland

<sup>2</sup> Griffith University, Nathan, Queensland

<sup>3</sup> CSIRO Land and Water, Hightett, Victoria

This poster describes research on Urban Metabolism and the water-energy nexus undertaken by Steven Kenway in his PhD studies as a component of the Life Cycle Analysis and Integrated Modelling project. It aims to identify and quantify key connections between water and energy within cities. It is motivated by the need to understand options to mitigate rapidly-rising energy demands of urban water provision. The work aims to increase the understanding of all links. It also aims to quantify larger evident connections in the residential and industrial sectors. The implication for South East Queensland is that water policy could offer great scope to significantly influence total urban energy use. Understanding the key factors will identify the levers of control. The key methodologies involve material flow analysis including sensitivity and uncertainty characterisation. This will identify knowledge, data, research and monitoring gaps. It will also help identify confidence levels, for example that measures have had an impact.

## **Molecular Methods for Detecting Pathogens in Water**

**Matthews, B.<sup>1</sup>, Stratton, H.<sup>1</sup>, Schroeder, S.<sup>1</sup>, Collins, S.<sup>1</sup> and Toze S.<sup>2</sup>**

<sup>1</sup> School of Biomolecular and Physical Sciences, Griffith University, Nathan, Queensland

<sup>2</sup> CSIRO Water for a Healthy Country, Queensland Biosciences Precinct, St Lucia, Queensland

The *Purified Recycled Water* project was tasked to undertake research on issues relating to the production of PRW. A recognised shortfall in routine monitoring of microbiological water quality is that many pathogens are not represented by the conventional faecal indicator organisms that are detected by culture based methods only. Another problem with culture based methods is that a final result takes two to five days to produce. In an attempt to work towards improving detection methods for waterborne pathogens, quantitative molecular genetic methods were optimised and validated against conventional culture based techniques. This involved addressing problems with extracting clean genetic material from wastewater samples, removing inhibitors that interfere with amplifying the DNA and developing an internal standard so that false positive or negatives are unequivocally determined.

The project examined pathogen levels, both before and after treatment in three wastewater treatment plants, using both conventional culture-based methods and quantitative PCR. This offered not only comparison for modern genetic techniques for pathogen detection in a water matrix that often presents difficulties using DNA-based analyses, but also assessed wastewater treatment efficacy in pathogen removal in water destined for further purification and reuse. Interestingly, the qPCR pathogen detection methods generally detected higher levels of bacteria than culture-based methods for the primary effluent at microbial numbers in excess of  $5 \times 10^6$  cells per 100 ml. Detection by qPCR ranged from 2-80 times higher levels than culture-based methods ( $p \geq 0.0001$ ). There was no statistically significant difference at most sampling locations between qPCR and culture-based methods in the treated effluent at cell numbers around  $10^4$  per 100 ml. It can be speculated that the increased level of detection with qPCR methods could be due to: increased sensitivity of qPCR methods over culture-based methods; bacterial targets entering a viable-but-unculturable state rendering them undetectable to culture-based methods; and the qPCR reaction detecting nucleic acids from lysed, non-viable bacteria. The primary cause of the disparity in detection levels between qPCR and culture-based methods at high concentrations of pathogens deserves further investigation. However, if qPCR methods over-estimate the number of viable bacteria, the impact on microbial risk management would be minimal as there would be a greater risk to community and public health from under-estimating them using a culture-based technique at lower detection limits, as culture-based methods often are, as a risk management strategy would be implemented sooner.

## **Understanding the Aquifer: 3D Visualisation and Groundwater Time-Series Animation in the Lockyer Valley**

**Cox, M.<sup>1</sup>, Hawke, A.<sup>2</sup>, James, A.<sup>2</sup> and Wolf, L.<sup>3</sup>**

<sup>1</sup> Institute for Sustainable Resources, QUT; Faculty Science and Technology, QUT; National Centre for Groundwater Research and Training, Brisbane, Queensland

<sup>2</sup> Institute for Sustainable Resources, QUT; High Performance Computing, QUT, Brisbane, Queensland

<sup>3</sup> CSIRO Land and Water, Indooroopilly, Queensland

A current project in the Lockyer Valley is considering introduction of purified recycled water (PRW) to augment groundwater supplies of the alluvial aquifers. Within these aquifers are over 5,000 bores extracting groundwater, however, management of the total system is limited to the central lower valley. In the investigation, a valley-wide MODFLOW simulation model is being upgraded and a new model of flow in the unsaturated zone is being developed. To underpin these studies, and to provide a realistic understanding of the extent and configuration of the alluvial aquifers, a 3D Groundwater Visualisation System (GVS) has also been developed. This model integrates all available bore data, including the aquifer solid geometry as three categories of materials, for which aquifer storage volumes can be calculated. The model can also be visually manipulated. Available data over a 40-year period for water levels and electrical conductivity (EC) as an indicator of groundwater quality has been incorporated and can be presented as a time-series animation for individual bores.



# Posters - Presented

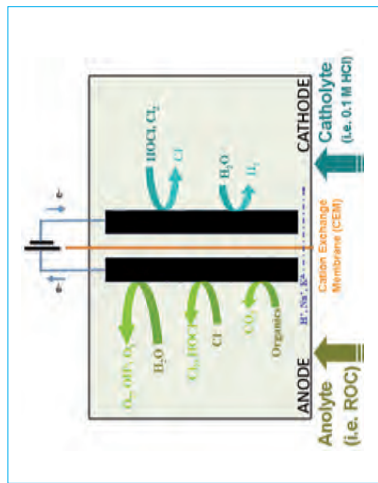
# Influence of Electrode Materials on the Electrochemical Oxidation of Reverse Osmosis Concentrates

Bagastyo, A., Radjenovic, J., Mu, Y., Rozendal, R., Batstone, D.J. and Rabaey, K.

## Project Summary

During reclamation of municipal wastewater effluents using reverse osmosis (RO) membranes, a reverse osmosis concentrate (ROC) is generated, which represents 15-25% of the feed water flow.

Electrochemical oxidation using five electrode materials (ie, titanium coated with IrOx, Ru<sub>0.7</sub>Ir<sub>0.3</sub>, Pt-IrO<sub>2</sub>, PbO<sub>2</sub>, and SnO<sub>2</sub>) has been conducted in laboratory-scale batch mode experiments for the treatment of ROC from Bundamba AWTP (current density 100 A m<sup>-2</sup> applied for 22 hours of operation).



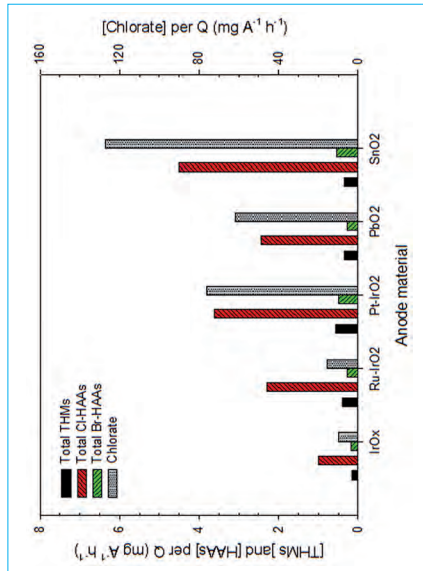
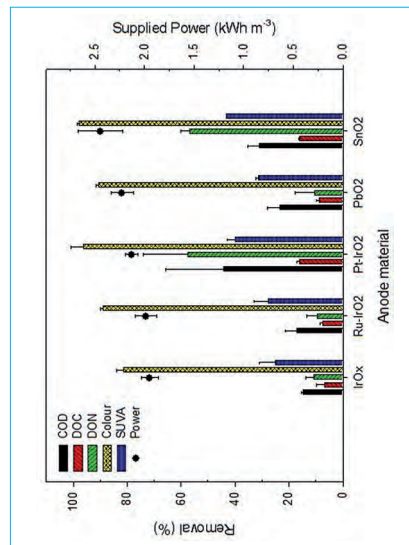
## Key Findings

More than 80% of colour removal was achieved by all five electrodes at Q = 0.55 Ah L<sup>-1</sup>. The highest current efficiency and the best oxidation performance was observed for Pt-IrO<sub>2</sub> anode, followed by the SnO<sub>2</sub> and PbO<sub>2</sub> anodes. The effectiveness of the treatment appears to correlate with the formation of free oxidants (eg, Cl<sub>2</sub>, O<sub>2</sub>, OH radicals).

## Results and Discussion

The decolourisation and removal of DOC, DON, SUVA<sub>254</sub> and COD increased with increasing the supplied charge (Q, Ah L<sup>-1</sup>). The best performance was noted for Pt-IrO<sub>2</sub> and SnO<sub>2</sub> electrodes.

The highest power consumption was observed for SnO<sub>2</sub> electrode (2.43 kWh m<sup>-3</sup>).



These electro-generated free oxidants led to the formation of oxidation by-products such as trihalomethanes (THMs) and haloacetic acids (HAAs). As a result, for the most efficient electrodes the amount of formed hazardous oxidation by-products was the highest, with measured concentrations decreasing in the order:

- Total THMs: Pt-IrO<sub>2</sub> > Ru-IrO<sub>2</sub> > PbO<sub>2</sub> ≈ SnO<sub>2</sub> > IrOx
- Total HAAs: SnO<sub>2</sub> > Pt-IrO<sub>2</sub> > Ru-IrO<sub>2</sub> ≈ PbO<sub>2</sub> > IrOx
- Chlorate: SnO<sub>2</sub> > Pt-IrO<sub>2</sub> > PbO<sub>2</sub> > Ru-IrO<sub>2</sub> ≈ IrOx

## Future Direction

- Electrochemical reduction will be investigated for dehalogenation of oxidation by-products formed during anodic oxidation of ROC.

# Critical Thresholds of Ecological Function and Recovery Associated with Flow Events in Urban Streams

Leigh, C.<sup>1</sup>, Dunlop, J.<sup>2</sup>, and Sheldon, F.<sup>1</sup>

<sup>1</sup> Australian Rivers Institute (ARI), Griffith University, Nathan QLD 4111; <sup>2</sup> Department of Environment and Resource Management (DERM), 80 Meiers Rd, Indooroopilly QLD 4068

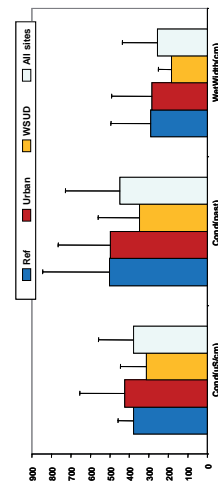
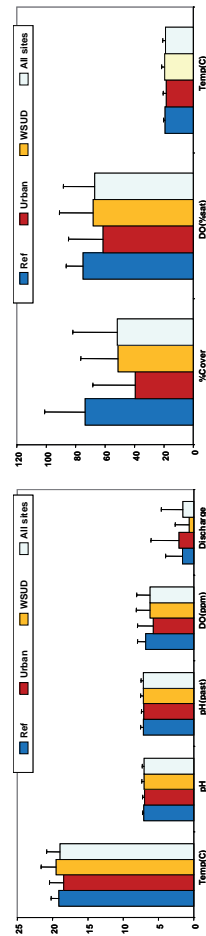
## Project Summary

Water flow from impervious (non-porous) surfaces and the direct connection of stormwater outflows has a major effect on stream ecosystems. This can lead to sudden pulses of water which may catastrophically dislodge fauna (like invertebrates) and affect ecological function. Subsequently, dissolved oxygen levels may become critically low. Important to the management of urban streams is the identification of critical thresholds of these ecological responses.

## Results and Discussion

Twenty four (24) sites were assessed for aspects of stream health along a gradient from natural (forested) to highly urbanised (modified). Results suggest upstream impervious area influences stream health: sites downstream of urbanised catchments tended to have lower canopy cover and dissolved oxygen (DO) but to also have greater discharge, conductivity and pH compared with reference and water-sensitive urban design (WSUD) catchments.

Analyses so far are preliminary and there was much variation in water quality data among sites within catchment types. However, conductivity and pH appeared consistent with previous data collected by DERM.



Mean water quality and other parameters measured for 24 sites in May 2010, compared among catchment types (reference, urban, WSUD) and for all sites combined. Error bars show one standard deviation. Comparison is also shown between May 2010 measures and those from the provided historical data ('past') for pH and conductivity.

## Future Direction

Disolved organic carbon (DOC) concentrations, macroinvertebrate and diatom assemblage data from the 24 sites are being analysed. In particular, numerical dominance by taxa tolerant of harsh conditions (eg, chironomids) and loss of sensitive taxa (eg, mayflies) is likely to indicate negative impact of urbanisation / increased impervious surface area via the effect of increased flow velocities and DOC loads (see Figure). These relationships will be explored in more detail in a temporal study starting after winter 2010.

## Key Findings

We expect that storm inflow events load urban streams with DOC and initially increase DO. Bacteria will metabolise the DOC, which uses up most of the available DO. In-stream fauna will only survive if they can tolerate the harsh, low-oxygen conditions and wait out the period between inflow events. This means that without management, urban streams may have little chance of recovering ecosystem health. **By monitoring DO and invertebrate diversity in streams around Brisbane, our research will provide knowledge on thresholds of ecological response, which may be critical for the future planning, management and health of urban streams in SEQ.**



# Purified Recycled Water Research Outcomes

Simon Toze

The PRW project was established to investigate the health risks and ecological impacts associated with the production and use of PRW. A particular emphasis was placed on determining the effectiveness of barriers 1, 2 and 6 and on the development of advanced monitoring techniques.

## Source Component

### Hospital Waste Discharge

(Christoph Ort)

This is showing that hospitals may only contribute a small amount to the concentration of pharmaceuticals in sewage.

See Hospital Waste Discharge details for more details

## Reservoir Component

### Pathogen Decay in Reservoirs

(Simon Toze, Leonie Hodgers and Darren Morrow)

See I told you pathogens will decay in reservoirs.

But I'm still worried about *Cryptosporidium*.

Effect of sunlight on *Salmonella*

See Pathogens and Trace Chemicals in Dams poster for more details

## Advanced Monitoring Component

### Pathogen Detection Methodologies

(Ben Matthews, Helen Stratton and Jatinder Sidhu)

(Well) the PCR internal standard is now working nicely.

Yes but determining what's causing PCR inhibition is proving harder to solve.

See Poster on qPCR detection of *E. coli* for more details

## Source Component

### Pathogen Removal in WWTPs

(Simon Toze, Leonie Hodgers, Warwick Ahmed, Jatinder Sidhu, Darren Morrow, Helen Stratton and Ben Matthews)

WWTPs	Approximate Log Removal Rates
Luggage Point	Bacteria 3-5, Viruses 2-4, Cryptosporidium 4
Osley Creek	2-3, 2-3, 4
Bundamba	1.5-3, 3, 4

It's pretty whiffy around here but we know the WWTPs are reducing the pathogens numbers.

## Reservoir Component

### Trace Organic Removal in Reservoirs

(Mike Williams, Declan Page, Simon Toze and Leonie Hodgers)

Is this the easiest way to test DBP decay in reservoirs?

Chemicals can enter the water from many different sources.

See Pathogens and Trace Chemicals in Dams poster for more details

## Advanced Monitoring Component

### Viral Concentration Methods

(Jatinder Sidhu)

Silica beads look like they'll be suitable for concentrating viruses out of raw and treated sewage. Real silica will be when we can increase the charge on the silica beads.

Virus	Sample number	Final virus number	% Recovery
Coxsackievirus	A	1.2 x 10 <sup>6</sup>	25.11
	B	1.7 x 10 <sup>6</sup>	20.40
Adenovirus	A	1.5 x 10 <sup>6</sup>	16.83
	B	2.5 x 10 <sup>6</sup>	16.83

## Source Component

### Trace Organic Removal in WWTPs

(Rai Kookana, Mike Williams, Ali Shareef, and Leonie Hodgers)

Compound	WWTPs	Log <sub>10</sub> Removal	DOC Creek
17β-estradiol	100.4	88.4	88.4
Ethoxycarbonyl	88.4	88.4	88.4
Nonylphenol	88.4	88.4	88.4
Clopyrifos	88.4	88.4	88.4
Chlorzoxazone	No removal	No removal	No removal
Ibuprofen	88.5	88.5	88.5

The WWTPs are capable of removing at least 90% of almost all trace organic chemicals we've tested.

## Reservoir Component

### Emerging Trace Organics

(Jochen Mueller)

Perfluorinated compounds seem to be in lots of water sources – but what are the risks?

We've been able to show that:

- Hospitals contribute less than 10% of most pharmaceuticals;
- WWTPs can achieve >90% removal of most organic compounds and 2-5 log reduction of pathogens;
- Natural processes: chemicals are removed within days or weeks in reservoirs by natural processes;
- Bioanalytical assays can be used to demonstrate water quality improvements in the production of PRW;
- High level concentration and detection of pathogens in wastewater is possible;
- We can efficiently set up new methodologies for the detection and study of novel chemical compounds.

## Advanced Monitoring Component

### Bioanalytical Tools

(Beate Escher, Miroslava Macova and Team)

Nice work ladies.

We've shown that PRW is at least as good as tap water and that treatment barriers work very well.

I-PAM assay

See Bioassays and risk communication project poster for more details

## Source Component

### Solid/Liquid Partitioning in WWTPs

(Mike Williams, Rai Kookana and Beate Escher)

There seems to be some unexplained things to do with DOC which would be exciting to investigate.

I agree but we need to know how chemicals are partitioning amongst all the organic fractions as well.

## Reservoir Component

### Passive Samplers in WW

(Jochen Mueller)

Sampling Method	Sample Score
Grab Samples	64
Primary Yellows	56
Secondary Effluent	68-77
Chemicals detected in Grab and Yellows	4
Chemicals detected in Primary Effluent	15
Chemicals detected in Secondary Effluent	17

Passive samplers can pick up chemicals in sewage but quantification is difficult.

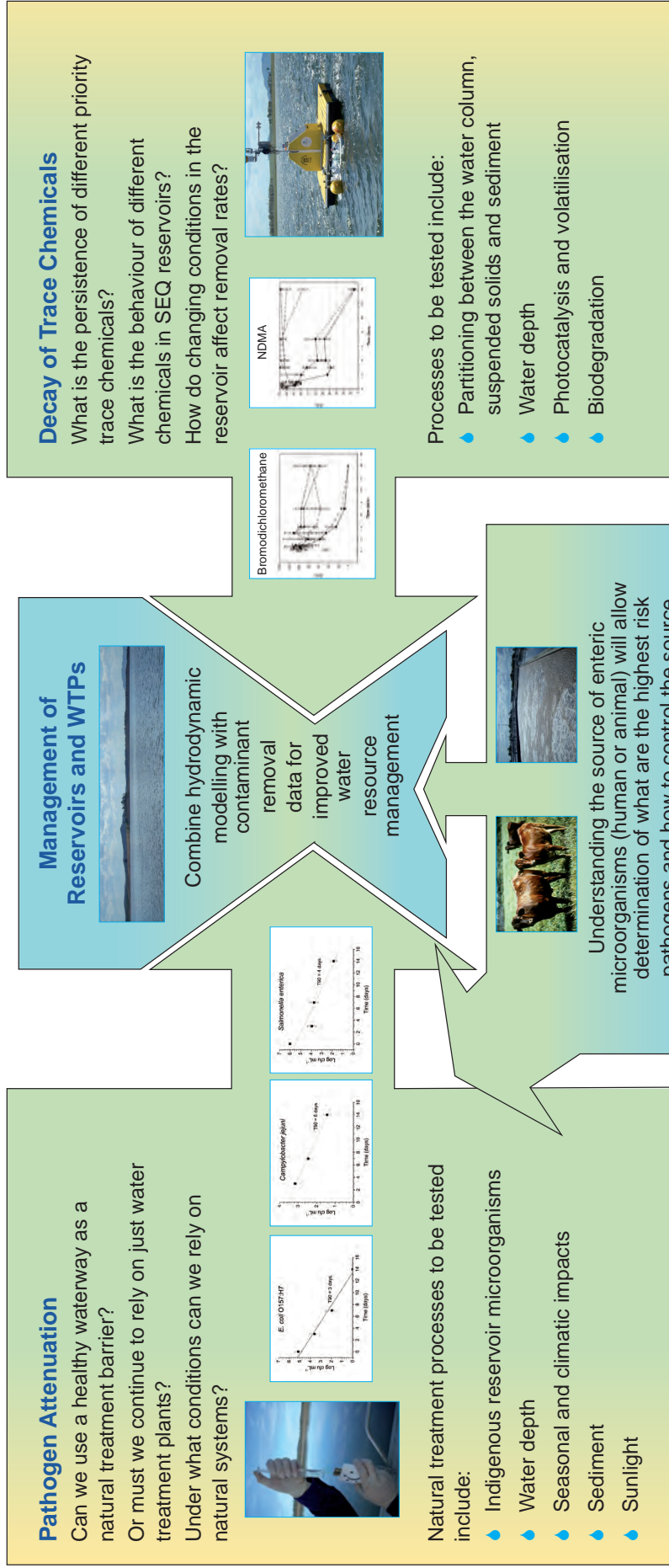
See Bioassays and risk communication project poster for more details

# Pathogens and Trace Chemicals in Dams

Toze, S., Hodgers L., Ahmed, W., Stratton, H., Kookana, R., Williams, M., Shareef, A., Bartkow, M. and Page, D.

## Project Summary

Can catchment health be used as a “generator of good water quality”? To answer this question, this project will investigate and document the most important processes in natural systems for the removal of biological and chemical contaminants under a range of climatic conditions. This information can then be incorporated into existing and future contaminant fate models to assist the development of improved management options that include natural systems as treatment barriers.



# The Meteorological Controls on Lake-Atmosphere CO<sub>2</sub> Exchange

Michael Gray and Hamish McGowan

Climate Research Group, School of Geography, Planning and Environmental Management

## Project Summary

The use of eddy covariance (EC) as part of the Evaporation Loss project at Logan's Dam enabled the measurement of the rate of carbon dioxide (CO<sub>2</sub>) flux between the water surface and the atmosphere. This study presents the only known EC measurements of lake-atmosphere CO<sub>2</sub> flux in the Southern Hemisphere, with previous work occurring in the Northern Hemisphere in areas subject to seasonal ice cover.

## Field Site

Logan's Dam, near Gatton in SEQ, is an on-farm reservoir (Figure 1). At full supply, the surface area is 17 ha and the maximum depth is 6.5 m, giving a storage capacity of 0.7 GL<sup>1</sup>.



Figure 1: Logan's Dam field site.

## Methodology

The primary instrumentation included a pontoon-mounted EC unit incorporating an open-path infrared gas analyser and 3D sonic anemometer (Figure 2). Ancillary data were collected at automatic weather stations on and around the dam (Figure 1).

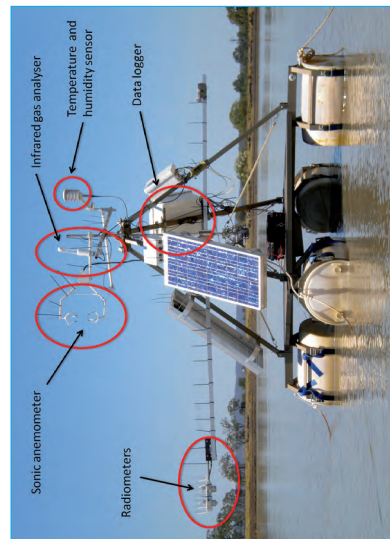


Figure 2: Eddy covariance unit on Logan's Dam.

**References**  
<sup>1</sup> CSIRO (n.d.) 'Comparison of techniques for determining evaporation from a large irrigation storage', Evaporation Experimental Plan V3, unpublished.  
<sup>2</sup> Geoscience Australia (n.d.) 'Waterbodies data, unpublished.'

## Results and Analysis

For the measurement period (14 August 2009 to 11 January 2010), Logan's Dam was found to be a net source of CO<sub>2</sub> to the atmosphere of the order of 0.63 mg m<sup>-2</sup> day<sup>-1</sup> (Figure 3), a smaller flux than that of previously studied Northern Hemisphere lakes. Total monthly CO<sub>2</sub> flux (Figure 4) varied in response to prevailing synoptic conditions.

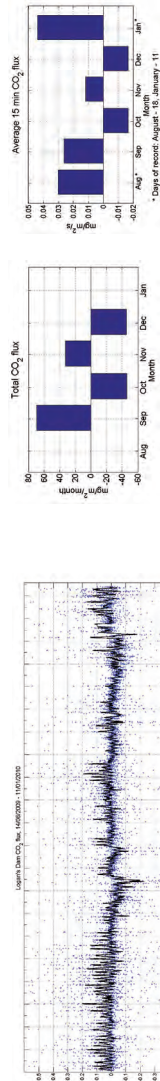


Figure 3: Time series of CO<sub>2</sub> flux with 6-hour moving average.

There were no clear correlations between CO<sub>2</sub> flux and individual meteorological parameters, however, wavelet analysis showed diurnal cycling of temperature, wind speed and barometric pressure to be significant (Figure 5). Periods of high amplitude CO<sub>2</sub> flux (Figure 5) coincided with the months where the dam was a source of CO<sub>2</sub> to the atmosphere (Figure 4).

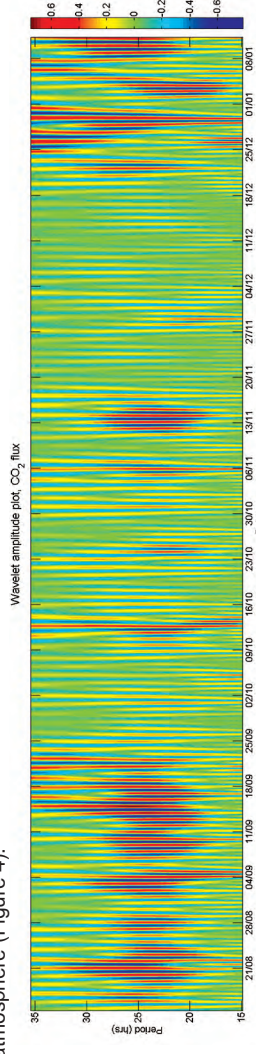


Figure 4: Wavelet amplitude plot of CO<sub>2</sub> flux. Darker colours indicate higher amplitude diurnal cycles.

The presence of a low-pressure trough over western Queensland was associated with Logan's Dam acting as a source of CO<sub>2</sub>. These conditions are also typically conducive to thunderstorm activity in SEQ. It is possible that pre-storm winds may have transported CO<sub>2</sub> over the dam from other sources, including urban areas to the east, however, further investigation of this hypothesis is required. Within a regional context, if the net CO<sub>2</sub> exchange between Logan's Dam and the atmosphere is extrapolated to cover the surface area of terrestrial water bodies in the nearby Wivenhoe analysis area (1,021.45 ha)<sup>2</sup> there is a potential annual CO<sub>2</sub> efflux of 2.35 t.

## Future Research

The acquisition of a longer dataset covering annual changes in local to synoptic scale weather patterns would permit an analysis of the influence of a much larger range of meteorological conditions on lake-atmosphere CO<sub>2</sub> flux.

# Validation and Monitoring of Cluster-Scale Wastewater Treatment Technologies

Chong, M., Gardner, T., Sharma, A., Cook, S., Palmer, A. and Carlin, G.

## Project Summary

This poster presents our research for cluster-scale wastewater treatment technologies (CWTT) in South East Queensland, which focuses on increasing knowledge of CWTT in the areas of: system robustness, energy efficiency and fugitive greenhouse gas (GHG) emissions. We have made progress through a continuous monitoring program which collected data on water quality, flow and energy consumption for two different types of CWTTs. A third CWTT at Sunrise, Town of 1770, is in the planning stage. The monitoring sites incorporate a range of treatment units and processes including: immersed membrane bioreactor (IMB), membrane filtration (MF/RO), biofilm textile filters, zeolite and sand filtration, septic tanks and UV disinfection. To explore the performance of the IMB, monitoring data was used to calibrate a biophysical computer model (BioWin) to investigate system robustness to shock loads. In addition, detailed instrumentation has allowed the energy consumption of individual components of the CWTT plants to be quantified.

## Results and Discussion

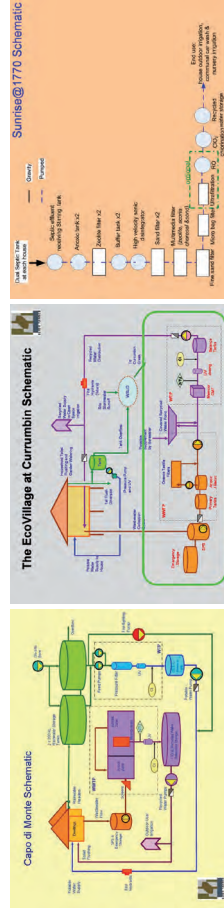


Figure 1: Schematic for three different CWTT developments at: (a) Capo di Monte (Mount Tamborine); (b) The Currumbin EcoVillage; and (c) Sunrise (Town of 1770)

## Future Directions

Future research efforts will quantify fugitive GHG fluxes from the CWTTs. In addition, a market survey of other commercially available IMBs is anticipated to gain an understanding of application trends and sourcing of IMBs of different scales for further monitoring work. All research outputs will be integrated into a decision-making framework to guide the selection of appropriate CWTT for future greenfield developments.

## Key Findings

### BioWin® Modelling

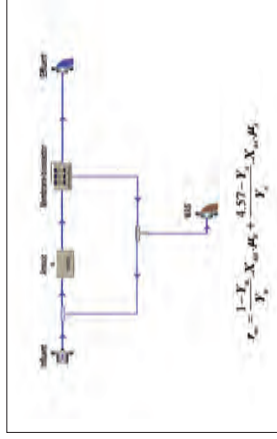


Figure 2: Wastewater process simulation using a calibrated Activated Sludge Model (ASM) 1 in BioWin®

### System Robustness:

- Can withstand ± 50% hydraulic loads.
- Sensitivity to N loads > COD loads.
- Highly tolerate to COD loads (no effect).
- Can only tolerate ± 30% of N loads without upsetting the IMB.

### Energy Monitoring

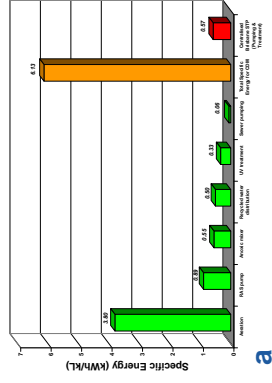


Figure 3: Specific energy consumption for different CWTT components: (a) Capo di Monte (CDM); (b) Currumbin EcoVillage (CEV) compared with a centralised STP (Kenway et al. 2008).



# Enhanced Treatment Project – PhD Fundamental Investigation on Biological Activated Carbon?

Maxime Rattier, Julien Reungoat, Gene Tyson, Qingxiang Yang, Wolfgang Gernjak and Jurg Keller

## Project Summary

### Scope:

It is essential to improve the quality of secondary treated effluents in order to protect the environment, preserve the quality of water sources used for human consumption, and provide high quality water for reuse. Biological activated carbon (BAC) filtration has a great potential for improving secondary effluent quality with low energy requirements.

### Aims:

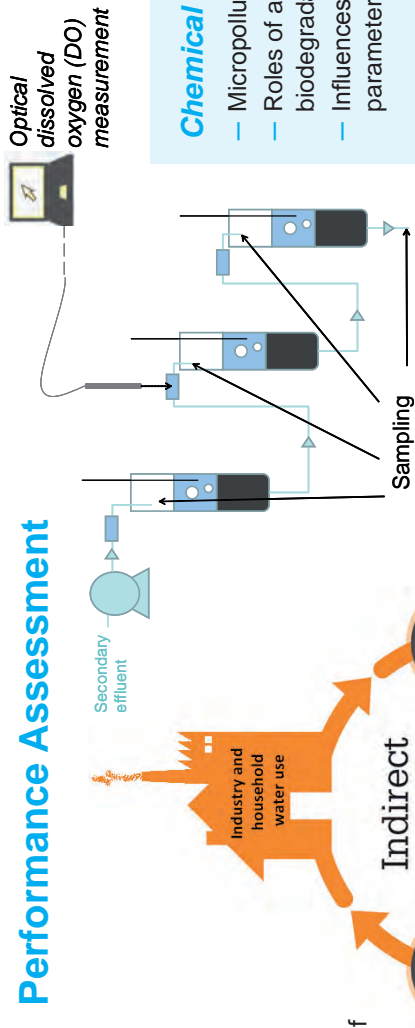
- Characterise BAC: properties, performances (removal of micropollutants, DBP precursors, fractions of EfOM)
- Elucidate the mechanisms of contaminants removal
- Identify the microbial communities in BACs

## BAC Material

### Characterisation:

- Adsorptive surface, pore volumes (micro-, meso-, macropores)
- Adsorption and biodegradation capacities
- Comparison to other granular media
- Influence on mechanisms and performances

## Performance Assessment

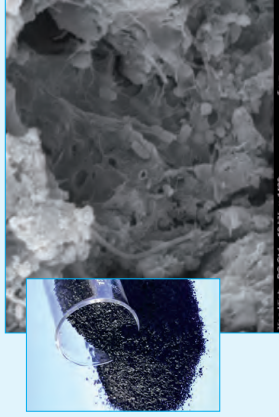


### Chemical analyses:

- Micropollutant removal
- Roles of adsorption and biodegradation
- Influences of operational parameters

### Investigation of the microbial communities with state of the art microbial tools:

- Which bacteria?
- Where?
- Quantity?



### Research about Biological filtration processes gave encouraging results:

- Slow sand filtration
- Managed Aquifer Recharge
- River Bank filtration



# Understanding Water Savings from Mandated Rainwater Tanks in South East Queensland

Mankad, A., Chong, M., Gardner, T., Beal, C. and Sharma, A.

## Project Summary

Under the revised QLD Development Code (QDC), homes built in SEQ after January 2007 are required to supply up to 70 kL/year from alternative water sources. This is usually achieved by connecting a minimum 5 kL rainwater tank to 100m<sup>2</sup> roof and supplying the toilet, laundry and outside tap. This study was developed to help understand the mains water savings by households with mandated rainwater tanks.

For example a recent study (Beal, *et al.*, 2010) hypothesised that differences in demographic and biophysical variables, such as household composition, tank size, collection set-up, and property water requirements may have contributed to the differences in mains water savings calculated for a range of local authority areas in SEQ. Further, we believe that an analysis of psycho-social variables may also offer a more contextual and behavioural understanding of water use amongst households with rainwater tanks.



Beal, C., Gardner, T., Sharma, A., & Barton, R. (2010). A desktop analysis of potable water reductions from internally plumbed rainwater tanks in South East QLD. Urban Water Security Research Alliance Technical Report

## Key Findings and Future Direction

- Explain difference between real and expected mains water savings from a socio-cultural perspective.
- Inform future research into community acceptance of rainwater tanks.
- Provide contextual understanding of preferred alternative water systems.



Phase 1

### Phase 1 – Telephone Survey

- Demographic and biophysical measures.
- N = 2,000 (Caboolture, Pine Rivers, Redlands, Gold Coast).
- Permission to access 2008-2012 water billing records for property.



Phase 2

### Phase 2 – Mail-Out Survey

- Social and psychological measures:
  - perceptions of rainwater and trust in alternative water technology.
  - emotional and cultural responses to alternative water sources.
- N ≈ 1,000 (Caboolture, Pine Rivers, Redlands, Gold Coast).



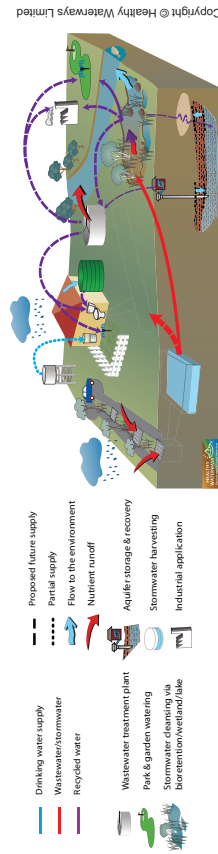
Phase 3

### Phase 3 – Household Audit

- Onsite inspection of rainwater tank systems and compliance with the Queensland Development Code (MP4.2).

### Data Analysis

- Statistical comparison of adjacent suburbs:
  - mandated sample vs. no-tank sample.
  - household water use records, adjusted for people per household.



# Energy Use and Prospective Governance Models for Rainwater Tank Water Supply

G.Tjandraatmadja, M.Moglia, C.Pollard, T.Gardner and A.Sharma

## Project Summary

Domestic rainwater tanks are a key component in the SEQ Water Strategy to augment potable water supplies and increase water security.

Understanding the energy footprint and the future governance needs for rainwater tanks (RWT) are important steps to help ensure the sustainability and public safety of rainwater supply.

These challenges are being addressed in two sub-projects:

## Governance Models for Rainwater Tanks

Responsibility for operation and maintenance of RWT lays with householders. Information on householders' long term ability to appropriately manage their tanks is limited.

### Objectives

- Understand roles, responsibilities and strategies to support governance of RWT.
- Provide policy makers with evidence based information to develop governance structures.

### Strategy

- Investigate existing needs and governance model options for rainwater supply.

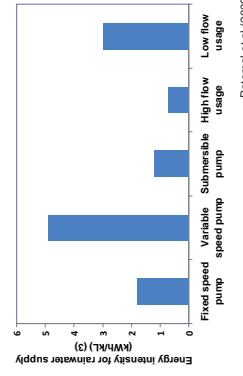
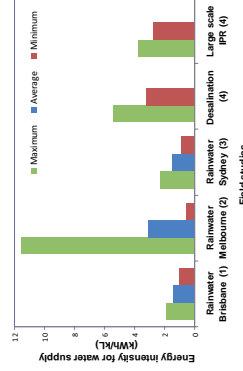
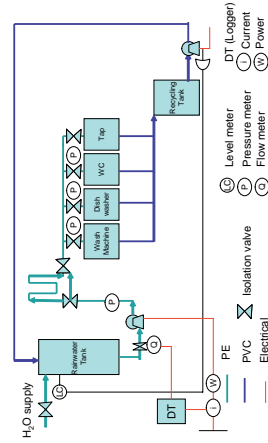


## Optimisation of Energy Use in Rainwater Tanks

Large variability in energy footprint for rainwater systems have been measured in Australian studies. The project will quantify specific energy needs for different pump types, configurations and end uses under controlled experimental conditions.

### Results:

- Specific energy consumption (kWh) and intensity (kWh/kL) varies with different water uses and appliances for different pump types.
- Each appliance has a characteristic energy requirement for rainwater supply.



References: (1) DERW, (2) SEWL (2009) Energy consumption in domestic water harvesting, Water Conservation Group, (3) Retamal et al (2009), The water energy-nexus, ISF, (4) NSW Legislative Council (2006) A Sustainable Water Supply for Sydney, Sydney

## Future Directions

- Influence manufacturers to design more efficient pumping systems.
- Field surveys to quantify maintenance behaviour by tank owners.



# Pharmaceutical Audit Data from Hospitals



Kristell Le Corre<sup>1</sup>, Jeremy Saiter<sup>2</sup>, Diana Kateley<sup>2</sup>, Belinda Allen<sup>2</sup> and Christoph Ort<sup>1</sup>

<sup>1</sup>Advanced Water Management Centre (AWMC), The University of Queensland, Queensland Services Queensland, Queensland Health, Herston, QLD

## Are Hospitals a Major Point Source of Pharmaceuticals? For Which Compounds? At Which Locations?

### Experimental Evaluation

Experimentally determining the contribution of hospitals towards the total pharmaceutical residue loads in domestic wastewater is a difficult task and limited by various factors:

- Restricted access to raw hospital wastewater.
- Effort to obtain representative samples is substantial and can only be carried out over a limited period of time.
- Analytical methods only provide results for a limited number of compounds.

### Pharmaceutical Audit Data Evaluation

Using audit data can overcome some limitations of sampling campaigns and is not prone to experimental uncertainties. Comparing the consumption of pharmaceuticals within hospitals with consumptions by the general public is a unique opportunity to identify, quantify and hence, predict the contribution of a hospital for a large number of compounds in various STP catchments.

Content	National Consumption Audit Data	Queensland Public Hospital Audit Data
Annual Consumption of Pharmaceuticals by the General Public in Australia*	904 entries corresponding to single and combined pharmaceutical compounds and their respective mass consumption/year.	65,448 entries corresponding to single and combined pharmaceutical compounds and their respective mass quantity used/year.
733 distinct generics	2,011 distinct generics	1,560 distinct generics to evaluate
Total in 6 hospitals* in the catchments of an AWTP	N/A	

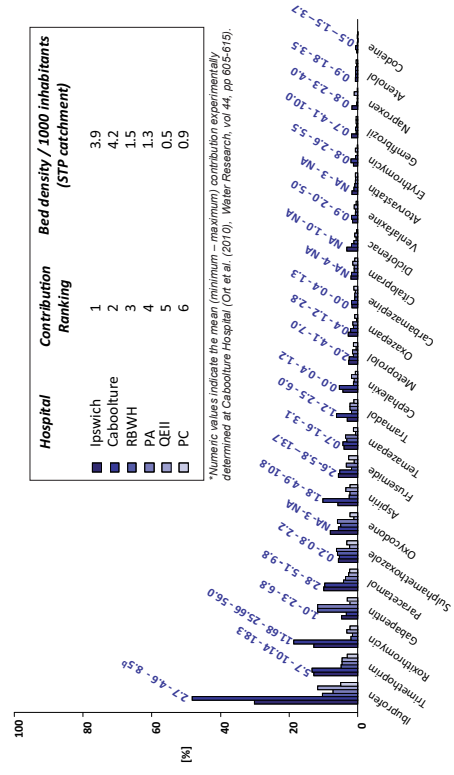
\* Caboolture Hospital, Ipswich Hospital, Queen Elizabeth II Hospital, Royal Brisbane and Women Hospital, Princess Alexandra General Hospital, The Prince Charles Hospital

### Key Results from Caboolture Case Study

Caboolture hospital offers the highest hospital bed density per 1,000 inhabitants (4.2 beds) within a STP connected to an AWTP in South East Queensland. The analysis of 59 compounds from a unique sampling campaign carried out in February 2009 revealed that the hospital contributes less than 15% for 28 investigated substances. Only two substances, roxitromycin and trimethoprim, exhibited larger contributions. The other 21 compounds were not detected at both sampling locations (effluent hospital or influent STP). Actual measurements agree well with the prediction based on audit data for 75% of the substances and suggest that National and Hospital audit data could be used as good predictors.

### Contribution of Six Hospitals in South East Queensland for the Year 2008

The evaluation (see graph below) focuses on 24 out of the 30 substances experimentally detected at Caboolture Hospital and for which pharmaceutical consumption data are available in both Hospital and National consumption audit data sets.

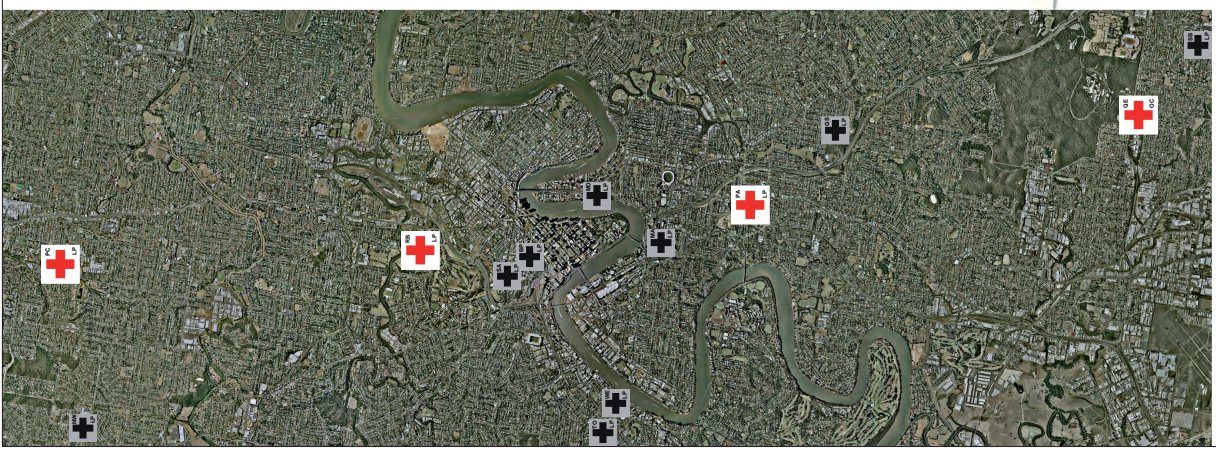


### Key Results from the Audit Data Evaluation

For 18 of the 24 substances evaluated, the predicted contribution for each of the six hospitals is below 10%. Only one substance has a predicted contribution of more than 20% from selected individual hospitals. This reveals similar trends to the ones observed at Caboolture.

Ibuprofen stands out as a substance for which Ipswich and Caboolture hospitals seem to contribute significantly to the loads in domestic wastewater (30% and 48% respectively). However, ibuprofen is widely available without prescription and the national consumption may therefore be underestimated (Pharmaceutical Benefits Scheme - PBS). In contrast, hospitals comprehensively cover prescription and non-prescription drugs. Consequently, our evaluation is a conservative estimate for the contribution of hospitals; it also does not take into account the ratio of out-patients.

The ranking of the six hospitals in terms of their predicted contribution shows that overall contributions of hospitals correlate with bed densities.





# Posters - Others

# NDMA and Trihalomethane Formation and Minimisation in South East Queensland Drinking Water

Kalinda Watson, Nicole Knight, Maria José Farré and Glen Shaw

## Project Summary

This project examined the use of Advanced Treatment using UV/H<sub>2</sub>O<sub>2</sub> or photolysis (UV) to determine how these strategies may be utilised for disinfection by-product (DBP) minimisation. NDMA and THM formation in SEQ waters was also investigated.

## Results and Discussion

- NDMA concentrations were <5 ng/L (detection limit) in all potable water samples and Water Treatment Plants.
- All THM formation potentials using SEQ source waters complied with the Australian Drinking Water Guidelines.

NDMA	Formation Potential	Actual concentration at WTP	Point of supply
Chlorination	<5 ng/L	<5 ng/L	<5 ng/L
Chloramination	5 – 21 ng/L	<5 ng/L	<5 ng/L
THM	Formation Potential	Actual concentration at WTP	Point of supply
Chlorination	41 – 151 µg/L	19 – 34 µg/L <sup>^</sup>	44 – 77 µg/L <sup>*</sup>
Chloramination	7 – 78 µg/L	36 – 81 µg/L <sup>**</sup>	39 – 55 µg/L <sup>*</sup>

<sup>^</sup> Moolendinar WTP, data from WTP 2009, <sup>\*\*</sup> Mt Crosby WTP, <sup>\*</sup> Data from 2007-2008 QH-FSS survey

- Advanced treatment of raw waters prior to disinfection was very effective in removing THM precursors and subsequent THM formation was low (Figure 1).
- THMs were not able to be destroyed by either UV radiation or UV in conjunction with H<sub>2</sub>O<sub>2</sub>.
- Photolysis experiments found that UV irradiation at a dose similar to that used for disinfection was effective in reducing existing NDMA concentrations in raw water (Figure 2).
- This outcome did not require H<sub>2</sub>O<sub>2</sub> and the degree of NDMA destruction was not improved by the presence of H<sub>2</sub>O<sub>2</sub>.

## Key Findings

The research presented here shows that both NDMA and THM concentrations can be minimised in the finished water by appropriate use of advanced treatment.

## Future Direction

- Assessment of emerging and regulated DBPs occurrence in SEQ water grid.
- Selection of a suitable indicator for DBPs arising from chloramination.
- Characterisation/removal of dissolved organic matter and halides.
- Evaluation of different strategies to reduce the DBPs generated in SEQ.

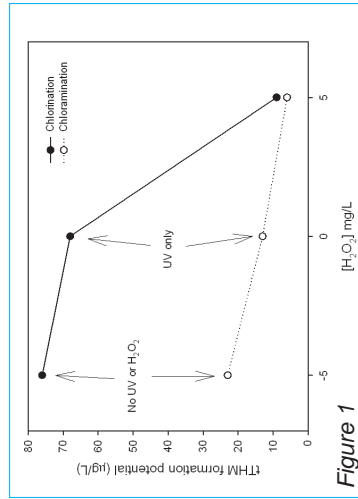


Figure 1

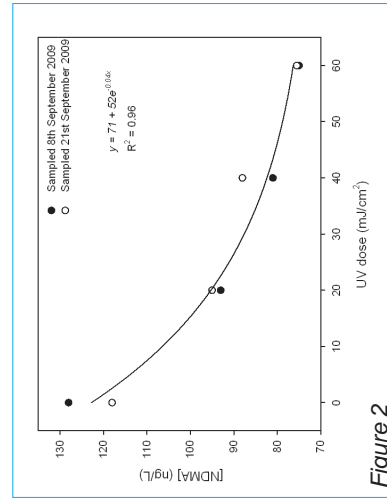


Figure 2



# Health Risk Assessment of Local Source Waters

Toze, S., Sidhu, J., Ahmed, W., Hodgers L. and Page, D.

## Project Summary

Alternative water sources such as urban stormwater and roof harvested rainwater have the potential to be the largest alternative water sources in South East Queensland. Currently, there are restrictions on the types of uses due to uncertainty about health risks associated with these water sources, in particular from pathogens. This project aims to gain a better understanding of the incidence and type of pathogens in stormwater and roof harvested rainwater and to assess the actual microbial health risks.

## Pathogen Risk in Stormwater

There is little documented on microbial pathogens and their sources in urban stormwater.

Data on the incidence, types and behaviour of pathogens can have a major impact on potential uses and treatment requirements.

Questions to be investigated include:

- What are the types and numbers of microbial pathogens in stormwater during a typical storm event?
- Is there any correlation between microbial indicators and pathogens?
- What is the actual quantifiable pathogen health risk?
- What are the sources of pathogens in stormwater?
- Can the types of pathogen detected be correlated with the presence of chemical contaminants?

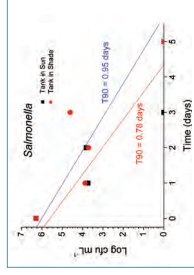
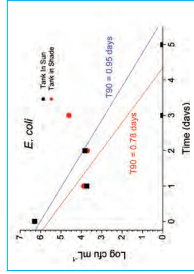
This research is in partnership with the UWSRA Stormwater Harvesting and Reuse project and the Monash University's *Cities as Water Supply Catchments* program.



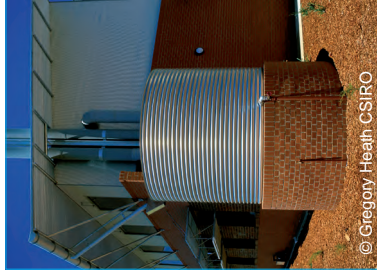
## Pathogen Risk from Roof Harvested Rainwater

Increasing the allowable uses for rainwater could have an impact on reducing potable water use in households.

Concerns exist relating to the microbial health risk through increased exposure to roof harvested rainwater.



Preliminary research outcomes on survival of *E. coli* and *Salmonella* in rainwater tanks



Issues to be tested include:

- Types and number of pathogens present;
- Linkages between pathogens and indicators;
- Potential sources of pathogens and impact of tank location.

In partnership with the UWSRA Decentralised Systems project, an assessment of the quantifiable microbial pathogen risk from additional potential uses within the household will be made.



Urban Water Security Research Alliance Science Forum, September 2010





# Water Quality Event Detection System

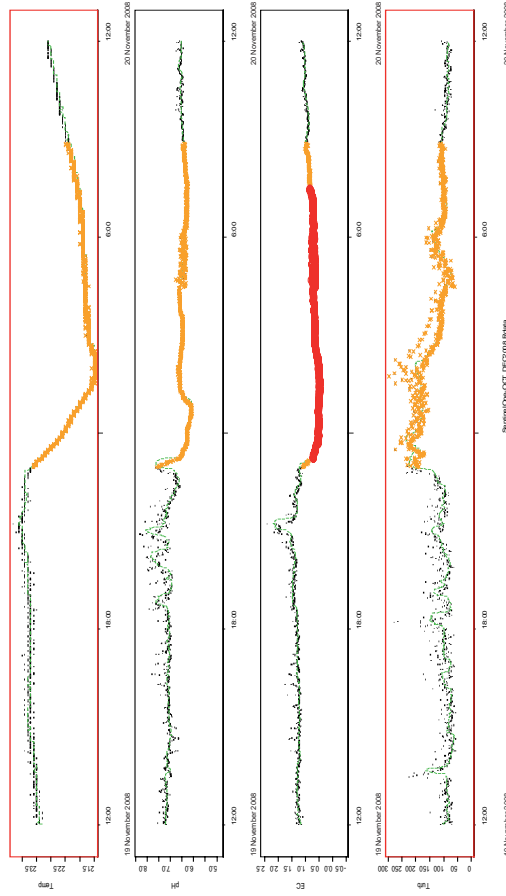
Ganther, W., Goodman, N., O'Halloran R., Toiffi, M., Winnel, M. and Zhao, H.

## Project Summary

We are developing 5 prototype real-time event detection systems for Barriers 1 and 2 of the South East Queensland water grid. They are designed to detect unusual conditions ('events') that indicate a major contaminant load has been discharged to sewer that could upset the treatment plant and treated effluent.

## Results and Discussion

- Univariate and multivariate event detection algorithms developed successfully.
- Computes a robust baseline, ignores 'normal' noise and variations.
- Successfully detects unusual events in real-time.
- Integrated electronic/computation module under development.



## Key Findings

- Simultaneous real-time measurement of simple parameters allowed water quality to be successfully predicted.
- A robust mathematical model was developed to detect events.
- Very tolerant of high noise levels - has very low false alarm rate.
- Accurately detects major discharges to sewer, which will enable source control and treatment plant protection.
- Enhanced turbulence manifold keeps sensors clean.
- Successful at Barriers 1 and 2; readily transferrable to other Barriers.
- Measure event impact by comparing results across barriers.

## Future Direction

- Re-designed electronics and computation module.
- Optimised flow manifold to minimise fouling.
- New inline sensors for turbidity, conductivity and organics.
- Planning with WSAA to continue this work Australia-wide.

# Assessment of Regulated and Emerging DBPs in SEQ Drinking Water

Maria José Farré, Nicole Knight, Kalinda Watson, Glen Shaw, Fred Leusch, Ross Sadler, James Birt, Michael Barkow, Jürg Keller, Wolfgang Gernjak and Paul Burrell

## Project Summary

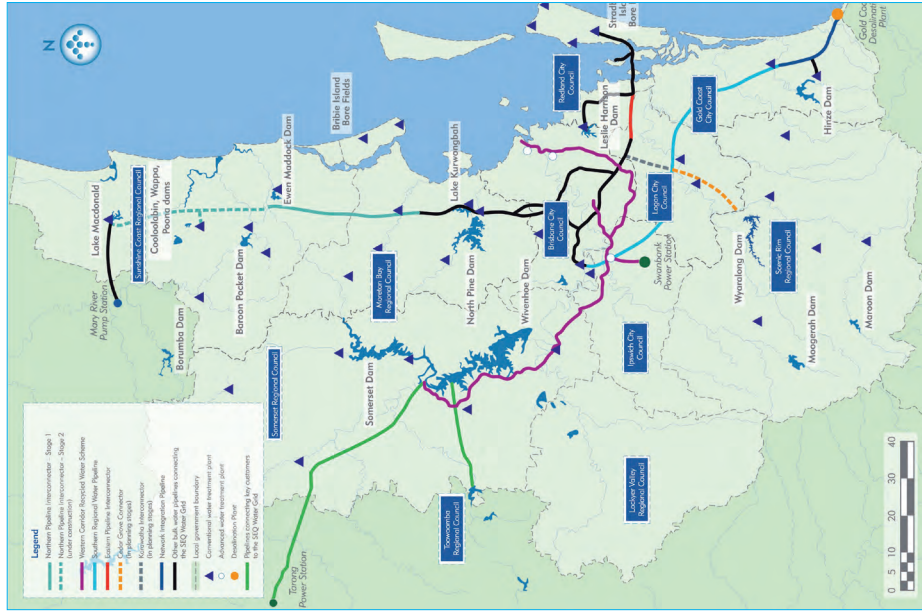
The SEQ Water Strategy aims to ensure that water in the region is managed on a sustainable and integrated basis to provide secure and reliable supplies of acceptable quality for all uses for the long term. Public health and safety will not be compromised and the highest water quality standards appropriate to use will always be maintained. **This project aims to understand which emerging and regulated disinfection by-products (DBPs) are generated during the production and distribution of drinking water in SEQ.**

## Key Research Questions

- Which emerging and regulated DBPs are of concern in SEQ, considering that two separate disinfection regimes (chlorination and chloramination) are used?
- What are the effects on DBP formation of blending drinking water of different qualities from different sources within the SEQ Water Grid?
- Can strategies to remove natural organic matter and halides be successfully applied to minimise the formation of DBPs in SEQ?

## Team

AWMC, SWRC, Seqwater, Bond University and The SEQ Water Grid Manager (*project champion*).



Key Outputs/Deliverables	
<b>Phase I</b>	<ul style="list-style-type: none"> <li>• Development of analytical capabilities to measure emerging DBPs in SEQ</li> <li>• Collection of historical data and literature review</li> <li>• Assessment of emerging and regulated DBPs occurrence in The SEQ Water Grid</li> <li>• Selection of a suitable indicator for DBPs arising from chloramination</li> </ul>
<b>Phase II</b>	<ul style="list-style-type: none"> <li>• DBP formation as a consequence of mixing different source waters in SEQ</li> <li>• Characterisation of natural organic matter that is not amenable to removal by enhanced coagulation</li> <li>• Evaluation of different strategies to reduce the DBPs generated in SEQ by improving halide and organics removal</li> <li>• Final report</li> </ul>

## Key Stakeholders

The key stakeholders for this project are **WaterSecure, Seqwater, Office of the Water Supply Regulator, LinkWater and Queensland Health.** Professor Urs Von Gunten (**EAWAG**) and Professor Howard Weinberg (**UNC**) will provide expertise by being members of our reference panel.



**Urban Water Security Research Alliance** Science Forum, September 2010



# Event-Based Stormwater Quality Measurements: Sampling Methodologies for Urban Catchments

Chong, M., Gardner, T., Chowdhury, R., Ort, C., Toze, S., Escher, B., Gardiner, R. and Tonks, M.

## Project Summary

Stormwater is one of the last major untapped water resources that can be used for urban water supply. In Brisbane alone, the volume of annual stormwater runoff is estimated to be 1.45 times the volume of potable mains water imported from external catchments. Current end-uses of treated stormwater are mostly for public open space irrigation. Potable substitution in urban developments and augmentation of drinking water reservoirs are attracting increasing interest but also warrant a better understanding of the health and environmental risks. In this study, we will measure event mean concentrations (EMCs) of individual stormwater contaminants with chemical analysis as well as mixtures of contaminants with bioanalytical tools in up to three contrasting urban catchments in SEQ over a range of runoff events. The risk analysis will be complemented by pathogen detection and quantification.

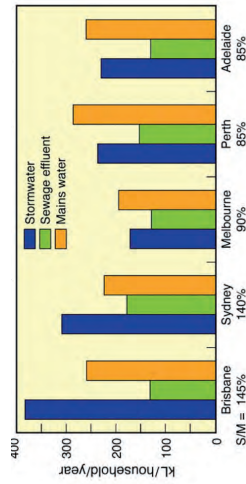


Figure 1: Volumetric availability of different water resources in every major Australia city (PMSEIC report, 2007)

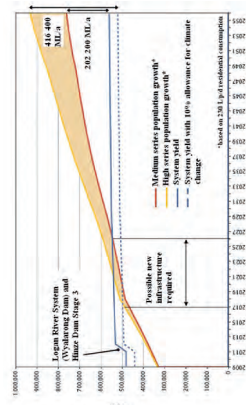


Figure 2: Future water supply and demand in SEQ (QWC, 2009)

## Future Direction

The measured EMCs from urban catchments will be complemented by research outcomes from similar studies in other Australian cities through a collaboration with the Cities as Water Supply Catchment program. From this, it is anticipated that a mathematical model can be established and calibrated to predict the stormwater quality from contrasting urban catchments.

## Project Approach

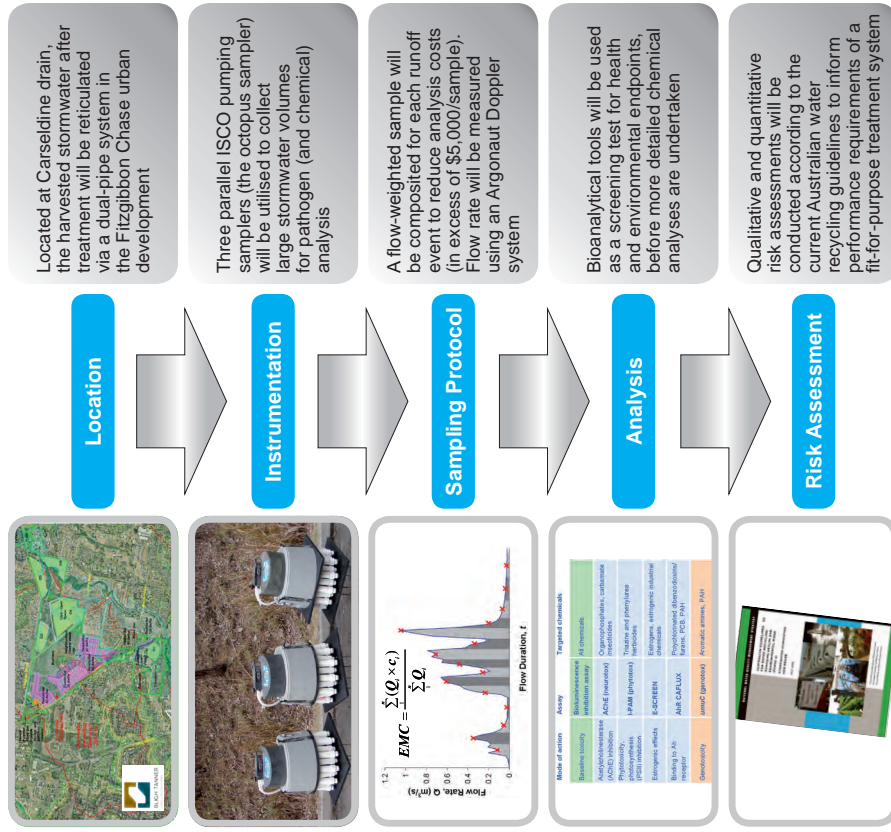


Figure 3: Proposed project approach for event-based stormwater quality measurements at peri-urban developments at Fitzgibbon

# SEQ Residential Water End Use Study: Baseline Results

Cara Beal, Rodney Stewart (Project Leader), Andrew Huang, Erasmo Rey, James Maitland and Reza Talebpour

## Project Summary

Water end use analysis was undertaken for a two week period in winter 2010 in 250 homes across the Gold Coast, Ipswich, Brisbane and Sunshine Coast. A mixed method approach was used, combining smart meters, loggers, household water appliance audits and a self-reported household water use diary (see Figure 1).

## Summary of Results

- Total per capita consumption ranged from 111 to 171 L/p/day.
- Average water usage measured in this study (145 L/p/d) was well below the Queensland Water Commission's permanent water conservation measure target of 200 L/p/d.
- Shower, tap and clothes washer had the highest end use volumes.
- Irrigation contributed < 5% of total consumption in the sampled winter period.

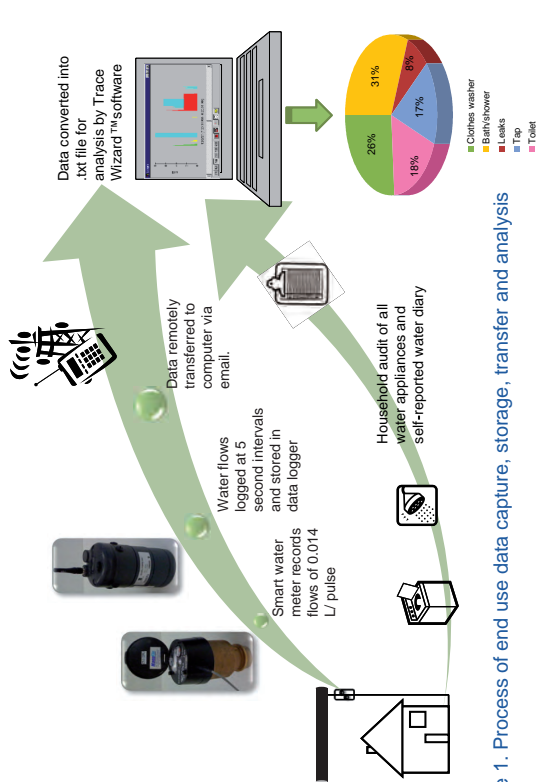


Figure 1. Process of end use data capture, storage, transfer and analysis

## Key Findings

- Low water consumption confirms the anecdotal and government reporting of a shift in general water consumption post drought in SEQ.
- Data can be used to inform future demand management policy (eg, targeting specific demographics / appliances).

## Future Direction

- End use analysis for other seasons.
- Diurnal patterns and leak typology assessment.
- Fixture appliance star ratings comparative analysis.
- End use analysis pre and post intervention.

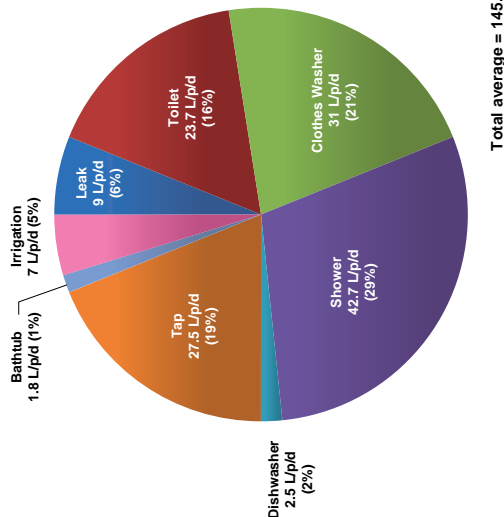


Figure 2. Pie chart of combined average end usage

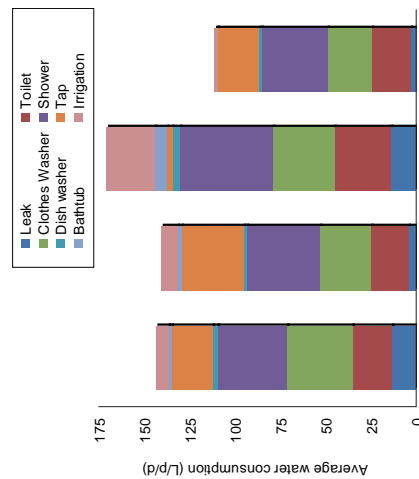


Figure 3. Break down of average end uses per region



# Spatial Analysis of Stormwater Harvesting Opportunities in SEQ

Laredo, L.<sup>1</sup>, Chowdhury, R.<sup>2</sup>, Gardner, T.<sup>2,3</sup> and Wolf, L.<sup>2</sup>

<sup>1</sup>CSIRO Ecosystem Sciences, <sup>2</sup>CSIRO Land and Water, <sup>3</sup>Department of Environment and Resource Management.

## Project Summary

Stormwater harvesting and reuse is a national research priority. This includes its capture, storage, appropriate treatment, maintenance and supply to end users in cost effective ways. By combining a set of biophysical rules with a range of GIS layers, it is expected that locations can be ranked on their stormwater harvesting and reuse opportunities.



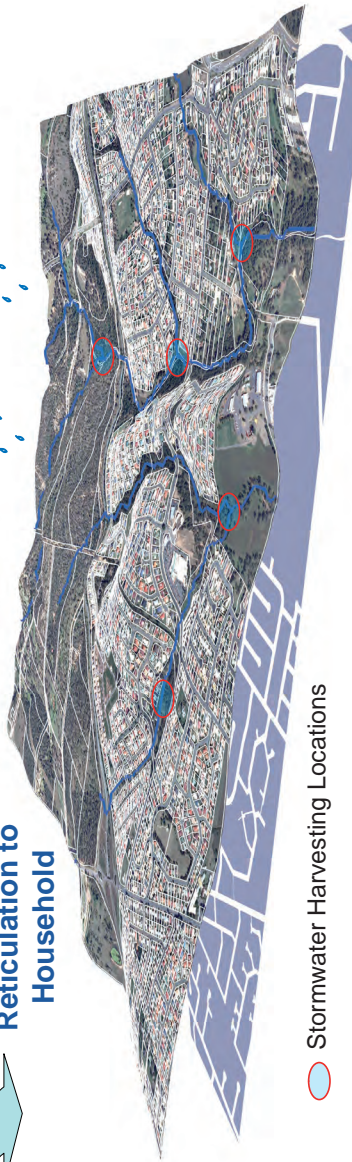
UV Disinfection



Microfiltration



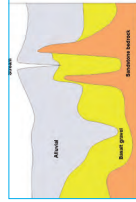
Reticulation to Household



Stormwater Harvesting Locations



Tank



Aquifer



Quarry Void



Reservoir



Lagoon

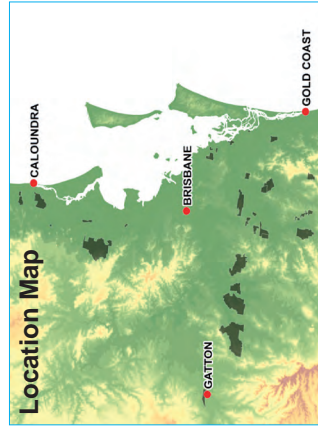
## Biophysical Rules

- High environmental value waterways downstream of greenfield development.
- Suitable aquifers, dams, or old quarry voids for storing stormwater.
- Development size > 20ha, but 100ha is preferable.
- Maximum catchment area per storage.
- Availability of open space for surface storage, eg, easements.
- Slope between 2% and 10%.

## Storage Options

Thirty-five identified greenfield areas in South East Queensland (shown in black) for an estimated 754,000 extra dwellings by 2031.

From SEQ Regional Plan (2009)



## Future Direction

Hydro-topographical analysis at sub-catchment scale in order to identify optimal storage volumes (from volumetric reliability vs storage relation) and suitable storage options (eg, aquifer, lagoon, reservoir, tank).



# Total Water Cycle Planning Project – PhD Quantifying Water-Related Urban Energy Use

Steven Kenway, Paul Lant, Peter Daniels and Tony Priestley

## Project Summary

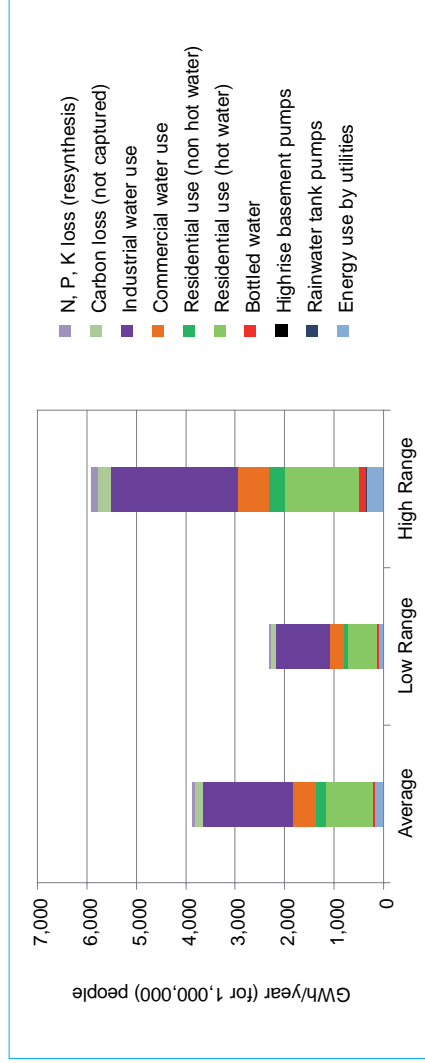
This analysis is a part of a PhD addressing urban metabolism and the water-energy nexus, as a component of the Total Water Cycle Planning Project. The objective is to systematically identify the direct and indirect links between water supply and consumption and energy use in cities. The work aims to contribute to an improved method for understanding and analysing these linkages so they can be better managed. The project will provide the water sector with options to mitigate the rapidly-rising energy intensity of water service provision in SEQ and other Australian cities (200% to 400% growth forecast by 2030).

## Results and Discussion

Figure 1 shows the principle linkages and places them in the context of a hypothetical Australian city of 1 million. Average, low and high-range estimates are shown.

## Future Directions

- Understanding key factors influencing residential and industrial water-related energy use will identify levers of influence.
- Sensitivity and uncertainty analysis will identify knowledge, data and monitoring gaps necessary to improve analysis rigour and confidence that measures will have an effect.



## Key Findings and Results

- Energy use by water utilities comprises a relatively small component of total water-related energy use which is likely to comprise 15-20% of SEQ energy use.
- Residential hot water conservation (showers, baths, taps) can have a significant impact on total energy use.
- Water-related energy use in the industrial and commercial sectors is particularly significant yet grossly understudied.
- Few residential water-energy studies have undertaken sensitivity or uncertainty (error) analysis critical to informing necessary monitoring.
- Lack of a consistent theoretical framework and research method to consider direct and indirect water-energy connections is a major existing limitation. Greater collaboration between the water and energy sectors would substantially help progress the understanding.

Urban Water Security Research Alliance Science Forum, September 2010



# Molecular Methods for Detecting Pathogens in Water

Matthews, B., Stratton, H., Schroeder, S., Collins, S. and Toze, S.

## Project Summary

We examined pathogen concentrations in samples taken before and after treatment in three wastewater treatment plants, using both conventional culture-based methods and quantitative polymerase chain reaction (qPCR). Issues such as inhibition of the PCR resulting in false negatives and underestimation of pathogen numbers were addressed by developing an internal standard (plasmid containing green fluorescent protein, pEGFP). This assessed technique efficiency and accuracy which allowed confident comparison of molecular and culture-based method. The outcome of the work justifies the future use of qPCR for routine monitoring of water quality.

## Results and Discussion

- The pEGFP plasmid internal standard was successfully used to assess the efficiency of the qPCR, providing confidence in results from samples containing high concentrations of PCR-inhibiting substances.
- qPCR pathogen detection methods generally detected higher levels of bacteria than culture-based methods for the primary effluent, ranging from 2-80 times higher levels than culture-based methods ( $p < 0.0001$ ).
- No significant difference between cell numbers determined by qPCR and culture-based methods in treated effluent, and very similar trends in log removal calculations were found.

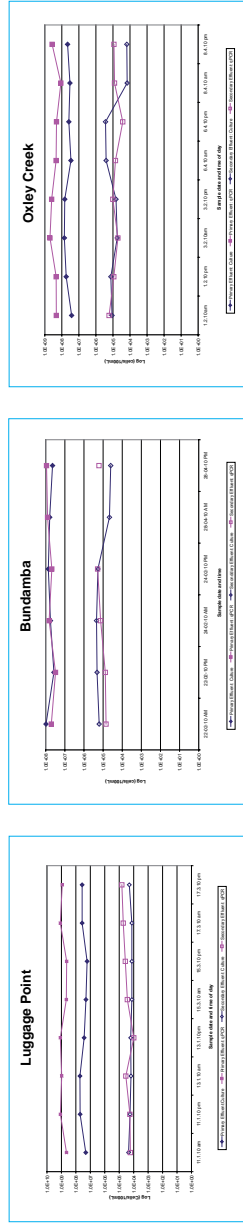


Figure 2: Comparison of qPCR and culture methods for quantification of *Escherichia coli*.

## Key Findings

- The application of qPCR for the quantification of *E. coli* in wastewater samples was **comparable** to culture-based methods, indicating that with some further work, full validation of these techniques is possible and could replace culture based methods in the future.
- With the addition of proper controls, qPCR provides a **rapid**, high through-put tool for **water managers** to effectively assess and manage microbial risk of pathogens, not just indicators.

## Future Directions

- Improve DNA extraction methods to reduce reaction inhibition.
- Refine internal standards and improve primer and probe design.
- Extend the list of pathogens that are validated against culture-based methods and develop multiplex assays to test multiple organisms in one reaction.

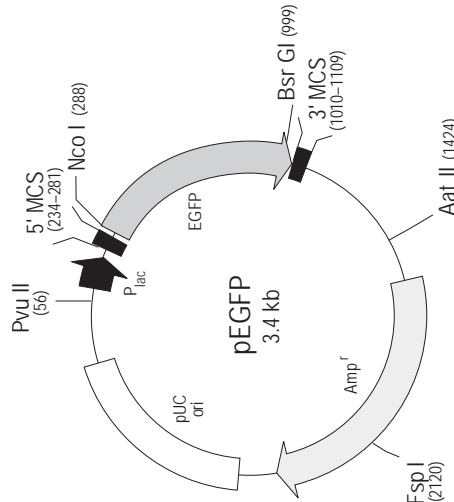


Figure 1: **Internal Standard.** Pathogen detection qPCR reactions (using a Taqman probe) were duplexed with a reaction targeting the EGFP gene. The plasmid pEGFP was added in known concentration to all reactions.

# Understanding the Aquifer: 3D Visualisation and Groundwater Time-Series Animation in the Lockyer Valley

Cox, M.E.<sup>1</sup>, Hawke, A.E.<sup>2</sup>, James, A.R.<sup>2</sup> and Wolf, L.<sup>3</sup>

<sup>1</sup>Institute for Sustainable Resources, QUT; Faculty Science and Technology, QUT; National Centre for Groundwater Research and Training. <sup>2</sup>Institute for Sustainable Resources, QUT; High Performance Computing, QUT. <sup>3</sup>CSIRO Land and Water, Indooroopilly.

## Project Summary

The Lockyer Valley, South East Queensland (SEQ), hosts intensive irrigated agriculture using groundwater from over 5,000 alluvial bores. The SEQ Water Grid Manager is considering the introduction of purified recycled water (PRW) from the Western Corridor Recycled Water Scheme to augment groundwater supplies. To assess potential impacts of this, a valley-wide MODFLOW simulation model is being developed plus a new unsaturated zone flow model. To further underpin these models and provide a realistic understanding of the aquifer framework a 3D visualisation model has been developed using Groundwater Visualisation System (GVS) software produced at QUT.

## Results and Discussion

The GVS model incorporates a topographic surface (DEM) with draped overlays: elevation, satellite and geology maps. The geology has been classified into (1) sedimentary bedrock, (2) basalts of the surrounding ranges, and (3) alluvium. The geology has been classified into a number of groups. Using borehole data, the alluvium has been divided into three groups based on grain size. This enables assessment of unsaturated zone deep drainage, transient flow in the middle zones, and assessment of flow/groundwater character in the lower, continually saturated zone.

The 3D visualisation integrates available bore data, including geologs described above, to produce a “solid” aquifer for which volumes can be calculated. The model supports animation, and incorporates time-series of water levels, and electrical conductivity (EC) as an indicator of groundwater trend. The model can also be zoomed, rotated and sliced to produce detailed 2D cross-sections.

## Conclusion

The GVS 3D visualisation clearly represents the configuration and relative volumes of this complex and irregular alluvial aquifer system. In addition, it reflects the general hydraulic variations within the aquifer material. Animation enables the spatio-temporal relations to be better understood. The scalability from valley-wide to individual bore detail is effective for management and scientific purposes.

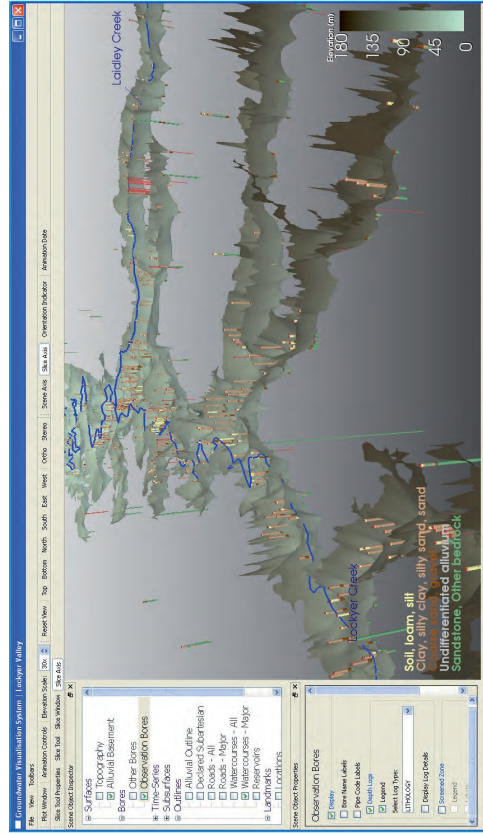


Figure 1. The GVS software user interface showing bores and hydraulic basement surface beneath the alluvium.

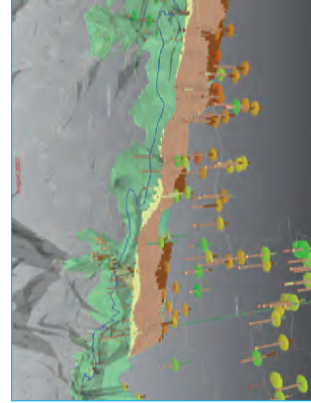


Figure 2. A slice through the alluvium showing internal geology and coloured markers indicating standing water levels.

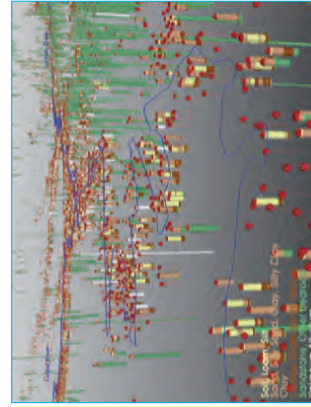


Figure 3. Boreholes showing geology intervals classified from raw geologs.



# Urban Rural Water Exchange: PRW in the Lockyer Valley

Wolf, L.<sup>1</sup>, Cresswell, R.<sup>1</sup>, Rassam, D.<sup>1</sup>, Ellis, T.<sup>1</sup>, Toze, S.<sup>1</sup>, Merrin, L.<sup>1</sup>, Morrow, D.<sup>1</sup>, Foley, J.<sup>2</sup>, Robinson, B.<sup>2</sup>, Silburn, M.<sup>2</sup>, Bleakley, A.<sup>2</sup>, Arunakumaran, J.<sup>3</sup>, Evans, P.<sup>3</sup>, Hawke, A.<sup>4</sup>, and Cox, M.<sup>4</sup>

<sup>1</sup>CSIRO Land and Water, <sup>2</sup>Department of Environment and Resource Management, <sup>3</sup>RPS Consultants, <sup>4</sup>Queensland University of Technology

## Project Summary

A significant amount (ca. 15-25 GL/a) of Purified Recycled Water (PRW) from urban areas is proposed to augment the depleted groundwater resources of the Lockyer Valley (approx. 80km west of Brisbane). The research project uses field investigations, lab trials and modelling techniques to address the key management challenges:

- how to determine benefits of **individual users** from the augmentation of a **natural common pool resource**;
- how to minimise impacts of **applying different quality water** on the **Lockyer soils, to creeks and on aquifer materials**;
- how to minimise **mobilisation of salts** in the unsaturated and saturated zones as a result of increased deep drainage;
- is there potential for **direct aquifer recharge using injection wells**?

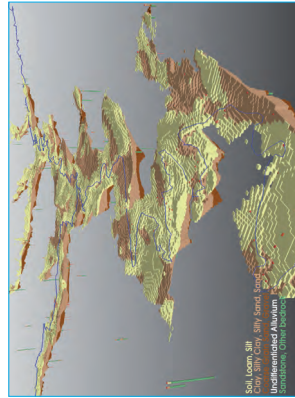


Figure 1: 3-D Hydrogeological Model constructed from well logs using High Performance Computing at QUT.

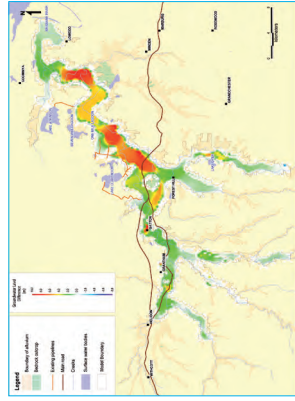
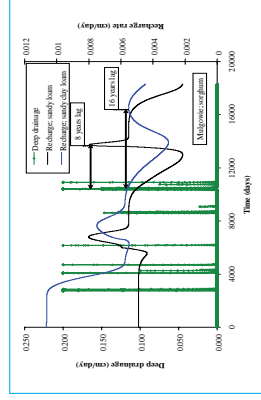


Figure 2: Spatial distribution of model sensitivity to a 20% increase in abstraction rates (eg. due to lack of metering).

## Key Findings



Figure 3: a) Geoprobe drilling b) soil dispersion tests c) unsaturated zone modelling.



- Updated 3D numerical groundwater model to 2010, but sensitivity studies indicate overriding influence of lacking information on groundwater pumping.
- Unsaturated zone models set up. Sensitivity study conducted using 1960-2010 climate data sets. Deep drainage under irrigated agriculture likely higher than previously assumed.
- Preferred scenario of common pool resource augmentation defined but found to require excellent baseline information and a major update of current models and metering programs.
- Geoprobe drillings performed for characterisation of future PRW test sites.
- PRW is characterised by low Sodium Absorption Ratios (SAR <2). Minor impacts of PRW to soil stability in lab tests.
- Direct aquifer recharge is promising.

## Future Direction

- Scientifically grounded, spatially distributed sustainable yields quantification for the Lockyer Valley with benchmarked model performance.
- Continuation of salt flux monitoring and modelling.
- Research impact of climate change on Lockyer Valley water resources and the PRW demand.



# Awards

## **Best Presentation**

Cara Beal – South East Queensland Residential Water End Use Study: Baseline Results

## **Best Abstract**

Rezaul Chowdhury – Catchment Hydrology Modelling for Stormwater Harvesting Study in SEQ: From Instrumentation to Simulation

## **Best Poster**

Maxime Rattier – Fundamental Investigation on Biological Activated Carbon?

Recipients were presented with a three pack of wine.

# Delegates

## Official Opening

Michael Choi, MP, Parliamentary Secretary to the Minister for Natural Resources, Mines and Energy, and Trade, QLD

## Keynote Speaker

Stuart White, Director, Institute for Sustainable Futures, University of Technology, Sydney, NSW

## Guest Speakers

Pat McCafferty, A/Chief Executive Officer, Yarra Valley Water, Mitcham, VIC

Adriano Joss, EAWAG, the Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland

## UWSRA Management Board

Chris Davis, University of Technology Sydney, NSW - *Chairman*

Scott Keyworth, CSIRO, ACT

John Mott, University of Queensland, QLD

John Mullins, Department of Environment and Resource Management, QLD (*rep for Christine Williams*)

## UWSRA Research Advisory Committee

Mark Pascoe, International Water Centre, QLD

## Cocktail and Networking Session Sponsor - Aurecon

Mark Roberts, Sustainability Leader – Water, VIC

Erik van der Berg, Competency Leader - Water Resources, QLD

Sanja Oldridge, Senior Water Engineer, QLD

Bruce Penman, Environmental and Sustainability Development Leader, QLD

Allan Charteris, Senior Civil Engineer / Water and Environment Leader Sunshine Coast, QLD

Kerry Tscherepko

## Stakeholders

Alan Hoban, Healthy Waterways Partnership Limited, QLD

Alex Coe, Marchmont Hill Consulting, QLD

Alex Fisher, Seqwater, QLD

Andrew Cook, Office of the Water Regulator (DERM), QLD

Andrew Palmer, CSIRO - Land and Water, QLD

Anjila Finan, MWH Australia, SA

Anne Simi, Brisbane City Council, QLD

Barry Holcroft, Unitywater, QLD

Barry Spencer, WaterSecure, QLD

Brad Dowling, Allconnex Water, QLD

Carrie Hillier, Local Government Infrastructure Services, QLD

Christobel Ferguson, ALS Environmental (Water Resources Group), QLD

Craig Walton, Department of Environment and Resource Management, QLD

Daniel Field, Queensland Health, QLD

Daniel Westall, Local Government Infrastructure Services, QLD

Dave McRae, Queensland Climate Change Centre of Excellence (DERM), QLD

David Cameron, Queensland Water Directorate, QLD

David Haug, Queensland Urban Utilities, QLD

Diana Dawson, Brisbane City Council, QLD

Emma Brewis, Queensland Water Commission, QLD

Evelyn Rodrigues, Water Services Association Australia, NSW

Gary Luck, Department of Environment and Resource Management, QLD

Grant Horton, SEQ Water Grid Manager, QLD

Ian Ramsay, Department of Environment and Resource Management, QLD

Janet Cumming, Queensland Health, QLD

Janet Robinson, Office of the Water Regulator (DERM), QLD

Johan Biermann, Department of Infrastructure and Planning, QLD  
John Ruffini, Department of Environment and Resource Management, QLD  
Julia Playford, Department of Environment and Resource Management, QLD  
Karen Pither, Office of the Water Regulator (DERM), QLD  
Kate Moore, International Water Centre, QLD  
Kelly O'Halloran, Allconnex Water, QLD  
Kylie Catterall, Allconnex Water, QLD  
Lily Chen, Griffith University, QLD  
Margaret Harlow, Smart Water Research Centre, QLD  
Mark Breen, Sunshine Coast Regional Council, QLD  
Mark Sherson, Queensland Urban Utilities, QLD  
Mary Boydell, Queensland Water Commission Board, QLD  
Michael Bartkow, Seqwater, QLD  
Michael Heery, ALS Environmental, QLD  
Michael Skroblin, GHD, QLD  
Michael Tonks, Department of Environment and Resource Management, QLD  
Michelle Walker, Lloyd Consulting, QLD  
Mick Capelin, Department of Infrastructure and Planning (DIP), QLD  
Mike Taylor, Seqwater, QLD  
Mohammad Katouli, University of the Sunshine Coast, QLD  
Nigel Garson, Office of the Water Regulator (DERM), QLD  
Nigel Hardie, Tyco Flow Control, QLD  
Nimish Chand, Urban Utilities, QLD  
Oz Sahin, Griffith University, QLD  
Padma Cuppala, Office of the Water Regulator (DERM), QLD  
Padmini De Alwis, Allconnex Water - Logan District, QLD  
Pam Kerry, South East Water, Melbourne, VIC  
Patricia Hurikino, Queensland Water Commission, QLD  
Paul Burrell, SEQ Water Grid Manager, QLD  
Paul Priebbenow, GHD, QLD  
Pushpa Onta, Department of Environment and Resource Management, QLD  
Richard Litsheng Kok, International Water Centre, QLD  
Rob Fearon, Queensland Water Directorate, QLD  
Rod Lehmann, Water Strategies Pty Ltd, QLD  
Ross Ahrens, Allconnex Water, QLD  
Ross Walduck, Department of Environment and Resource Management, QLD  
Ruth Cottingham, University of Queensland, QLD  
Ryan Barton, Department of Environment and Resource Management, QLD  
Sarah Jones, Healthy Waterways Partnership Limited, QLD  
Sayed Kahn, Allconnex Water, QLD  
Sean Hinton, Allconnex Water, QLD  
Simon Cowland-Cooper, Broadwater Consultants, Irrigation and Water Solutions, QLD  
Simon Lees, Smart Water Fund, VIC  
Tamara Stevenson, Allconnex Water, QLD  
Thomas Moore, MWH Australia, SA  
Tim Ellis, CSIRO, QLD  
Trevor Lloyd, Lloyd Consulting, QLD  
Tsu-Te (Andrew) Huang, Griffith University, QLD  
Vicki Ross, Griffith University, QLD  
Vourn Lutton, Queensland Water Commission, QLD  
Wai-Tong Wong, Queensland Water Commission, QLD  
Warish Ahmed, CSIRO, QLD  
Yvan Poussade, Veolia Water Australia, QLD

## **Project Teams**

Adam Brook, Griffith University, QLD  
Aditi Mankad, CSIRO, QLD  
Anneliese Spinks, CSIRO, QLD  
Arseto Bagastyo, University of Queensland, QLD  
Ashok Sharma, CSIRO, VIC  
Beate Escher, University of Queensland, QLD  
Cara Beal, Griffith University, QLD  
Catherine Leigh, Griffith University, QLD

David de Haas, GHD / University of Queensland, QLD  
David Kent, CSIRO, VIC  
Declan Page, CSIRO, SA  
Fernanda Helfer, Griffith University, QLD  
Fiona Henderson, CSIRO, QLD  
François-Xavier Argaud, University of Queensland, QLD  
Grace Tjandraatmadja, CSIRO, VIC  
Hanne Thoen, University of Queensland, QLD  
Helen Stratton, Griffith University, QLD  
Huijun Zhao, Griffith University, QLD  
Jatinder Sidhu, CSIRO, QLD  
Jelena Radjenovic, University of Queensland, QLD  
Joe Lane, University of Queensland, QLD  
Julien Reungoat, University of Queensland, QLD  
Kalinda Watson, Griffith University, QLD  
Katrin Doederer, University of Queensland, QLD  
Kelly Fielding, University of Queensland/CSIRO, QLD  
Korneel Rabaey, University of Queensland, QLD  
Kristell Le Corre, University of Queensland, QLD  
Leif Wolf, CSIRO, QLD  
Leonie Hodggers, CSIRO, QLD  
Luis Laredo, CSIRO, QLD  
Luis Neumann, CSIRO, QLD  
Maria José Farré Olalla, University of Queensland, QLD  
Maxime Rattier, University of Queensland, QLD  
Melissa Green, CSIRO, QLD  
Meng Chong, CSIRO, QLD  
Miroslava Macova, University of Queensland, QLD  
Nicholas Stuckey, University of Southern Queensland, QLD  
Nicole Knight, Griffith University, QLD  
Pam Pittaway, University of Southern Queensland, QLD  
Peter Schouten, Griffith University, QLD  
Peter van Rensch, CSIRO, VIC  
Rodney Stewart, Griffith University, QLD  
Roger O'Halloran, CSIRO, VIC  
Ryan McGloin, University of Queensland, QLD  
Simon Toze, CSIRO, QLD  
Stephen Cook, CSIRO, VIC  
Ted Gardner, Department of Environment and Resource Management/CSIRO, QLD  
Tim Cowan, CSIRO, VIC  
Vlad Matveev, CSIRO, QLD  
Wenju Cai, CSIRO, VIC  
Wolfgang Gernjak, University of Queensland, QLD

## **UWSRA Executive**

Don Begbie, Director, QLD  
Sharon Biermann, Program Manager, QLD  
Sharon Wakem, Executive Officer, QLD



# Urban Water Security Research Alliance

