

Urban Water Security Research Alliance

Science Forum and Stakeholder Engagement

Building Linkages, Collaboration and Science Quality

17-18 August 2009

Brisbane, Queensland

Program and Abstracts



National Research
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Water for a Healthy Country



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

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

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Welcome from the Chair

Water is fundamental to our quality of life, to economic growth and the environment. With its booming economy and growing population, Australia's South-East Queensland (SEQ) region faces increasing pressure on its present water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

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 SEQ's emerging urban water issues, with a focus on water security and recycling and will seek to align research, where appropriate, with other water research programs such as those of local SEQ water agencies, eWater CRC, Water Quality Research Australia Limited (WQRA) and the Water Services Association of Australia (WSAA). The Alliance is the largest regionally focused urban water research program in Australia. The program will bring new research capacity to SEQ, tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

Answering the big questions

Research for the Alliance is delivered under three research themes:

Closing the Loop in our Water Supply System
Informed Decision Making
Managing our Future Water Supply

These will examine fundamental issues associated with delivering the region's water needs, including:

- ensuring the reliability and safety of recycled water systems
- advising on infrastructure and technology for the recycling of wastewater and stormwater
- building scientific knowledge behind the management of health and safety risks in the water supply system.

In addition to increasing community confidence in future water supply, the potential benefits from the program include:

- the economic, with new employment opportunities and the freeing up of economic growth from the increasing uncertainty of rainfall and climate change
- the environmental, closing the water cycle loop and reducing dependence on the environment to supply water and assimilate waste
- contributing to the adoption of new practices in urban wastewater and stormwater recycling to increase our national water security.

The Alliance is operating in a dynamic environment and needs the capability and capacity to deal with emerging issues and priorities. As well as the existing projects under way, new project topics and issues for consideration for contestable funds will also be identified and considered by the Alliance Management Board, the Research Advisory Committee or by Alliance stakeholders. Funding additional projects will be done by considering the direction, achievements and gaps in current research and alignment with the focus and goals of the Alliance.

It is with great pleasure that I welcome you to the Alliance's inaugural Science Forum being held on Monday, 17 and Tuesday, 18 August 2009, in Brisbane.

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 from key projects. The intended audience includes project scientists undertaking urban water research in South East Queensland and invited external reference panel experts. Key external stakeholders are invited to the open forum session.



Chris Davis
Chair, Urban Water Security Research Alliance

The Alliance Research Program and Project Leaders

Purified Recycled Water	<i>Project Leader:</i> Dr Simon Toze, CSIRO	07-3214 2698 Simon.Toze@csiro.au
This project will focus on the relative contribution of hospital waste to sewage treatment plants, pathogen and contaminant attenuation within wastewater treatment plants and reservoirs and development of advanced monitoring tools.		
Stormwater Harvesting and Reuse	<i>Project Leader:</i> Mr Ted Gardner, DERM/CSIRO	07-3896 9488 Ted.Gardner@derm.qld.gov.au
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.		
Decentralised Systems	<i>Project Leader:</i> Dr Ashok Sharma, CSIRO	03-9252 6151 Ashok.Sharma@csiro.au
This project will focus on validating 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.		
Systematic Social Analysis	<i>Project Leader:</i> Mr Jeff Camkin, CSIRO	08-9333 6398 Jeff.Camkin@csiro.au
This project has conducted extensive community surveys around community attitudes to purified recycled water. The project is now moving to research household water use with demand management interventions.		
Institutional Change for Water Management in SEQ	<i>Project Leader:</i> Professor Brian Head, UQ	07-3346 7450 Brian.Head@uq.edu.au
This project investigates and maps how the policy, planning and delivery systems for water in SEQ have changed since 2000.		
Climate and Water	<i>Project Leader:</i> Dr Wenju Cai, CSIRO	03-9239 4419 Wenju.Cai@csiro.au
This project has completed 40-year simulations of historical climate and analysed the extent to which observed climate changes in SEQ can be attributable to anthropogenic forcings. The impact of climate change on inflows to dams is also being investigated.		
Life Cycle Analysis and Integrated Modelling	<i>Project Leader:</i> Dr Shiroma Maheepala, CSIRO	03-9252 6072 Shiroma.Maheepala@csiro.au
This project has initially focussed on energy and greenhouse gas analysis through the existing and proposed water system as well as preliminary life cycle analysis of the SEQ Water Strategy. A prototype integrated urban water modelling tool is being developed to predict water quantity and quality implications of water supply and management options in SEQ.		
Water Quality Information Management	<i>Project Leader:</i> Professor Huijun Zhao, GU	07-5552 8261 h.zhao@griffith.edu.au
This project has focussed on on-line real-time monitoring of water quality in sewage systems. A proof-of-concept system has been installed to monitor inflows to the Bundamba wastewater treatment plant to identify sudden changes in the matrix.		
Water Loss	<i>Project Leader:</i> Dr Stewart Burn, CSIRO	03-9252 6032 Stewart.Burn@csiro.au
This project is analysing evaporative losses throughout SEQ as well as system reticulation losses. The potential use of monolayers, hard covers, destratification and other techniques to reduce evaporation from large dams have been considered. The project is now moving to more detailed field analysis of selected technologies for reducing evaporative loss from large dams.		
Enhanced Treatment	<i>Project Leader:</i> Dr Julien Reungoat, UQ	07-3365 9070 j.reungoat@awmc.uq.edu.au
This project is working closely with the South Caboolture recycled water plant to monitor and evaluate the effectiveness of non-microfiltration and reverse osmosis technology options to achieve potable water quality.		
N-nitrosodimethylamine (NDMA) Formation Potential	<i>Project Leader:</i> Dr Maria Farré, UQ	07-3346 6251 m.farre@awmc.uq.edu.au
This two-year project will research pathways for possible NDMA formation and identify possible problem source streams or operating conditions leading to NDMA formation in purified recycled water.		
Disinfection By-Product (DBP) Formation in Drinking Water	<i>Project Leader:</i> A/Professor Glen Shaw, GU	07- 55528352 g.shaw@griffith.edu.au
Chlorination and chloramination of drinking water has the potential to produce elevated levels of a range of disinfection by-products (DBPs). This project will monitor and assess formation of disinfection by-products at water treatment plants in SEQ.		
SEQ Residential Water End Use Study	<i>Project Leader:</i> Dr Rodney Stewart, GU	07-5552 8778 r.stewart@griffith.edu.au
This project will install "Smart Meters" in 400 homes in SEQ to collect detailed water end use data for quantifying the impact of urban water demand management strategies researched through the Systematic Social Analysis project.		
PRW in the Lockyer Valley	<i>Project Leader:</i> Dr Richard Cresswell, CSIRO	07- 3214 2767 Richard.Cresswell@csiro.au
This project will research the implications of using PRW as an adjunct to groundwater resources for irrigation in the Lockyer Valley and Warrill Creek. It will review existing models and data and evaluate a series of "what if?" scenarios.		

Alliance Research Projects 2009-2010

Leading water research and knowledge in South East Queensland

Urban Water Security Research Alliance

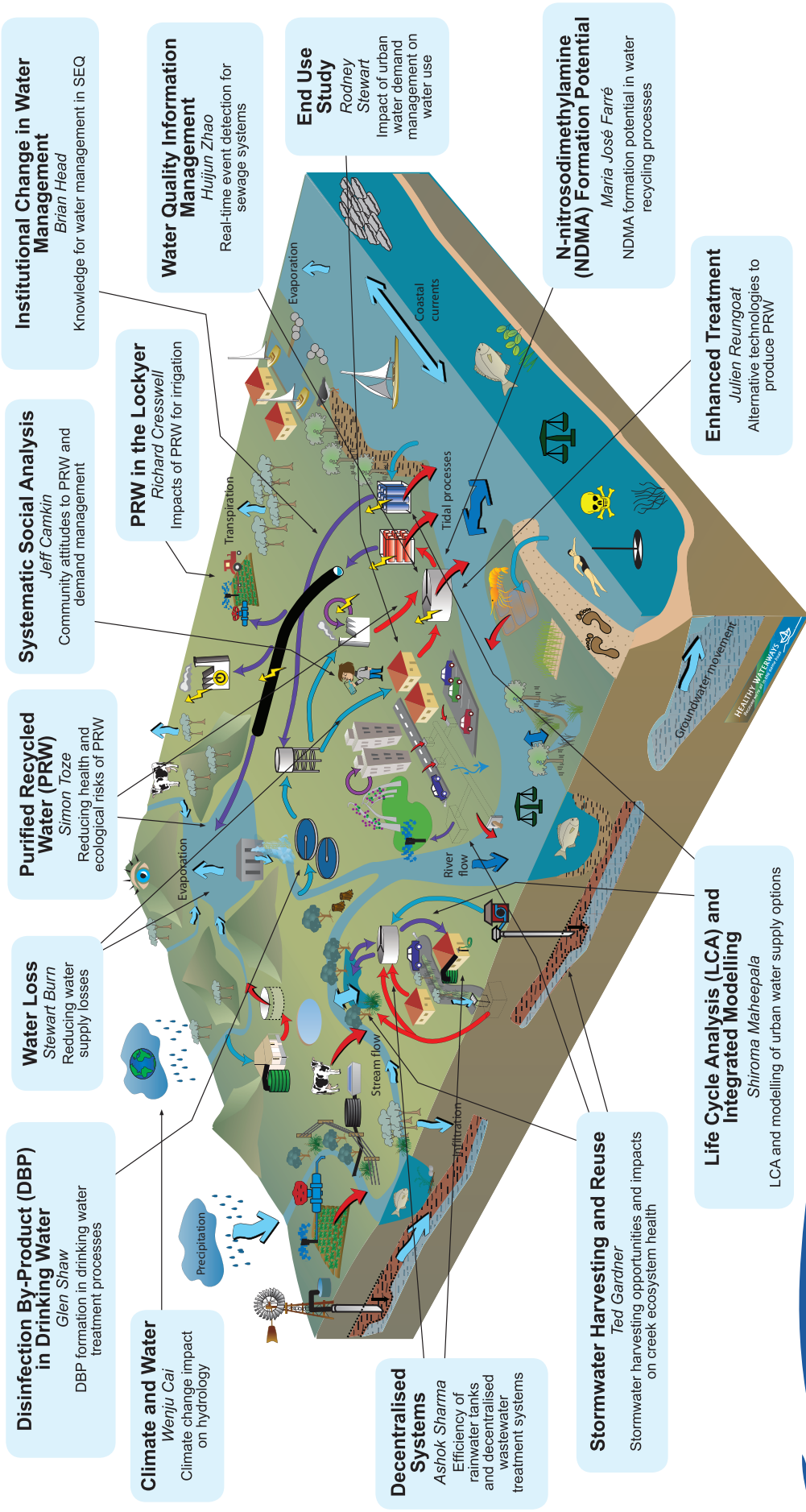


Image © South East Queensland Healthy Waterways Partnership

Purified Recycled Water (PRW)

Project Summary

The PRW project was established to fill knowledge gaps on the safety and sustainability of producing purified recycled water. Research effort has primarily focused on:

- The influence of hospitals on trace organics in the sewage system.
- The efficiency of wastewater treatment plants to remove biological and chemical contaminants.
- The fate and behaviour of pathogens and trace organics in South East Queensland (SEQ) reservoirs.
- The development of improved methods for detecting and studying pathogens and chemicals in wastewater and fresh water.



Project Progress

- Hospitals may have minimal impact on pharmaceuticals in sewage.
- Pathogens do decay in reservoir water but decay rates are type dependant.
- Large percentage of viruses can be captured on charged surfaces.
- Wastewater treatment plants can remove 2–3 log of enteric bacteria and bacteriophage.
- Wastewater treatment plants can remove >80% of most trace organics (apart from Carbamazepine which is not removed).
- Wastewater treatment and advanced water treatment can significantly reduce the cell toxicity of the treated water.

Project Team

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Team Leaders and Senior Team Members:

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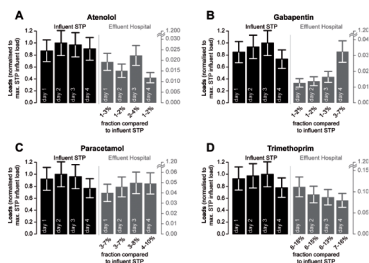
Dr Helen Stratton (GU)

Prof Jochen Mueller (UQ)

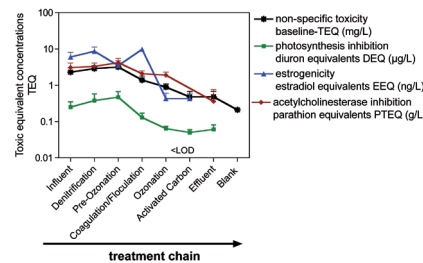
Dr Jatinder Sidhu (CSIRO)

Prof Beate Escher (UQ)

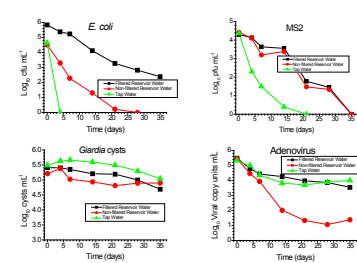
Dr Michele Burford (GU)



Pharmaceuticals discharged from a regional hospital



Changes in toxic equivalent concentrations for micropollutants across an advanced wastewater treatment system



Decay rate of pathogens in Lake Wivenhoe water

Future Direction

- Combining pathogen decay and trace organic degradation rate data with Seqwater hydrologic modelling to determine residual risks.
- Assessing actual reduction in cell toxicity across the entire seven treatment barriers.
- Assessment of the pharmaceutical load released from major Queensland tertiary hospitals into the sewage system.
- Further development of pathogen and chemical detection methodologies suitable for use in Queensland waters.

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Stormwater Harvesting and Reuse

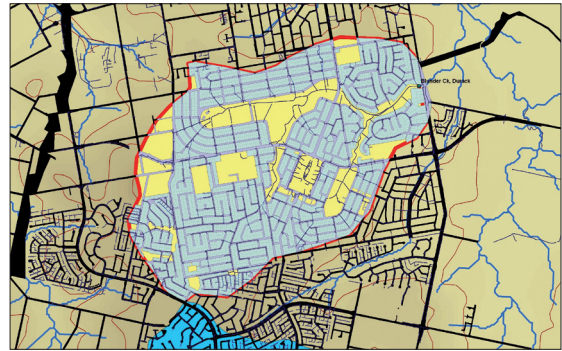
Project Summary

Stormwater is the **last major untapped source** of alternative water supply for urban areas. Two key challenges that this project will focus on are (i) the efficient and sustainable capture, treatment, storage and distribution of stormwater, and (ii) using stormwater to reduce demand on traditional potable water supplies.

Project Progress

Philp, M. *et al.*, 2008. *Review of stormwater harvesting practices*, Urban Water Security Research Alliance Technical Report No. 9 (in publication).

Helm, L. *et al.* 2009. *Facilitating Recycling of Stormwater and Reclaimed Water via Aquifers in Australia*. Milestone Report 3.3.2 – South East Queensland Opportunity. Assessment. CSIRO: Water for a Healthy Country National Research Flagship



GIS map of SEQ urban catchment

Project Team



Project Leader:

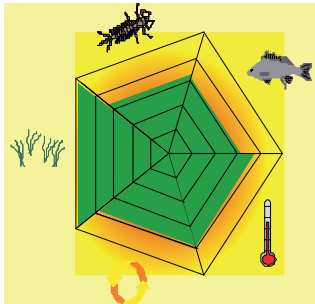
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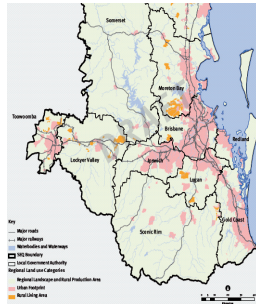
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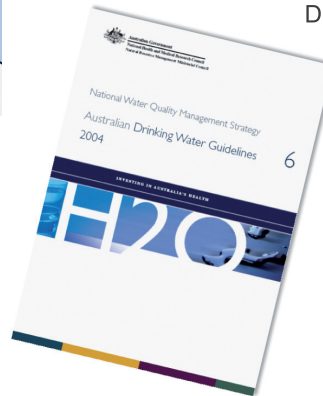
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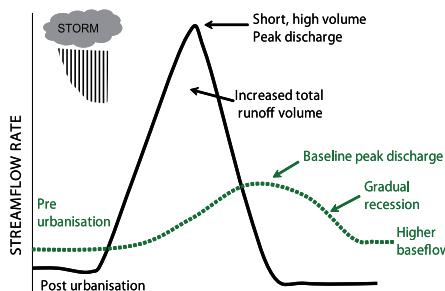
EHMP reporting format



SEQ urban footprint, Draft SEQ Regional Plan 2008



ISCO automatic water sampler



Effects of urbanisation on the stormwater hydrograph

Future Direction

- GIS analysis, informed by biophysical argument and exemplar typologies, to identify stormwater harvesting opportunities in South East Queensland.
- Measuring the ecosystem health of urban creeks to define stormwater harvesting practices which will maintain, or even improve, their health and geomorphic form.
- Implementing event based water quality measurement in selected urban catchments to characterise contaminants (human pathogens, heavy metals, trace organic chemicals) which impact on higher end uses of stormwater.

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Decentralised Systems

Project Summary

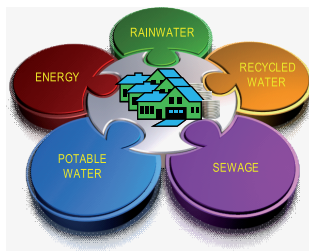
The research is focused at quantifying whether the 70kL/house/year potable water savings target, defined by *Queensland Development Code MP 4.2*, can be achieved using rainwater tanks. The project also aims to understand the reproducibility of decentralised systems in greenfield sites, as well as reduce the knowledge gaps impeding their adoption. The project will focus on system validation, monitoring and modelling.

Project Progress

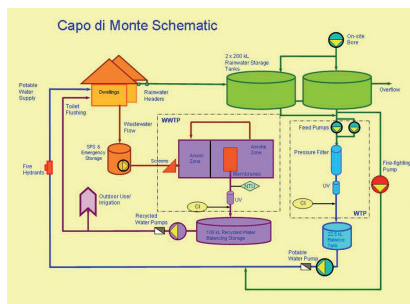
To provide context for the project development, the team has defined decentralised systems and identified drivers for their use in South East Queensland.

Instrumentation is in progress for monitoring at greenfield and commercial developments at:

- Capo di Monte
- Currumbin Ecovillage
- Green Square North Tower



Water meter and rain gauge on communal tank, Capo di Monte



Capo di Monte hydraulic schematic (Bligh Tanner Pty Ltd)



The Ecovillage at Currumbin

Project Team



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Future Direction

- To understand overall annual water savings through mandated rainwater tanks, we will undertake a large (n>20,000) statistical analysis of paired homes (with and without tanks). We will also instrument 20 homes with mandated tanks to provide insight into water use patterns.
- We will monitor two communal rainwater tank systems for capture efficiency, energy and water quality. A water balance analysis will identify any gains compared with individual tanks.
- The Green Square North Tower rainwater tank use patterns will be monitored to understand the potential for rainwater use and potable water savings in high-rise commercial developments.
- We will investigate treatment efficiency, energy use, greenhouse gas footprint, and financial aspects of commonly adopted treatment technologies. This data will help guide the design of decentralised wastewater treatment systems to greenfield urban sites.

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Systematic Social Analysis

Project Summary

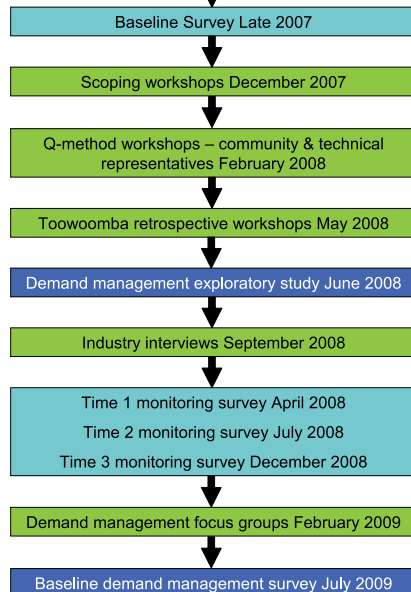
The systematic social analysis project aims to inform bio-physical science and policy and management decisions by providing a gauge of community perceptions of water management options and developing strategies that help to promote sustainable solutions to urban water needs. A range of inclusive community processes have been used to collect both qualitative and quantitative data.

Project Progress

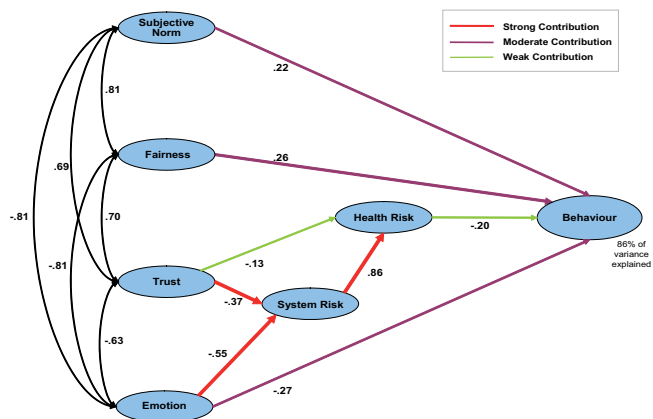
The project to date has investigated the following areas:

- Perceptions of PRW for indirect potable use and the drivers of support for the scheme.
- How scientific assessments of risk align with community judgements of acceptable risk.
- The drivers of community water usage behaviours in urban areas and the effectiveness of strategies designed to encourage sustainable water use behaviour.

Overview of research conducted to date



What determines people's intended behaviour toward PRW?



The model was developed as part of the PRW baseline survey and captures the key variables that significantly predicted people's intention to support or reject the PRW scheme.

Project Team



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Mr David Tucker (CSIRO)

Dr Sally Russell (GU)

Ms Pat Hallett (CSIRO)

Future Direction

The systematic social analysis project aims to answer the following questions:

- What are the key psycho-social and social-demographic drivers of residential water conservation behaviours?
- What interventions produce long-term positive changes in household water conservation behaviours?
- How do attitudes and acceptance of the range of decentralised systems compare? What factors impact on support for these systems?
- What are the most effective methods to communicate scientific information about water management strategies?

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Institutional Change

Project Summary

This project examines how the emerging water crisis in South East Queensland (SEQ) raised questions about the capacity of traditional institutions for water management and policy to meet future water needs. The social and institutional context is integral for key innovations in water policy, planning and technical innovation.

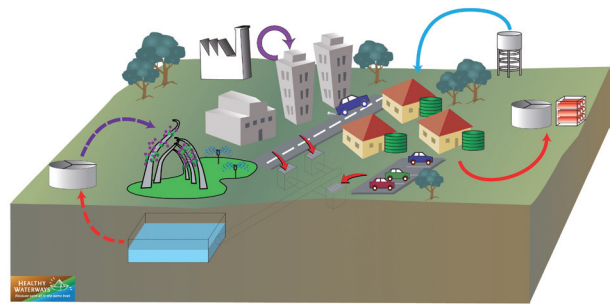


Image: © South East Queensland Healthy Waterways Partnership

Project Progress

- The research team has analysed the recent history of SEQ water management and policy in three periods: the 1970s-80s when water engineers were in control; the 1990s and the Water Act 2000, responding to NRM concerns about over-allocation and water quality; and the recent years marked by new approaches required by uncertainty and climate variability.
- Analysis of strategy documents is being supplemented by confidential interviews with key players, to provide insights into the reasons for these major shifts over time.
- The project attempts to show the close relationship between how problems are framed by participants, the range of expertise used for solving problems, and the regulatory systems used in various periods of time.



Image: © South East Queensland Healthy Waterways Partnership

Project Team



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Dr Cathy Robinson (CSIRO)

Future Direction

- The research team will analyse the increased complexity in types of relevant knowledge and new forms of expertise for integrated water management in SEQ – eg, environmental and biological sciences, environmental flow analysis, energy and productivity expertise, demographics, water use in the home, public attitudes, and demand management.
- We will analyse how innovation capacities have developed in response to emerging issues, including climate modelling, contingency planning, and technical innovations for water purification. These shifts demonstrate the importance of operational flexibility in developing capacities for technical and organisational learning.
- We will also investigate what kinds of alliances and collaborations might provide vehicles for better integration of the forms of expertise required for integrated water cycle goals.

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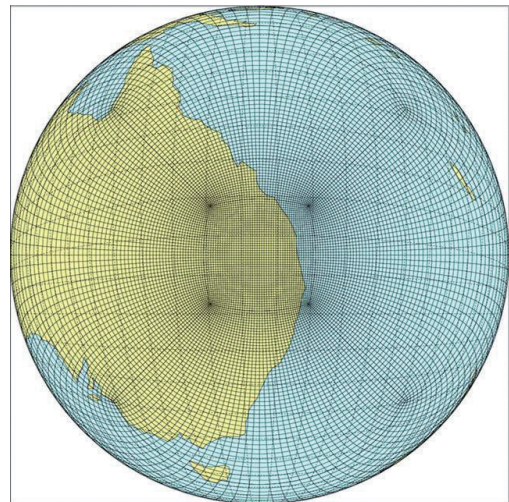
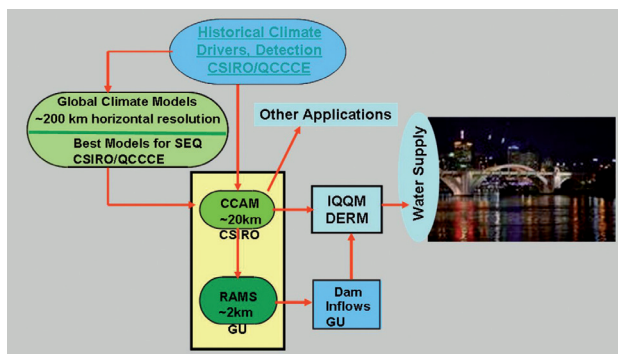
Climate and Water

Project Summary

Currently, there are uncertainties in climate projections because: climate models produce different results; there are a range of emission scenarios; and there is uncertainty about the relative importance of normal climate variability and climate change as drivers in the decline of South East Queensland (SEQ) rainfall. Global climate models do not provide enough regional detail to be effective in local water strategy development. This project assesses drivers of the recent rainfall decline and provides regional-scaled future climate data needed for water availability assessment.

Project Progress

- Output from the CSIRO Mk3 climate model was used to downscale three future climate scenarios, each covering 110-year simulations. These results are being coupled with hydrological models to determine the main drivers for climate change in SEQ and inform the SEQ Regional Plan Climate Change Strategy.
- The project also examines the relative importance of increasing carbon dioxide, ozone depletion and increasing aerosols, in driving the observed climate change in SEQ. The results show that the observed rainfall reduction in SEQ may be driven to a large extent by multidecadal variability.
- The project team is investigating how to best apply the outputs to a calibrated raster-based hydrologic model for Wivenhoe and Somerset storage reservoirs, as well as to the Brisbane Integrated Quantity and Quality Model (IQQM).



Project Team



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Future Direction

- The downscale modeling will continue using other global models as a host to reduce uncertainty associated with models.
- The project will continue to assess the relative impact of various climate change factors on long-term rainfall changes.
- Researchers are examining how the data produced by these high resolution downscaled models differs from the large-scale climate models, and the sensitivity of the hydrological models to outputs from the high-resolution downscaled experiments.
- They hope this will ensure more accurate use of large-scale (global) and downscaled data to help predict future rainfall, droughts and water availability in SEQ.

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Life Cycle Analysis and Integrated Modelling

Project Summary

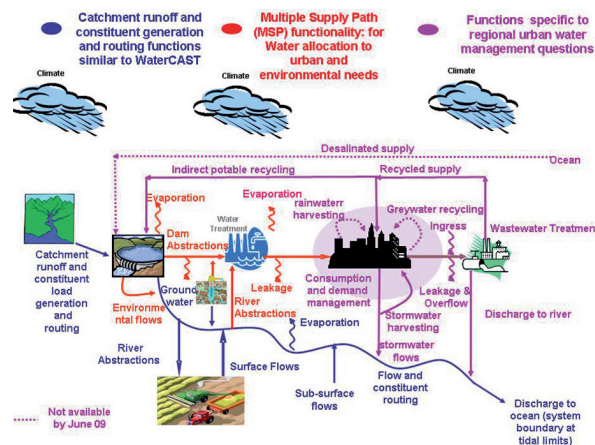
This project is building a method and tool to enable the adoption of Integrated Urban Water Management (IUWM) to urban water systems planning in South East Queensland (SEQ). The modelling processes will enable planners and researchers to quantify water flow and quality implications, energy consumption and green house gas emissions of different IUWM options.

Project Progress

The capabilities and limitations of existing urban water system modelling processes have been examined to enable the adoption of the IUWM approach. Energy and greenhouse gas (GHG) emissions for the SEQ Water Strategy have been quantified and areas for mitigation and further research defined.

The team has also developed a proof-of-concept regional urban modelling tool for the Logan/Albert catchment in collaboration with the eWater CRC.

Key functionalities of the IUWM tool:



Project Team



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Team Leaders:

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Dr Paul Lant (UQ)

Dr Peter Daniels (GU)

Future Direction

- Conduct a system-wide water quantity and quality analysis and complete an energy and emission analysis. Project outcomes will be benchmarked and linked to project outcomes with the SEQ Water Hub.
- Develop fully functioning prototypes of the modelling tools for the test case study including energy and GHG capabilities.
- Complete a Life Cycle Assessment of options for the case study including application of detailed data from other SEQ catchments and explore costing of externalities.
- Monitor reservoir methane emissions for Little Nerang Reservoir and propose mitigation strategy.
- Interim report on enhancing the interchange between SEQ Water Hub Water Accounts and an assessment how data can be used in evaluating and improving IUWM modelling.

Urban Water Security Research Alliance

Science Forum, August 2009



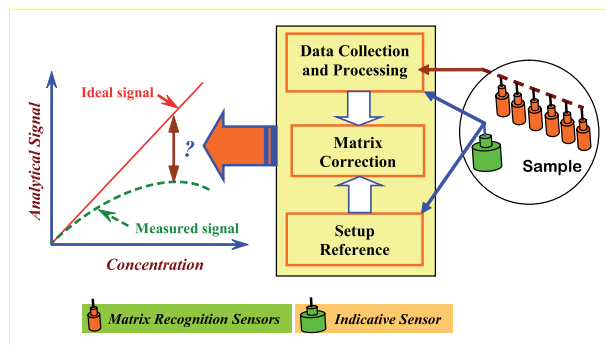
Water Quality Information Management

Project Summary

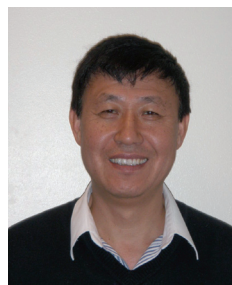
We are developing an event detection system for sewers and wastewater treatment plants to allow real-time protection of the PRW system and control waste discharges in the sewer catchments. Robust online sensors continuously monitor the wastewater matrix. Events are recognised by departure from the baseline and inter-correlation of sensor signals.

Project Progress

Four effluent monitoring units have been installed at Bundamba STP: raw sewage inlet (Barrier 1) and treated effluent (Barrier 2). A number of events have been detected, and development of mathematical methods to automatically detect events has been commenced. Design of the flow manifold is being optimised to minimise fouling and sensor performance. Event simulation trials are currently in progress to confirm the detection capability. The electronics control module needs redevelopment to enable reliable performance and to incorporate the fault and event detection software.



Project Team



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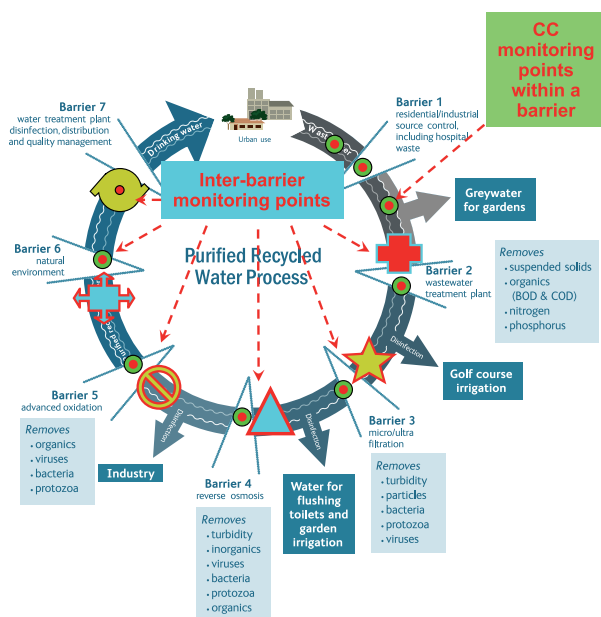
Ms Trang Nguyen (GU)

Ms Melissa Winnel (CSIRO)

Mr Wayne Ganther (CSIRO)

Ms Melissa Toifl (CSIRO)

Mr Nigel Goodman (CSIRO)



Future Direction

- Completion of event simulation trials using real effluent plus added contaminants.
- Redesign of flow manifold to minimise fouling.
- Testing of event detection software.
- Selection of improved sensors for pH, DO and turbidity.
- Incorporation of fault recognition and automatic sensor calibration routines.
- Development of sensors to measure organics.
- Deployment of monitoring units at other barriers.

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Water Loss

Project Summary

This project will develop a full understanding of the potential costs, feasibility, side effects and benefits of reducing evaporation from South East Queensland (SEQ) water storages.

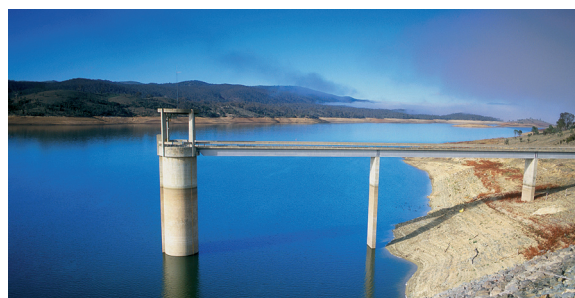
It will also develop advanced leakage detection methodologies to enable the reduction of leakage from reticulation systems, thus allowing savings in water losses from SEQ water supply.

Project Progress

In the area of evaporation control from dams, all the techniques have been assessed for their suitability to apply across dams in Queensland.

A range of preferred techniques such as monolayers and suspended and floating covers have emerged as the most preferable options for further assessment. To assess performance properly, instrumentation has been deployed at a dam near Forest Hill, Queensland. This enables us to develop a technique for accurate measurement of evaporation over a water body.

To reduce leakages from reticulation systems we have developed a methodology based on Support Vector Machines. A training database has been generated of pressure measurements, leak sizes and locations and network attributes from real leak detection tests. Pattern recognition algorithms have been benchmarked against results from new leak detection tests outside the training data set.



Project Team



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A/Prof Charles Lemckert (GU)

Dr Hong Zhang (GU)

Ms Fernanda Helfer (GU)

Mr Erik Schmidt (USQ)

Dr Nigel Hancock (USQ)

Dr Pam Pittaway (USQ)

Future Direction

Storage systems:

- We will undertake detailed field studies to develop methods to enable accurate measurement of evaporation and then assess the impact of a number of evaporation control techniques on evaporation and water quality.
- We will undertake engineering analysis of suspended and floating covers to determine the required performance requirements of each technique. We will also undertake laboratory and wind tunnel trials.

Reticulation systems:

- We will further develop pattern recognition techniques and tools to automatically detect and interpret changes in pressure and flow as the onset of pipe network deterioration and leakage.

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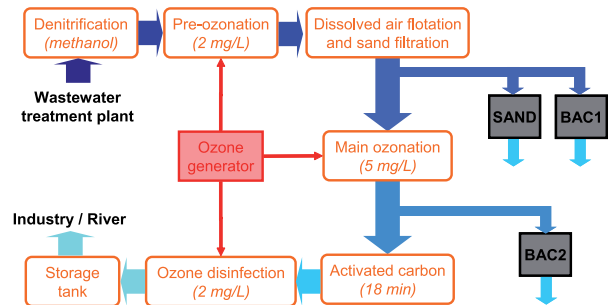
Enhanced Treatment

Project Summary

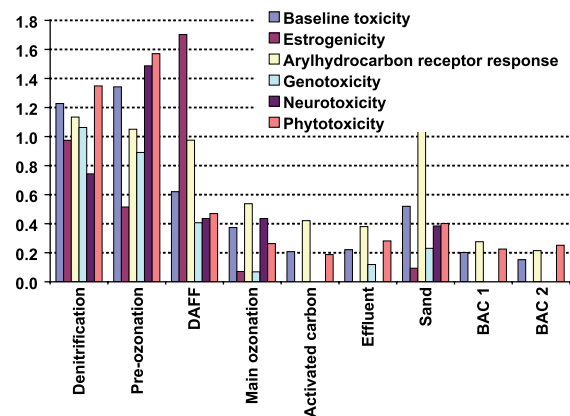
The production of **purified recycled water (PRW)** using **reverse osmosis (RO)** produces a **15% concentrate waste stream** which has to be disposed of. This concentrate is **highly saline** and thus **can not be discharged in fresh waterways**. It makes this technology **unsuitable for cities situated far from the sea or brackish waters**. The aim of this project is to look at **alternatives to RO**.

Project Progress

- **Removal of micropollutants** (pharmaceuticals and pesticides) have been monitored through the **South Caboolture Water Reclamation plant** and **pilot scale biofilters** (sand and BAC).
- Water quality has been assessed also using a **battery of bioassays**.

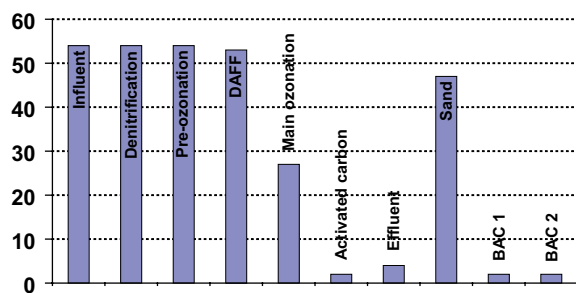


Relative biological activity in bioassays compared to the influent



- **Only 4 micropollutants out of the 54** present in the influent were detected in the effluent.
- Micropollutants were **removed by more than 95%** along the process.
- **BAC filtration showed similar performances**.
- Bioassays showed a simultaneous **decrease of biological activity**.

Number of compounds detected after the treatment step



Project Team



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Prof Beate Escher (UQ, EnTox)

Dr Miroslava Macova (UQ, EnTox)

Future Direction

- **Confirm results** obtained at South Caboolture by sampling **other similar plants**.
- Investigate the **mechanisms of micropollutants removal** in BAC filtration.

Urban Water Security Research Alliance

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NDMA Formation Potential in Purified Recycled Water

Project Summary

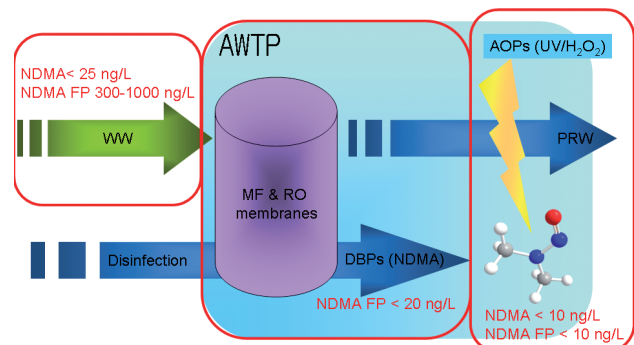
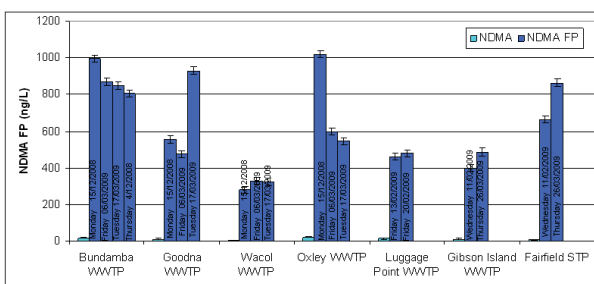
N-nitrosodimethylamine (NDMA) is a toxic and carcinogenic chemical compound that has been found in Advanced Water Treatment Plants when **disinfecting wastewater by means of chloramination**. The aims of this project are:

- Review the chemistry of NDMA formation in South East Queensland context.
- Establish the NDMA formation potential test.
- Determine the NDMA FP of source waters for Purified Recycled Water.
- Identify the NDMA precursors in source waters.

Project Progress

Source wastewaters for purified recycled water in South East Queensland have been monitored for NDMA formation potential.

NDMA values measured were lower than 25 ng/L in all the WWTPs prior to disinfection. On the other hand, NDMA FP values of the secondary effluent of the WWTP were between 350 and 1020 ± 20 ng/L showing remarkable differences between single WWTPs. More than 98.5% of NDMA precursors are effectively removed by Reverse Osmosis membranes used at the AWTPs.



Project Team



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Prof Jurg Keller (UQ, AWMC)

Prof Jochen Mueller (UQ, Entox)

Future Direction

- Study the NDMA FP of different wastewater after fractionation (molecular weight, hydrophilic/hydrophobic etc).
- Assessment of NDMA FP based on molecular descriptors (QSAR) and literature data on NDMA FP yield.
- Determining the NDMA FP of the micropollutants identified at the AWTP water source.
- Testing the NDMA FP of selected industrial possible precursor compounds.
- Assessment of the biodegradability of NDMA precursors in nitrification, denitrification and biological activated carbon filtration (link with the Enhanced Treatment project).

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

Project Summary

Chlorination and chloramination are widely used in South East Queensland (SEQ) for disinfection of potable water. These processes can potentially form a range of disinfection by-product (DBPs) including trihalomethanes (THMs), haloacetic acids (HAAs) and nitrosamines such as NDMA (N-nitrosodimethylamine). NDMA is a well known carcinogen, whose concentration in potable water is currently unregulated in Australia, however the World Health Organisation recommends a maximum of 10 ng/L. This study aims to determine existing NDMA concentrations in SEQ drinking water, as well as to evaluate the NDMA and THM formation potential of various SEQ source waters using a variety of disinfection methods. Disinfection methods studied will include Ozone/BAC and UV/H₂O₂ as well as chlorination and chloramination, in order to establish best practice for minimising DBPs in SEQ drinking water.

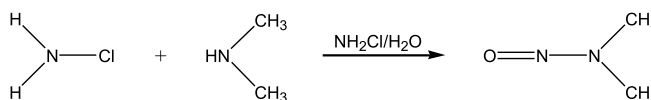


Figure 1 Simplified reaction showing NDMA formation in water from dimethylamine and monochloramine.

Project Progress

Research to date focussed first on establishing the NDMA formation potential of waters from Mt Crosby and North Pine water treatment plants. NDMA formation potential was found to decrease when water is pre-chlorinated at the filtration stage of treatment, prior to chloramination.

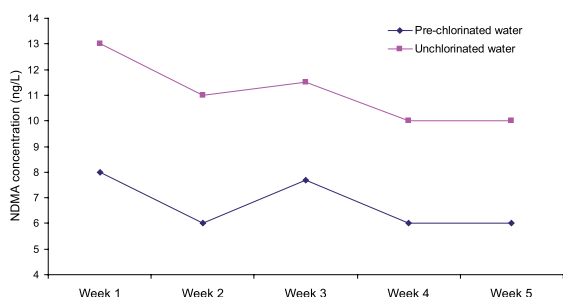


Figure 2 Pre-chlorination prior to chloramination leads to a lower NDMA formation potential. Data shown is from West Bank, Mt Crosby WTP.

More recently we have been investigating both the NDMA and THM formation potential of source water from Cedar Grove weir and the proposed Wyaralong dam site. THM formation potential for raw water from both sites has been consistently below Australian guideline values, regardless of whether chlorination or chloramination is employed as the disinfection method, using similar procedures to those used at actual SEQ water treatment plants.

Project Team



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Dr Maria José Farré (UQ)

Ms Kalinda Watson (GU)

Ms Cherie Yin Lam Ng (City Uni, HK)

Future Direction

- Determine the extent of NDMA formation possible in various SEQ source waters when using advanced oxidation techniques such as O₃/BAC or H₂O₂/UV rather than chloramination or chlorination alone.
- Expand our investigations in NDMA and THM formation potential to include other SEQ source waters such as Molindinar WTP, Landers Shute WTP and the proposed Traveston Crossing dam site.
- Conduct preliminary measurements for NDMA in water sourced from Tugun desalination plant.

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Potable Recycled Water in the Lockyer Valley

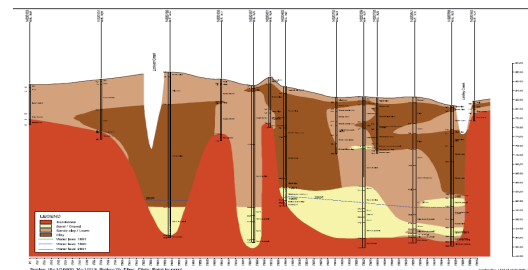
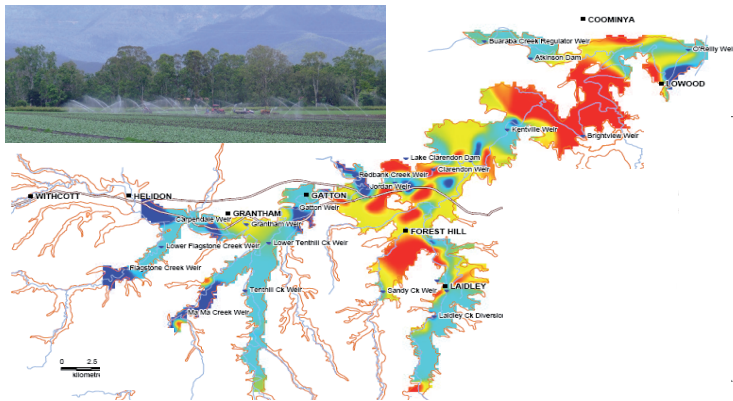
Project Summary

The Western Corridor Recycled Water Project could potentially provide 25 GL/a to the Lockyer Valley for irrigation of agricultural land. This project will investigate the implications of this application on water table levels, mobilisation of salts stored in the soils and their possible discharge to the Brisbane River.

Project Progress

Since project approval in March 2009:

- Existing groundwater models have been assessed for suitability to project goals.
- Preliminary 3D visualisations in key sub-catchments of the Lockyer Valley have been produced.
- A review of recharge in the region has been completed.



Future Direction

Project milestones will be accomplished through collaboration between teams from CSIRO, DERM, QUT and Environmental Hydrology Associates (EHA) and encompass:

- Creation and sensitivity analysis of HYDRUS-1D models of regional soils.
- HYDRUS-2D modelling of key soil types.
- Running of re-calibrated MODFLOW and MT3DMS models.
- Incorporation of newly collected field data into the above models.
- 3D visualisation of the modelling results.

The modelling and visualisation tools developed will be used to evaluate a series of 'what if?' scenarios regarding the use of PRW as either a substitute for groundwater or as an adjunct to groundwater use for the irrigation of crops in the Lockyer and Warrill Valleys.

Project Team



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Dr. Mark Silburn
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Assoc. Prof. Malcolm Cox
 (QUT team leader)

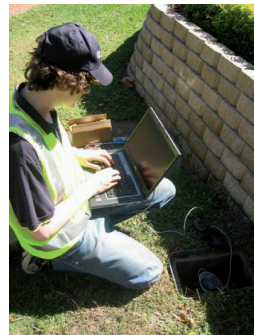


Mr Peter Evans
 (EHA team leader)

SEQ Residential Water End Use Study

Project Summary

The water end use study on 320 domestic households aims to develop a greater understanding on the current domestic end use water consumption patterns for households with various demographic characteristics in South East Queensland (SEQ). Wireless, smart water meters will be installed to determine the degree of impact that demand management initiatives have on end use water levels. This project is aligned with the water demand management research being undertaken through the Systematic Social Analysis project.



Project Progress

The project consists of the following major stages:

- Stage 1:** Research design and project plan development
- Stage 2:** Procurement of project equipment and obtaining consenting participant group
- Stage 3:** Meter deployment and data collection
- Stage 4:** Water audit and questionnaire survey
- Stage 5:** Analysis of end use data, water audits and questionnaire surveys

Stage 1 has been completed, and Stage 2 is underway. The research team is in the process of procuring project equipment.

Project Team



Project Leader:

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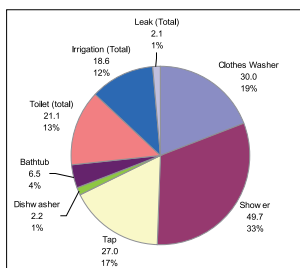
Dr Kriengsak Panuwatwanich (GU)

Ms Rachele Willis (GU)

Ms Mabelle Wong (GU)

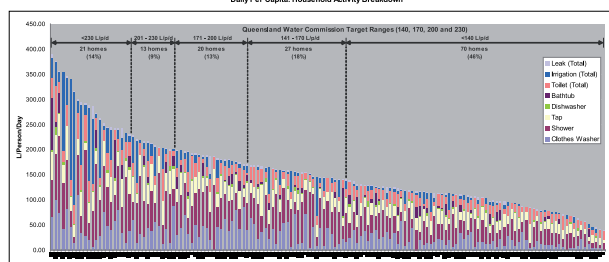
Mr Alireza Mousavinejad (GU)

Average Daily Per Capita: Single+Dual (n=151)

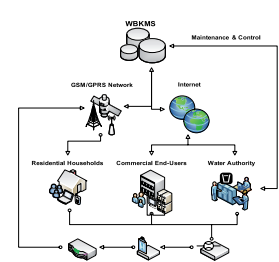


End use water consumption breakdown example

Daily Per Capita: Household Activity Breakdown



Example of individual household daily end use per capita



WBKMS Structure

Future Direction

The formation of data from the end use study will lead to the conceptualisation of the integrated smart metering and web-based knowledge management system (WBKMS). The WBKMS with associated smart meters, loggers and wireless networks allows for the empowerment of individuals by providing them with instant intelligent information. Such information has implications for better targeted rebate programs, water use regulations, leak identification, and water infrastructure planning.

WATER UTILITY: WEB-BASED KNOWLEDGE MANAGEMENT SYSTEM

Welcome: 5 Smith Street, South Brisbane, Queensland Log out

Please make a selection from the following:

- News
- My Usage
- Consumption Break Down**
- Comparative Usage
- Rebate Schemes
- Reduce your Consumption
- View / Pay Bills
- View Statements
- F.A.Q's

Period 2, 2009 Report: 12-25 January - 2 weeks)

Quick Summary: My Usage

Target Usage Per Day: 170 L/p/day Yesterdays Usage: 162 L/p/day

Last Weeks Average Daily Consumption: 210 L/p/day

Last Months Average Daily Consumption: 172 L/p/day

Fixture category	Water Usage (L)	Percent (%)
Leak	15.28	0.55%
Toilet	539.08	19.35%
Clothes washer	200.59	7.2%
Shower	962.21	34.54%
Dishwasher	29.20	1.05%
Tap/Faucet	587.52	21.09%
Irrigation	451.54	16.21%
Total	2785.42	100%

WBKMS water customer interface illustrative example

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

Monday, 17 August 2009, 8:30am – 5:00pm
Tuesday, 18 August 2009, 8:00am – 4:45pm

Venue: The Auditorium, John Hay Building [#80], Queensland Bioscience Precinct
The University of Queensland, St Lucia (see map following)

Program

DAY 1 – Monday, 17 August		
Time	Session	Presenter
8:30am	<i>Registration and Welcome Coffee</i>	
9:00am	Welcome and Opening Remarks from the Chair (Auditorium) <ul style="list-style-type: none"> - Forum objectives and intended outcomes - Where is the Alliance at now in its journey? Where is it going? Expectations of the Alliance - key outputs used so far 	Chris Davis Alliance Chair <i>Don Begbie, Director, MC</i>
9.15am	Official Opening <i>Maintaining the Value</i>	Dr Tom Hatton, Director, Water for a Healthy Country Flagship, CSIRO
9.30am	Keynote Speaker <i>The emerging trends and issues in urban water security, role of quality science and potential impacts and outcomes for the UWSRA in South East Queensland</i>	Prof Paul Greenfield, AO, Vice-Chancellor, The University of Queensland
10:15am	<i>Morning tea</i>	
10.45am	SESSION 1 - (Chair – Simon Toze) (Combined Small and Large Seminar Rooms) Theme A: Source Control, Pollutant Formation and Pathogen Monitoring and Removal	
	Determination of Disinfection By-Product Formation and their Minimisation in Potable Water Treatment Plants in South East Queensland	Glen Shaw
	Occurrence Of NDMA Precursors in Wastewater Source for Purified Recycled Water	Maria Farré
	Effective Removal of Micropollutants Without Reverse Osmosis Processes	Julien Reungoat
	Monitoring the Biological Activity of Micropollutants during Enhanced Wastewater Treatment Processes	Miroslava Macova
	A Real Time Event Detection System for WWTP Protection	Roger O'Halloran
	Development of Methods for the Improved Recovery and Detection of Viruses in Water	Jatinder Sidhu
12:45pm	<i>Lunch</i>	
1.45pm	SESSION 2 - (Chair – Jeff Camkin) (Auditorium) Theme B: Community Perceptions of and Reactions to Risk; Water Knowledge and Accounting	
	Understanding Different Community Reactions to Water Recycling Policy in Australia: the Influence of Emotions and Fairness	Jennifer Price
	Systematic Social Analysis of Household Water Demand Management	Kelly Fielding

Time	Session	Presenter
	SEQ Residential Water End Use Study: Closing the Loop on Urban Water Planning and Management	Rodney Stewart
	Why Good Water Accounting is Critical to Economic Decisions, Modelling and Sustainable Management of Water	Peter Daniels
	Knowledge Requirements for Water Management in South East Queensland	Tabatha Wallington
3:15pm	<i>Afternoon tea</i>	
3:45pm	SESSION 3 - (Chair – Stewart Burn) (Auditorium) Theme C: Saving Water and Finding More	
	Purified Recycled Water in the Lockyer Valley: Issues and Research	Richard Cresswell
	An Application of Pattern Recognition for the Location and Sizing of Leaks in Pipe Networks	John Mashford
	Comparison of Techniques for Determining Evaporation from a Large Irrigation Storage	David McJannet
	Revisiting Artificial Monolayers as a Strategy to Reduce Evaporative Loss from Large Open Water Storages	Pam Pittaway
5:00pm	Close – Day 1	
6:30pm	Forum Dinner – The Royal Thai Orchid, 45 Little Cribb Street, Milton [Ph: 3229 2588]	

DAY 2 – Tuesday, 18 August (Auditorium)		
Time	Session	Presenter
8:00am	<i>Registration and Welcome Coffee</i>	
8.25am	Brief Synopsis from Day 1, highlights, etc.	Chris Davis Don Begbie
8.30am	SESSION 4 - (Chair - Wenju Cai) Theme D: Climate Change, Greenhouse and Energy	
	Modelling Tool to Aid Development of Integrated Urban Water Management Strategies in South East Queensland	Shiroma Maheepala
	The Impact of Anthropogenic Forcings and El-Niño Southern Oscillation on South East Queensland Rainfall	Tim Cowan
	Dynamical Downscaling of Rainfall over South East Queensland	Kim Nguyen
	Energy and Greenhouse Footprints of Wastewater Treatment Plants in South-East Queensland	David De Haas
	Quantitative Comparison of Centralised and Decentralised Options for the Urban Water Cycle	Joe Lane
	Who Will Take Responsibility for the Indirect Energy Impacts of Urban Water Supply Choices?	Steven Kenway
10:30am	<i>Morning tea</i>	
11:00am	SESSION 5 - (Chair – Rodney Stewart) Theme E: Decentralised Systems and Stormwater	
	A Preliminary Analysis of Potable Water Savings from Mandated Rainwater Tanks in New Residential Properties in South East Queensland	Cara Beal
	Complexities in Decentralised and Distributed Systems	Ashok Sharma

Time	Session	Presenter
	Decentralised Systems Why Do We Care?	Grace Tjandraatmadja
	The Transferability of Recycled Water Treatment Systems across Various Decentralised Scales	Angel Ho
	Decentralised Systems - the Complexities of Communal Rainwater Systems	Barry Hood
	Stormwater Harvesting and Reuse in South East Queensland: to Dream the Impossible Dream?	Ted Gardner
12.40pm	<i>Lunch</i>	
1:30pm	STAKEHOLDER FORUM	
	Welcome and Introductions	Chris Davis
1:35pm	Are Hospitals a Major Point Source of Pharmaceuticals in Wastewater?	Christoph Ort
1.55pm	Measurement of the Decay of Microbial Pathogens in South East Queensland Reservoirs	Simon Toze
2.15pm	Community Perceptions of Risk and Purified Recycled Water	Zoe Leviston
2.35pm	Energy and Greenhouse Gas Emissions for the SEQ Water Strategy	Murray Hall
3.00pm	Open Discussion - Stakeholder Questions and Answers	Don Begbie
3:30pm	<i>Afternoon tea</i>	
4.00pm	Science Forum in Review	Chris Davis
	Overview of Presentations - Interactive session – what have we learnt? - Highlights, challenges and development opportunities for the Alliance - Overview of where Alliance is going – future directions	
4.30pm	Awards for Best: ➤ Paper ➤ Presentation	Chris Davis / Don Begbie
4.40pm	Feedback / Evaluation process - What went well, what to improve	Don Begbie
	Summing Up and Close	Don Begbie / Chris Davis
4:45pm	Close	

Abstracts

Determination of Disinfection By-Product Formation and their Minimisation in Potable Water Treatment Plants in South East Queensland

N. Knight¹, M. Farré², G. Shaw¹

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²Advanced Wastewater Management Centre, University of Queensland, St. Lucia, Queensland, Australia

Summary

The current project investigates which disinfection practices are most appropriate in providing South East Queensland's potable water, in terms of disinfection by-product minimisation. The research presented here examines the factors affecting N-nitrosodimethylamine (NDMA) formation as a consequence of drinking water disinfection practices using chlorination and chloramination. We investigate the NDMA formation potential of South East Queensland source waters, as well as actual NDMA concentrations occurring at South East Queensland water treatment plants and at the point of supply.

Keywords

NDMA; disinfection; nitrosamines.

Background

Disinfection of drinking water by chlorination was introduced in Australia in the early 1900's, and subsequent incidences of water-borne disease being transmitted via drinking water have been rare (Block 2001). Today, drinking water treatment plants in South East Queensland (SEQ) continue to use chlorination (including pre-filter chlorination in some instances) or a mixture of chlorination and chloramination in order to maintain effective disinfection. However, disinfection by either of these processes can create potentially harmful chemical by-products as a result of the reaction between the disinfectant and existing organic matter in the source water (Sadiq et al 2004). These disinfection by-products are primarily trihalomethanes (THMs) such as chloroform, and nitrosamines such as N-nitrosodimethylamine (NDMA). While chloramination generally leads to lower concentrations of THMs than chlorination, it has the potential to produce elevated levels of NDMA and other nitrosamines. NDMA is known to be a potent carcinogen, however, there is also some evidence of the carcinogenicity of the THMs, as well as possible deleterious reproductive effects (Bove et al 2004, Richardson et al 2007). With the development of the SEQ water grid, booster chlorination or chloramination may be required to ensure disinfectant residuals in the distribution system, which may lead to increased disinfection by-product formation.

This project investigates the factors affecting NDMA formation as a consequence of chloramination, taking into account the source water used (in particular its organic component) and the processes employed during water treatment and distribution. As such, we are assessing a number of different SEQ source waters in order to determine the potential for NDMA formation, while also analysing existing potable water supplies to determine NDMA concentrations at the point of supply. This knowledge will be used to make informed decisions about which disinfection processes should be used in both proposed and existing water treatment plants in SEQ, to allow consistently low NDMA concentrations to be achieved.

Upon conducting a short-term monitoring program for NDMA in chloraminated Brisbane waters, we found water sourced from both Mt Crosby and North Pine water treatment plants (WTPs) generally had very low NDMA concentrations (<5 ng/L), both before and after disinfection at the plant, as well as at the point of supply. However, one potable water sample point was found to have a high NDMA concentration of up to 17 ng/L (a guideline value would be expected to be 10 ng/L) which reached a maximum at approximately the fourth litre fraction. The results implied formation in the distribution line in this case, however the cause and extent of this is as yet unknown. NDMA formation potential experiments were also conducted on water sourced from Mt Crosby and North Pine WTPs, and it was found that pre-chlorination at the filtration stage of treatment led to a lower NDMA formation potential, with water that had been through pre-chlorination having an average NDMA formation potential of 7 ng/L and unchlorinated water having an NDMA formation potential averaging 11 ng/L (Figure 1). Although pre-chlorination at the filters may be useful in lowering NDMA formation potential, this process may lead to higher THM concentrations.

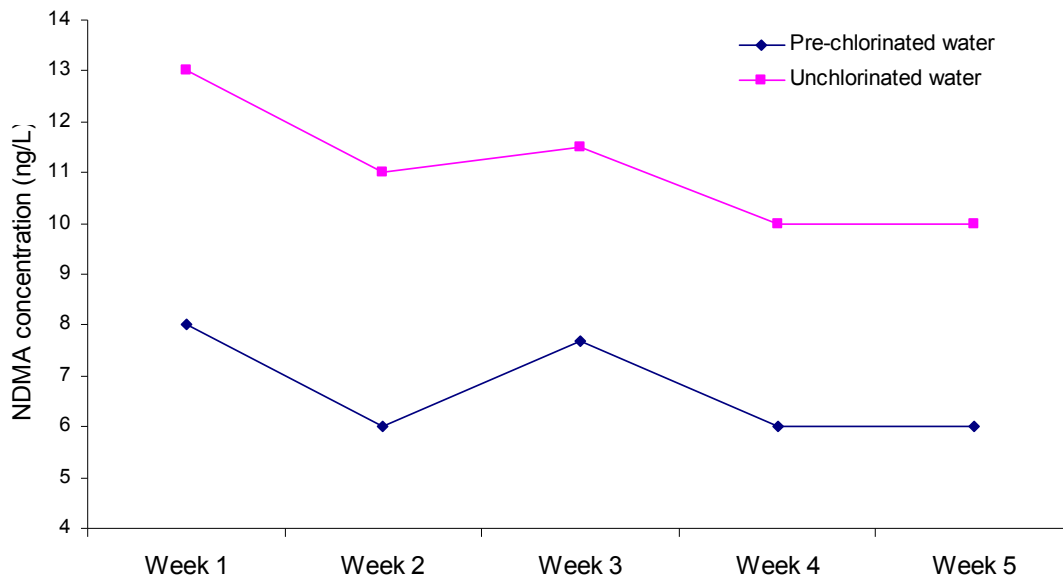


Figure 1. Variation in NDMA formation potential of water from West Bank Mt Crosby filters over five weeks. Pre-chlorinated filters have consistently lower NDMA formation potential than unchlorinated filters.

References

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Occurrence of NDMA Precursors in Wastewater Source for Purified Recycled Water

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Summary

The formation of N-nitrosodimethylamine (NDMA) is of major concern among wastewater recycling utilities practicing disinfection with chloramines. The NDMA formation potential (FP) test is a simple method to evaluate NDMA precursor concentrations in waters. In this abstract we show the NDMA FP results of source waters for Purified Recycled Water (PRW) in South East Queensland (SEQ). The results indicate that NDMA FP of different source waters in SEQ range from 350 to 1000 ng/L. In addition, we present complementary data based on nitrogen measurements that can be used to approximately predict the formation of NDMA.

Keywords

N-nitrosodimethylamine, water recycling, South East Queensland, chloramination, disinfection by-product, formation potential.

Background

The production of Purified Recycled Water (PRW) at the Advanced Water Treatment Plants (AWTP) is a core component of the South East Queensland Water Strategy. Within that treatment, water is disinfected at several points. Although chlorine disinfection is widely applied (Haase, 1936), the reverse osmosis membranes used in the train can be easily corrupted by chlorine in solution, thus chloramines are normally used for disinfection purpose at the AWTP. Nevertheless, the main disadvantage of using chloramines as a disinfection agent is the formation of carcinogenic nitrosamines. Among the different nitrosamines that can be formed during this process, N-nitrosodimethylamine (NDMA) has caused some major concerns among wastewater recycling utilities because it is poorly rejected by the different membranes employed in the treatment. The US Environmental Protection Agency (EPA) classifies NDMA as “B2 carcinogen - reasonably anticipated to be a human carcinogen” (EPA, 2008). Moreover, Public Health Regulations in Queensland require that NDMA concentrations in recycled water to augment a supply of drinking water are less than 10 ng/L (QPC, 2005).

Although NDMA is satisfactorily removed at the last step of the AWTP, which is an Advanced Oxidation Process by means of H₂O₂/UV, a need for a better understanding of the nature of the precursors has been identified. To this aim, the first step of the current project (funded by the UWSRA) is the assessment of NDMA formation potential of water sources for Purified Recycled Water systems.

Method

The NDMA Formation Potential (FP) test is a method to quantify the concentration of the organic precursors of NDMA that could be formed during chloramination of water and wastewater. This method was first developed by Mitch and co-workers (Mitch et al., 2003) and has been widely and continuously referenced and used. The method involves applying a high dose of monochloramine to a pH-buffered water sample during a pre-determined contact time to produce NDMA. Although the test is not thought to predict concentration levels of nitrosamine formed during disinfection systems, the levels of nitrosamine formed in this test can be used to compare the potential of different waters to form nitrosamines during chloramination.

For the NDMA FP test, 24-hour composite samples were taken at the secondary effluent of the WWTPs, except for WWTP B, C and G where grab samples were taken. For direct analysis of NDMA, grab samples were taken and quenched immediately after sampling with sodium thiosulphate to avoid further NDMA formation. All samples were taken in amber glass bottles and kept chilled until analysed.

Samples were analysed at Queensland Health Forensic and Scientific Services (QHFSS). The method used for this analysis is based on EPA Method 251 (Munch and Bassett, 2004). In that analysis, water is passed through a Carbon SPE cartridge and the nitrosamines are eluted off with dichloromethane. The extracts are concentrated by evaporation under nitrogen and analysed by capillary GC-MS in Positive Chemical Ionisation (PCI) mode with anhydrous ammonia as the chemical ionisation gas.

Results

The concentration of NDMA and NDMA precursors has been assessed in source waters for PRW. The NDMA FP test has been applied to all water sources for PRW in SEQ in order to examine the presence of NDMA precursors (see Figure 1).

All Wastewater Treatment Plants (WWTP) supplying water to the different AWTPs in SEQ are currently implementing biological nutrient removal as advanced treatment. Nevertheless, in order to better understand the effect of this advanced treatment on the removal of NDMA precursors, a secondary WWTP without biological nutrient removal treatment was also included in this study (i.e., WWTP G).

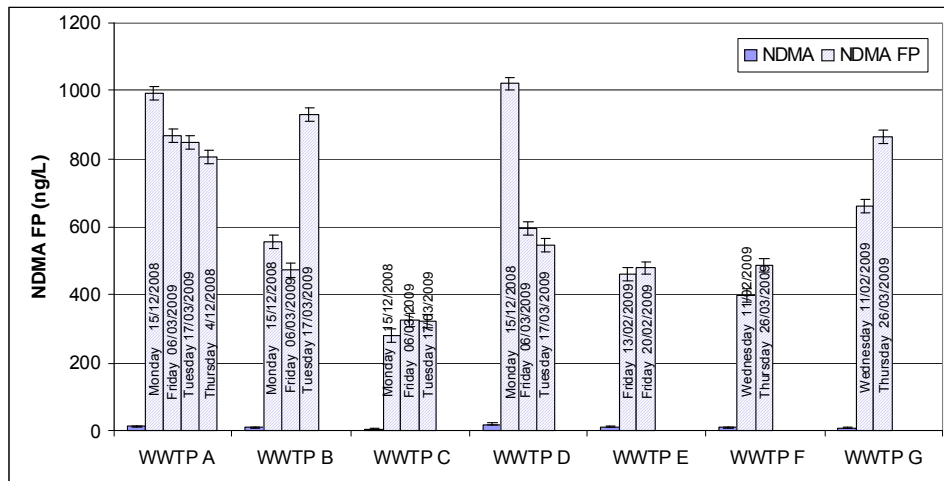


Figure 1. NDMA and NDMA FP of the different WWTPs providing water to the AWTP in the SEQ context. WWTP G is not a water source for PRW

NDMA values were lower than 25 ng/L in all the WWTPs prior to disinfection, as observed in Figure 1. On the other hand, NDMA FP values of the secondary effluents of the WWTP were between 350 and 1000 ng/L showing remarkable differences between WWTPs. These results are in accordance with previous research performed on secondary effluents in other countries (Sedlak et al., 2005). To assess the effect of biological nutrient removal treatment, results concerning WWTP C and G were compared. These WWTP both treat 100% domestic wastewater and the main difference is the biological nutrient removal treatment in WWTP C. NDMA FP values of WWTP G were two times higher than the values obtained from WWTP C. Thus, we can suggest that the biological nutrient removal is an efficient barrier to control further formation of NDMA during disinfection of secondary effluent through chloramination.

We also studied the relation between NDMA FP and Dissolved Organic Nitrogen (DON). As seen in Figure 2, there appears to be a trend of increasing NDMA FP with increasing DON which may assist with predicting the formation potential of a specific water source for PRW. Further research will investigate the nature of the specific DON related to NDMA formation in the SEQ context in order to better understand the nature of the problem and to be able to propose technologies to remove those precursor compounds before chloramination. This research will investigate chemical and physical properties of DON related to a high NDMA formation potential.

High ammonia concentrations in secondary effluent indicates a certain nitrification inhibition in the WWTP and can be an indicator for a non-optimal process performance in the WWTP. Contrary to this assumption, ammonia 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 both high and low concentration of NH_4^+ .

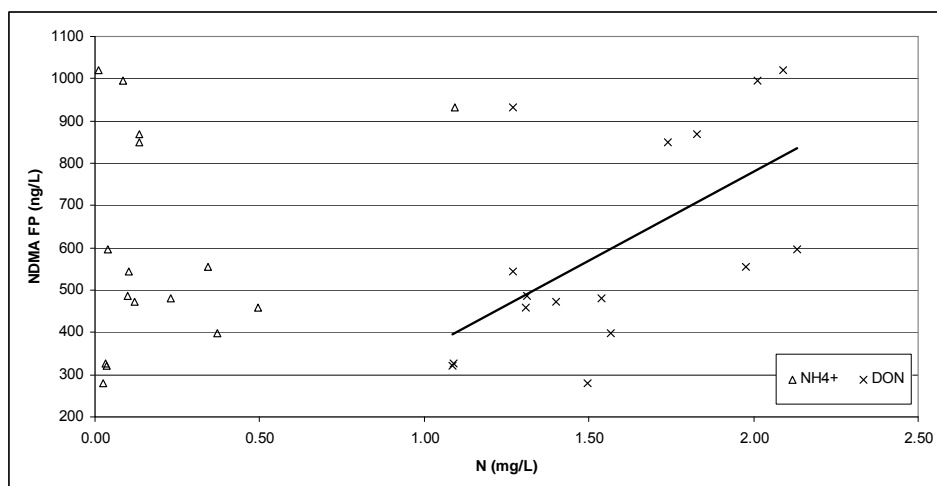


Figure 2. Dissolved Organic Nitrogen and Ammonium (NH_4^+) concentration of different water sources for the Advanced Water Treatment Plants in South East Queensland.

WWTP G was not included in this part of the study due to the high levels of nitrogen present in the secondary effluent (no biological nutrient removal is applied in that WWTP). Average values of NH_4^+ and DON were 47 mg/L and 4.5 mg/L respectively for WWTP G.

Conclusions

We conclude that both source control and DON removal during secondary treatment are good strategies to reduce NDMA formation in PRW production. Moreover, DON can be used as an approximate parameter to predict the NDMA FP of specific source waters. More research is being undertaken within this project to better understand the nature of NDMA precursors in the specific SEQ context.

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Effective Removal of Micropollutants Without Reverse Osmosis Processes

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Summary

This study evaluates the chemical quality of the water produced by a full-scale reclamation plant based on the combination of ozonation and activated carbon filtration and by pilot scale biofilters (sand and activated carbon). The chemical quality was assessed by the quantification of micropollutants (pharmaceuticals and pesticides) along the full scale treatment train and after biofiltration. Results show that the full scale process efficiently removes the targeted micropollutants, the key steps are the main ozonation and the activated carbon filtration. The sand biofilter did not show significant removal of micropollutants whereas as the biological activated carbon filters were able to remove most of the detected micropollutants below their limit of quantification.

Keywords

Water reuse, ozonation, activated carbon, biofiltration, micropollutant.

Background

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 a safe 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. Therefore, alternatives to MF/RO have to be developed to promote indirect potable reuse for inland locations. But can these alternatives produce water with a quality suitable for indirect potable reuse?

Materials and Methods

South Caboolture reclamation plant consists of the following steps: denitrification, pre-ozonation (2 mg L⁻¹), coagulation/flocculation/dissolved air flotation-filtration (DAFF), main ozonation (5 mg L⁻¹), activated carbon filtration (18 min contact time) and post-ozonation (2 mg L⁻¹). The influent water comes directly from a nutrient removal activated sludge plant of 40,000 equivalent people, a storage tank between the two plants insures a continuous flow rate (approximately 8,000 m³ d⁻¹) in the reclamation plant. Three pilot scale biofilters are installed in the plant in parallel of the main stream: the sand biofilter and one biological activated carbon filters (BAC 1) are fed with water from the DAFF and another biological activated carbon filters filter (BAC 2) is fed with water from the main ozonation. The empty bed contact time in the filters was set to approximately 2 hours. A sampling campaign was carried out over one month in 2008 during which 4 composite samples (over 24 h) were collected from the influent and the effluent flow of the reclamation plant as well as after each treatment step in the process train. For dissolved organic carbon (DOC) measurements, samples were filtered through 0.45 µm membrane before performing non-purgable organic carbon analysis. For micropollutants analysis, samples were concentrated using solid phase extraction (SPE) within 24 h, and later analysed by HPLC/MS-MS to measure the concentration of 56 pharmaceuticals and 28 pesticides, with a limit of quantification (LOQ) of 0.01 µg L for most analytes.

Results and Discussion

Fifty-four compounds were detected in the influent of the full scale plant with a median concentration above their LOQ (Figure 1). The concentrations of these compounds ranged from 0.01 µg L⁻¹ to 2.10 µg L⁻¹, except for gabapentin which ranged from 5.63 µg L⁻¹ to 6.50 µg L⁻¹. The influent DOC was between 14.2 and 19.7 mg L⁻¹. The first treatment steps, i.e. denitrification, pre-ozonation and DAFF, had no influence on the number of compounds detected and their concentration generally decreased by less than 20%. In the meantime, the DOC was reduced by 40 to 50% in the DAFF stage. Ozonation reduced the concentration of the compounds generally by more than 75% and 26 compounds were removed below their level of quantification indicating that oxidation by ozone is a very efficient way to remove micropollutants from treated wastewater. During ozonation, the DOC did not decrease

significantly showing that oxidation of micropollutants and organic matter lead to the formation of by-products. The activated carbon filtration was able to further reduce the concentration of 25 compounds below LOQ and only 2 compounds remained in the water: roxithromycin and gabapentin with median concentrations of 0.01 and 0.70 $\mu\text{g}\cdot\text{L}^{-1}$ respectively. Activated carbon also removed 20 to 30% of the DOC. Finally, the post-ozonation did not have a significant effect on the micropollutant concentrations or DOC. Four compounds were detected in the final effluent: gabapentin (0.45 $\mu\text{g}\cdot\text{L}^{-1}$), roxithromycin (0.01 $\mu\text{g}\cdot\text{L}^{-1}$), caffeine (0.02 $\mu\text{g}\cdot\text{L}^{-1}$) and DEET (0.03 $\mu\text{g}\cdot\text{L}^{-1}$). The detection of caffeine and DEET was probably due to sampling and/or analytical variations.

Fifty-three compounds were detected in the fed water of the sand and BAC1 filters and the DOC was 10.8 to 11.6 $\text{mg}\cdot\text{L}^{-1}$. The sand filter removed 6 compounds below their limit of quantification and the concentration of other compounds did not vary significantly, the DOC decreased by 20 to 25%. Only 2 compounds were still detected after filtration through BAC 1 and the DOC was reduced by around 40%. The BAC 2 filter showed similar performance although the number of compounds in the fed water was lower (27) because of the ozonation. This shows that biological activated carbon filtration is very effective at removing organic matter and micropollutants compared to sand biofiltration. The performances of the BAC filters were similar to the combination of ozonation and activated carbon filtration in the full scale plant. Ozonation before BAC filtration did not lead to higher removal performances.

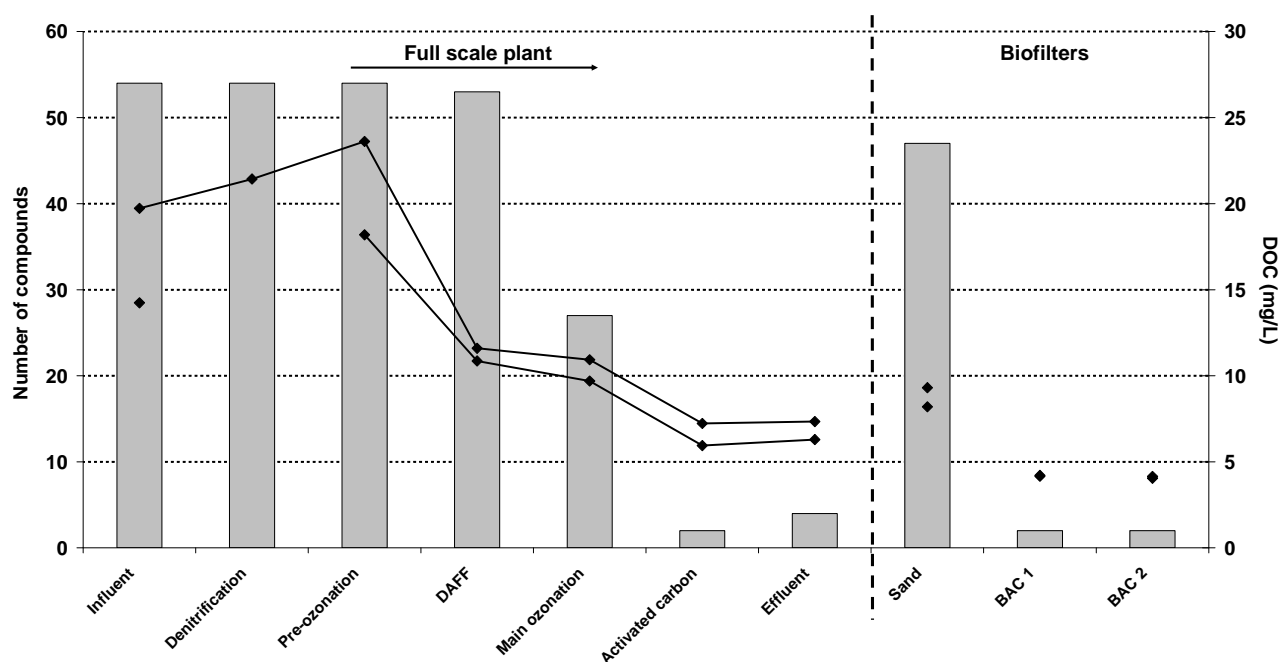


Figure 1. Number of compounds detected with a median concentration above the limit of quantification and dissolved organic carbon (DOC) along the treatment train and after biofiltration.

Conclusion

The combination of ozonation and activated carbon adsorption was able to effectively remove the targeted micropollutants from treated wastewaters, as were the biological activated carbon filters. Most of the compounds measured were below LOQ in the final waters. This indicates that concentrations were several orders of magnitude below the guideline values of the Australian Water Recycling Guidelines – Augmentation of Drinking Water Supplies. Additional quality assessment with bioassays (Macova et al., 2009) demonstrated a decrease of toxic biological activity consistent with the removal of micropollutants. They also confirmed that no negative effects appear to be generated from possible ozonation by-products at least on the range of tests used in this study. These processes are well known and already widely used in drinking water treatment, thus could be easily implemented in wastewater treatment plants to achieve further removal of micropollutants before discharge of the effluent to the environment or reuse of the water. These results also suggest that it is possible to produce reclaimed water of a quality comparable to reverse osmosis treated water processes for indirect potable reuse without using reverse osmosis. Nevertheless, before this process is being recommended for indirect potable reuse, additional consideration needs to be given to the overall risk management strategies of the overall process train, as well as the potential to form disinfection by-products due to the remaining DOC levels.

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Monitoring the Biological Activity of Micropollutants during Enhanced Wastewater Treatment Processes

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Summary

This study is focused on the use of a range of bioanalytical tools to determine the efficacy of monitoring the potential presence and activity of groups of micropollutants across advanced water treatment systems. Overall, the toxicity of samples was reduced through the treatment chain. Typically, treatment with main ozonation significantly reduced response in baseline toxicity, acetylcholinesterase inhibition assay, estrogenic and Ah-receptor response. Genotoxic response was significantly reduced earlier in the process by coagulation, flocculation and dissolved air flotation and sand filtration. Activated carbon treatment further reduced responses in all bioassays to the level not significantly different from blank or below detection limit.

Keywords

Bioanalysis; micropollutants; toxicity; estrogenicity; wastewater treatment.

Introduction

Bioanalytical techniques are based on toxicological methods. In the last decade EnTox in collaboration with colleagues from other organisations such as the Swiss Federal Institute of Aquatic Science and Technology have worked towards the establishment of a 'mode of action' battery of bioanalytical techniques that supports water quality assessment. Specific bioanalytical techniques have been selected on the basis of relevance for assessing a specific endpoint (eg, genotoxicity, endocrine activity, neurotoxicity, dioxin-like activity and non-specific cell toxicity); allowing relatively rapid throughput; and requiring only relatively small sample volumes. An important assumption underlying the use of these methods is that the test can provide valuable information to predict potential exposure/risk of pollutants to humans and/or other biota, and that the limitation and strength of a given tool is sufficiently understood and defined to assure that the results are not misinterpreted and/or misrepresented. In this paper, we focus on the applicability and limitations of using bioassays for the purpose of determining the treatment efficacy of advanced water treatment and for water quality assessment in general.

Material and Methods

Twenty four hour composite samples were collected from 7 sampling points along the enhanced treatment chain of the South Caboolture Reclamation Plant (Reungoat et al, 2009). The aqueous samples were enriched using solid-phase extraction to separate the organic micropollutants of interest from metals, nutrients and matrix components. The bioassays chosen cover selected relevant modes of toxic action. The integrative effect of all micropollutants in the sample caused by baseline toxicity was quantified with the bioluminescence inhibition test using the marine bacterium *Vibrio fischeri*. Groups of chemicals with specific modes of toxic action were targeted with five 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)), genotoxicity (chlorinated byproducts, aromatic amines, PAHs), neurotoxicity (organophosphates and carbamate insecticides), and phytotoxicity (triazine herbicides). The different endpoints give information on groups of chemicals with a common mode of toxic action.

Results and Discussion

Results of all but one assay are reported in toxic equivalent concentrations (TEQ), that is, the concentration of a reference compound required to elicit the same response as the unknown and unidentified mixture of micropollutants actually present. Genotoxic effect of the samples was expressed as effective concentration required for eliciting a genotoxic response – induction ratio (IR) of 1.5 ($EC_{IR1.5}$). The TEQ in the influent of advanced water treatment plants ranged in the same order of magnitude as typically seen in effluents of conventional sewage treatment plants. The effect-based micropollutant burden is typically decreased but the extent of the reduction is dependent not only on the type of treatment step but also on the type of bioassay used (Figure 1, Table 1). Main ozonation significantly decreased baseline toxicity, parathion equivalent concentration (PTEQ) and estradiol equivalent concentration (EEQ) of the influent by 60%, 40% and 93%, respectively. Baseline toxicity was further reduced by activated carbon treatment to 23% of the original activity, while estrogenicity and PTEQ were reduced to below the detection limit. Main ozonation was the most efficient step also in the removal of the compounds assessed

in the AhR-CAFLUX assay. The 2,3,7,8-tetrachloro-dibenzodioxin equivalent concentration (TCDDEQ) was significantly decreased by ozonation to 0.44 ng/L in comparison with the TCDDEQ of 0.83 ng/L in influent. The TCDDEQ of the samples after the sulphuric acid silica gel clean-up, performed to remove most organic chemicals (e.g. PAH) except persistent chemicals, was reduced to a level not significantly different from the blank. These results indicate that almost all observed effect in the CAFLUX assay may be attributed to chemicals other than polychlorinated dibenzodioxins/furans and PCBs. Genotoxicity and diuron equivalent concentration (DEQ) were reduced earlier in the treatment process by coagulation/flocculation/dissolved air flotation/sand filtration (DAFF) by 57% and 59%, respectively. Activated carbon treatment further decreased DEQ to 24% of the original activity and genotoxic response below the detection limit of the assay.

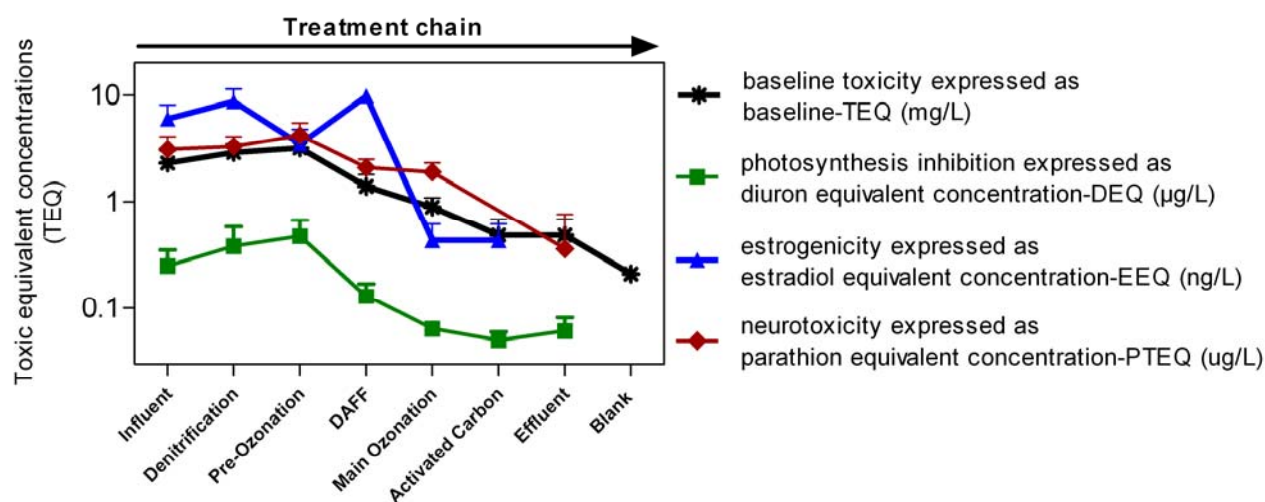


Figure 1. Toxic equivalent concentrations of the samples through the advanced water treatment chain expressed as average of 4 samplings. Bars indicate the standard deviation.

Table 1. Summary of the bioanalytical results representing the average ± standard deviation of 4 samplings

Site description	Baseline toxicity	Neuro-toxicity	Phyto-toxicity	E-SCREEN	AhR-CAFLUX	Genotoxicity
	Baseline-TEQ (mg/L)	PTEQ (µg/L)	DEQ (µg/L)	EEQ (ng/L)	TCDDEQ ^c (ng/L)	1/EC _{IR1.5} (1/REF)
Blank	0.21 ± 0.01	<0.3	<0.01	<0.02	0.06 ± 0.01	<0.01
Influent (WWTP Effluent)	2.3 ± 0.4	3.2 ± 0.5	0.12 ± 0.1	6.0 ± 2.1	0.09 ± 0.03 ^b	0.21 ± 0.1
Denitrification	2.9 ± 0.5	3.3 ± 0.4	0.30 ± 0.1	8.7 ± 2.7	0.10 ± 0.01 ^b	0.16 ± 0.02
Pre-ozonation	3.2 ± 0.7	4.2 ± 1.2	0.34 ± 0.2 ^a	3.5 ± 1.3	0.11 ± 0.01 ^b	0.17 ± 0.06
Coagulation/ Flocculation/DAFF	1.4 ± 0.5	2.1 ± 0.4	0.05 ± 0.04	9.8 ± 1.3 ^a	0.11 ± 0.04 ^b	0.08 ± 0.06^a
Main ozonation	0.9 ± 0.2^{ab}	1.9 ± 0.5^a	0.03 ± 0.03	0.4 ± 0.2^a	0.09 ± 0.02 ^b	0.02 ± 0.01 ^a
Activated carbon	0.5 ± 0.2 ^{ab}	<0.3	0.02 ± 0.02	<0.02	0.10 ± 0.06 ^b	<0.01
Effluent	0.5 ± 0.2 ^{ab}	<0.3 ^d	0.02 ± 0.01	<0.06	0.10 ± 0.01 ^b	<0.01

^a significantly different from influent, P<0.05, ^b not significantly different from the blank; Analysis of variance, Bonferroni's post test. analysed by Prism 5.0 software, (GraphPad, San Diego, USA) ^c TCDDEQ after acid silica gel clean-up, ^d one replicate showed effect above detection limit

Conclusion

The toxicity of samples expressed as TEQ was reduced through the treatment chain. Results of this study indicate that the key processes responsible for the decrease of toxic effects were the main ozonation and the activated carbon filtration step. The results obtained by bioanalytical tools were reproducible and robust. Detection limits were remarkably low; for example, estrogenicity could be resolved to levels below the quantification limit of routine chemical analysis. TEQ proved to be useful and easily communicable despite some limitations in its applicability for water quality monitoring, allowing comparison with the chemical analysis results and guidelines values.

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A Real Time Event Detection System for WWTP Protection

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Summary

The Western Corridor Recycled Water Project in South East Queensland (SEQ) has adopted a 7-barrier approach to enable safe reuse of treated sewage effluent as purified recycled water (PRW). Reliable performance of the first two barriers (sewer discharge control and the wastewater treatment plant) is critical to remove the bulk of contaminants. It is essential that major discharge events are detected before they compromise treatment plant performance, however no suitable monitoring systems are commercially available. Our project is developing a novel online method to detect discharge events in real time based on a new philosophy of analysis. Macerated sewage is directed through a sensor manifold where a number of physicochemical parameters are monitored continuously. Because the sewer system exhibits natural and anthropogenic cycles, there are regular diurnal, weekly and seasonal patterns in the data, which allow 'normal' behaviour to be defined. Using customised mathematical methods, hazardous events can be identified, along with sensor faults and the need for calibration.

Keywords

Online monitoring, effluent event detection, wastewater reuse, fault recognition, treatment plant protection.

Introduction

The purified recycled water (PRW) system is an important part of the Western Corridor Recycled Water Project (WCRWP) that consists of a number of key components including sewage treatment, advanced water treatment, surface water return to storages, and potable water treatment and distribution. Such a large scale closed loop water system gives rise to potential water quality risks from possible contaminants in the treated wastewaters. Consequently, the WCRWP has adopted a 7-barrier approach to ensure safe, reliable and efficient operation of the PRW system. In this regard, reliable performance of the first two barriers (sewer discharge/catchment and the wastewater treatment plant) is critical, as they are responsible for removing the bulk of contaminants, which is essential to safeguard the subsequent advanced treatment processes. For this reason, the Water Quality Information Collection System (WQICS) Project was established to reduce the associated risks by developing an effective real-time event detection system for barriers 1 and 2. To our knowledge, no commercially available water quality monitoring system currently in operation is capable of effectively and reliably detecting significant sewer discharge events.

Over the last two decades, the hardware of most analytical instruments has been revolutionised due to advances in materials science, microelectronics and computing power. An enormous effort has been devoted to improving the reliability, robustness and accuracy of analytical signal measurement by developing highly sophisticated analytical instruments. As a result, most existing online sensors/sensing systems generally perform well in laboratory environments using pre-treated samples. However, in spite of these advances, limited improvement has been achieved for the applicability of online instruments to field-based analyses. Only a few systems have demonstrated satisfactory performance in field environments, especially for applications involving difficult sensing media such as raw sewage (Vanrolleghem and Lee, 2003; Bonastre et al, 2005). The reason for this is that existing online instruments were developed by directly adopting traditional laboratory-based analytical principles that were not originally designed for field applications. They largely rely on being able to control or manipulate the sample and the measurement environment to comply with a defined set of conditions, which is often very difficult to implement outside of the laboratory. In order to significantly improve the applicability of an analytical system for field applications, new analytical approaches must be developed.

Real-Time Event Detection System

In this work, we report a real-time event detection system capable of detecting significant discharge events that could potentially compromise the performance of the wastewater treatment plant, hence affecting the quality of product water feeding to the downstream advanced treatment plant. The method employs a multi-sensor hardware platform consisting of six robust and reliable water quality sensors located in a flow through manifold where suitable hydrodynamic conditions are employed to ensure effective sensor cleaning and a stable response (Figure 1.1). Each sensor represents different aspects of the water matrix that reflect its composition and quality:

1. Temperature
2. Electrical conductivity (dissolved ionic matter)
3. pH (acids and bases)
4. Dissolved oxygen (organic matter, biological activity, toxicity)
5. Redox potential (chlorine surrogate, aerobic/anaerobic conditions)
6. Turbidity (suspended solids)

The essential system requirements are a sensing platform incorporating multiple sensors that can physically tolerate the effluent matrix conditions. Ideally the sensors should be self-contained, requiring no additional chemical reagent to generate a response. Each selected sensor responds to one or more physical/chemical aspects of sample matrix change. Simultaneous analytical signals from all sensors are continuously acquired in real-time, and the matrix change information required for event detection can be collectively represented by all of these sensor signals.

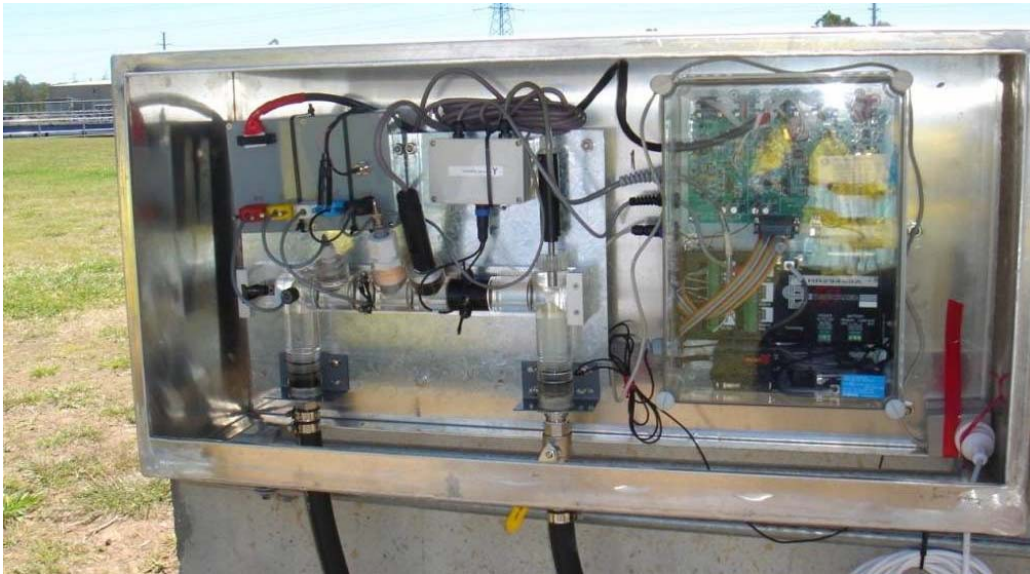


Figure 1.1 Online event detection system (Bundamba Wastewater Treatment Plant).

New Philosophy of Analytical Measurement

The water quality data collected from all sensors is collectively treated and processed using intelligent event recognition software that is being developed based on a new philosophy of analytical measurement. This novel approach utilises changes in the analytical signals and the logical relationships between different sensors along the time dimension as the reference line to allow real-time self-calibration of the sensing signal (Figure 1.2).

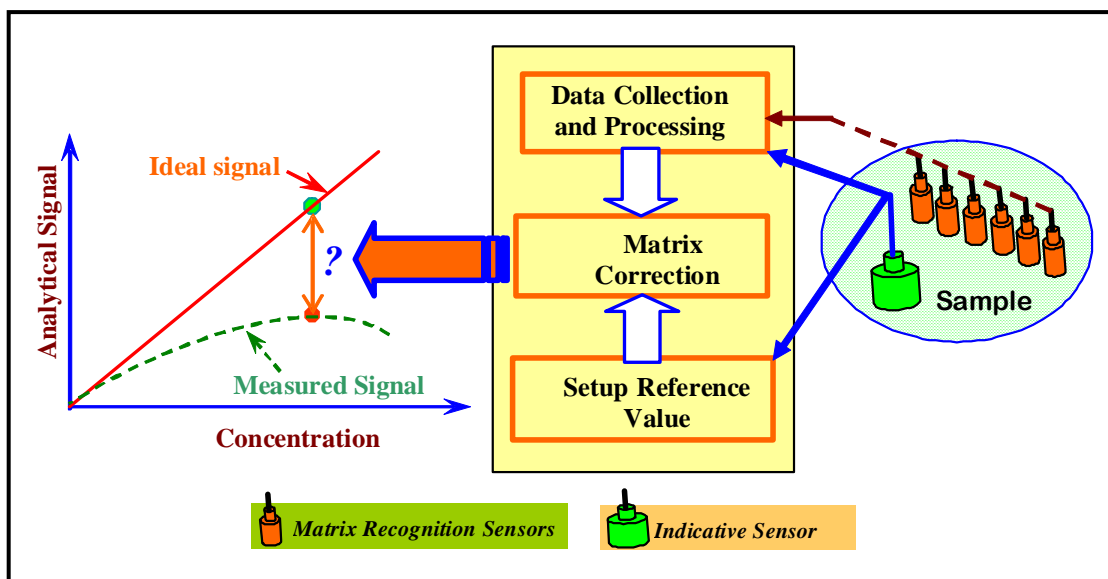


Figure 1.2 Schematic showing new measurement principle based on collective multi-sensor matrix response.

Event Detection

The methodology being developed is based on real-time interpolation of the baseline of the time plots of each sensor; recognition of departures from baseline based on slope, magnitude and duration; and comparison and correlation of the responses of all sensors. An example of the features that will be used is shown in Figure 1.3, where two events were recorded consistent with dumping of an acidic waste into the sewer catchment.

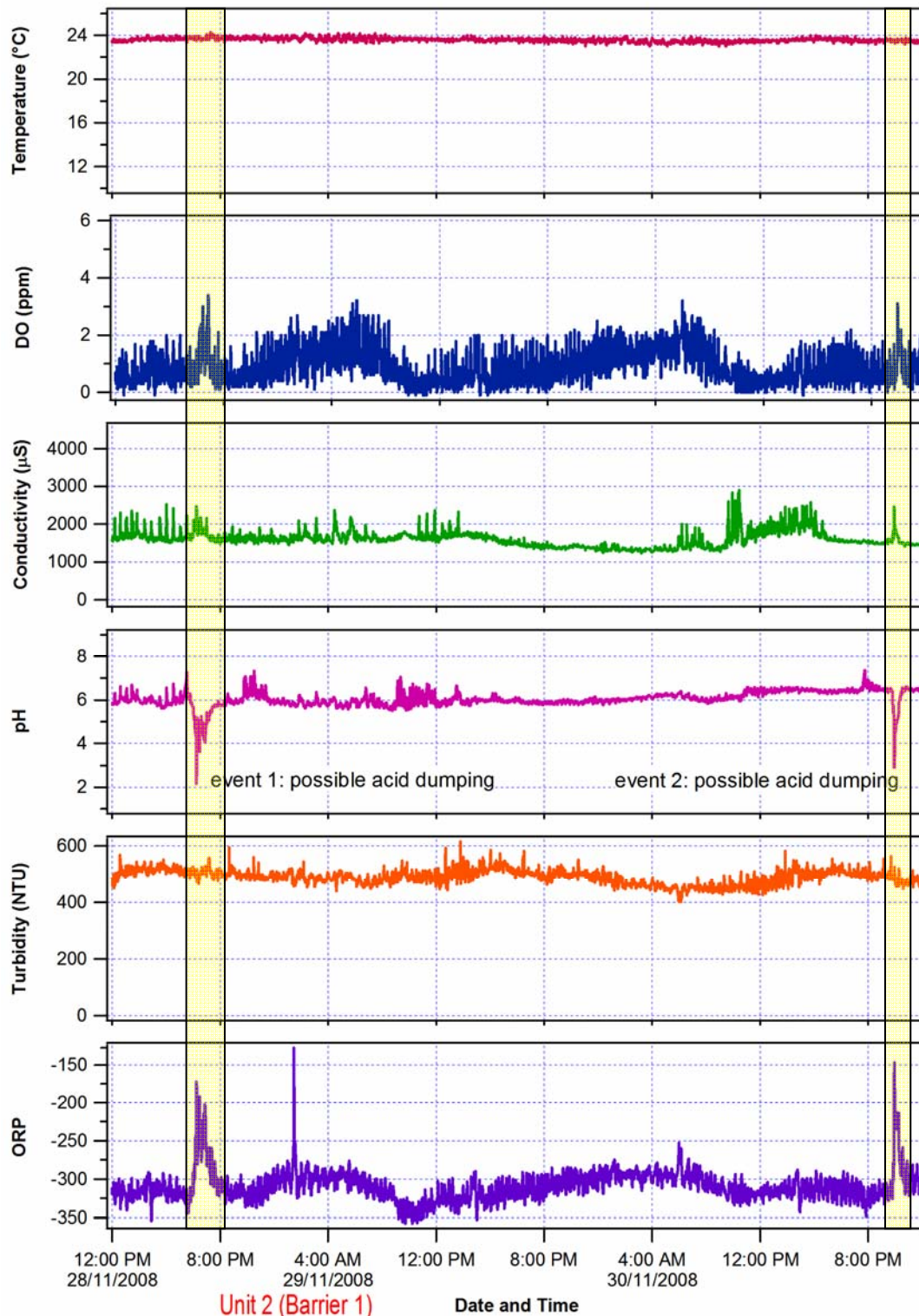


Figure 1.3 Multi-sensor time plot from raw sewage inlet to Bundamba WWTP showing two discharge events.

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Development of Methods for the Improved Recovery and Detection of Viruses in Water

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Summary

The detection of enteric viruses is hampered by the need to concentrate low numbers of viruses from large volumes of water. When the water to be tested is of low quality, for example raw and treated sewage, interference can occur due to the presence of particulate matter and other contaminants. This interference can cause low recovery and detection efficiencies. Research is being undertaken to develop a simple method that can improve the recovery efficiency of enteric viruses from low quality water and assist in the improved detection of the viruses in the concentrate.

Keywords

Enteric virus, concentration, recycled water, adsorption.

Introduction

The detection of enteric viruses in water is complicated by the fact that the viral particles are in low numbers and randomly distributed in large volumes of water. The viruses need to be concentrated to a volume that is suitable for the detection method used. For example, for use in Polymerase Chain Reaction (PCR) a final concentrate volume of less than 1 mL is usually needed to efficiently detect any viral nucleic acid present. There are a number of methods in the scientific literature and commercially available. The most common methods currently used to concentrate viruses from water are listed in the US EPA Methods for Virology (EPA/600/4-84/013) using adsorption-elution methods, for example using positively charged cartridge filters (US EPA 2001). Other methods include treated glass wool (Gantzer et al. 1997, Lambertini et al. 2008) and immunomagnetic capture (Casas and Suñén, 2002). Most of these methods suffer from low recovery efficiency, or are unable to be used in low quality water. They are all time consuming and expensive and require the collection of large volumes of water, particularly treated water, in order to be able to detect any viruses present.

This paper provides information on the potential development of a virus concentrator device that combines the ability to cheaply and efficiently capture viruses from large volumes of water and the attributes of an autosampler where volumes of water are sampled over long periods of time.

Methodology

Enteric viruses behave as negatively charged particles in the water, this property can be used to capture viruses on a suitable surface with electrostatic binding. In order to develop a suitable prototype virus capture system we have tried positively charged and negatively charged membranes. Tap water samples ranging from 10 mL to 1L were used in these experiments. The method outlined by Katayam et al. (2002) was used to bind and release viruses from the negatively charged membranes. The ability to capture different enteric viruses was tested on negatively charged and positively charged membranes and other potential capture media such as polystyrene beads. The viruses tested to date have been the enteric viruses (adenovirus and coxsackievirus).

Recovery Efficiencies

In the initial experiments, positively charged nitrocellulose (Millipore) cut membranes (1 cm²) were used to recover seeded adenovirus in tap water with recovery rates of 1% or less. Then HA negatively charged membrane (Millipore) with a 0.45µm pore size and 47 mm diameter was used with a recovery efficiency of 14 to 18% (Table 1). Passage of water (100mL) seeded with adenovirus through the 47 mm diameter HA type filter resulted in higher recovery efficiency (60-70%), which is comparable to Katayama et al. (2002).

In the second set of experiments, 1L tap water was seeded with two different concentrations of adenovirus and coxsackievirus to determine the virus capture capacity of the HA negatively charged membrane (0.45µm pore size and 47 mm diameter). The results are summarised in the Table 2.

Table 1. Adenovirus capture and recovery efficiency with HA negatively charged membranes.

Sample ID	Initial virus concentration in water 100mL (PDU/mL)	Virus concentration in eluate 1mL (PDU/mL)	% Recovery
Adenovirus			
Cut membrane A	6×10^5	9.15×10^6	18.30
Cut membrane B	5.85×10^5	8.50×10^6	14.53
Full membrane A	6.80×10^5	4.91×10^7	72.21
Full membrane B	5.35×10^5	3.17×10^7	59.25

Table 2. Virus capture and recovery efficiency with 1L water sample at different virus numbers.

Sample ID	Initial virus concentration in water 1L (PDU/mL)	Virus concentration in eluate 1mL (PDU/mL)	% Recovery
Adenovirus			
High virus con. A	5.55×10^6	6.70×10^8	12.07
Low virus con. B	1.80×10^5	8.15×10^7	45.27
Coxsackievirus			
High virus con. A	4.17×10^6	4.91×10^7	11.51
Low virus con. B	8.85×10^4	3.17×10^7	30.62

Higher virus concentration in the water resulted in lower recovery rates which suggested that higher membrane surface area results in higher capture of virus. This also suggested that 47mm diameter membrane was possibly not sufficient when more than 100mL is used with higher numbers of viruses. Un-treated polystyrene spheres were tried for their ability to capture enteric virus from the seeded tap water (Table 3). As expected, results of this experiment suggested that coating of polystyrene spheres with higher negatively charged compounds is required for improving virus capture capacity.

Table 3. Results from the experimentation with the polystyrene beads.

Sample ID	Initial virus concentration in water 10mL (PDU/mL)	Virus concentration in eluate 1mL (PDU/mL)	% Recovery
Coxsackievirus			
A	6×10^7	3.01×10^6	0.50
B	1.07×10^8	4.64×10^6	0.43
Adenovirus			
A	1.70×10^8	2.13×10^7	1.25
B	2.58×10^8	1.60×10^7	0.62

Conclusions

Negatively charged membranes have worked better than positively charged membranes. The added advantage of working with negatively charged surfaces to capture viruses is that release of captured viruses does not require solutions with extreme pH and beef extract which can inhibit PCR reactions. Surface area plays an important role in the capture of viruses, with more virus capture with higher surface area. In future, efforts will be made to determine suitable functional groups which can be used to coat beads (latex or polystyrene) to capture viruses from the water samples without co-purification of PCR inhibitors.

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Understanding Different Community Reactions to Water Recycling Policy in Australia: the Influence of Emotions and Fairness

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Summary

Emotional reactions to recycled water, such as disgust - commonly termed the 'yuk factor' - are used as a primary explanation for why many people are unwilling to adopt recycled water for potable use (Dolnicar and Schafer, 2006; Po, Kaercher and Nancarrow, 2004; Po et al, 2005; Marks, 2003) and as a rationale for disregarding proposed water recycling schemes (Russell and Lux, 2009). Fairness however, has been found to be a major predictor of community reactions, including acceptance and compliance, to a wide range of urban and rural water management and policy issues (Syme, Nancarrow and McCreddin 1999). Research on recycled water use in an urban Australian context has demonstrated that processes that are perceived as fair are positively related to satisfaction (Hurliman, Hemphill, McKay and Geursen, 2008) and negatively related to risk perceptions (Hurlimann, 2007). There is limited research specifically on the relationship between fairness, emotions and intended behaviours in response to water recycling policy. This paper uses data collected in a study of community attitudes towards a proposed water recycling scheme in South East Queensland (SEQ) to discuss the: a) different attitudes of supporters, opponents and those who are uncertain about the scheme b) relationship between emotion and intended behavioural reactions and c) the role of perceived fairness in this observed relationship. Implications for communicators and policymakers are considered.

Keywords

Procedural fairness; emotion; recycled water; behavioural intentions.

Theoretical Background

There are two basic types of fairness that are predominately discussed in the literature: the perceived fairness of the distribution of resources, risks or burdens - known as distributive fairness; and the fairness of the decision-making process used to determine such distribution- procedural fairness (see Tyler and Blader, 2000 for reviews). Research has demonstrated that individuals' reactions to decisions made by another person or an authority are influenced by how fairly they perceive the decision-making process to be, independent of how desirable the outcomes of that process may be (Thibaut and Walker, 1975). Theoretical models (Lind and Tyler, 1988) suggest that fair procedures are important because they indicate to community members that they are valued by the authority, and are therefore more likely to lead to acceptable outcomes. Social justice research also indicates that people pay more attention to fairness when they are uncertain, as explained by fairness heuristic theory (Van den Bos, 2001). For example, fairness appraisals are often used by people as an analytical tool to help them make a decision when they are uncertain.

The relationship between emotions and the perceived fairness of decision-making processes or outcomes is predominately presented in the literature as unidirectional: that is, the presence or absence of fairness results in positive or negative emotional reactions respectively (Krebheil and Cropanzo, 2000); however, there is empirical evidence that people's cognitions can influence and be influenced by their emotional state (Murphy and Tyler, 2008; Isen 1993). Traditional risk analysis tends to emphasise cognitive processes and disregard emotional responses which are typically viewed as irrational (Slovic et al, 2004). Emotional appraisals of risk are fast, largely automatic, and have enabled human survival throughout evolution. Information processing involves two interactive and parallel systems: the rational system (e.g. logic and probability) and the experiential system (e.g. stories and emotions) (Epstein, 1994). As such, decisions informed by the experiential system need not be framed as irrational.

Methodology and Results

As part of the ongoing Systematic Social Analysis research activities of the Urban Water Security Research Alliance a series of community workshops and four telephone surveys of people's attitudes towards the proposed Purified Recycled Water (PRW) scheme were conducted. The first survey was conducted in November 2007 to provide an indication of baseline behavioural intentions and attitudes towards the scheme (Nancarrow et al, 2007). The three monitoring surveys that followed (Time 1 in May 2008; Time 2 in July 2008; and Time 3 in December 2008) were designed to track changes in attitudes towards the scheme over time, and examine how the supporters, opponents and those who are uncertain about the scheme differ. The final monitoring survey was conducted after the

Queensland Government announced the decision to only add PRW to Wivenhoe Dam when levels fall below a critical point of 40%, and as such provided an opportunity to assess the impact of this outcome on attitudes and behavioural intentions of supporters, opponents and those who were uncertain.

Differential changes in attitudes were recorded post-announcement for the supporters of the scheme compared to those who were uncertain and those who opposed the scheme. A decrease in support for the PRW scheme was evident after the government's announcement, but the shift in support was only evident amongst those respondents who had initially supported the scheme.

Respondents' overall perceptions of others' attitudes toward PRW were biased in the direction of their own attitudes, suggesting that there is a false consensus effect emerging (Marks and Miller, 1987). For instance, supporters of the scheme perceived significantly greater support from the community and their family for PRW than those who are uncertain or those who oppose. Results also indicate that people attribute emotional motivations to those with an opposing view of the scheme. For instance, supporters of the scheme reported that those who oppose the scheme are driven by emotion; similarly, opponents of the scheme reported that those who support the scheme are driven by emotion.

It is also evident that respondents differentiate between family and the broader SEQ community depending on their own level of support ($p < .01$). Supporters of PRW perceive significantly greater support from family than the SEQ community for the scheme, whereas opponents perceive significantly less support from family than the SEQ community. Furthermore, respondents' level of support for PRW significantly influenced their beliefs about the necessity for consultation about PRW ($p < .01$). Opponents were unhappy that they had not been consulted and felt that others in SEQ were also unhappy, whereas uncertain respondents and supporters on average were not unhappy that they had not been consulted. The current research clearly shows that the perception by opponents of the scheme that others in the SEQ share their lack of support for the PRW scheme is inaccurate.

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Systematic Social Analysis of Household Water Demand Management

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Summary

The research presented in this paper aims to understand the drivers of household water conservation and how water conservation can be supported as a 'way of life' in South East Queensland (SEQ). The research draws on the Theory of Planned Behaviour and comprises three phases. In the first phase, focus groups were conducted to identify the salient costs and benefits, barriers and facilitators, and normative influences on two types of behaviours: everyday water conserving behaviours and installation of water efficient appliances. The second phase of the research involves a baseline survey of SEQ households to identify the key psycho-social and socio-demographic determinants of household water conserving behaviours. In the third phase, interventions that address the key drivers of household water conservation will be evaluated to assess their long-term effectiveness. Data from the current research will be integrated with data from the Residential Water End Use study being conducted within the Urban Water Security Research Alliance to provide a comprehensive analysis of household water demand management in SEQ.

Keywords

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

Introduction

The availability of freshwater resources for urban populations has become a focal issue in recent years. Predictions of the Intergovernmental Panel on Climate Change suggest that freshwater water resources are vulnerable to the impacts of climate change, and moreover, that existing stressors on water demand including population growth, land use change and urbanization will be exacerbated by climate change (Bates et al., 2008). These predictions further suggest that residential water demand is an important area for focus given projected and actual population growth in relatively water-scarce urban areas (Bates et al., 2008). Thus, future reductions in water supply and increasing water demand will be critical issues world-wide (Bates et al., 2008) requiring policy and strategies that specifically address urban water demand management.

We argue, however, that to develop effective policy in this area, there needs to be an understanding of the key psycho-social and socio-demographic drivers of water conservation (Abrahamse et al., 2005) and an evaluation of mechanisms that aim to address these drivers. It is evident, however, that there is a dearth of research addressing these issues, and the research that exists has serious limitations. The main limitations are the lack of appropriate measurement of household water use behaviour and the use of individual-level psycho-social variables to predict a collective level outcome (i.e., household water use) (cf. Steg and Vlek, in press). The Systematic Social Analysis of Household Water Demand Management project seeks to investigate the social dimensions of residential water demand management in SEQ and in so doing provide valuable information to water policy makers and address limitations of previous research in this area. Specifically, the project aims to: 1) identify the psycho-social and socio-demographic drivers of water conservation practices, 2) determine the effectiveness of targeted intervention strategies for achieving long term sustainable residential water use, 3) gain an understanding of how best to tailor intervention strategies for different sectors of the community, and 4) significantly advance the scientific literature on water demand management.

Conceptual Framework

The research draws on the Theory of Planned Behaviour (TPB; Ajzen, 1991) as the framework to guide the research. The TPB is an extensively used and well-supported model of the informational and motivational factors that combine to predict behaviour. In the TPB, the most immediate determinant of behaviour is an intention (i.e., a motivation or plan) to engage in the behaviour (e.g., water conservation). The TPB proposes intention to be determined by the additive effects of attitude (i.e., overall positive or negative evaluation of water conservation behaviours), subjective norm (i.e., perceptions of whether important others support water conservation behaviour) and perceived behavioural control (i.e., extent to which water conservation behaviour is within an individual's control). The TPB also proposes that attitudes, subjective norms, and perceived behavioural control are underpinned

by context specific beliefs. For example, attitudes to water conserving behaviours are formed through an individual's assessment of the perceived costs and benefits associated with water conservation behaviours. As a parsimonious model of human decision-making, the TPB allows for the inclusion of additional variables that can help to improve the explanatory power of the model in relation to the focal behaviour (in this case household water conservation). A review of the literature suggests that in addition to the TPB variables, habits, personal norms and collective-level variables such as community norms and identification, and household culture, may be important additional determinants of household water conservation behaviours. Figure 1 provides a summary of the basic TPB model that will guide the research program.

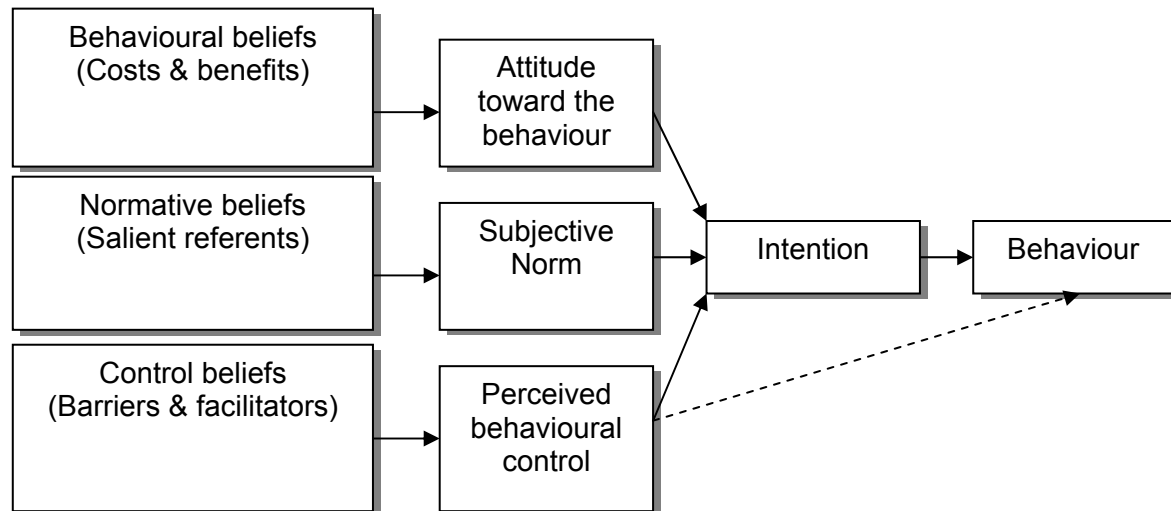


Figure 1. Theory of planned behaviour

Methodology

The research will proceed in three phases with participants recruited from four regions of SEQ: Sunshine Coast, Gold Coast, Ipswich, and Brisbane. The first phase, which has already been conducted, involved 12 focus groups (N = 84 participants) across the four regions of SEQ. The focus groups elicited the salient beliefs associated with everyday water conserving behaviours and installing water efficient appliances in the home through posing questions about the advantages/disadvantages, facilitators/barriers, and sources of approval/disapproval of these actions. In the second phase, a baseline survey will be conducted to assess the expanded TPB model (see Figure 1). Attempts will be made to collect data from the adult-decision makers of the household and this data in conjunction with the inclusion of collective-level social variables will help to address previous limitations in the research area. The psycho-social and socio-demographic measures in the survey will be linked to household water use data drawn from council records. In addition, a subset of households will be recruited into the Residential Water End Use study being conducted in the Urban Water Security Research Alliance and, for these households, survey responses will be linked to water end use data. Thus, psycho-social and socio-demographic variables can be linked to objective measures of overall household water use as well as to specific household water use. The third phase of the research will be an evaluation of intervention strategies developed to address the key drivers of water conservation as identified from the Baseline survey. The short-term and long-term effectiveness of interventions will be assessed using data from the Water End Use study.

Preliminary Findings

Findings from the focus groups indicated that financial considerations underpinned some of the beliefs associated with water conservation. The short-term and long-term monetary savings associated with everyday water conservation behaviours or installation of water efficient appliances was a major benefit identified by participants. On the other hand, the upfront cost associated with installing water efficient appliances was highlighted as a disadvantage. Environmental protection and water security for future generations were also cited as major benefits of water conservation, a finding that may reflect concerns with intergenerational equity and resilience to climate change. An important belief was that installation of water efficient appliances has the advantage of lowering the need to monitor and be vigilant about everyday water using practices. This latter belief raises questions about whether water savings achieved from installation of efficient appliances will be fully realised if householders consequently believe they do not need to monitor their everyday behaviour. Beliefs about the disadvantages of

everyday water conserving behaviours related mainly to their impact on lifestyle. These types of actions were perceived by some to be time consuming and inconvenient, and to impact negatively on quality of life, health and hygiene. Social marketing reminders (e.g., advertising, feedback on rates notices) were the most often cited facilitator of everyday water conserving actions (i.e., curtailment behaviours). This finding suggests that government media and educational campaigns and information service provision by water retailers that aimed to promote water conservation in homes, have been received positively and perceived as effective by participants in the study.

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SEQ Residential Water End Use Study: Closing the Loop on Urban Water Planning and Management

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Summary

Australia's climate and prolonged droughts instigated the need for strategic water and wastewater planning and management. To address this need, water corporations must invest in the development and implementation of advanced water metering technologies and the associated information management systems that can provide real-time water end use data to both water corporations and customers, thus enhancing their current level of understanding on how, when and where water is being consumed. The Urban Water Research Security Alliance (UWRSA) has commissioned a South East Queensland (SEQ) water end use study on 320 domestic households. This paper reports on the project plan and key deliverables of this significant study, as well its implications for government and water corporations with respect to: (1) urban water infrastructure planning and management; (2) water demand management; and (3) water consumption information provision to customers.

Keywords

Smart metering, water end use, water planning and management.

Introduction

Water security is becoming one of Australia's greatest issues of concern. The ever more restrictive water supply situation will accelerate the cost of water whilst simultaneously constricting its use, forcing users to apply best practice water conservation measures for their water intensive activities. Water end use studies are becoming an essential means to understand why, how and when water is being utilised and actively facilitates the proactive management of precious water resources (Loh and Coghlan, 2003).

The present water end use study on 320 domestic households aims to develop a greater understanding on the current domestic end use water consumption patterns for households with various demographic characteristics in Australia's South East Queensland (SEQ) region through a smart metering approach, and to determine the degree of impact that demand management initiatives have on end use water levels. This end use project is aligned with the Systematic Social Analysis (SSA) of household water demand management study.

End Use Analysis and Results

The standalone end use project will produce the following outcomes:

- Volumes for water end use categories for participating homes including most appliance/fixture categories (i.e. dishwasher, shower, washing machine, taps, etc) over each season and after demand management interventions. End uses will be provided as both average total daily volumes and litres/person/day.
- Comparative analysis on water end uses between different household demographic categories (e.g. family structure, socio-economic status, etc).
- Comparative analysis on water end uses of households with different fixture/appliance star ratings.
- Seasonal diurnal patterns for hourly water use for sampled households.
- Leakage volumes and leak typology pattern analysis.
- Water end uses before and after a range of natural and instigated interventions (e.g. restrictions, provision of information, etc).

End Use Findings Combined with SSA of Household Water Demand Management Study

The combined data will provide in-depth explanation as to some of the socio-demographic and psychological factors that influence water consumption behaviours as well as possible strategies to affect them, including:

- The human and social behaviours that influence both overall and specific end use water consumption levels and patterns.
- The nature of the household social dynamics and how they influence overall and specific end use water consumption levels and patterns.

- Targeted water demand management interventions (i.e. to particular water end uses) that can best influence the behaviours of groups with socio-demographic and/or psychological factors that undervalue the importance of potable water.

Method

This study adopted a smart water metering approach, utilising high resolution meters and a wireless data logging system. End use data will be collected continuously through daily data transfers via GPRS to a remote server for the life of the project. Computerised end use data analysis for representative sample periods (e.g. baseline survey, etc) will be conducted using the Trace Wizard® program. The study's main tasks for the first year are summarised below:

- Task 1: Research design and project plan development (April-June 2009)
- Task 2: Procurement of project equipment and obtaining consenting participant group (April-August 2009)
- Task 3: Meter deployment and commencement of end use data collection (September-November 2009)
- Task 4: Self assessment water audit and follow up (September-December 2009)
- Task 5: Baseline study end use analysis and intervention study design (November-December 2009)
- Task 6: Commencement of intervention as well as advanced trace analysis study (January-March 2010)
- Task 7: Summer end use data analysis, formal report and research paper (April-June 2010)

Project Progress and Outputs

Once the data has been collected, the presentation of results obtained is expected to be similar that of the recent Gold Coast water end use study conducted by Willis *et al.* (2009), as exemplified in Table 1 and Figure 1. However, the combined study will derive world first outcomes in this field.

Table 1. Example of end use data comparison based on different study locations (Willis et al. 2009)

	Perth (2003)		Melbourne (2005)		Auckland (2007)		Gold Coast (2008)	
	L/p/d	Percent	L/p/d	Percent	L/p/d	Percent	L/p/d	Percent
Clothes washer	42.0	13%	40.4	19%	39.9	24%	30.0	19%
Shower	51.0	15%	49.1	22%	44.9	27%	49.7	33%
Tap	24.0	7%	27.0	12%	22.7	14%	27.0	17%
Dishwasher	NA	NA	2.7	1%	2.1	1%	2.2	1%
Bathtub	NA	NA	3.2	2%	5.5	3%	6.5	4%
Toilet (total)	33.0	10%	30.4	13%	31.3	19%	21.1	13%
Irrigation (total)	180	54%	57.4	25%	13.9	8%	18.6	12%
Leak (total)	5.0	1%	15.9	6%	7.8	4%	2.1	1%
Total Consumption	335.0	100%	226.2	100%	168.1	100%	157.2	100%

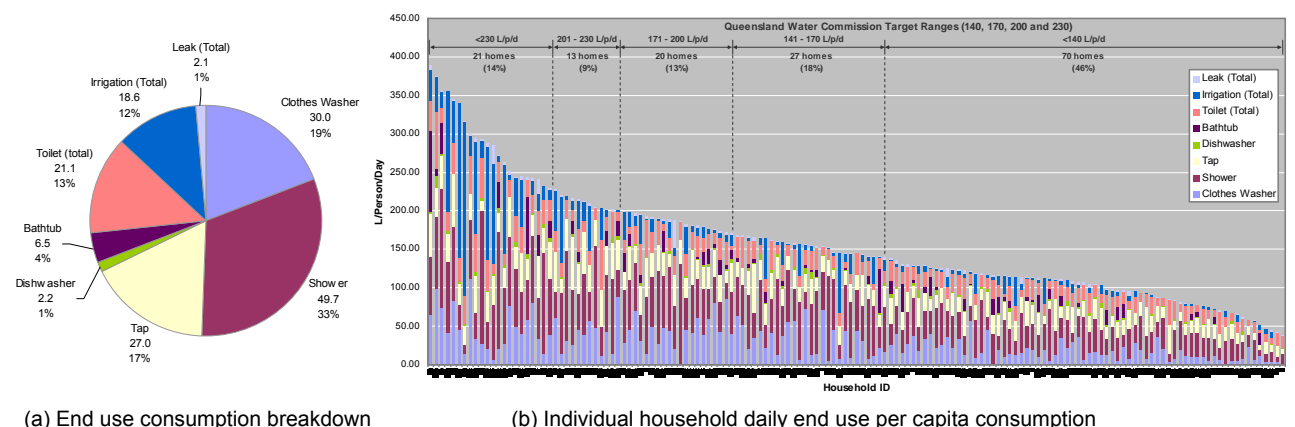


Figure 1. Examples of end use data analysis results (Willis et al. 2009)

Benefits

The end use project will yield numerous benefits with respect to: (1) urban water infrastructure planning and management; (2) water demand management; and (3) water consumption information provision to customers. Some of these benefits include:

- Better targeted: (1) marketing and education program for reducing water consumption levels within different urban communities and demographic groups; and (2) rebate programs (e.g. washing machines) to ensure that only the least cost rebate schemes are implemented.
- Better understanding on: (1) household leakage and measures to reduce current levels; and (2) how socio-demographic and psychological factors influence water consumption levels within the specific fixture/appliance end uses of residential households.

In summary, the study will facilitate the optimisation of water management policies and practices to ensure that potable water savings are achieved in the most efficient manner and at the least cost.

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Why Good Water Accounting is Critical to Economic Decisions, Modelling and Sustainable Management of Water

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Introduction

This paper summarises recent draft reports on water accounting undertaken for the Urban Water Security Research Alliance (UWSRA) (McBean et al 2008, 2009; and Daniels et al 2009). The analysis considers how systematic water accounting across the environment and the South East Queensland (SEQ) economy, have the potential to provide mission-critical data for the effective implementation and assessment of the SEQ Water Strategy. Without good water accounting frameworks and data, it will be almost impossible to (i) make accurate determination of the economic consequences of alternative water policy and management options (ii) accurately model future scenarios and (iii) assess impacts of alternatives. This work has been undertaken as a component of the Life Cycle Assessment and Integrated Modelling (LCA-IM) Project which aims to support the SEQ Water Strategy and associated water supply and demand management decision-making over the medium to long term.

Keywords

Water accounting, economic decisions, modeling, sustainable water management.

National and International Trends in Water Accounting

Water accounting is relatively new in terms of methodology and practice. However, in response to growing pressures and awareness of serious supply-demand imbalances across many regions of the world, and the underpinning nature of water in many economies, its recent development has been rapid. There are now several, partially-related water accounting frameworks in various stages of design and implementation:

- the SEQ *WaterHub* (prepared by the Queensland Water Commission (QWC)) is perhaps the most detailed of these schemas and currently one of the most sophisticated and comprehensive water information system in the world. Its regional database compiles and standardises water-related data and information (QWC 2008). Understandably, the emphasis to date has been on urgent short-term priorities. Although the measurands covered are grouped according to distinctive features of the water cycle, the scheme is not based on existing water or other resource accounting frameworks and mainly represents a response to priorities of the QWC.
- the national Australian Water Resources Information System (AWRIS), stems from the National Water Initiative (NWI) and compiles information from over 200 entities (Bureau of Meteorology 2008). Water use in AWRIS, has a supply-side focus on the natural water system in its current state (unlike the distinct economic analysis framework adopted in the SEEAW).
- the United Nations' System of Environmental and Economic Accounts (SEEA) as extended to water resources (SEEAW) has an emphasis upon economic supply and use biophysical flows and integrating physical and economic data. This framework will soon become the essential standard for guiding the accounting linkages between physical water flows and human intervention.

Benefits of Water Accounts

1. Accounting Can Enable Economic Analysis of Water Policy

Amongst a multitude of potential capabilities good water accounts can provide detailed information on all users of water, the relative economic value-added of that water use, and the relative costs and most cost-effective way of reducing water use to sustainable levels. Good water accounts provide the basis for identifying those supply and use options that provide the most efficient way (least cost to society) to manage water. Water account data enable analysts to quickly determine \$ impact to Sector y caused by Policy j. To undertake such analysis, consistent definitions and data storage across water, economic and other sectors is needed. Recent analysis of the Victorian economy (Lenzen 2008) links the water accounts of the Australian Bureau of Statistics with the more detailed economic data of the Australian Input-Output tables to derive a rich basis for tracking water flows through the Victorian economy. A concise summary of benefits of linking to the System of National Accounts 1993 is outlined in Foran et al (2004). They include integration with critical socio-economic policy data, analytical flexibility and internationally consistency.

Ensuring data consistency and complementarity between economic and water accounts has great potential for guiding effective and economically strategic water policy. For example, our research has revealed that the non-residential land use classification planned in the current version of the SEQ WaterHub does not align with the only sources of economic data available about water users (notably ABS economic statistics). If water use cannot be matched to information about industries and sectors, a major basis for efficient management strategies for the resource will be lost.

2. Accounting Underpins Modelling

Access to detailed, relevant and timely empirical water data is essential for hydrological modelling. The urgent need to ground abstract hydrological models in an empirical base is clearly evident in contemporary scientific publications:

As modelling power has increased there has been a concurrent reduction in “data power”, particularly in the collection of hydrological data. (Silberstein (2006))

The first step is to use the model uncertainties (which represent those aspects of the hydrological systems that are least understood) to collect new or better data, improve data assimilation techniques or study specific processes. In the second step, the model should be improved using these data, methods and concepts. (Buytaert, Reusser et al (2008))

Empirical water data plays a critical role in hydrological modelling throughout all stages of model development, calibration, implementation and validation. In so-doing it helps create more realistic, transparent and accountable hydrological models. Good frameworks also help minimise error and uncertainty associated with model outputs (Kirchner 2006, Beven 2007, Silberstein 2008). Without access to such information, the accuracy of models and their capacity to be used as a predictive tool is compromised.

3. Accounting Enables Assessment of Water Management Options

The network of dynamic water flows throughout a region is intrinsic to assessing the relative material, energy and other environmental impacts of the range of possible supply-demand options for managing water in a region. Measurement of these flows in appropriate spatial and temporal “locations” provides not only (1) the benchmark for assessing impacts in terms of water service, but is also (2) the essential biophysical unit for the whole range of relevant biophysical and economic indicators and (3) the empirical base for identifying related changes throughout the hydrological system.

Trends in Water Accounting and Conclusions

More recently water accounts are integrating within spatial database systems which offers dramatic and powerful new capacities. Accounts are also increasingly integrating other water quality, climatological and hydrological data (ABS 2006; NWC 2007). While economic analysis and some forms of life cycle analysis are driven by standards (such as the United Nations System of National Accounts 1993 and ISO14040 respectively), many water analysis techniques such as water footprint and virtual water flow are yet to be standardised (Daniels and McBean 2009). It is clear that this development is necessary.

This work describes how well-formed water accounts are critical for the analysis of water options, particularly if any economic criteria are to be considered. Regional and national water data structured to match economic and hydrological modelling formats and requirements will help meet the analysis needs of strategic water policy. The research identifies areas for improved alignment and data collection in relation to integrated hydrological modeling, scientific and policy analysis, and the draw upon national and international accounting frameworks. There remains a clear need to ensure that water accounting in SEQ remains abreast of accounting approaches to ensure that the multiple benefits of systematic accounting are realised. The SEQ IUWM project aims to ensure this is the case.

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Knowledge Requirements for Water Management in South East Queensland

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Summary

The onset of the ‘millenium drought’ in South East Queensland (SEQ) has raised questions about the capacity of traditional knowledge bases and institutions for water management to secure a reliable supply of water to meet future needs. In response to these challenges, the aim of this research project is to determine the characteristics of institutions that are not only dependable, despite uncertain science, but are also flexible enough to adapt to changing social and environmental conditions. This paper reports on the results of an initial round of interviews conducted with key individuals involved in water management in SEQ. The development of ‘knowledge capacities’ for water management has emerged from this research as one of the most important institutional challenges currently faced by water managers in SEQ. Several key questions arise from the analysis of these results, which will guide future research.

Keywords

Knowledge, institutional capacities, water management, adaptive management, South East Queensland.

Background

The recent ‘millennium drought’ in SEQ has raised questions about the capacity of traditional knowledge bases and institutions for water management to secure a reliable supply of water to meet future needs. A number of challenges have contributed to this questioning. First, the uncertainties associated with the science that has traditionally informed water planning are now widely recognised, so that established methods of water planning based on historical average rainfall patterns are being revised. Second, the possibility of increased climate variability and surprise events due to climate change has led to a questioning of traditional approaches to ‘management’ based on prediction and control. Third, the emphasis on ensuring a reliable supply of water is shifting in response to concerns about sustainability, so that water storage solutions are being complemented with other approaches, such as demand management.

In response to these challenges, this research project aims to identify the drivers of institutional stability and change, and the lessons for building institutional capacity for sustainable water management in SEQ. Specifically, the goal is to identify the institutional conditions that underpin the ‘resilience’ of institutions – institutions that are stable and dependable despite uncertain science, and are also flexible enough to adapt to changing social and environmental conditions. This paper reports on the first phase of this research, which sought to identify the institutional characteristics associated with water policy reform in SEQ between the early 1990s and 2006.

Method

Interviews were conducted with 15 key stakeholders with extensive experience in water management in SEQ. The duration of each interview was 50–90 minutes. Interviews were recorded and transcribed, and coded into themes using Filemaker Pro qualitative data analysis software. The institutional analysis framework developed by Scott (1995) guided the research design and analysis. This approach suggests that three interdependent elements influence the degree of institutional stability and change: (1) the shared understandings, which influence the kinds of knowledge and expertise considered legitimate to shape and address the problem; (2) the underlying values, which define roles and responsibilities for action; and (3) the organisational base, including the rules and sanctions that regulate social interaction.

Results

The development of ‘knowledge capacities’ for water management has emerged from this research as one of the most important institutional challenges currently faced by water managers in SEQ. The forms of knowledge and expertise considered to be important to water management have changed over time, so that new disciplinary expertise and evidence bases not previously integral to water management in SEQ have been introduced – from the

environmental and biological sciences, to expertise in environmental flows, energy and productivity, demographics, water use in the home, public attitudes, and demand management. Innovation capacities have also developed and shifted over time, from analytic innovation relating to climate modelling, to operational innovation in the realm of contingency planning, to technological innovations such as membrane technologies.

These shifts in knowledge capacity are related to changing roles and responsibilities. As the integrated approach to healthy waterways developed in the 1990s and early 2000s, a diversity of organisations became involved in water management. Since around 2004, drought response strategies have involved a dynamic reform of roles and responsibilities to secure water supply. At the same time, there is an increasing recognition of the need to develop adaptive capacity by sharing responsibility and spreading risk across the water system.

In terms of the organisational base, the influence of COAG agreements around the mid-1990s promoted new forms of collaboration between government and non-government actors. The need to develop collaborative capacity to structure the interactions between water management organisations was considered to be important to facilitate integrative thinking and organisation. Nonetheless, the role of alliances and collaborations has waxed and waned over time with the changing influence of hierarchical regulative modes.

Analysis

The results of this research indicate that there are a range of different organisational responses to uncertainty and the associated challenges facing water management. As the influence of different values constrains existing decision systems, new organisational forms, structures and responses are created. Rather than replacing existing management strategies, however, these emerging responses introduce additional strategies for dealing with uncertainty so that a range of institutionalised practices exist in a dynamic state of ebb and flow.

At the same time, the development of an integrated approach to water management in SEQ is being hindered. Key issues raised include the need to integrate diverse forms of knowledge, to address the schism between water quantity and quality, and to bridge the gap between science and strategy development. Related water management research has demonstrated the value of brokers to translate knowledge across the interface between science, management and policy (Cash et al. 2002). This issue, in turn, points to a requirement for collaborative capacity, or the formal and informal arrangements to facilitate structured interaction between water management organisations. Information sharing between organisations and the need for collaborative inter-organisational relationships have also been identified as important for sustainable urban water governance in Sydney (van de Meene et al. 2009). Building capacities to transfer and integrate knowledge promotes technical and organisational learning, contributing to the problem solving and innovation that underpin effective and flexible water systems (Pahl-Wostl 2008).

Conclusion

The results of this research resonate with related work, which has identified the capacity of government, industry and community organisations to transfer, translate and integrate different types of knowledge to inform water policy and management responses as a key challenge (Lane and Robinson 2009). The next phase of this research aims to identify the institutional conditions required to build knowledge capacities in the SEQ water system. Key questions include: What knowledge transactions occur and need to occur within and between organisations, and who are the key knowledge brokers? What concepts allow knowledge to be translated across professional boundaries? What kinds of alliances and collaborations might provide vehicles for knowledge integration? What institutional conditions enable learning within and between organisations? This work will contribute to the broader understanding of how institutions actually affect water management options and outcomes.

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Purified Recycled Water in the Lockyer Valley: Issues and Research

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Summary

We have conducted an assessment of previous work carried out in the Lockyer Valley with relevance to future application of purified recycled water (PRW) as an adjunct to groundwater as a source of irrigation water. Three broad areas of necessary research were highlighted:

1. Social and economic consequences of recycled water use
2. Practicalities (technical feasibility) of recycled water distribution and use
3. Biophysical consequences of recycled water use

This paper addresses factors related to the biophysical consequences of importing and using PRW. Specifically:

- a. Groundwater quality consequences
- b. Surface water quality consequences
- c. Groundwater-surface water interaction
- d. Water storage constraints
- e. Contaminant (including salinity and nutrients) mobilisation
- f. Sustainable water supplies

Keywords

Lockyer Valley, hydrogeology, hydrology, groundwater, modelling, 3D visualization.

Background

Previous studies of soils of the Lockyer Valley have identified a variety of soil types with properties conducive to agriculture (Heiner, et al., 1999). However, models for water transport through these soils and into the underlying aquifers have been constrained to regions immediately adjacent to the irrigation areas of the valley floor (Ellis and Bajracharya, 1999; KBR, 2002). A catchment-wide study of groundwater chemistry and stable isotopes confirms the main recharge to the alluvial aquifers is from stream recharge from the peripheral ranges, but also that there can be substantial evaporative changes to irrigation waters within the alluvium (Cox and Wilson, 2005). To date, soil analyses have focussed on disturbed profiles within the irrigation district, and hence do not reflect the regional equilibrium conditions that prevailed prior to development of the area. There is a need to consolidate existing knowledge across the catchment and for further analyses of alluvial materials. Such testing is to establish the pre-existing pristine conditions of the region and the likely effects of applying both groundwaters and PRW as irrigation water on the region's soils. Essential factors to consider are the processes within soils of deep drainage and potential structural changes.

Changes in the hydrological balance will have effects on both surface and groundwater transport through the region. If these effects are adverse, there will be implications both to the regions ability to produce irrigated crops and potentially on downstream discharge to the Brisbane River upstream of the main Brisbane water processing plant at Mt Crosby. These effects must therefore be understood, quantified and modelled prior to application of introduced water to the region (and commensurate reduction in groundwater application). This is regardless of the nature of the additional water, be this PRW or alternate schemes, such as managed aquifer recharge.

The region is strongly affected by the seasonality of rainfall and the shallow alluvial groundwater systems generally respond rapidly where close to streams, both during recharge and the subsequent discharge of waters. Response is spatially variable, however, and strongly determined by soil-type and land-use. The system switches between one in which surface and groundwaters are strongly connected and interactive, to one in which they are disconnected and isolated. Understanding contaminant mobility (salts, nutrients and pathogens) is vital for sustainable management of the region. Modelling of these changeable interactions poses many problems, but new models are being developed that successfully link the processes operating at the surface and within aquifers, linking the shallow, variably saturated and unsaturated zone with the continuously saturated zone.

We propose to carry out linked field studies and desk-top modelling. The field trials will require soil coring and groundwater sampling to assess the effects of application of PRW to soils of the Lockyer Valley. This will provide the empirical parameters to populate models of soil water movement and reaction kinetics that will be determined initially for 1D, then 2D models (HYDRUS) of the unsaturated zone. This data will finally be incorporated into a 3D surface-groundwater model (MODFLOW) of the region. These models will provide outputs that will be incorporated into 3D visualisation software and combined with existing data and conceptualisations, with animation of water tables to enable a time series evaluation. The 3D visualisations will allow interrogation of the data and assessment of areas where there is a mismatch between field and modelled data. Assessment will be made of the potential consequences to the Brisbane River from the application of water to the valley under current extraction regimes, with and without additional water from groundwater sources. An assessment will also be made of Aquifer Storage and Recovery (ASR) potential for the valley's alluvial aquifers.

Consideration of the characteristics of the PRW suggests there will be little consequence to the soils of the region, as absolute concentrations of ions is very low. However, if application follows a prolonged period of surface storage and evaporation (and hence concentration of ions), the high sodium may be detrimental. Strategies for monitoring and evaluation will be investigated to address possible concerns.

The goal of the project is to provide conjunctive water use options for the region. A projected 25,000 ML of PRW from the Western Corridor Recycled Water Project is potentially available to the Lockyer region irrigators. The actual distribution mechanism is still under debate and results from this project will help inform those decisions. While the regulatory arrangements for the supply of the recycled water are far from settled at this time, there will be a requirement for the recycled water to replace an equivalent volume of groundwater currently extracted. It is likely that a range of local management arrangements will need to be implemented for different subcatchments to achieve the balance of surface and groundwater use. For example, groundwaters in the Sandy Creek subcatchment are relatively saline and have a rising trend with potential for significant salinity expressions. A conjunctive use option of groundwater and recycled water would seem an appropriate solution in preventing downstream salinity impacts.

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An Application of Pattern Recognition for the Location and Sizing of Leaks in Pipe Networks

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Summary

This paper presents a method of mining the data obtained by a collection of pressure sensors monitoring a pipe network to obtain information about the location and size of leaks in the network. This inverse engineering problem is affected by support vector machines (SVMs) which act as pattern recognisers. In this study, the SVMs are trained and tested on data obtained from the EPANET hydraulic modelling system. Performance assessment of the SVMs showed that leak size and location are both predicted with a reasonable degree of accuracy. The information obtained from this SVM analysis would be invaluable to water authorities in overcoming the ongoing problem of leak detection.

Keywords

Leak detection, pipe networks, pattern recognition, support vector machines.

Method

The method used for leak size and location prediction is to monitor the pressure at a number of nodes in the pipe network under consideration and to feed these pressure values into SVMs trained to predict leak size and leak location. The SVMs are trained on a number of cases representing the presence of leaks of various sizes and locations in the pipe network.

The SVMs require hundreds or possibly thousands of cases in their training sets. Therefore it is not feasible to generate the training sets by introducing actual leaks into the real pipe network. The training sets can be obtained by simulation of the pipe network under consideration. The simulation tool EPANET can be used to achieve this. EPANET is a computerised simulation model produced by the Environmental Protection Agency of the USA that predicts the dynamic hydraulic and water quality behaviour within a drinking water distribution system operating over an extended period of time. Leaks of various sizes can be simulated in EPANET and the resulting pressures and flows in the network can be calculated. In order to generate the large number of cases required for the SVM training set, the implementation of EPANET can be automated by developing a program which calls EPANET many times with various values of the leak size.

Results

The EPANET model was applied to simulate the pipe network in an area in South Eastern Melbourne. The site was selected with a view to validating simulation outputs with *in-situ* measurements to be collected later in the project prior to field studies at a location in Ipswich, Queensland.

The first experiment carried out was to determine how effectively a SVM regressor (function approximator) predicts leakage rates when a given fixed node is leaking. Leakage from zero to a high rate of approximately 3.0 l.s^{-1} was modelled in these experiments. The EPANET driving program was used to generate a data set of 300 cases. In each case, a certain node was leaking and its emitter coefficient value was varied from 0.000 to 0.300 in steps of 0.001. The emitter coefficient is related to the leak size, the pressure and a quantity called the pressure exponent. From these, 200 and 100 cases were randomly selected to form a training set and a testing set respectively. The SVM was trained using the radial basis function kernel. The training converged very rapidly and when the trained SVM was applied to the testing set the mean squared error (MSE) and the squared correlation coefficient (R^2) were $\text{MSE} = 4.47569\text{e-}005$ and $R^2 = 0.994289$. Thus the testing results are considered to be good because of the relative values of MSE and R^2 .

The next experiment carried out was to determine the effectiveness of using a SVM classifier for leak location. Tests were done using a high value of the emitter coefficient of 0.3, corresponding to a leak size of 2.5 l.s^{-1} , with good prediction accuracy results. Having established the procedure to generate the required data through EPANET and apply the data to train the SVM to predict the position and size of leaks, the next step was to establish the limitations of the procedure in detecting small (100 l.hr^{-1} or less) leaks. It was found that the lowest leakage rate successfully

processed by EPANET was 3.45 l.hr^{-1} . However at this leakage rate EPANET did not register a pressure difference between the leak and no-leak scenarios. It was determined that the lowest leakage rate that produced a pressure difference in EPANET was 90 l.hr^{-1} . When the SVM was trained on EPANET data corresponding to this leak rate the prediction of the exact location had a 35% success rate. As the distance between actual and predicted leak locations increased, the success rate increased. A 100% success rate was predicted by 500 m as is shown in Figure 1 (the diameter of the study region is 1243.4 m). The accuracy at shorter distances could be improved at the expense of larger leak volumes.

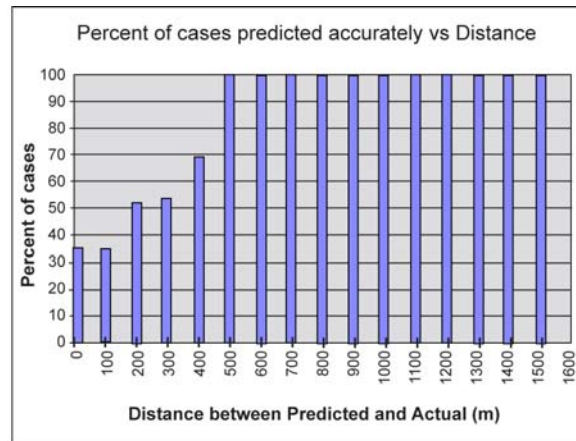


Figure 1. Prediction accuracy with Emitter Coefficient 0 to 0.0025 (max leak size 90 l.hr^{-1}).

The pressure changes registered by EPANET for a leak size of 90 l.hr^{-1} are of the order of 0.00001 m (0.1 Pa). The viability of a detection method based on these measurements depends on instrumentation with the required sensitivity. The applicability of the technique in practice depends on the ability of pressure sensors to detect small changes in pressure and the accuracy to which EPANET models real pipe networks.

Future Work

Because of the difficulties of measuring very low pressure changes, the team has been looking at complementary methods that will allow detection of small leakages in pipe networks. Thus the project team has been working with another group in CSIRO towards the development of a sensitive device for measuring flows in a pipe network. Flows at monitoring nodes in a pipe network can then be used as inputs to a SVM which has been trained on flows simulated by EPANET. After the device has been developed, experiments will be carried out in a real piping system to determine its efficacy. It is then envisaged that devices will be installed in the field as monitoring nodes for the experimental evaluation of the leak detection system. The validated system will be field tested in Ipswich before it is rolled out to other parts of SEQ.

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Comparison of Techniques for Determining Evaporation from a Large Irrigation Storage

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Summary

The project is part of a larger research program under the Urban Water Security Research Alliance (UWSRA) which aims to determine the potential for cost effectively reducing evaporative losses from water storages in South East Queensland (SEQ). An initial desktop analysis has identified techniques (e.g. surface films, floating covers) which may be employed to reduce evaporation under conditions experienced in SEQ and the next step in the process is to assess some of these products under field conditions. Central to this testing will be the ability to accurately determine evaporation from an open water body and to assess potential water quality impacts. The project aims to test available techniques to measure evaporation from water storages and to assess the suitability of each for determining evaporation changes as the result of application of evaporation reducing technologies. This presentation will discuss the experimental design to be implemented for this project.

Keywords

Evaporation, scintillometry, eddy covariance, water balance, water quality.

Introduction

In SEQ, the volume of water lost through evaporation each year is roughly equal to that supplied through the reticulation system i.e. two units of water need to be collected and stored for each unit of water supplied. These numbers suggest that there is much benefit to be gained through the development of new and innovative techniques for reducing evaporation. Realisation of the magnitude of evaporative losses in SEQ lead to the formation of a research project with UWSRA to investigate these issues. In its first year, this System Losses project undertook a desktop study of available evaporation reduction options and assessed their applicability to SEQ. Existing techniques for reducing evaporation that were investigated included floating covers (Yao et al. 2009), surface films (McJannet et al. 2009a), shade structures (Yao et al. 2009), windbreaks (Helfer et al. 2009), storage shape modification (McJannet et al. 2009b) and destratification (Lemckert et al. 2009). Additionally the impacts of farm dams (McJannet et al. 2009c) and potential of runoff enhancement (McJannet et al. 2009d) were investigated. Out of all these techniques, floating covers and surface films showed the greatest potential for further investigation. In these reports it was acknowledged that it is unlikely that such techniques would be applicable to entire large scale storages (e.g. Wivenhoe Dam) due to wind speed and safety constraints. However, the potential for partial treatment or treatment of smaller storages within the catchment was highlighted and this has led to the development of a field based experimental program designed to measure and assess the potential for reducing evaporation without having detrimental impacts on water quality.

To be able to assess the potential to reduce evaporation it is first necessary to be able to confidently measure evaporation rates. This is not a trivial exercise due to spatial variation in evaporation. Due to complexities of such measurements a three staged project is planned which also addresses potential water quality concerns:

Stage 1 – Testing of ability to measure evaporation and collection of baseline water quality data.

Stage 2 – Testing of evaporation reduction techniques (in conjunction with CRC Polymers) and further water quality assessment.

Stage 3 – Development of evaporation models for application to other locations.

Stage 4 – Assessment of applicability of techniques and potential benchmarking of a large scale storage facility in conjunction with stakeholders and monitoring of changes in evaporation over time.

Each stage is dependent on the success of the previous one.

Experimental Methods

A large farm dam located near Forest Hill in SEQ has been selected for testing available evaporation measurement techniques. The storage, called Logan's Dam, has a storage capacity of 0.7 gigalitres and a full storage surface area of about 17 hectares. The storage has a maximum depth of 6.5 m. The three methods have been identified for providing independent measurements of evaporation at this location and each of these is discussed below. In addition to these measurements, land based measurements of humidity, temperature, rainfall and wind speed will be made at locations around the storage. As part of the larger evaporation project it is also required that detailed knowledge of the surface wave field of the dam be gained. The knowledge will be used to drive laboratory studies of how the wave field may influence the performance of surface films use for evaporation reduction.

Water Balance

The water balance method relies on measuring all inputs and outputs of water from the water storage except evaporation which is calculated by difference between all other inputs and outputs. Being a residual term, evaporation will contain the error of the other input and output terms. It is therefore important to have the best possible measures of water inputs and outputs. The selected irrigation storage was chosen because water is pumped into and out of the storage through pipes. Precise water level and flow metering will be implemented.

Energy Balance - Scintillometry

The evaporation from the storage will be determined using an energy balance approach which involves determining all energy fluxes from the storage except evaporation which will be determined by difference between all other inputs and outputs. The sensible heat flux from the storage will be determined using an infrared scintillometer. The scintillometer will give a path average of sensible heat flux across a 450 m pathlength over the storage. The scintillometer also requires measurement of temperature at two heights above the water and these will be made on a floating weather station platform that will also be instrumented to determine the radiation budget above the water surface. Changes in heat storage within the water body itself are crucial to accurate evaporation assessment, therefore five thermistor chains will be installed at locations around the storage (one on the floating weather station and 4 on self supporting buoys). Each of these thermistor chains will have 20 individual temperature measurements.

Eddy Covariance

The most readily used method for determining evaporation from water bodies is the eddy covariance (ECV) method. This method has been widely used for determining energy fluxes over many different surfaces, and as such, many of the analysis routines are founded on many years of research. The ECV method will determine fluxes from an up-wind area commonly referred to as a footprint. This footprint will vary based on instrument heights and wind characteristics. The ECV device will be deployed on the dam on a floating platform. The ECV device can directly measure evaporative flux.

Water Quality Measurements

The aim of the water quality assessment is to establish whether there are effects of surface film application on the major ecosystem processes. This will include the assessment of potential outbreaks of toxic blue-green algae in the modified environment. Fortnightly sampling will be done of nutrients (Nitrogen species and Chlorophyll a), phytoplankton biodiversity and abundance, zooplankton biomass, temperature and oxygen profiles, turbidity, pH and conductivity.

Conclusion

This presentation will discuss the experimental design to be implemented for this project and will provide details of the measurement equipment being used. The pros and cons of each measurement methodology will be discussed, the field site will be described and progress to date will be outlined.

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Revisiting Artificial Monolayers as a Strategy to Reduce Evaporative Loss from Large Open Water Storages

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Summary

Applying an artificial monolayer to a large water storage offers the most economic and environmentally benign option for reducing evaporative loss. In July this year, the Urban Water Security Research Alliance commenced a project to evaluate the sensitivity of scintillation and eddy covariance technologies in monitoring evaporative loss. Seasonal changes in water quality and the limnology of surface and subsurface water samples in the absence of an applied artificial monolayer will also be documented. Provided the instrumentation is sufficiently sensitive, the project will also evaluate the effectiveness of a selected artificial monolayer in reducing evaporative loss, and its ecological impact. Recent studies on South East Queensland (SEQ) water storages have established the existence of natural microlayers, which also affect the properties of the air-water interface. If the ecological impact of an artificial monolayer is equivalent to pre-existing microlayers, but more effective in reducing evaporation, the technology may be appropriate for use on urban water storages.

Keywords

Monolayer, microlayer, evaporative loss, urban water storages.

Introduction

In the 1960s, laboratory trials with artificial monolayers based most commonly on long-chain fatty alcohols, indicated that evaporative loss could be reduced by as much as 40% (Barnes 2008). However, results from field trials were extremely variable, discouraging the commercial adoption of the technology. More recently in Australia, the technology has been revisited to investigate the cause of poor field performance and to develop improved monolayer compounds. In part, poor field performance was due to inaccuracies in monitoring evaporative loss from water storages, associated with seepage losses and rainfall events. As part of the Co-operative Research Centre for Irrigation Futures, researchers at the University of Southern Queensland have undertaken small-scale trials of artificial monolayer products, using pressure-sensitive transducers and impermeable small-scale troughs to more accurately evaluate monolayer performance.

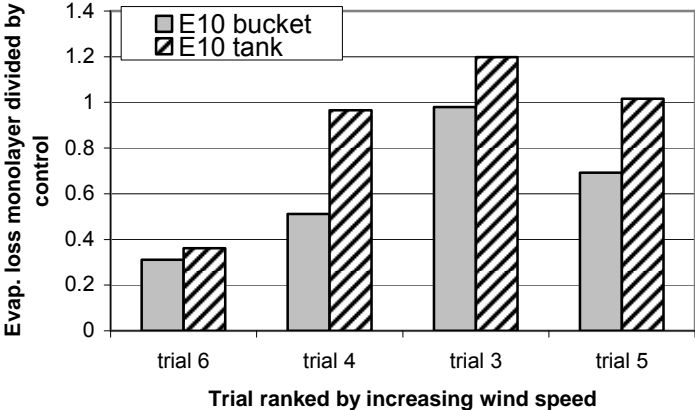


Figure 1. Relative evaporative loss with an experimental monolayer compound E10 applied to potable water, divided by the control (no surface film). Trial results at two experimental scales, are ranked from the left in order of increasing wind speed. The proportion of the trial when the average wind was less than 10 km/hr is listed as a percentage.

Improving Data Compilation and Analysis

Results obtained in replicated buckets (18 L, 0.064m²) and in larger trough (1.2 kL, 2.93m²) trials indicate that monolayer products could effectively reduce evaporative loss, provided the data was analysed appropriately (Figure 1). Successive trial results need to be standardised to allow comparisons over time, by dividing treatment evaporative loss by the control evaporative loss.

Results also need to be interpreted as a function of the time intervals during which climatic conditions optimised product performance. Monolayer compounds differ in their resistance to dispersion by wind, and also in their resistance to sublimation (Barnes 2008). In Figure 1, data for both smaller, replicated bucket trials and larger trough trials have been ranked according to increasing wind speed. The experimental product used (E10) is more resilient than commercially available products based on hexadecanol, being less prone to sublimation and microbial degradation.

A third key factor affecting results from field trials is the rate of monolayer application. By definition, artificial monolayers are one molecule thick. However, to achieve the uniform surface pressure required to reduce evaporative loss on larger water storages, up to three times this rate must be applied. At the molecular level, the extra application may be necessitated by the increase in surface area associated with capillary waves (Saylor and Handler 1999). In Figure 1, the application rate for trial 3 allowed for one molecule only on a flat surface. Evaporative loss exceeded the control, due to preferential evaporation through ‘holes’ in the warmer surface film. All subsequent trials used 3 times the dose, with wind speed primarily dictating the efficacy of the product.

Assessing Water Quality

The other factor responsible for field trial variability is the interaction between water quality and the monolayer compounds. All water bodies have natural, hydrophobic surface films, referred to as microlayers (Norkrans 1980). Hydrophobic leachates derived from leaf and bark litter are responsible for microlayer formation and for the brown colour of many water storages. The properties of microlayers and monolayers are very similar (Table 1), except microlayers are chemically too heterogeneous to develop the high surface pressure required to reduce evaporative loss (Barnes 2008).

Table 1. A comparison of the properties of natural microlayers and artificial monolayers.

Attribute	Natural Microlayer	Artificial Monolayer
Surface Film Formation	Multi-molecular layer of diverse hydrophobic compounds exerting a low surface pressure	Monomolecular layer of a specific hydrophobic compound, exerting a high surface pressure
Wave Calming Impact	Dampens capillary waves, wind >6m/sec breaks up film on open water	Dampens capillary waves, wind resistance varies with compound
Temperature Impact	Temperature increased by wave calming	Temperature increased by wave calming and reduced evaporative loss
Bio-degradation	Used as a substrate by surfactant-producing aquatic bacteria	Rate of bacterial degradation varies with the compound
Photo-degradation	Humified compounds are very photoreactive, responsible for surface ‘cleansing’	Compounds are UV stable, but sensitivity to combined photo and microbial degradation is unknown

SEQ UWSRA Evaporation Study

The first challenge for the Alliance’s evaporation study (a collaboration across USQ, UQ, CSIRO and Griffith Uni) is to evaluate the accuracy of scintillometry and eddy covariance technologies in monitoring evaporative loss from a 16 ha storage dam. Aligned with this study, seasonal changes in water quality and the ecology of both microlayer and subsurface water samples will be documented, to establish a base-line for the natural dynamics of the air/water interface in the absence of any applied monolayer compounds. If the instrumentation proves to be sufficiently accurate, future studies will investigate the feasibility of autonomous application of selected monolayer compounds at only those times when the prevailing weather conditions favour product performance. Provided the ecological impact of an artificial monolayer is equivalent to naturally occurring microlayers, the advantage of autonomously applying a monolayer is repeatable product performance, at the lowest environmental and economic cost.

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Modelling Tool to Aid Development of Integrated Urban Water Management Strategies in South East Queensland

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Introduction

Integrated Urban Water Management (IUWM) is an emerging and alternative approach for planning and management of urban water systems. The aim of IUWM is to plan and manage water supply, wastewater and stormwater systems in a coordinated manner to minimise their impact on the natural environment, to maximise their contribution to economic development and to engender overall community wellbeing and improvement (Maheepala and Blackmore, 2008). Development of IUWM strategies requires undertaking of modelling to quantify performance of the urban water system under different urban water management options such as roof water use, stormwater use and wastewater recycling against a defined set of performance criteria. Commonly used performance criteria include level of service (i.e. duration, frequency and severity of water restrictions) and consumption, water quality, energy and greenhouse gas emission targets.

Keywords

Integrated urban water management, whole-of-urban water systems, integrated modelling, Regional Urban Tool.

Background

Development of a regional scale IUWM Tool (the Regional Urban Tool) is being undertaken collaboratively with eWater CRC and the Urban Water Security Research Alliance. The purpose of this paper is to describe the current status of software development of the Regional Urban Tool and its test application to Logan basin in the SEQ. This tool enables urban water planners and managers to obtain an improved understanding of how water, wastewater and stormwater systems interact with each other and with natural water systems in terms of water, contaminant and nutrient flows at city and regional scales, under different integrated urban water management options, by accounting for changes in climate, urban development, land use and urban water infrastructure technologies.

The Regional Urban Tool is intended to be used to:

- identify and quantify spatial and temporal distribution of different water streams at city and regional scales;
- identify and quantify sources, sinks and transport of sediments, nutrients and contaminants;
- quantify changes to water and constituent balances at city and regional scale due to different integrated water management options;
- quantify the potential impact of different integrated water management options on supply system yield, shortfalls, resilience, reliability and vulnerability, levels of water service and receiving water quality;
- identify the sensitivity of system yield, reliability, resilience and vulnerability to various environmental flow regimes, land-use change, and climate change by linking Global Circulation Model outputs with hydrological, demand and supply system simulation models; and
- identify the optimal urban water management option that has the potential to maximise supply reliability while minimising adverse impact on receiving waters.

Modelling Approach and Software Features

The Regional Urban Tool has been developed as a product of the eWater CRC, and along with WaterCAST and RiverManager software, it forms a suite of software products for water management. Like most of the CRC products, the Regional Urban Tool has been developed in the E2 river modelling framework (Argent et al., 2005) within TIME (The Invisible Modelling Environment) (Rahman et al., 2003) model development framework. The concept of the Regional Urban Tool has been derived from HydroPlanner software (Maheepala et al., 2008; Maheepala et al., 2007; Grant et al. 2006; Maheepala et al. 2005). The Regional Urban Tool provides capabilities for modelling urban supply and demand, local and regional alternative supplies, and city and regional catchment scale impacts in a spatial view. It is applicable to assessing water quantity and quality implications of urban water management options in predominantly urban river basins.

Key functionalities of the Regional Urban Tool when fully developed are shown in Figure 1. The Regional Urban Tool includes all functionalities of eWater CRC’s WaterCAST software (shown in ‘blue’), some functionalities of eWater CRC’s RiverManager software (shown in ‘red’) and functionalities specific to the Regional Urban Tool itself (shown in ‘purple’).

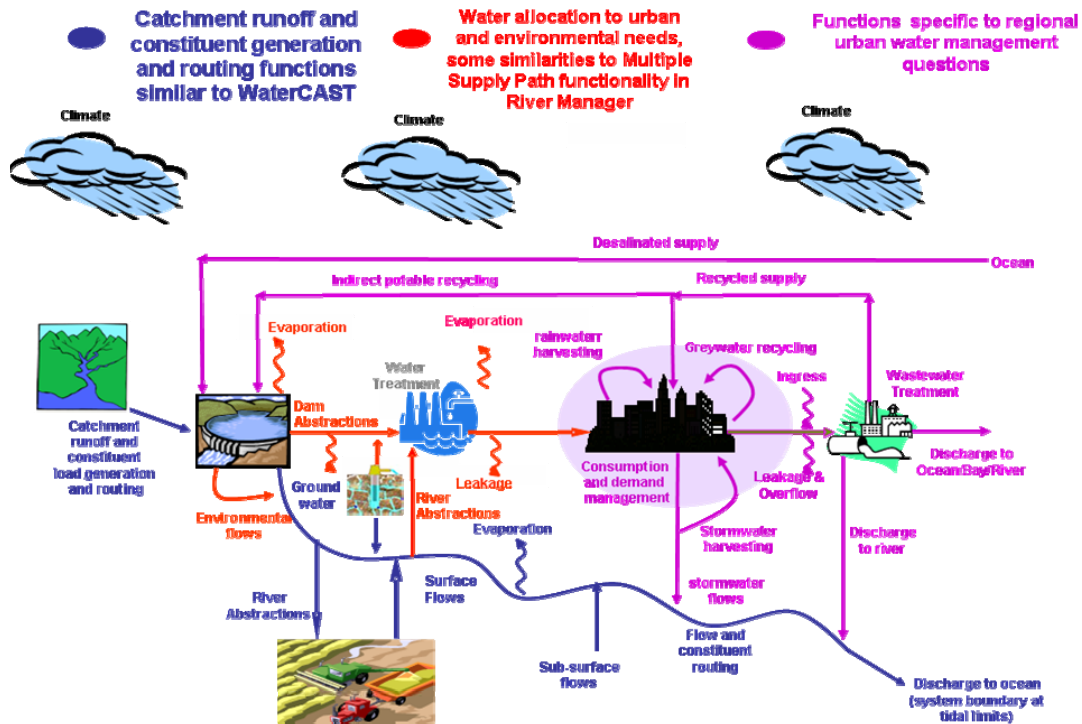


Figure 1. Schematic diagram of the Regional Urban Tool illustrating key functionalities.

Test Application for the Logan Basin

A prototype version of the Regional Urban Tool was completed in June 2009 for the Logan Basin in SEQ. The prototype includes all WaterCAST functionalities and a rule based multiple supply path (MSP) functionality. The rule-based MSP functionality allows multiple sources (e.g. reservoirs, recycled water and stormwater) to supply water to meet consumptive needs as per priorities specified by the user for supply sources. An optimisation-based MSP functionality will be developed in the future to maximise the usage of water available in both conventional and non-conventional sources. The test case is aimed at demonstrating the ability to quantify the potential impact of proposed urban development and climate change over the next 50 years. It particularly considers: management options (eg recycling and stormwater harvesting); receiving water quality; and performance criteria (eg for supply system storage levels, system reliability, resilience, shortfall and vulnerability).

The test application has been able to quantify and predict water cycle implications of wastewater recycling and large scale stormwater harvesting on supply security and receiving water quantity. It has also demonstrated calibration to an acceptable level. Key assumptions have been documented.

Figure 2 shows the Regional Urban Tool with the Logan test application. It shows sub-catchments and node-link network of the test case and the potential impact of wastewater recycling to all urban demands in the Logan basin on the total system storage volumes.

Conclusions

A software tool called the Regional Urban Tool is being developed in collaboration with the eWater CRC and the Urban Water Security Research Alliance. A prototype is now operational for the Logan Basin in the SEQ as a test case. The test case can demonstrate how to quantify the potential implications of centralised wastewater recycling and large scale stormwater harvesting on system storage levels, system yield, vulnerability, resilience and reliability of the supply system, environmental flows and flows at any location in the Logan Basin. The test application and software development are in progress to demonstrate water quality implications of wastewater recycling and large scale stormwater harvesting in the Logan Basin. Upon completion of the Logan test case, the applicability of the Regional Urban Tool will be reviewed by key stakeholders (Queensland Water Commission and Queensland Department of Environment and Resources Management) before commissioning full development of the tool as a regional urban water management tool for SEQ.

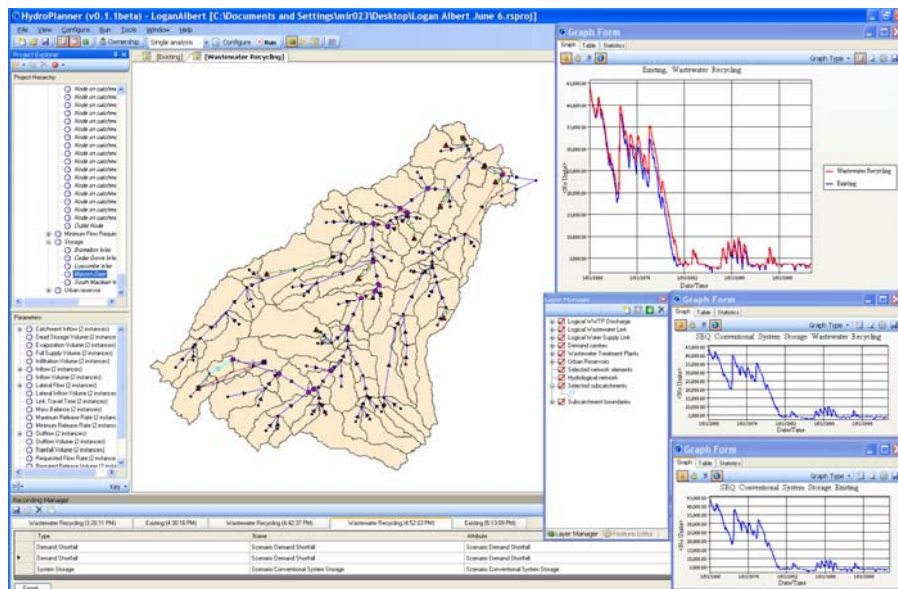


Figure 2. Regional Urban Tool showing node-link network and sub-catchment map of the Logan Basin and system storage in ML for cases with and without wastewater recycling to all urban demands.

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The Impact of Anthropogenic Forcings and El-Niño Southern Oscillation on South East Queensland Rainfall

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Summary

The observed rainfall reduction over South East Queensland (SEQ) is not reproduced in an all-model average of climate models used for the Coupled Model Intercomparison Project (CMIP3), which contain all climate change forcing factors. Outputs from targeted experiments forced by increasing aerosols and ozone depletion are deployed to evaluate their impacts. The result highlights that to a large extent the observed rainfall reduction might be driven by multidecadal variability, which may or may not be a consequence of climate change. If it is, the CMIP3 models do not simulate this well. Further analysis suggests that the recent rainfall reduction may be in part associated with an asymmetry in the impact between El Niño and La Niña. The impact from La Niña is greater than that from El Niño, and over the past decades, there has been a general decrease in the number of La Niñas.

Keywords

South East Queensland rainfall change, El Niño Southern Oscillation, decadal variability.

Introduction

Long-term seasonal rainfall trends across Australia show quite a lot of contrast (Figure 1, left column). Summer and autumn rainfall shows almost a dipole-pattern, with north-west Western Australia having experienced quite large increases since 1950, whilst the east coast shows a drying trend. Much of the decline in rainfall has occurred in winter across coastal southern Australia, with SEQ and New South Wales reducing by over 50 mm. In the SEQ region (150.50°E-154.50°E, 20.50°S-30.50°S) the reduction reaches close to 50% in winter and autumn in recent years (Figure 1f-g). In all seasons, SEQ rainfall shows a degree of multi-decadal variability, as highlighted by the 11-year running average (thick-black line in Figure 1, right column). There are no obvious trends in SEQ rainfall, not beyond the bounds of this variability; therefore it is not uncommon to have 5-10 years of lower-than-average rainfall in all seasons. In this paper, we focus on the SEQ region, and address whether the observed rainfall changes are attributable to changes in climate forcings such as stratospheric ozone depletion and anthropogenic aerosols. We will also look at the impact of El Niño and La Niña events, particularly in the summer and autumn seasons.

The Impact of Ozone Depletion and Anthropogenic Aerosols

Climate model outputs forced by observed climate change consist of two signals: the model's own variability (e.g. interannual) and a response to climate change (e.g. decadal-scale). If we average outputs from many models then the variability component is largely removed, leaving only the lower frequency climate change signal. To this end, we use 20th century climate simulation outputs from 24 models used for the CMIP3 (Randall et al. 2007). Of these models, 16 contain a stratospheric ozone depletion forcing in their 20th century realisations (the remainder do not). For the SEQ region, there is some coherence between the ozone ensemble and observations in autumn and winter, but in general the model results are weaker. For the non-ozone ensemble, the greatest coherence with the observed trends are in summer and winter for SEQ, however again the modeled trends are much smaller. Reasons for these discrepancies could lie in the models' resolution, or model error in their ocean-atmospheric teleconnection between the main climate drivers for this region and the rainfall.

Another forcing which is regarded as important for Australia rainfall is anthropogenic aerosols. The Asian aerosol haze is believed to alter the north-south temperature and pressure gradients over the tropical Indian Ocean, thereby increasing the tendency of monsoonal winds to flow toward Australia (Rotstayn et al. 2007). We use a set of climate runs from the CSIRO Mk3A model to look at an aerosol-induced effect. This is carried out by running a number of experiments with all forcings (called ALL), and then running another set with all forcings except for anthropogenic aerosols, called AXA. The difference between the two sets of experiments is called aerosol-induced (or AER). We can compare ALL to the observed, as well as the AER ensemble to isolate the effect of anthropogenic aerosols. In summer and autumn, both ALL and AER show an increase in rainfall over SEQ, inconsistent with the observations. In winter and spring, the SEQ rainfall trends are very weak, and not spatially coherent with the observed. Thus, increasing aerosols, if anything, tend to increase SEQ rainfall in the wet season, opposite to what has been observed. This could mean, however, that aerosols are mitigating the rainfall impact over SEQ; that without an aerosol forcing the rainfall trends over SEQ could be substantially larger (i.e. stronger decline). Future analysis using separate climate models is warranted to gather more statistical certainty on the modeled results.

Asymmetry of El-Niño Southern Oscillation

For SEQ, El-Niño Southern Oscillation (ENSO) is the dominant climate driver, and is defined through the NINO3.4 index (average sea-surface temperature over 170°W-120°W, 5°N-5°S). To understand whether the rainfall reduction over SEQ (in summer and autumn) is due to changes in ENSO or the frequency of El Niños and La Niñas, we conducted a correlation analysis between NINO3.4 and SEQ rainfall starting from 1900 using a 13-year sliding window. In summer there is a high degree of decadal variability; during the early part of the 20th century ENSO tended to be quite strongly negatively correlated with rainfall (e.g. an El Niño leads to less rainfall). These fluctuations are a consequence of the modulation of the Interdecadal Pacific Oscillation (Power et al., 1999). From the 1930s to the 1940s ENSO tends to have little influence on rainfall, which follows through into autumn. From the 1950s through the 1980s, a period that included a number of above-average SEQ rainfall years, ENSO tends to again show a strong negative coherence with rainfall.

We next focus on the asymmetry between El Niño and La Niña events. Both in summer and autumn, negative values of NINO3.4 (La Niña episodes) lead to increases in SEQ rainfall, with the slope (sensitivity) in summer more than double the El Niño sensitivity. Both sensitivity values for La Niña and El Niño against SEQ rainfall are significant at the 95% confidence interval in summer. For positive values of NINO3.4 (El Niño events) SEQ rainfall tends to decrease in summer, but slightly increase in autumn. This autumn sensitivity, however, is solely due to the outlier year of 1983; without it, there is only a weak and insignificant correlation. These results seem to suggest that ENSO impacts SEQ rainfall in summer, however the impact from La Niña is greater than that from El Niño. In autumn the impact of La Niñas and El Niños on SEQ rainfall is less clear; over Australia as a whole, La Niña has a statistically significant relationship with autumn rainfall, whereas El Niño does not (Cai and Cowan, 2009). Over the past few decades, there has been a reduction in the number of La Niña events (Cai and Cowan, 2008) and an increase in the amplitude of ENSO. This is consistent with a weakening trend in the Walker Circulation during the late 20th century (Vecchi et al. 2006). A reduction in La Niñas could at least in part explain the decline of SEQ rainfall in summer during the post-1980 period, although the recent decrease in autumn rainfall (Figure 1f) and the recent strengthening teleconnection between ENSO and autumn rainfall requires further investigation.

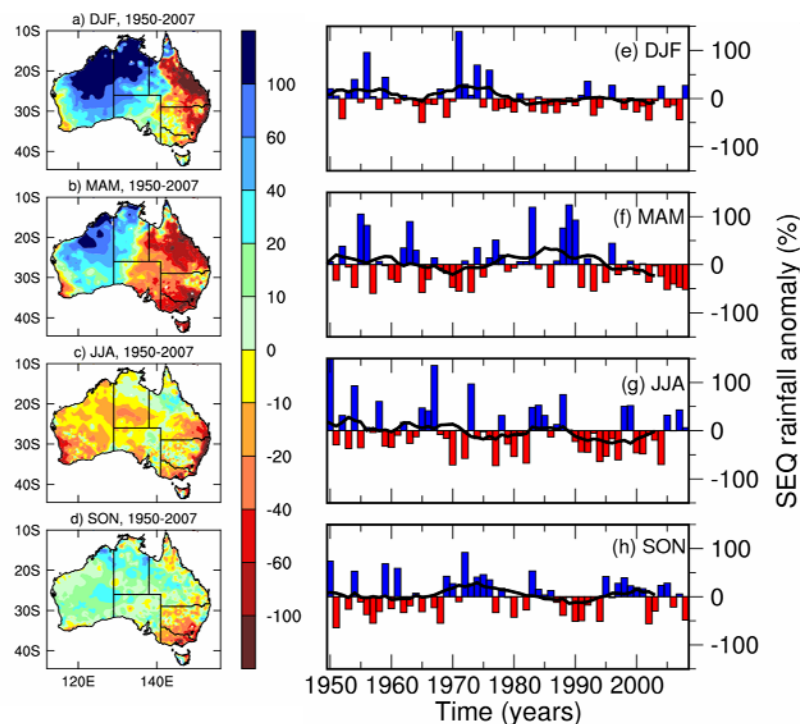


Figure 1. Left column, seasonal trends in Australian rainfall over 1950-2007 for (a) December, January, February (DJF), (b) March, April, May (MAM), (c) June, July, August (JJA), and (d) September, October, November (SON). Units are in mm/58 yrs. Right column, time series of SEQ rainfall anomalies (% from 1950-2008 average), with blue (red) bars indicating higher (lower) than average rainfall. The thick black line is the 11-year running average.

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Dynamical Downscaling of Rainfall over South East Queensland

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Summary

This presentation describes a simulation, downscaling 55 years (1951-2005) of the National Centres for Environmental Prediction (NCEP) reanalyses to a resolution of 20 km over eastern Australia. The simulation uses the Conformal-Cubic Atmospheric Model (CCAM). The simulated results are compared with available observed gridded data from the Bureau of Meteorology. The model reproduces accurately the current climate condition over the region. It also captures the observed rainfall trend from 1970 to 2005. The future climate over the region is then studied by downscaling for the A2 emission scenario from the CSIRO Mk 3.5 Global Climate Model (1961-2100) using sea surface temperatures only. Both CCAM and Mk 3.5 predict annual rainfall will decrease towards the end of the century. The model projections for the various seasonal changes are consistent, except for December, January, February (DJF) where the two models disagree on the changes.

Keywords

Dynamical downscaling, southeast Queensland rainfall, climate change.

Introduction

Since the 1950s, much of eastern Australia has experienced a severe rainfall deficiency. Using a high quality observed rainfall data set between 41°33'S – 22°23'S and 143E - 147E, Nicholls and Kariko (1993) demonstrated a positive trend in rainfall from 1910 to 1998, with an increase in the number of rain days, but a decrease in the intensity of rain events. The influence of the El Niño-Southern Oscillation (ENSO) on changes in the number and intensity of rain events was emphasized. Alexander et al. (2007) showed that over the period 1951-2005, rainfall decreased along the east coast in the summer season (DJF). The projection of future annual precipitation scaled by the amount of global warming averaged over models from the Coupled Model Intercomparison Project phase 3 (CMIP3) suggests that the region will experience drier conditions compared to 1961-1990 (CSIRO, 2007). In this study, we perform two simulations. The first simulation is downscaled from NCEP Reanalyses for the purpose of model validation against the current climate. The second simulation downscales from the CSIRO Mk 3.5 General Circulation Model (GCM) to study future climate over the region.

Model Description and Experimental Design

CCAM is formulated on the quasi-uniform conformal-cubic grid. Details of the model dynamical formulation can be found in McGregor and Dix (2008). The Geophysical Fluid Dynamics Laboratory (GFDL) parameterizations for long-wave and short-wave radiation (Schwarzkopf and Fels, 1991) are employed, with interactive cloud distributions determined by the liquid and ice-water scheme of Rotstayn (1997). A canopy scheme is included (Kowalczyk et al., 1994) with six layers for soil temperatures and soil moisture (solving Richard's equation), and three layers for snow.

The first experiment is a 55-year simulation from January 1951 to December 2005, carried out with initial conditions, sea surface temperatures (SSTs) and global forcing of wind provided by the National Centers for Environmental Prediction (NCEP) Reanalyses (Kalnay et al., 1996). The second experiment is a 140-year simulation from January 1961 to December 2100. In this experiment, the regional climate simulation is generated using a multiple downscaling technique where a CCAM 200 km quasi-uniform global simulation is driven by bias-corrected sea surface temperatures of the host CSIRO Mk 3.5 coupled General Circulation Model (CGCM). Next, the 200 km resolution simulation is dynamically downscaled to 20 km resolution, to provide local-scale forcing from detailed topography and surface characteristics.

Results and Discussions

Current Climate Condition and the Trend in Rainfall

The current climate condition of rainfall the first experiment and its bias over South East Queensland (SEQ) are shown in Figure 1. In general, CCAM skillfully captures the seasonal variation of precipitation over the region. Both observations and model show that rainfall is high in the warm seasons (SON, DJF and MAM) and low in JJA. However, the model slightly under-estimates rainfall in DJF over the northern region and along the east coast; it over-estimates the rainfall along the east coast in other seasons. The rainfall trend under the current climate from

1970 to 2005 is also captured by the model (Figure 2) even though the model under-estimates the magnitude of the drying along the coast in DJF and annually (ANN). In JJA the model shows a widespread positive rainfall trend, but that is not seen in the observations.

Projected Future Changes for SEQ Rainfall

Present-day rainfall patterns (not shown) from CCAM and Mk 3.5 are both reasonable. Because of its finer resolution and bias correction of SSTs, CCAM provides better agreement with observations for all seasons, except MAM when it is somewhat too dry. CCAM and Mk 3.5 both predict that during 1961-2030, annual, winter and spring rainfall over the region will experience a downward trend. A stronger signal is seen in the Mk 3.5 results. There is some disagreement between Mk 3.5 and CCAM in DJF and MAM. CCAM projects increased rainfall along the coast whereas Mk 3.5 projects decreased rainfall almost everywhere, except for a coastal strip in DJF and the northern coast in MAM. There is signal of increasing rainfall over the nearby ocean in DJF for Mk 3.5, but this has not spread as far inland as in CCAM. A similar signal is seen in MAM over the northeast corner.

The model results disagree regarding the future rainfall trend for 1961-2100 in DJF (Figure 4), whilst there is reasonable agreement for the other seasons. The intensity of the DJF drying has been reduced in Mk 3.5 compared to the 1961-2030 period (Figure 3), whereas the drying in the northeast is more intense in CCAM compared to the 1961-2030 period.

Overall, both simulations provide fairly similar projections for the changes in rainfall over SEQ, with decreases in annual rainfall. The main differences are for the convective conditions of DJF (and to a lesser extent MAM); the CCAM results should be more credible because of its better present-day performance for the convectively active seasons.

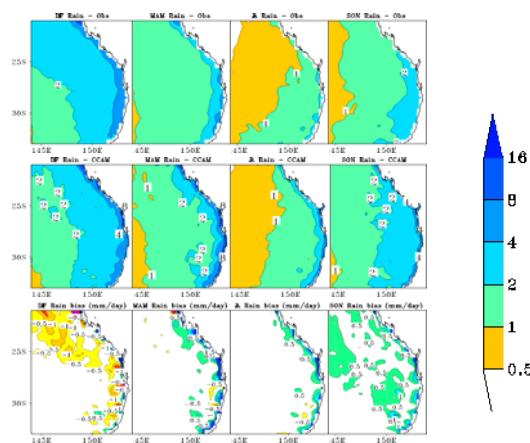


Figure 1. Current climate (1961-2000) rainfall (mm/day) for DJF, MAM, JJA and SON from observations (top) and CCAM (middle) and the rainfall bias (bottom).

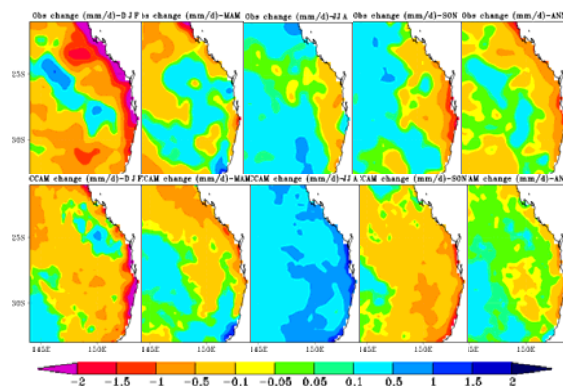


Figure 2. Rainfall trend (1970-2005, change in mm/day) from observations (top) and CCAM (bottom) for DJF, MAM, JJA, SON and annual.

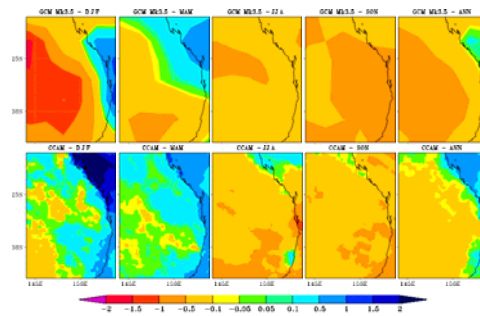


Figure 3. Future rainfall trend (change in mm/day) for 1961-2030 from Mk 3.5 (top) and CCAM (bottom) and from left to right: DJF, MAM, JJA, SON and annual.

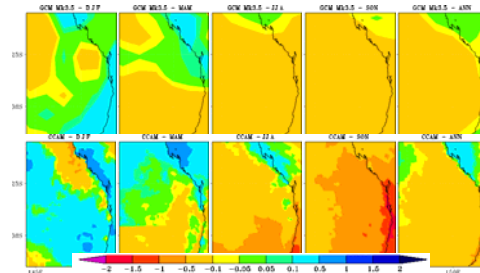


Figure 4. Future rainfall trend as for Figure 3 from Mk 3.5 (top) and CCAM (bottom), but for 1961-2100.

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Energy and Greenhouse Footprints of Wastewater Treatment Plants in South-East Queensland

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Summary

In this study an inventory of operational data was collected from thirty-five wastewater treatment plants in South East Queensland (SEQ). Typical results lay in the range approximately 1.0 to 2.5 (overall mean 1.7) tonnes CO₂-e/ML. Combined probability analysis suggested that 5th and 95th percentile values typically lie in the range Mean \pm 20% due to the uncertainties in fugitive emissions and non-biogenic influent organics. The potential for long-term carbon sequestration via biosolids disposal is also uncertain. However, the potential for emissions offsets (carbon credits) for Waste Water Treatment Plants (WWTPs) in this respect appears to be relatively small.

Keywords

Greenhouse gas emissions, wastewater treatment, nitrous oxide, methane, carbon dioxide, operating data, uncertainty analysis, Monte Carlo.

Introduction

The aim of this paper was to collect good baseline operating data from as many WWTPs in SEQ as possible, with a view to using the data to estimate greenhouse gas (GHG) emissions from these plants. Early results from this Urban Water Security Research Alliance project suggests that GHG emissions over the next 50 years from the (largely centralised) WWTPs in SEQ will be roughly equivalent to those associated with water supply, including 'high energy' supplies in the form of desalinated or recycled water. The ultimate objective is to use the data to build an LCA model of the new Water Grid currently under construction in SEQ.

Full detail of the method, assumptions, plant descriptions, data collected and results and discussion including breakdown of emissions in accordance with the Carbon Pollution Reduction Scheme (CPRS) Scope 1, 2 and 3 definitions is presented in De Haas et al (2009).

Methodology

Operational data was collected from thirty-five WWTPs in SEQ. The plants fell into two main categories of 'type' according to their overall process format. Type 1: With primary sedimentation tanks (PSTs) and anaerobic digesters for treating a combination of primary sludge and thickened waste activated sludge, followed by activated sludge processes achieving biological nutrient removal (BNR) to a variable degree, sometimes with chemical supplementation. Type 2: Extended aeration activated sludge, (no PSTs, no anaerobic digesters) including those with aerobic digestion for further stabilisation of waste activated sludge. Of the thirty-five plants surveyed, the six plants with PSTs and anaerobic digesters (which includes two large plants) plus the seven largest extended aeration plants account for approximately 81% of the total average dry weather flow (ADWF) and approximately 79% to 91% of the effluent Total N and Total P total loads respectively (annual 50thile basis).

In this study a similar approach was used to that of Foley et al. (2008) and De Haas et al. (2008), developed at The University of Queensland. In order to compare more broadly all the plants surveyed across SEQ, it is necessary to (1) normalise the results in some manner; and (2) undertake a combined uncertainty analysis for emission factors not well understood. To normalise the data, the results were expressed as GHG emissions per unit flow (average dry weather). For the uncertainty analysis, Monte Carlo simulations were performed on all surveyed plants. Since several of the WWTPs included lift pumps for either raw influent or treated effluent that contributed significantly to the plants' power consumption, the data was also analysed to exclude these pumps in order to make more valid comparisons between WWTPs.

Results and Discussion

Table 1 summarises the GHG estimates of four WWTPs in this study across a range of plant types and sizes.

Table 1. Summary of GHG emission estimates (kg CO₂-e/day) for four illustrative WWTPs in this study

Key assumptions: 10% non-biogenic raw influent organics; 8 mg/L dissolved sewage methane; 1% N₂O-N denitrified

	Plant I	Plant II	Plant III	Plant IV
Plant type	1 + Cogen	1	2 (large)	2 (medium)
Current ADWF (ML/d)	124	24	54	6
Imported Electrical Power	28,972	22,746	51,050	4,949
Chemical and Fuel Consumption	2,586	2,305	770	193
Secondary Treatment Off-gases	31,298	4,542	12,115	943
Disposal of Screenings and Grit	4,955	1,445	1,572	236
Anaerobic digesters/ biogas, incl. combustion	4,487	994	0	0
Disposal of Biosolids	10,217	3,335	10,931	824
Disposal of Effluent	724	164	355	34
Raw Sewage Dissolved Methane	24,745	4,820	10,800	1,200
Total excluding sewer methane fugitives	83,239	35,531	76,793	7,179
Total including sewer methane fugitives	107,984	40,351	87,593	8,379
Potential GHG credit due to biosolids C sequestration (assumed)	-6,361	-1,338	-3,857	-289

Figure 1 presents the normalised data on GHG emissions for surveyed WWTPs excluding lift pumps.

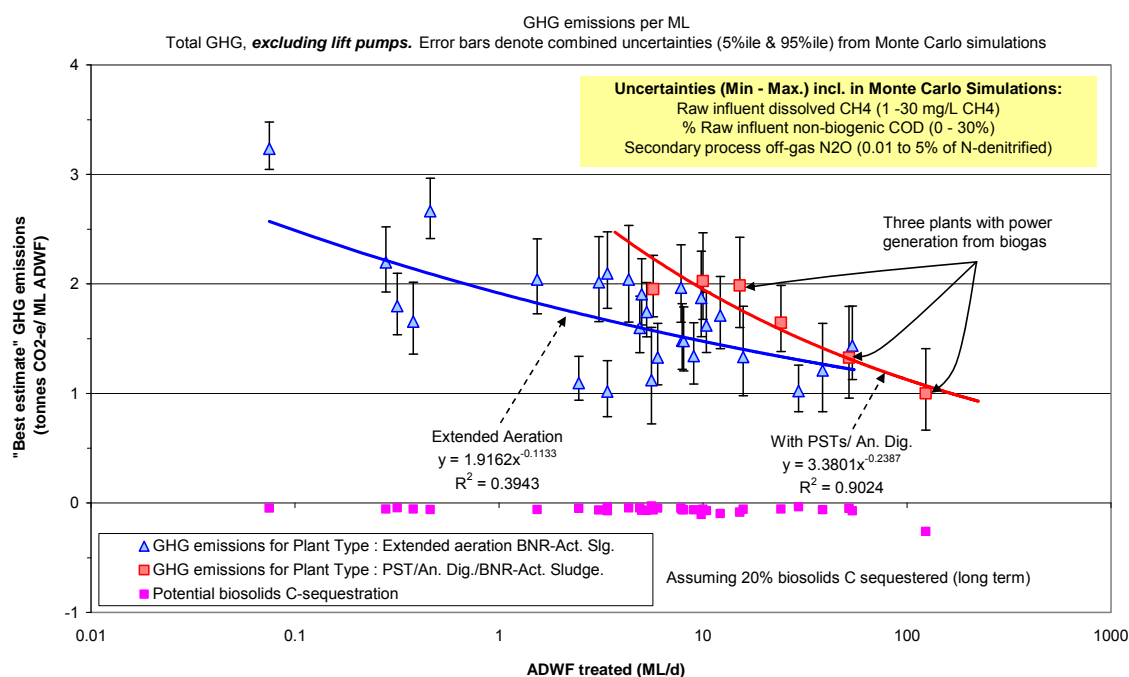


Figure 1. Normalised data on GHG emissions for surveyed WWTPs excluding lift pumps

The following overall conclusions can be drawn from the results.

- There is a weak correlation showing decreasing GHG emissions (on a tonnes CO₂-equivalent per ML basis) with increasing plant size (ADWF). The correlation is somewhat stronger for the plants with PSTs-Anaerobic Digesters than for the Extended Aeration plants. This might be fortuitous to some extent since the largest plant (Plant I) has cogeneration from biogas, which reduces its GHG emissions.
- For the extended aeration plants (Type 2), the average emissions were 1.5, 1.7 and 2.4 tonnes CO₂-e per ML in the size categories <1 ML/d, 1-10 ML/d and > 10 ML/d respectively.
- For the smaller data set of Type 1 plants (with PSTs-Anaerobic Digesters), without and with cogeneration from biogas, the averages were 1.2 and 2.1 tonnes CO₂-e per ML respectively.
- When taking into account all Scopes (1 to 3) and neglecting potential sequestration of carbon in biosolids disposed to either agricultural land or landfill, the range in uncertainty in estimates of GHG emissions is typically the Mean ±20%, but might be as small as Mean ±6% or as large as Mean ±40% for the assumptions adopted and the predicted 5th and 95th percentile limits from the combined probability analysis.
- The potential for carbon sequestration due to biosolids disposal does not appear to be very large in relation to the total likely GHG emissions, on a CO₂-equivalent basis.

Summarising, it appears that a number of site-specific factors arising from the design and operation of the WWTP, rather than the type of plant per se most strongly affect the GHG emissions per ML flow treated. Obviously cogeneration has the potential to significantly reduce emissions (indicatively up to 38% reduction for a given plant – De Haas and Hartley, 2004). Similarly, design of aeration and pumping systems strongly influences power consumption and hence mainly Scope 2 emissions. Contributions to direct emissions (typically non-biogenic CO₂, N₂O and CH₄ fugitives) are not readily under the control of the WWTP designer or operator, except perhaps leaks from anaerobic digesters and gas holders. On the basis of this study, there is little potential for making WWTPs of this type in SEQ carbon neutral by sequestration of biosolids.

Conclusions

A survey of WWTPs in SEQ provided very useful inventory data from which greenhouse gas emissions could be calculated, for benchmarking purposes. The GHG calculation procedure from first principles highlighted a number of uncertainties in emission factors, particularly in respect of the non-biogenic organic component of raw wastewater and potential fugitive emissions of nitrous oxide and methane. These uncertainties can influence the results over the range indicatively Mean \pm 20% (5th to 95th percentile), based on simulations of combined probabilities. Further research into the emission factors that are highly uncertain (e.g. fugitive emissions of nitrous oxide and methane; and the non-biogenic carbon content of typical wastewaters) is clearly required. Based on the assumptions in this study, on a dry weather-flow specific basis the typical average GHG emissions from WWTPs lie in the range 1 to 2.5 (overall mean 1.8) tonnes CO₂-e/ML treated. The potential for long-term carbon sequestration in the form of biosolids disposal to land or landfill appears to be limited (indicatively <15% of total emissions, when counting all estimated direct and indirect emissions for the wastewater treatment plant operations).

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Quantitative Comparison of Centralised and Decentralised Options for the Urban Water Cycle

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Summary

The Life-Cycle Assessment (LCA) methodology was used to generate quantitative comparisons of centralised and decentralised options for a new housing development in South East Queensland (SEQ). Key aspects of the systems under consideration were then examined in more detail. The results suggest that household rainwater tanks and cluster scale wastewater treatment and reuse systems could deliver advantages over the centralised alternatives in terms of reduced freshwater extraction and reduced nutrient discharge to the region's receiving waters. However, all the decentralised technologies we considered showed the potential for a greenhouse gas penalty when compared with the centralised benchmarks. The poor quality of data available to predict the performance of decentralised technologies remains a key impediment to more informed water cycle planning, and our results identified a number of priorities for more detailed research to address these knowledge gaps. Our findings also suggest that there is an important role for further LCA analysis to consider a number of areas not yet adequately addressed, and that this work would have maximum benefit when undertaken early in the research or planning process.

Background

While recent history has seen plenty of debate on the relative merits of centralised and decentralised approaches, there is very little information available that is sufficiently systematic or comprehensive to guide decision makers on the relative environmental tradeoffs involved. Given the ongoing need for new urban water cycle services in SEQ as the population grows over the next 50 years, this is clearly an information gap that could prevent water cycle planning from achieving environmentally optimal outcomes. The LCA methodology has been used to guide decision making in other urban water jurisdictions in Australia (eg: Grant and Opray 2005, and Lundie et al 2005), demonstrating its capacity to quantitatively compare dissimilar options across a diverse set of environmental issues. We applied this LCA methodology in the SEQ context - focussing specifically on the tradeoffs between decentralised and centralised infrastructure approaches and the opportunities for environmental optimisation of decentralised technologies.

Results and Discussion

Our analysis considered different alternatives, at a range of scales, for the provision of water supply and wastewater services to a new 109 house development in SEQ. While the development chosen was in a peri-urban setting, the results suggest that the analysis provides useful guidance for decision making related to the more typical residential densities of future population growth in SEQ. First, we compared the alternatives across a broad suite of environmental and resource-use impact categories (see Lane et al 2009a, and Lane et al 2009b). In order to provide some context on the relative significance of the different impacts considered, the results presented here are normalised against estimates of the total Australian impact using the same metrics. We then considered some of the key issues in more detail.

Figure 1 compares different **water supply** options, split into those using desalination vs. local dam extractions as the default mains supply. These two choices of centralised supply represent the extremes (of those likely to be used in SEQ) in terms of specific energy consumption. The scenarios were: (a) fully centralised water supply; (b) centralised mains supply with a 5kL tank providing toilet, laundry and outdoor use; and (c) a large rainwater tank providing all water uses, with mains water occasionally trucked in to top up the tank.

The results suggest that rainwater tanks could deliver improvements over desalination in all the impact categories considered, but that there would be tradeoffs involved in choosing between rainwater tanks (lower freshwater extraction) and dams (lower greenhouse gas emissions). Ascertaining a preference between centralised infrastructure and rainwater tanks will therefore require an understanding of the long term marginal supply mix for mains water – a complex task given the integrated regional supply grid being implemented in SEQ. It would also require more detailed consideration of the environmental significance of freshwater extraction from new and existing SEQ dams, particularly when compared to the hydrological changes associated with household rainwater capture.

This comparison is also challenged by uncertainties over rainwater tank performance. The greenhouse gas burden of rainwater tanks is dominated by operational energy use, and the comparisons in Figure 1 are based on fairly conservative assumptions (tending towards higher energy use) for rainwater tank operations. However, the overall energy burden is a function of a large number of design, operational and behavioural factors for the rainwater tank system, and these might vary widely given the large number of separate installations involved (>1 million tanks expected in SEQ by 2056). Figure 2 illustrates the potential for this energy burden to vary substantially – it compares our default assumptions for Figure 1 (the 2 datapoints) with the range (2.5→97.5 percentile) of outputs from a Monte-Carlo simulation that used uncertainty estimates for many of the parameters that can affect rainwater tank energy use.

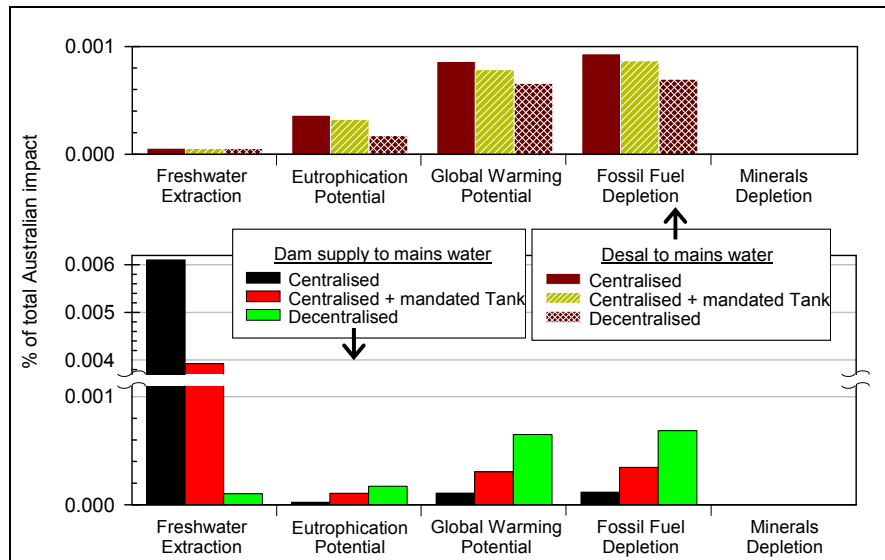


Figure 1. Normalised results for a life-cycle comparison of water supply options to a 109 house development, across 5 impact categories

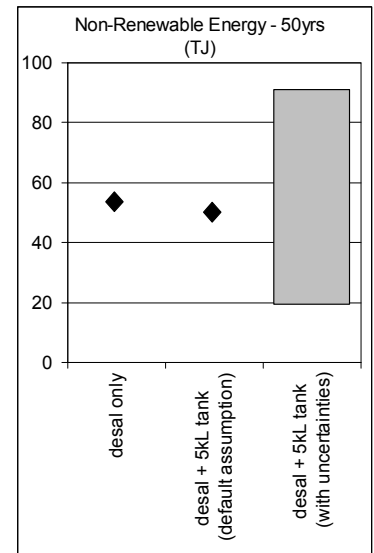


Figure 2. Importance of uncertainty on rainwater tank operations

Figure 3 presents a comparison of three different **wastewater management** options: (a) connection to the existing centralised sewerage system; (b) a clustered sewerage system with reuse of treated wastewater on the development site; and (c) household sewage treatment and disposal. This shows that while the household scale (onsite) system is the worst performer across all impact categories, the cluster (development) scale system has the potential for the best nutrient discharge performance but at the cost of higher greenhouse gas emissions.

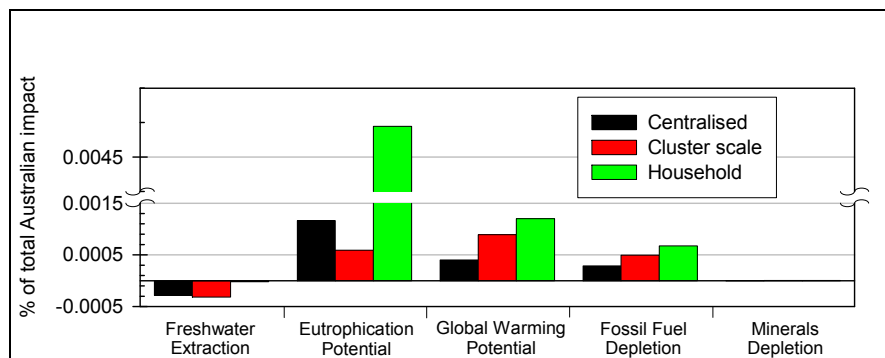


Figure 3. Normalised results for a life-cycle comparison of wastewater management options for a 109 house development, across 5 impact categories

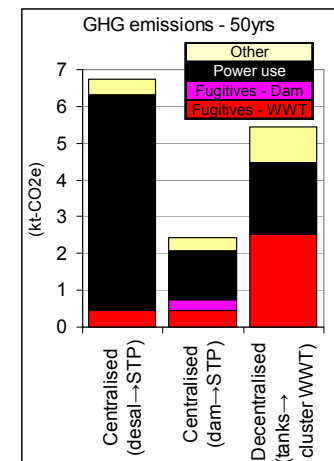


Figure 4. GHG comparison of total water cycle alternatives for a development of 109 houses

This result is subject to the high uncertainty associated with estimating nutrient export from land application of treated wastewaters. Also, our survey data suggests that the operational energy use for the cluster-scale wastewater technology that we considered is likely to be at the low end of the spectrum for small to medium systems. As with rainwater tanks, there is little available validated performance data on these issues.

The main cause of the greenhouse gas penalty for the cluster scale system in Figure 3 was our estimate of high fugitive greenhouse gas (N₂O and CH₄) emissions. The significance of this issue is highlighted in Figure 4, which partitions the source of greenhouse gas emissions over the life cycle of a fully centralised water cycle (dam/desalination sourced mains supply and centralised sewerage) and a fully decentralised water cycle (large rainwater tanks with a clustered wastewater treatment and reticulation system). The fugitive greenhouse gas emissions from the cluster scale wastewater system are clearly a big point of difference between the scenarios.

Table 1 therefore compared the fugitive greenhouse gas emissions from a range of different small-scale technologies for sewage treatment and disposal by land application. It suggests a tradeoff between high energy use and high methane emissions for comparing most systems; hence the system with the lowest greenhouse gas emissions uses minimal mechanical aeration (hence very low energy use) and avoids the methane generation of septic tank treatment.

Table 1. GHG comparison of different scenarios for small scale wastewater treatment and land application

	Equivalent emissions (kg-CO ₂ e/hh/y)					
	Septic	Septic with greywater separated	Septic + Aerobic (high energy)	Septic + Aerobic (low energy)	Aerobic (high energy)	Aerobic (very low energy)
N₂O	50	50	50	50	55	55
methane	395	315	400	400	5	5
power use	0	85	660	200	840	95
Total	445	450	1110	650	900	155

Our estimates of N₂O emissions used the default factor recommended by Foley and Lant (2008) for large scale sewage treatment plants. However, they highlighted the very large uncertainty on STP emissions of N₂O, noting that carbon constrained denitrification could increase the potential for N₂O emissions. Furthermore, recent measurements by Foley (pers comms 2009) suggest that the level of N₂O emissions can vary significantly across different large scale Australian STP technologies. Since the systems that we considered are less effective at denitrification than these large scale plants, it is possible that Table 1 underestimates both the magnitude and variation in N₂O emissions. Further investigation on this topic is needed to inform comparisons across small-medium and centralised wastewater systems.

Conclusions

Sensitivity analysis (see Lane and Gardner 2009a) suggests that, if the results presented here (Figure 1 and Figure 3) were applied to a multi criteria optimisation across the three dominant issues of freshwater extraction, nutrient discharge and greenhouse gas emissions, the first two issues would be most influential to the optimisation outcomes. This means that the decentralised approaches would likely be favoured. However, the data underpinning our decentralised systems performance models is highly uncertain. Consequently, further investigation is warranted into predicting key aspects such as: rainwater tank throughputs and yields; effluent quality from small to medium wastewater treatment systems; and nutrient export from wastewater systems based on land application. Long term water grid balances would also improve any comparisons with centralised alternatives.

However, greenhouse gas constraints are likely to become an increasingly big challenge for SEQ water cycle institutions over the medium term. Institutional reluctance to embrace decentralised infrastructure would therefore seem likely if it were to risk an increase in the greenhouse gas profile of the local water industry. This concern would be exacerbated by the relatively large uncertainty associated with the core performance of decentralised technologies when compared to the much better understood centralised alternatives. Along with the collection of basic energy usage and performance data, our analysis suggests that future water cycle planning would be enhanced by further research into a range of issues that include: the scope for rainwater tank energy use optimisation; the infrastructure or planning constraints required to avoid worst case energy outcomes for large scale rainwater tank implementation; and the quantum of, and potential to reduce, fugitive greenhouse gas emissions from decentralised wastewater systems.

Our analysis has demonstrated the value of applying the LCA methodology to deliver systematic, quantitative comparisons across complex and dissimilar options, enabling decision makers to move beyond the traditionally polarised debate over different water cycle options. Our findings, in conjunction with those of de Haas et al (2009) and Foley (2009 pers comms), have identified:

- key uncertainties that should inform future research priorities - highlighting the advantage in undertaking such assessments early in the process of researching water cycle alternatives;
- a need for further LCA screening analysis in a number of areas that have not yet been sufficiently addressed - investigating the optimal scale for wastewater treatment and reuse systems, and a broader consideration of the environmental impacts of rainwater tanks;
- that detailed LCA modelling of centralised alternatives for the entire SEQ region would provide robust guidance on opportunities for reducing the environmental burden of the main components of the SEQ urban water cycle;
- that further consideration is required on key decision making aspects of the methodology, such as the impact metrics and normalisation approaches, so as to maximise the benefits of this analysis to decision makers.

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Who Will Take Responsibility for the Indirect Energy Impacts of Urban Water Supply Choices?

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Introduction

This paper argues that the contribution of urban water management to energy use and associated climate change has been largely overlooked. This is potentially because many of the influences are indirect or outside the typical boundary of “urban water” responsibilities. This topic is currently being explored in detail by the author as part of a PhD scholarship from CSIRO with funding through the Urban Water Security Alliance.

Climate change is impacting urban water reliability in Australia (WSAA 2005; Qld Government 2006). In response, energy use for water supply is anticipated to grow between 200 and 500% by 2030 as “climate independent” desalination and reuse supplies grow (Kenway et al. 2008). There is an increasing urgency to find approaches which break this “positive-feedback” and enable the water sector to contribute more markedly to energy and associated greenhouse gas savings, for example to the 80% reduction levels proposed by some governments.

While many utilities are focussing on energy issues within “organisational boundaries”, additional solutions exist. Common energy or greenhouse strategy elements adopted by the Australian water sector largely follow the waste hierarchy: avoid (organisational) emissions first, switch to greener fuel sources second and offset when other options have been exhausted (WSAA 2007). This paper argues that while such an approach is commendable there are also further energy efficiency opportunities which utilities can influence indirectly including product use and resource recovery. Consequently there is a wider set of potential solutions by looking beyond the boundary of direct influence.

A suggested point of entry is anticipated to be in performance reporting. Sustainability, triple bottom line or corporate social responsibility reports are produced by many businesses annually. The trend towards accountability for the use of products is also suggested by the World Business Council where they note that “*current reporting practices are often performed within the boundaries of the reporting organization. In the coming years, it is likely that companies will increasingly report across the value chain including wider downstream (consumer related) impact of products and services*” (Heemskerk et al. 2002). The global reporting initiative (GRI 2005) sector supplement for public agencies flags a similar direction.

Keywords

Water provision, energy use, greenhouse gas emission, urban system, system boundary.

System Boundaries, Direct and Indirect Emissions

The approach adopted in this paper draws on the concept of urban metabolism (Wolman 1965; Sahely et al. 2003; Kenway et al. 2008) to place water-related influences in context with the total material and energy throughput of urban systems. The urban “system boundary” offers new perspective because its wider scope suggests that for urban communities to move towards sustainable futures it is necessary to systematically reduce the materials and energy throughput of cities (Pamminger et al. 2008).

While the water sector uses a small component (0.2%) of urban systems energy directly, it can indirectly influence much larger amounts (Table 1). For example, residential water heating consumes around 1.2% of urban systems energy use. Similarly non-residential energy use related to water is estimated to be approximately 1.4% of urban systems energy use. Both these substantial pools of energy use can and are being influenced by water conservation strategies including home retrofits, efficient appliance rebates and improved customer information programs (Sydney Water 2006). Industry innovation in water and energy efficiency too has been supported by some utilities with “connectionless steamers” (Larabee et al. 2007) and “waterless wok stoves” (Waterset Pty. Ltd. in Kenway et al. 2007) which simultaneously save water and energy. Other similar innovations can be expected.

Table 1. Energy use of components of the urban water system.

Component Considered	PJ/a	% of urban system
Utility energy use (energy to provide water and wastewater services)		
Direct energy use by water utilities to provide water and wastewater to 12 million persons ¹	6	0.2%
“Product Use” – energy used when water is used		
Residential hot water ¹	40	1.2%
Industrial and commercial ²	50	1.4%
“Resource loss” – energy needed to resynthesis nutrients lost in wastewater flows		
Nitrogen in sewage (energy to recapture as ammonia) ³	3	0.1%
Carbon as methane ⁴	6	0.2%
Total urban system energy use for 12 million persons		
Total urban system⁵	3450	100%

¹ (Kenway, Priestley et al. 2008), Note that the energy value is the energy necessary to heat the water – the actual primary energy need will depend on the fuel source (coal/gas) and heating system and will be larger than the value indicated above ² (AGO 2002) energy value derived from greenhouse gas emissions cited. Note a similar ratio was identified in California where residential water consumed 13,500 GWh and commercial and industrial 14.3 GWh (Klein 2005).³ Nitrogen flows in raw sewage for 12 million Australians is estimated at around 65,000 tonnes based on approximately 1400 GL/a flow from 12 million persons (WSAA 2007) and 55mg/L nitrogen. To synthesise nitrogen for agriculture using the Haber-Bosch process uses around 36 GJ/tonne of ammonia. ⁴ Each ML of sewage contains around 5,900 MJ of energy potentially recoverable as methane. ⁵Includes pro-rata all state-wide energy use including agriculture, mining and transport energy use.

Nutrient loss from our wastewater systems requires energy to resynthesis equivalent nutrients back into our agricultural systems. Nitrogen alone requires significant energy to synthesise the equivalent ammonia lost in wastewater. Historically, this has not been the case. For example in 1913, approximately 30% of the Nitrogen in food consumed by Paris was sourced from reuse nitrogen from human waste (Barles 2007).

In addition to the quantified examples in Table 1, energy is used for other residential and non-residential purposes related to water (for example cooling, filtering, air-conditioning). Similarly energy is embedded in chemicals (e.g. chlorine, alum) and materials (concrete, steel) used by industry. There are energy implications too in the consideration of centralised versus decentralised (e.g. rainwater tank) options for cities. Finally, management and policy surrounding water and sewerage systems can influence many other aspects of energy use associated with water, for example, decentralised systems (rainwater tanks and pumps), bottled water use (which is extremely energy intensive), the form, function of cities through development planning and also the heat-island effect of cities (where cities are 2-3 degrees warmer than their surrounding areas). All of these indirect influences have energy implications though they have not been considered here.

The authors note that analysing a system for energy implications is different to analysing a system for greenhouse gas emissions. This paper focuses on energy because the data sets and influencing processes are better defined. Energy use can be rapidly converted into greenhouse gas emissions. However, it is acknowledged that fugitive emissions such as nitrous oxide or methane from wastewater treatment processes or methane emissions from water storages as examples are not discussed here, and could potentially be significant in some systems.

Conclusions and Implications

Collectively urban water management can influence at least 3% of urban systems energy use. Considering a wider “system boundary” helps reveal this influence. It also helps identify where more significant energy savings could be found by considering policy implications rather than through seeking solutions solely within “organisational” boundaries. Water conservation strategies, pricing regimes and restrictions policy are examples.

This paper speculates that the indirect influences on energy use and resource recovery have not been widely considered previously for many reasons. Among these could be the challenge of identifying the relative contributions to savings that could be attributed to utilities versus householders or businesses. Who gets the credit? Who pays? Who benefits? How do you prove the water “saved” wasn’t used or sold elsewhere? Also, as most water businesses are remunerated in accordance with the volume of water sold, strategies which reduce the volume of water can impact on profitability – unless alternative incentives are provided. A component of the solution is suggested to lie in emphasising the benefits or “value derived from” water and energy: for example clean clothes or bodies, cooked food, or production of goods or services rather than simply provision of the water.

As the challenges of climate change continue to unfold, and mitigation targets progressively aim to reduce emissions further, it is argued that taking a wider perspective will be necessary for the water sector to contribute in proportion with other sectors in achieving target reductions. A wider boundary could offer myriad opportunities and lead to paradigm change in the way our urban water systems designed and managed.

Aims of this research are to help inform this transition by (1) quantifying the indirect effects of urban water management and to (2) evaluate methods for analysing these effects. How well do current methods and analyses deal with the “system boundary” and how far through the “cause and effect” chain does the method function. Methods may include life cycle analysis, input-output modelling, ecological footprint calculation and urban metabolism.

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A Preliminary Analysis of Potable Water Savings from Mandated Rainwater Tanks in New Residential Properties in South East Queensland

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Summary

This desktop statistical analysis forms part of the Decentralised Systems research theme for the Urban Water Security Research Alliance. In 2007, a significant amendment was made to the Queensland Development Code (QDC) in the form of mandating all residential homes to achieve a target of 70 kL/hh/year potable water savings (MP4.2 – *Water Savings Targets*). The primary aim of this study is to investigate the potable water savings from mandating rainwater tanks in new developments using council water use data. A preliminary analyses was undertaken with the aim of determining the size and type of data required for statistical pairing of cohort and control members and identifying key problems with data manipulation prior to undertaking a full analysis with large datasets ($n \geq 30,000$). Preliminary results show water savings of up to 52 kL/yr for Gold Coast properties, but no significant differences in water use for Caboolture properties. The disparity in these results highlights the complexity of such a study where many factors contribute to water demand including water restrictions, tank rebates and household demographics.

Keywords

Rainwater tanks, mains substitution, Queensland Development Code, South East Queensland, water efficiency.

Background

The Urban Water Security Research Alliance themes have been developed to address fundamental issues necessary to deliver South East Queensland (SEQ) region's water needs. This desktop statistical analysis forms part of the Decentralised Systems research theme and focuses on potable water savings from mandated rainwater tanks.

In 2007, a significant amendment was made to the Queensland Development Code (QDC) requiring all residential homes to achieve a target of 70 kL/hh/year potable water savings (MP4.2 – *Water Savings Targets*). The most common means of achieving this water savings is through the installation of rainwater tanks plumbed to toilet, laundry and an outside tap. However, the evidence to support the viability of 70 kL/hh/year is based on non validated modelling. In addition, the key factors driving rainwater usage patterns in SEQ requires further investigation, particularly given that domestic water use reduction is a key component of the SEQ Water Supply Strategy (QWC 2008). Gardiner (2009) described the different circumstances to which residential rainwater tanks have been installed in SEQ, noting there are over 300,000 tanks in SEQ with about 30,000 installed under the MP4.2 rule.

This study is the first to examine the potential savings to mains water from domestic rainwater tanks although water demand for Brisbane and Australian urban settings has been discussed in recent research (Hoffman *et al.* 2006; Barrett and Wallace 2009; Worthington *et al.* 2009). This study will focus on comparing water consumption data from a large number ($n > 30,000$) of paired residential properties in five local authorities in SEQ: Moreton Bay Regional Council; Gold Coast City Council; Ipswich City Council; Redland City Council; and Sunshine Coast Regional Council. Council water billing data will be analysed and statistical comparisons made on water savings between mandated and non-mandated houses using methods similar to previous studies such as Turner *et al.* (2005). A preliminary analysis was undertaken with the aim of determining the amount and type of data required for statistical pairing of cohort and control and identifying key problems with data manipulation prior to undertaking a full analysis with large datasets.

Research Aims

The aim of this research study is to (i) investigate whether the 70 kL/hh/year savings target is achievable for the typical mandated home, and (ii) to identify whether there are there certain demographic (suburb, age, no. of people) and residential features (lot size) that influence potable water savings and water demand. This information will be useful to update the SEQ Water Strategy (QWC 2008) which assumes such savings are feasible. It will also provide a basis for further experimental work for the Decentralised Systems project involving water use and some end use measurements from rainwater tanks.

Methods for Data Collection and Statistical Analysis

Data Collection

Water consumption data was obtained from the water demand management section of councils. Some of the data was provided through the Queensland Water Commission, once permission was obtained from the local authority. The main steps in the preliminary analysis were:

1. The raw data set was filtered for duplicate and ambiguous data (*e.g.* incomplete, repeat records).
2. This data set was then filtered for the Land Use Code representing a Class 1 building as per the QDC mandate requirements (only single, detached dwellings were considered further).
3. All properties constructed after January 1st 2007 were isolated (cohort). Further to this, only 2008 consumption data from these 'new' properties were used to reduce likelihood of choosing new developments that were constructed after January 1st 2007, but yet to be fully occupied.
4. All properties that were constructed prior to 2007 were also isolated (control).
5. Cohort and control data were divided into four treatments based on suburb and lot size; < 700 m² and > 700 m². This size was used as it generally represented an equal divide between the smaller and larger lot sizes within each council.
6. A comparison of the means between cohort and control for each treatment was carried out. A two-tailed, paired t-test was also performed on the data using ExcelTM.

Preliminary Results and Discussion

Water consumption and water savings from two council datasets were analysed (Caboolture and Gold Coast). The pattern of water use for the Caboolture properties is shown in Figure 1. Water use for newly constructed (mandated) houses in Caboolture did not significantly differ from pre-2007 houses with lot sizes < 700 m² (Figure 1). For properties with > 700 m² lots, water use was significantly higher ($p < 0.05$) in the rainwater mandated houses (*i.e.* post 2007). There was no obvious mains water savings in the post 2007 houses - a somewhat surprising result. One factor that may be driving the increased water use in the newly constructed properties is household demographics, where larger and younger families are moving into the subdivisions. Detailed analysis of census district data will allow this theory to be explored in more depth.

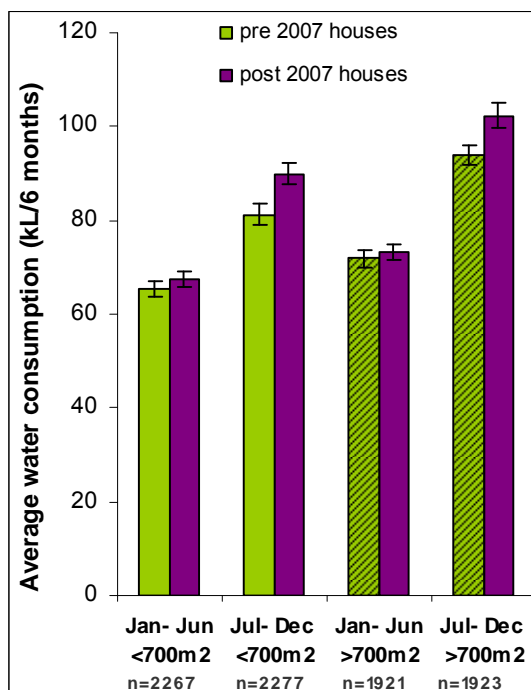


Figure 1. Water use comparisons of Caboolture Shire properties (2008 data)

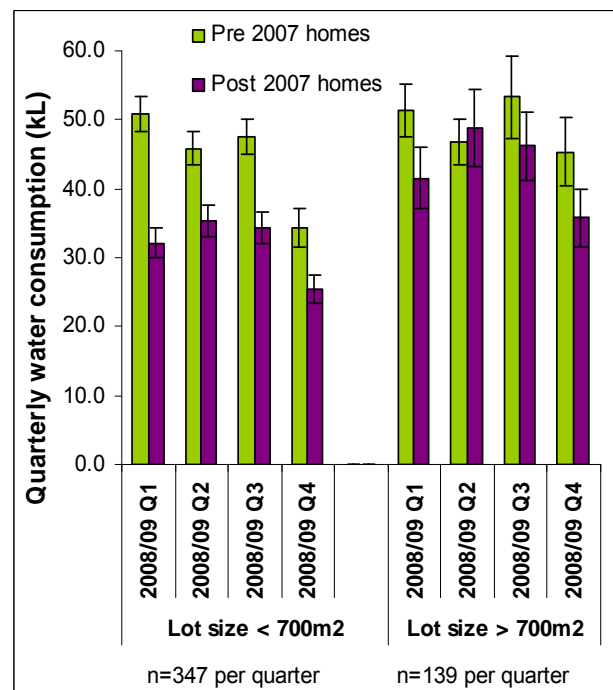


Figure 2. Water use comparisons of Gold Coast City Council properties

In contrast to the Caboolture data, water consumption in newly constructed Gold Coast dwellings is less than the pre 2007 dwellings (Figure 2). With the exception of the second and third quarter in lots > 700 m², water use was significantly lower in the post 2007 houses. Although the sample sizes are considerably smaller than Caboolture (100 to 350 pairs vs 2,000 – 2,300 pairs), the average savings per quarter from post 2007 houses is about 13 kL for lot sizes < 700m² and 6 kL for lot sizes > 700 m² lots. Overall, annual savings from mains water in the Gold Coast sample range from approximately 52 kL/yr (<700m²) to 25 kL/yr (> 700 m²). Water restrictions were eased on July 31st 2008, which allowed hand held hoses to water gardens and lawns and car washing. This is likely to be a factor in the increase in water use during the second half of the year in Caboolture, and the last two quarters in the Gold Coast. However, teasing out the effects of the restrictions and Waterwise features from the effects of internally plumbed tanks on total water use is a significant challenge for future analysis.

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Complexities in Decentralised and Distributed Systems

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Summary

Conventional centralised water, wastewater and stormwater systems have been installed all over the globe for urban municipal services. These systems center around the protection of human health, ensure reliable water supply and minimise flooding often with minimal consideration of the environmental and ecological impacts associated with discharges. The sustainability of centralised systems is increasingly being questioned as water service provision in an urban context faces unprecedented challenges in this new century from the emerging issues of climate variability, population growth, aging infrastructure, urbanisation and resource constraints. Water service providers and managers are thus considering alternative and sustainable means for providing water services in the current environment. Decentralised and distributed water and wastewater systems, which are planned within an integrated water management concept, are being promoted either in combination with centralised systems or alone as the sustainable solution for urban water servicing. These systems are new and complex and thus wide knowledge gaps exist in their planning, design, implementation, operation and management, which may impede their uptake. This paper summarises some of the complexities in the implementation of these systems and the research needed to address some of the knowledge gaps for increased uptake of decentralised systems.

Keywords

Decentralised, centralised, water, wastewater, economics, climate change, sustainability.

Introduction

Conventional urban water supply systems are characterised by the procurement of fresh water from outside of the urban area, treatment of raw water and distribution via large-scale pipe networks. Conventional wastewater systems can be stereotyped by the collection of sewage via piped collection system, transportation out of urban areas to a treatment plant and discharge of treated effluent into receiving water bodies (Wilderer, 2001). These systems have provided considerable benefits to modern society via the provision of reliable services and increased health benefits. However, the increased pressure on water resources due to rapid urbanisation and population growth and the need to minimise contaminant loads to receiving environments has meant that conventional water and wastewater systems are not always the most suitable solution for urban development.

A centralised approach can constrain the potential to adapt water services to local opportunities and needs. For example in centralised systems, a large amount of high quality water is used for toilet flushing and transportation of human waste through sewers to the treatment plant. A decentralised approach offers the opportunities to use local water sources and close the loop on waste streams through taking a 'fit for purpose' approach that matches the quality of source water to the quality requirements of each end-use. Decentralised systems also allow a flexible approach to the provision of water services that considers multiple objectives in the local context; such as flood alleviation, landscape amenity and environmental protection. Decentralised systems offer an alternative approach to providing water, wastewater and stormwater services to urban areas, which may be integrated with centralised systems or as standalone solution where the provision of centralised systems is not technically, economically or environmentally feasible.

The provision of water services to urban developments is undergoing a major transition in the current environment aimed at improving sustainability and ensuring the long-term security of water resources. Integrated urban water management concepts are now being considered for providing water and wastewater services. The provision of integrated urban water systems for greenfield developments has attracted much interest and research across the globe. The area of retrofitting existing developments with integrated water management techniques is also new and has yet to be explored to a significant extent. Only the planning and conceptualisation of integrated water systems have been explored in detail. The design, delivery, management, verification, reliability, sustainability and associated externalities of these integrated water systems have yet to be investigated. These systems, being complex in nature, need to be assessed in detail for their economic, health and environmental, system implementation, operational and management challenges.

A number of structural and non-structural solutions can be used to achieve integrated urban water management and water sensitive urban design objectives, the selection of which will be dependent on a large number of factors including: the type of development; scale; catchment conditions; climate; customer acceptance; and allocation of financial resources. Some examples of structural solutions are rainwater tanks, greywater treatment and reuse, wastewater reuse, stormwater use, on-site detention tanks, buffers, swales, bioretention devices and ponds (Sharma et al., 2008). There are numerous technologies and systems available to select for an implementation approach. These technologies should satisfy the requirements to meet scarcity of water, community expectations, financial constraints, changing spatial configurations, population densities, community behaviour, flood risk and wastewater related ecological problems etc. As mentioned above, the selection from available systems for an integrated water-servicing solution is complex and thus requires the development of a cohesive framework.

The development of a framework is critical because assessment of individual technologies in isolation can lead to incorrect analysis. For example, initial investigation of a simple decentralised 'rainwater tank' system has highlighted the highly variable energy usage from 1.3 to 5 kWh/kL (Beal et al. 2008 and Retamal et al. 2008) associated with their use, thus raising the question whether the saving of one resource (water) is at the cost of another resource (energy). This highlights the need for better understanding of an optimal configuration of rainwater tank systems and analysis of the energy-water nexus. Similar investigations are required for a number of decentralised water and wastewater treatment technologies for water-energy interaction and the impact on their planning and environmental aspects.

In a centralised servicing approach, publically-funded water utilities bear the cost of installing the water and wastewater systems, while in decentralised systems allotment owners largely bear the direct cost of capital investment and ongoing maintenance and operation, the extent of which depends upon the nature of the system (Sharma et al., 2009). No generally accepted economic model exists to allow equitable distribution of the cost between utilities, state and allotment holder. In this context, consideration of environmental benefits to both the wider community and the local community is required in evaluating the suitability of decentralised systems. Additionally, in decentralised systems many of the management responsibilities are being shifted towards allotment owners without much social research into the receptivity of householders and the impact on performance and reliability over the lifetime of the system. A number of other issues need to be addressed for mainstream application, for example: the need for the water sector to foster the development of workforce skills required in the maintenance and operation of decentralised systems; updating of design guidelines; development of appropriate management, governance and regulatory frameworks; and increased understanding of the reliability and risks associated with these systems over their lifetime.

Conclusions

Decentralised and distributed systems may have benefits over centralised systems in the current environment. As these systems are new and complex, wide knowledge gaps exist in their planning, design, implementation, operation, management, governance and understanding, reliability, resilience and risk. Research at all levels is required to reduce knowledge gaps for the greater uptake of these systems.

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Decentralised Systems Why Do We Care?

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Summary

Decentralised systems have been around for over 50 years, traditionally adopted in rural areas, given the absence of mainstream water and wastewater services. They were often considered an alternative to be relied upon until centralized services became viable. Yet, given the passage of time these systems are not only still in use, but more importantly are increasingly being adopted in mainstream and greenfield developments as a tool to achieve greater sustainability for the constructed environment in peri-urban and urban areas. What has changed? Why do they persist? What purpose is there for their adoption in an urban context? These and other questions were explored through the analysis of such systems in South East Queensland (SEQ): recent case studies, government initiatives, the local context and the opinions of water professionals experienced with the implementation of such system. This paper discusses the drivers, potential benefits and explores the context to their adoption.

Keywords

Decentralised systems, provision of water and wastewater services, recycling, system infrastructure.

What are Decentralised Systems?

Definition: “Systems for water, wastewater and stormwater services at the allotment, cluster and development scale that utilise alternative water resources; including rainwater, wastewater and stormwater. Based on a ‘fit for purpose’ concept they can be standalone, or integrated with centralised systems. All liquid streams are partially or completely utilized at or close to the point of generation and any discharge to the environment is managed as part of an integrated approach that aims to control quality and quantity at or near the source to minimise the impact of development on a natural ecosystem” (adapted from Cook *et al.* 2009).

The history of decentralised systems (DCS) in developed countries such as the USA, Germany and Japan has been driven by the local context and needs. DCS have been applied in a variety of urban settings where they have been effectively adopted for a range of purposes including the protection of public health and the environment and the augmentation of water supply in infill and greenfield based on economic merits and performance. The shift of DCS to urban areas is a more recent event in Australia (<15years), yet recent years have seen an increase in the rate of their adoption in urban developments that take an integrated approach to the provision of water services. Examples of such developments in South East Queensland (SEQ) include: Capo di Monte, Sunrise @ 1770 and Currumbin Ecovillage among others.

Decentralised systems need to be tailored to each specific site conditions and appropriately managed to perform adequately. Achieving such objectives is strongly linked to overarching legislation, policies and institutional arrangements, yet the history of water services in major Australian urban cities is based on an existing reference framework designed for the model of centralised service provision (Diaper *et al* 2008). This can often dissuade the implementation of any alternative systems for which authorities and other stakeholders lack familiarity. Given such added complexity and difficulty we wonder: What purpose does the adoption of decentralised systems fulfil? What does it offer to developments and particularly to SEQ? Exploring such questions will assist in understanding the forces that are shaping the future provision of water and wastewater services in SEQ. Furthermore, elucidation of the drivers provides a foundation for understanding the role of decentralised systems in addressing the critical sustainability challenges threatening security of water services.

Methodology

The research questions were explored by the analysis of literature on decentralized case studies in South East Queensland, the review of government initiatives and local context and a web-based opinion survey with a group of 10 water professionals experienced with the implementation of decentralised systems in SEQ.

Discussion

SEQ has undergone fundamental changes in recent years. Analysis of literature and consultation with professionals has revealed the existence of **primary drivers for sustainable services**, i.e. overarching triggers that are responsible for the search for sustainable water services in SEQ which are forcing government to develop planning, strategies and regulations/guidelines that support more sustainable water systems.

The two major triggers are the rapid growth in population, and changes to climate. Housing an additional 4.3 million people by 2026 increases the demand for water and is creating the need to develop the peri-urban and rural fringe in many SEQ areas, which are often in proximity to ecologically significant areas (Queensland Government 2005). Climate change characterised by extended dry periods interspersed by wet periods and increased temperatures are predicted to result in a water shortage of 308 GL/year by 2056. This shortage will compromise the reliability of traditional inland water supplies (dams) (Queensland Government, 2007). Such factors are driving the need for alternative water supplies, increasing efficient water use and mitigating negative impacts on the environment caused by bulk transfer of water and wastewater disposal.

To address the challenges created by the primary drivers, developers have focused on the best use of resources at local level: climate and rainfall, geology and topography, soil and hydrology, existing infrastructure and any plans for future development in a region. For example, whilst rainfall inland at major dams is scarce, rainfall in coastal areas such as Noosa and the Gold Coast can be a more reliable supply, thus increasing the feasibility for adoption of rainwater through decentralised collection and storage in coastal areas.

Based on the experience of survey respondents, DCS have the potential to offer a range of attractive benefits at the local and regional level. These benefits could include:

- Reduced environmental impact by increasing a development's flexibility to deal with local pollution;
- Use of local water sources, reducing the risks associated with bulk transfer of waste and water;
- Better use of capital as infrastructure tends to have a smaller footprint and can often be implemented in a staged process, allowing expenditure to be staged to the growth of the development;
- Lower capital requirements attract private funding and/or private-public partnerships;
- Promotion of more community ownership and awareness of sustainability given the closer link between source and water/wastewater use/reuse;
- Opportunities for technology development as the sector matures could lead to creation of a new industry segment and associated employment; and
- Overall DCS promote increased sustainability.

Consultation with professionals who have participated in the implementation of developments with decentralised systems has revealed that these benefits and others act as *secondary drivers*, i.e. drivers initiated by regional/local needs and context. Some universal and others SEQ specific drivers identified by the professionals are:

- Overcoming local water/wastewater limitations. Analysis of existing developments in SEQ indicated that a significant number of developments (12 in SEQ) would not have been developed if decentralised systems had not been adopted to overcome the lack of access to centralised water and wastewater infrastructure and in doing so allowed the promotion of sustainable development. DCS are also able to explore multiple sources, promote water conservation and reuse thereby reducing demand on potable supplies. In addition, recycle and reuse options in DCS, such as greywater reuse, offer the additional benefit of a reliable and continuous supply of water that is independent of climate conditions.
- Environmental protection and enhancement of local amenity. DCS minimise the impact of large water discharges and extractions, their transport and also allows the preservation of local landscapes through effective water harvesting and reuse for irrigation of gardens and public land.
- Technology showcase. The adoption of innovative technologies and the opportunity to showcase proof-of-concept in water/energy use have been strong drivers in many decentralised systems.
- Deferment of infrastructure upgrades. Given the need for rapid development and expensive capital investment in SEQ, DCS allow the deferring of expenditure in areas where existing infrastructure might be unavailable (e.g. greenfield sites that adopt water supplementation via rainwater tanks and on-site treatment) or constrained by capacity, for example, built areas where sewer mining, on-site treatment and reuse make it possible to increase population density in developments. In addition, as mentioned by one of the respondents, peculiarities in architecture, such as the elevated floor in Queenslander houses can also more easily accommodate retrofit for appropriate DCS.

In addition, the experience of the long drought that has affected Queensland, reforms and initiatives at government and institutional level and the existence of local know-how and expertise in Queensland via universities, government and private industry can facilitate the acceptance of DCS and the adoption of integrated water management.

The model for the inter-relation between the different drivers and the context in SEQ is shown in Figure 1. Challenges still remain in this sector and will need to be explored, yet SEQ has opportunities to advantageously explore DCS as a tool for sustainable development given the existing drivers in the region, the history of developments with DCS and the changes on government and public perception towards alternative systems.

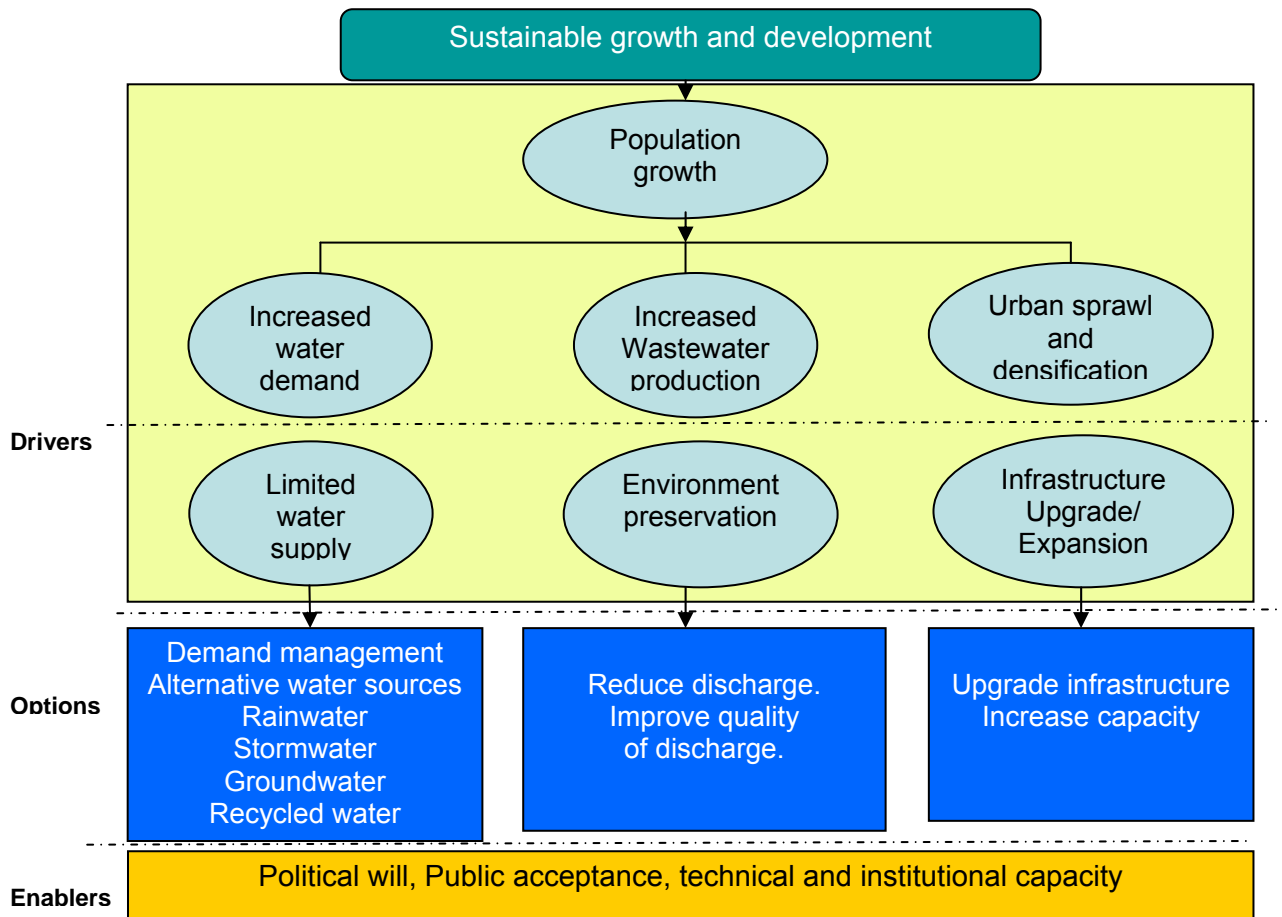


Figure 1. Major drivers and incentives for the implementation of DCS in SEQ.

Conclusions

Rapid population growth, changes in precipitation and overall changes in climate have diminished the reliability of traditional water supplies and created the need to urgently develop sustainable water services for SEQ.

Under such conditions, the need to rapidly expand existing local water and wastewater services, defer infrastructure upgrade and offer economic benefits, protect the environment, showcase sustainable approaches and innovative technologies, adopt water conservation and enhance landscape amenities and lifestyle, are all strong drivers for the adoption of decentralised systems. Such systems have the potential to promote community ownership and awareness of the water cycle, allow for technological innovation and sustainable use of water resources.

Yet, to transition decentralised systems from a niche to a more widely accepted engineering strategy also has challenges and requires enabling through government support (legislation, industry reform and strategic planning), increase in public acceptance for alternative water sources and water reuse, and development of know-how and human capital on decentralised systems.

SEQ already has developed a number of these enabling factors to a certain degree, given recent changes to planning and building legislation, local expertise, existing developments and the prolonged exposure to the drought. To ignore such opportunities and neglect to at least investigate the possibilities that decentralised systems could offer, would be to bypass the potential to achieve true sustainability.

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The Transferability of Recycled Water Treatment Systems across Various Decentralised Scales

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Summary

Water reuse can provide up to a 50% substitution of urban potable water use, is independent of climate change and reduces the environmental impact of effluent discharge to waterways. Decentralised water reuse has additional benefits that each system can be tailored to suit local settings, water quality objectives and end uses. There is also a potential to reduce the costs associated with flow conveyance, which otherwise would be necessary for connection to distant centralised treatment plants. However, the decentralised option has not been widely adopted. There is a lack of scientific research on decentralised water recycling systems in terms of technologies, design, operation, performance, reliability, costs and greenhouse gas emissions. This study will develop enhanced knowledge on these aspects through monitoring and validating three full-scale decentralised recycled water treatment plants. The plants utilise a range of different advanced technologies including membrane bioreactors, membrane filtration (microfiltration and reverse osmosis), biofilm textile filters and zeolite filtration, and service urban developments ranging from small (50 lots) to medium (172 lots). Samples will be taken on a regular basis to assess water quality during the treatment processes, calibrate the model used in this study, and evaluate fugitive greenhouse gas emissions. Meters will also be installed to measure water flows and energy consumption. In addition, a cost estimation model and treatment analysis model will be developed in order to identify the effects of significant differences in treatment technologies, operation, performance, reliability and costs as the scale of recycled system changes. The study outcome will assist decision-making on selection of appropriate decentralised scales and technologies for water recycling in greenfield urban developments.

Keywords

Decentralised, sewage treatment, membrane, biofilms, cost, technology, quality, model.

Background

Rapid urban growth, aged and capacity constrained infrastructure, and uncertainty associated with climate change are challenging our limited water resources and the existing urban water infrastructure paradigm. Recycled water is increasingly considered as a sustainable approach to face the challenges and secure water supply for urban developments. Recycled wastewater can provide up to a 50% substitution of potable water use and also offers the advantage that it is largely independent of climatic change, reduces environmental impact of effluent discharge to waterways, and potentially offsets the need for supplemental fertilisers due to nutrients in wastewater. When used at decentralised scales, the systems can be tailor-designed to fit into the local physical characteristics, as well as meet quality requirements for various end uses. Another potential benefit of decentralisation is reduced capital and operational costs due to reduced flow conveyance infrastructure, compared to centralised systems for new developments, which are commonly located on the urban fringes.

South East Queensland's urban footprint is continually expanding, with 32,767 hectares being planned for urban residential developments by 2031 (DIP, 2009). Decentralised wastewater treatment and recycling are expected to become increasingly popular in urban infrastructure planning and development. Most of the current recycled water treatment systems are essentially derived from those used in conventional wastewater treatment systems, with added advanced technologies such as membrane reactors (MBR, a substitution for sedimentation and filtration in the conventional suspended growth systems), microfiltration and reverse osmosis to produce high quality recycled water. Scientific investigations have been undertaken into the advanced technologies, such as MBR (Nichanan, *et al.* 2007; Melin, *et al.* 2006) and disinfection (Summerfelt, *et al.* 2009; Montemayor, *et al.* 2008). However, there is a significant lack of studies on whole treatment and recycling processes. In particular, decentralisation has a greater flexibility in selecting various treatment system components to suit the local settings and quality objectives. Knowledge gaps exist on the interaction among various system components, their long-term performance, reliability (resilience to shock loads), energy efficiency and fugitive greenhouse gas emissions.

This study is investigating cluster-scale recycled water systems, with a focus on emerging technologies such as MBR, membrane filtration and biofilm filters. A key objective is to identify the significant differences in treatment technologies, performance, resilience to shock loads, cost, energy consumption and greenhouse gas emissions as the scale of recycled system changes from small (e.g. 50 lots), medium (e.g. 1000 lots) to large (e.g. 5000 lots). It also aims to identify how the differences apply to selecting scale and process for a wastewater treatment and recycling for a given greenfield development and which factors are the most sensitive in the selection process. The study outcomes are expected to provide options on what appropriate size clusters and technologies might be used in a given urban development.

Experimental Design

A wastewater treatment and recycling system can have many possible design options depending on a large number of factors. Metcalf and Eddy (2003) identified 23 important factors to be considered when selecting processes for wastewater treatment. Our study has grouped the factors into seven categories and will evaluate using a range of methods, such as system monitoring, modelling, life-cycle assessment (LCA) and sensitivity analysis, to determine which factors have the greatest impact on selecting appropriate technology and size clusters for a given greenfield site. A number of greenfield sites in SEQ will be analysed as “virtual” applications to illustrate the selection process. Figure 1 shows the factors and the methodology we will apply to quantify and qualify the factors.

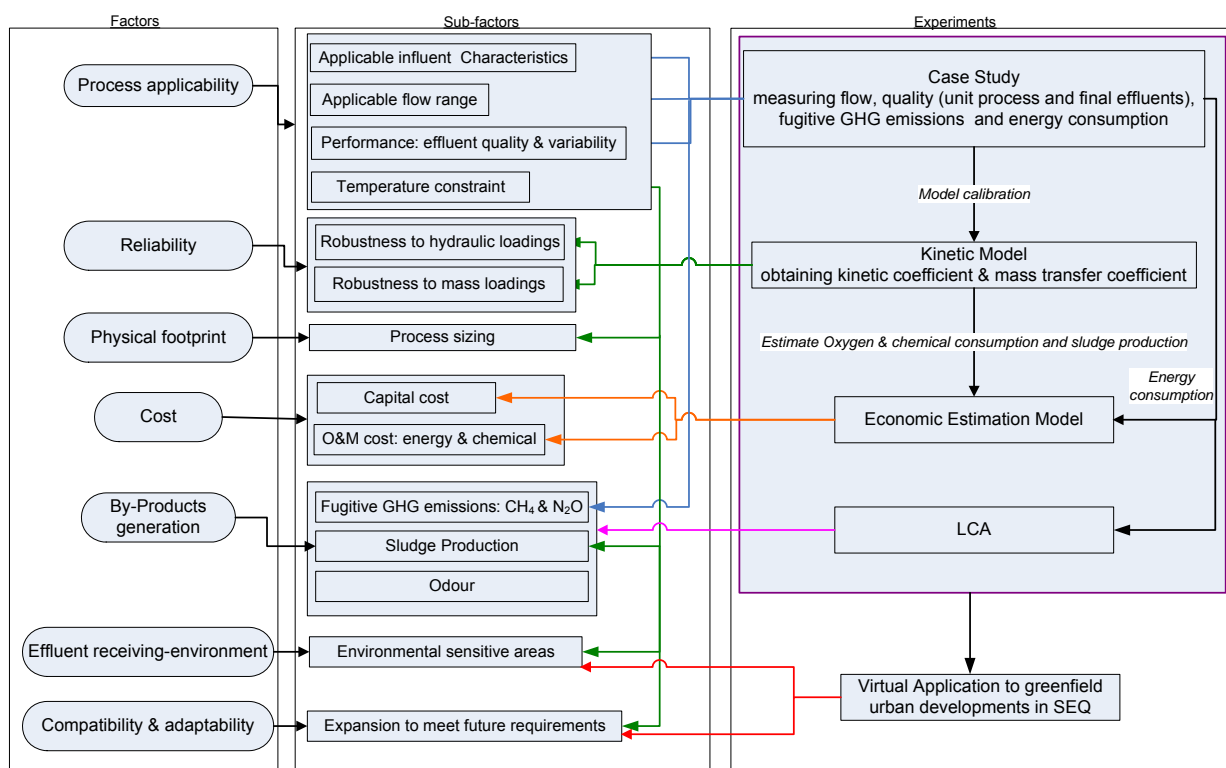


Figure 1. Methodology applied to evaluate the factors for wastewater treatment and recycling system selection.

Three developments have been selected as case studies: Capo de Monte at Mt Tambourine; Sunrise@1770 near Gladstone; and The Ecovillage at Currumbin. These developments differ in their recycled water treatment technologies, geography, development scales, lot sizes and licensed limits although they all produce Class A⁺ water for potable substitution (mainly toilet flushing and irrigation). Therefore, by comparison, we will develop an enhanced knowledge of the design, operations, cost, management, performance, reliability and greenhouse gas emissions of different types of decentralised systems for water recycling and their applicability for various urban developments.

Capo de Monte is a 4.3 ha development comprising 46 detached and semidetached residences and a community centre. Each residence has one or two bedrooms catering for “over-50’s” people. The recycled water treatment system utilises a Kubota submerged flat sheet membrane bioreactor, incorporating raked screen, anoxic/aerobic zones, alum precipitation of phosphorus, UV disinfection and sodium hypochlorite chlorination. The Class A⁺ effluent is reticulated to each house for toilet flushing and outdoor uses. A 6,000 m² vegetated buffer zone is used for land application of excess treated wastewater in order to avoid direct discharge into the local waterway.

Sunrise@1770 is a 650 ha development for 172 houses. Wastewater is pre-treated in household dual septic tanks before pumping via pressure sewers to a cluster-scale recycled water treatment system. The treatment system consists of an aerobic tank, anoxic tanks, zeolite filters, high velocity sonic disintegrator unit, sand filter and disinfection with chlorine dioxide. Ultrafiltration (UF) and reverse osmosis (RO) units were also built in the system, but their operations are on an “as needed” basis. Class A⁺ recycled water is distributed via dual reticulation to provide each house with water for toilet flushing and external use. It is also used for irrigation of a native plant nursery, a communal car washing facility and emergency fire-fighting.

The Ecovillage at Currumbin constitutes 109 lots, ranging 400 to 1600 m², and extensive communal open areas. Wastewater is collected from individual households and pumped via pressure sewers to a communal wastewater treatment and recycling plant. The plant utilises a textile biofilm filter system. Specifically, this included three septic treatment tanks in series, an anoxic and recirculation tank, textile biofilm filters, microfiltration, UV disinfection and chlorination. Class A⁺ water is produced and distributed back to the houses for non-potable uses such as toilet flushing, garden watering and car washing. The water is also used for communal open space irrigation and fire fighting.

To evaluate the system performance and energy efficiency, a range of flow meters, pressure sensors and energy meters will be installed on the studied sites. Grab samples including liquids and gases will be taken from various locations of the treatment systems on a regular basis for physical, chemical and biological analyses. Where applicable, sludge will be occasionally sampled to measure solid and organic contents.

To better understand the important design and operational variables that affect treatment performance and reliability, a well developed stoichiometric model such as the Activated Sludge Model No. 1 (ASM1) (Henze et al., 1987), will be adapted and calibrated for each treatment system. The economics of recycled wastewater collection, treatment and distribution will be analysed using a model based on the model of Booker (1999) who estimated the relationship between costs and system scale of greywater collection and treatment. Both models (kinetic and economic) will be validated using the respective raw wastewater characteristics and system performance data sets obtained from the cluster-scale recycled water systems. In addition, a LCA will also be performed to quantify total environmental burden posed by clustered-scale treatment of wastewater and recycling.

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Decentralised Systems - the Complexities of Communal Rainwater Systems

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Summary

In response to the extended drought in South East Queensland (SEQ), the Queensland Government introduced new legislation in January 2007 that all new residences must comply with mandated water savings targets. These targets in the SEQ region are 70kL/yr for detached and 42kL/yr for other residential dwellings. Commercial buildings also have imposed water saving requirements which essentially require a minimum of 50m² roof area connected to a 1500 litre storage for each toilet pedestal in the building. Rainwater tanks (individual or communal) and greywater treatment systems are two of the acceptable methods to comply with the domestic and commercial targets. Key aspects of the design and operation of these systems will be examined in our study at two locations; Capo Di Monte (CDM) at North Tambourine and Green Square North Tower (GSNT) in Fortitude Valley, Brisbane. The system at CDM is the sole water supply for an urban development, whereas the system at GSNT, a commercial building, utilises a variety of water sources, including rainwater, to substitute a fraction of the potable supply for toilet flushing and amenity irrigation. Both systems will be monitored for captured volume, outflows, energy used for treating/distributing water, and water quality.

Keywords

Rainwater tanks, potable substitution, communal tanks, commercial buildings, energy use, Queensland Development Code.

Communal Rainwater Systems

The key objectives in decentralised water systems are to supply users with water of a quality that is comparable at least to municipal supply, and to reliably supply sufficient volume to meet all of the client needs. As communal rainwater tanks are a relatively uncommon strategy in residential developments, a number of design aspects of these systems will be assessed. Two decentralised communal rainwater systems will be examined in this study, one at Capo di Monte (CDM), a residential development at North Tambourine in the Gold Coast hinterland, and the second at Green Square North Tower (GSNT), a 12 storey office tower in Fortitude Valley, Brisbane with a 6 star sustainability rating. Communal rainwater harvesting systems, being uncommon in Australia, therefore need to be quantitatively and qualitatively assessed for their comparative performance against existing systems. Overseas examples of similar systems, such as the mandated systems for commercial buildings in Japan with floor areas greater than 300,000m², will provide some comparative data to validate the local system strategies. However, ascertaining the constraints of the systems is also an important objective of the study. For example, studies in Australia focusing on individual rainwater tanks (ISF, 2008, Marsden-Jacobs Associates, 2007, Beal et al., 2008) have demonstrated that pumping in these systems incurs an energy penalty compared to municipal supply systems. Information on the water/energy interaction in communal rainwater tanks for residential cluster scale and high-rise commercial developments is missing. Hence, one of the main aims of this study will be to fill that knowledge gap for the benefit of professionals engaged in this area.

Capo Di Monte

The system at Capo di Monte collects rainfall from the roofs of 46 semi-detached and detached residential units, and stores the water in a communal 400kL storage. A water treatment plant, comprising sand filter, UV sterilisation and chlorination sends water to a 20kL balance tank for distribution of potable water to each house, and a small community centre. A local bore provides supplemental water in times of insufficient rainfall, or excess demand. The communal tanks at CDM are operated to retain at least 50% capacity to allow for emergency fire-fighting capability. This reduction in working volume has prompted the developer to source other forms of water for potable substitution to reduce the demand on the rainwater tank. Treated wastewater is therefore utilised for irrigation and toilet flushing at each residence, and for irrigation of communal areas. The inclusion of both rainwater harvesting and wastewater treatment has allowed the residents to be completely self-sufficient for water supply and unlike many other decentralised examples, the system is managed by an appropriately trained person who is directly responsible to the body corporate entity.

Green Square North Tower

Green Square North Tower, on the other hand, collects rainwater as one of a number of sources of water for non potable substitution within the building. Rainwater, air conditioner chiller condensate, cooling tower blowdown and fire system test water (tested weekly) are all collected by a gravity system into an 80kL basement storage tank, before being pumped to two smaller tanks (40kL and 27kL) on the roof that supply the toilet flush system, and a small amount of irrigation on the site. The building services are managed by a contracted entity which has highly qualified personnel.

Assessment of System Parameters

At both sites, gravity provides the driving force of the collection system. Therefore the hydraulic design of the collection system must size the pipes to cope with a wide range of rainfall intensities. Roof gutter design and diameter of collection pipes are the critical limiting factors in the system, and these components must be sized to meet the performance criteria of at least 1 in 20 year event rainfall intensities. Hence, in communal rainfall collection systems collecting water from a number of roofs, the pipe size entering the storage can be quite large, and if not sized appropriately can cause significant losses in collection efficiency. Alternative hydraulic designs will be explored, including the use of distributed buffering systems to smooth out peak discharge, and hence reduce the size of the conveyancing pipework required. In addition, the yield from individual “virtual” tanks will be modelled to assess the collection efficiency gains (kL yield/year/kL tank storage) from a communal system.

Thus, in case of the CDM water system validation process, understanding of the hydraulics, hydrology and economics of communal rainwater tanks in comparison to individual tanks will be developed. The validation of rainwater usage for non-potable purposes in GSNT and the associated water energy interaction, total water balance analysis and actual savings in municipal water will inform better design of rainwater collection, distribution and storage systems in high-rise commercial developments.

Water quality is also another area of communal rainwater systems that is relatively unknown. The two communal systems have two very different requirements for use of the collected water, and the water will be tested for compliance with the relevant requirements for each end use. This will give, particularly in the case of GSNT, some guidance of the treatment requirements if the water were to be used for potable substitution in the building. However, the water collected at CDM is used as “potable rainwater”, i.e. a direct replacement for treated municipal potable water, so the quality will need to meet the Australian Drinking Water Guideline values.

Conclusion

The results from these studies will provide quantitative benchmarks for the application of communal rainwater harvesting and storage in other decentralised systems. The output will also be compared with conventional systems, such as individual tanks or municipal supply, to understand the suitability of these approaches and their availability/security of supply. For GSNT, the system performance will provide guidance on the types of systems needed to be fitted to future commercial buildings as well as information on other opportunities for potable substitution. The experimentation for system validation and monitoring at CDM and GSNT sites are designed to fulfil all of these research objectives.

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Stormwater Harvesting and Reuse in South East Queensland: to Dream the Impossible Dream?

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Summary

Stormwater is the last major untapped source of alternative water supply for urban areas. Desktop analyses consistently report that the average annual volume of urban runoff equals or exceeds imported potable water for most of our capital cities. However the implementation of using this resource is challenged by the key issues of capture, treatment, storage and distribution (to customers). Our project has reviewed 61 Australian case studies and identified the vast majority is used for public open space or golf course irrigation. However, if stormwater is to be used for reducing potable water demand, it must be incorporated into the urban water fabric, either as potable substitution (i.e. dual pipes) or as indirect potable reuse. Our project is addressing this challenge by using GIS analysis, informed by biophysical argument and exemplar typologies, to identify stormwater harvesting opportunities in South East Queensland (SEQ); implementing event based water quality measurement in selected urban catchments to characterise contaminants (human pathogens, heavy metals, trace organic chemicals) which impact on higher end uses; and measuring the ecosystem health of urban creeks to define stormwater harvesting practices which will maintain, or even improve their health and geomorphic form. This latter question involves extensive field experimentation, calibration of catchment scale hydrology models and their application to harvesting regimes.

Keywords

Stormwater harvesting; stormwater quality; GIS; hydrology models; ecosystem health; environmental flows; water sensitive urban design.

Background

Stormwater runoff from urban areas is one of the last untapped sources of alternative water supplies for cities and towns. Desktop studies have identified the potential volumes available, as well as conceptual designs that match storage volumes with water demand and reliability. However, if stormwater reuse is to expand beyond the irrigation of local parks etc. then issues of collection, storage, treatment and distribution must be resolved. This paper will present an overview of stormwater harvesting success stories in Australia, a brief review of progress to date, and a description of future directions for this Urban Water Security Research Alliance project.

Findings

The original Alliance project aimed to deliver a review of stormwater harvesting practices in Australia; a review of appropriate hydrology/hydraulic models to quantitatively describe stormwater capture/reuse; analysis of some case studies in SEQ that focused on potable water substitution; and an analysis of the creek ecosystem health consequences of stormwater harvesting.

An extensive review of stormwater end uses in Australia identified 61 reuse schemes, the majority of which were for public open space and golf course irrigation (Philp *et al.* 2008). Less than 4 schemes were identified where water was incorporated into the urban fabric to reduce mains water use (i.e. potable water substitution).

Given the absence of available case studies in SEQ, the project has been refocused to deliver data that will inform the design and regulatory processes. In particular the project will:

- Use GIS based methodologies to define the potential opportunities for stormwater reuse schemes based on criteria including future greenfield areas; available storages including aquifers, parks, quarry voids and reservoirs; topographic analysis using DEM, and urban development typologies which weld stormwater harvesting opportunities to water sensitive urban design (WSUD) performance criteria. This latter aspect is particularly important as new stormwater guidelines in the SEQ Regional Plan (2008, Guideline No. 7) not only require reduction in contaminant export load (ranging from 45% to 80%), but also the **retention** of the first 10mm to 15mm of runoff from impervious areas. In addition, the 1 in 1 year ARI pre development peak discharge rate must be maintained. As “traditional” WSUD focuses on stormwater **detention** behaviour (to

reduce peak discharge and containment load), the new retention criteria provides considerable opportunities to incorporate stormwater harvesting and reuse.

- A recent contract by the QWC has commissioned local expert stormwater / WSUD consultants to develop case study exemplars which provide design and costing information for a range (density, land use, topography) of urban development types. The typologies from this contract will provide biophysical information which should be well suited for the development of GIS based rules for analysis of stormwater harvesting opportunities in SEQ greenfield sites.
- Another recent study of aquifers suitable for managed aquifer recharge (MAR) in SEQ has also been released by CSIRO (Helm et al. 2009) and this too will be of critical importance in defining subsurface storage opportunities. The Helm et al. (2009) analysis suggests that 25 MAR sites are available in SEQ, with a potential to store/supply an additional 27GL/year.

Knowledge of raw water quality is of fundamental importance in deciding on the treatment processes required to produce water suitable for particular end uses. Recent national stormwater reuse guidelines (EPHC 2008) have defined the log reduction in pathogens required for end uses focused on public open space irrigation. However if the large urban water market is to be captured, dual reticulation for non potable uses is essential, whilst indirect potable reuse (IPR) is even better to create a regular, predictable demand. In these cases (and in particular IPR) knowledge of pathogens, heavy metals and trace organic chemicals is critically important, but largely unmeasured for stormwater.

Consequently, the second component of the reuse project is focused at event based monitoring of stormwater in a range ($n \leq 4$) of urban catchments with expected differences in quality due to land use (industry, domestic or commercial) and sewage outflow frequency. The results should identify the suite of treatment processes needed to produce high quality water, and help inform the design of novel non membrane treatment methods such as artificial aquifers using engineered media with excellent filtering and adsorptive behaviour. These non membrane systems will integrate with biofiltration pre treatment (the core technology of WSUD) and perhaps ozone / GAC post treatment.

The key regulatory question for stormwater harvesting is ensuring that acceptable environmental flows are maintained once significant stormwater harvesting is implemented. The traditional performance criteria in rural catchments are to ensure that water is not extracted too often nor in too large a quantity. However in urban catchments where impervious areas are likely to at least double the run off ratio to 0.6, the issue is how to reduce the frequency, volume and peak discharge of run off to its predevelopment behaviour, or an approximation of it (Fletcher *et al.* 2007). Superimposed on this hydrology is a measure of creek ecosystem health which, at least in an empirical sense, appears well related to the fraction of impervious catchment area directly connected to the creek (via stormwater drains – Walsh et al 2005).

Consequently this component of the project will measure the ecosystem health of a range of urban creek reaches in SEQ and relate their score (as well as channel form and bed characteristics) to the fraction of directly connected impervious area and runoff hydrology (frequency, volume, base flow, peak discharge) using a calibrated model (i.e. SIMHYD). Some progress has been made on this subproject in that 12 catchments in SEQ have been instrumented for discharge and regularly measured (2 seasons x 2 years) for ecosystem health using the EHMP methodology (EHMP 2007). The catchments covered a gradient of fractional impervious areas due to selecting traditional urban, WSUD, and unimpacted catchments. Preliminary results presented in Dunlop *et al.* (2008) show that catchments with elements of water sensitive urban design had less degradation to downstream ecosystem health than was observed at comparable locations employing traditional urban stormwater designs. The next stage is to complete the rating curves of the gauging stations, calibrate SIMHYD using experimental data, and then implement a range of hypothetical stormwater harvesting regimes, and explore the predicted hydrological flow outputs with their likely ecosystem response.

Clearly the philosophy is at its most useful in preventing high value ecosystems in greenfield catchments from becoming degraded as urban development occurs (there is about 47,200 ha of remaining greenfield areas in SEQ - DIP Broadhectare study 2009). However there still remain numerous creeks of moderate ecosystem health which could almost certainly be improved if stormwater hydrology were moved in the direction of pre development behaviour. This of course will require WSUD / stormwater harvesting in brownfield catchments where storage areas and demand for alternative water supplies are more constrained than greenfield sites. Nonetheless the fitting of WSUD “appliances” to all the brownfield sites in SEQ by 2026 is a clearly stated aspirational goal of the SEQ Healthy Waterways Strategy (2007) (<http://www.healthyywaterways.org/TheStrategy.aspx>).

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Are Hospitals a Major Point Source of Pharmaceuticals in Wastewater?

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Summary

It has been suspected that hospitals could be a major point source for pharmaceuticals entering the sewage system. If this is the case then the contribution of these chemicals from hospitals could potentially be controlled at the source. Any ability to control point sources of contaminants in sewage could have a major impact on the management of water reclamation systems such as Purified Recycled Water (PRW). A study was undertaken to determine the proportion of 59 specific pharmaceuticals detected in wastewater entering a sewage treatment plant that came from a nearby regional hospital. The study found that only two compounds in the hospital wastewater contributed to over 15% of the concentration detected in the wastewater entering the wastewater treatment plant. The results from this study indicate that hospitals are not likely to be a major source of pharmaceuticals in wastewater. Large amounts seem to be taken and excreted by the general public on a regular basis in their households.

Keywords

Pharmaceuticals, antibiotics, antidepressant, diuretic, hospital waste, wastewater treatment.

Introduction

Pharmaceutical residues in water are frequently analysed and discussed in connection with sewage treatment, ecotoxicity and natural and drinking water quality. Among different localities, hospitals are suspected, or implied, to be a major and highly variable source of pharmaceuticals substantially contributing to the total wastewater load. In this study, the contribution of pharmaceuticals from a hospital to a sewage treatment plant (STP) serving around 45,000 inhabitants was evaluated. Approximately 200 hospital beds result in a typical developed world hospital bed density of 4.4 beds per 1,000 inhabitants. The hospital provides all services common to a modern regional hospital. More detailed data, results, discussion and references on this study are described in Ort et al (2009).

Systems Analysis

The prediction and experimental quantification of pharmaceutical mass fluxes in the wastewater of a specific STP catchment are very laborious. A sound understanding of the whole system is imperative for both setting up a predictive model, and performing a confirmative sampling campaign. This particularly holds true when different fractions should be attributed to a multitude of individual sources. Collecting representative samples requires a profound knowledge of the sewer layout and awareness of potentially highly variable concentrations and loads in the course of a day. If this is not taken into account one may analyse a sample with a very sophisticated method but one will not be able to prove if the accurate result is representative to characterise the system under investigation. The large variation observed in previous hospital wastewater studies may not be “true natural variation” but caused by inadequate sampling.

Sampling Protocols and Chemical Analysis

All hospital wastewater is collected in a sewage pumping station (SPS), with no residential premises connected to this SPS. A tap was fitted in the rising main and an actuator opens each time when the pumps empty the pump sump. At the influent of the sewage treatment plant a pump was installed. Its speed was controlled by the signal of the flow meter in the influent. By applying these continuous flow-proportional sampling modes the sampling error was minimised. Samples were collected over four consecutive weekdays and analysed for 59 substances by Queensland Health Forensic and Scientific Services (accredited by National Association of Testing Authorities, Australia and ISO 9001 certified).

Results

The hospital contributes less than 1% of the total wastewater volume at the influent to the STP. To obtain pharmaceutical loads, measured concentrations were multiplied by the corresponding 24-hour flow measured at each sampling location. Representatives for four pharmaceutical groups are charted in Figure 1A-D: venlafaxine (an antidepressant); erythromycin (an antibiotic); salicylic acid (a metabolite from acetylsalicylic acid, e.g. Aspirin); and

frusemide (a diuretic). In the influent to the STP, an average of 18 g d⁻¹ of venlafexine were found, showing only little day to day variation; slightly smaller than the estimated overall uncertainty (see figure caption). On average, the venlafexine loads in the hospital effluent only contributed 2% to the total influent loads at the STP. For each day, a maximum contribution was calculated by dividing the upper uncertainty value of the hospital effluent by the lower uncertainty value of the STP influent; and vice versa for a minimum contribution. Over all four days, the smallest minimum contribution for venlafexine was 1% and the highest maximum 5%, reflecting a conservative range of the hospital's contribution during the sampling campaign.

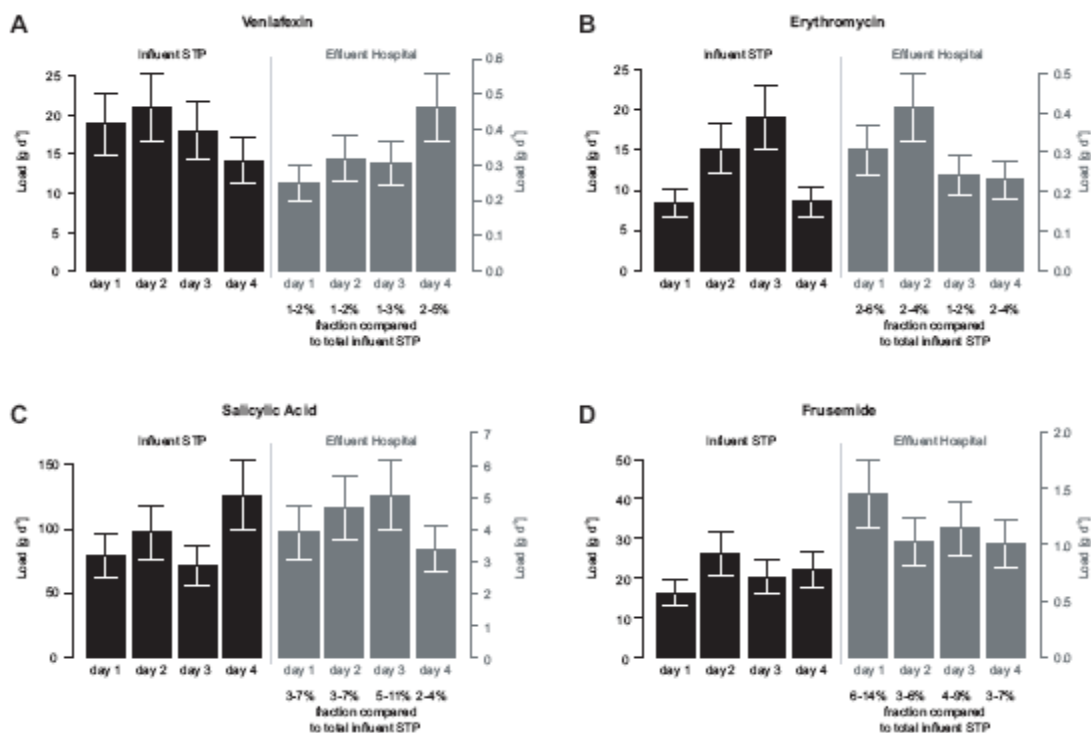


Figure 1. Measured pharmaceutical loads over 24-hour periods in the influent of the STP and effluent of the hospital for four consecutive weekdays. Error bars include uncertainty in flow ($\pm 6\%$) and chemical analysis ($\pm 20\%$), resulting in an overall uncertainty of $\pm 21\%$ (single standard deviation).

The 59 investigated substances were classified for the hospital's contribution to the total influent at the STP using the maximum observed contribution including uncertainty as a conservative estimate. The hospital's contribution for 18 substances was at all times "smaller than 5%", 11 additional substances fall in the category "smaller than 15%" and only 2 substances were "above 15%". Five substances were quantified in the HWW but not in the influent of the STP and the rest (23 substances) were not detected in any of the samples above the limit of quantification (LOQ).

Conclusions

For many pharmaceuticals residues in wastewater, the general public in their households seem to be the major source. With the current trend in health systems for shorter hospitalization, even more specific drugs - exclusively administered for treatments in hospitals - will be increasingly excreted at home by out-patients. With regard to pharmaceuticals and on-site treatment of hospital wastewater this is an important aspect. Furthermore, in catchments with multiple health care facilities resulting in a high(er) hospital bed density, there will be several sources to be considered for potential wastewater treatment prior to discharge to the sewer system. For pharmaceuticals of concern administered to a manageable small group of patients, separate collection of urine and faeces may technically be the most favorable solution. However, administrative and health issues also need to be taken into account.

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Measurement of the Decay of Microbial Pathogens in South East Queensland Reservoirs

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Summary

More information is needed on the potential persistence of enteric microorganisms in reservoirs in South East Queensland (SEQ). An initial laboratory based microcosms experiment and preliminary data from an initial in-situ experiment have shown that bacteria and enteric viruses may have limited survival potential in reservoir water. The results also indicate pathogenic protozoa such as *Giardia* and *Cryptosporidium* could survive for longer periods in the reservoir than enteric bacteria and viruses.

Keywords

Pathogens, enteric microorganisms, decay, SEQ reservoirs.

Introduction

The SEQ reservoirs and other water bodies receiving purified recycled water (PRW) are listed as one of the treatment barriers (barrier 6) for the PRW system. At present however, there is no scientifically based information on the level of treatment for the removal of pathogens that can be expected for the reservoirs, or how the treatment capabilities of these water bodies change with changing conditions (eg seasonal variations and event based changes). Also, the ability to predict the survival of pathogens in environmental systems relies on knowledge of the factors that drive the decay of the pathogens (Sidhu et al. 2008, Sinton *et al.* 2007). This paper lists the outcomes of research to-date on the measurement of pathogen decay in SEQ reservoirs.

Initial Laboratory Test

Selected enteric microorganisms were initially tested in microcosms of Lake Wivenhoe water in the laboratory to determine relative decay times. This decay of the microorganisms was compared to decay in Lake Wivenhoe water where the indigenous lake microorganisms had been removed via filtration and in dechlorinated Brisbane tap water. The decay times obtained from this initial microcosm decay experiment are given in Table 1 and the decay patterns can be seen in Figure 1.

Table 1. Time taken for a 1 log loss (T90) of selected enteric microorganisms in microcosms of Lake Wivenhoe water.

Microorganism	Water Type		
	Filtered Wivenhoe	Non-filtered Wivenhoe	Tap Water
<i>E. coli</i>	10	6	1
<i>Giardia</i> cysts	52	84	53
MS2	8	8	5
Adenovirus	22	8	9 [#]

[#] decay rate up to Day 14. After Day 14 decay rate was 0

These results show that the bacterium *E. coli* and the bacteriophage MS2 have limited survival in the reservoir and that the indigenous lake microflora had little influence on the decay of these microorganisms. Adenovirus had a similar rate of decay to *E. coli* and MS2 in the non-filtered lake water but the removal of the indigenous lake microflora caused a large reduction in the decay rate of this virus. The survival of adenovirus and MS2 in Brisbane tap water was very similar to the decay rates in the non-filtered lake water. In comparison, the *E. coli* cells had very limited survival in the dechlorinated tap water, possibly due to the lower levels of nutrients in the tap water compared to the lake water. The *Giardia* cysts were found to be much more resistant to decay under the conditions tested in the microcosms which suggest that the persistence of pathogenic protozoa such as *Giardia* and *Cryptosporidium* in SEQ reservoirs may be more of a concern than enteric viruses and bacteria.

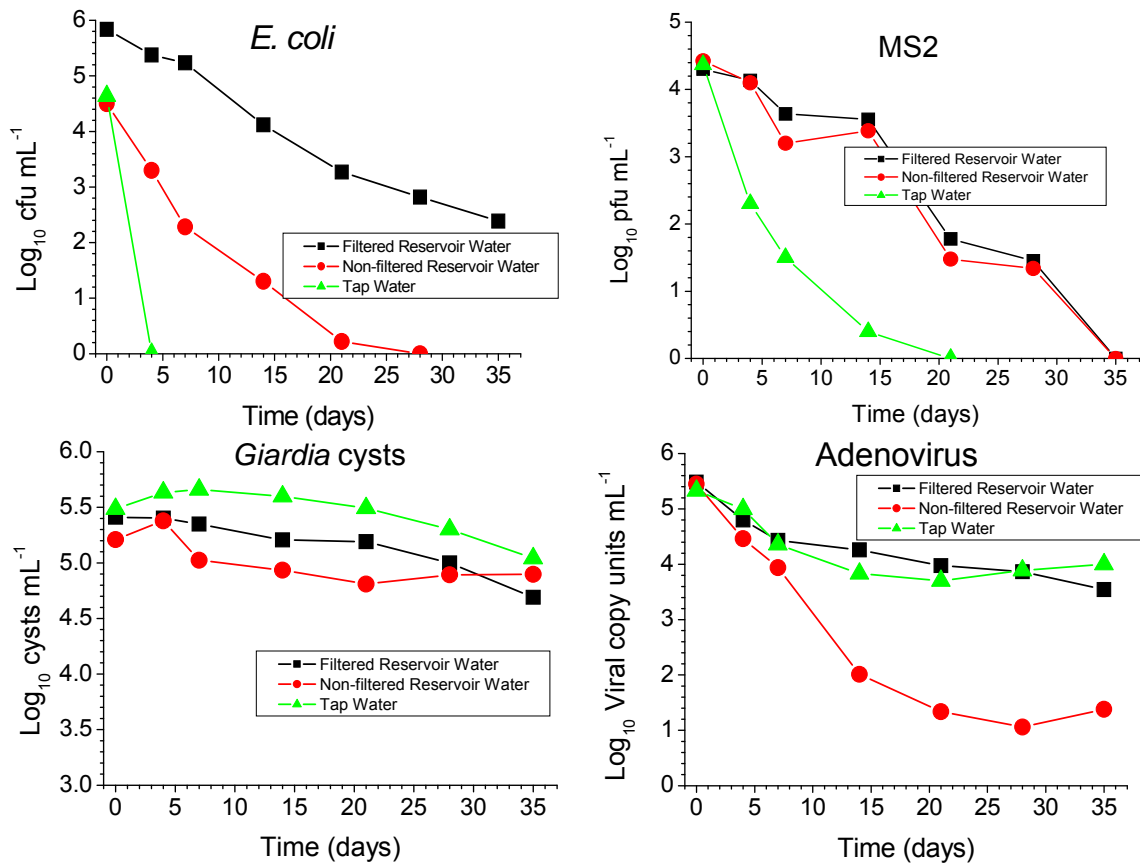


Figure 1. Decay patterns of selected enteric microorganisms in filtered and non-filtered Lake Wivenhoe water and dechlorinated tap water.

In Situ Decay Studies

Following on from the initial laboratory based microcosms decay studies a series of *in situ* decay studies are commencing in Lake Wivenhoe. The aim is to determine the decay of target enteric microorganisms directly in the lake using diffusion chambers previously developed and used elsewhere by CSIRO (Toze *et al.* 2003) (Figure 2). The range of experiments should give an insight into the factors driving the decay of pathogens within the reservoir (eg, sunlight, nutrients, and temperature) and allow a coordination of pathogen decay data with hydrologic modeling of the reservoir and quantitative risk assessment of the health risks from different pathogens entering the reservoir (regardless of their source). The results achieved to-date will be given in this presentation at the UWSRA forum.



Figure 2. Set up of pathogen decay chambers in Lake Wivenhoe

Preliminary results are available for some of the microorganisms tested in an initial *in situ* decay experiment conducted in Lake Wivenhoe (results are still pending for adenovirus and coxsackievirus). This initial experiment is aimed at setting the base line data for decay of pathogens in Wivenhoe Dam without separation of any of the potential variables that may influence decay. The results up to day 28 are available in Table 2. These preliminary results show that the decay of the toxigenic *E. coli* is more than two times slower than has been observed for the laboratory *E. coli* strain (14 vs 6 days). The decay for the bacteriophage MS2 is similar to the results from the preliminary laboratory microcosm experiment (5 vs 8 days), however, *Cryptosporidium* oocysts appear to be less resistant to decay in Lake Wivenhoe than *Giardia* cysts (49 vs 84 days). The other bacteria, *Salmonella*, *Enterococcus* and *Campylobacter*, although not studied in the preliminary laboratory experiment, have decay rates similar to those previously observed elsewhere by the CSIRO research team. Further work is currently being planned to investigate why the toxigenic *E. coli* appears to be more resistant to decay than the non-toxicogenic form; and to determine the influence of the indigenous microflora of the lake on the decay of enteric microorganism.

Table 2. Preliminary data for time taken for a 1 log loss (T90) of selected enteric microorganisms in microcosms in Lake Wivenhoe.

Enteric Microorganism	T90 (days)
<i>E. coli</i> H7:O157	14
<i>Enterococcus faecalis</i>	2
<i>Salmonella</i>	7
<i>Campylobacter</i>	8
<i>Cryptosporidium</i>	49
Bacteriophage MS2	5

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Community Perceptions of Risk and Purified Recycled Water

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Summary

While the threat of water shortage is growing rapidly in many parts of the world, communities continue to reject water augmentation options that are considered by many experts to be safe. This is particularly so where the use of recycled wastewater is incorporated into a water supply scheme. Previous research has indicated that perceptions of risk play a significant role in determining people's likely acceptance of, and intended behaviour towards, proposed recycled wastewater schemes for potable use. This paper presents the findings of a longitudinal study designed to investigate the psycho-sociological drivers associated with people's intention to support or reject the proposed potable Purified Recycled Wastewater (PRW) scheme in South East Queensland (SEQ). Structural Equation Modelling revealed that 83% of the variance in people's intended behaviour towards the scheme could be explained by a variety of risk perception components. Further, longitudinal analyses revealed that the salience of the concepts of trust in institutions and emotion differ over time and are dependant on overall attitudes of acceptance or rejection of the scheme. Implications for planners, communicators and policy makers are discussed.

Keywords

Risk perceptions; Perth; managed aquifer recharge; recycled water; trust; behavioural intention.

Background

There has been much research in the past several decades suggesting that perceptions of risks associated with technological solutions to environmental challenges are key to determining whether a posited solution will be accepted or rejected (Slovic, 1987). With regards to water recycling, a number of empirical studies support this notion (eg Leviston, 2006; Ross, 2005). Perceived risk refers to subjective evaluations of risk inherent in a given situation. Broadly, it applies to any process with potentially negative consequences, or any hazard that is publicly perceived and discussed as a risk (Bayerische, 1993). Perceptions of risk may also include the distinction between personal and impersonal risks, and the relevance of the risk to people. In summarising much of this literature, Kahlor et al. (2006) conclude that perceived personal relevance is a powerful predictor of individuals' use of health-related messages. Notions of immediacy of threat and notions of 'dread' associated with a risk have also been cited as powerful determinants of formulations of perceived risk (Slovic, 1987).

Trust in expert institutions has also been demonstrated as being strongly associated with perceptions, tolerability and acceptability of risk (eg Beck, 1992; Giddens, 1991). Specifically, it is argued, we need to invest trust in authorities who oversee systems that lie outside our technical understanding. There are consequences for our risk evaluations then, when this trust is shaken, either by poor past performance or other undermining elements. Perceptions of risk, it is argued, cannot be extracted from questions of trust.

The role of emotion has been similarly closely linked to risk perceptions. There is empirical evidence that the way people process information (their cognitions) can influence and be influenced by emotions (Constans and Mathews, 1993; Isen 1993; Johnson and Tversky, 1983; Keltner et al., 1993; Lazarus, 1991). As such, there is support for a two way connection between risk assessments and emotion. It is possible therefore, that emotional states (which are open to manipulation by media and special interest groups) can have a direct influence on people's judgements about a PRW scheme's levels of risk, fairness and acceptability. Emotions have been shown to play a key role in the way people rate environmental risks, demonstrating a relationship with perceived acceptance, riskiness and destructiveness or potential damage (McDaniels et al., 1995), thus indicating that people might rely on emotional appraisals as a primary cue when assessing potential risks and benefits (Loewenstein et al., 2001).

To investigate the role of risk perceptions in how people make decisions in relation to PRW, the following hypotheses were formulated:

- (i) That perceived risk will be a significant contributor to predicting people's acceptance or rejection of a proposed purified recycled water scheme;
- (ii) That perceptions of risk will be correlated with levels of trust in institutional bodies associated with the proposed purified recycled water scheme, as well as emotional appraisals made in relation to the scheme; and

- (iii) That perceived risk will increase the closer the scheme comes to being implemented (NB. some attenuation was expected due to the announcement by the Queensland Government to delay injecting PRW into Wivenhoe Dam until water levels dropped below 40% - time data is referred to as pre-announcement and post-announcement).

A further objective was to investigate the relative salience of risk perceptions on decisions made in relation to the PRW scheme and to investigate whether salience changes over time.

A Structural Equation Model analysis was performed to see if Risk could significantly predict Behaviour in relation to the PRW scheme. The analysis revealed that, along with the concepts of Trust and Emotion, Risk accounted for 83% of the variation in Intended Behaviour scores. Both Trust and Emotion were found to correlate strongly with Risk.

An INDSICAL analysis (Individual Difference Scaling)* revealed that the most salient factor for people who did not support the scheme changed from Trust/Risk (pre-announcement) to Emotion (post-announcement). In contrast, those who were unsure about the scheme changed from Emotion (pre-announcement) to Trust/Risk (post-announcement). Meanwhile, those who supported the scheme changed from Emotion (pre-announcement) to a more complex decision-making process (that is, where all concepts were of equivalent salience).

The results suggest, firstly, that the perception of risk is an important predictor of whether people will support or reject a PRW scheme. The results also suggest that risk perceptions are founded on different constructs for people who support than people who oppose the scheme. Further, the proximity of the scheme to implementation, coupled with the arrangements of when the scheme is activated, can change what concepts are top of mind in people's decision formulations.

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*INDSCAL is a multi-dimensional scaling technique that allows differences in responses of individuals to be identified (using Euclidean distances) on a number of matrices simultaneously. Basically it allows the analyst to i) identify dimensions that differentiate individuals or groups of individuals (eg, trust items); and ii) identify the salience of a dimension, that is, ascertain how much that particular dimension is used in people's decision-making about their responses to behavioural items (eg, will you drink PRW?).

Energy and Greenhouse Gas Emissions for the SEQ Water Strategy

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Summary

Greenhouse gas emissions will rise faster than growth in population and more than double for water and wastewater services in South East Queensland (SEQ) over the next 50 years. New sources of water supply such as rainwater tanks, recycled water and desalination currently have greater energy intensity than traditional sources. In addition, potentially the largest source of greenhouse gas emissions for the sector are poorly understood and often overlooked completely. Diffuse greenhouse gas emissions from reservoirs as well as emissions from wastewater treatment and handling are potentially much greater than emissions from the use of energy. Centralised water, wastewater and decentralized systems were considered over a 50 year scenario based upon the SEQ Water Strategy (QWC 2008). Many sources of data had large uncertainties which were estimated following IPCC Good Practice Guidelines (IPCC 2000). Important sources of emissions with large uncertainties such as rainwater tanks and diffuse emissions were identified for further research and potential mitigation.

Keywords

Energy, greenhouse gas emissions, water supply, wastewater treatment, South East Queensland.

Background

The sustainability challenge for water and wastewater services in SEQ is framed by water shortages, a rapidly growing population, stressed aquatic ecosystems and uncertain climate change. In turn, measures to provide water and wastewater services in this context have implications for energy and greenhouse gas emissions. The study aimed to inform long term planning strategies such as the SEQ Water Strategy by identifying the largest contributors as well as long term trends for energy and greenhouse gas emissions for provision of urban water and wastewater services. In particular, relative contribution to greenhouse gas emissions was sought for:

- centralised water and wastewater services;
- decentralised water and wastewater systems; and
- diffuse emissions from wastewater treatment and handling and urban water reservoirs.

Results

The following figures provide an overview of greenhouse gas emissions for water and wastewater services in SEQ over the next 50 years. Uncertainties for data are shown in dashed lines and are very large for the upper range of diffuse greenhouse gas emissions. Uncertainties are also shown in Table 1.

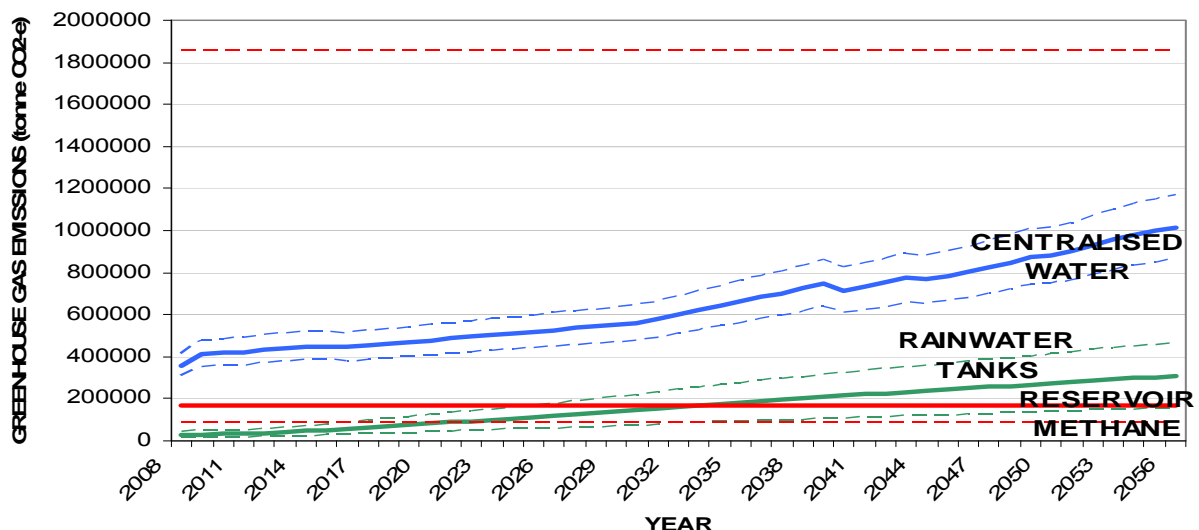


Figure 1. Greenhouse gas emissions for water services in SEQ

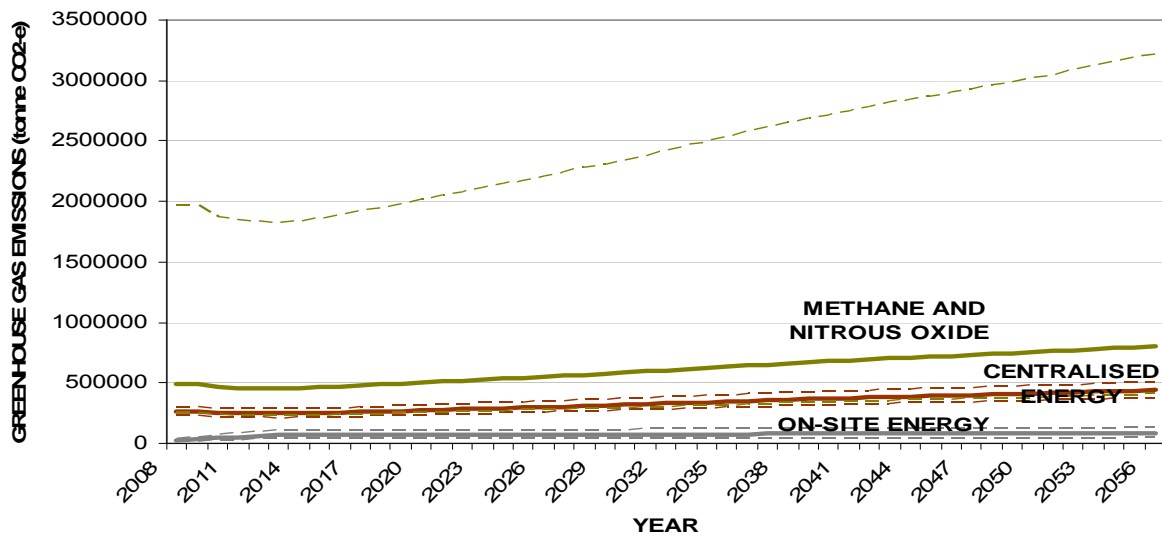


Figure 2. Greenhouse gas emissions for wastewater services in SEQ

Table 1. Summary of Data Sources and Uncertainty Estimates

	Interval from mode	Data accuracy*	Summary of data sources
Energy for centralised water	+/-15%	Good	SEQ utility surveys (Kenway et al. 2008) and reports for SEQ grid energy performance (Jacob and Whiteoak 2008).
Energy for rainwater tanks	+/- 50%	Poor	Monitoring of a few SEQ sites (Beal et al. 2008 ; Lane and Gardner 2009) and a number of others across Australia (Retamal et al. 2009).
Energy for wastewater	+/-15%	Good	Data collected for 35 SEQ WWTPs (De Haas et al. 2009).
Energy for decentralised wastewater	+/- 50%	Poor	SEQ review of systems installed and general performance of systems (Beal et al. 2003).
GHG emissions from reservoirs	+1000% - 50%	Poor	Very limited SEQ data available and worst performing reservoir extrapolated for upper uncertainty based on catchment and reservoir characteristics. Data provided by Alan Grinham UQ pers. comm. 2009. Calculated uncertainties of a similar order of magnitude as estimated for emissions factors by (IPCC 2006) – ppAp 3.6.
GHG emissions from wastewater treatment N ₂ O	+300%	Poor	SEQ plant data collection by UQ and emission factors and assumptions outlined in (De Haas et al. 2009) and largely based upon literature review from (Foley and Lant 2007). Literature review by UKWIR was also considered (Andrews et al. 2008).
GHG emissions from wastewater treatment CH ₄	+50% -50%	Poor	SEQ plant data collection by UQ and emission factors and assumptions outlined in (De Haas et al. 2009) and largely based upon literature review from (Foley and Lant 2007). Literature review by UKWIR was also considered (Andrews et al. 2008).
GHG emissions from biosolids N ₂ O	+ 300% - 50%	Poor	SEQ plant data collection by UQ and emission factors and assumptions outlined in (De Haas et al. 2009) and largely based upon literature review from (Foley and Lant 2007). Literature review by UKWIR was also considered (Andrews et al. 2008).
GHG emissions from biosolids CH ₄	+ 300% - 50%	Poor	SEQ plant data collection by UQ and emission factors and assumptions outlined in (De Haas et al. 2009) and largely based upon literature review from (Foley and Lant 2007). Literature review by UKWIR also considered for uncertainty UKWIR (Andrews et al. 2008).

*(GHGProtocol 2001)

Significance and Impact

The results provide the long term trends for energy and greenhouse gas emissions from the water and wastewater sector in SEQ. This provides the starting point for setting targets for improved performance as well as understanding potential opportunities for mitigation as well as liabilities under new greenhouse regulation.

Estimates of greenhouse gas emissions for the water and wastewater sector have traditionally focussed on energy use for centralised water and wastewater services. However, this research illustrates that diffuse emissions are potentially one of the largest sources of greenhouse gas emissions for the sector. Uncertainties for the upper range of emissions are very large and require more research. However, even low range estimates such as diffuse wastewater emissions are similar to the mode for centralised wastewater energy use. The addition of 800,000 rainwater tanks over the next 50 years will potentially use as much energy in 2056 as the current centralised water supply in 2008. The large uncertainty reflects the variability in tank design and set-up.

Large uncertainties also present large opportunities for mitigation. Guidance for energy efficient design of rainwater tanks as well as management of reservoirs and wastewater treatment and handling could dramatically improve the greenhouse gas performance of the sector over the next 50 years.

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