Water Research AUSTRALIA

next water '25

Riding the wave of resilience

FULL PAPERS

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Table of Content

171 A resilient water supply requires a resilient operator workforce.

Dr Kathy Northcott[1]
[1]Veolia Anz

185 Kiep Benang - Water for Tomorrow

Dr Stacey Hamilton[1], Mrs Collene Castle[2], Mr Josh Whiteland[3], Mr David Hughes-Owen[1], Dr Richard Walley OAM
[1]Busselton Water, [2]Wonnil Partner, [3]Koomal Dreaming

179 An Improved Method for Modelling Solar Brine Evaporation

Dr Bruce Atkinson[1], Mr Benjamin Croxon[2], Mr Nathan Dick[1]
[1]Beca HunterH2O, [2]Tamworth Regional Council

196 PROBLEMATIC MICROALGAE AND CYANOBACTERIA COMMUNITIES WITHIN DRINKING WATER TREATMENT PLANTS ACROSS EASTERN AUSTRALIA

Dr Daisy (Xiaoran) Chu[1], Dr Fitri Widhiastuti[1], Dr Arash Zamyadi[2], Dr Bojan Tamburic[1], Dr Nick Crosbie[3], Dr Deb Gale[4], Dr Steven Newham[5], Professor Rita Henderson[1]
[1]UNSW, [2]Monash Univerisity, [3]Melbourne Water, [4]Seqwater, [5]Goulburn Valley Water

161 Purified recycled water public outreach and education: Successes and lessons learnt from the US and globally

Ms Danielle Francis[1]
[1]Water Services Association Of Australia

162 The Californian Reuse Journey towards a Resilient Water Supply

Mrs Suzanne Sharkey[1]
[1]NWRI

199 Researching Emerging Contaminants (RECON) monitoring program for the Eastern and Western Treatment Plants: Passive Sampler Program - soluble micropollutants in recycled water and raw sewage.

Dr Kathryn Hassell[1], Dr Jackie Myers[2], Dr Erica Odell[2], Dr Sara Long[2], Professor Vin Pettigrove[2], Dr Hao Nguyen[3], Dr Nick O'Connor[4], Dr Nick Crosbie[5]
[1]RMIT University (Applied Chemistry and Environmental Science), [2]RMIT University (AQUEST Research Group), [3]National Measurement Institute, Department of Industry, Science and Resources, [4]Ecos Environmental Consulting, [5]Melbourne Water Corporation

220 Cyanotoxin risk in recycled water used for food crop irrigation

Dr Peter Hobson[1]
[1]Sawater

174 Tracking Tyre Pollution: Detecting and Mitigating Rubber Microplastics and Anti-Degradants in Stormwater

Dr Julia Jaeger[1]
[1]Eurofins Environment Testing

205 50 Years since the Discovery of Disinfection By-Products: New Approaches to the Management of Disinfection By-Products in Australian Drinking Water

Dr Ina Kristiana[1], Professor Cynthia Joll[1], Associate Professor Anna Heitz[1], Dr Yolanta Gruchlik[1], Adjunct Professor Keith Cadee[2]
[1]Curtin Water Quality Research Group, [2]Independent Industry Consultant

177 Granular sludge-based technology for managing high ammonia landfill leachate
Miss Ying Liu[1], Dr Yang Lu[1], Mr Michael Roll[2], Mr Ryan Trinne[2], Prof. Yang Liu[1]
[1]Queensland University Of Technology, [2]City of Gold Coast

217 Hydrological modelling to mitigate bushfire-related risks to water security
Dr Petter Nyman[1], Mr Joel Rahman[2], Dr Kristen Joyce[1], Dr Jabbar Khaledi[1], Dr Gary Sheridan[3], Tom Keeble[3], Dr Paul Richards[1]
[1]Alluvium Consulting, [2]Flow Matters, [3]The University of Melbourne

192 OZOFRACTIONATION OF WASTEWATER – REDUCING BIOLOGICAL AND CHEMICAL CONTAMINANTS INCLUDING PFAS
Mr Sean Paul[1], Mr Jason Barnett[1], Ms Hannah Goss[1], Mr Michael Dickson[2]
[1]Taswater, [2]Green Shadows

186 Rethinking Centralised Water Services Systems
Dr Reba Paul[1]
[1]University Of Technology Sydney

172 The Impact of Coagulants and Flocculants on Cyanobacterial Cell Viability and Integrity
Dr Naras Rao[1], Dr Xiaoran Chu[1], Dr Fitri Widhiastuti[1], Ms Laurine Courcier[1], Professor Rita Henderson[1]
[1]UNSW

202 The real cost of managing risks posed by contaminants of emerging concern to Queensland's water sector
Dr Louise Reeves[1], Dr Georgina Davis[1], Mr David Wiskar[1]
[1]Queensland Water Directorate

198 PATHWAY FOR LAND APPLICATION OF BIOSOLIDS DERIVED BIOCHAR
Dr Aravind Surapaneni[1,2], Dr Louise Reeves[3], Dr Nimesha Ratnayake[2,4], Dr Kalpit Shah[2,4]
[1]South East Water, [2]ARC Training Centre for the Transformation of Australia's Biosolids Resource, [3]Queensland Water Directorate, [4]RMIT University

175 ICE PIGGING FOR WATER MAINS CLEANING: A RISK-BASED APPROACH
Dr Salman Tariq[1], Mr Charles Swain[1], Mr Dat Pham[1], Ms Christine Giang[1], Mr Andrew Nyholm[2], Mr Ed Petts[3]
[1]South East Water, Melbourne, Australia, [2]CMP Consulting, [3]Suez Australia & New Zealand

212 Ozone Nanobubble Technology for the Removal of Microbial and Chemical Contaminants in Water Supply
Dr Arash Zamyadi[1]
[1]Monash University

211 Harmful algal blooms in water supply and recovery systems: Investigating accumulation phenomenon and management strategies
Dr Arash Zamyadi[1]
[1]Monash University

188 Performance of Stormwater Treatment Systems for Heavy Metals and Organic Chemicals: A Comprehensive Review
Dr Zhaozhi Zheng[1], Dr Kefeng Zhang[1]
[1]UNSW Sydney

181 Wastewater Network Performance Benefits from Rolling Out Derived Flow at Hunter Water
Mr Chris Farragher[1], Mr Daniel Livingston[1]
[1]Hunter Water

204 Satellite remote sensing for improving the WaterNSW Integrated Water Quality Model
A/Prof Fiona Johnson[1]
[1]UNSW

197 A robust solid-state reference electrode and its application in environmental monitoring
Mr David Macedo[1], Mr Stephen Peacock[1], Ms Daniella Caruso[1], Mr Dylan Marley[1], Mr Tony Kilpatrick[1], Dr Krishnan Murugappan[1]
[1]CSIRO

218 Evaluating Electrolysis-Derived Oxygen for Aeration in Wastewater Treatment: Lessons learnt
Dr Deepak Surendhra Mallya[1], Emily Rahles-Rahbula[1], Aprilia Vellacott[2]
[1]Barwon Water, [2]Jacobs

170 HARMFUL ALGAL BLOOM MANAGEMENT FOR DRINKING WATER SAFETY: A GLOBAL PERSPECTIVE
Dr Kathy Northcott[1], Mr Boris David[2], Ms Magali Dechesne[2]
[1]Veolia Anz, [2]Veolia

213 Empowering water utilities: Crafting an end-user-friendly reliability ranking for evaluating satellite remote sensing advances
Dr Arash Zamyadi[1]
[1]Monash University

203 Optimising Autosampler Use for Enhanced Event-Based Monitoring and Decision-Making
Dr Zhaozhi Zheng[1], Dr Alex Rubin[1], Ms Angelica Badrous[1], Dr Lisa Hamilton[1]
[1]WaterNSW

167 The Urgent Molecular Shift: A Paradigm Change for Water Quality and Public Health through Multi-Omics
Prof Nicholas Ashbolt[1,2], Dr Claire Hayward[1,2]
[1]Future Industries Institute, University Of South Australia, [2]CRC SAAFE

165 Conceptual models of risk posed from wet weather overflows to both human health and of adverse ecological effects in urban receiving waterways
Mr Colin Besley[1], Dr Warish Ahmed[2], Ms Michele Cassidy[3]
[1]Sydney Water Laboratory Services, [2]Commonwealth Scientific and Industrial Research Organisation, [3]Sydney Water, Water and Environment Services

214 A National Intelligence System for Water Quality: A Platform Set to Transform Environmental Monitoring
Mr Keith Dimech[1], Dr Fabian Kohlmann[1], Dr Samuel Boone[2], Dr Wayne Nobel[1]
[1]Lithodat, [2]University of Sydney

194 Integrating Expert Knowledge and Bayesian Networks for Antimicrobial Resistance Management Related to Water Uses: A Collaborative Approach for Water Resource Resilience
Dr Claire Hayward[1,2], Professor Nicholas Ashbolt[1,2], Dr Steven Mascaro[2,3,4], Dr Owen Woodberry[2,3,4]
[1]University Of South Australia, [2]SAAFE CRC, [3]Bayesian Intelligence, [4]Monash University

190 Beyond human health: The need for environmental AMR endpoints to manage risks in waters
Dr Claire Hayward[1,2], Professor Nicholas Ashbolt[1,2], Dr Lara Settimio[3]
[1]University Of South Australia, [2]SAAFE CRC, [3]South Australian Environment Protection Authority

208 Imagining a partnership between the Australian CDC and the Australian Water Sector in wastewater surveillance - wastewater as a resource for public health
Ms Lyn Metcalf[1], Dr Monica Nolan[2,3]
[1]Interim Australian Centre for Disease Control (iCDC), [2]Promoting Health4All , [3]World Health Organization

201 Foundations for understanding and managing antimicrobial resistance challenges across the water sector
Dr Hannah Sassi[1], Professor Erica Donner[2], Professor Nicholas Ashbolt[2], Professor Aaron Jex[2], Professor Ricardo Magalhaes[2]
[1]Water Research Australia, [2]CRC SAAFE

189 An unconventional stormwater approach for an industrial precinct
Ms Niranjana Vetrivelu[1], Mr Phillip Birtles[1], Mr Craig Bush[1]
[1]Sydney Water

180 Circular Economy Sausage-Making Workshop 101
Mr Benjamin Bryant[1], Ms Nupur Khanna[1], Dr Nicola Nelson[2], Mr Jason Mingo[3], Mr Vincent Bianchini[4]
[1]Icon Water, [2]Australian Water Association, [3]Water Services Association of Australia, [4]Water Research Australia

209 Customer acceptability, customer preferences and social license to operate: what does all this mean for the water sector?
A/Prof Bethany Cooper[1,2], Dr Saeideh Khosroshahi[3], Prof Lin Crase[1], Prof Dan Rigby[4], Mr Marcus Crudden[3]
[1]University Of South Australia, [2]Australian Research Council (ARC) Industry Fellow, [3]Essential Services Commission, [4]University of Manchester

183 Novel operating strategies for sustainable treatment of regional community wastewater using high rate algal ponds
Mr Felipe Sabatte[1,5], Mr Sam Butterworth[1,5], Prof Harriet Whiley[1,5], Prof Enzo Palombo[2,5], Prof Melissa Brown[1,5], Dr Ryan Cheng[3,5], Dr Ben van den Akker[4], Prof Howard Fallowfield[1,5]
[1]Flinders University, [2]Swinburne University of Technology, , [3]SA Water Corporation, [4]University of South Australia, [5]ARC Training Centre for Biofilm Research and Innovation

210 Beyond treatment efficacy: Expert-driven modelling for uncovering hidden AMR hazards in potable reuse supply networks
Miss Stephanie Faulks[1], Professor Anne Roiko, Associate Professor Samantha Low-Choy
[1]Univeristy of South Australia

221 WaterNSW Catchment and River Health Research Strategy
Dr Lisa Hamilton[1]
[1]Waternsw

207 Like Parent, Like Metabolite: Do Antibiotic Transformation Products Exert Comparable Selective Pressure for Antimicrobial Resistance as Their Parent Antibiotic?
Ms Pooja Lakhey[1,2], Dr April Hayes[2], Dr Anne Leonard[2], Dr Aimee Murray[2], Prof. Kevin Thomas[1], Prof William Gaze[2], Dr Jake O'Brien[1]
[1]The University Of Queensland, [2]University of Exeter

184 Feasibility and Viability of Large Floating Solar Electricity Generation at Hunter Water

Mr Daniel Livingston[1]
[1]Hunter Water

195 Building resilience through better collaborations

Dr Ann-Marie Rohlfs[1], Dr Hannah Sassi[2], James Gardner[3], Prof. Yang Liu[4], Monique Binet[5], Dr Mariah Sampson[6]
[1]WaterNSW, [2]Water Research Australia, [3]WSAA, [4]Queensland University of Technology, [5]CSIRO, [6]Barwon Water

166 12-MONTH OPERATIONAL PERFORMANCE OF A DEMONSTRATION SCALE UASB AND HIGH-RATE ALGAE POND SYSTEM TREATING DOMESTIC REGIONAL SEWAGE

Dr Andrew Ward[1], Dr Jason Dwyer[2], Professor Damien Batstone[1]
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WaterSmart Farms - Water Security and Resilience in a Drying Climate

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WaterSmart Farms – Water Security and Resilience in a Drying Climate

Conference Topic

Creating Thriving Communities: Water and Liveability

Introduction

Prior to 2010, practically all local freshwater for agricultural purposes in rural Western Australia (WA) came from dams that collected and stored surface runoff, direct rainwater collection from engineered structures, and fresh groundwater bores or seeps. These resources were augmented in some areas by water delivered from the Water Corporation scheme. Despite an abundance of brackish and saline ground and surface waters in much of regional WA, the cost and lack of understanding of desalination systems for converting these impaired water resources into a freshwater supply has practically prevented the use of these resources. However, the drying climate over the last 30 years has substantially decreased the supply and reliability of freshwater from historical sources. Combined with the greater availability and increasing experience with small-scale desalination technologies; this has motivated an increasing number of Western Australian farms to implement desalination. (Hauck and Associates, 2016; Ela and Gustafsson, 2016). These factors motivated both Water Corporation and the WA Department of Primary Industries and Region Development (DPIRD) to initiate the WaterSmart project. The WaterSmart Farms (WSF) aims to identify and increase the reliability, capacity, and sustainability of brackish water resources (groundwater bores, fractured rock aquifers) and encourage the use on farm desalination. WSF collaborated with Murdoch University (MU) focussing on identifying sustainable, technology options for farmers and small regional communities. The project depends on the involvement of numerous other relevant national and state agencies, local governments, farmers, grower groups and technology providers.

This paper reports on the status of the WSF Desalination project's assessment and monitoring of the 30+, small-scale, desalination sites inventoried since 2019 in the wheatbelt of Western Australia. It details information from on-farm desalinisation units treating brackish groundwater for livestock, crop agronomy and other agribusiness and regional community activities. This is to provide an independent and up-to-date source of information for the many stakeholders involved in rural water management, use, and investment. The research project scope addresses three objectives:

- Develop an ongoing inventory of existing small-scale desalination installations in the Wheatbelt region regarding the adoption criteria and technical information.
- Investigate the adoption motivations for and the use of small-scale desalination including, the reason for adoption, equipment installed, costs, energy sources, site conditions, installation approaches and performance, and brine/reject management strategies.
- Present qualitative and quantitative information on the efficiency and economics of the desalination operations assessed; and development of a detailed database of representative, small-scale, on-site regional desalination units.

Method/Experimental Design

A list of sites on which a desalination system was installed or purchased for installation was gathered from Perth desalination equipment vendors, DPIRD, Water Corporation and MU records, and farmers. As of August 2024, the list included 48 farms covering 52 desalination units, plus the units of 4 rural communities. Attempts were made to contact the owner of each of the sites identified. For those sites responding and on which the desalination units were in use site assessments were undertaken at up to three levels of depth:

i) Farm water assessments were conducted on 31 units at 27 sites;
ii) Technical assessments were conducted on 13 of these units at 12 of the sites; and
iii) Remote monitoring equipment installation, followed by data assessment was completed on 3 units on 3 separate farms.

The farm water assessment was a general survey of water use and availability on the farm, combined with qualitative information gathering on the choice of desalination technology and its characteristics. Based on the farm water assessments, a subset of the respondent sites were chosen for additional technical assessment. The technical assessment aimed to gather more quantitative information on the technical and quantitative aspects of the desalination installation and its performance, using data gathered and the installation and monitoring of additional equipment performance instrumentation that could be remotely monitored. This provided the most in-depth level of site performance analysis that is termed remote monitoring data assessment.

In addition to the farm desalination inventory, WSF, Water Corporation (WC) and the National Water Grid (NWG) funded purchase and installation of four community desalination systems. These desalination systems were adapted for use on four trial sites, that were selected through an Expression of Interest (EOI) process managed by WSF. The community units were commissioned at the Shires of Katanning, Dumbleyung, and Merredin. The fourth unit was commissioned at the Wongutha CAPS, Gibson, WA in about December 2023.

The four community units were essentially the same units as were implemented on the farms. These community units were of the same small-scale capacity (<100 kL/d), supplied by the same vendors, and incorporated the same process components as the farm systems in the inventory. In addition, their performance was monitored by the same personnel using the same methods and equipment as for the farm units. Consequently, data from the community units was included in the operational performance aspects of the technical assessments and the remote monitoring data assessments of the inventory.

Outcomes/Results

Farm Water Assessment Results

The information collected from the adopters of the 31 farm units investigated, suggests the main reasons motivating farmers to adopt a desalination system were:

- Water deficiencies for spray, livestock, domestic and garden water.
- Increased water security and resilience due to unreliable water sources.
- Poor water quality in dams and bores.
- Unpredictable and limited rainfall patterns.
- Expense of scheme water.
- Expense and unreliable availability of water for carting.
- Lack of alternatives other than desalination.

This study found that most farmers are using the desalination product water mainly for crop spraying, livestock drinking water, gardening, household use and livestock feedlot demands (e.g., livestock water, sanitation, feed wetting) as illustrated in figure 1. When the earliest on-farm desalination sites were inventoried in 2018-2019, the primary rationale for adoption of desalination was to supply livestock drinking water. Western Australia (and Australia generally) had been experiencing a near decade long drought; so, the livestock carrying capacity of properties was largely limited by drinking water availability and/or the cost of drinking water where carting or scheme supply was an option. It was found however, from 2020 onwards that there has been a steady increase in the use of desalination units and purchase of new desalination units primarily to provide for consistently high-quality water for crop spraying. It is likely this change has been accelerated by several wet years since 2019, as well as the recognition that the high quality of desalinated water can often increase the effectiveness of pesticide and herbicide chemicals and, consequently, reduce overall crop spraying costs.

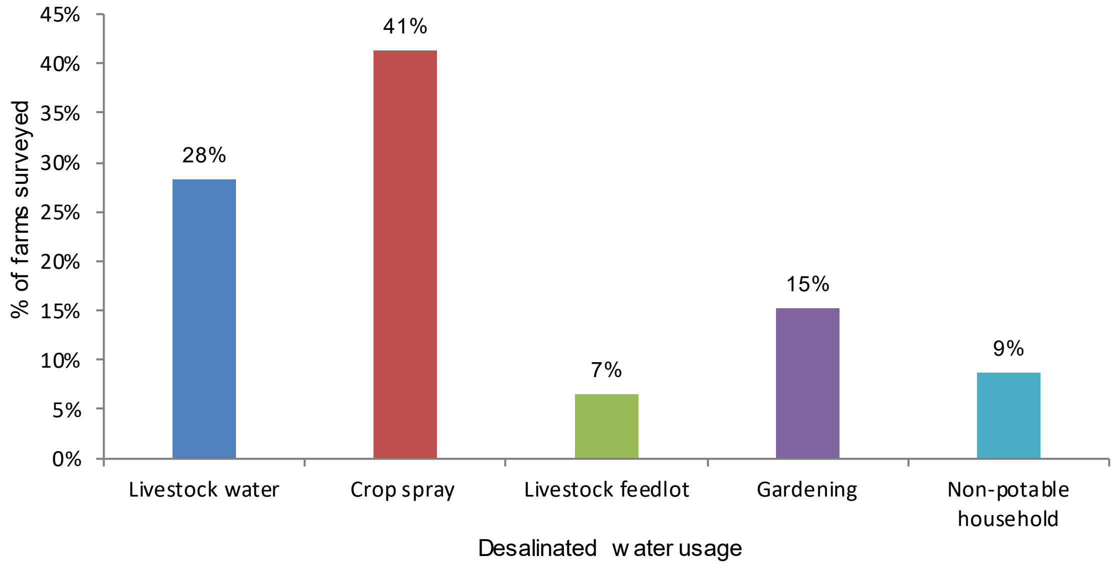

Figure 1 Primary use(s) of farm desalinated water. Where a unit was described as having multiple primary uses, each of the uses was entered into the analysis. Hence, the total number of primary uses reported here was 46, despite only 31 RO units being interrogated.

Based on feedback from the surveyed sites, most of the farmers/owners were satisfied that their desalination system was meeting their needs. They were happy with the quantity and quality of desalinated water and found noticeable advantages with desalination compared to other water sources. Although, there were also concerns expressed with desalination.

Anecdotally, most of the concerns came from system owners who opted for lower capital cost systems or for various reasons did not (either themselves or through a provider) do regular maintenance of their system. This included such tasks as changing of cartridge filters, backwashing of media filters (where it was not automated), periodic membrane cleaning and system flushing (where it was not automated). These maintenance issues could be lessened by increasing user awareness of the importance and nature of routine maintenance requirements through more information and training which can be difficult in regional areas due to expense, distance and lack of resources. Many of the highest satisfaction comments were from sites with automated cleaning systems or with service contracts (nearly always with the original vendor) that ensured regular maintenance checks.

Technical Assessment Results

Analyses of early adopters of on-farm desalination shows that their small-scale systems differ from those of the rest of the desalination industry in equipment characteristics, operational methods, system performance, financing, and otherwise accepted cost/benefit paradigms. Unlike larger desalination systems, these on-farm systems are not operated continuously; but are run only seasonally or intermittently based on both short-term and seasonal fluctuations in water demand. Whereas operating a conventional desalination system on average for less than 80% of the time annually would be considered too highly inefficient and costly; only 14% of the farm-based units were operated above this threshold and over 50% of the units were in run more than half of the time annually. Consequently, most surveyed systems operate well below their design capacity; producing an annual, average of 10-20kL/d of product water despite a much larger design capacity. Likewise, these small scale systems do not show the strong economy of scale relative to production capacity or the increased energy usage with increasing feedwater salinity (figure 2) that are well-documented, in larger desalination plants. However, an inverse correlation between unit production capacity and specific energy consumption (SEC) (kWh consumed per kL permeate produced) was observed, which raises the possibility that the unique economics of small-scale desalination system sizing versus storage system sizing is driving the farm adopter's rationale. The on-farm units were relied primarily on power from the central grid, but several systems were powered solely by photovoltaics. The central grid connected units produced water at about half the cost ($/kL) of the solar units assessed, but the small number of units assessed makes this finding essentially anecdotal. For instance, other recent research suggests hybrid systems that combine renewable and conventional energy sources may offer a more sustainable cost structure, however the limited scope of this study precluded analysis of this alternative.

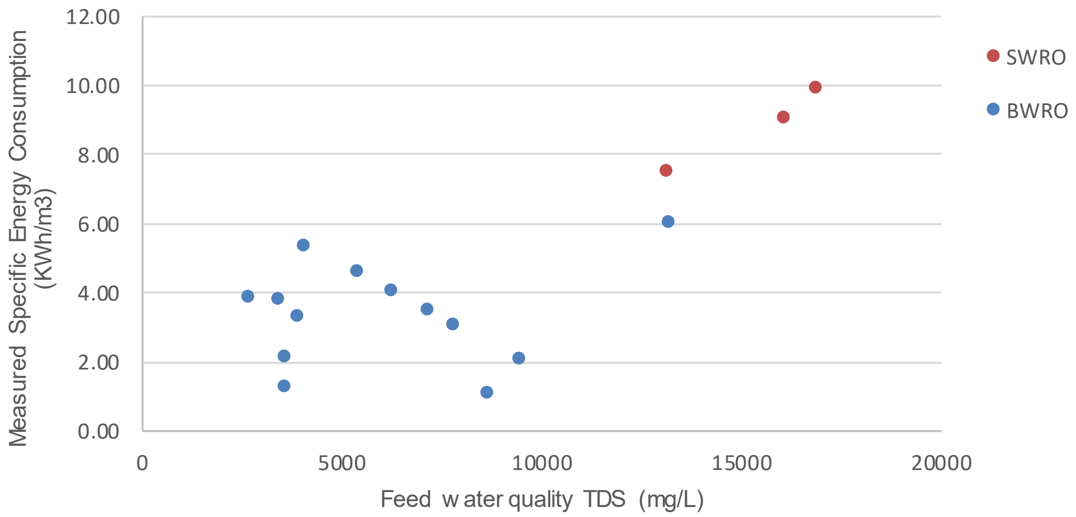

Figure 2 SEC dependence on feedwater TDS. Although within the BWRO range and the SWRO range there is little correlation between SEC and feedwater TDS, there is a clear step increase in SEC going from the BWRO plants to the SWRO plants surveyed (16 sites, including 2 community plants).

Conclusions

Desalination provides additional water supply, but also offers a source of very high-quality water, while assisting in mitigation of salinisation of agriculturally valuable land. The positive feedback and experiential knowledge gained from the early adopters of these small-scale desalination systems has been a notable contributor to the steadily rising number of desalination units being installed in regional WA.

- Analyses of on-farm desalination shows that their small-scale systems differ from those of the rest of the desalination industry.
- Unlike larger desalination systems, these on-farm systems are not operated continuously; but are run only seasonally or intermittently based on both short-term and seasonal fluctuations in water demand to provide water security and resilience.
- Most surveyed systems operate well below their design capacity.
- The small-scale desalination units do not show the strong economy of scale relative to production capacity or the increased energy usage with increasing feedwater salinity.
- The on-farm units were relied primarily on power from the central grid, but several systems were powered solely by photovoltaics. The central grid connected units produced water at about half the cost ($/kL) of the solar units assessed, but the small number of units assessed may influence this statement.

The increasing use of small-scale, decentralised, on-farm desalination reflects necessity, increasing technology adaptation, and response to less certainty in climate and markets. It is also clear that its level of proven capability now makes these units ripe for improvement and broader application. While desalination is not a universally applicable solution to agricultural water security, it is an essential component of a diversified water resilience plan. It is a largely underutilised and still inadequately understood means to achieve greater agricultural drought-proofing, productivity, and sustainability.

Knowledge Gaps

The analyse in this project has exposed that the operation of rural small-scale desalination systems are quite unique from those of the more-well studied, larger desalination systems. A non-exhaustive list of highlighted knowledge gaps includes:

- What are the quantitative pros and cons of desalinated water within the available sources of on-farm water? Some of the key considerations are to quantify:
    - To what degree does the use of very low TDS water decrease the dosage of spray chemicals and/or increase their efficacy compared to the use of lesser quality water?
    - To what degree does the use of very low TDS water affect the growth rate and health of livestock which drink it?
    - To what extent and at what cost does the corrosivity of desalinate permeate impact equipment, pipework, and fittings and to what extent and cost can the corrosivity be mitigated by re-blending brine back into the permeate?
    - What is the frequency of replacement and application of non-energy consumables (e.g., cartridge filters, membrane cleaning, antiscalant dosage) for small-scale desalination units?
- To what extent does operating desalination units infrequently and/or intermittently impact the maintenance frequency and life expectancy of non-energy consumables and the capital equipment?
- How should the long-term disposal capacity of reinjection bores be modelled, or alternatives (e.g., deep infiltration trenches) be engineered?
- As desalination becomes a more mature agricultural water supply alternative, will the on-farm uses of the permeate and/or the management of the brine change, and therefore the cost/benefit outcome of the investment change?
- With the major exception of crop spray water, the on-farm uses of desalination product water are well met with water with a salinity of 600 to 1000mg/L TDS. However, the TDS of permeate of the surveyed units was typically less than 200mg/L TDS. This production of water of a quality substantially better than needed increases the cost ($/kL), as well as increases the brine volume. Consequently, what are the economic benefits, of better matching the TDS of permeate to the TDS required for the use? Options for study to achieve better matching of product to required water include permeate blending with lower quality water (e.g., feedwater) and/or use of lower rejection membranes.
- What role can energy recovery devices (ERD) play, if any, in reducing the specific energy consumption (SEC) of on farm desalination units? To date none of the RO units assessed incorporated ERDs, despite most units operating with notably higher SECs than industrial norms.

This project owes its success to several people including Dr Richard George and Prof. Wendell Ela who have spent countless days working tirelessly to promote the use of groundwater and desalination on farms throughout the Wheatbelt of WA

The Safe Water Pub Test: communicating Water Safety

Dr Marty Hancock[1]
[1]Water Research Australia

The Safe Water Pub Test: Communicating Water Safety

Conference Topic

Optimising Resilient Water Supply Systems

MODERATOR:

Dr Marty Hancock, Water Research Australia

PARTICIPANTS:

Dr David Cunliffe, SA Health

Professor Stuart Khan, University of Sydney

Danielle Francis, Water Services Association of Australia

IDEAS TO BE PRESENTED, DEVELOPED AND DISCUSSED:

Rationale

Communicating the quality of drinking water to the consumer is an essential component of drinking water supply management and is a requirement of the Australian Drinking Water Guidelines (ADWG). So how we communicate the safety of drinking water and messaging we use is critical.

Learning Expectations

Improve methods to communicate water quality to the consumer.

Ways to communicate the safety of water from alternate water supplies when diversifying water sources for a more resilient water supply.

Outcomes

Better understanding of how to communicate Water Safety to a broad range of customers, many without scientific knowledge and understanding of water treatment.

GENERAL STRUCTURE OF THE WORKSHOP/PANEL:

Introduction (5min) – Dr Marty Hancock

Safe water is the widely used term to indicate water quality to the consumer and is also used in most national and international guidelines. However, there is no universally accepted definition of "safe drinking water." A quick 'Pub Test', Australian standard for testing the public acceptability of an idea, reveals that consumers have very different ideas of what Safe Water means. This workshop will explore how the water industry communicates the quality of drinking water and its fitness for purpose and explores the challenges and opportunities to improve our messaging on drinking water quality. A message that will require fine tuning as the need for more resilient water supplies drives the integration of diverse sources and new contaminate hazards to be managed.

Introduction of the Panel and perspectives

Panel Presentations

Presentation 1 (15min) – Dr David Cunliffe

The ADWG makes it clear that Consumers are the final judges of water quality and should be active partners in the decision making and that it is the responsibility of drinking water suppliers to keep the community fully informed about water quality. But how do we communicate scientific and technical information so that the 'Judges' can make well informed decisions?

Presentation 2 (15min) – Professor Stuart Khan

Various jurisdictions around the world have effectively defined safe drinking water by the way they present and implement guidelines, standards and regulation. The approach used in the ADWG is an important departure from what came before 2003/4, by the fundamental importance of the risk management frameworks. Thus 'safe drinking water' is no longer defined simply by the quality of water. Instead, the concept of 'safe' takes into account the potential for future incidents and accidents. This is an important risk management philosophy, but it is equally important that it is well understood and managed.

Presentation 3 (15min) – Dr Marty Hancock

The ABC of SafeWater: from QMRA (quantitative microbial risk management) to HBT (health based target) to LRV (log reduction values) to CCP (critical control point) to PPM (parts per million), a comprehensive process to ensure Safe Water but how does this translate for the customer? Options for informing consumers about water quality without the need for a science degree.

Presentation 4 (15min) Danielle Francis

Exploring what safe water means from a customer lens, and drawing on research learnings from local and international studies. Should we communicate safe water in terms of its outcome, its composition, source and treatment, or the thresholds it has to meet, or all of these aspects? Some international experts have studied perceptions of risk and stigma, and this has formed a basis for education programs on purified recycled water.

Attendee Questions and Panel responses (20min)

Conclusions (5min)

The moderator will provide a precise of the panel presentations, audience comments and panel responses to questions.

LINKS TO RESEARCH

Perceptions of Water Safety and Tap Water Taste and Their Associations With Beverage Intake Among U.S. Adults - PMC

Park et. al (2023) Am J Health Promot. 2023 June; 37(5): 625–637.

Kan, S.J. and Cwiertny, D.M. (2020) Environmental Science Water Research & Technology, 6,12.

Integrated Water Supply Planning for the Greater Busselton Area: A Multifaceted Approach to Resilience

Mr David Hughes-Owen[1], Miss Leticia Marinho[2], Dr Fabiana Tessele[2], Mr Brendan Tapley[3], Mr Chris Temple[1], Dr Stacey Hamilton[1]
[1]Busselton Water, [2]Tessele Consultants, [3]Decarbonate Consultants

Title of Full Paper

Integrated Water Supply Planning for the Greater Busselton Area: A Multifaceted Approach to Resilience
David Hughes-Owen[1], Leticia Marinho[2], Dr Fabiana Tessele[2], Brendan Tapley[3], Chris Temple[1], Dr Stacey Hamilton[1]
[1] Busselton Water, [2] Tessele Consultants, [3] Decarbonate Consultants

Conference Topic

Creating Thriving Communities: Water and Liveability

INTRODUCTION

Busselton Water (BW) is the local water provider for Busselton, a major regional centre 220 kilometres south of Perth. BW is a small Government Trading Enterprise owned by the Government of Western Australia. BW is responsible for water source treatment and distribution of drinking water to 16,000 residential customers as well as industrial and bulk supply customers. Drinking water is sourced from deep artesian aquifers, which provide high quality groundwater. The operating licence is issued by the Economic Regulation Authority under the *Water Services Act 2012* and authorises BW to provide potable water supply services to the areas shown on the map (Figure 1).

Figure 1: *Map of Busselton Water's operating licence area boundary.*

The Greater Busselton area is facing increasing challenges in securing a reliable and sustainable water supply due to climate variability, declining rainfall, saline intrusion, population growth, seasonal tourism peaks and competing water demands that have placed significant pressure on existing sources, necessitating a strategic and adaptive response. To address these complexities, BW in collaboration with Water Corporation of WA, Department of Water and Environmental Regulation (DWER) and City of Busselton (CoB) has developed an Integrated Water Service Plan (IWSP) that presents a strategic, forward-looking approach to securing the region's long-term water resilience.

METHOD/EXPERIMENTAL DESIGN

The IWSP adopts a systems-based approach combining demand forecasting, water balance evaluation, and alternative supply modelling.

A detailed desktop review established the system baseline by analysing historical abstraction volumes, consumption profiles, and licence allocations. These datasets were integrated into a dynamic Power BI platform designed to simulate the impact of various policy, demographic, and climate drivers on long-term water demand. The model incorporates parameters such as per capita usage, non-revenue water, short-stay accommodation growth, and the staged implementation of demand management strategies.

Geospatial overlays derived from ArcGIS were used to delineate coastal and inland borefield vulnerability zones, land use intensification areas, and potential sites for decentralised treatment or Managed Aquifer Recharge (MAR) schemes. This spatial component facilitated the identification of infrastructure investment priorities and highlighted risks associated with saline intrusion and borefield depletion [1].

Stakeholder consultation, including a regional workshop held in October 2024, informed scenario calibration and ensured alignment with broader regional planning initiatives [2,3].

OUTCOMES / RESULTS

The IWSP was released in May 2025. The IWSP integrates climate adaption measures, demand management strategies and circular economy principles to enhance the resilience and diversification of water supplies. A key aspect of the IWSP involves the transition from vulnerable coastal aquifers (at risk of saline intrusion) to a more secure, inland borefield. Demand management measures include digital water metering, pressure regulation, water efficient fixtures, pricing adjustments and public awareness initiatives aimed at reducing per capita consumption. Opportunities for water reuse and recycling are being explored as well as desalination and the feasibility of MAR.

Four key themes are discussed throughout the IWSP:

1) Optimising Existing Infrastructure with Demand Optimisation

A detailed analysis of current system performance led to the identification of a suite of demand-side strategies designed to reduce per capita consumption and mitigate network losses. Key measures include deployment of digital water metering, pressure optimisation, water-efficient fittings, public awareness campaigns, and exploration of time-of-use and volumetric pricing mechanisms. These interventions are expected to yield tangible reductions in non-revenue water and peak demand [4,5].

2) Investments in Non-Potable Infrastructure

The IWSP outlines a pathway for expanding non-potable reuse to support irrigation, open space, and industrial applications. Opportunities for MAR were evaluated based on regional hydrogeology and successful case studies [6,7]. Decentralised reuse schemes within growth corridors were identified to enable local water cycle management, with potential to defer major centralised investments [8].

3) Diversification of Water Supply

Busselton Water will progressively reduce reliance on coastal aquifers by shifting abstraction to an inland borefield, offering greater long-term yield security. Additionally, the IWSP explores contingency options including modular desalination units powered by renewables, aligning with sustainability benchmarks and cost-effective innovation [9-11].

4) Funding and Implementation

The successful implementation of the IWSP requires a hybrid financing model. This includes leveraging public sector investment, private capital partnerships, and eligibility for strategic infrastructure co-investment programs such as those promoted by Infrastructure WA [2]. Financial feasibility assessments accompanied each recommendation to ensure scalability and fiscal responsibility.

The IWSP outlines a phased delivery program with the following priority initiatives:

Short-term (2025–2027): Deployment of smart meters, development of a MAR feasibility study, and early-stage tariff reform exploration.

Medium-term (2028–2035): Constructing recycled water schemes and piloting decentralised reuse systems.

Long-term (2036 onwards): Full transition to inland borefields, deployment of modular desalination, and implementation of MAR infrastructure.

As shown in Table 1 of the final report, the cumulative water savings from these measures are expected to extend Busselton Water's licence horizon and provide a resilient supply foundation for future growth.

Table 1: *Short Term Actions Identified in the IWSP and their Expected Cost and Water Saving Measures.*

Action	Difficulty of Implementation	Cost of Implementation	Expected Water Saving Outcome (GL/y)
Smart Water Metering Expansion	Low	Low	0.05 – 0.1
Tariff reform	Low	Low (admin costs only)	0.007 – 0.014
Public Awareness Campaigns	Low	Low (campaign costs only)	0.87 – 1.76
MAR Feasibility	Moderate	Moderate	3.41 – 6.82
Infrastructure Pressure Management	Moderate	Moderate	0.06 – 0.13

Medium term actions shift towards expanding recycled water infrastructure and implementation of both decentralised water systems and a potential small scale desalination pilot plant. These initiatives will increase potable water savings whilst strengthening groundwater sustainability. The medium-term actions identified and their expected outcomes in water saving are shown in Table 2.

Table 2: *Medium Term Actions Identified in the IWSP and their Expected Cost and Water Saving Measures.*

Action	Difficulty of Implementation	Cost of Implementation	Expected Water Saving Outcome (GL/y)
Recycled Water Infrastructure Expansion	High	Moderate	3 - 5
Decentralised Water Systems	Moderate	Low	0.87 – 1.76
Small-scale desalination pilot	Moderate	High	3.65 – 5.47

Longer term actions (2035 and beyond) focus on the full integration of alternative water sources, ensuring BW remains at the forefront of sustainable water management, delivering long-term environmental and economic benefits.

CONCLUSIONS

The IWSP affirms that no single intervention can meet the complex and evolving water security needs of the Greater Busselton Area. Instead, a coordinated portfolio of strategies spanning technological upgrades, decentralised reuse, source diversification, and adaptive planning is essential to navigate climatic, demographic, and regulatory uncertainties. The plan exemplifies how collaborative planning, supported by data-driven modelling and stakeholder engagement, can deliver integrated outcomes that balance environmental sustainability, economic viability, and social equity.

WHAT’S NEXT – HOW WILL THIS HELP BUILD RESILIENCE

The implementation of the IWSP represents more than a blueprint for infrastructure investment. It lays the foundation for systemic resilience in the face of climate change, population growth, and shifting regulatory landscapes. The IWSP creates a flexible framework that can respond dynamically to emerging pressures by embedding adaptive planning principles, integrating technical, regulatory, and socio-economic dimensions. The model’s modular structure allows for refinement as new data becomes available, ensuring ongoing alignment with community expectations, environmental thresholds, and operational realities.

Importantly, the IWSP positions Busselton Water as a leader in forward-thinking regional water management. Its emphasis on local-scale reuse, distributed systems, and coordinated investment planning offers a transferable approach for other regional utilities confronting similar challenges. By demonstrating how robust scenario modelling, collaborative governance, and circular economy principles can be operationalised at scale, the IWSP contributes to the broader national dialogue on climate-resilient water supply planning.

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Harnessing rainwater for hot water: Lessons and pathways from a decade of innovation at Aquarevo

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Title of Full Paper

Harnessing rainwater for hot water: Lessons and pathways from a decade of innovation at Aquarevo

Conference Topic

Creating thriving communities: Water and liveability
Learn about climate adaptation, catchment management, and reimagining water systems for community wellbeing.

INTRODUCTION

Aquarevo is a 467-home, 42-hectare residential development in southeast Melbourne, delivered in partnership by South East Water and Villawood Properties. During this journey South East Water pioneered Victoria's first large-scale rainwater harvesting system for hot water, demonstrating how smart, decentralised infrastructure can enable more sustainable resilient and liveable communities.

Now approaching completion, Aquarevo has generated over a decade's worth of performance data and research, offering a rare case study in water-sensitive urban design (WSUD) and Integrated Water Management (IWM). This paper presents findings across three key domains: water quality, water balance, and asset management, demonstrating measurable outcomes in potable water savings, stormwater runoff mitigation, and operational resilience. We also explore how this model can be scaled or adapted to meet future urban water challenges.

METHOD/EXPERIMENTAL DESIGN

System overview

Aquarevo homes are provided with a multi-source water strategy:

- **Potable water** for kitchens, bathroom vanities, and cold taps in laundry, bath and shower.
- **Heated rainwater** for showers, baths, and laundry troughs.
- **Recycled water** from sewage for toilets and garden irrigation.
- **All three sources** are available for washing machines, with a preference for recycled water to be utilised.

Rainwater is collected via roof runoff, filtered, UV-treated, and heated using an electric heat pump system. Each property is equipped with a OneBox+® controller for real-time monitoring and a Tank Talk® smart tank system that predictively releases rainwater in anticipation of storms, reducing overflows and aiding flood mitigation (Figure 1). The system has been developed and researched by South East Water in collaboration with partners including Villawood Properties (land development), specialist consultants and contractors, universities, and community trial site participants.

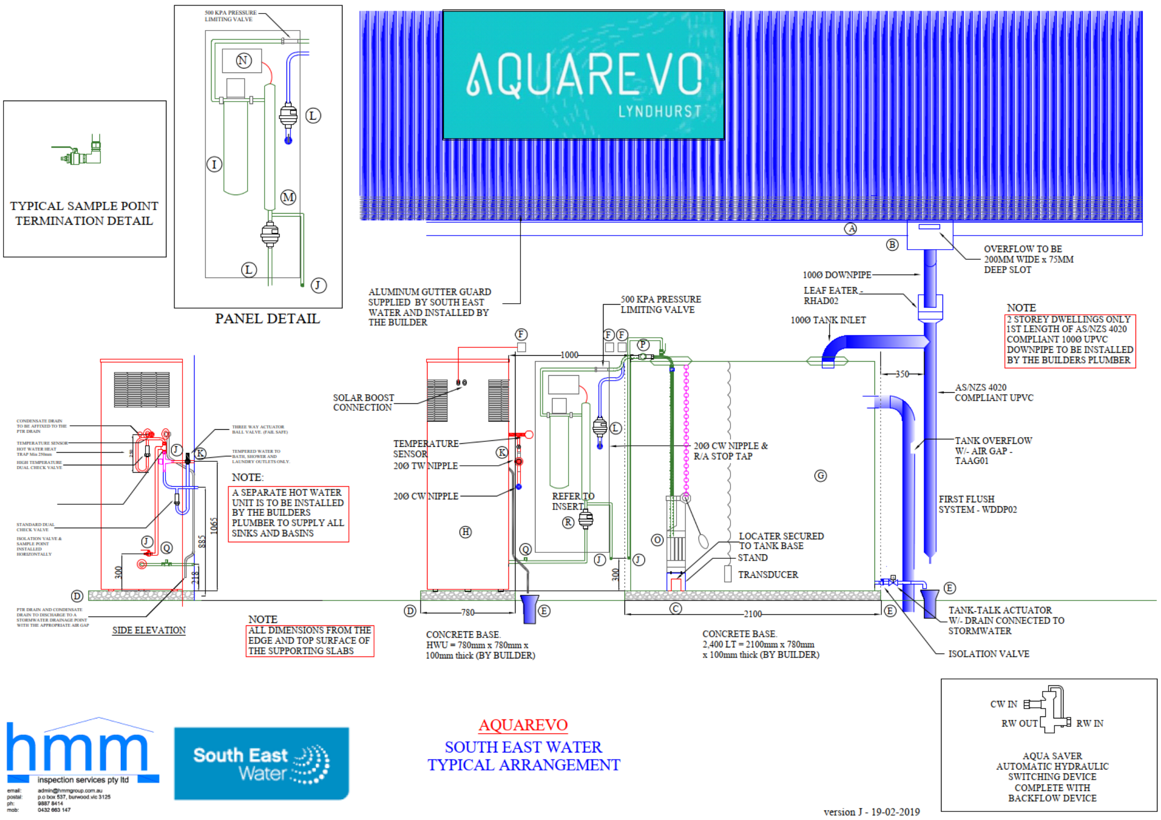

Figure 1 Aquarevo rainwater-to-hot water system setup

Water quality

South East Water is conducting a comprehensive monitoring program, which included between 2018 and 2024:

- **6.5 years of data**
- **1,069 site visits** across 395 occupied homes.
- **Over 63,000 analytical reports** from 1,185 sampling points.
- **Sampling stages** included commissioning (base suite of 5 parameters), 3-month post-install (57 parameters), and annual follow-up (base suite).

Each treatment system is subject to continuous online monitoring, with plumbing and electrical inspections conducted at completion and annually thereafter. Independent microbial and chemical risk assessments were benchmarked against the Australian Drinking Water Guidelines (ADWG) (South East Water, 2020; Deere and Gao, 2021; and Deere and Gao, 2022).

Water balance

Aquarevo was designed to reduce potable water use by up to 70 %, using both rainwater and recycled water, and to reduce stormwater runoff from hard surfaces by up to 25 %.
Since home occupancy began in 2019, South East Water has monitored and evaluated water usage using digital meters, the OneBox+® controller and customer feedback.
A preliminary analysis of 2021–22 data from 251 occupied homes revealed:

- **36 % average reduction** in potable water use.
- **19 % reduction** in stormwater runoff.

While these results demonstrate substantial progress, they also revealed opportunities for system optimisation and highlighted broader limitations in meeting the original water balance targets (Dharmadhikari et al., 2022).

The optimisation opportunities included:

1. Refining Tank Talk® algorithms.
2. Addressing downpipe blockages due to bird nesting, which was delayed due to COVID-19 access restrictions.

3. Enhancing customer engagement to increase recycled water use in washing machines, building on the existing uptake in 53 % of households.
4. Investigating UV-based treatment to function as the primary disinfection barrier, maximising yield from the heat pump storage and removing the need for the additional pasteurisation barrier. This will increase rainwater flow while maintaining water quality for high-use households.

Identified limitations included rainfall variability, larger than anticipated homes, higher than average occupant numbers, smaller garden sizes and less opportunities to irrigate public open spaces with recycled water, all of which constrained the potential for rainwater and recycled water use. Due to reduced demand and rainfall availability, the maximum achievable average reduction in potable water consumption was estimated at no more than 45 %.

Asset management

Operating assets beyond the meter – traditionally the homeowner's domain – represents a significant shift in the operational model for a water utility and was a key innovation of the Aquarevo model.

South East Water and Villawood Properties collaboratively developed design guidelines for plumbing and electrical specifications to ensure the rainwater harvesting systems, their roof catchments, and monitoring meet strict regulatory standards and quality expectations.

The maintenance strategy consists of:

- **3-month post-install inspection** to ensure system performance is achieved.
- **Annual maintenance cycle**, including replacement of the filter cartridge, UV lamp and UV sensor, and first flush system clean and visual inspection, with earlier repair or replacement if a fault is detected by the OneBox+® controller.
- **Continuous asset monitoring** through South East Water's real-time monitoring system and customer call centre.

OUTCOMES / RESULTS

Water quality

The independent microbial and chemical risk assessments confirmed the following key outcomes:

- **No concerning or persistent exceedances** of drinking water quality guidelines were detected in water sampled post-treatment at hot water outlets. Any exceedances were small in magnitude and isolated to sporadic occurrence.
- **The multi-barrier approach can be safely adjusted**: The reliance on a UV-only approach eliminates the change to potable water despite not reaching the hot water pasteurisation temperature of 62 degrees for 32 minutes. Microbial and chemical risk assessments confirmed that this change does not significantly increase health risks from enteric or opportunistic pathogens, remaining within acceptable safety thresholds (Deere and Gao, 2021).
- **Monitoring can be scaled back**: Consistent results support transitioning from the intensive laboratory testing verification program to a preventative risk-based approach, with targeted spot sampling across the estate. This shift reflects alignment with Hazard Analysis Critical Control Points (HACCP), ISO 22000, and ADWG risk-based frameworks, where prevention takes precedence over verification. At the time of writing the scheme HACCP plan is being revised.

Water balance

As of May 2025, 428 of the 467 lots in the estate have houses completed and occupied. The optimisation strategies identified in 2022 have since been implemented resulting in the following outcomes:

1. Optimisation actions implemented, including bird-proof mesh, algorithm improvements, and targeted engagement.
2. **Long-term average estate-wide potable water savings improved to 45 %**, with rainwater contributing 10 % and recycled water 35 %. Some households achieve up to **69 % reduction.**
3. Average rainwater use across the estate increased only slightly, from 50 to 57 L/day/house, confirming that further significant gains in rainwater use are limited by both rainfall variability and rainwater availability for high-use households.
4. Updated stormwater runoff analysis is underway, with early indications showing improvement toward the 25 % reduction goal.
5. The UV-only treatment control has been developed and is under review as part of the scheme's HACCP Plan. It is earmarked for future testing. **This change could increase rainwater uptake across the estate**

by up to 5,500 L/day, as it eliminates the need to switch to potable water for high-use households where average shower times exceed 20 minutes per person. (Dharmadhikari et al., 2022).

Asset management

South East Water's ongoing monitoring and management strategies have ensured the rainwater-to-hot water system performance and customer experience are of a high standard.
This proactive and predictive asset management approach has resulted in:

- **Ability to predict maintenance events,** preventing out of hours maintenance.
- **Early detection** of issues (e.g. UV disinfection performance) through anomaly monitoring.
- **Update of building guidelines** to minimise compliance delays (e.g. installation of bird-proof mesh).

CONCLUSIONS

The Aquarevo model demonstrates a viable and safe pathway for decentralised rainwater-to-hot-water systems that:

- Reduce potable water consumption and assist in the reduction of stormwater runoff volumes and peak flows.
- Deliver resilient, water-sensitive design at lot and precinct scale.
- Enable water utilities to take on active roles beyond the meter, ensuring high system performance and customer satisfaction.

Its success was underpinned by:

- A scalable model, small enough to manage effectively, yet large enough to prove viability at scale.
- Rigorous health-based water quality management.
- Digital monitoring and smart controls.
- Strategic optimisation and engagement.

Aquarevo sets a benchmark for future developments, offering a replicable model for climate adaptation, urban resilience, and integrated water management.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

The next major Aquarevo phase includes the planned implementation of a closed-loop wastewater recycling plant to enhance water self-sufficiency and climate resilience. This will further reduce reliance on centralised infrastructure, strengthen local sustainability and circular economy at the precinct scale.
Explorations of next steps for rainwater harvesting include:

- Transitioning this pilot model to a business-as-usual delivery model.
- Scalability of decentralised infrastructure comparing benefits and challenges of rainwater harvesting at lot-scale versus community-scale.
- Understanding how these systems can improve water cycle management in other development contexts, such as high density, and other parts of Australia.

Aquarevo's experience reinforces that smart, decentralised water systems can underpin the thriving, liveable communities of the future.

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Catchment health metrics to inform management of Australian catchments

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Title of Full Paper

Catchment health metrics to inform management of Australian catchments

Conference Topic

Creating Thriving Communities: Water and Liveability

INTRODUCTION

Integrated catchment management in Australia is often a complex collaboration between agencies that are trying to achieve complementary or competing management objectives. However, it lacks consistent methods and metrics to inform and support it.

Alluvium is working with Water Research Australia and water utilities in Victoria (Melbourne Water, Coliban Water and Wannon water), New South Wales (Sydney Water, Water NSW and Hunter Water), and Western Australia (Water Corporation) to develop a catchment health framework and associated catchment health metrics.

The catchment health framework is a method for measuring the condition of a catchment, where:

- Condition is defined by the user to reflect the management objectives they are trying to achieve.
- Catchment health is a subset of condition, focused on how the catchment functions in terms of delivering desired ecosystem services.

The catchment health metrics feed into that framework, where the metrics:

- Cover the physical, chemical, biological, or socioeconomic aspects of catchment health.
- Enable benchmarking, monitoring, and communication of management activity effectiveness relative to objectives.

METHOD/EXPERIMENTAL DESIGN

Developing the framework

The framework was developed based on engagement with the project partners and a review of established approaches. The framework guides evaluation of the state of a catchment, focusing on five key elements that provides consistency in approach whilst allowing for flexibility to accommodate different management contexts and environmental settings (Figure 1).

1) Establish the management context	• **Why are you planning**? • **Document values, objectives and pressures.**

2) Understand catchment context and function	• **Conceptualise the catchment**. Develop a conceptual model of the system.
	• **Identify the assets**. Two key questions:
	  • Which key components or processes need to be protected to sustain the value?
	  • What is the relationship between system condition and status of value?
	
	• **Catchment planning (if this has not been developed)**. Defining goals and objectives of the assessment. Collating information on the system.

3) Design the assessment	• **Prioritise objectives of assessment.** Opportunity to adapt the objective hierarchy in response to planning decisions. • **Identify and prioritise assessment metrics** based on criteria. • **Design assessment and implementation.**

4) Analyse and interpret	• **Analysis to generate metrics.**
	  • Data QA/QC and pre-processing.
	  • Select methods and tools.
	  • Analysis and documentation.
	• Reporting in alignment with the purpose of the assessment.

5) Evaluate the assessment	• **There are a variety of methods available to evaluate the assessment that can be broadly grouped into:**
	  • Objectives and questions. Are the questions being addressed adequately with the assessment?
	  • Methods. How well is the assessment performing in terms of detecting trends and effectiveness of management interventions?
	  • Value to end users. How does the assessment perform in terms of communicating results to end users?

Figure 2. Locations of the five case study catchments.

Implementing the framework in case studies

The framework is being implemented in five case study catchments around Australia (Figure 2). The case studies reflect diverse management contexts and management priorities and pressures (Table 1).

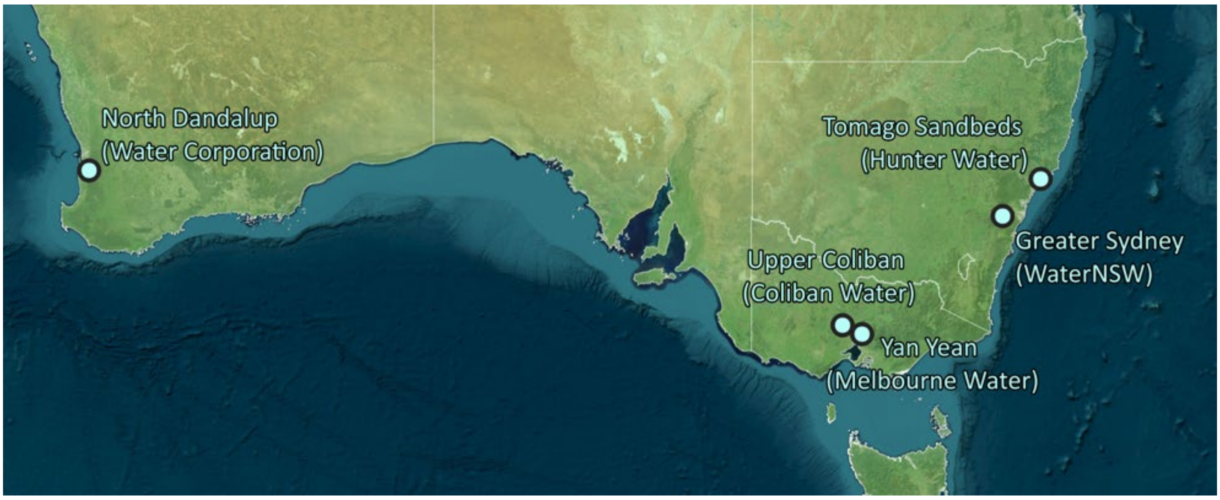

Figure 3. Locations of the five case study catchments.

Table 1. Pressures and their relevance (low, moderate or high) to case studies.

Pressure	Upper Coliban (Coliban Water)	North Dandalup (Water Corp)	Greater Sydney (WaterNSW)	Tomago Sandbeds (Hunter Water)	Yan Yean (Melbourne Water)
Climate change	High	High	High	High	High
Bushfires	Moderate	High	High	Moderate	Moderate
Unsealed roads	Low	Moderate	Moderate	Low	Low
Mining (including GW extraction)	Low	High	High	High	Low
Land use – Agriculture	High	Low	High	Moderate	Moderate
Land use – Urbanisation	High	Low	Moderate	High	Moderate

Developing a toolbox

In the process of implementing the framework in the case study catchments, we are developing a toolbox writing the Python, consisting of workflows that will enable users to efficiently measure and report on catchment health. The toolbox architecture consists of two levels:

- Level 1 - Catchment profiles and pressures. This involves standard national or jurisdictional databases, such as data on land use, hydrology, and climate. The workflows are generic, widely applicable, and able to be automated and delivered as a package of scripts or spreadsheets.
- Level 2 – Catchment monitoring. This data is sourced from the utilities to inform site-specific assessments, where the metrics are tailored to the utilities' datasets (e.g., water quality, macroinvertebrates). The workflows and scripts are tailored specifically for each case study but can be adapted and applied to other settings.

Conceptually, the health metrics considers threats as a combination of the magnitude of pressures and their connectivity to surface water and groundwater (Figure 3).

Developing metrics

The catchment health metrics are being developed and documented as we work through the case studies, with consideration of pressures, connectivity, and risk. The analysis brings together Level 1 and Level 2 and links monitoring data from utilities with regionally available spatial data. This produces a database that cross references point-based monitoring with catchment data, and facilitates investigations into the relationships between catchment activities and waterway response.

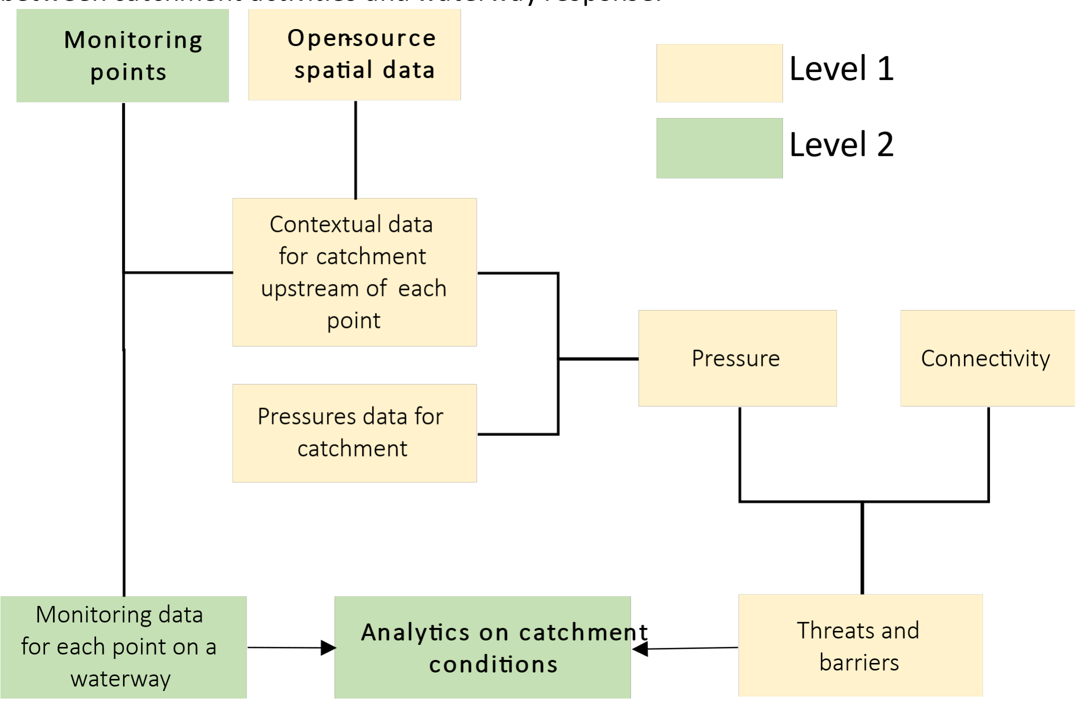

Figure 4. Conceptual representation of the Level 1 and Level 2 assessments.

OUTCOMES TO DATE

The framework is currently being applied in the five case study catchments. The relevant project partners have been engaged to discuss the management context of their catchments and their priorities for the case studies. They have also supplied information including strategic documents, monitoring data, and spatial data such as catchment areas and sampling locations. In summary:

- The Upper Coliban catchment (Coliban Water), northwest of Melbourne and at the southern extent of the Murray-Darling Basin, faces pressures such as development, agriculture, and changes to hydrological regimes. The metrics will help to understand the distribution of those pressures across the catchment to inform interventions, and to track progress in relation to 20-year initiative called *A Healthy Coliban Catchment*. They will also build a narrative beyond compliance with water quality guidelines, to holistic management of catchment values across multi-generational timescales.
- The North Dandalup catchment (Water Corporation) is a water supply catchment for Perth that is also managed for bauxite mining. The mining causes changes in hydrology, including groundwater process and longer-term hydrological instability. The metrics for North Dandalup are therefore focused on tracking the impacts of mining on water quality and water yield.
- The Greater Sydney catchment (WaterNSW) is by far the largest case study catchment, and one of the most significant and complex catchments in Australia. Over 30 agencies are involved in its management, and the pressures are diverse and widespread. Metrics for Greater Sydney will help to develop a sense of common purpose across agencies and to communicate the state and trajectory of catchment health to inform interventions for drinking water quality.
- The Tomago Sandbeds (Hunter Water) are a critical groundwater source for the Lower Hunter region but are impacted by groundwater contamination from many potential sources such as Defence facilities, industry, and past mining. Its metrics will have synergy with a project about groundwater dependent ecosystems (GDEs). They will also provide a more holistic view of the catchment, including the trajectories of the various pressures.
- The Yan Yean Reservoir (Melbourne Water), north of Melbourne, is the city's oldest water supply reservoir. While much of its catchment is forested and protected, it is supplied by a unique aqueduct system that is subject to runoff from urban development and agriculture. The reservoir has been subject to taste and odour issues, but the exact drivers are unknown. The metrics will help map the connection between land use pressures and water quality.

The project outputs will be a reference manual and toolbox for assessing catchment health in a variety of management contexts. The toolbox will consist of workflows that enable end users to efficiently measure and report on catchment health. It will ensure that the framework establishes a clear and efficient pathway for implementation, which is something typically missing from existing frameworks.

CONCLUSIONS

The catchment health framework and associated metrics will provide a practical and adaptable tool to assist catchment management across diverse Australian catchments. By enabling consistent benchmarking, monitoring, and communication, they can lead to more informed decision-making and greater collaboration among stakeholders.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

The catchment metrics will help water utilities with benchmarking and monitoring, and with assessing and communicating the effectiveness of management activities relative to objectives. In a broader sense, they will help build resiliency and thriving communities by developing shared understanding and coordination amongst stakeholders in catchment management, which will better inform interventions and support long-term management objectives. The modular and adaptable nature of the toolbox will enable the framework to be applied to various catchments with different management contexts and data availability.

Lime Stabilisation of Sludge to Reduce Greenhouse Gas Emissions from Western Treatment Plant's Sludge Drying Pans

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Title of Full Paper

Lime Stabilisation of Sludge to Reduce Greenhouse Gas Emissions from Western Treatment Plant's Sludge Drying Pans

Conference Topic

Creating Thriving Communities: Water and Liveability

INTRODUCTION

A major source of greenhouse gas (GHG) emissions at Melbourne Water's wastewater treatment plants is the sludge drying pans (SDP). Addressing the GHG emissions from SDPs with priority would greatly assist with Victoria's Net Zero Emissions target.
Lime stabilisation has been recognised as one of the stabilisation methods to minimise the potential for odour generation, destroy pathogens, and reduce the material's vector attraction potential. Meanwhile, lime can be potentially used to elevate the pH of sludge to inhibit the methanogenesis to generate methane and carbon dioxide (both GHG). This workshop trialled quicklime (CaO, one form of lime) dosing in sludge to primarily reduce both methane and carbon dioxide emissions.

METHOD/EXPERIMENTAL DESIGN

1) Benchtop Experiments

The benchtop experiment was to verify the performance of quicklime in reducing GHG generations and if so determine the minimum dosage.
The benchtop experiment is done following a standard piece of testwork called biochemical methane and carbon dioxide potential (BMP) test. It is to analyse the potential of methane and carbon dioxide (biogas, also GHG) of an organic material (i.e. sludge, food, etc.) by creating an anaerobic condition. In this test, 100 mL of freshly dredged sludge is put into a 160 mL serum bottle. The headspace is purged with nitrogen gas before an aluminium cap is applied to seal the bottles. Periodically, a 2 mL gas sample is extracted from the bottles and run through a gas chromatograph to analyse the concentrations of methane, carbon dioxide, hydrogen (if exists), and nitrogen. The dosage (on a mass ratio) of quicklime starts from 0% and gradually increases to 0.3% with an increment of 0.037%. A series of nine tests was conducted.

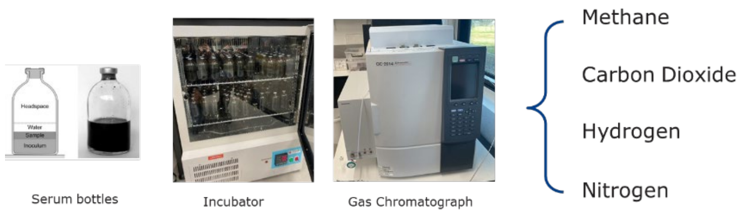

Figure 5 Biochemical methane and carbon dioxide potential test.

2) Small-Scale Trial

The objective of a small-scale trial was to keep verifying the performance at a relatively larger scale while also testing the best dosing strategy to minimise both capital and operational cost.

An airtight 3.1 L container was selected as the testing vessel. A hole was drilled in the lid before a rubber septum was plugged in. This was to allow gas sampling while maintaining its air-tightness. 2 L of sludge was put into each of six vessels. Three dosage were selected including 0%, 0.5%, and 1.0%. Dosing strategies included sprinkling sludge at the surface of sludge, sprinkling at the bottom of vessels before applying sludge, as well as mixing quicklime with sludge homogenously prior to filling. Gas samples were analysed with a GC.

3) Large-Scale Trial

Large-scale trials were to simulate real SDPs and assess the performance taking into account of air diffusion, temperature, air pressure, ambient humidity, wind, UV, etc. The results should be relatively closer to a full-scale trial.

A total of five tests was conducted under an outdoor condition at 205W SDP manifold. The first three tests were to test solids settling performance, while the last two were to quantify the GHG emissions (under sealed conditions). Table 1 summarises the setup. All sludge was given a well-mixing with quicklime.

Table 2 Large-scale trial setup.

Test ID	Date	Test	Quicklime Dosage	Open/Sealed	Location	Purpose
#1	21/3/2025, 11am	35L of sludge in 52L of container	0%	Open	205W SDP manifold	To test solids settling performance
#2	21/3/2025, 11am	35L of sludge in 52L of container	0.5%, well mixed	Open		
#3	21/3/2025, 11am	35L of sludge in 52L of container	1.0%, well mixed	Open		
#4	24/3/2025, 2pm	50L of sludge in 75L of container	0%	Sealed		To quantify GHG emissions
#5	24/3/2025, 2pm	50L of sludge in 75L of container	0.5%, well mixed	Sealed		

OUTCOMES / RESULTS

1) Benchtop Experiments

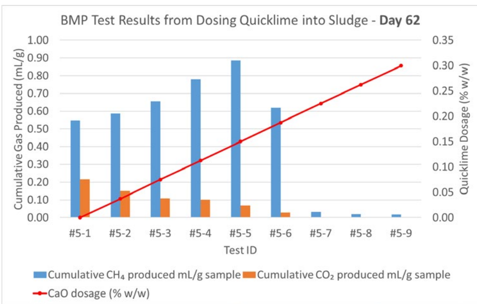

Figure 6 BMP test results of quicklime dosing.

The benchtop discovers a minimal dosage of 0.22% to be able to reduce methane and carbon dioxide production effectively and significantly (90% reduction). The experiment also reveals that when the dosage is below 0.2%, GHG generation risks being increased by up to 60%. The tests were monitored for 62 days, demonstrating the long efficacy of lime dosing. Theoretically, quicklime reacts with both acetate and carbon dioxide generated by acetogenesis of anaerobic digestion so that both reactants would not be able to be converted to methane and carbon dioxide by methanogen in the phase of methanogenesis.

2) Small-Scale Trial

Table 3 Small-scale trial tests and results.

Test ID	Sludge Vol (mL)	Lime Dosage (m: m)	Dosing Strategy	Mixing?	Start Date	Sampling Date	CH_4 (%)	CO_2 (%)	H_2 (%)
1	2000	0	n/a	No	20/2/2025	31/3/2025	9.669	4.599	-
2	2000	0.5%	Surface	No	20/2/2025	11/3/2025	3.231	-	4.198
3	2000	1.0%	Surface	No	20/2/2025	11/3/2025	2.462	-	4.088
4	2000	0.5%	Bottom	No	20/2/2025	31/3/2025	2.672	-	1.796
5	2000	0.5%	n/a	Yes	21/2/2025	31/3/2025	0.751	-	2.556
6	2000	1.0%	Bottom	No	21/2/2025	11/3/2025	2.837	-	4.460

Among the three strategies, dosing and mixing (Test #5) was found to be the most effective - a 92% reduction in methane and 100% reduction in carbon dioxide, which confirmed the benchtop experiments. Taking into account of benchtop experiments, where lower than min. dosage may cause higher methane generation, it is a prerequisite that to make sure GHG emissions are reduced, a well mixing of sludge and quicklime is to be implemented prior to the filling of SDP.

3) Large-Scale Trial

As shown in Table 3, in three or four days after dosing, it was observed that,

1. In Test #1, a solid and moist crust was formed on the surface of sludge. This crust would stop water from evaporating and what is even worse, form a cap to create an anaerobic condition, which is ideal for GHG generation.
2. In both Test #2 and 3, however, solids of sludge settled to the bottom of containers. Supernatant water appeared to be clear on the sludge blanket, which is ideal for water to evaporate.

After breaking apart the crust, a large amount of bubbles appeared. These bubbles were regarded as either methane or carbon dioxide. Comparing Test #1 with Test #2&3, where no visual bubbles were observed, it was obvious that GHG emissions were mitigated by lime dosing. As Figure 3.

Table 4 Photos of the large-scale trials (Test #1 to 3).

Test ID	Photos of Trials at Day 0		Photos of Trials at Day 3 & 4	
#1				
#2				
#3				

GHG testing results were summarised in Table 4. Methane was reduced by 96%, while carbon dioxide was not detected. The results, plus the emerging of hydrogen gas, are consistent with the results in benchtop and small-scale trials.

Figure 7 Photos of Test #1 after breaking apart the crust (left), comparing to Test #2 (right).

Table 5 Results of GHG emissions for Test #4 & 5.

Start Date	Test	Quicklime Dosage	Test Date	N_2 (%)	CH_4 (%)	CO_2 (%)	H_2 (%)
24/3/2025, 2pm	50L of sludge in 75L of container	0%	31/3/2025, 11am	21.45	36.39	17.69	-
		0.5%		73.74	1.32	-	0.27

CONCLUSIONS

Based on the trials, the mechanism of lime stabilisation of sludge to reduce GHG emissions has been concluded via two pathways,

i. inhibited methanogenesis which reduced GHG emissions;
ii. coagulation of solids which accelerated the drying process.

Apart from a reduced GHG emission that quicklime dosing brings, it is also worth noting that the coagulation of solids is highly favourable to WTP in two aspects,

1. it shortens the drying process so that sludge has less time to produce GHG emissions;
2. it enables faster turnover of SDP, which saves considerable OPEX in turning and windrowing of the sludge, and CAPEX in repairing the SDP, etc.

A schematic diagram of benefits of quicklime dosing is as follows.

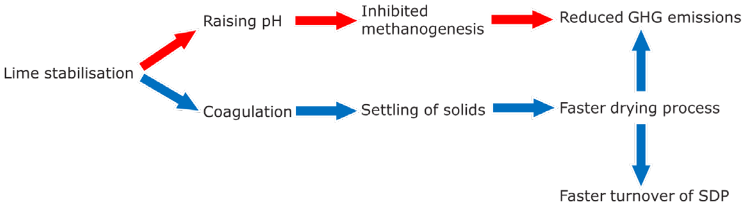

Figure 8 The mechanism of how quicklime stabilisation reduces GHG emissions.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

A full-scale trial is recommended to test the performance of lime in terms of GHG emissions reduction. Once successful, the technology can be of great application in a wastewater treatment plant in reducing their GHG emissions.

Drone-Based Multispectral Monitoring of Vegetation Health in Constructed Stormwater Wetlands

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Title of Full Paper

Drone-Based Multispectral Monitoring of Vegetation Health in Constructed Stormwater Wetlands

Conference Topic

Creating Thriving Communities: Water and Liveability

INTRODUCTION

Constructed wetlands for stormwater management can improve runoff water quality and temporarily store runoff to mitigate impacts of urbanisation on waterways. Healthy vegetation and storage capacity which is available following storm events are required to achieve these outcomes. Yet, these two conditions can be difficult to achieve with passively controlled water levels in constructed wetlands. As such, real-time control strategies are suggested to improve the storage capacity of constructed wetlands when it is needed (Kerkez et al., 2016). Extended periods of inundation and the deep water levels decrease wetland macrophyte survival (Greenway et al., 2007; Robertson et al., 2018). Consequently, actively controlling water level to achieve better storage capacity (or to increase residence times) may have unintended consequences on the health of vegetation.

Traditional wetland vegetation monitoring using plot-based methods is labour-intensive (Ambrose, 2002) and resource-demanding, requiring specific expertise in taxonomy and health indicators. Remote sensing techniques can alleviate these drawbacks of ground-based methods, but require calibration and testing to evaluate their accuracy. Multispectral imagery and high-resolution RGB photographs captured by drones can be used to classify vegetation (Bertacchi et al., 2019; Chabot et al., 2018) and evaluate plant health status (Boon & Tesfamichael, 2017). Image analysis often uses machine learning, such as Random Forest (Bhatnagar et al., 2021; Chabot et al., 2018).

This study evaluates the application of drone-mounted multispectral imagery as an efficient alternative for monitoring vegetation health, with a focus on assessing the impacts of real-time water level control on wetland vegetation communities. Ultimately, we plan to use a combination of high-resolution, multispectral drone imagery, satellite data, ground-truth assessments, and photogrammetry to demonstrate the viability of remote sensing technologies for wetland management applications. At the time of writing this paper, we have analysed preliminary results using multispectral imagery which indicate that this approach effectively captures spatial variations in vegetation health metrics.

METHOD/EXPERIMENTAL DESIGN

The eventual aim of this project is to evaluate whether there are impacts on vegetation health from implementing real-time control for water quality improvement on at constructed wetland. To do this, we will collect drone imagery from multiple wetland sites and compare changes across vegetation communities. We also aim to up-sample classified drone imagery to high frequency satellite imagery with appropriate spatial resolution (e.g., Sentinal-2 or PlanetScope) At the time of writing this report (June 2025), we have collected imagery from two drone flights and developed a workflow for image processing and cover classification using a Random Forest machine learning algorithm which relies on multiple bands. We have also identified a process for evaluating plant heath using the normalised difference vegetation index (NDVI) and normalised difference water index (NDWI).

Site description

Troups Creek Wetland is a 9 ha free water surface constructed wetland for stormwater treatment which as been fitted with valves which can be opened on-demand, remotely, and using real-time monitored information. The real-time control (RTC) setup was installed over 2022-2024 through several trials and upgrades. The site and RTC setup are detailed in Pang et al. (2023). The site has underperformed at improving water quality, potentially due to poor vegetation cover (Meng et al., 2018). Vegetation cover may have been diminished by prolonged inundation (Robertson et al., 2018; Shi et al., 2024). The site was revegetated as part of a 2018 wetland rectification project by Melbourne Water. Potential RTC strategies include managing water level for maintaining vegetation health (Pang et al., 2023).

Data collection

A DJI Mavic 3M fitted with factory-installed cameras (20 MP RGB; 5 MP multispectral) capable of collecting multiband images. The multispectral camera collected band in the following wavelengths: Green (G, 560nm), Red (R, 650nm), Red Edge (RE, 730nm), and Near infrared (NIR, 860nm). A light sensor on the drone provides data on sunlight intensity, which was used in data pre-processing. We flew between 11am-1pm on 15 November 2024 and 28 March 2025 at an altitude of 65 m with image overlap to 85%. This resulted in a 1.72 cm/pixel resolution for orthomosaic and single-band images.

Data Processing and Analysis

Drone imagery files were stitched and compiled into single-band images using Agisoft Metashape Professional (Agisoft LLC, St Petersburg, Russia). We used ground control points to anchor images to known coordinates. Prior to stitching, we visually inspected individual images for corruption, over- or under-exposure, blurriness, and obstruction. Following image stitching, we generated orthomosaics and rasters from single-band images for NDVI (Eq. 1),

$$NDVI = \frac{NIR-Red}{NIR+Red} \qquad \text{Equation 1}$$

where NIR is the light reflected in the near infrared wavelength (860nm in this case) and Red is the light reflected in the red wavelength (650 nm in this case), and NDWI (Eq. 2),

$$NDWI = \frac{Green-NIR}{Green+NIR} \qquad \text{Equation 2}$$

where Green is the light reflected in the green wavelength (560nm in this case).

Rasters of red edge, NIR, NDVI and NDWI were used in machine learning models to classify cover of the wetland and evaluate plant health. We used QGIS for spatial analysis and summary information and Python for generating machine learning models.

Machine learning model

A Random Forest machine learning model was trained using red-edge and NIR data (Table 1) and manually confirmed using RGB images. Another random forest model was trained to evaluate plant health using NDVI and NDWI (Table 2) based on values from the literature (Dupasquier & McDonald, 2025). Training data were collected from the first flight's images. These training sets were applied to the test set of the first flight's images and from images collected during the second flight.

Table 1. Training classes and ranges for plant type classifications (Pimentel, 2025).

Band/Index	Recognised Training Classes	Associated Value Range
NIR	Water/Non-Vegetation	0 - 0.07
	Submerged/Shallow	0.07 - 0.13
	Wetland Plant Type 1	0.13 - 0.20
	Wetland Plant Type 2	0.20 – 1
Red-Edge	Water/Non-Vegetation	0 - 0.08
	Submerged/Shallow	0.08 - 0.13
	Wetland Plant Type 1	0.13 - 0.20
	Wetland Plant Type 2	0.20 – 1

Table 2. Training classes and values for NDVI and NDWI (Pimentel, 2025).

Band/Index	Recognised Training Classes	Associated Value Range
NDVI	Water/Non-Vegetation	-1 - 0
	Submerged/Unhealthy	0 - 0.4
	Healthy Vegetation	0.4 - 1
NDWI	Healthy Vegetation	-1 - -0.15
	Submerged/Unhealthy	-0.15 - 0.20
	Water/Non-Vegetation	0.20 - 1

Finally, we evaluated accuracy scores and relative importance of bands for the models. Notably, the models were not ground-truthed in this study.

OUTCOMES / RESULTS

The models for health-based and type-based classification achieved good overall accuracy (Table 3). Kappa and Model Accuracy scores higher than 0.85 indicate a strong performance of classification in a random forest model (Talukdar et al., 2020). These models had Kappa and Model Accuracy scores above 0.999 (Table 3). NDVI was indicated as a relatively important index for classifying both cover and health, whereas red-edge was relatively unimportant (Table 3).

Table 3. Model accuracy scores and importance of bands and indices (Pimentel, 2025)

Model Name	**Health-Based Classification**	**Type-Based Classification**
Model Accuracy:	0.9996	1.0000
Kappa:	**0.9991**	**0.9999**
Band Importance:	NDVI: 0.4941 NDWI: 0.3653 NIR: 0.1494 Red-Edge: 0.0013	NIR: 0.4550 NDVI: 0.3341 NDWI: 0.1988 Red-Edge: 0.0121

The models showed high accuracy when the applied to the first flight's drone imagery (Figure 1), where the training data was sourced, with an overall model accuracy of 97.1% for the health-based classification model and 93.8% accuracy for the type-based model.

When applying the models to the second flight's imagery (Figure 2), the model accuracy decreased overall, with the health-based classification accuracy of 93.5% and the type-based classification model achieving just 65.7%. Large sections of misclassified types (e.g. unhealthy/submerged and submerged/shallow) can be seen in the sedimentation pond in the upper right section of each image (Figure 2). Although the health-based classification appeared to have high accuracy, this misclassification requires further analysis. For the type-based classification, it is recommended to include other sources of data, such as the digital elevation model, which may improve submerged and emergent vegetation classification.

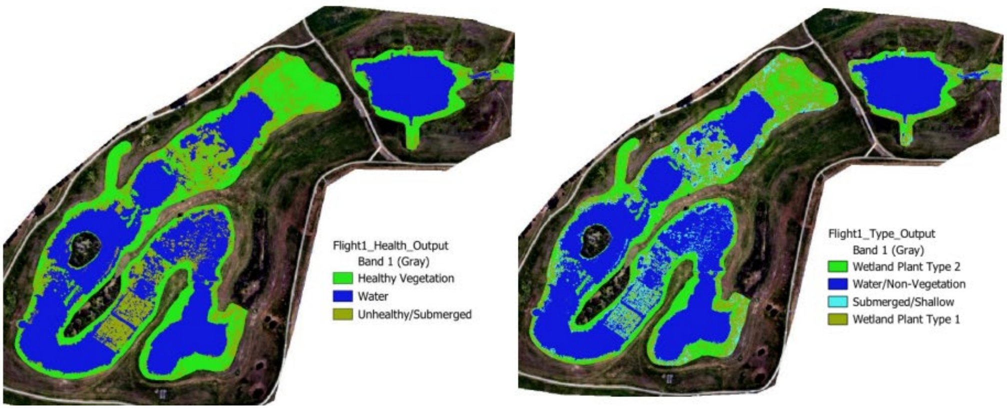

Figure 1. Health-based (left) and type-based (right) classification model outputs for imagery collected during first flight, which was used for training.

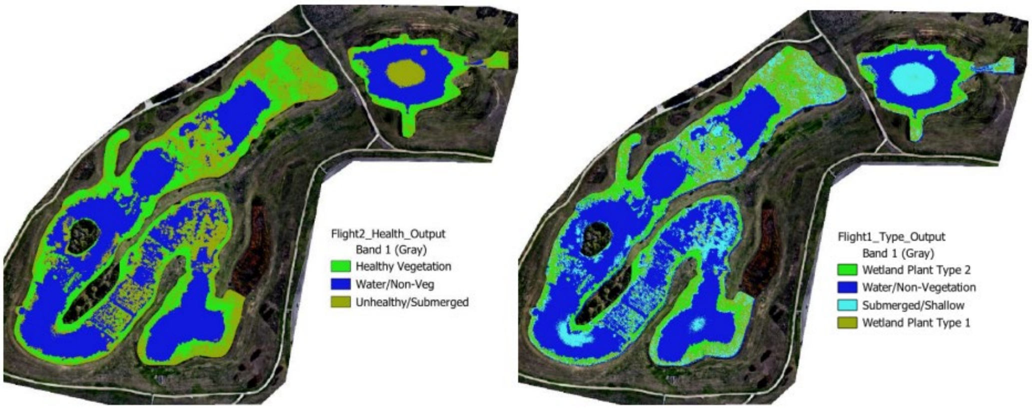

Figure 2. Health-based (left) and type-based (right) classification model outputs for imagery collected during second flight, which was used for testing.

CONCLUSIONS

A machine learning model classification of vegetation type and health showed that drone-based imagery can be used to monitor wetlands and may be helpful for detecting change. More work is needed to upscale drone imagery to high frequency satellite imagery and better understand temporal changes.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

This tool can be used to classify wetland vegetation types and plant health without requiring costly plot-based measurements. However, it is necessary to ground-truth this model and evaluate a wider variety of seasons and wetlands. This approach may also be useful in identifying invasive species.

This research contributes to the growing field of smart water infrastructure management by providing tools for vegetation monitoring that can inform adaptive management strategies. The findings suggest that drone-based multispectral monitoring can be effectively deployed as part of regular wetland assessment protocols, potentially reducing monitoring costs while increasing data resolution and coverage.

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Surveillance of Antimicrobial Resistance in Australian Wastewater and Air: Integrating National Trends and a Low-Cost Monitoring Tool

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Surveillance of Antimicrobial Resistance in Australian Wastewater and Air: Integrating National Trends and a Low-Cost Monitoring Tool

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Conference Topic: Creating Thriving Communities: Water and Liveability

INTRODUCTION

Antimicrobial resistance (AMR) is one of the most pressing global health threats, with the World Health Organization (WHO) projecting up to 10 million deaths annually by 2050 if left unaddressed. A cornerstone in tackling AMR is the surveillance of antimicrobial usage and dissemination routes of resistance genes. Wastewater-based epidemiology (WBE) has gained significant traction for monitoring population-level health indicators, including antimicrobial consumption and AMR burden. However, while WBE effectively captures waterborne signatures, it often overlooks other transmission pathways such as aerosols.

Wastewater treatment plants (WWTPs) are recognised not only as collection points for antibiotics and resistant bacteria but also as potential sources for airborne dissemination of antibiotic resistance genes (ARGs). Aerosols generated during wastewater treatment can carry ARGs into the surrounding environment, particularly during aeration and sludge processing. Despite the growing concern, airborne ARG monitoring is limited by high equipment costs and a lack of standardised tools.

This paper combines two complementary studies to address these knowledge gaps. First, a nationwide chemical surveillance study quantifying 102 antimicrobials across 50 WWTPs in Australia, representing ~50% of the population. Second, a pilot metagenomic study employing a 3D-printed, low-cost air sampler to investigate ARGs in aerosols and compare them with waterborne ARGs at a municipal WWTP. This integrated approach aims to (1) reveal AMR spatial trends and socioeconomic drivers and (2) evaluate ARG transmission dynamics between water and air media.

This study provides actionable insights for environmental microbiologists, public health agencies, and wastewater authorities seeking scalable, cost-effective AMR surveillance approaches across diverse settings.

METHOD / EXPERIMENTAL DESIGN

National Wastewater-Based AMR Surveillance Wastewater influent samples were collected on 10 August 2021 from 50 WWTPs spanning all Australian states and territories. These catchments collectively represent 11.3 million Australians. Samples were analysed via LC–MS/MS for 102 antimicrobials and transformation products (TPs). For population-level analysis, concentrations were converted to population-normalised mass loads

(PNMLs) using plant-specific inflow rates and population estimates. Detection frequency, concentration ranges, and exceedance of predicted no-effect concentrations (PNECs) for AMR selection were calculated.

To identify drivers of antimicrobial consumption, PNMLs for 33 commonly detected compounds were statistically correlated with matched 2021 Australian Census socioeconomic indicators. These included age, education, income, occupation, ancestry, transport modes, and housing conditions.

Airborne ARG Monitoring with a Low-Cost Sampler A 3D-printed active air sampler was constructed using readily available components. Multiple samplers were deployed around a Brisbane WWTP at key sites: above effluent discharge (Waterair), within the biosolids/sludge treatment area (PVair, GFair), and a commercial Bobcat sampler (BOair) was included for benchmarking.

Samples were collected over 24-hour periods. DNA was extracted (PowerWater Kit), sequenced (DNBSEQ-G99ARS), and analysed using fastp, metaSPAdes, and Kraken2/Bracken for microbial profiling. ARGs were annotated using ARGs-OAP 3.0 and CARD 3.2.1. PlasFlow and an MGE database were used to evaluate ARG mobility potential. Homology was assessed by BLAST comparison of contigs across sample types.

OUTCOMES / RESULTS

Antimicrobial Trends and Socioeconomic Drivers Out of 102 target compounds, 56 antimicrobials and TPs were detected in at least one sample. Thirty were detected in >50% of WWTPs. Amoxicilloic acid, cephalexin, and ciprofloxacin had the highest median PNMLs (Figure 1). Quinolones and β-lactams often exceeded PNEC thresholds, indicating a strong potential for AMR selection.

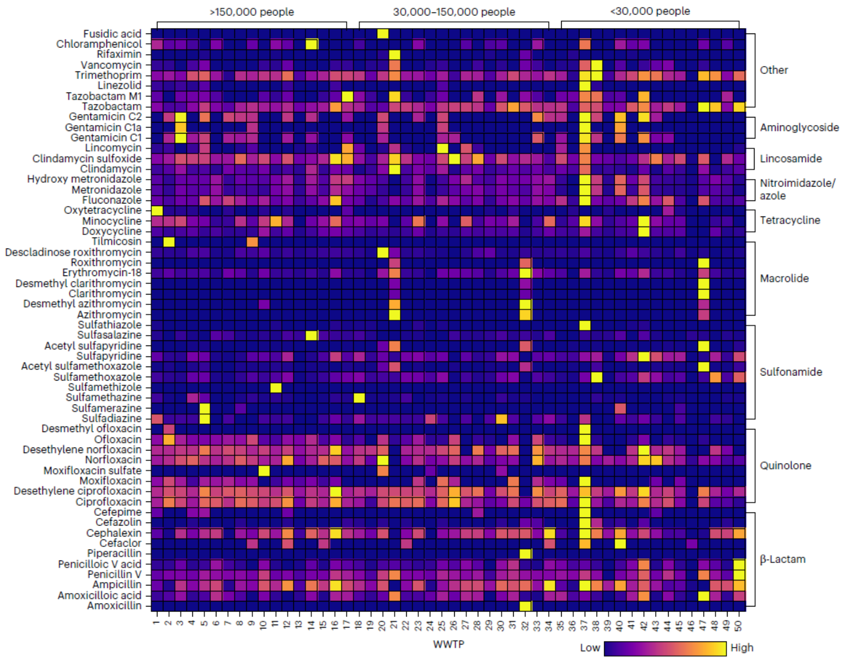

Figure 1. *Population-normalised mass loads (PNML) of selected antimicrobials across 50 WWTP catchments.*

Correlation analyses revealed stronger associations between antimicrobial usage and high-income, high-education, and densely housed populations. For example, ofloxacin showed a strong positive correlation with household income (R=0.66). Conversely, β-lactams and sulfonamides showed uniform distribution, likely reflecting prescription ubiquity.

Performance of Low-Cost Air Sampler The 3D-printed sampler equipped with glass fibre filters (GFair) outperformed both PVDF filters and the commercial device in terms of ARG recovery, microbial diversity, and contig coverage. GFair captured 301 ARGs vs 209 in BOair. Multidrug resistance genes (e.g., qacH, sul1) were most abundant (Figure 2).

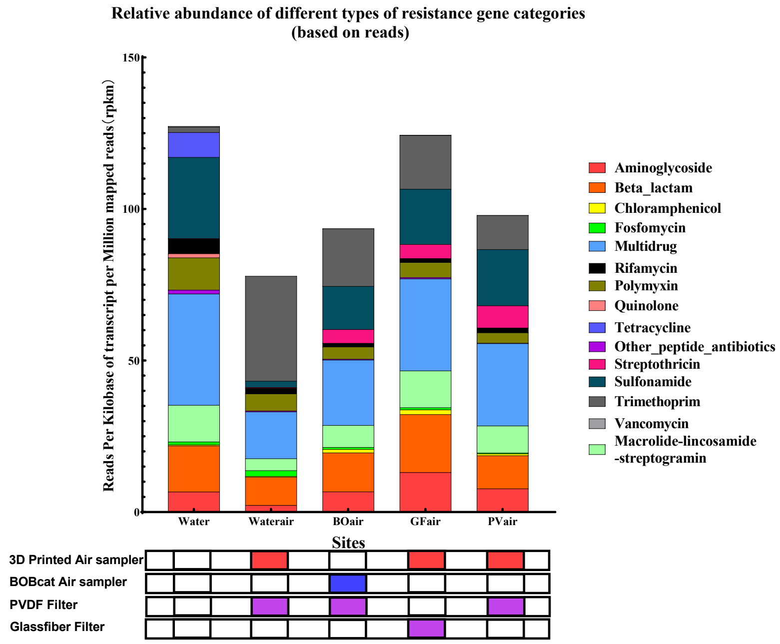

Figure 2. *Relative abundance and diversity of ARGs captured by air samplers at a municipal WWTP.*

Overlap of ARGs in Air and Water A striking 89% of ARG-containing contigs in Waterair matched those from the Water sample, confirming wastewater as a dominant source of airborne ARGs. GFair shared 42.7% of its ARGs with Water and 65% with Waterair (Figure 3). This supports the notion of ARG dissemination from sludge and water to ambient air.

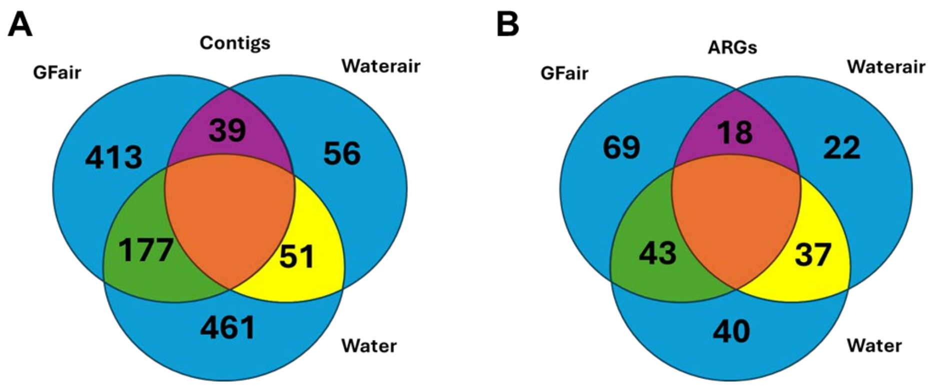

Figure 3. *Venn diagram showing overlap of ARG-carrying contigs among GFair, Waterair, and Water samples.*

ARG Transmission Potential Mobile Genetic Element (MGEs) including integrons, transposons, and plasmids were commonly detected in air samples, particularly GFair. Plasmid-associated ARGs such as *msrE* and *mphE* were found in both air and water, indicating cross-compartment mobility. Risk ranking showed that up to 36% of ARGs in Waterair belonged to WHO-defined level 1 or 2 categories (Figure 4).

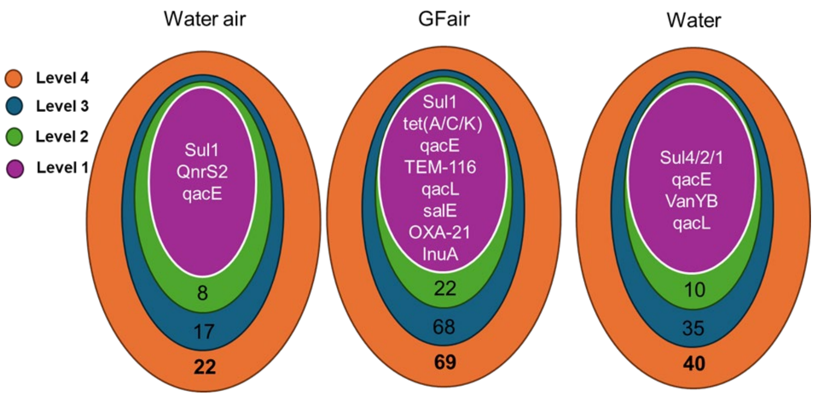

Figure 4. *Transmission risk levels of ARGs based on WHO framework and plasmid/MGE associations.*

CONCLUSIONS

This combined study provides novel, multi-media evidence of antimicrobial use and ARG dissemination pathways in Australian WWTPs. Nationwide wastewater surveillance offers a macroscopic view of population-level antimicrobial exposure and its socioeconomic determinants. In parallel, the airborne ARG analysis highlights the importance of including air as a significant but often neglected transmission route.

The low-cost air sampler successfully captured high-resolution ARG profiles, with performance comparable or superior to commercial tools. Homology and mobility analysis further suggest that air serves as a conduit for wastewater-derived ARGs, including those of high public health concern.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

By integrating WBE with airborne ARG surveillance, this work paves the way for a more holistic AMR monitoring framework in Australia. The validated low-cost air sampler makes it feasible to expand surveillance across remote or resource-limited regions, contributing to environmental justice.

On a policy level, this work supports the establishment of a national AMR surveillance network that includes both water and air pathways, with real-time capacity. It also highlights the need for socioeconomic equity in antimicrobial stewardship policies. Future research should focus on scaling up air sampling, integrating AI for exposure forecasting, and linking findings with clinical AMR trends under a One Health framework.

Empowering teams during systems upgrade via Tacit knowledge management and transfer

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Riding the wave of Resilience

INTRODUCTION

Christies Beach Wastewater treatment plant (WWTP) located 30 Km South of Adelaide Central Business District, South Australia is operated and maintained by SUEZ together with South Australian Water (SA Water) Corporation The plant was first commissioned in 1971, holding a capacity of 50,000 equivalent population (EP). This capacity was doubled in 1979, with further process changes made in 1994 to bring the plant capacity to 145,000 EP (45 ML/d). In 2012, the plant received another major upgrade, commissioning a Membrane Bioreactor Train (C plant) delivering enhanced nutrient reduction and water quality improvement. This new C plant comprised of 6 membrane trains (detailed in Figure 1), comprising of 2016 individual membranes enclosed within 42 membrane cassettes. Since commissioning in 2012, these membranes have reached their end of life based on an asset life between 8-10 years. With the membranes replaced in 2022-2023, an asset renewal program was subsequently launched.

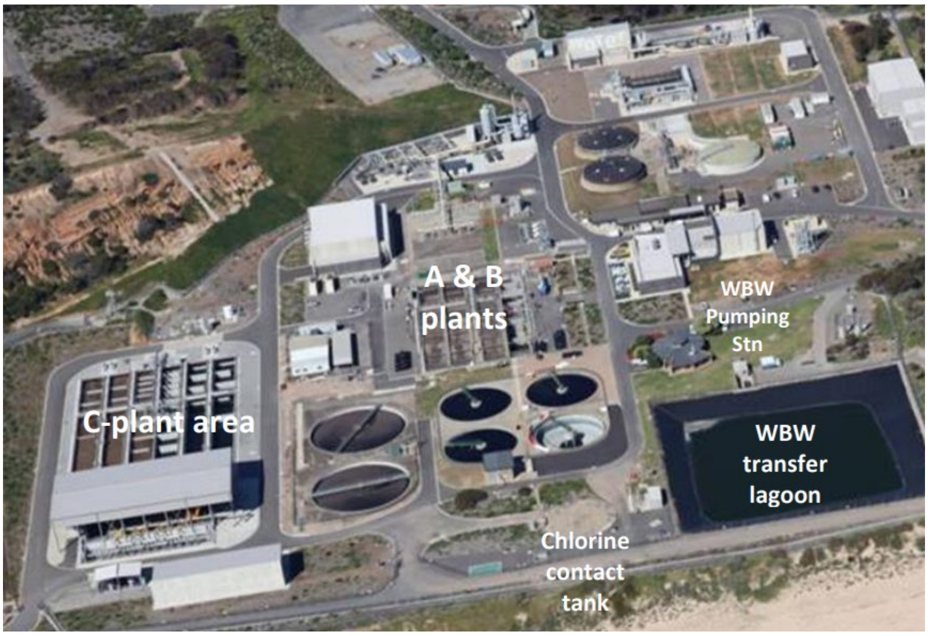

Figure 1- Overview of Christies Beach WWTP

Prior to their replacement, the membranes encountered multiple operational issues throughout their service life, including failures and trash accumulation. The membrane replacement project was designed to harness the in-depth operational knowledge to maximise the life of the replaced membranes, while additionally reducing the associated risks.

Employee training, which included membrane operations, maintenance and troubleshooting were identified as key aspects for future operation of the membranes – leading to the creation of a tailored process training program, thanks to the unique opportunity the membranes replacement project presented.

SUEZ together with SA water is committed to empowering its workforce and understands the importance of capturing explicit and tacit knowledge to reduce the loss of know-how, acquired through decades of experience. To address this, a dedicated "Knowledge Transfer Program" (KTP) has been developed to increase employee engagement and drive business outcomes. Knowledge trainings have been recently developed under the scope of this program to capture more tacit knowledge and provide the platform for problem identification and solving – helping build a more resilient workforce. With the unique opportunities for capturing tacit knowledge, the membrane training opportunity aligned within the scope of the knowledge transfer program and was scheduled for 2022-23 financial year delivery.

The key objectives for the training were defined as:

1. Capturing Tacit knowledge to develop future refresher trainings available on demand
2. Review the operational performance of the membranes over the previous 10 years
3. Overview of general operation principles of membranes
4. Visual inspections of the old membranes to identify signs of aging
5. Identify and document key signals of early failure

METHOD/EXPERIMENTAL DESIGN

The training scope was developed, which aligned to the needs of the operational staff. The method of Capture, Share, Utilize, Sustain (described in Figure 2) was the approach used to develop the program.

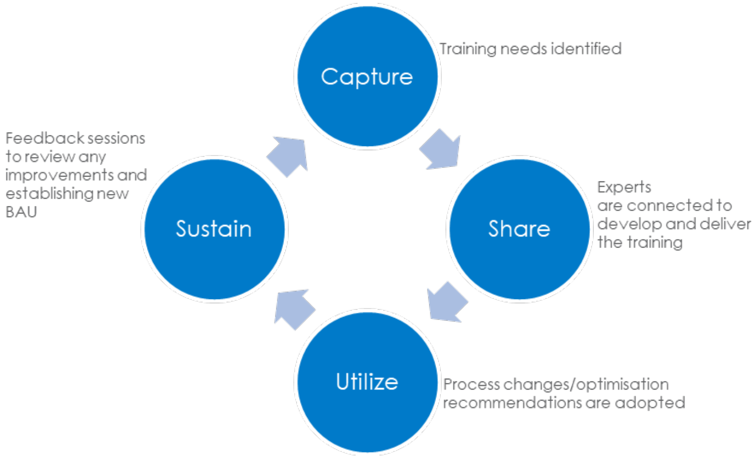

Figure 2- Training program development approach

Training needs were systematically identified through a series of consultations with operational staff. To select appropriate training delivery experts, relevant SUEZ global research centres were contacted to source a qualified training lead, who subsequently liaised with local teams to develop and tailor the training materials. The training was developed into three major modules:

1. **Recorded Theory Session**: The training was recorded as a video with the target duration of approximately 60 minutes. This theoretical training session focussed on the fundamentals of membrane filtration and operations and maintenance troubleshooting guide. The recorded training session was then delivered onsite by the lead and site Engineer and attended by the all the operational teams at Christies Beach WWTP.
2. **Site specific session**: Following the first theory session, site specific data was provided to the delivery lead who then adapted the training to be specific for the Christies Beach membranes. To enhance the delivery, a live on-site session with the training lead was held on a day when the membranes were extracted from the bioreactors. This session also included live inspections alongside the freshly extracted membranes. These inspections brought together the membrane manufacturers, delivery leads and plant managers to train the operational staff visually.

3. **Feedback and review**: Following the second session, a detailed action plan was developed to follow up on after the install of the new membranes.

OUTCOMES / RESULTS

The prerecorded theory sessions formed a baseline of expectation for the following site-specific sessions. It refreshed the basic understanding of membrane operations and maintenance and provided a refreshed troubleshooting guide. It also provided measurable approaches to identifying early signs of failures and presented actions to mitigate such situations to occur less frequently.

The live training sessions delivered results based on the 11 years online monitoring over the entire age of membranes – establishing a baseline for new membranes. This provided a list of critical operational parameters and defined Key performance Indicators (KPI's) for ongoing online monitoring. A detailed technical action plan was developed as detailed in Figure 3.

Based on your last 11y feedback of membrane operation, proposed action plan:

- ❑ Update of the membrane surface in the SCADA: 12331,2 m²/train
- ❑ Update of the Backpulse, maintenane and recovery backpulse (see proposed table)
- ❑ Update permeat flow triggered SP (see proposed table)
- ❑ Physical measurement and modification of the tube for LIT sensors cables
- ❑ Update of the TMP/permeability calculation be the PLC
- ❑ Modification of the PLC to distinguish backpulse & mantenance cleaning BP flow
- ❑ Adjust of schedules and the chemical dosage of the maintenance citric acid cleaning
- ❑ Restart the early signs of process failures
  - ❑ Once a month: trash, VCF, sludge filtrability, ΔUV,
  - ❑ Every 3 days with a:b plant: SVI + inspection of le liquid
  - ❑ During chemical cleaning: membrane inspection, at least position A + a additional one
- ❑ Recovery cleaning :
  - ❑ No more manual trash removal: « live with trash! »
  - ❑ Proceed to the desludging procedure to wash the membrane TK before chemical dosing (drainage, refill, aeration, ..etc)
  - ❑ Monitoring of pH, chlorine during the soaking duration
  - ❑ Write a report : data sheet to be produced (Lp before/after, chemical dosage before/after soaking duration, temperature) / use of aquadvanced?
- ❑ Update of Aquadvanced Widgets

Figure 3- Detailed action plan

New cleaning and recovery procedures, along with a host of Programmable Logic Controller (PLC) modifications were developed and recommended, with the most insightful training module proving to be the inspections and captured learnings from the live membrane extraction. This particular session brought the operators together to inspect the extracted membrane module form the bioreactor with operational staff using their expertise to support the development of the recorded training modules.

The tacit knowledge videos developed throughout this training included Sludge filterability methods, routine visual inspection guides, method of the Delta Chemical Oxygen Demand (COD) test and Mixed Liquor Suspended Solids (MLSS) trash content measurement methodology. A still from one of the videos training videos is captured in Figure 4.

Figure 4- A still from the live MLSS- filterability method demonstration

CONCLUSIONS

The team appreciated the theoretical knowledge gained, the opportunity to obtain live demonstrations for different methods and tips for future monitoring and early failure detection. The monitoring program will continue and the changes in membrane performance will be documented as the new procedures and learnings are implemented. Most importantly, the training program developed key operational skills and prepared the operations team to navigate future disruptions whilst capturing valuable tacit knowledge. The training has been well received by the business and the wider SUEZ community, with the process to be replicated for future applications

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

The training outcomes go far beyond a one-off training session as they are designed for long term use by teams and individuals, making them far reaching too. The site inspections and recorded live demonstrations from the training lead, membrane manufacturer and the plant managers will be readily accessible for the teams/staff to view on demand, ensuring the shared knowledge is easily accessible. These sessions have successfully captured the knowledge of these experts along with their hands on experience from the live demonstrations. This training will not only benefit the company in obtaining the best asset life of the membranes and but will improve the employee engagement experience by offering new ways to absorb knowledge in a practical setting.

Fostering Workforce Resilience by Bridging Operational Excellence and Capital Delivery for the Next Generation

Mr James Gourley[1]
[1]Sydney Water

Fostering Workforce Resilience: Bridging Operational Excellence and Capital Delivery for the Next Generation

James Gourley[1], ASM Mohiuddin[1] Zoe Heytman[1] Ben Blayney[1]
[1]Sydney Water Corporation, Parramatta, NSW, Australia

Introduction

Many Australian water utilities, including Sydney Water, are operating in an increasingly complex and high-pressure environment. Climate change is driving more frequent and severe events—droughts, bushfires, and floods—that degrade raw water quality and place sustained pressure on treatment systems. At the same time, the sector faces compounding challenges: ageing infrastructure, workforce shortages, rising performance expectations, tighter regulation, and a retiring workforce critical to operational continuity. Difficulty retaining skilled staff at operating sites has also increased psychosocial hazards.

Sydney Water is also delivering a large-scale capital program over the next decade. While essential, this investment brings new challenges, including the need to operate and maintain a broader range of assets and technologies. These pressures demand a workforce model that supports infrastructure delivery and ensures teams are ready to operate and maintain emerging technologies from day one—while reducing psychosocial risks.

Sydney Water has responded with an 'Integrated Water Hub' workforce model within its Water Supply & Production group. In this model, engineers, scientists, and project interface managers work in centralised technical teams but are outposted to three water treatment hubs, collaborating directly with site-based operators. This enables real-time support, trust-based relationships, and rapid mobilisation of expertise during routine operations and extreme events.

Adding complexity, some of Sydney's Water Filtration Plants (WFPs) are operated by long-term private partners—SUEZ, TRILITY, and Veolia. These mixed operating models require strong coordination, consistent standards, and shared knowledge. Through shared staffing and close collaboration, Sydney Water has established integrated support across all plants, ensuring operational alignment, mutual learning, and a system-wide approach to performance, risk, and resilience.

Method

To support operational resilience and capital delivery, Sydney Water's Integrated Water Hub model has established the following interconnected strategies and practices.

Integrated Incident Response

By embedding engineers within operational teams, strong relationships are built through daily collaboration. These established connections enable rapid, effective incident response, as engineers already understand each plant's context and challenges.

Integrated Science and Technology Programs

Sydney Water's R&D program, developed over 25 years, follows an integrated model where engineers and operators collaborate closely. This ensures innovations like the SWIFT model (Figure 2)—which automates chemical dosing and optimises filter performance under variable raw water conditions—are designed with operational needs in mind.

Joint Maintenance & Project Delivery Programs

A five-year integrated maintenance plan is collaboratively developed and maintained by engineers and operators across treatment plants, networks, and the catchment authority. This joint approach ensures coordinated execution of maintenance and capital projects, while maintaining continuity of water supply through unified team efforts.

System Wide Water Quality Management

In our integrated water hubs, we manage water quality from catchment to customer through a unified team overseeing raw water supply, treatment performance, and network quality. This system-wide approach brings together the expertise of engineers, operators and water quality scientists to enable informed decision-making, delivering optimal water quality and cost efficiency for customers.

System-Wide Risk Management

The engineering team leads a standardised annual risk assessment process (Figure 3) across all filtration plants and networks, involving operations, asset management, planning, and external partners. Their integration with operations enables practical insights and accurate documentation of system-wide risks.

Capital Delivery Integration

Project Interface Managers (PIMs) embedded in operational hubs maintain daily visibility of plant performance and challenges. Their role bridges frontline knowledge and capital delivery, supporting early design input and aligning investments with operational risks (Figure 4) to deliver more operable, maintainable assets.

Workforce Development and Capability

The Integrated Water Hub model supports early-career engineers by embedding them in operational environments while connecting them to central technical teams. This accelerates learning, builds networks, and fosters a deep understanding of treatment performance across diverse contexts. It also promotes continuous improvement and innovation, as engineers are empowered to implement practical solutions in real time.

Additionally, the model embeds knowledge transfer into daily operations, helping mitigate the impact of an ageing workforce.

Partner Collaboration and Process Network

Sydney Water's model enables delivery and operational partners—including SUEZ, TRILITY, and Veolia—to operate as a unified team. Shared engineering resources and quarterly technical forums support knowledge exchange, consistent standards, and coordinated risk responses.

In integrated hubs, where both Sydney Water and private partners operate plants, a single operations meeting enables joint performance review and drives collaborative innovation.

Outcomes

The Integrated Water Hub model has delivered measurable improvements in operations, capital alignment, and workforce capability.

Improved Incident Response

Close collaboration between engineering and operations has enabled Sydney Water to manage several extreme water quality events. Tools like the SWIFT model (Figure 2), developed through Integrated Science and Technology Programs, have supported real-time optimisation. For example, during the 2022 flood event, engineers used SWIFT to help the Orchard Hills WFP maintain supply to over 300,000 customers despite severe raw water deterioration (Figure 6).

Faster Technology Adoption

The integrated model's emphasis on early engagement has accelerated the adoption of new technologies. Engineers and operators jointly trial, commission, and optimise new systems, ensuring smoother transitions and long-term operability.

Integrated operational, maintenance and capital delivery planning

Through the Joint Annual Maintenance Program and Capital Delivery Integration, Sydney Water now aligns capital, operational, and maintenance planning across the network. This coordination improves system performance, reduces risk, and delivers cost efficiencies.

Risk-Driven Capital Alignment

Over 400 risks and 700 actions have been identified and consolidated through the risk assessment process, creating clear links between operational challenges and capital investment priorities. Standardised scoring and deep operational input have improved transparency and alignment across a complex system.

Fit-for-Purpose Planning & Project Delivery

Embedding Project Interface Managers, as described in Capital Delivery Integration, ensures operational insights inform every stage of project development. This alignment results in assets that are more operable, maintainable, and aligned with long-term risk reduction.

Faster Workforce Readiness

The Workforce Development and Capability strategy has accelerated the readiness of early-career engineers. Through hands-on exposure to operations and critical events, new engineers are contributing to optimisation and emergency response within 6–12 months (Figure 5).

Improved Sector Collaboration

As highlighted in Partner Collaboration and Process Network, shared training, technical forums, and joint innovation initiatives have strengthened cross-sector alignment. These partnerships support consistent approaches to optimisation, incident response, and risk management.

Together, these outcomes validate the Integrated Water Hub model as a resilient, adaptable, and strategically aligned approach to meeting the evolving challenges of the water industry.

Conclusions

Sydney Water's Integrated Water Hub model demonstrates how embedding technical expertise within frontline operations enables a smarter, more connected, and resilient approach to managing drinking water systems. It breaks down silos across incident response, risk management, and capital delivery, while shared structures with external partners ensure consistency across a complex value chain.

This integrated approach drives better water quality and cost outcomes, while helping Sydney Water remain agile and innovative in the face of climate pressures, infrastructure demands, and workforce challenges. It also strengthens the utility's ability to deliver its capital program with greater speed and assurance.

What's Next – How Will This Help Build Resilience?

The Integrated Water Hub model is central to how Sydney Water is future-proofing its operations. As the sector faces rising climate risks, complex stakeholder demands, and rapid technological change, this model provides a blueprint for resilient, adaptive service delivery. Key next steps include:

- Expanding digital tools like SWIFT and integrating them into operational training.
- Evolving in-house training to support diversity and succession planning.
- Applying operational knowledge earlier in project life cycles to boost capital effectiveness.
- Deepening collaboration with delivery partners to enhance cross-utility knowledge exchange.

By maintaining a system-wide view while empowering local teams, Sydney Water is equipping its workforce to thrive amid uncertainty — and lead the sector in building resilient, responsive water systems.

Acknowledgement

The authors acknowledge the cooperation of Sydney Water's internal teams and external partners SUEZ, TRILITY, and Veolia in implementing this integrated workforce model.

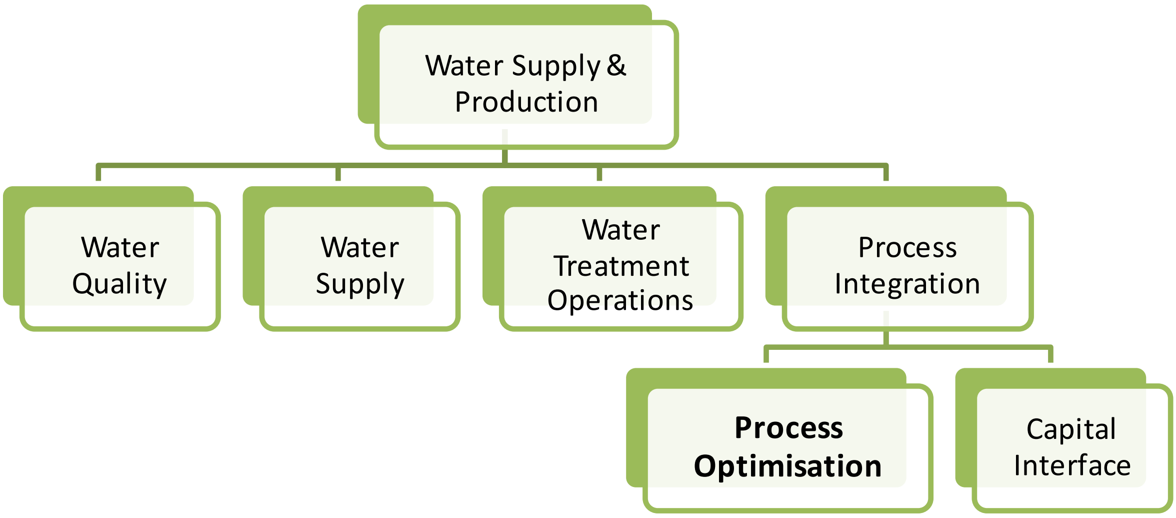

Figure 1: Sydney Water - Water Supply & Production 'Integrated Water Hub' model.

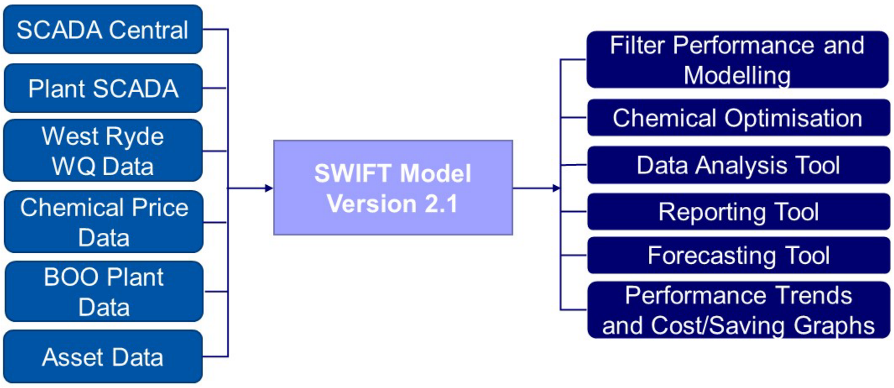

Figure 2: Structure of the SWIFT model developed for real-time plant optimisation.

Figure 3: Risk management framework showing system-wide assessment integration.

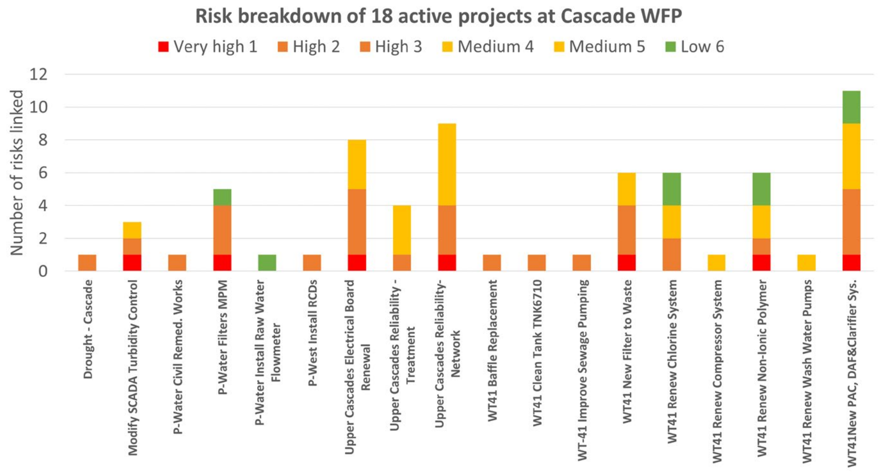

Figure 4: Summary of risk linkage to capital planning via the CAP tool.

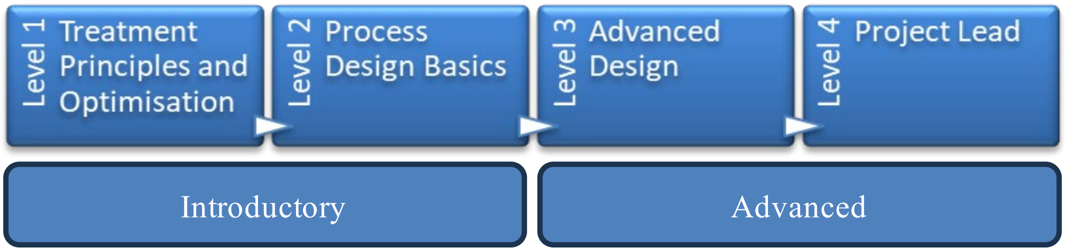

Figure 5: Structure of the internal training and mentoring program.

Warragamba Dam spill, July 2022

Warragamba Dam water quality degradation, post July 2022

Figure 6: Extreme water quality challenges during the 2022 Orchard Hills incident response.

171

A resilient water supply requires a resilient operator workforce.

Dr Kathy Northcott[1]
[1]Veolia Anz

A resilient water supply requires a resilient operator workforce.

Conference Topic

Theme 1 Empowering a Resilient Workforce

MODERATOR:

- Kathy Northcott, Veolia ANZ, Sydney, NSW, Australia

PARTICIPANTS:

- Lisa Andersons, NSW Department of Climate Change, Energy, the Environment and Water (NSW DCCEEW)
- Peter Thomas, Yarra Valley Water
- Andy Salveson and Brian Bernados, CalVal

IDEAS TO BE PRESENTED, DEVELOPED AND DISCUSSED:

Main contents of the workshop/panel. Include:

- **The WaterRA Project 1139 – Technical Competency Benchmark** was designed to facilitate the development, delivery and maintenance of appropriate training and skills needed for frontline water industry operators. A Benchmark Report and Audit Tool provides guidance for regulators, regulatory auditors, and water utilities, relating to the technical competency of water industry operators.

- **Competency Benchmark application to develop a Trainee Development Plan.** At Yarra Valley Water (YVW) the Benchmark assisted in aligning training with regulatory requirements, as well as including elements that focus on YVW strategy. A formal training matrix was also developed and implemented within the People, Performance & Culture (PP&C) framework.

- **Competency Benchmark – a national approach with state implementation**. NSW DCCEEW has worked with stakeholders to implement key elements of the national benchmark for local water utilities in NSW. These projects demonstrate a collaborative approach to addressing water industry operator training needs, while raising awareness and promoting fit-for-purpose learning and development programs for the benefit of the water industry.

- **International approaches to achieving technical competency of water industry operators**. The need for well-trained operators for purified recycled water (PRW) systems in California is significant. The California Water Environment Association, the Cal-Nevada AWWA, and the Water Research Foundation, all with the oversight of California regulators, saw this need well ahead of time, and developed an entire program for the Advanced Water Treatment Operator (AWTO). California now has an AWTO job requirement and job needs, detailed training materials, and three grades of AWTO certification testing.

GENERAL STRUCTURE OF THE WORKSHOP/PANEL:

Water Research Australia led the development of a National Technical Competency Benchmark to address the need for a more consistent approach towards operator training needs, as well as raise awareness and promote the need for more fit-for-purpose learning & development programs.
This workshop will present the experience of regulators and utilities in implementing the benchmark and identify future initiatives to build a highly skilled and resilient operator workforce. The workshop will also

explore the need for programs to support the skills and training needed to operate advanced treatment plants with multiple highly technical treatment processes:

1. Introduction to the panel - A resilient water supply requires a resilient operator workforce. (5 mins)
2. WaterRA Project 1139 – Technical Competency Benchmark. (10 mins)
    a. Benchmark implementation – Veolia case study
3. Panel presentations:
    a. Peter Thomas (YVW) - Benchmark application to develop a Trainee Development Plan (10 mins)
    b. Lisa Andersons (NSW DCCEEW) – The Technical Competency Benchmark – a national approach with state implementation (10 mins)
    c. Andy Salveson, Brian Bernados (CalVal) - International approaches to achieving technical competency of water industry operators (20 mins)
4. Panel discussion/ audience Q&A (30 mins)
5. Acknowledgements and closing words (5 mins)

LINKS TO RESEARCH

Technical Competency Benchmark for Water Industry Operators: https://www.waterra.com.au/project/water-operations-technical-competency-benchmark/

Kiep Benang - Water for Tomorrow

Dr Stacey Hamilton[1], Mrs Collene Castle[2], Mr Josh Whiteland[3], Mr David Hughes-Owen[1], Dr Richard Walley OAM

[1]Busselton Water, [2]Wonnil Partner, [3]Koomal Dreaming

Title of Full Paper

Keip Benang – Water For Tomorrow
Mr Josh Whiteland, Mrs Collene Castle, Mr David Hughes-Owen, Dr Stacey Hamilton, Dr Richard Walley OAM.

Conference Topic

Integrating Indigenous Wisdom: Pathways to Resilience

INTRODUCTION

Busselton Water operates in *Wadandi Noongar Boodja* (country). The Wadandi water story is the connection of *Wadandi Noongar moort* traditional families to the six Noongar seasons which sustain life, foods, and the songlines of *gabbi boodja* water country.

Each season represents a subtle, yet powerful shift in nature's cycles. The 6 seasons within the Wadandi water story is reflected in Figure 1, with a brief description of the seasons below:

Birak (December – January) is the first summer and the season of the young. It is extremely dry and hot weather. Colours of the season are green, blue, orange and yellow.

Bunuru (February- March) is the second summer and the season of adolescence. It is the hottest part of the year. Colours of the season are yellow, orange and red.

Djeran (April – May) is the season of adulthood, when the cooler weather begins. Colours of the season are red, brown and grey.

Makuru (June – July) is the season of fertility with the first rains. It is the coldest and wettest part of the year with frequent gales and storms. Colours of the season are grey and black.

Djilba (August – September) is the first spring and the second rains and is the season of conception. The season is a mix of wet days, cold clear nights and pleasant warm days. Colours of this season are black, blue and green.

Kambarang (October – November) is the second spring, the wildflower season and the season of birth. The season consists of longer dry spells weather wise. Colours of the season are blue and green.

Figure 1: Keip (water) the element of life (artist Natalie Clark from Djrliny Designs), representing the 6 Noongar seasons.

Busselton Water is the local water provider based in Busselton, a major regional centre 220 kilometres south of Perth, Western Australia. The South West region of WA is rapidly growing in population as well as being a renowned tourist destination over the summer period creating challenges for our water supply.

Busselton Water has developed an Integrated Water Service Plan (IWSP) which presents a strategic, forward-looking approach to securing the region's long term water resilience. With the increasing population growth, seasonal tourism demand and climate variability placing pressure on local fresh water (gabbi) sources, the IWSP provides a structured and adaptive response to ensure a sustainable, efficient and environmentally responsible water future. A key feature of the IWSP is "Keip Benang" Water for Tomorrow and recognises our journey to incorporate reconciliation principles and cultural engagement into our future water supply planning. The IWSP also builds on our commitment to a culturally grounded and respectful approach to working with local Wadandi community to recognise their traditional role as custodians of the water and land which we operate in.

The IWSP focuses on optimising existing infrastructure, diversifying water supply sources, managing demand effectively, and integrating climate resilience measures. These priorities align with state and national sustainability goals and will support Busselton's continued economic growth while ensuring the long-term security of its water resources.

METHOD/EXPERIMENTAL DESIGN

Kaart Koort Waarnginy (Head, Heart, Talking) Aboriginal Engagement Framework developed by Dr. Richard Walley OAM was adopted by Busselton Water for the IWSP. The Kart Koort Waarnginy Framework (Figure 1) is built around six principles:

Building Relationships and Partnerships by fostering trust and mutual respect with the Wadandi First Nations communities through active collaboration and inclusion in decision-making processes.

Promoting Employment Opportunities by creating economic pathways and meaningful job opportunities for First Nations people through construction contracts and engagements.

Cultural Recognition and Heritage Promotion by honouring and educating about Wadandi First Nations' culture and heritage to bridge cultural understanding gaps.

Supporting Professional Development through empowering First Nations individuals and communities by fostering personal and professional growth.

Providing Technical Advice and Support through enhancing the success of First Nations Suppliers and Corporations by offering tools and advice for tender bids and project delivery.

Continual Cultural Awareness Development by promoting ongoing cultural awareness within the project team to embed understanding of Wadandi Noongar culture and the reconciliation process.

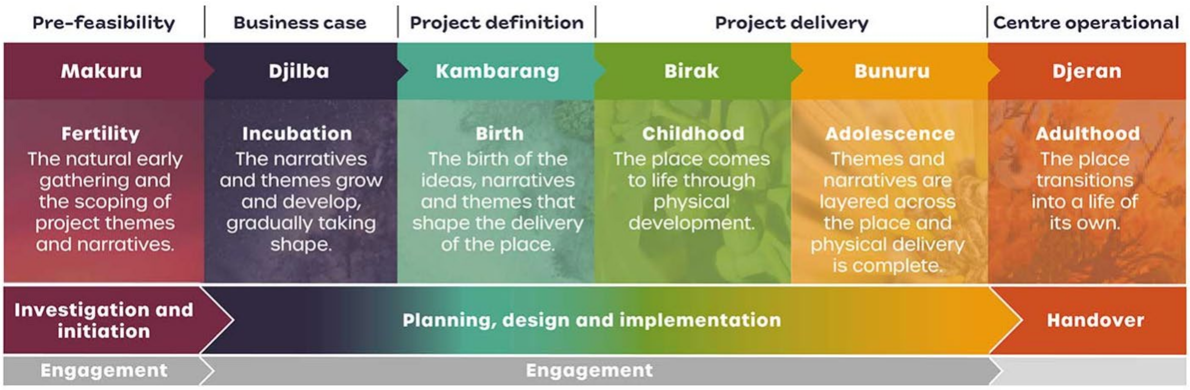

Figure 1: Kart Koort Waarnginy Framework (6 Seasons Framework).

Kaart Koort Waarnginy represents a pivotal shift towards meaningful and respectful dialogue between Aboriginal people and organisations or agencies, particularly in the context of project engagement and development in Western Australia. This approach acknowledges the need for mutual respect, shared understanding, and collaboration, aligning with a philosophy of genuine cultural engagement.

To evaluate stakeholder acceptance of the proposed measures and adaptive strategies, stakeholder engagement was paramount to ensure the IWSP reflected community needs and regulatory priorities. A workshop was held in October 2024 with community and business stakeholders as well as governmental and regulatory agencies to provide feedback on the proposed IWSP.

The workshop provided an overview of the rapid changes affecting the South West region, particularly rising temperatures and consequent increase in water demand amid declining rainfall. Busselton Water highlighted its upcoming challenges to maintain supply due to these changes.

Direct feedback was provided from the workshop which ensured the proposed measures in the IWSP aligned with immediate and medium-long term water security goals. This feedback shaped the IWSP's recommendations, particularly in defining alternative water supply options, demand management strategies, and climate adaptation pathways. The IWSP was released in May 2025.

OUTCOMES / RESULTS

Community engagement and respect for Aboriginal values are integral to Busselton Water's strategy, with the IWSP a key document for the future for water security. Long term water security strategies highlighted in the IWSP will enhance resilience against future supply constraints. Any projects to enable Busselton Water to diversify its water sources highlighted in the IWSP will ensure project planning is aligned with the Kaart Koort Waarnginy Framework. Embedding the Kaart Koort Waarnginy Framework into the IWSP offers a culturally grounded, respectful approach to working with Aboriginal and Torres Strait communities. Strengthening climate resilience will mitigate risks associated with water scarcity, while ongoing community engagement will ensure that water management strategies remain equitable, transparent, and inclusive.

CONCLUSIONS

The IWSP was published in May 2025 and the roadmap for implementation includes short (2025 – 2027), medium (2028 – 2035) and long-term (2035 and beyond) strategies. Busselton Water is taking steps towards embedding reconciliation principles in the IWSP by implementing *"Keip Benang"* Water for Tomorrow practices. The journey has only just begun, and Busselton Water will continue to contribute to advancing positive outcomes for Aboriginal and Torres Strait Islander people and the broader community with delivering our IWSP outcomes.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

The IWSP presents a proactive approach to securing water for future generations while safeguarding the region's natural assets. Through collaborative planning, technological innovation, and policy alignment, the plan sets a foundation for sustainable water use, incorporating conservation and efficiency measures to optimise current resources.

An Improved Method for Modelling Solar Brine Evaporation

Dr Bruce Atkinson[1], Mr Benjamin Croxon[2], Mr Nathan Dick[1]

[1]Beca HunterH2O, [2]Tamworth Regional Council

An Improved Method for Modelling Solar Brine Evaporation

Bruce Atkinson[1], Benjamin Croxon[2], Nathan Dick[1]

1. Beca HunterH2O 2. Tamworth Regional Council

Conference Topic

Optimising resilient water supply systems

INTRODUCTION

Management of brine and salt process residuals from RO projects at inland locations is particularly challenging. Lagoon evaporation rates are substantially lower than published pan evaporation rates; brine evaporates more slowly than fresh water; and the rate of evaporation decreases as salinity increases.

A proposed Water Purification Facility (WPF) for Tamworth in regional NSW, purifying up to 12 ML/d, will require brine management.

Ultimately, the problem is not necessarily the liquid brine, but the salt arising from that brine. In an ideal world, brine, or its components would be reused. However, brines resulting from municipal or industry recycling, or groundwater desalination, are of mixed salts, meaning that a wide range of different elements and compounds are present.

For a project such as the WPF, there is no current option but to treat the brine through to concentrated or moist salt, and store that salt indefinitely.

For the WPF, thermal concentration (zero liquid discharge, ZLD) would accelerate the evaporation process, but in this case, the lagoon volume is driven by having sufficient emplacement volume to accommodate 50 years of salt production. Thus, even if the evaporation aspect were to be separately managed, the lagoon volume just to accommodate resulting salt would remain the same, leaving no advantage to ZLD.

The published guideline for design of solar evaporation ponds is from AWWA, 2019[1] as summarised in Table 1.

Table 1 AWWA Manual 69 approach to estimating net brine evaporation rate

Factor	Purpose as applied to Net Average Evaporation (Pan A Evaporation less rainfall)
0.70	Caters for the difference between lagoon evaporation of fresh water versus Class A pan evaporation
0.70	Salinity Factor: caters for the difference between saline water aeration rate and fresh water evaporation rate
0.83	"Safety Factor"
0.41	Overall factor applied to net average evaporation rate

While this approach notionally caters for the difference between evaporation rate of saline versus fresh water, it does not account for the progressive reduction in evaporation rate as the brine concentrates, and nor does it cater for the granularity of daily and seasonal impacts.

Lagoons have to be constructed to minimise risk to environment, and so a minimum of dual-layer containment is required inclusive of underdrains and leak detection. The construction of solar evaporation ponds is an

[1] Bond, R. and Sethi, S. (2019), "Discharge Options for Concentrate Disposal", American Water Works Association, Manual M69, Chapter 4.

expensive exercise, and the WPF lagoons are designed with three layers of lining, including 300 mm of clay and two HDPE liners.

Due to the very large cost (~30% of the total project budget), it is critical to get the design correct to ensure sufficient capacity for evaporation while avoiding regret capital. It is not readily possible to stage construction of brine lagoons because they operate in a rotating fill and evaporate cycle, meaning that the other lagoons need to be available as each one fills, long before each has evaporated sufficiently to accommodate another fill cycle.

METHOD/EXPERIMENTAL DESIGN

An experiment was devised to measure actual progressive brine evaporation rate through a full evaporation cycle for the geographic location of Tamworth. Table 2 lists the two configuration options which were considered. It was decided to conduct the experiment using a 30,000L PE tank. The tank wall height was 2.7m, allowing a 2.4m commencing brine depth.

Table 2 Evaporation experiment options

Option	Advantages	Disadvantages
Small-scale lined earthen lagoon (1:4 batter on internal walls) emulating full-scale depth Minimum area requirement 35 x 35 m	Emulates full-scale configuration and lining Eliminates shading on lagoon	Average depth much lower than full-scale (dominated by shallow-angle lagoon walls) High construction cost including netting to preclude bird access and perimeter fencing to preclude animal and personnel access Large salt quantity to establish experiment (large water volume) High remediation cost – earthworks and salt disposal. More difficult access to instrumentation at full-depth location
Tank emulating full-scale depth	Low cost (PE tank) Earthen insulation accommodated by providing earthen surround to tank Small land area (10 m x 10 m) Easy access to instrumentation at full depth Minimum tank area to net. Minimum land area to fence.	Need to maintain minimum of 300 mm tank wall freeboard for storm events – leading to some tank shading. {shading minimised by progressively cutting down tank wall whilst maintaining minimum freeboard}

It was originally planned that a tankerload of mixed-salt brine (5 to 8% salt) from an operating desalination site would be used as the starting point for the experiment. However, that did not turn out to be possible, and instead a starting concentration of 4.4% salt was made-up on-site using pool salt. The tank was instrumented with a level transmitter and brine temperature transmitters located at three separate depths. A local weather station was installed adjacent the tank, allowing full-time online access to the weather and tank instrument data. Figures 1 and 2 show the initial installation and subsequent cut-down.

Figure 9 Initial brine tank installation December 2023 (in-ground 0.6m, 2.1 m above ground) showing dedicated weather station (left) and rain gauge (foreground)

Figure 10 Second wall cut-down February 2025. Brine level visible inside tank, 300mm below new wall height.

OUTCOMES / RESULTS

A daily timestep model was created better understand the long-term operation of the brine lagoons over an anticipated 50 years of operation. This utilised the SILO gridded climate data[2] set with daily timesteps from 24/11/1970 to 24/11/2024. That data set is a comprehensive database providing daily meteorological datasets in ready-to-use formats for research and climate applications.

Three approaches were taken to modelling evaporation which included adjusting both daily pan and Moreton Lake evaporation rates for salinity by factors of 0.775[3] and 0.83[4] respectively, and creating a regression model based on the first year of measured data from the experiment and the daily timestep SILO data set. The Scikit-learn Python library[5] was utilised to implement and compare the results from a range of regression models with a 'gradient boosting model' showing the best correlation and R^2 value of 0.90 and mean squared error of 2.8 mm/d.

As the concentration in the brine tank has only risen from 4.4% salt to 6.4% salt in the process of evaporating from 2400 mm level to 1650 mm level, there are insufficient data thus far to confirm the impact of salinity upon evaporation rate. The evaporation model therefore assumes a factor of (100 – volume % salt)/(100-initial volume % salt) to estimate the progressive reduction in brine evaporation rate relative to its current measured evaporation rate.

The daily timestep model was run using various daily brine production rates and total dissolved solids (TDS) concentrations to consider the impact of the various evaporation rates. Table 3 shows an overview of a

2 Queensland Treasury and BoM. "SILO Grid Point." CSV. Accessed January 3, 2025. https://www.longpaddock.qld.gov.au/cgi-bin/silo/PatchedPointDataset.php?station=55003&format=standard&start=20100101&finish=20241121&username=noemail@net.com&dataset=Official&comment=standard.

3 Oroud, I. M. "Effects of Salinity upon Evaporation from Pans and Shallow Lakes near the Dead Sea." *Theoretical and Applied Climatology 52*, no. 3 (September 1, 1995): 231–40. https://doi.org/10.1007/BF00864046.

4 Department Biodiversity, Conservation and Attractions, 2023, "Long-term salinity changes in the wetlands and lakes of southwest Australia".

5 Pedregosa, Fabian, Gaël Varoquaux, Alexandre Gramfort, Vincent Michel, Bertrand Thirion, Olivier Grisel, Mathieu Blondel, et al. "Scikit-Learn: Machine Learning in Python." *Journal of Machine Learning Research* 12, no. 85 (2011): 2825–30.

scenario for brine inflows of 250 m³/d of TDS of 80,000 mg/L, assuming the past 50 years of weather data. The maximum lagoon volume showed a lower sensitivity to evaporation values as it was largely driven by rainfall.

Table 3 Overview of modelling scenarios

Parameter	Unit	Pan	Pan	Moreton Lake	Regression Model
Co-efficient	-	1	0.775	0.83	-
Feed Volume	m^3/d	250			
Feed TDS	mg/L	80,000			
Lagoons	n	4			
Low Lagoon Volume Scenario					
Surface Area at TWL	m^2 per lagoon	48,850			
Volume at TWL	m^3 per lagoon	124,000			
Max Volume	%	96.4%	100.2%	98.3%	99.0%
Mean Net Q	m^3/d	5.09	5.35	5.17	5.23
Max Net Q	m^3/d	4810	4930	4970	4860
Min Net Q	m^3/d	-800	-628	-373	-442
High Lagoon Volume Scenario					
Surface Area at TWL	m^2 per lagoon	59,220			
Volume at TWL	m^3 per lagoon	153,000			
Max Volume	%	77.9%	81.8%	79.8%	80.4%
Mean Net Q	m^3/d	5.02	5.31	5.13	5.17
Max Net Q	m^3/d	5710	5800	5850	5720
Min Net Q	m^3/d	-887	-761	-445	-522

This is reinforced by the highest daily net inflow (Q = brine inflow + rainfall – evaporation-overflow) within the 50-year modelling period representing approximately 4% of the total lagoon volume in a single day, and 10% of lagoon volume for a cumulative major rain event. This represents a significant risk for overflows to occur towards the end of operational life and reinforces the need for minimum freeboard (500 mm allowed in this case). Salt accumulation in the lagoons was incorporated into calculation of instantaneous available volume. Figure 3 shows how consumed lagoon volume was modelled to vary for the final selection, and demonstrates the impact of two major rain events during the 50-year period.

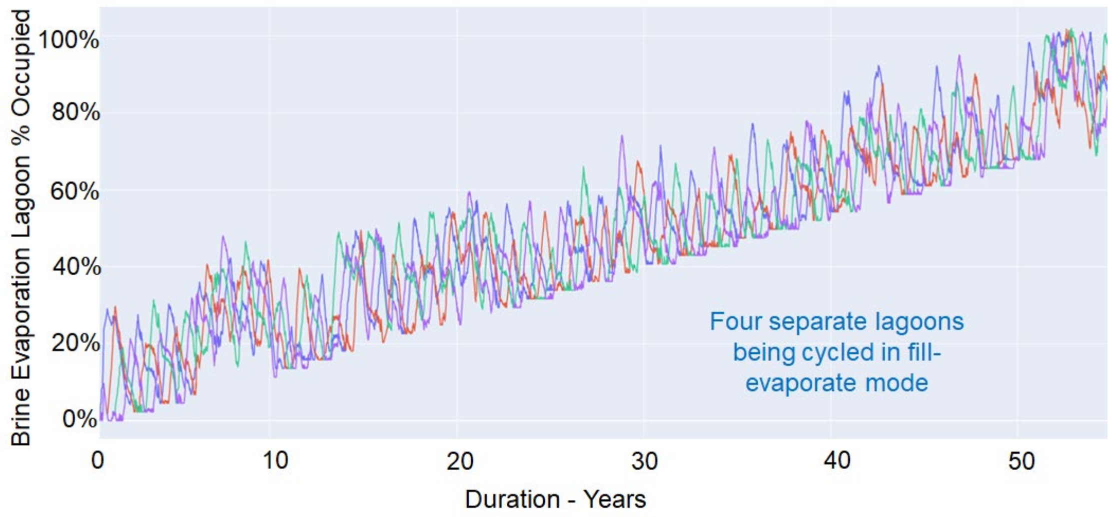

Figure 11 Modelling Outcome for 220 m³/d brine, 4 x 170ML lagoons, 3.0m TWL

CONCLUSIONS

The experiment will not be complete until the brine fully evaporates to concentrated salt, however preliminary data have served a useful purpose to update the brine lagoon sizing for business case development.

Originally, the brine lagoon design included four (4) x 135 ML lagoons. However, as a result of the data assessment thus far, applied to the past 50 years of actual recorded weather, the design has been updated to four (4) x 170 ML lagoons. While that is a significant increase, the incremental additional cost at time of construction will be much lower than what the cost would be if retrospective additional (urgent) construction were to be required after the scheme was in operation.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

As the experiment progresses, the latest-available data will allow the model to be refined before lagoon design parameters are finalised. While this project is based in Tamworth, the model developed will be able to be applied to any location providing that its detailed weather data are available.

PROBLEMATIC MICROALGAE AND CYANOBACTERIA COMMUNITIES WITHIN DRINKING WATER TREATMENT PLANTS ACROSS EASTERN AUSTRALIA

Dr Daisy (Xiaoran) Chu[1], Dr Fitri Widhiastuti[1], Dr Arash Zamyadi[2], Dr Bojan Tamburic[1], Dr Nick Crosbie[3], Dr Deb Gale[4], Dr Steven Newham[5], Professor Rita Henderson[1]

[1]UNSW, [2]Monash Univerisity, [3]Melbourne Water, [4]Seqwater, [5]Goulburn Valley Water

PROBLEMATIC MICROALGAE AND CYANOBACTERIA COMMUNITIES WITHIN DRINKING WATER TREATMENT PLANTS ACROSS EASTERN AUSTRALIA

Chu X.[1], Widhiastuti F.[1], Tamburic B.[1], Zamyadi A.[2], Crosbie N.[3], Gale D.[4], Newham S.[5], Henderson R.K.[1]

Conference Topic

Optimising Resilient Water Supply Systems

INTRODUCTION

The growth and accumulation of nuisance and harmful algae and cyanobacteria within drinking water treatment plants (WTPs) have been observed and reported both in Australia and worldwide. This phenomenon poses significant challenges to water treatment efficiency and water recycling, particularly when the cells produce toxins and taste and odour compounds, or when cells are reintroduced to the water inlet due to internal sludge supernatant recycling.

To identify effective mitigation strategies for algal and cyanobacterial accumulation within WTPs, with a focus on processes downstream of pre-treatment, an analysis of available historical datasets was conducted. This study aims to understand the composition of algal and cyanobacterial communities within 16 WTPs across Eastern Australia. The commonly detected algal and cyanobacterial genera from the raw water inlet (e.g., inlet to WTPs) and downstream of treatment (e.g., post-treatment, sludge lagoons, supernatant) were identified and compared.

Despite inconsistent sampling frequencies across the 16 WTPs, the existing data indicated that cyanobacterial genera had the highest cell concentrations both before and after treatment. Some green algae and diatoms were also frequently detected across different WTPs. However, community variations differed from plant to plant, likely due to different treatment techniques and operational conditions, warranting further analysis and correlation studies in the future.

METHOD/EXPERIMENTAL DESIGN

To elucidate changes in algal and cyanobacterial communities across WTP units, cell populations were sampled at various treatment stages, including source water, raw water inlet, post-treatment, sludge thickeners, backwash tanks, and supernatant return. Samples were characterised based on detection frequency and cell concentrations, with cell concentration (cells mL^{-1}) being the most consistently reported parameter. Consequently, this study reports on cell concentrations.

Historical datasets from different WTPs, spanning 10 to 30 years, were analysed. New columns were added to standardise taxonomic ranks (genera, classes, phyla) across all plants. The top 20 most frequently detected genera were identified, and their average cell concentrations were visualised using heatmaps. For post-treatment datasets, all recorded genera were included in the heatmaps.

OUTCOMES / RESULTS

Community analysis on raw water inlets to water treatment plants

The algal and cyanobacterial community was analysed for all raw water inlets to the 16 WTPs (Figure 1). A total of 83 different genera were recorded, with the top 20 most frequently detected genera identified across all WTPs. Specifically, cyanobacteria (*Planktolynbya, Pseudanabaena, Aphanocapsa*), green algae (*Oocystis, Monoraphidium, Scenedesmus, Chlorococcoids, Chlamydomonads*), diatoms (*Urosolenia, Synedra, Centrales, Aulacoseira*) and Charophyta (*Staurastrum*) were the most commonly recorded genera from the raw water intake of more than eight out of 16 WTPs. Among these, *Planktolyngbya, Aphanocapsa*, *Oocystis, Monoraphidium* and *Aulacoseira* were the most commonly identified in the raw water intake of more than 11 out of 16 WTPs.

In addition to the most common phyla- cyanobacteria, green algae and diatoms- Cryptophytes and Charophytes were also frequently observed in the raw water inlets of more than 11 plants (Figure 2-phyla-level analysis). In terms of cell concentrations, the highest average cell concentrations were found for certain cyanobacteria genera, including *Synechococcales, Cyanogranis, Chroococcales* and *Cyanonephron*, with concentrations approximately 10^6 cells mL^{-1} in the raw water inlets (Figure 1).

Community analysis on the water samples within water treatment plants

The algal and cyanobacterial communities present within, or in the effluent of, the WTP unit operations were less frequently measured compared to the raw water inlet. Therefore, the opportunity for data comparison across 16 WTPs is limited and has been undertaken only on the currently available data. In the provided data, the terms for the samples included "settled water", "post-treatment" and "post-filtration", with samples taken from different locations after the treatment train in various WTPs. Given this ambiguity, Figure 3 combines all data marked as "settled water", "post-treatment", and "post-filtration" from multiple plants, reporting all of these as "within treatment train" samples for simplicity to enable community comparison with the influent to the plant.

The most commonly detected genera within the treatment train were cyanobacteria *Pseudanabaena* (5 out of 7 WTPs) and *Planktolyngbya* (5/7), both filamentous genera. Interestingly, some green algae (such as *Chlorococcoids* and *Oocystis*) and diatoms (such as *Aulacoseira*) were also seen to survive treatment (Figure 3). The highest averaged cell concentrations found within WTPs were still the cyanobacterial genera, including *Synechococcales, Planktolyngbya, Dactylococcopsis, Cyanonephron* and *Aphanizomenonaceae*, with approximately 10^4 cells mL^{-1} average cell concentrations. The existing data indicate that cyanobacteria cells were still the most dominant within the treatment train for most WTPs, followed by green algae, then diatoms and cryptophytes.

However, when comparing individual WTPs, the community composition changes between the raw water inlet and the treated water varied significantly from plant to plant. For example, in WTP8, the raw water inlet was dominated by cyanobacteria and diatoms (Figure 2), whereas the samples within the treatment train were dominated by green algae (Figure 4). Similarly, in WTP2, the raw water was dominated by cyanobacteria (Figure 2), but the treated water within the WTP showed an equal dominance of both cyanobacteria and green algae (Figure 4). These observations indicate that different plant designs, including treatment methods, operational design, and hydrodynamics, may play a crucial role in the selective removal of certain phyla or genera over others. This highlights the necessity of analysing community changes in each WTP throughout individual treatment units and building correlations with the treatment techniques used and hydrological conditions to suggest the best mitigation methods.

CONCLUSIONS

The analysis of algal and cyanobacterial communities in 16 drinking water treatment plants across Eastern Australia identified 83 frequently detected genera. Cyanobacteria, green algae, diatoms, and Charophyta were the most commonly detected in both raw water inlets and post-treatment samples. These findings provide a comprehensive overview of the prevalent algal and cyanobacterial populations and highlight the varying effectiveness of different WTPs in targeting specific genera. The detection of these common genera downstream of treatment revealed their persistence through existing treatment processes, underscoring the need for more extensive monitoring programs and the identification of effective mitigation methods.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCE

The next steps for this project include: i) identifying the problematic algal and cyanobacterial build-up locations within WTPs, ii) conducting a detailed analysis of community changes within each WTP and correlation studies on community dynamics, selective removals, and operational conditions in the context of drinking water treatment, and iii) based on the outcomes of these correlations, proposing both proactive and reactive engineering strategies to enhance the resilience of drinking water treatment plants against algal and cyanobacterial challenges.

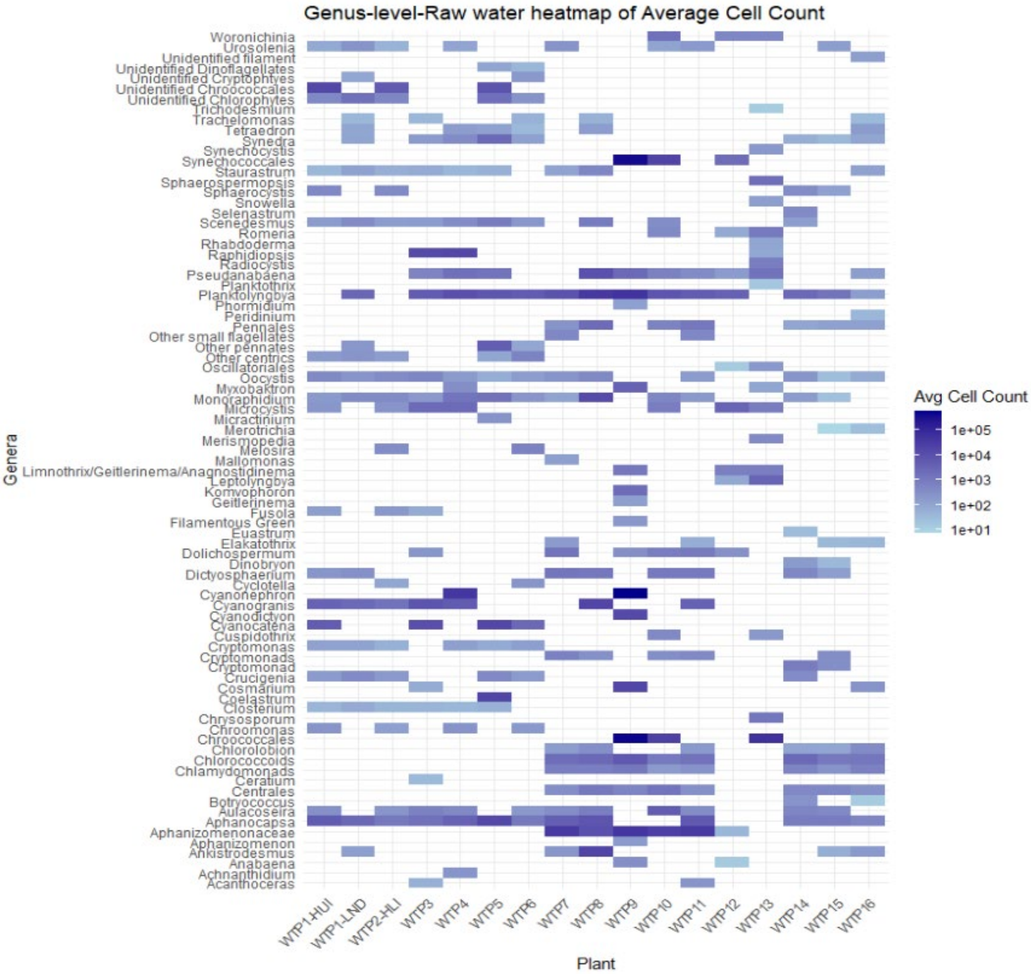

Figure 1. *Top 20 frequently detected genera from raw water intake in 16 water treatment plants and their average cell concentrations, represented in light to dark blue colours (out of a total of 83 genera).*

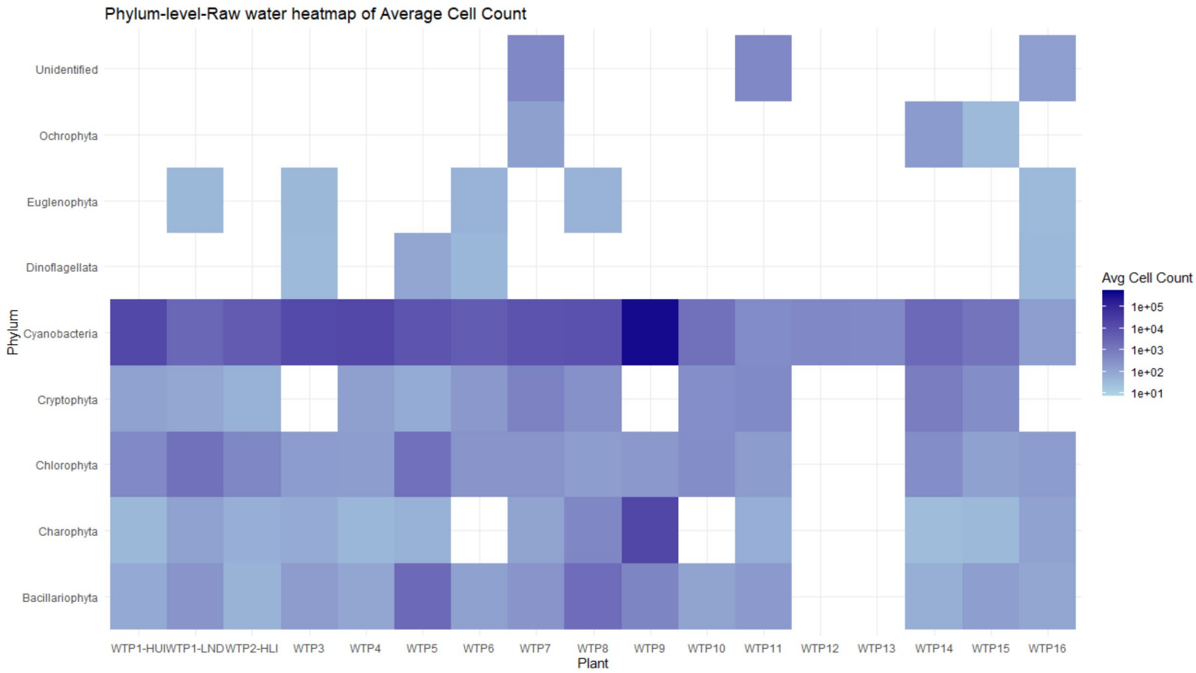

Figure 2. *Phylum-level analysis of the top 20 frequently detected genera from raw water intake in 16 water treatment plants and their average cell concentrations, represented in light to dark blue colours.*

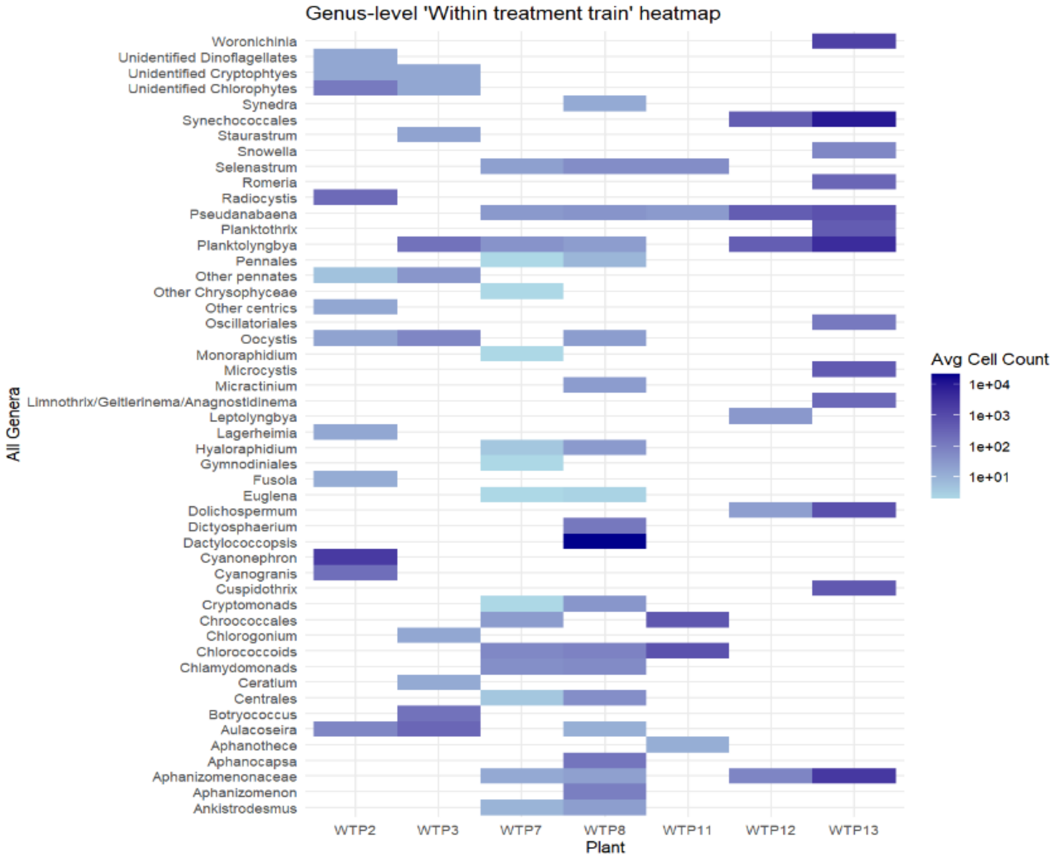

Figure 3. *All genera recorded "Within treatment train" and their average cell concentrations. The dataset includes sampling data reported as "settled water," "post-treatment," and "post-filtration" from all available data across 16 water treatment plants (total of 50 genera combined). Average cell concentrations are represented in light to dark blue colours.*

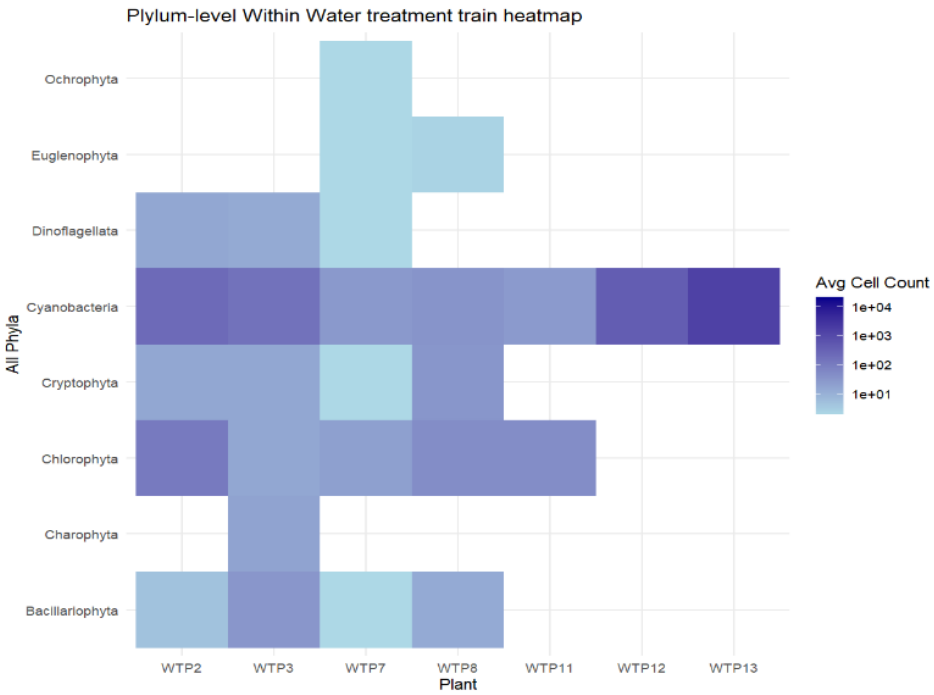

Figure 4. *Phylum-level analysis of the genera "Within treatment train", and their average cell concentrations, represented in light to dark blue colours.*

Purified recycled water public outreach and education: Successes and lessons learnt from the US and globally

Ms Danielle Francis[1]

[1]Water Services Association Of Australia

Purified recycled water public outreach and education: Successes and lessons learnt from the US and globally

Conference Topic

Optimising Resilient Water Supply Systems

MODERATOR:

- Danielle Francis, Manager Customer & Policy, Water Services Association of Australia

PARTICIPANTS:

- Andy Salveson – Water Reuse Chief Technologist Carollo Engineers, USA. Former Water Reuse Person of the Year (USA) & first award winner of Bahman Sheikh Award.
- Brian Bernados – former water quality Regulator in California, USA, now consultant.
- Clare Porter, Head of Strategic Communications and Corporate Social Responsibility, Sydney Water
- Nanda Altavilla, Principal Policy Officer, NSW Department of Climate Change, Energy, Environment & Water (or alternative representative of NSW DCCEEW)

IDEAS TO BE PRESENTED, DEVELOPED AND DISCUSSED:

Main contents of the workshop/panel. Include:

- Rationale

With various water utilities in Australia/New Zealand now actively exploring PRW for the future, and others considering it for down the track – it is critical for them to have a good understanding of some key issues to consider. Globally, PRW projects can fail if they approach community engagement the wrong way, so this session will be a vital overview of key considerations. We will hear from US experts who have lived through multiple real projects and whose experience is extremely helpful for Australia.

- Learning Expectations

Attendees can expect to come away with an understanding of the most important 'to dos' of PRW, plus some 'not to dos' from people with real world experience. They will also learn about some key resource tools available locally and globally.

- Outcomes

Attendees will have an enriched understanding about where to begin if they are contemplating PRW in future. They will also have resources and contacts they can follow up with. They can also apply these learnings to all other aspects of community engagement on water quality and safety including PFAS, desalination and more.

GENERAL STRUCTURE OF THE WORKSHOP/PANEL:

(Assuming it's a 90 minute session):

5mins: Intro by Danielle

10 mins: Andy Salveson – overview of experience / perspectives, projects involved in

10 mins: Brian Bernados – overview of experience / perspectives of a regulator in California observing successes and learnings on PRW projects

10 mins: Danielle Francis – global maps of the update of PRW & learnings

10 mins: Clare Porter – overview of Sydney Water journey

10 mins: NSW DCCEEW guest – overview of NSW Recycled Water and PRW Roadmap

15 mins: Moderator pre-prepared discussion questions

20 mins: Audience Q&A

LINKS TO RESEARCH

www.water360.com.au/map/

WSAA's Purified Recycled Water toolkit

The Californian Reuse Journey towards a Resilient Water Supply

Mrs Suzanne Sharkey[1]

[1]NWRI

Purified Water and the Journey to a Resilient California Water Supply

Conference Topic

Theme 2: Optimizing Resilient Water Supply Systems

MODERATOR

Kevin M. Hardy, JD, National Water Research Institute

PARTICIPANTS

- State of California Division of Drinking Water (presenter TBD)
- Lydia Holmes, PE, Carollo Engineers
- Mike McCullough, MPA, Monterey Peninsula Water Management District
- Andrew Salveson, PE, Carollo Engineers
- Shane Trussell, PhD, PE, Trussell Technologies
- California State Water Board Division of Drinking Water (TBD)

IDEAS TO BE PRESENTED, DEVELOPED AND DISCUSSED

Rationale. Purified Recycled Water (PRW) is a critical component of the State of California's integrated planning to sustainably provide healthy and abundant water for all Californians. PRW projects produce 200 MLD of water today, and developing projects will result in more than 800 MLD of purified water in the next 10 to 15 years. With more than a dozen projects permitted and another dozen in late stages of implementation, PRW has emerged as a solution of choice for our thirstiest communities. The Panel will provide an insider look at PRW's journey to social legitimacy and the development of the Golden State's PRW regulatory regime. Into this context, the Panel will explore human and environmental health themes common to PRW projects through a deep dive into emerging science and standards for catchment management and enhanced source control in the PRW context. The Panel will examine established PRW programs and their influence on the development and application of California's leading-edge PWR treatment and monitoring systems. Panel remarks will conclude with an integrating case study from the Monterey Peninsula. We also look forward to audience Q&A.

Learning Expectations

1. Practical understanding of how PRW is implemented and regulated in California.
2. Awareness that catchment management is a critical public-health issue in PRW.
3. Knowledge of PRW treatment trains and monitoring systems used in California.
4. Appreciation for California's emerging PWR implementation success matrix.

Outcomes

1. Achieve better clarity on California's journey to, and current challenges with, PRW.
2. Introduce attendees to resources they can use to grow their brand and practice.

3. Have fun, make a new friend, and find gratitude in our shared experiences.

GENERAL STRUCTURE OF THE WORKSHOP/PANEL

1. **An Overview of Water Reuse in California (20 min) – Kevin Hardy (NWRI)**. California has developed PRW from modest projects in the 1960s to multi-billion-dollar projects today. These projects include spreading of tertiary recycled water, injection of PRW, augmentation of lakes with PRW, and now, direct potable reuse. Examples of each project will be profiled, along with a discussion of engineering, public, and regulatory challenges and solutions.

2. **Managing Environmental and Health Risk: Catchment Management (30 min) Lydia Holmes and Andy Salveson (Carollo Engineers).** In the context of PRW, utilities must understand and manage the source water inputs into treatment plants from trade waste customers (industrial and business), residential customers, and unknown uncontrolled inputs. A disciplined, methodical, and comprehensive approach is essential to enable utilities to effectively manage feed water quality challenges, understand impact on treatment processes, and engineer treatment and diversion approaches to ensure the provision of safe drinking water. Water Research Australia (WRA) Project 3056 will build upon the existing Australian wastewater quality management guidelines and the Enhanced Source Control Program framework established in the USA. The framework proposes specific uniform guidelines among all utilities engaged in PRW, thereby making it easier for regulators and utilities to minimize water quality risk. Case studies of PRW catchment management efforts will be detailed and progress on Water RA 3056 will be provided. Digital surveys will be used to solicit feedback and perspective from NextWater conference attendees.

3**. Indirect and Direct Potable Reuse Treatment Trains and Public Health Protection (20 min) – State of California Division of Drinking Water (two speakers).** California is seen as an example for PRW success. That success is based upon years of careful study and conservative regulation of treatment and monitoring systems. California's regulations will be reviewed, and example projects will be discussed, highlighting the treatment and monitoring systems necessary for regulatory compliance.

4. **A One Water Approach to Ensure a Resilient Water Supply(20 min) – Mike McCullough (Monterey Peninsula Water Management District) and Shane Trussell (Trussell Technologies).** One water is a core concept in Monterey California, where for years high quality tertiary water has been provided to agriculture. Recently, Monterey has developed a parallel PRW scheme, providing critical potable water supply to their groundwater aquifer while also sustaining the non-potable reuse program.

LINKS TO RESEARCH

California Reuse Projects: WSAA Global Connections Map
https://wsaa.asn.au/Web/Web/News-and-Resources/Resources/Map-of-the-35--cities-using-purified-recycled-water-for-drinking.aspx

Catchment Risk
Water Research Foundation Project 4960: An Enhanced Source Control Framework for Industrial Contaminants in Potable Reuse
https://www.waterrf.org/research/projects/enhanced-source-control-framework-industrial-contaminants-potable-reuse

Water Research Australia Project 3056: **Enhanced Source Water Monitoring for Purified Recycled Water**

Potable Reuse Treatment and Public Health
Water Research Foundation Project 5277: Cal-Val Guide to Treatment Credits for Indirect Potable Reuse in California
https://www.waterrf.org/research/projects/cal-val-guide-treatment-credits-indirect-potable-reuse-california

Researching Emerging Contaminants (RECON) monitoring program for the Eastern and Western Treatment Plants: Passive Sampler Program - soluble micropollutants in recycled water and raw sewage.

Dr Kathryn Hassell[1], Dr Jackie Myers[2], Dr Erica Odell[2], Dr Sara Long[2], Professor Vin Pettigrove[2], Dr Hao Nguyen[3], Dr Nick O'Connor[4], Dr Nick Crosbie[5]

[1]RMIT University (Applied Chemistry and Environmental Science), [2]RMIT University (AQUEST Research Group), [3]National Measurement Institute, Department of Industry, Science and Resources, [4]Ecos Environmental Consulting, [5]Melbourne Water Corporation

Researching Emerging Contaminants (RECON) monitoring program for the Eastern and Western Treatment Plants: Passive Sampler Program - soluble micropollutants in recycled water and raw sewage.

Conference Topic

Optimising Resilient Water Supply Systems: Key Focus Areas: Innovations in stormwater management, advanced treatment technologies (Waterval), and tackling emerging water quality challenges like chemicals of concern.

INTRODUCTION

To advance our knowledge of what types of chemicals are retained in recycled water after treatment, a collaborative research project was initiated between Melbourne Water and EPA Victoria, with funding provided through Water Research Australia. The project, entitled “Researching Emerging Contaminants (RECON) monitoring program for the Eastern and Western Treatment Plants” involves comprehensive chemical monitoring of hundreds of emerging contaminants in recycled water, raw sewage and biosolids. The project is being led by Ecos Environmental Consulting, and RMIT University led the passive sampler monitoring program. This paper presents findings from the passive sampler monitoring program only.

In Melbourne, Victoria, there are two major sewage treatment facilities: the Eastern and Western Treatment Plants (ETP and WTP), which treat over 90% of Melbourne’s sewage. Both treatment plants are managed by Melbourne Water and receive a mixture of domestic, commercial and industrial wastewaters. The Eastern Treatment Plant uses advanced tertiary processes including ozone, biological filters, ammonia, ultraviolet light and chlorine to produce Class A recycled water. The Western Treatment Plant uses anaerobic and aerobic lagoon treatment to produce Class C recycled water, followed by ultraviolet light and chlorine treatment to produce Class A recycled water. Recycled water is sewage wastewater that has been through a treatment process sufficient to meet standards set by regulators – in this case EPA Victoria and the Department of Health. The quality of recycled water, and the allowable uses for it are categorised into three different classes: Class A, B and C (EPA Victoria, 2021). Treatment standards for recycled water are based on meeting water quality objectives for pH, turbidity, biological oxygen demand (BOD) and suspended solids (SS), as well as pathogen log reduction values for bacteria, viruses and protozoa (EPA Victoria, 2021). For hazards and risks associated with metals, metalloids and organic chemicals, the EPA Victorian Guideline for Recycled Water refers to The Australia and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018). The ANZG guidelines provide default guideline values for over 160 toxicants in freshwater, which identify a concentration below which no ecological impacts would be expected. However, there are currently no guideline values for several pesticides, pharmaceuticals and personal care products that may be associated with sewage wastewater. These chemicals, collectively referred to as emerging contaminants, or contaminants of emerging concern (CECs) are often present at very low concentrations and therefore can be difficult to detect using standard sampling and analytical methodologies. To address this need, an online decision support tool called ECHIDNA (Emerging Chemicals Information Database for National Awareness), has been developed to assist with classifying and prioritising CECs for potential risks to human health and the environment (Leusch, et al., 2021).

Passive samplers are monitoring devices that provide a time-integrated measurement of the emerging contaminants present in water, which enables detection of chemicals that are present at very low concentrations and may not be detected by conventional grab water sampling. Usually, passive samplers are deployed for 1-4 weeks and will absorb and concentrate chemicals to levels that are easily detectable by analytical chemistry. Different types of passive samplers can be used to target different types of chemicals and can provide valuable information on a wide range of emerging contaminants. A recent study conducted by the EPA Victoria reported 126 emerging contaminants detected by passive samplers in sewage influents and effluents from 31 treatment plants around Victoria (Saaristo et al., 2023). The aims of this study were to measure soluble organic micropollutants (emerging contaminants) in recycled water and raw sewage from 6 sites managed by Melbourne Water. This information allows identification of which emerging contaminants are present in different types of recycled water, and to inform options for managing any risks associated with the intended reuse options for this valuable, alternative water resource.

METHOD/EXPERIMENTAL DESIGN

Recycled water was sampled from fast flowing channels (raw sewage), storage ponds (Class C) and final effluent directly from a piped supply (Class A) at both ETP and WTP. For Class A sites, the passive samplers were attached to a steel cable and then placed inside a bucket that received a constant flow of recycled water. For the two Class C storage pond sites, passive samplers were placed inside steel cages and deployed in the ponds attached to steel tether cables. Due to issues with ragging in sewage streams, a torpedo-style sampling unit was developed to house the passive samplers that were deployed into raw sewage.

Five types of passive samplers were utilised, including three different Polar Organic Chemical Integrative Sampler (POCIS) samplers, Chemcatchers (SDB-XC-PES) and Trimethylpentane containing passive sampler (TRIMPS). Different passive samplers were used to maximise the coverage of emerging contaminants in recycled water and raw sewage. Whilst the passive sampler screening methods used cannot detect all emerging contaminants that may be present, they offer a broad and representative range of chemical types and different chemical properties. The method we have used is qualitative and has not been normalised to flows, and therefore all results are presented as presence/absence, rather than an actual concentration. This approach is suitable for comparing between sampling sites to look at differences in detection frequencies but cannot be used to directly infer concentrations or expected ecological impacts. The passive samplers were deployed for 28 days in recycled water or 72 hr in raw sewage (based on previous studies, Hassell et al. 2023). Monitoring was done over 4 separate sampling rounds, to capture seasonal differences in emerging contaminant presence and frequency. Monitoring occurred in Winter 2023, Spring/Summer 2023, Summer 2024, and Autumn/Winter 2024. Grab samples were collected at the end of each deployment period but very few chemicals were detected. For future studies we would recommend concentrating the samples prior to analysis, and/or considering the use of composite samples, comprised of multiple grab samples collected at different time points. The National Measurement Institute (NMI) conducted all the chemical screening of passive samplers and grab water samples for this study, and in total 284 different chemicals were screened from 11 different chemical groups.

OUTCOMES / RESULTS

A total of 107 different chemicals were detected, including fungicides, herbicides, insecticides, organochlorine (OC) pesticides, organophosphate (OP) pesticides, synthetic pyrethroid (SP) pesticides, pharmaceuticals and personal care products (PPCPs) and per- and poly-fluoroalkyl substances (PFAS). Eighty different chemicals were detected in raw sewage and 85 in recycled water. The most frequently detected chemicals were Imidacloprid (insecticide), Tebuconazole (fungicide) and multiple PFAS (PFHxA, PFHpA, PFOA, PFHxS, PFOS) (Table 1).

Table 1. List of all chemicals detected in passive samplers from raw sewage (RAW) and recycled water (RCW) during this study across all sampling sites and seasons. Chemicals in bold text were found in every sample (100% detection rate).

RAW ONLY	RCW ONLY	Found in both RAW and RCW	
Acesulfame	8:2 FTS (39108-34-4)	6:2 FTS (27619-97-2)	Paracetamol
Bendiocarb	Acephate	Acetamiprid	PFBA (375-22-4)
Bromacil	Ametryn	Atrazine	PFBS (375-73-5)
Captan	Boscalid	Azoxystrobin	PFDA (335-76-2)
Ciprofloxacin	Chlorantaniliprole	Bifenthrin	**PFHpA (375-85-9)**
DDD - o.p.	Chlorthal dimethyl	Buprofezin	**PFHxA (307-24-4)**
DDT - Total	Dicofol	Carbamazepine	**PFHxS (355-46-4)**
Dicloran	Dieldrin	Carbendazim	PFNA (375-95-1)
Diphenylamine	Diflufenican	Chlorpyrifos	**PFOA (335-67-1)**
Ketoprofen	Hexazinone	Clothianidin	**PFOS (1763-23-1)**
Malathion	Methamidophos	Cyproconazole	PFPeA (2706-90-3)
Mandipropamid	Methoxyfenozide	Cyprodinil	PFPeS (2706-91-4)
Methidathion	Metribuzin	Diazinon	Praziquantel
Norfloxacin	Myclobutanil	Diuron	Propamocarb
Oxyfluorfen	Naldixic acid	Epoxiconazole	Propiconazole
Oxytetracycline	N-EtFOSAA(2991-50-6)	Erythromycin	Propyzamide
Pendimethalin	N-MeFOSAA (2355-31-9)	Ethofumesate	Pyrimethanil
Permethrin	PFDoA (307-55-1)	Fipronil	Roxithromycin
Piperonyl butoxide	PFDS (335-77-3)	Fludioxonil	Simazine
Pymetrozine	PFHpS (375-92-8)	Imazalil	Sulfafurazole
Sulfachlorpyridazine	PFOSA (754-91-6)	**Imidacloprid**	Sulfamethoxazole
	PFTrDA (72629-94-8)	Iprodione	Sulphapyridine
	PFUdA (2058-94-8)	Levofloxacin	**Tebuconazole**
	Spirotetramat	Lincomycin	Thiabendazole
	Sulfadimidine	Metalaxyl	Thiamethoxam
	Thiacloprid	Methabenzthiazuron	Triadimenol
	Trifloxystrobin	Metolachlor	Trifluralin
		Ofloxacin	Trimethoprim
		O-Phenylphenol	Venlafaxine
		Paclobutrazol	

In recycled water from WTP (Class A and Class C), 61 different chemicals were detected and in recycled water from ETP (Class A), 40 different chemicals were detected. Class A water from ETP generally showed the lowest numbers of chemicals from each group, and Class C from WTP showed the highest numbers (Figure 1). The greatest numbers of detects were fungicides, herbicides and PFAS. We also calculated the percent composition of different chemical groups (number of chemicals in specific group/total number of chemicals detected x 100). The composition of raw sewage from ETP and WTP was similar, with PPCPs and fungicides contributing about half of all chemicals detected (Table 2). There was more PFAS detected at ETP (20.4%) compared to WTP (15.5%), but less herbicides and insecticides. In Class A recycled water, the composition varied between the two treatment plants, with ETP showing lower PCPPs (1.2%) compared to WTP (11.1%), but more PFAS and Fungicides. Class C recycled water had more PCPPs and insecticides than Class A recycled water, but less PFAS and herbicides (Table 2).

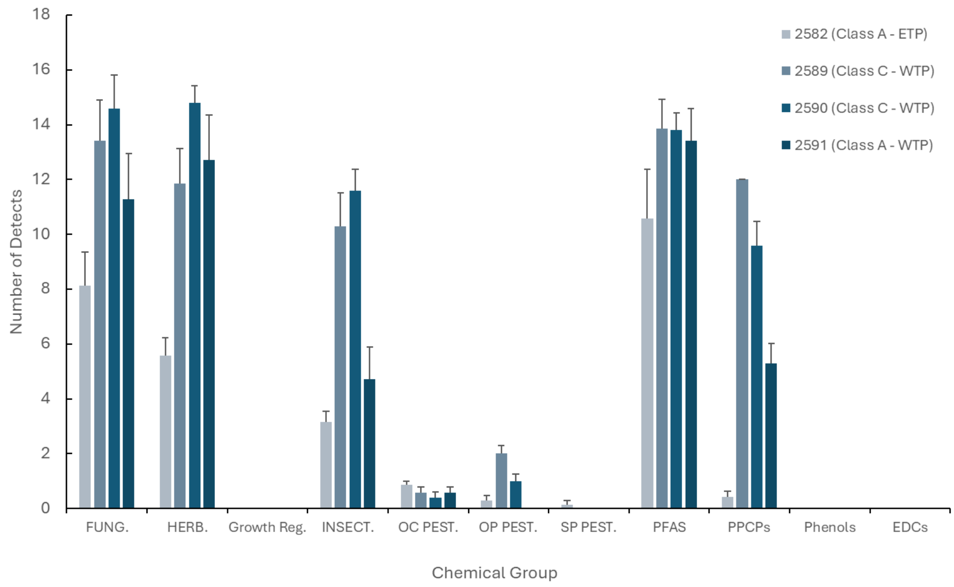

Figure 1. Mean (±SEM) number of chemicals detected in Class A and Class C recycled water from the Western Treatment Plant (2589, 2590, 2591 WTP) and the Eastern Treatment Plant (2582 ETP) across entire project (n=5-7).

Seasonal differences were observed in the number of chemicals detected in both raw sewage and recycled water. Winter and Summer sampling showed the highest number of detects at both ETP and WTP, whilst Autumn/Winter showed the lowest number of detects. In Class A recycled water from ETP, the highest numbers were in Summer, whilst for Class A recycled water from WTP, this was in Winter. Class C water from the two sites at WTP showed generally similar numbers of chemicals detected in Spring/Summer and Autumn/Winter and less in Summer. There were 10 chemicals that were only detected in Winter, 4 only detected in Spring/Summer, 4 only detected in Summer and 1 that was only detected in Autumn/Winter. The seasonal specific chemicals included 6 fungicides, 2 herbicides, 1 insecticide, 1 synthetic pyrethroid pesticide, 5 PFAS and 4 PPCPs.

Table 2. Mean (±SEM) total number of detects and percent composition of different emerging contaminants in raw sewage (RAW) and recycled water (RCW) across the entire project sampling period (June 2023-June 2024).

	RAW		RCW (Class A)		RCW (Class C)	
Site	ETP 2621	WTP 2533	ETP 2582	WTP 2591	WTP 2589	WTP 2590
n	*8*	*8*	*7*	*7*	*7*	*5*
Total Detects (#)	45.6±4.5	48.4±6.3	29.1±3.2	48.0±5.3	64.0±3.5	65.8±4.1
Percent Composition (%)						
PPCPs	25.8±3.1	27.3±4.5	1.2±0.6	11.1±1.0	19.1±1.1	14.5±1.0
PFAS	20.4±3.3	15.5±3.6	34.6±6.1	29.7±3.4	22.2±2.5	21.2±1.2
Fungicides	25.8±0.6	23.2±0.8	29.1±5.0	22.9±1.9	20.6±1.4	22.0±1.2
Herbicides	11.5±1.6	15.7±1.0	19.5±1.3	26.0±1.0	18.3±1.4	22.6±0.9
Insecticides	8.8±0.8	10.3±1.0	10.9±0.8	8.8±1.6	15.7±1.2	17.6±0.9
OP Pesticides	2.5±1.3	3.5±1.1	1.4±0.9	0.0±0.0	3.1±0.4	1.5±0.4
Synthetic Pyrethroids	2.7±0.9	2.3±0.7	0.5±0.5	0.0±0.0	0.0±0.0	0.0±0.0
OC Pesticides	0.8±0.6	0.8±0.5	2.8±0.5	1.5±0.6	1.0±0.3	0.5±0.3
Phenols	1.5±0.5	1.3±0.4	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
Growth Regulators	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
Hormones (EDCs)	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0

CONCLUSIONS

This study provides a comprehensive assessment of chemicals moving through sewage wastewater, and indicates there are several chemicals, of several different chemical classes that should be considered in recycled water reuse programs. Whilst the mere presence of a chemical in recycled water does not indicate that it poses any environmental or human health risks, it does help focus efforts in identifying which emerging contaminants should be prioritised for further investigation. Less than 30% of all the chemicals detected in this study have guideline values in either the Australian Guidelines for Water Recycling (AGWR) (NRMMC, 2008), Australian Drinking Water Quality Guidelines (NRMMC/NHMRC, 2022) or Australia and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018). We recommend targeted research on some of the specific emerging contaminants detected in this study, to determine environmental concentrations coupled with identifying likely exposure routes, sensitive pathways and ecotoxicology to assist in developing both new, as well as refining existing risk assessments. High quality, reliable risk assessments are crucial to ensuring that recycled water can be utilised safely, and to its full extent across all allowable uses.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Knowledge of what is present in recycled water is fundamental to identifying appropriate end uses and maximising its potential as a sustainable alternative water source. This knowledge contributes to building resiliency in several ways. Firstly, through strengthening water security by enabling the safe and targeted application of recycled water across various sectors such as agriculture, industry, and non-potable urban uses, to reduce reliance on traditional potable supplies and better withstand periods of drought or water scarcity. Secondly, through informing improved risk management, to ensure the recycled water meets health and environmental standards, which assists in developing public confidence in the safety and reliability of recycled water systems. And, thirdly, supporting integrated water resource planning for the strategic integration of recycled water into broader water management frameworks and a circular water economy, where water is reused efficiently, reducing environmental impacts and enhancing overall system resilience and ability to respond to changing conditions such as climate variability and population growth. In summary, comprehensive knowledge of recycled water quality underpins safe usage, fosters innovation in water reuse, and enhances the long-term resilience of water supply systems.

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Cyanotoxin risk in recycled water used for food crop irrigation

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Title of Full Paper

Cyanotoxin risk in recycled water used for food crop irrigation

Conference Topic

Optimising Resilient Water Supply Systems

INTRODUCTION

Access to water has been identified as one of the most limiting factors to economic growth for the Worlds food crop production. Water reclaimed from wastewater is increasingly recognised as a way to maximise the use of this finite resource, and the agricultural sector is currently its largest consumer. The key to the success of its ongoing use is to ensure that this resource is used in a sustainable manner without impacting adversely on human health or the environment. Cyanobacterial blooms and their toxins are a common occurrence in wastewater storages that can be used as an irrigation water source for food crops. The forecasted increase in the occurrence and intensity of cyanobacteria blooms due to climate change and the projected increased use of this resource for agricultural purposes drives the need to investigate and understand the interaction of these toxins with food crops. Over the last two decades there have been many peer-reviewed papers reporting uptake of cyanotoxins by plants and bioaccumulation in edible components which has raised concerns around risks to the consumer. A project, Cyanotoxin risk in recycled water used for food crop irrigation (Water RA #3049), initiated by SA Health and developed by SA Water, Water RA and Flinders University, with support from One Basin CRC and water authorities across Australia, is currently underway to better understand the issue from an Australian perspective. The presentation will provide an overview of the project and its findings to date with emphasis on one component, evaluating the health risk to consumers.

METHOD AND OUTCOMES

1. Current Project Outcomes

Cyanotoxin risk in recycled water used for food crop irrigation project (Water RA #3049) commenced in 2022 with a completion date of June 2026. It is envisaged that the outcomes of the project will be used to guide future policies and guidelines on the use of recycled water on food crops. The project consists of several components:

- *Literature Review*: Conduct comprehensive review of scientific literature to determine current understanding of the issue. This work has been published.
  Faulkner, S., Sweetman, C., Hutson, J. *et al.* Uptake of the cyanobacterial toxin microcystin by crop plants irrigated with contaminated wastewater: a review. *Rev Environ Sci Biotechnol* **24**, 217–238 (2025). https://doi.org/10.1007/s11157-024-09716-0
- *SA Water Investigation*: Review the extent of recycled water use on crops in Australia, and Worldwide. Martin Faulkner sent a survey questionnaire to 225 water authorities in Australia and some international groups. Questionnaires were initially sent in January 2024 with a follow up in July 2024. Data is currently being collated, and a report will be available in near future.
- *Honours Project*: Fate of microcystin within soils. This has been completed, and Paul Canala will be presenting a poster at Next Water 2025 on his findings.
- *PhD Project*: Fate of cyanobacterial toxin in the journey from wastewater through to uptake by irrigated crops. Shayne Faulkner is two years into this project and will be presenting a poster at Next Water 2025 on her findings.

- *Risk assessment*: what concentration of toxin in food crops would constitute a health risk. This will be presented in more detail in the current presentation.

2. Risk Assessment

2.1 Acceptable cyanotoxin levels in food crops

While it would be preferable that there be no cyanotoxin in food crops it may be unavoidable and so it is important to understand at what levels they will pose a health risk to consumers. This will aid in assessing risk of exposure and the development of any required guidelines and irrigation protocols to protect consumers. The following uses a simple formula to determine risk levels for cyanotoxin in food crops.

An important part of assessing the risk of exposure to toxins is determining the maximum acceptable concentration of toxin that can be present in a food crop before the Tolerable Daily Intake (TDI) is exceeded. To determine this concentration the following is needed:

1. Consumption patterns for the fruit and vegetable being assessed.
2. Tolerable daily intakes (TDI) for chronic exposure to the cyanotoxin of concern.

The Australian Bureau of Statistics released the Australian Health Survey conducted in 2011/2012 financial year which provides a snapshot on food and nutrient consumption patterns in Australia (ABS, 2014). This survey provides median daily amounts of a particular food crop that are expected to be consumed by an individual.

The TDI for microcystin-LR is 0.04 µg/kg body weight/day (WHO, 2020). Insufficient data is available to derive a TDI for microcystin variants except microcystin-LR so this will be used throughout this assessment even though some food crop uptake studies included here have used other variants. The Maximum Allowable Microcystin-LR Content (MAMC) in various common food crops before exceedance of TDI based on Australian consumption patterns was calculated using the following formula:

TDI for Microcystin in 70kg adult = 2800 ng/day (WHO, 2020)	÷	Median daily consumption of food crop for an Adult (g) (ABS, 2014)	=	Maximum Allowable Microcystin Concentration (MAMC) in food crop, if sole source of toxin, before exceedance of TDI (ng/g)

MAMC for several common food crops are presented in Table 1. These have also been the choice of crop for international studies on toxin uptake.

Table 1:

Food Crop	Median Daily Consumption for an Adult (g)	TDI for 70kg adult if sole source of Microcystin (ng)	Maximum Allowable Microcystin Concentration (MAMC) in food crop before exceedance of TDI (ng/g)
Leaf and Stalk Vegetables	24.6	2800	114
Root Vegetables	37.2	2800	75
Tomato	38	2800	74
Rice	167.5	2800	17

2.2 Risk Assessment

Over the last two decades there have been several studies reporting the impact of cyanotoxins on food crops not only in terms of plant health and yield but also the risk associated with human consumption of edible components. The source of these toxins includes water and wastewater storages. A number of these studies looked at toxin levels in other plant components which are not considered edible (e.g., roots of a tomato plant) and these results have been omitted as they are not relevant to human health. Table 2 summarises the results from published investigations on edible components of food crops irrigated with cyanotoxins. To help simplify the data presented in the publications the results have been divided into four separate groups in terms of trial type and irrigation method.

Table 2: Summary of published investigations on edible components of food crops irrigated with Microcystin.

Experiment Type	No. of Papers	Plant type Tested	Toxin Source	Plant showing exceedance of MAMC
Field	4	Root Veg., Leafy Greens, Rice, Fruiting Veg.	• 1 x ground water • 3 x bloom	All 4 papers - cabbage, dill, lettuce, parsley, spinach, rice
Laboratory/ Hydroponics	3	Leafy Greens	• 2 x cyano extract • 1 x pure toxin	1 paper, MIC, lettuce
Laboratory/Soil/ Water at base	10	Leafy Greens, Fruiting Veg., Root Veg., Rice, Tomato	• 5 x pure toxin • 5 x cyano extract • 4 x bloom	4 papers, MIC, root veg, rice
Laboratory/Soil/ Water over whole plant	7	Leafy Greens, Root Veg.	• 3 x pure toxin • 3 x cyano extract	4 paper, MIC, lettuce

The following caveats should be considered when reviewing the data presented in Table 2.

- The application rate of toxins in laboratory-based studies may be higher than would normally be expected.
- Toxin analysis of plant material in the literature may include levels within the food as well as on the surface (e.g., if crop is spray irrigated).
- Limitations in extraction and analytical methods may over or underestimate toxin content.
- Consumption rates of foods by individuals is only a guide and may be higher or lower than presented in ABS 2014 data for some individuals.

However, even after taking these caveats into consideration, the data presented in the literature highlights a need for further investigation to properly assess the health implications.

CONCLUSIONS – HOW WILL THIS HELP BUILD RESILIENCY

Cyanotoxin risk in recycled water used for food crop irrigation project (Water RA #3049) will provide important information to understand the issue of toxin uptake by food crops from an Australian perspective. It is envisaged that the outcomes of the project will be used by health regulators to guide future policies and guidelines on the use of recycled water on food crops.

Tracking Tyre Pollution: Detecting and Mitigating Rubber Microplastics and Anti-Degradants in Stormwater

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Title of Full Paper

Tracking Tyre Pollution: Detecting and Mitigating Rubber Microplastics and Anti-Degradants in Stormwater

Conference Topic

Optimising Resilient Water Supply Systems

INTRODUCTION

The increasing use of cars and trucks has raised growing environmental concerns, particularly regarding the release of tyre wear particles (TWPs) into the environment. These microscopic particles are generated through the abrasive interaction between tyres and road surfaces during normal vehicle operation. Once released, TWPs accumulate on roadways and are easily transported by stormwater runoff during precipitation events, eventually entering aquatic ecosystems. This diffuse and often unmonitored source of pollution contributes to a phenomenon known as Urban Runoff Mortality Syndrome (URMS), characterised by acute mortality events in aquatic organisms due to toxic chemical exposure (Tian et al., 2021).

A critical aspect of this pollution stems not only from the physical wear particles but also from the presence of tyre anti-degradants. These are chemical additives used to enhance rubber durability for instance against oxidative and environmental stressors. Upon environmental exposure, some of these compounds transform into toxic byproducts. Three compounds of particular concern are N-(1,3-dimethylbutyl)-N′-phenyl-1,4-phenylenediamine quinone (6PPDq), an ozonation product of the widely used anti-ozonant 6PPD, Hexamethoxymethyl melamine (HMMM), a crosslinking agent used to improve adhesion in tyres and 1,3-diphenylguanidine (1,3 DPG), a synthetic chemical used in rubber vulcanisation. These are some substances amongst others that have emerged as contaminants of emerging concern due to their acute toxicity to aquatic organisms. Especially, 6PPDq has been linked to mass mortality events in coho salmon (Oncorhynchus kisutch) at concentrations as low as 95 ng/L, and has also been shown to be toxic to brook trout (Salvelinus fontinalis, LC_{50} = 590 ng/L) and rainbow trout (Oncorhynchus mykiss, LC_{50} = 1000 ng/L) (Tian et al., 2021). HMMM, while lacking fully defined lethal concentration thresholds, has demonstrated acute toxic effects on freshwater invertebrates (Peter et al., 2018). And 1,3 DPG has been classified by ECHA as a substance toxic to aquatic life with long lasting effects (ECHA, 2020).

Despite the ecological significance of TWPs the current detection methods are often inadequate and globally the occurrence of TWPs is highly underestimated. Pyrolysis gas chromatography–mass spectrometry (Py-GC-MS) represents a powerful tool for the direct identification of TWPs, but its application remains niche due to its technical complexity. Instead, many studies rely on spectroscopic methods, which fail to detect TWPs with sufficient accuracy, resulting in significant underestimation of environmental concentrations.

Simultaneously, the analysis of tyre anti degradants as 6PPDq has emerged providing more insight about these chemicals leaching into the environment. USEPA method 1643, the first draft method for the detection of 6PPDq was released in January 2024. Which enabled more data being gathered on these chemicals to be toxicologically assessed individually and they impact to the environment determined.

Additionally, environmental risk assessments can be conducted, and mitigation strategies can be drawn up. These include the phase-out of toxic anti-degradants such as 6PPD, HMMM, and 1,3 DPG and the development of alternative, less harmful additives or other environmental barriers to reduce the concentrations in the environment.

To better understand the interactions between tyre anti-degradants and filtration media such as sand and clay, a recent study investigated the physicochemical properties required for effective removal. The findings aim to inform future treatment designs and improve the efficiency of stormwater retaining systems.

METHOD/EXPERIMENTAL DESIGN

Eurofins Environment Testing Australia has developed a sensitive and selective analytical method for detecting tyre anti-degradants, specifically 6PPDq, HMMM, and 1,3 DPG using isotope dilution and liquid chromatography–tandem mass spectrometry (LC-MS/MS). This method is closely aligned with USEPA 1643 with the addition of HMMM and 1,3 DPG. The analytical workflow begins with sample extraction via solid-phase extraction (SPE), which enables effective pre-concentration and cleanup of target compounds from matrices as liquids and solids. This method is validated for a wide range of environmental sample types, including drinking water, stormwater, sand, sediment, rubber materials, and leachates. The use of isotope-labelled internal standards ensures accurate quantification by compensating for matrix effects and instrumental variability.

To investigate the partitioning behaviour and sorption characteristics of tyre-derived chemicals, an experimental study was conducted under controlled laboratory conditions. The objective was to assess how selected compounds distribute between aqueous and solid phases in the presence of environmentally relevant materials such as sand and clay.

In this study, 100 mL of deionised water was spiked with HMMM, 6PPDq, and 1,3-DPG at a concentration of 1,000 ng/L for each compound. The spiked solutions were transferred into three types of containers: (1) a control with no solids, (2) bottles containing 5 g of dry, acid-washed quartz sand, and (3) bottles containing 5 g of dry natural clay. Each setup was placed in plastic bottle and was gently tumbled continuously at room temperature to ensure thorough mixing and simulate environmental interaction. The samples were collected at two points: after 3 hrs and after 3 days of reaction, to evaluate both short-term and longer-term partitioning dynamics. Following reaction, the bottles were allowed to settle to enable phase separation. The aqueous phase was carefully decanted and collected for analysis, while the remaining solid material was isolated and extracted. Both phases were then analysed independently to quantify the distribution of target analytes. Procedural blanks were included to control for background contamination and evaluate potential artefacts from containers, reagents, and sorbents. Quantitative results were processed by LC-MS/MS using isotope-dilution to ensure reliability and comparability across samples. This experimental approach provided insight into the environmental behaviour of tyre anti-degradants and their interaction with common sedimentary materials, informing potential mitigation and remediation strategies for stormwater pollution.

OUTCOMES / RESULTS

The comparative analysis of the partitioning behaviour of 6PPDq, HMMM, and 1,3-DPG in sand and clay matrices reveals significant differences in sorption dynamics as shown below in the Figures 3-4.

When analysing the Blank samples (shown in Figure 1) it can be observed that there has been no background contamination.

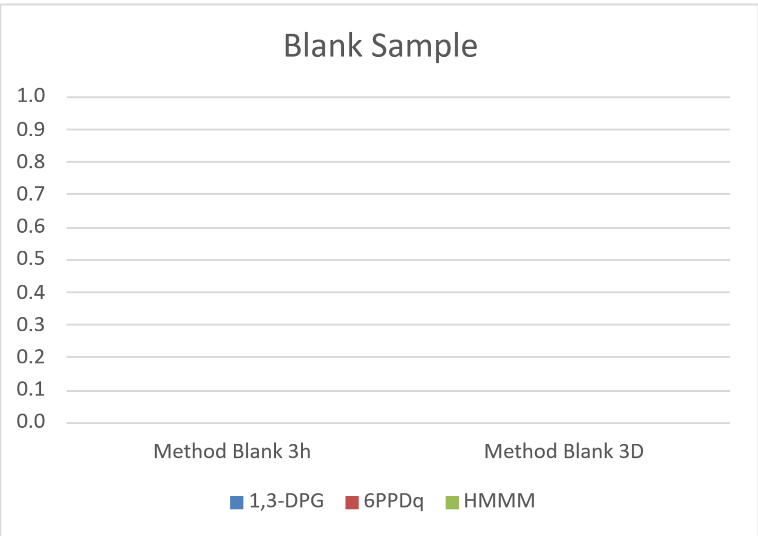

Figure 12: QC sample Recoveries for the different analytes.

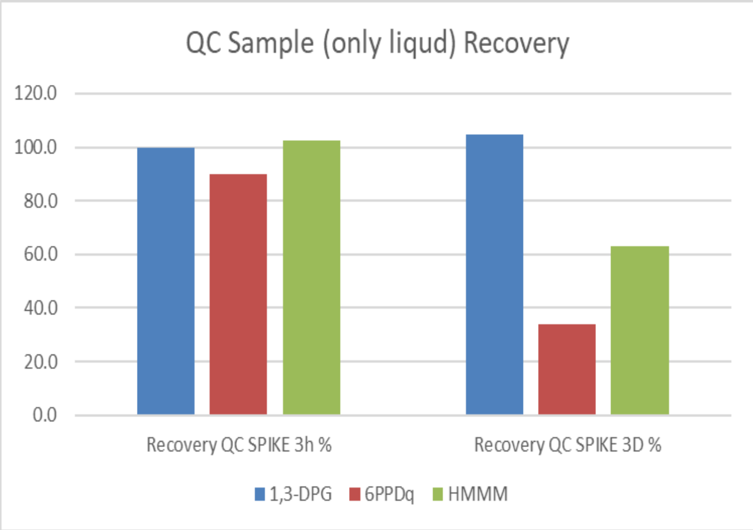

Figure 13: QC sample Recoveries for the different analytes.

Figure 2 shows the recovery of the spike placed in the same bottle as the samples and treated in the same way as the samples but without solid addition. It can be observed, that after 3 hrs, 1-3 DPG and HMMM were recovering close to 100%, but there was a small decrease in the 6PPDq. This looks very different for the data analysed after 3 days, where 6PPDq and HMMM are recovering low. It can either be concluded that the compounds degraded, reacted further or sorbed to the bottle.

When analysing the sand and clay samples, similar phenomena can be observed.

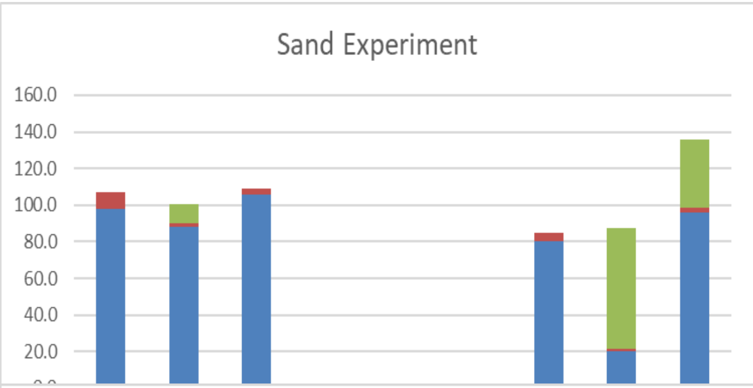

Figure 14: Liquid and solid recoveries for the sand experiment

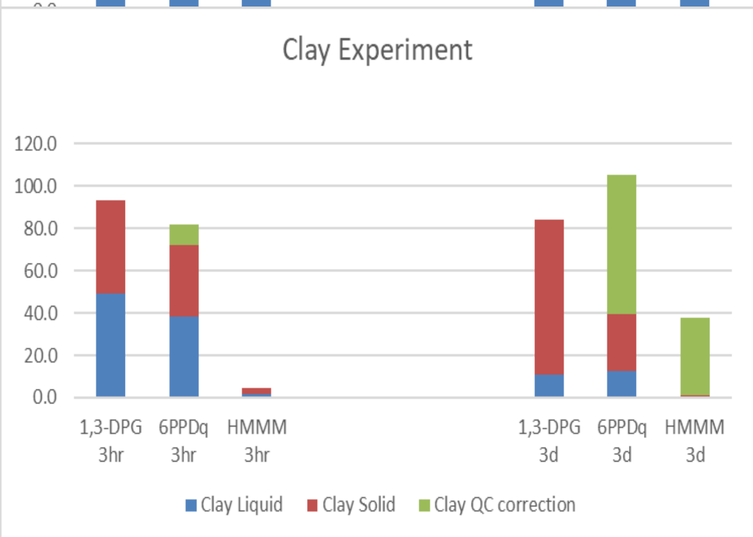

Figure 15:Liquid and solid recoveries for the clay experiment

In the sand experiment, all three compounds were initially found predominantly in the aqueous phase after the 3 hrs, indicating limited early-phase interaction with the sand matrix. After the 3 days only 6PPDq demonstrated a large decrease in the aqueous phase. But it could also not be analysed in the solid phase at larger concentrations. But when observing the accompanied QC sample as similar decrease in concentration could be observed in the liquid for 6PPDq. So, when adding this to the recovery the mass balance can be closed, and it can be assumed that the 6PPDq has either sorbed to the plastic bottle over time or degraded. When doing correcting for the QC sample in the HMMM experiment it is over recovering, it is over recovering which is interesting and can't be explained with the data available. This suggests that these compounds may gradually partition into sand or undergo chemical transformation, although the effect remains moderate due to sand's limited surface area and reactivity.

In contrast, the clay matrix exhibited substantially greater sorption affinity for all three compounds, particularly for HMMM. This notably, showed almost complete removal from the aqueous phase by 3 hrs and was not substantially recovered from either phase after 3 days, suggesting possible irreversible binding or degradation. The higher sportive capacity of clay is consistent with its finer particle size, greater surface area, and higher cation exchange capacity, making it a more effective medium for contaminant retention. For 1,3-DPG and 6PPDq, after 3hrs the compounds are partitioned rather equally between the solid and liquid phase. This changes after 3 days where the larger amount can be found in the solid phase and less found in the liquid.

CONCLUSIONS

The experiments show that clay has a much higher capacity than sand to retain or bind tyre-derived pollutants like 6PPDq, HMMM, and 1,3-DPG. While these compounds mostly stayed in water when mixed with sand, they strongly bound to clay, especially after 3 days. This suggests that clay-rich environments are more effective at trapping these contaminants, reducing their mobility in stormwater. Therefore, soil type plays a key role in managing tyre-related pollution.

This is useful information for effective stormwater management which plays a crucial role in reducing the environmental impact of tyre-related pollutants. Technologies such as sand and media filters are capable of capturing suspended solids and some dissolved substances, while activated carbon filtration has proven highly effective at adsorbing organic contaminants including 6PPDq and HMMM.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Understanding how tyre-derived pollutants such as 6PPDq, HMMM, and 1,3-DPG interact with different soil types is a critical step toward building environmental resiliency in urban stormwater systems. These findings can inform the design and placement of more effective stormwater treatment infrastructures—such as filtration systems using clay-based media—to enhance the capture and retention of harmful contaminants before they reach sensitive aquatic ecosystems.

Future work should explore the long-term fate of these chemicals in real-world settings and assess the regeneration or disposal strategies for saturated filter media. Additionally, evaluating alternative, less toxic tyre additives will further reduce pollutant loads and enhance urban water quality resilience.

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50 Years since the Discovery of Disinfection By-Products: New Approaches to the Management of Disinfection By-Products in Australian Drinking Water

Dr Ina Kristiana[1], Professor Cynthia Joll[1], Associate Professor Anna Heitz[1], Dr Yolanta Gruchlik[1], Adjunct Professor Keith Cadee[2]

[1]Curtin Water Quality Research Group, [2]Independent Industry Consultant

Title of the workshop/Panel

50 Years since the Discovery of Disinfection By-Products: New Approaches to the Management of Disinfection By-Products in Australian Drinking Water

Conference Topic

Optimising resilient water supply systems

MODERATOR:

Dr Ina Kristiana, Curtin Water Quality Research Group

PARTICIPANTS:

- Professor Cynthia Joll (Presenter 1), Curtin Water Quality Research Group
- Dr Kristal Jackson (Presenter 2), NHMRC
- Group discussion facilitators

IDEAS TO BE PRESENTED, DEVELOPED AND DISCUSSED:

Rationale:

It has been 50 years since the discovery of trihalomethanes (THMs), the first reported group of disinfection by-products (DBPs), in drinking water. Since then, many other DBPs have been identified. Epidemiological and toxicological studies have shown some associations between exposure to DBPs and adverse health effects. Consequently, guidelines and standards have been developed in many countries to limit the concentrations of some DBPs in drinking water. The expectation is that these regulated DBPs would serve as surrogates for unregulated and unknown DBPs, such that if the risks from the regulated DBPs are minimised, the risks from the unregulated and unknown DBPs would also be low. However, recent epidemiological studies have indicated that, even after implementation of these DBP standards, there is still a small, but important, possible increased risk of bladder cancer from chlorinated drinking water. Hence, new approaches to managing the risks from DBPs are required.

Learning Expectations:

This workshop will highlight new approaches to the management of DBPs and the work being undertaken by the NHMRC Water Quality Advisory Committee on DBPs in drinking water. The workshop will commence with two short presentations (2 x 15 minutes) on the following topics:

- New Roadmap to DBP Management
- NHMRC Update on Revisions to DBP Fact Sheets and Disinfection/DBP Guidance in the Australian Drinking Water Guidelines

Following these presentations, attendees will have the opportunity to participate in group discussions (2 x 20 minutes), choosing two of the following topics:

- Standards and Guidelines for DBPs
- Relative toxicity of brominated, iodinated, and nitrogen-containing DBPs; the relative merits of using few selected individual DBPs or bulk parameters and surrogates for guidelines.
- DBP Management Roadmap
- Discussion and feedback on the proposed Roadmap.
- Preparedness for Potential Lower DBP Guideline Values
- Opportunity for water utilities and stakeholders to discuss their strategies and plans, e.g. strategies to address high DBP formation in water systems.
- Indicators for Potential Risks from DBPs in Drinking Water
- Opportunity for utilities and stakeholders to discuss indicator parameters used to predict DBP formation; discussions on the role of bioassays for predicting toxicity.
- Trifecta in DBP Management
- Discussion on the roles of utility, regulator, and community in DBP management.

Outcomes:

At the end of the workshop, key messages from these group discussions will be shared (10 minutes). A summary of outcomes from the workshop will later be made available to all participants. Outcomes will contribute to the DBP Management Roadmap and the preparation of an Australian Best Practice Guidelines for the Management of DBPs.

GENERAL STRUCTURE OF THE WORKSHOP/PANEL:

Introduction	5 min
Presentation 1	15 min
Presentation 2	15 min
Break into groups	5 min
Group Discussion round 1	20 min
Group Discussion round 2	20 min
Groups Report and Conclusion	10 min

LINKS TO RESEARCH

Granular sludge-based technology for managing high ammonia landfill leachate

Miss Ying Liu[1], Dr Yang Lu[1], Mr Michael Roll[2], Mr Ryan Trinne[2], Prof. Yang Liu[1]

[1]Queensland University Of Technology, [2]City of Gold Coast

Granular sludge-based technology for managing high ammonia landfill leachate

Ying Liu[1], Yang Lu[1], Michael Roll[2], Ryan Trinne[2], Yang Liu[1]

- Queensland University of Technology, Brisbane, QLD, Australia
- City of Gold Coast, Gold Coast, QLD, Australia

Conference Topic

Optimising Resilient Water Supply Systems

1 INTRODUCTION

Landfill leachate, characterised by high concentrations of ammonia (400 - 3,000 mg/L) and complex organic pollutants (chemical oxygen demand, COD up to ~15,000 mg/L), poses significant challenges to conventional wastewater treatment systems due to its toxicity and variability. To address such severe conditions, it is essential to develop treatment technologies that are not only efficient but also resilient—capable of sustaining stable performance under fluctuating loads.

Granular sludge reactors (GSRs) have emerged as a promising solution for managing high ammonia wastewaters, offering enhanced biomass retention, excellent settling capacity, resilience to toxic stocks, and structural robustness that contribute to improved treatment performance (Zou et al., 2023). The dense microbial structure of granular sludge facilitates microbial self-organization and functional redundancy, enabling microbial communities to adapt to harsh conditions and enhancing system resilience. Despite these advantages, optimising operational parameters for specific wastewaters—such as landfill leachate—remains critical to achieving consistent performance and microbial robustness (Zou et al., 2025).

This study aims to enhance microbial resilience and operational stability in GSRs treating high-strength landfill leachate (>2,000 mg/L NH_4^+-N) by optimising the carbon-to-nitrogen (C/N) ratio. Using raw leachate samples, the research evaluates long-term stability and the metabolic adaptability of the microbial community. By optimising key parameters, the study demonstrates how granular sludge can sustain high nitrogen removal efficiency under extreme ammonia loads. These findings contribute to the development of biologically robust and adaptable treatment systems, supporting the resilience of future water infrastructure for managing challenging wastewaters.

2 METHOD/EXPERIMENTAL DESIGN

2.1 Bioreactors configuration and operation

Two cylindrical reactors (working volume: 4 L) were operated in sequencing batch reactor (SBR) mode at 25 °C for over 300 days to treat landfill leachate, with a 40% volumetric exchange ratio. Aeration was supplied at 6 L/min via a bottom-mounted air diffuser. The system achieved complete ammonia removal at a hydraulic retention time (HRT) of 17.5 hours, which could be further reduced through process optimisation.

2.2 Seed sludge and landfill leachate feed

The seed sludge was sourced from a lab-scale granular sludge reactor previously acclimated for over two months using diluted landfill leachate. The C/N ratio was adjusted through granular activated carbon (GAC) pretreatment applied to the test reactor (Reactor 2, R2), achieving a target ratio of 2.5, while the control reactor (Reactor 1, R1) maintained a C/N ratio of 5 without pretreatment. Both reactors were acclimatised by stepwise reduction of the dilution ratio of raw landfill leachate, gradually transitioning to undiluted leachate conditions. Corresponding ammonia concentrations increased in stages—from 500 to 800, 1,300, and ultimately over 2,000 mg/L NH_4^+-N.

2.3 Sampling and chemical analysis

Both influent and effluent samples were collected from the bioreactors every second day and filtered through 0.45 µm membrane filters. These samples were subjected to chemical characterisation, including NH_4^+-N, NO_2^--N, NO_3^--N, and COD. Nitrogen species were analysed with HACH test kits (Nessler, NitriVer® 2, TNT 835), while COD, mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), and 30-minute sludge volume index (SVI_{30}) were determined following Standard Methods (APHA et al., 2012). pH was monitored using a benchtop pH meter (Model B40PCID, VWR, USA).

2.4 Specific microbial activity tests

Nitrogen transformation activities, including ammonia and nitrite oxidation as well as denitritation and denitrification, were evaluated using specific microbial activity tests as described in Zou et al., (2023) (Zou et al., 2023). Sludge samples (4 g/L MLVSS), collected during the aerobic phase, were tested under controlled F/M ratios. Ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB) activities were measured under aerobic conditions using synthetic media containing NH_4^+-N or NO_2^--N, while anoxic tests employed NO_2^--N or NO_3^--N with sodium acetate as the carbon source. All tests were maintained at pH ~7.5 and 25 °C and conducted in triplicate with periodic sampling and filtration for nitrogen analysis. Specific activity rates were expressed as g N/ (g VSS·d).).

2.5 DNA extraction, sequencing, analysis

Total genomic DNA was extracted from sludge samples using the DNeasy PowerSoil Pro Kit (QIAGEN, Hilden, Germany) following the manufacturer's protocol. DNA quality and concentration were assessed using a NanoDrop™ One spectrophotometer (Thermo Fisher Scientific, USA). The V4 region of the 16S rRNA gene was amplified using universal primers 515F and 806R and sequenced on the Illumina MiSeq platform at the Australian Centre for Ecogenomics (University of Queensland, Australia). Raw reads were pre-processed to remove adapter and primer sequences using Cutadapt (v1.18), followed by denoising, dereplication, error correction and chimera removal using the DADA2 pipeline (v1.16). High-resolution amplicon sequence variants (ASVs) were subsequently identified and taxonomically classified based on sequence inference against GTDB database (release 220).

2.6 Statistical analysis

Statistical significance was evaluated using Student's t-test in Microsoft Excel, with a p-value < 0.05 considered statistically significant.

3 OUTCOMES / RESULTS

3.1 Biomass Characteristics and Sludge Settleability

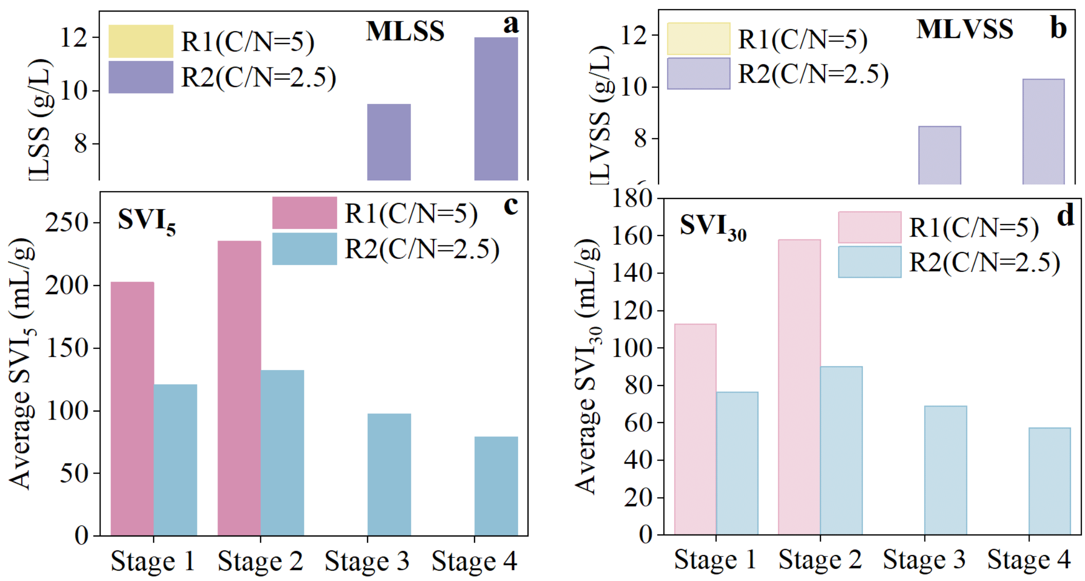

Figure 1 Comparison of (a) mixed liquor suspended solids (MLSS), (b) mixed liquor volatile suspended solids (MLVSS), (c) 5-minute sludge volume index (SVI_5) and 30-minute sludge volume index SVI_{30} between reactor 1 (R1) and reactor 2 (R2) across different operational stages

R1, operated under a higher C/N ratio (5), exhibited only limited increases in MLSS and MLVSS throughout the operation time, which was accompanied by a substantial rise in SVI values (SVI_5 from 202.72 to 235.43 mL/g and SVI_{30} from 113.00 to 158.20 mL/g), suggesting deteriorated sludge settleability likely due to excessive organic loading and free ammonia inhibition disrupting sludge structure.

In comparison, R2, operated at a lower C/N ratio (~2.5), exhibited better biomass retention and settling properties. From Stage 1 (influent ammonia ~500 mg/L) to Stage 2 (~800 mg/L), MLSS and MLVSS concentrations increased significantly in R2, reaching 6.61 g/L and 5.77 g/L, respectively—nearly tripling their initial values. Furthermore, R2 maintained steady biomass growth under rising influent ammonia concentrations, with average MLSS increasing from 9.5 g/L at 1,300 mg/L NH_4^+-N to 12.01 g/L at >2,000 mg/L (Stage 4)—a high biomass level that contributes to system stability and reactor resilience. The SVI, an indicator of settleability and compressibility, also changed significantly throughout long-term operation. Compared to R1, R2 exhibited superior settleability, not only at Stage 2 (SVI_{30} = 90.43 mL/g), but also under higher ammonia loading conditions (> 2,000 mg/L), where SVI_{30} further decreased to 57.33 mL/g, indicating the formation of mature granules.

These findings demonstrate that optimising C/N ratio not only enhances microbial activity but also promotes the development of stable, well-structured granular biomass, which is critical for robust reactor performance in treating high-strength landfill leachate (Wu et al., 2021). In addition, high biomass levels in the GSR played a crucial role in enabling effective treatment of high ammonia wastewater.

3.2 Reactor performance

Ammonia removal performance was evaluated under increasing influent ammonia concentration, and the two reactors displayed marked difference. Under moderate ammonia loading (Stage 1, ~500 mg/L), both R1 and R2 achieved comparable ammonia removal efficiencies near 90%, with ammonia oxidation rates reached 17.40 mg N/L·h for R1 and 16.48 mg N/L·h for R2. However, under elevated ammonia stress, their performances diverged significantly.

For R1, at an influent ammonia concentration of ~800 mg/L, ammonia oxidation rate decreased to 15.64 mg N/L·h, accompanied by a drop in removal efficiency from 89.74% to 72.15%. Effluent ammonia concentration increased sharply to 231.87 mg/L, indicating process inhibition.

In contrast, R2 exhibited remarkable resilience. As influent ammonia concentrations increased beyond 2,000 mg/L, the ammonia oxidation rate rose to 91.40 mg N/L·h and ammonia removal efficiencies consistently above 99%. Following stabilisation, effluent ammonia concentrations in R2 remained below 10 mg/L, with most ammonia converted to nitrate, indicating complete and stable nitrification.

After C/N optimisation, the GSR efficiently achieved complete ammonia removal from high-strength raw leachate (NH_4^+-N >2,000 mg/L; COD >11,000 mg/L). Furthermore, optimised operational conditions effectively mitigated inhibitory effects, ensuring robust ammonia oxidation under high-strength wastewater loading.

3.3 Microbial Community and Functional Activity

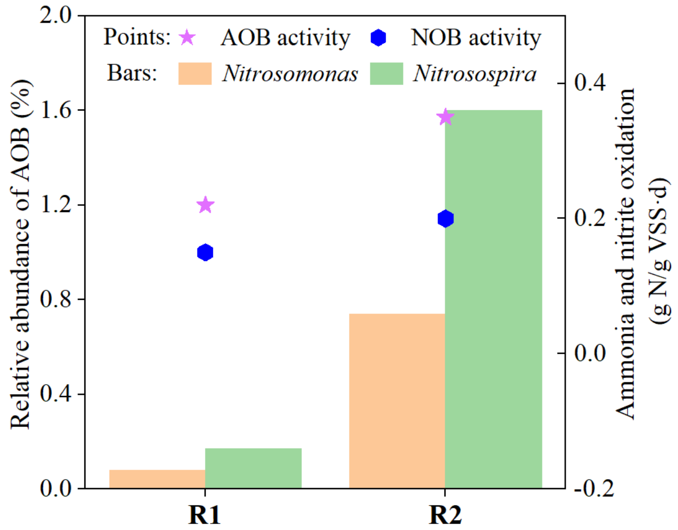

Figure 2 Comparative analysis of the relative abundance of nitrifying bacteria (Nitrosomonas and Nitrosopira) and associated ammonia- and nitrite-oxidising activities in R1 and R2

Microbial community analysis revealed clear enrichment of key nitrifying populations in R2 compared to R1. In both reactors, AOB were dominated by *Nitrosomonas* and *Nitrosospira*. However, the relative abundance of these functional nitrifiers in R2 (optimised reactor, C/N=2.5) was approximately 6-8 times higher than in R1 (figure 2).

This compositional shift was reflected in the functional activity tests, where overall nitrogen metabolism activity—including ammonia and nitrite oxidation—in R2 increased by approximately up to 60% compared to R1. Such enhanced microbial activity corresponded with R2's superior ammonia oxidation performance, as discussed in Section 3.2.

These results suggest that the optimisation of operational parameters not only supports microbial resilience but also selectively enriches and activates key functional guilds responsible for nitrification. This microbial reinforcement underpins the stability and efficiency of ammonia removal in granular sludge systems treating high-strength landfill leachate.

4 CONCLUSIONS

This study demonstrates that a lower C/N ratio (~2.5) can significantly facilitate the start-up of GSRs by enhancing microbial robustness, with AOB exhibiting up to eightfold higher abundance and 60% greater activity. The optimised system demonstrated stable and efficient treatment of extremely high-strength ammonia wastewater (> 2,000 mg/L), achieving over 99% ammonia removal efficiency within a 17.5-hour HRT, alongside a notably high MLSS concentration of 12.01 g/L. These findings highlight the importance of operational optimisation in developing robust treatment systems capable of sustaining high performance under extreme conditions—an essential step toward advancing resilient and sustainable water infrastructure.

5 WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

These findings underscore the pivotal role of microbial community engineering in strengthening treatment system resilience. Granular sludge technology, by promoting microbial self-organization and maintaining stable microbial populations, offers a scalable and adaptable solution for managing high-strength wastewater. The integration of this technology into wastewater infrastructure has the potential to improve treatment efficiency, mitigate environmental risks, and contribute to the development of more resilient and sustainable water management practices.

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Hydrological modelling to mitigate bushfire-related risks to water security

Dr Petter Nyman[1], Mr Joel Rahman[2], Dr Kristen Joyce[1], Dr Jabbar Khaledi[1], Dr Gary Sheridan[3], Tom Keeble[3], Dr Paul Richards[1]

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Title of Full Paper

Hydrological modelling to mitigate bushfire-related risks to water security

Conference Topic

Optimising Resilient Water Supply Systems

INTRODUCTION

The 2019-20 bushfire season in Australia was unprecedented in its impact on communities and the natural environment. The combination of catastrophic fire and subsequent heavy rainfall mobilised ash, sediment, and other potential contaminants (constituents), which were transported into receiving waterways and water supply reservoirs. This created various treatment challenges for water suppliers and highlighted the need to improve our collective capability to assess risk.

In this project for Water Research Australia and the project partners (WaterNSW, Melbourne Water, Seqwater, Water Corporation, SA Water, and Hunter Water), we are developing a catchment modelling tool to assess bushfire impacts on water supplies. The tool will be nationally consistent but with options to make it regionally bespoke.

METHOD/EXPERIMENTAL DESIGN

Scoping and planning

To inform development of the hydrological modelling, a literature review and scoping workshops were held with water utilities in 2023. The literature review included an assessment of potential modelling approaches and key research programs that have informed models for assessing water quality risk in Australian catchments. The workshops were focused on the bushfire experience, current practise, management questions, and modelling needs of each project partner.

Catchment modelling was determined to be the most practicable approach for quantifying contaminant mobilisation at the landscape scale, particularly given the unpredictable nature of bushfires and the logistical difficulties of post-event sampling.

The scoping phase was followed by detailed model development planning that included consultation with leading research groups based at Swansea University, the University of Melbourne, and Edith Cowan University.

A coupled modelling approach

It was clear from the scoping and planning exercises that a standalone library of bushfire water quality modules coupled with a rainfall-runoff model for understanding constituent transport was the best approach. The coupled approach means that users have the flexibility to integrate the modules with the rainfall-runoff model of their choice, and the modelling has a level of robustness that would not be possible if the modules were created within an existing catchment modelling framework. The development of the tool, currently in progress, is comprising those two distinct parts (Figure 1).

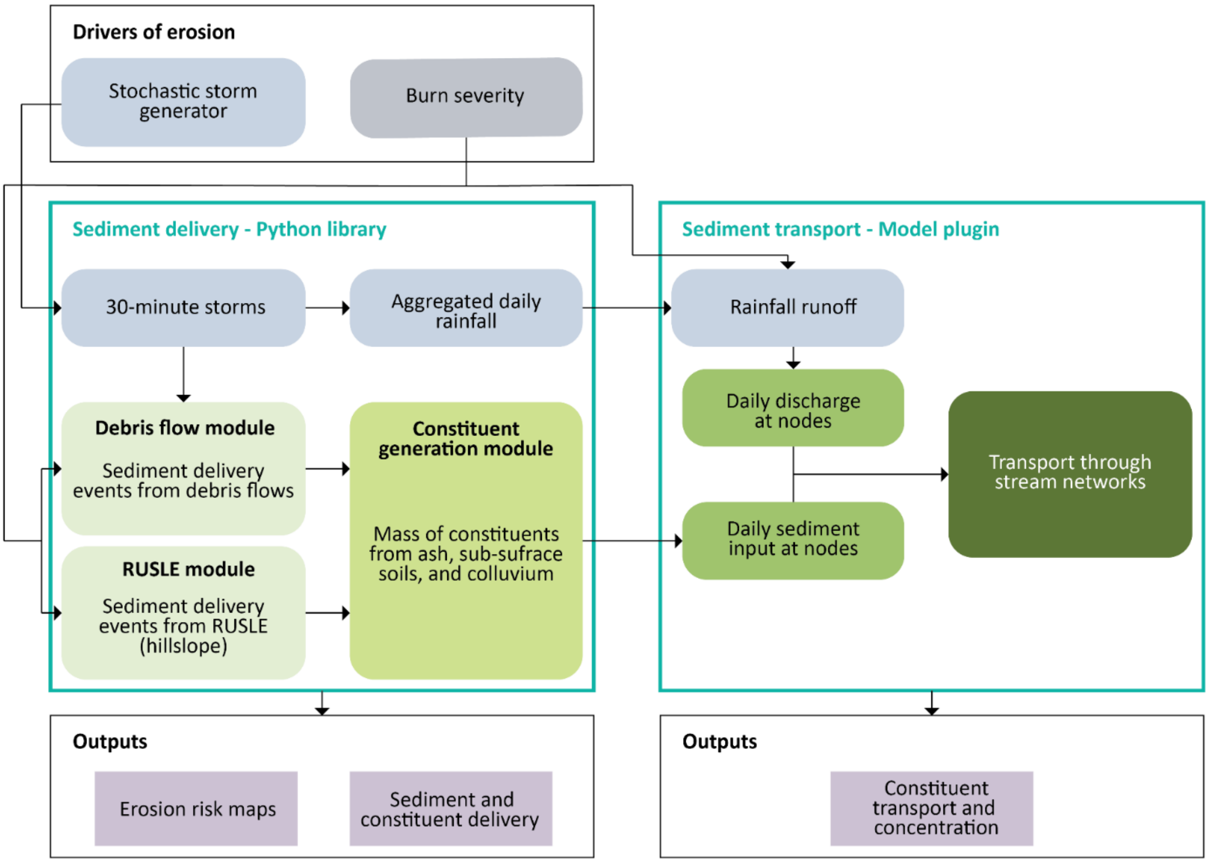

Figure 16. Conceptual representation of the coupled modelling approach.

Module development

Modules have been developed that predict the transport of ash, sediment, and nutrients from burned catchments into water supply assets, through debris flows and hillslope erosion. The modules include workflows for pre-processing data for:

- Rainfall, where a python package called Pyraingen – a stochastic rainfall model – is used to generate synthetic rainfall data. It uses rainfall statistics and observed rainfall data from weather stations to generate rainfall time series, from which 30-minute rainfall events can be extracted.
- Soil, where relevant soil properties for unburnt soil conditions (e.g., percent clay, silt, and sand) are extracted for a catchment, and soil aridity is extracted from a soil aridity raster.
- Topography, where digital elevation models (DEMs) are processed to produce spatial files on slopes, stream networks, headwaters, and flow accumulations.
- Fire severity, where satellite imagery is processed to produce spatial files for delta Normalized Burn Ratio (dNBR).

The module for debris flows (Figure 2) estimates the total mass and volume of sediment delivered via hillslope and channel erosion during post-fire debris flow events. Generally, upstream forested catchments have a higher likelihood of debris flow events following bushfires due to the decreased infiltration of soils and increased sediment availability on hillslopes caused by fire. The model assumes debris flows initiate from 2 ha headwaters that are steep enough to propagate debris flow events.

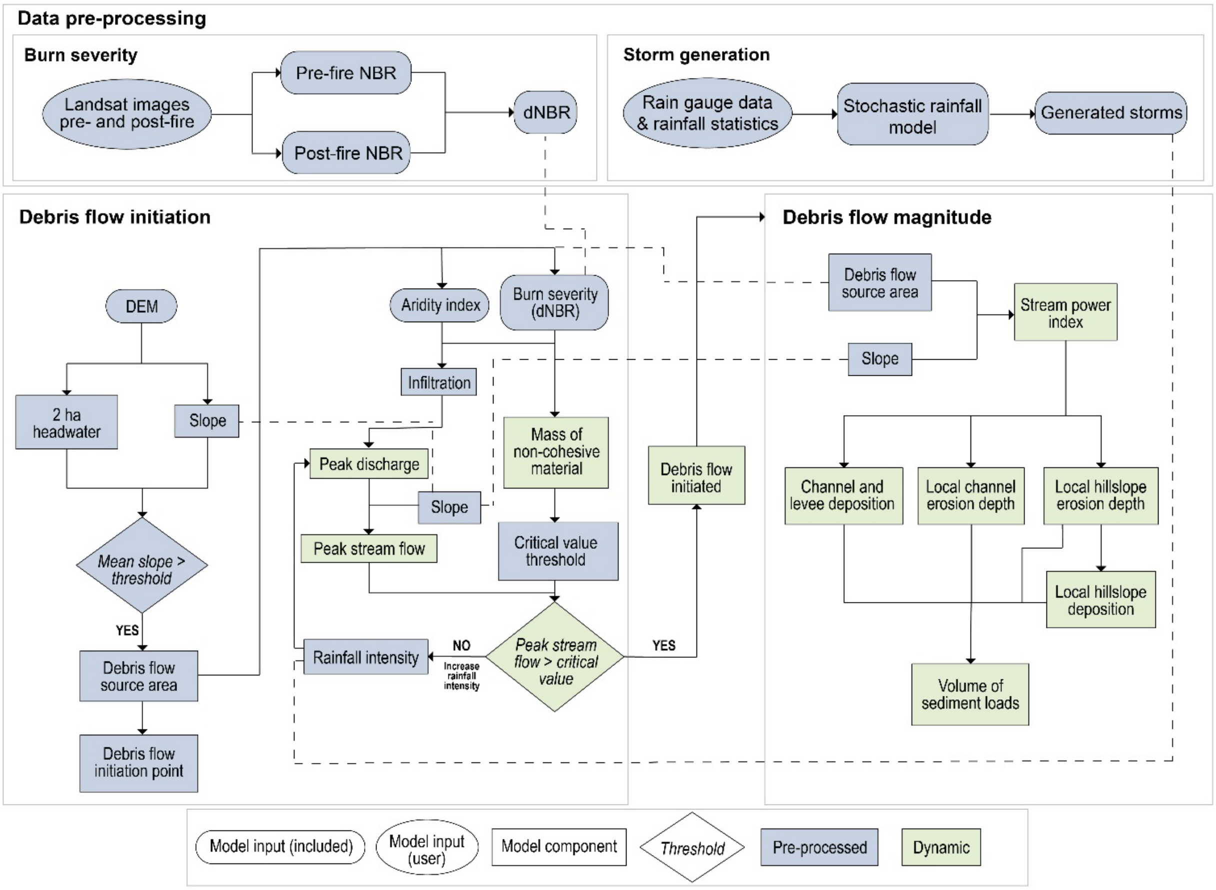

Figure 17. Conceptual representation of the debris flow module.

The module for hillslope erosion (Figure 3) is based on the Revised Universal Soil Loss Equation (RUSLE). It is implemented as an event-based erosion model using 30-minute rainfall intensities as an input. The soil erodibility and land cover factors are modified by the dNBR data.

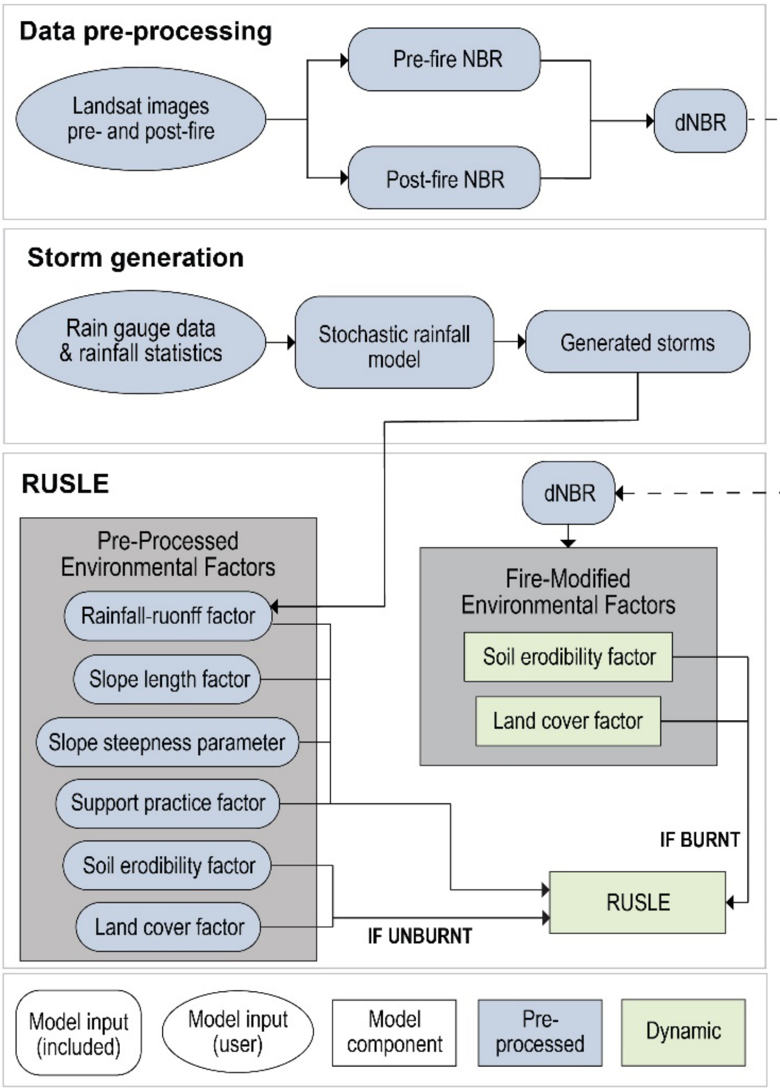

Figure 18. Conceptual representation of the hillslope erosion (RUSLE) module.

Module development has primarily been based on data for the Upper Yarra catchment in Victoria. The standalone modules can potentially be used to address management questions related to constituent generation, such as developing spatial risk maps.

Rainfall-runoff model development

The next stage of the project is integrating those modules into a rainfall-runoff model, with a view to integration with existing modelling workflows used by project partners (such as, but not limited to, the eWater Source model). In other words, the modules will be used to generate inputs for rainfall-runoff modelling.

The integrated model can then be used to assess questions related to the delivery – in addition to generation – of constituents to assets such as water supply reservoirs. For example, it includes questions that relate to delivery timing and constituent concentrations.

The integration will include validation and testing, and revision based on user feedback. The integrated model is expected to be completed in early 2026.

Future stages of the project

The latter stages of the project (in 2026-27) will expand model implementation to other regions of Australia and use case study catchments for more detailed calibration and testing.

OUTCOMES / RESULTS

The modelling will be delivered as a python library to the project partners, which includes the completed pre-processing workflows and modules described above. End users will be able to integrate this python library into their current workflows based on supporting documentation and training, which will also be provided as part of this project. The library will be implementable in python scripts, notebooks, and online data science environments such as the Open Data Cube.

The results of testing the integrated model, expanded model implementation, and case studies will be available in 2026-27.

CONCLUSIONS

This hydrological modelling will enhance Australia's resilience to bushfire-related water quality risks. It is a modular, flexible, and scientifically robust modelling tool, that combines debris flow and hillslope erosion modules with rainfall-runoff modelling. This will enable water utilities to better understand both constituent generation and delivery, and therefore to better predict, assess, and manage the impacts of bushfires on water supplies. Over the coming stages, the tool will be refined and expanded through collaboration with project partners.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

The modelling tool will help build resiliency by guiding strategic planning, risk assessment, catchment fire management, and incident response. This will ultimately help maintain safe and secure water supplies across Australia following bushfires.

This project is receiving funding from the Australian Government. The current and future stages of the project are being conducted under the Disaster Ready Fund, in addition to ongoing funding from project partners.

OZOFRACTIONATION OF WASTEWATER – REDUCING BIOLOGICAL AND CHEMICAL CONTAMINANTS INCLUDING PFAS

Mr Sean Paul[1], Mr Jason Barnett[1], Ms Hannah Goss[1], Mr Michael Dickson[2]

[1]Taswater, [2]Green Shadows

Title of Full Paper

Ozofractionation of Wastewater – Reducing Biological and Chemical Contaminants Including PFAS

Conference Topic

Optimising Resilient Water Supply Systems

INTRODUCTION

Background

Ozofractionation is an innovative technology employs micro-ozone bubbles within a fractionation chamber to treat wastewater by separating contaminants through foam fractionation. The process - developed by Green Shadows and patented by Evocra Pty Ltd – was originally designed for the remediation of hazardous chemicals including per- and polyfluoroalkyl substances (PFAS).

Three trials were conducted at the Riverside Sewage Treatment Plant (STP) in 2020, 2023, and 2024, utilizing pilot-scale tanks to assess the technology's efficacy in a municipal sewage context. This study represents its first application in municipal wastewater treatment.

Research objective

The primary objective of these trials was to evaluate the viability of ozofractionation as a supplementary or replacement technology for primary and secondary wastewater treatment, particularly in addressing emerging contaminants such as PFAS.

The treatment of key organic and inorganic contaminants was compared to conventional treatment processes currently used at Riverside STP. Operating variables (including ozone dose and hydraulic residence) were varied to investigate optimal treatment performance.

Process overview

Ozofractionation operates on principles similar to dissolved air flotation, but with enhanced contaminant removal due to the interaction of micro-ozone bubbles with wastewater contaminants (including smaller bubble formation, enhanced attraction to cationic contaminants and direct chemical oxidation).

Influent wastewater is circulated through a set of venturis which ensure effective gas-liquid mixing. The resulting fine bubbles rise through the reaction chamber, forming a foam field that collects at the top for dewatering. Although ozofractionation is not capable of complete destruction of wastewater contaminants, it concentrates them into a waste stream that can be subject to further treatment (e.g., anaerobic digestion or thermal treatment).

EXPERIMENTAL DESIGN

Figure 1 provides an overview of the ozofractionation experimental set–up. The inlet pump and composite sampler intake were submerged in the STP influent flume (post-screening).

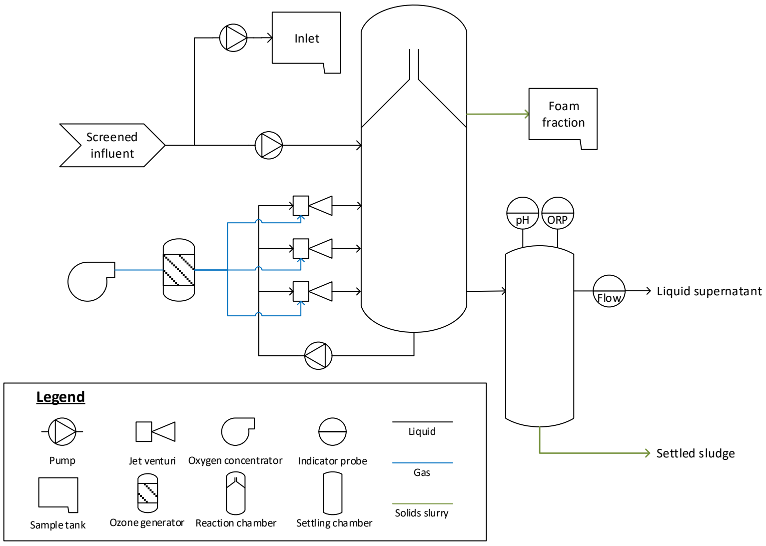

Figure 19: Process flow diagram of trial ozofractionation unit

Liquid sampling began 1.5 hrs after the process had stabilized following any adjustments to operating conditions. Liquid supernatant and settled sludge were collected as hourly grab samples, while inlet and foam fractions were collected as a mixed composite.

All samples were analysed at the NATA certified TasWater Selfs Point Laboratory. Any analytes (e.g. PFAS) not supported by the Selfs Point Lab were outsourced to ALS Australia.

OUTCOMES / RESULTS

2020 trial summary

An initial Evocra-led trial conducted in 2020 sought proof-of-concept for using ozofractionation in a municipal sewage application. The trial analysed PFAS partitioning under general operating conditions. It achieved an 89% reduction of ∑PFAS at 30 mins (to below 60 ng/L), achieving Australian drinking water criteria. Key contaminants of concern (PFOA and PFOS & PFHxS) were reduced by >99.9% in both the 30 and 120 minute hydraulic residence time (HRT) tests.

2023 trial summary

The 2023 trial sought to investigate variations in ozone dose rate (2, 5 and 10 g/hr) while maintaining an optimal 60 min HRT, although due to impacts caused by algae accumulation on the inner walls of the reaction chamber, the results were determined to be inconclusive.

2024 trial summary

An ozone dose rate of 2 g/hr was selected based on the 2023 trial. The HRT was varied between 30 min, 60 min and 120 min to represent diurnal variations in plant inflows.

Results of the trial were compared to the existing Riverside Primary Sedimentation Tank (PST), which operates under ideal conditions due to the extended HRT of 6.8 hrs compared to typical design ranges of 1.5 to 2.5 hrs. Total carbon removal within the ozofractionation process out-performed traditional primary sedimentation for all carbon fractions at all HRT (refer Table 1). Furthermore, the ozofractionation process was able to achieve a comparable removal rate for Chemical Oxygen Demand (COD) in 30 minutes, or approximately 8% of the tank volume of the existing Riverside PST.

Table 6: Comparison of organics removal in a PST vs ozofractionation treated effluent

Parameter	Riverside PST Decrease	30 HRT	60 HRT	120 HRT
Chemical Oxygen Demand (COD)	50%	56%	64%	74%
Filtered COD (fCOD)	10%	30%	33%	36%
Filter and Floc COD (ffCOD)	-11%	39%	48%	40%
Biological Oxygen Demand (BOD)	50%	59%	65%	80%
Carbonaceous BOD (cBOD)	48%	61%	65%	83%
Filtered BOD (fBOD)	-2%	47%	63%	57%

A reduction in organic loading (represented as COD and BOD) on secondary treatment processes is expected to:

- Decrease power consumption in mechanical aeration systems (estimated offset of 260 kW/d for a full-scale system at Riverside STP).
- Improved aeration efficiency due to increased effluent Oxidation Reduction Potential (ORP) and decreased Total Suspended Solids (TSS).
- Increased nitrification rates by limiting heterotrophic bacteria growth and decreasing aerobic demand for BOD decomposition.

Ozofractionation significantly outperformed traditional primary sedimentation in the removal of dissolved and fine particulate carbon fractions (fCOD, ffCOD and fBOD). These fractions typically correlate to readily biodegradable carbon. The improved partitioning of digestile carbon to the solids stream is expected to improve digester performance and biogas production.

Figure 2 displays the effect of HRT on the accumulation of organics in the foam fraction. For most carbon elements, peak accumulation was observed at 60 min HRT potentially because:

- 30 min HRT is too short a residence time to get ideal physical separation of carbon fractions due to decreased liquid to bubble contact time, resulting in a less concentration fraction rising to the dewatering column.
- 120 min HRT has a reduced rate of accumulation in the foam fraction and the settled solids, although the highest rate of removal from the liquid treated effluent (refer Table 1). This supports the theory of direct oxidation of organics. A mass balance across the ozofractionation process at 120 min HRT showed that approximately 8.8 g COD/hr (or 24% of the influent COD) was removed via oxidation. This could be considered inefficient due to the cost associated with its generation (approximately 12 kW/ kg COD vs 0.44 kW/ kg COD for an aerated activated sludge system). The COD load concentrated to the foam fraction would be better treated in an anaerobic digester, due to lower power consumption and the capture of biogas.
- 60 min HRT appears to be the ideal balance between high bubble attraction and removal through fractionation, while minimising the excessive use of ozone leading to direct chemical oxidation.

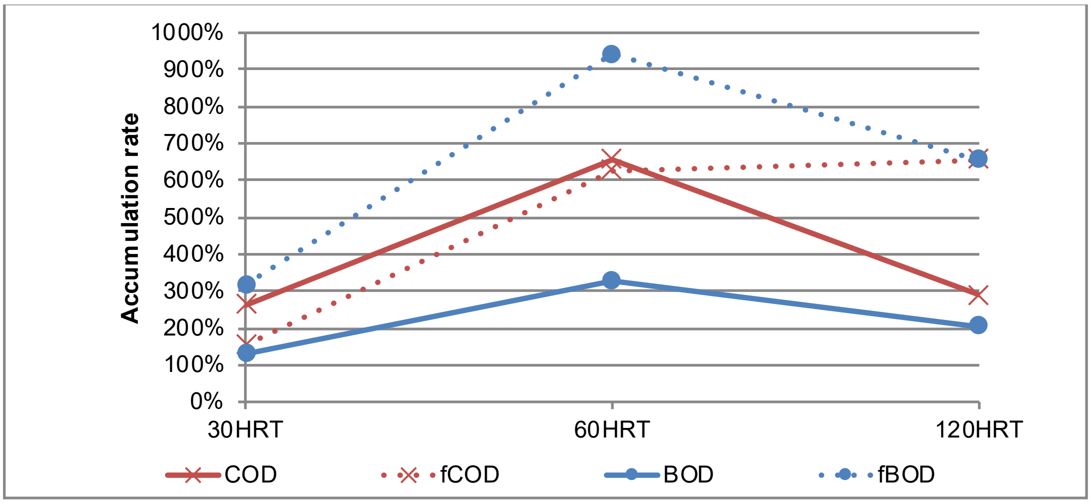

Figure 20: Accumulation rate of COD and BOD in the foam fraction

A similar overall trend is observed in the treatment of suspended solids, which is expected in a primary treatment process where a significant portion of COD and BOD are in a non-soluble state.

Reduction of solids in the treated liquid stream showed comparable results to traditional primary sedimentation, albeit at significantly faster rates (refer Table 2). For example, TSS and VSS removal was comparable through ozofractionation in 60 minutes, compared to 6.8 hrs in the existing Riverside PST.

Table 7: Comparison of solids removal in a PST vs ozofractionation treated effluent

Parameter	Riverside PST Decrease	30 HRT	60 HRT	120 HRT
Total Suspended Solids (TSS)	73%	69%	72%	85%
Volatile Suspended Solids (VSS)	74%	70%	74%	86%

The investigation found that the treatment of Oil and Grease (O&G) significantly outperformed traditional gravity sedimentation (refer Table 3). O&G represents a high strength organic load that can be partitioned to anaerobic digestion for the generation of biogas, rather than passing through to secondary treatment where it exerts a high aeration demand.

Table 8: Comparison of O&G removal in a PST vs ozofractionation treated effluent

Parameter	Riverside PST Decrease	30 HRT	60 HRT	120 HRT
Oil and Grease (O&G)	20–40%	76%	80%	92%

The ORP of the treated effluent was maintained above 300 mV across the duration of the trial. The increase in ORP from raw influent (typically below negative 50 mV) has the potential to enhance downstream nitrification and aeration efficiency for cBOD degradation, reduce hydrogen sulphide generation, optimise biological phorphorus removal and aid disinfection efficacy.

CONCLUSIONS

The ozofractionation process reduced total organics, solids and O&G in the liquid supernatant stream by concentrating them in the foam fraction stream. The trial concluded that the 60 min HRT with 2 g/hr ozone dose is optimal due to the balance between adequate bubble contact time and minimisation of direct oxidation.

The 60 min HRT trial was found to improve treatment when compared to the existing PSTs at Riverside STP, within 16% of the equivalent HRT. When paired with a secondary treatment processes capable of nutrient reduction, ozofractionation is expected to decrease effluent BOD, COD, TSS and O&G with indirect improvements to effluent ammonia and pathogens.

Additional benefits of ozofractionation observed during the trials include:

- **Increased primary effluent ORP**: Expected to reduce aeration demand, minimise onsite odour and corrosion of downstream assets and reduce pathogens.
- **Conversion of organics**: Higher ozone doses or contact time is hypothesized to aid the conversion of unbiodegradable / poorly biodigestible COD to more readily biodegradable forms for improved downstream treatment.
- **Partitioning of PFAS and other contaminants of concern:** Wastewater contaminants are concentrated into the foam fraction to be subjected to destructive treatment.
- **Increased sludge volatility:** Improved partitioning of readily biodegradable carbon is expected to increase overall biogas production through anaerobic digestion (estimated over 40% increase).

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Additional modelling, trials and pilot scale research are warranted for detailed investigation of STP performance indicators including BOD / COD removal, nutrient management, carbon to nitrogen ratios and effects on secondary treatment processes, biogas production, implications to tertiary processes, PFAS performance and circular economy opportunities.

Model conditions will investigate ozofractionation as a PFAS polishing retro-fit to a conventional STP, or as a novel integrated treatment solution. Onsite trials will broaden the available data set, leading to decreased design uncertainty and maximise opportunities to leverage ozofractionation in the sector. TasWater has engaged Hatch for further modelling and trial design.

Rethinking Centralised Water Services Systems

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Title of Full Paper

Rethinking Centralised Water Services Systems

Conference Topic

Optimising Resilient Water Supply Systems

INTRODUCTION

Under growing population and climate change, centralised water service systems face tremendous challenges to meet the growing urban water demand and provide cost effective services. Energy is one of the major operating costs for water services (Paul et al. 2019; JICA 2017; KERC 2018, 2017; IBNET 2017; Copeland 2014; ISF 2013; IBM, 2010; Chandrashekar 2006). Many cities are now moving towards distant sources of water, deep aquifers or desalination, due to urbanisation for water supplies all of which are energy intensive and expensive (Paul et al. 2019). Further, in a centralised water service system, a single quality of water is used for all purposes which is not necessarily needed when 70-80% of city water is used for non-potable purposes (SANRDP 1999). This does not require high quality drinking water (Stillwell, Hoppock & Webber 2010) and can be potentially met from recycled water. In California, outdoor water use can be as high as 53% (Gleick et al. 2012), and in Perth, Australia, as high as 54% (Hammer, Rogers & Chesterfield 2018). Alternative sources of water, such as treated wastewater, rainwater, or stormwater, can be significant sources of water to meet this non-potable water demand or even for potable or drinking water, provided the quality of the water is ensured and public acceptance is secured.

Many countries, particularly water stressed cities such as Nabimia, Singapore, and many states in the USA, for example, California, Texas, Australia, are using recycled water for non-potable and potable purposes as direct or indirect potable reuse, but those are energy intensive and expensive (Paul et al. 2019; Paul et al. 2018; Water in the West 2013; ISF 2013; Kenway et al. 2011; Kenway et al. 2008). Producing recycled water from centralised water systems though requires less energy as the energy needed for treatment of wastewater to maintain effluent water standards before its disposal to water bodies or for many beneficial uses, is considered as 'sunk' cost (meaning unavoidable that it is needed whether it is required or not) (CEC 2005; Water in the West 2013), sending the recycled water back to the end users is often energy intensive and expensive requiring dual pipe systems (Apostolidis et al., 2011; Cook et al., 2012). A case study completed by Inland Empire Utility Agency (IEUA) identified recycled water as the least energy intensive option (0.32 kWh/KL)[6] and a local source of water but sending back the water to the end users is very high but still less than desalinisation of water.

Many decentralised recycled water systems have been implemented all over the world but those have again encountered many challenges due to involvement of high cost, poor operation and maintenance and other factors such as the use of excess recycled water and prices of recycled water. Further, though many recycled water systems have been implemented, the use of recycled water has not increased to a satisfactory level due to its high costs and public acceptance for direct or indirect potable water reuse.

Japan has implemented over 2500 decentralised water and wastewater systems (Yamagata et al. 2003). The Metropolitan Government Facilities in Tokyo used this recycled water for toilet flushing, gardening and other purposes such as cooling purposes (Bernal & Ines 2012; Gikas & Tchobanoglous 2009). Bengaluru (India) has installed over 2000 decentralised wastewater treatment systems at individual/residential complexes under the

[6] kWh/kL (Kilowatt hour/kiloliter)

'Zero Liquid Discharge' programme. However, only 200 of these plants are reportedly functioning because of high operational and maintenance costs (Kuttuva et al., 2017).

Another system has been promoted recently which is known as distributed recycled water system. These are systems connected with existing sewerage network or can be connected with an existing sewerage network (ISF 2013c; Biggs et al. 2010, 2009). These works like energy grid system where water from one point can be transferred to another point and can work as water grid.

This paper reviews existing literature and investigate whether distributed recycled water systems and 'fit-for-purpose' water have the potential to reduce energy use for water services and provide cost effective, reliable and resilient water supplies.

METHODS

A systematic literature review was done using the whole water use cycle (Chan 2013; CEC 2005) as mentioned below to know the energy intensity of centralised, decentralised and distributed water service systems and how energy intensity of a system varies with scale and technologies/quality of water used, or 'Fit-for-purpose' water as mentioned below in Figure 1 and Figure 2 respectively.

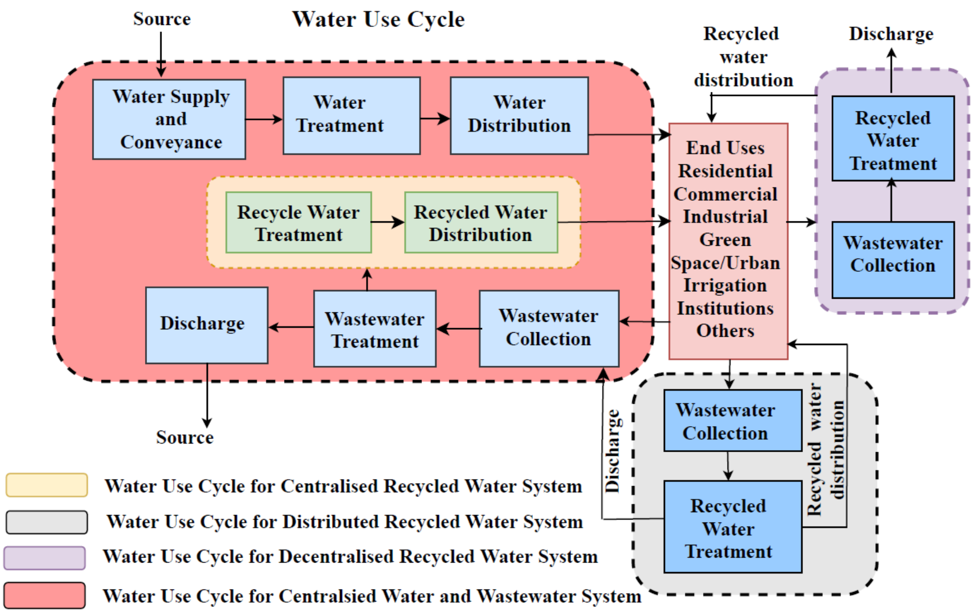

Figure 1: Whole Water Use Cycle of Centralised, Decentralised and Distributed Recycled Water Service Systems (Paul et al. 2019; CEC 2005)

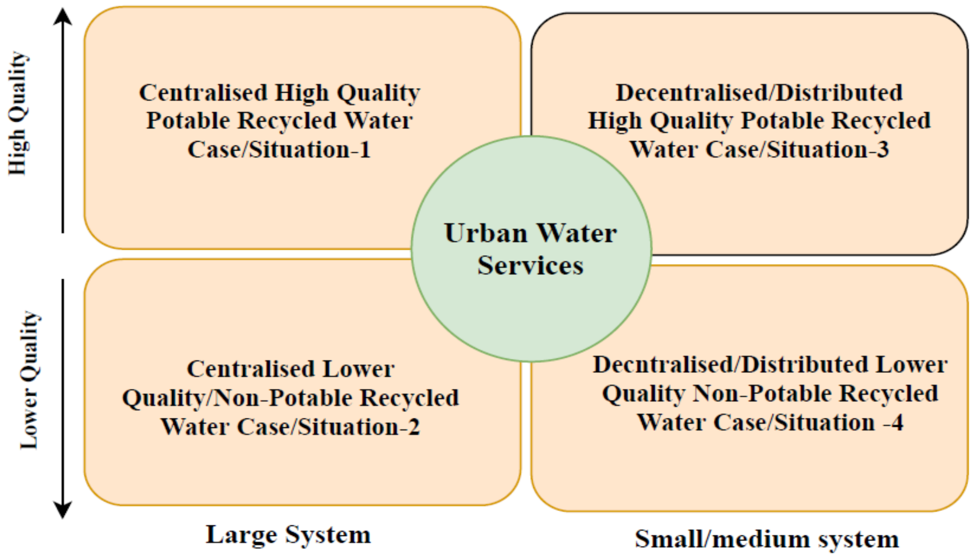

Figure 2: Four Cases of Fit-for-Purpose Recycled Water which has the potential to reduce the EI of Urban Water Service Systems (Paul et al. 2019).

Producing high-quality water requires advanced technologies, particularly for drinking water. However, many non-potable water uses such as toilet flushing, gardening, firefighting, washing, and construction purposes don't require drinking water quality water and if this is followed, it can save huge energy.

Four "cases" as shown in Figure 2 was considered to review the literature how those have been followed to generate recycled water and its reuse.

OUTCOMES / RESULTS

Studies show that the EI for Direct Potable Reuse (DPR) using centralised potable water recycling systems, ranges from 1.7 to 2.22 kWh/kL. A number of studies state that DPR can be less energy intensive than long distant water transfer (CEC, 2005) (2.83 kWh/kL) or desalination (2.2 to 5.8 kWh/kL) (CEC 2005; Cooley & Wilkinson 2012; Hummer & Eden 2016; Lahnsteiner, van Rensburg & Esterhuizen 2018; NRC of NAS 2012) or IPR where the engineering buffer is expensive (Lahnsteiner et al., 2018). However, pumping back the recycled water to end users makes it very energy intensive and expensive for non-potable water reuse as it requires a dual pipe system. Pumping energy for this might involve 0.34 kWh/kL energy on average (Hall et al., 2009). Cooley and Wilkinson (2012) shows the average is 0.37 a slightly higher and can vary from 0.26 to 0.79 kWh/kL. On the other hand, small decentralised recycled water systems have higher EIs than large centralised systems. But larger decentralised systems (distributed systems connected to existing sewerage network or can be connected with it) have lower EIs.

Figure 3 as studied by Paul et al. 2019 shows that the current trend is to produce high-quality recycled water even higher than drinking quality for all non-potable purposes (just like the practice of single high quality for all purposes by centralised water supply system) example for Caboolture in Australia (the same treatment train is used in Goreangab Water Reclamation Plant (GWRP) in Namibia for Direct Potable Reuse), Singapore, SEQ region using AWT (Advanced Water Treatment) technologies such as MBR (Membrane Bioreactor and RO (Reverse Osmosis). Stringent water quality standards and risk concerns drive the necessity to produce high-quality recycled water at a significant energy cost (Paul et al. 2019; Mukheibir & Mitchell 2018), which is not necessarily required. There is limited data on the energy intensity of water service systems, particularly for recycled water systems that use the whole water use cycle. Paul et al. 2019 did a comprehensive study of the energy intensity of various centralised and decentralised/distributed recycled water systems around the world available which is presented in Figure 3.

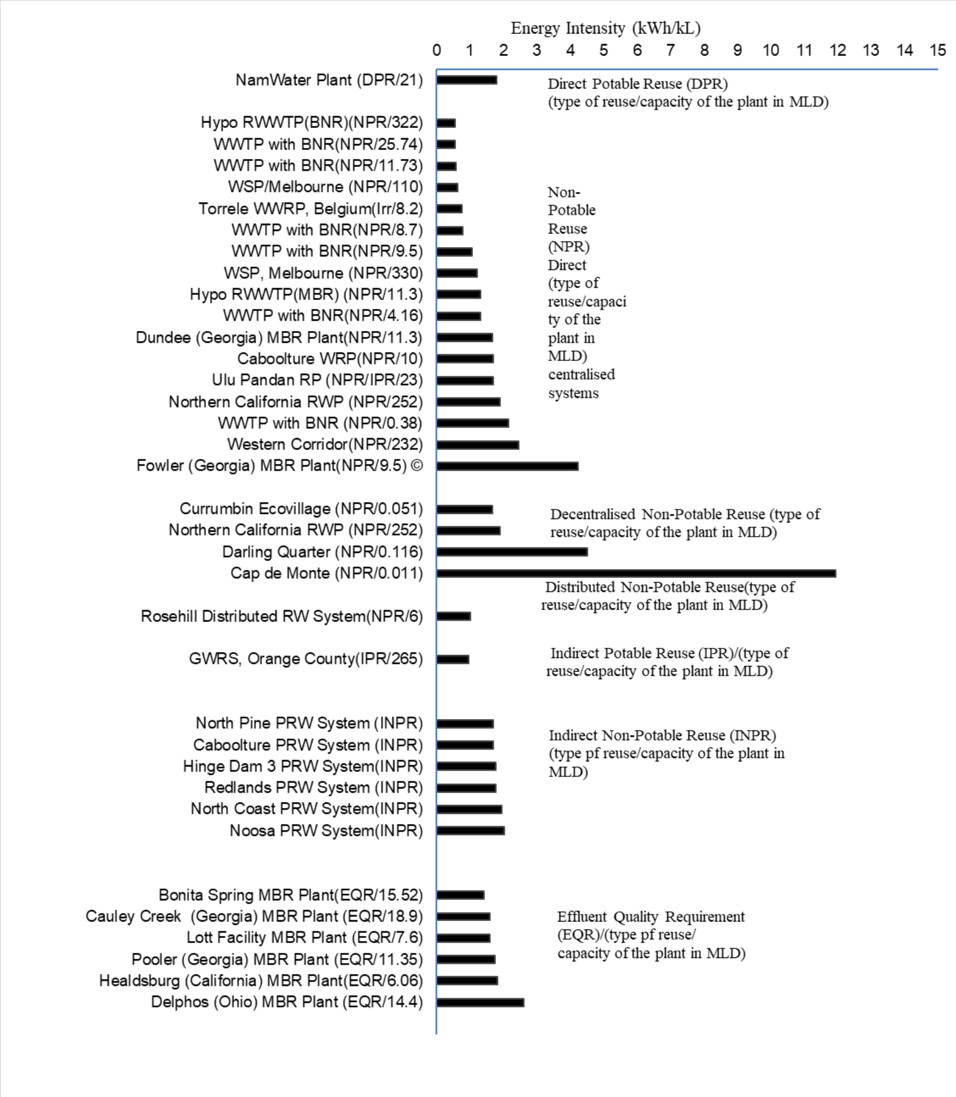

Figure 3: Energy Intensity of centralised and decentralised recycled water plants around the world available from literature (Paul et al. 2019)

Limited data were also found to understand how EI varies with the size of a plant for a particular treatment technology. To understand the variation of EI with the size of a plant, available EI data with the same technology and treatment train are required. In this respect, Goldstein and Smith, (2002), EPRI and WREF (2013) and ASTE (2012) have done some extensive studies on centralised water recycling systems how EI varies with the size of a plant. Other notable studies have been done by Cooley and Wilkinson (2012), Eaton (2013), and Scales et al. (2015). Some EI data of recycled water plants using the same treatment train, and RO technology was found from the SEQ region, but their associated capacity could not be found in the literature (Hall et al., 2009). The EI data of small-scale water systems is further rare, mainly those that have been conducted in Australia and the USA (Kavvada et al. 2016; Sharma et al. 2012; Shehabi et al. 2012). Their studies found that small-scale, decentralised systems have higher EIs and GHG emissions (Kavvada et al. 2016; Sharma et al. 2012).

A comprehensive survey was supported by Water Reuse Research Foundation (WRRF) of AWWA, the California Electric Commission (CEC) and the New York State Energy Research and Development Authority (NYSERDA) in 2007 for the assessment of EI of various steps of the water use cycle of 266 WWTPs and 125 water supply systems serving a population of more than 10,000 and having a capacity greater than 5.7 MLD (Cooley & Wilkinson 2012; NYSERDA 2008) (AwwaRF 2007). The data shows a good relationship between EI and the size of a system. Hall et al. (2009) also shows there is a strong relationship of EI with scale/size of a system.

Shehabi et al., 2012 and Stokes and Horvath, 2012 state that life cycle energy and GHG emissions of decentralised wastewater/water recycling systems can be lowered if a significant amount of wastewater is recycled. It further strengthens the view that larger decentralised water recycling systems (distributed water recycling systems or mid-scale systems) have less EIs. An extensive and systematic literature review done by Paul et al. 2019 shows that systems below 5 MLD has higher EIs; systems from 5-75 MLD has moderate EIs and systems from 75-200 MLD have less EIs. After 200 MLD, systems have a flat intensity. So prudent selection of an appropriate size and technologies have enough opportunity to reduce Energy Intensity (EI) for urban water services. The Energy Intensities (EIs) with sizes/scales of water recycling systems can be shown in Table 1.

Table 1: Energy Intensity of potable and non-potable water reuse with various scale or size of centralised water recycling systems (Paul et al. 2019)

Size (MLD)	Energy Intensity (Potable Water) kWh/kL	Energy Intensity (Non-Potable Water) kWh/kL
<5	2-0.75	2-0.48
5-75	0.9-0.4	0.75-0.3
75-200	0.8-0.2	0.55-0.25
>200	<0.8	<0.55

Systems between 5-200 MLD have EIs from 0.8-0.2 kWh/kL for potable water reuse and 0.55-0.25 kWh/kL for non-potable water reuse. Provided distributed recycled water systems are used in this range, energy use could be further reduced as the residuals (effluent) from such plants can be discharged into the existing sewerage network and conveyed to centralised treatment plants. As these systems follow a basin-wide approach of water management in a city, these can sustainable, robust, and resilient.

CONCLUSION

Though there is limited literature on the EIs of recycled water systems using the whole water cycle, existing literature helped interpret that distributed recycled water systems have huge potential to reduce EI for urban water services. Though the implementation of such systems could be challenging against the age-old centralised systems, this can provide reliable and resilient water supplies and help create water circularity within a city and achieve a circular economy.

The regulators and policymakers should understand the necessity to develop appropriate regulations/standards for various end uses, rather than using uniform standards for all end uses of recycled water to overcome the problem. Using 'Fit for Purpose' water together with the selection of appropriate technologies for the associated water quality, the EI of a water recycling system can potentially be reduced.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

There is an urgent and priority need to work on regulations for recycled water, seriously enabling the expansion of recycled water, but not without compromising the health and only 'fit for purpose' water is the solution for cost-effective water supplies that can help achieve SDGs.

The water supply of cities is still heavily dependent on centralised water systems. More investment should be channelised for distributed recycled water. Further, institutional reform that helps implement recycled/one water management is essential for the transition from centralised to distributed recycled water systems.

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284

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The Impact of Coagulants and Flocculants on Cyanobacterial Cell Viability and Integrity

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The Impact of Coagulants and Flocculants on Cyanobacterial Cell Viability and Integrity

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Conference Topic

Optimising Resilient Water Supply Systems

INTRODUCTION

Global climate change has exacerbated the proliferation of nuisance and harmful cyanobacterial blooms in our already limited surface water resources. Although cyanobacteria are similar to plants, the increasing frequency and intensity of these blooms pose significant challenges, including: (1) poisoning of animals, fish, and humans through cyanotoxins; (2) disruptions within water treatment processes, leading to toxic cell accumulation and increased treatment costs.

In response, water utilities worldwide have implemented various methods to address cyanobacterial blooms. The most common approach during these blooms involves the aggregation and removal of cyanobacterial cells from the water. This is typically achieved through coagulation-flocculation processes, which aggregate the cells, followed by separation techniques such as sedimentation, filtration, or dissolved air flotation (DAF). Since the toxins and undesirable metabolites are primarily contained within the cyanobacterial cells, the goal of these processes is to remove the cells intact, without rupturing their membranes.

However, coagulants and flocculants, particularly cationic ones, can interact with the negatively charged surfaces of cyanobacterial cell membranes, potentially destabilising and damaging them. This membrane disruption can lead to the release of intracellular contents, including toxins and other harmful metabolites, into the surrounding water. This not only reduces the efficiency of cell removal but also risks contaminating the treated water with the very toxins the treatment aims to mitigate. Such contamination increases the potential health risks to humans, animals, and marine life, particularly as they are in close proximity to the final treatment barriers.

Furthermore, after the treatment, the cyanobacterial cell sludge is often stored in sludge lagoons for extended periods. During this time, additional cell damage can occur, leading to further toxin release, complicating sludge management. However, it is unclear whether the commercially available coagulants and flocculants contribute to cell rupture and the subsequent release of harmful intracellular material. This represents a significant research gap and is the focus of this study.

Overall, the primary aim of this study is to evaluate the effectiveness of commercially available coagulants and flocculants in cyanobacterial management. The evaluation will consider not only cell removal efficiencies following coagulation-flocculation-sedimentation but also the potential for toxin release during the storage of treated cells. A toxic strain of *Microcystis aeruginosa*, the most commonly found cyanobacteria species worldwide, was used as the model microorganism in this study. The outcomes will provide insights into whether commonly used methods suffer from inefficiencies, high costs, and a general lack of sustainability.

METHOD/EXPERIMENTAL DESIGN

Microcystis aeruginosa (CS – 555/01; toxic strain) was cultured in MLA media. Cells were harvested for experiments at their late exponential growth phase. Each species was then resuspended in a bicarbonate buffer at a concentration of $3 \times 10^6 – 5 \times 10^6$ cells·mL^{-1}. The solutions were then subject to coagulation and flocculation jar tests using seven different commercially available coagulants and flocculants commonly used in academic studies and in the water industry including poly(diallyldimethylammonium chloride) (PDADMAC), aluminum chlorohydrate (ACH), ferric chloride, poly(aluminuim chloride), aluminium sulphate (alum), alkaline floculation (induced by dosing NaOH and increasing pH to > 12) and the cationic polyacrylamides Magnafloc™ LT22s (LT22S).

Toxin analysis in the supernatants of control and treated solutions was then undertaken using an LC-MS/MS method developed in-house based on the US EPA method. Nine different toxins were analysed. Only total toxin data is presented in this study.

OUTCOMES / RESULTS

Cell removal efficiencies exceeding 90% were achieved for all coagulants and flocculants tested, indicating that each of these coagulants and flocculants was effective in significantly reducing cyanobacteria cells in water treatment scenarios (Fig.1). This high removal rate suggests that minimal cyanobacteria would carry over to subsequent treatment stages, thereby reducing the likelihood of cell accumulation and growth within the treatment plants.

However, when toxin levels were measured, release of toxins in the first 6 h after the treatment was observed with several coagulants and flocculants including PDADMAC, ACH, ferric chloride, alum and NaOH (Fig.2). When the flocs were stored upto 168 h, gradual release of toxins into the water was observed, indicated via increasing toxin concentrations over the entire duration, reflecting increasing cell damage. The rising total toxin concentrations eventually exceeded guideline limits (Fig.2). MC-RR (demethylated) was the predominant toxin released, accounting for approximately 90% of the total toxins detected (data not shown). MC-LR was also present and near guideline limits (data not shown) but was less prevalent compared to the overall microcystin concentrations (Fig.2).

Interestingly, some toxins appeared to be released more rapidly than others (data not shown). For instance, MC-RR (demthylated) was found to be released rapdily upon cell lysis while MC-LR released only when stored for 168 h (data not shown). Further experiments are required to determine whether this phenomenon is due to the preferential complexation of specific toxins with coagulants and flocculants, or if it results from poor interaction of the toxins within the testing column.

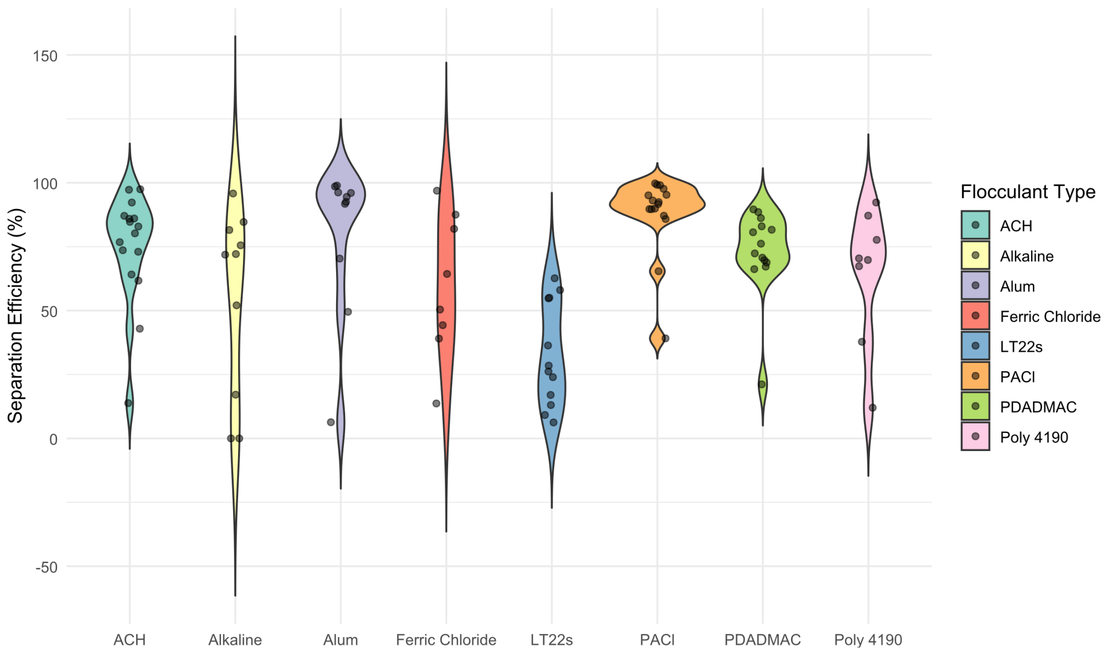

Figure 1: Cell removal efficiencies for different coagulants and flocculants trailed. Data points within the violin plots represent different concentrations.

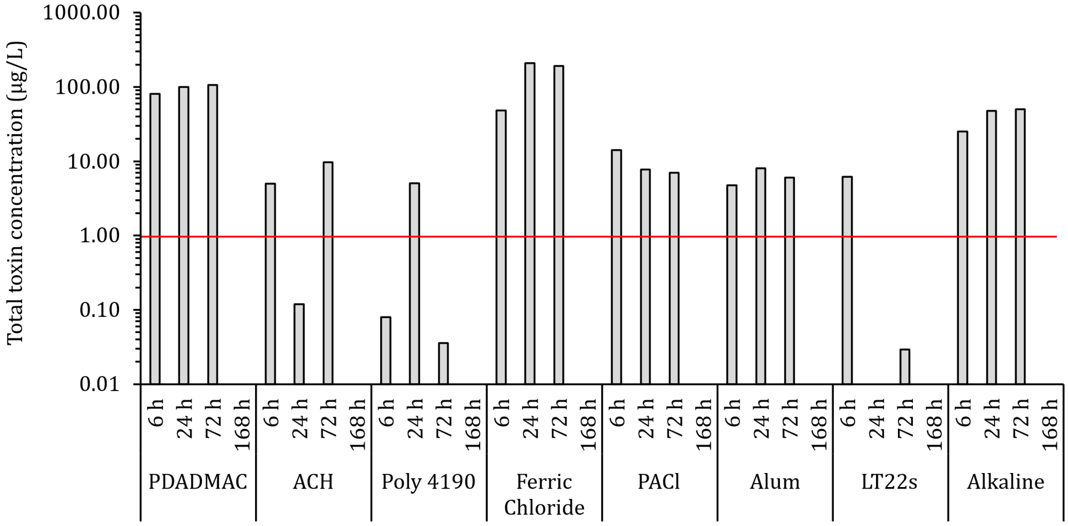

Figure 2: Toxin concentrations in the supernatant. Toxins are released due to damage of cells when using different coagulants and flocculants. Red line represents the Australian Drinking Water Guideline limits for MC-LR.

CONCLUSIONS

In conclusion, this study demonstrated the effectiveness of various commercially available coagulants and flocculants in removing cyanobacteria cells from water, with removal efficiencies exceeding 90% across all tested agents. However, the findings also highlighted a critical challenge: the risk of toxin release during and after treatment, particularly when using PDADMAC, ACH, ferric chloride, alum and NaOH as coagulants and flocculants. The progressive release of toxins over time, especially MC-RR, underscores the need for careful selection and monitoring of treatment agents to minimize potential health risks. Further research is necessary to explore the mechanisms behind the differential toxin release and to develop strategies that ensure both effective cell removal and toxin containment in water treatment processes.

WHAT’S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

This study underscores the urgent need to re-evaluate current cyanobacteria treatment practices in light of climate-driven bloom intensification. While conventional coagulants and flocculants achieve high cell removal, their potential to trigger toxin release—both during treatment and prolonged sludge storage—introduces new risks that compromise water safety and undermine treatment resilience.

By identifying specific treatment agents (e.g. PDADMAC, ACH, alum, ferric chloride) associated with early and sustained toxin release, this work enables utilities to make more informed chemical choices, balancing removal efficacy with toxin containment. These findings provide a foundation for rethinking coagulation-flocculation protocols to prevent inadvertent exposure to cyanotoxins post-treatment.

Moving forward, the results will inform the development of improved guidelines and operational frameworks for bloom management under variable conditions. This includes the design of next-generation coagulants, the optimisation of sludge handling protocols, and real-time toxin monitoring strategies. Together, these efforts will strengthen utility preparedness, enhance public health protection, and future-proof drinking water systems against increasingly frequent and severe bloom events.

The real cost of managing risks posed by contaminants of emerging concern to Queensland's water sector

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The real cost of managing risks posed by contaminants of emerging concern to Queensland's water sector.

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INTRODUCTION

Over the past two years, interest in PFAS contamination in Australia has surged, beginning with the settlement of a class action against the Commonwealth in May 2023 and peaking in June 2024 with a Sydney Morning Herald article alleging that PFAS compounds have contaminated the drinking water of up to 1.8 million Australians.

This recent media attention has brought renewed focus to an issue that has long been a concern for the urban water sector. As analytical techniques advance, so too does awareness of PFAS in drinking water and the environment, and interest from the media and regulators.

In response, new and proposed regulations have escalated expectations for monitoring and managing PFAS and other emerging contaminants. However, compliance with these standards imposes substantial financial and operational costs—particularly for regional and remote water service providers (WSP) with limited resources. The disproportionate focus on PFAS risks diverting funding away from more pressing and well-understood public health threats, such as microbiological contamination.

DRINKING WATER SUPPLY RISKS

Data from Queensland's water supply regulator highlights the persistent vulnerability of regional water systems. Boil water alerts are issued as a precautionary measure to protect public health when a community is at risk from supplied drinking water. Records from the water supply regulator[7] show that 111 boil water alerts were issued by 35 providers in regional Queensland over 3 years to 30 June 2024. Of these alerts, providers resolved 108 with an average duration of 62 days indicating sustained microbiological risks.

Approximately 30 communities across 13 LGAs do not disinfect their drinking water, relying on high-temperature bores from the Great Artesian Basin to supply the network at temperatures commonly more than 50 degrees Celsius. Chlorination of the network at these temperatures is technically challenging and cost-prohibitive.

For communities reliant on surface raw water sources, most water treatment plants (WTP) in Queensland are old, especially in smaller communities where capacity expansions (and thus modernisation) have not been required due to declining populations. Older WTP typically have a single microbial treatment barrier for protozoa.

Most surface water drinking catchments in Queensland would be in the highest risk category (uncontrolled), due to proximity to grazing pasture. Implementation of Australian Drinking Water Guidelines Health Based

[7] Contained in Queensland Audit Office Report 7: 2024–25 Managing Queensland's regional water quality https://www.qao.qld.gov.au/reports-resources/reports-parliament/managing-queenslands-regional-water-quality

Targets recommends multiple microbial barriers to achieve a log reduction value of pathogenic concentration (LRV) of 5 for such catchments[8]. Most WTP, even at current best practice provide a LRV of 4.

UNDERINVESTMENT IN INFRASTRUCTURE

There is a significant water and sewerage infrastructure deficit (the so-called infrastructure cliff) across all regions and local government areas of Queensland. Chronic under-investment in water and sewerage infrastructure can be attributed to the cessation of dedicated water and sewerage grant and subsidy programs, in favour of competitive grant programs. It is challenging for small regional, rural and remote councils to compete for grant funding with larger, better resourced councils.

A recent report by the Queensland Audit Office[9] has highlighted that 48 of Queensland's 77 councils are financially unsustainable, dominated by regional and remote councils. This leads to a dependency on grants because councils, due to their remoteness and low population, cannot generate enough income to cover their costs.

Councils without the capacity (technical or financial) to undertake integrated planning activities for their assets are trapped in a cycle of reactive asset maintenance and repair, which increases budgetary pressures and reduces the capacity of council to undertake proactive infrastructure renewal.

A recent regional infrastructure criticality assessment underscores the systemic risk:

- 40% of WWTPs and 35% of WTPs are at high/major risk of failure.
- 75% of sewer networks and 30% of water reservoirs fall in the same category.
- 40% of water bores—critical for supply—are also at high/major risk.

Figure 1: A drinking water bore from WSP in south-west Queensland, which is more than 100 years old. This bore provides backup drinking water supply.

REGULATORY BURDEN OF PFAS

Recent regulatory developments signal an increasing burden for WSPs:

- **PFAS NEMP 3.0**: Mandates Maximum Allowable Soil Contaminant Concentration (MASCC) for key PFAS in biosolids reuse, with stringent QA/QC protocols.
- **NSW Biosolids Guideline Review**: Introduces new contaminants and stricter limits.
- **National Health and Medical Research Council (NHMRC) Review of PFAS in Australian drinking water**: Suggests lower guideline values for PFAS in drinking water.
- **Queensland End of Waste Code for Biochar**: Imposes low PFAS limits for multiple PFAS congeners and costly testing regimes.
- These initiatives are on top of existing compliance requirements:
- **Queensland End of Waste Code for Biosolids**: Imposes low PFAS limits for multiple PFAS congeners and costly testing regimes.
- **Queensland's *Environmental Protection Regulation 2019***: PFAS is a prescribed water contaminant and cannot legally be discharged to the environment at any detected concentration.

[8] https://www.waterquality.gov.au/guidelines/drinking-water
[9] Queensland Audit Office Report 8: 2023–24 Local government 2023 https://www.qao.qld.gov.au/reports-resources/reports-parliament/local-government-2023

Compliance with these regulations requires high-resolution, low-detection-limit analytical testing that is expensive and, for regional Queensland is logistically difficult, labour-intensive (particularly if specialist sampling personnel must be used), and operationally challenging.

COSTS OF PFAS

Challenges that the sector is already facing from PFAS include:

- Increased capital costs for treatment to deal with PFAS in both water and wastewater.
- Increased treatment plant operating and testing costs to manage PFAS.
- Impacts on capital delivery programs from delays and increased costs from land remediation.
- Legacy risk issues from historical biosolids and water reuse activities.
- Regulatory uncertainty, undefined and inconsistent limits particularly from environmental regulators.

Case Study 1: Cost of PFAS Compliance in Regional Queensland

In 2018, PFAS was detected in groundwater in a Queensland community (population < 20,000). The affected WSP responded by sourcing alternative water from adjacent borefields, incurring:

- $650,000 in infrastructure costs, labour, and consulting fees (excluding testing).
- $280,000 for laboratory testing of 500+ samples, plus $180,000 in freight—a total PFAS monitoring cost of $460,000.

PFAS remains detectable in raw water below current guideline values but near proposed health-based thresholds. The limit of reporting (5 ng/L) exceeds some proposed guideline values, complicating compliance efforts.

Case Study 2: Cost of PFAS treatment

A large WSP in SEQ assessed the capital cost associated with infrastructure to remove of PFAS from the treated effluent stream of its WWTPs[10].

Treatment of wastewater to remove PFAS will require many pretreatment steps due to the complexity of wastewater which has many contaminants and high concentrations of organic matter. The capital costs for improvements, when scaled up to all Queensland WWTPs amount to $13.2 billion in CAPEX alone.

WWTP size	**Plant capacity (EP)**	**Urban Utilities**		**Queensland**	
		WWTPs (n)	Average Capital Investment Required per WWTP	WWTPs (n)	Capital Investment Required
Small	<5,000	16	$19 million	102	$1.9 billion
Medium	5,000-50,000	6	$69 million	63	$4.3 billion
Large	>50,000	6	$367 million	19	$7.0 billion
	Total	**28**		**184**	**$13.2 billion**

Table 1: Summary first approximation costs to remove PFAS from the liquid stream at 184 Queensland WWTPs.

SOURCE CONTROL

The NHMRC review of the PFAS[11] in drinking water recognised that drinking water is not the only potential source of PFAS exposure in Australia and the contribution from other sources might be significant. The community can be exposed to PFAS through many sources including personal care products, food packaging, clothing, furniture, air and dust, many of which are currently unregulated for PFAS.

[10] Urban Utilities 2023 Submission to the consultation on the PFAS NEMP 3.0.
[11] https://www.nhmrc.gov.au/health-advice/environmental-health/water/PFAS-review

The Industrial Chemicals Environmental Management Standard[12] (IChEMS) Schedule 7 listing of PFOA, PFOS and PFHxS and their salts (effective 1 July 2025) is often acclaimed as the means to control PFAS entry into the community. However, it is at best an incomplete and impractical solution to the problem:

- IChEMS does not cover articles that are regulated under other Australian laws (e.g. pharmaceuticals personal care products, veterinary medicines and pesticides, food packaging materials).
- The levels for unintentional contamination with PFAS are too high – much higher than environmental and drinking water limits for the same compounds.
- Compliance with the standard is not being enforced at a federal level, and the responsibility is being left to industrial chemicals end users.

The adoption and implementation of IChEMS is the responsibility of state and territory jurisdictions. In Queensland compliance with IChEMS has been incorporated into the General Environmental Duty under the Queensland *Environmental Protection Act 1994*.

CONCLUSIONS

The risks associated with known legacy PFAS contamination, especially from Defence, airport, emergency services sites, and downstream effects (landfills, soil and groundwater contamination) are not adequately addressed by existing regulation, resulting in the cost for management and clean-up of contamination being borne by the community.

Until the flow of PFAS into the community is halted, and legacy PFAS is resolved, it is counterproductive to divert the scarce resources that are available to council-owned WSPs away from ageing water and sewerage infrastructure to address what are currently, lower community-level and environmental risks. The priority for WSPs and regulators alike must be to provide safe and secure water to the communities they serve.

NEXT STEPS

The solution to this problem requires federal and state governments to work together with the urban water sector to set good policy. Two immediate policy principles would be:

- Source control of PFAS – Effective and comprehensive measures to prevent PFAS flow to the community.
- Polluter pays – and if the polluter is unable to pay, especially for legacy contamination, the costs should not be borne by the local community.

The urban water sector takes its responsibilities to the communities it serves very seriously and is keen to help with the development of good policy to address these risks.

[12] https://www.dcceew.gov.au/environment/protection/chemicals-management/national-standard

PATHWAY FOR LAND APPLICATION OF BIOSOLIDS DERIVED BIOCHAR

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PATHWAY FOR LAND APPLICATION OF BIOSOLIDS DERIVED BIOCHAR

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Conference Topic

Optimising Resilient Water Supply Systems

INTRODUCTION

Biosolids management has become an increasing concern for the wastewater sector due to the large volumes produced, high processing costs, and more importantly the presence of contaminants such as per- and polyfluoroalkyl substances (PFAS), microplastics, and pharmaceuticals and personal care products. Victorian utilities have to comply with the PFAS guidance in Queensland End of Waste Code Biosolids (August 2021) and more recently with PFAS National Environment Management Plan 3.0 (March 2025). Thermal treatment of biosolids is gaining increasing interest in the water sector as a biosolids management strategy to remove PFAS. South East Water, in collaboration with RMIT, initiated biochar research in 2015 through lab, semi-pilot, and pilot trials with the goal of developing a novel pyrolysis technology (PYROCO) to convert biosolids to biochar. Currently, there are no readily available markets for biosolids derived biochar. Soil application of biochar in agriculture is the most preferred option. Since pyrolysis of biosolids results in increased total metal concentrations, regulators might be less inclined to approve biochar for land application. This is because metals release characteristics and their fate (e.g. leaching and runoff) in biochar receiving soils is unknown. Other questions regulators ask are how stable are the metals in biochar? and will biochar undergo physical and chemical degradation in soil over time? The only guidance in Australia on how biochar must be considered as a resource is provided in the Queensland End of Waste Code (EOWC) Biochar. Consultation with the Queensland environmental regulator on the EOWC biochar has been underway for more than 2 years and was completed in April 2025. The final EOWC biochar was released in May 2025. Similar to PFAS guidance, Vic EPA might direct Victorian utilities to comply with this EOWC biochar.This paper will (i) explore if biochar from pyrolysis of South East Water biosolids will meet resource quality criteria in the EOWC biochar, (ii) explore boundary conditions under which biochar receiving soil concentrations will exceed limits. in the EOWC biochar, and (iii) provide comments on the EOWC biochar.

METHOD/EXPERIMENTAL DESIGN

Biochar production

The PYROCO Mark 2 pilot plant, operated at the Greater Western Water Melton site, features RMIT's patented fluidised bed heat exchanger technology. The process flowsheet is shown in Figure 1.The system includes two fluidised bed reactors: the Gas Producer (GP) and PYROCO. Biosolids are fed to both units, with the GP operating autothermally at 800–850°C to gasify a portion of the feedstock, producing syngas and gasification char. This syngas fluidizes the PYROCO unit, where the other portion of biosolids undergoes pyrolysis at 500–600°C under inert conditions. Pyrolysis vapours are partially oxidised in an adjacent combustion chamber, generating heat transferred to the pyrolysis zone via heat exchanger tubes. A small cyclone captures carryover solids, and the combustion gases are treated in a thermal oxidiser at ≥850°C for 2 seconds to destroy polyaromatic hydrcarbons (PAH), dioxins, furans, PFAS, and volatiles, with optional AdBlue injection for NOx control. Post-oxidation, flue gases pass through a venturi scrubber and packed column for removal of PM, SOx, NOx, and acid gases, with pH control and NaOH dosing. An optional activated carbon filter ensures odour removal. All main units include LPG pilot burners require only for startup and ignition support.

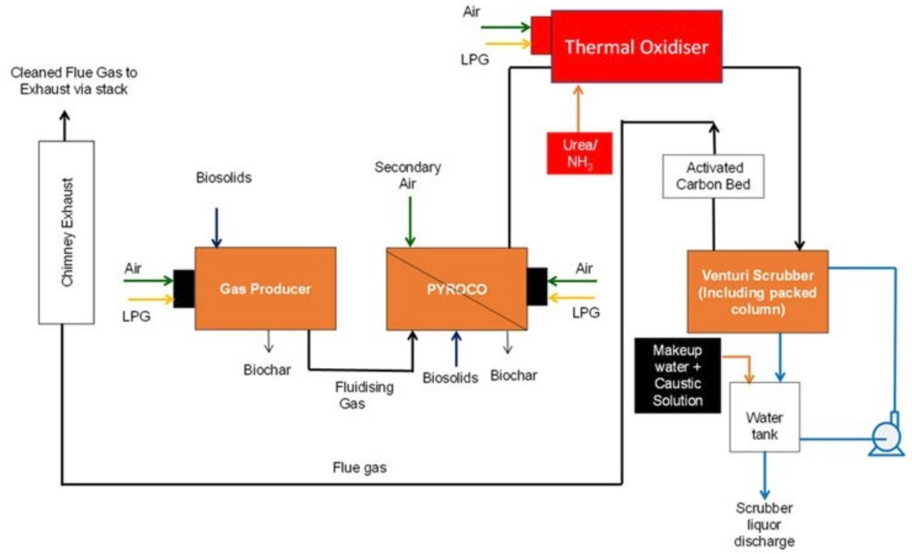

Figure 1: *Process flowsheet of PYROCO Mark 2 pilot plant*

Biochar analysis

Composite biochar samples were collected in designated sample bottles obtained from a NATA accredited laboratory. During sampling for PFAS and microplastic analysis, a more cautious approach (only cotton clothing and no rubber gloves) was taken to prevent any cross contamination. Biochar was analysed for contaminants listed in Table 1. It should be noted that instead of Toxicity Characteristic Leaching Procedure (TCLP) as per EOWC biochar, in the current study Australian Standard Leaching Procedure (ASLP) has been used. The ASLP is often preferred and widely used over the TCLP in Australian laboratories because it offers a more site-specific and flexible approach to simulate leaching conditions. ASLP allows for a wider range of leaching reagents and is not limited to the specific acidic conditions of the TCLP.

Queensland End of Waste Code Biochar (May 2025) End of waste code for biochar (EOWC010002177)

The Queensland EOWC biochar specifies resource quality criteria for biochar producers and conditions of use for biochar users. Three types of biochar applications are listed in the code viz., bound, unbound and soil (land application). This paper will only focus on soil application end use. To qualify for soil application, biochar must meet stringent resource quality criteria, including total concentration limits for selected heavy metals, organic contaminants such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs), and per- and polyfluoroalkyl substances (PFAS). In instances where a biochar sample exceeds the total concentration limits for any heavy metal element, the code permits its use in soil applications provided that leachability assessments demonstrate compliance with established thresholds. Resource (biochar) quality criteria for soil application and maximum allowable soil contaminant concentration (MASCC) are provided in Table 1.

Table 1: Resource (biochar) quality criteria for unrestricted soil application and maximum allowable soil conatminant concentrations (MASCC) in the biochar receiving soils from Qld EOWC biochar including South East Water (SEW) biochar results

Contaminant	Biochar quality criteria						EOWC receiving soil MASCC (mg/kg)
	Total (mg/kg)			TCLP/ASLP (mg/L)			
	EOWC maximum concentration	SEW PYROCO biochar results (n=3)	SEW GP biochar results (n=3)	EOWC TCLP maximum concentration	SEW PYROCO biochar results for ASLP (n=3)	SEW GP biochar results for ASLP (n=3)	
As	20	5	5	0.1	<0.01	<0.01	20 or BG+3
B	100	**114**	**153**	0.5	**0.74**	**3.4**	-
Cd	1	2	<0.2	0.01	<0.002	<0.002	1
Cr (Total)	100	59	94	0.1	<0.01	<0.01	100 or BG+10
Cu	150	**1400**	**1500**	0.2	<0.01	<0.01	100 or BG+10
Pb	150	70	9	0.0034	<0.01	<0.01	150
Hg	1	<0.05	<0.05	0.002	<0.001	<0.001	1
Ni	60	26	**99**	0.2	<0.01	<0.01	60 or BG+10
Se	5	**8**	4	0.02	0.01	0.02	5
Zn	300	**2233**	**1287**	2	0.02	0.01	200 or BG+10
PCBs	<0.2	<0.6	<0.6	-	-	-	-
PAHs	6	**7**	6	-	-	-	-
PFOS+PFHxS	0.002	<0.0002	<0.0002	-	<0.01	<0.01	0.002
PFOA	0.001	<0.0002	<0.0002	-	<0.01	<0.01	0.003
Sum of PFAS	Not specified	<0.0002	<0.0002	-	<0.01	<0.01	-
PFAS Leachability	Minimum practicable			-	-	-	-

Notes: BG- Background; MASCC for PFAS combinations are not presented here; Exceedances are highlighted in **bold**

OUTCOMES / RESULTS

Biochar quality criteria

In this study, biochar produced from South East Water's Mt Martha biosolids using the PYROCO Mark 2 Phase 2 pilot plant was assessed against the EOWC biochar criteria, and the results are included in Table 1. Both PYROCO and GP biochar complied with all PFAS thresholds (PFOA and PFOS+PFHxS) in the EOWC biochar. However, total concentrations of certain heavy metals namely Boron, Cadmium, Copper, Selenium, and Zinc exceeded the respective EOWC biochar total concentration limits. Consequently, leachability testing was conducted using the ASLP to determine the potential environmental risk associated with these metals. The results indicated that, except for boron, all metals in both biochar samples were below the leachability thresholds set by the EOWC biochar. However, testing for Boron is required only if the feedstock used for biochar production has a component of cardboard packaging. Compliance of PCBs in biochar cannot be evaluated properly due to the higher limit of reporting (LOR) in the analytical method used. PAH levels in PYROCO biochar slightly exceeded the threshold, while those in GP biochar were at the limit. After further investigation it was identified that this marginal exceedance of PAH in PYROCO biochar can be attributed to the absence of a polishing step in the current Mark 2 plant pilot plant, which can be addressed by modifying the reactor's biochar discharge system in future trials.

Overall, the assessment confirms that, except for boron ASLP results, PCB limitation and slight PAH elevation in one sample, the biochar evaluated meet the EOWC biochar requirements for unrestricted soil application. These findings support the potential for biosolids-derived biochar use in soil application if process optimization and analytical testing are ramped up to address specific exceedances in this study.

Conditions for soil application

If biochar complies with quality criteria in Table 1, it can be used in various soil applications – composting, fertilisers, irrigation management, land remediation and stabilisation, and soil conditioner. As expected, all reasonable and practical measures must be taken to prevent or minimise environmental harm caused using biochar in line with biosolids guidelines. Most importantly, application of biochar to land must not result in soil contaminant concentrations exceeding the MASCC limits in Table 1. We estimated the maximum biochar application rate as 60 kg/ha below which South East Water biochar will not result in the receiving soil contaminant (heavy metals) concentrations exceeding the MASCC limits (Table 2). This was based on using heavy metals data in Table 1 and assuming a soil mixing depth of 10 cm and a bulk density of 1.1 g/cm³, resulting in an estimated soil mass of 1100 kg/m².

***Table 2**: Estimated receiving soil heavy metals concentartions (mg/kg) at various biochar application rates*

Biochar application rate (kg/ha)	As	Cd	Cr	Cu	Pb	Hg	Ni	Se	Zn
10	0.05	0.02	0.85	14	0.63	0.00	0.89	0.07	20
25	0.11	0.04	2.09	33	1.56	0.00	2.20	0.18	49
50	0.22	0.09	4.09	65	3.04	0.00	4.30	0.35	97
60	0.26	0.10	4.86	78	3.62	0.00	5.12	0.41	115
80	0.34	0.14	6.37	**102**	4.75	0.00	6.71	0.54	151
EOWC MASCC limits (mg/kg)	20	1	100	100	150	1	60	5	200

Note: Receiving soil MASCC exceedance is highlighted in bold

Commentary on EOWC biochar

Stringency of PFAS limits

The Queensland EOWC Biosolids was introduced in 2019 and led the industry in the setting of limits for PFAS compounds in soil following land application, well in advance of the development of the biosolids guidance in the PFAS NEMP. It was anticipated that similar limits to biosolids (for Queensland) would be employed for biochar, but the PFAS limits for biochar are even more stringent than for raw biosolids, despite biochar's lower environmental risk due to reduced mobility and bioavailability of contaminants. Pyrolysis of PFAS-containing biosolids effectively reduces detectable PFAS in biochar, with studies showing removal rates exceeding 90% for long-chain compounds like PFOS and PFOA, and no detectable PFAS in some cases. Leachability of PFAS from biochar is significantly lower than from biosolids, and in the case of PYROCO biochar, TCLP testing yielded PFAS below detection limits.

TOPA testing requirements

There is no PFAS detected in our biochar after pyrolysis (Table 1). Despite this, the EOWC biochar requires Total Oxidisable Precursor Assay (TOPA) in conjunction with standard PFAS analysis. However, in the case of biochar derived from feedstocks containing PFAS, it is yet to be ascertained whether the TOPA assay will provide any greater level of risk assurance, especially when leachability is considered. At the present time, TOPA lacks a robust methodology for biochar, is expensive, and may not be warranted given the low risk of PFAS precursor mobility and considering the trace levels at which PFAS precursors will be present in biochar.

PFAS testing requirements

PFAS testing is required for biochar that is derived from feedstock that has the potential to contain contaminants such as biosolids. For biochar without PFAS in feedstock, the EOWC biochar requires PFAS to be tested in biochar biannually or every 120 dry tonnes, whichever is more frequent. This is equivalent to a fortnightly testing regime (to include TOPA as well as standard PFAS analysis) for a typical-sized plant that produces 30,000 dry tonnes per annum biochar. In addition, pre- and post- soil application testing will be required should PFAS be detected in the biochar to ensure compliance with the MASCC. Post application receiving soil contaminant concentration modelling for biochar was conducted yielding the following outcomes..

- Assuming 90% destruction of PFAS is achieved in the production of biochar, in situ soil contaminant concentrations post application will be below detection limits for all PFAS congeners and congener groupings.
- The MASCC will not be exceeded when biochar is applied to virgin soil.
- The in-situ soil contaminant concentration is most sensitive to the starting soil contaminant concentration.

Thus, post-application monitoring offers negligible environmental value at high cost.

CONCLUSIONS

While it has been demonstrated that biosolids-derived biochar produced from South East Water's PYROCO Mark 2 pilot plant meets the requirements for the new EOWC biochar, the current regulatory approach lacks proportionality and scientific justification, especially considering the environmental benefits of advanced thermal treatments for biosolids (destruction of PFAS and other contaminants of emerging concern). A revised, risk-based framework is needed to support sustainable biochar use without imposing unnecessary economic and procedural burdens for biochar producers and end users.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Biochar is a multifaceted solution that builds resiliency by improving soil health, water management, carbon storage, and agricultural productivity. Its ability to address both the causes and effects of climate change makes it a critical tool for creating robust, adaptive systems capable of withstanding environmental stresses now and in the future.

ICE PIGGING FOR WATER MAINS CLEANING: A RISK-BASED APPROACH

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ICE PIGGING FOR WATER MAINS CLEANING: A RISK-BASED APPROACH

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Conference Topic

Optimizing resilience water supply systems

ABSTRACT

South East Water implemented ice pigging - an innovative and eco-friendly technology - to clean large water mains in high-risk areas which were selected using a risk-based prioritization tool. Cleaning over 22 KM of large water mains in three areas, South East Water removed an impressive 53 kg of sediment per kilometre using half the water typically required for such cleaning using traditional methods. Ice Pigging not only minimized disruption to customers at an average of <1.50 hours per operation but also demonstrated sustainability by saving over 2 megalitres of water. This case study highlights the exciting potential of ice pigging in enhancing water quality and network operational performance.

Keywords: ice pigging; water mains cleaning; scheduled maintenance

INTRODUCTION

Over the recent decades, water utilities have strived to ensure the highest standards of water quality for customers by adopting drastic measures such as changing water sources or introducing advanced technologies to clean water. South East Water (SEW) serves 1.8 million people through 14,639 KM of water pipelines across 176 water distribution zones. At SEW, the majority of water is sourced from protected catchments in the Yarra Ranges. Owing to the high quality of sourced water, it typically does not require filtration before being supplied to customers. However, this unfiltered water can result in the buildup of sediments and biofilms in the distribution system. Although this is a natural process it can still impact the water quality over time.

In the past, SEW relied on flushing, air scouring and other reactive methods for mains cleaning. These methods are effective for smaller pipes but are less effective for larger pipes, i.e., flushing is only effective in pipes up to 150 mm, and air scouring up to 250 mm [1] [2]. This posed challenges for SEW in adhering to the Department of Health's increased focus on achieving a minimum free chlorine residual target of 0.2mg/L throughout the water network, especially in high-risk areas.

In response, SEW has recently implemented Ice Pigging - a promising, environmentally friendly, innovative, and non-invasive technology - to clean water mains over 250 mm in high-risk areas. Ice Pigging involves injecting a saline ice slurry into the mains and using system pressure to propel the ice through the network, removing sediments and biofilms in the process [3] [4]. Cleaning over 22 KM of large water mains in different distribution zones, SEW removed an impressive 53 kg of sediments per kilometre using half the water typically required for cleaning using traditional methods. Ice Pigging not only minimized disruption to customers at an average of <1.50 hours per operation but also demonstrated sustainability by saving over 2 megalitres of water.

This real-life case study analysis, firstly, demonstrates the risk-based approach implemented by SEW for ice pigging, and then highlights the exciting potential of ice pigging in enhancing water quality and network operational performance. This study will serve as a useful reference for water utilities and researchers interested in alternative cleaning technologies as ice pigging offers significant advantages over flushing and air scouring, i.e., reducing the volume of water required, minimizing the risk of damaging pipe walls, and eliminating the risk of 'stuck pig'.

METHOD

Zone Selection: SEW has developed a risk-based prioritization tool to rank zones for mains cleaning based on several risk factors. Key factors include water quality complaints such as dirty water and taste and odour issues, and water quality parameters such as coliforms, plate counts, and free chloride residuals. Using this tool, areas with higher water quality complaints, poor water quality results, and lower chlorine levels are prioritized for cleaning. For this case study, 24 Ice Pigging operations were implemented over a span of 21 days in three different areas, successfully cleaning 22 KM of DN300/450 pipes.

Ice Production and Delivery: The ice pigging process begins with the production of slurry ice at the Ice Pigging Production Plant in Melbourne. This plant can produce 10 tonnes of ice slurry per day by crushing freshwater flake ice and mixing it with a brine solution, which acts as a freezing point depressant. The ice slurry is stored and transported in an insulated vehicle, keeping it viable for up to 24 hours. This method ensures that the ice slurry is ready for use upon arrival at the site without compromising quality.

Ice Pigging Implementation: Once on-site and after isolating the main, the ice slurry is pumped into the pipeline through an inject hydrant (Figure 1). The non-Newtonian properties of the ice slurry allow it to adapt to the pipeline's flow conditions. The slurry solidified during insertion but flows around obstacles such as valves and bends once the system pressure is applied. The pig works by lifting sediment from the pipe wall rather than pushing it, reducing the risk of blockages.

The ice pigging progress through the main is monitored in real-time using parameters such as flow rate, pressure, conductivity, and turbidity. As the pig approaches the discharge hydrant, rising conductivity indicates the arrival of saline ice. The ice and collected sediment are captured and safely disposed of, which is followed by flushing to ensure that all trace of salt and sediment are removed before returning the main to service (Figure 2). Water displaced by the pig is dechlorinated and safely discharged, while the ice slurry, containing sediment, is captured in tankers for disposal at an approved waste facility.

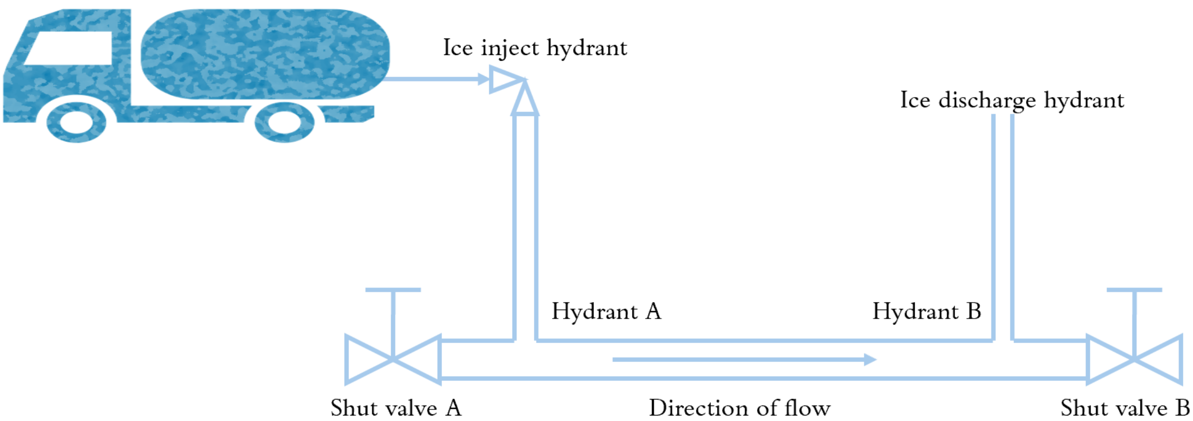

Figure 1: Ice pigging process schematic

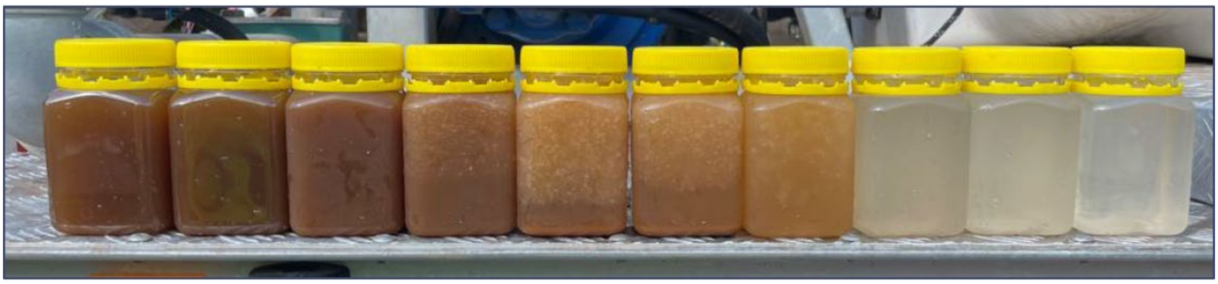

Figure 2: An example of Ice pigging samples taken at different intervals

OUTCOMES / RESULTS

The summary of results is given in Table 1. Samples were taken at the discharge location during the ice pig arrival. These samples were later dried out and weighed in grams. The weight of the sediment, combined with flow rate data taken at the discharge location, was used to calculate the value of total sediments removed. The ice pigging operations successfully removed significant amounts of sediment from the mains, with an average of 52.96 kg of sediments removed per kilometre of mains.

Table 1: Summary of results

Observations	Outcomes
Number of operations	24
Total length of mains cleaned	22.12 km
Average customer disruption time per operation	<1.5 hrs
Average volume of water used	1.49 x pipe volume
Number of pipe excavations required for ice pigging	Zero

Water usage was reduced by nearly half compared to conventional methods such as flushing and air scouring (Table 2). Additionally, customer disruption time was minimized to less than 1.5 hours per operation.

Table 2: Water usage during ice pigging operations

Total volume of pipes ice pigged (kl)	Total volume of water used (kl)	Ratio
1484.46	2250.94	1.49

The success of each operation was closely monitored via various parameters such as flow, pressure, turbidity, and conductivity, with key indicator being the temperature drop below zero at the discharge point. This confirms that the entire section of mains was cleaned, and ice retained its form throughout the operation (Figure 3).

Figure 3: Parameters from discharge point during ice pigging operation (operation 18)

Critical Success Factors

Zone selection: Prioritize zones based on risk criteria to maximize the effectiveness of ice pigging.

Advanced planning: Initiate ice pigging planning sufficient time in advance to allow testing shutdown trials, and hydrant/valve maintenance.

Communication: Communicate continuously with contractor and stakeholders to ensure a clear understanding of zone specifics such as significant feed points and system redundancies.

Precautions: Implement temporary valve caps to prevent accidental operation of key valves during the cleaning process, and ensure customers are notified and recommended to close their stop taps to eliminate water quality complaints during operations.

CONCLUSIONS

Ice pigging has proven to be a low-risk, efficient and effective method for cleaning large water mains. The method's ability to minimize water usage, reduce customer disruption, and safely remove sediment and biofilm without risking pipe integrity makes it valuable for SEW's water quality improvement initiatives. By implementing this innovative solution, SEW has achieved substantial improvements in water quality and operational efficiency, supporting compliance with health regulations and enhancing customer satisfaction.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Ice pigging boosts water network resilience by offering a highly effective, low disruption cleaning method. It thoroughly removes sediments, biofilm, and deposits, restoring hydraulic capacity and improving water quality. With minimal water usage, cleaning can be done without major interruptions, ensuring water supply during peak demand. This proactive approach extends asset life, supports regulatory compliance, and strengthens the network's ability to withstands stress and recover from disruptions.

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Ozone Nanobubble Technology for the Removal of Microbial and Chemical Contaminants in Water Supply

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Title of Full Paper

Ozone Nanobubble Technology for the Removal of Microbial and Chemical Contaminants in Water Supply

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Conference Topic

Optimising resilient water supply systems

INTRODUCTION

Water treatment systems worldwide face increasing challenges from microbial pathogens, chemical contaminants, and harmful algal blooms (HABs). These threats are exacerbated by climate change, evolving regulatory expectations, and public demand for safe, sustainable water reuse. Conventional approaches such as chlorination and bulk ozonation often struggle to meet these demands due to limitations in contaminant removal efficiency, formation of disinfection by-products (DBPs), and operational inefficiencies.

Ozone nanobubble (O_3-NB) technology offers a promising next-generation solution. By leveraging the unique physicochemical properties of nanobubbles—including enhanced gas transfer, prolonged stability, and reactive oxygen species (ROS) generation—O_3-NBs can achieve superior disinfection and oxidation outcomes compared to traditional treatments. Nanobubbles persist longer in water, enabling extended contact time with contaminants (Jia et al., 2023; Singh et al., 2024). Recent field trials and collaborative research between Monash University, The University of Melbourne, Intelligent Water Networks (IWN), WaterRA, the Water Research Foundation (USA), and other international partners have demonstrated the potential of O_3-NB to tackle both biological (cyanobacteria, antibiotics and antibiotic resistance genes) and chemical (PFAS, cyanotoxins) contaminants in water and wastewater systems.

Hence, this paper aims to address the follow research questions: What are the detailed characteristics of O3-NB (size, structure, distribution, concentration, persistence and surface characteristics of bubbles) when generated in bulk? What are the reactive oxygen species (ROS) exposure pathways and what are their residuals? Does O3-NB application effectively oxidise and/or disinfect microbial contaminants, including antibiotics and antibiotic resistance genes housed within the bacteria, in treated wastewater effluents thus providing novel sustained disinfection capabilities in complex water matrices? The project combines laboratory-scale, pilot-scale, and real-world field studies to evaluate the efficacy of ozone nanobubbles. The goal is to develop a scalable, sustainable, and adaptable treatment platform suitable for both drinking water and recycled water applications.

METHOD/EXPERIMENTAL DESIGN

Our study investigates the application of ozone nanobubble technology for the simultaneous removal of microbial pathogens, organic contaminants, and algal blooms in drinking water and wastewater treatment systems. Key performance indicators include pathogen inactivation rates, breakdown efficiency of persistent organic pollutants, and reduction in algal-derived toxins. The research further examines the integration of O_3-NBs with existing water treatment processes to enhance multi-barrier safety, minimize DBP formation, and optimize operational cost-efficiency. Additionally, the role of real-time monitoring and AI-driven adaptive dosing is explored to improve process control and ensure responsive contaminant management under dynamic water quality conditions.

ROS such as singlet oxygen, superoxide anion, and hydroxyl radical are powerful oxidants. Ozone is increasingly used in water treatment through ozone nanobubbles (less than 200 nm), which address the challenges of effective and efficient ozone distribution in water by providing a high surface area and remaining suspended for extended periods, allowing ample time for contact with target pollutants. This paper presents outcome of our collaboration on this technology, benefiting from energy-efficient on site nanobubble generators used in Victoria.

Analytical methods are used to characterize and quantify the bubble distribution (gas phase) and the ozone concentration in both nanobubbles and dissolved aqueous phases over time employing different nanobubble generation methods (i.e., pressure differential/Venturi and shear force). These quantification/characterization techniques include nanoparticle tracking, cryo-transmission electron microscopy, dynamic light scattering, optical and flow imaging microscopy and zeta potential enabling a systematic evaluation and providing a deep understanding of O3-NB characteristics.

Characterising and quantifying oxidant residual is more complex in O3-NB solutions than conventional ozonation due to: (i) there being two stages of ozone concentration - short-term ozone residual in the mg/L range and long-term ozone residual in the low µg/L to ng/L range, likely requiring different measurement approaches; (ii) a combination of ROS (e.g., •OH, •O2, H2O2) are reportedly produced in higher concentrations than conventional ozonation and contribute to improved chemical oxidation and potentially disinfection; and (iii) there are two phases of ozone to account for - nanobubble (gaseous) and dissolved ozone (aqueous). Hence a novel combination of probe compounds (i.e. para-chlorobenzoic acid, cinnamic acid, which are selective compounds with known reaction rate constants), electro paramagnetic resonance, offgas analysis for purged nanobubble ozone, indigo, dissolved ozone monitoring, ozone and oxidation reduction potential monitoring, UVA and ΔUV254 are used to this end. Bromate formation over time are also evaluated as a potential water quality challenge associated with any form of ozonation.

Biological organisms possess enzymatic (e.g., catalase, peroxidase) and non-enzymatic (e.g., glutathione, carotenoids) defences against ROS. However, when these defences are overwhelmed, oxidative stress occurs, leading to cellular damage and death, affecting biomolecules like DNA, ARGs, and cyanotoxins.

As part of our ongoing Discovery Project (DP250101804 – Howden, Blackall, Zamyadi), we are investigating oxidation effects on cyanobacterial cultures, addressing the limited data on oxidant applications, particularly in *Microcystis*. This research explores novel aspects, including the impact of oxidants on cyanobacteria and their epibionts (bacteria tightly connected to cyanobacteria), oxidative cell damage rates, and the release of intracellular compounds like cyanotoxins and DNA. Additionally, we aim to clarify oxidation's effects on DNA, especially ARGs found in cyanobacteria, epibionts (genomes/plasmids), and extracellular polymeric substances (EPS). We determine the efficacy of O3-NB applications for oxidation and/or disinfection/inactivation by comparing chemical and microbial contaminants before and after different O_3-NB dosing treatments. From the samples (pre and post oxidant treatment), cyanobacteria and pathogenic bacteria are isolated in pure culture, using appropriate methods. For example, for cyanobacteria, media devoid of fixed carbon will be used with incubation under lights, whereas a suite of media suitable for the growth of different pathogens will be used and carried out at the Peter Doherty Institute's (PDI) Microbiological Diagnostic Unit.

OUTCOMES / RESULTS

Across three trial sites, the application of O_3-NB consistently demonstrated promising outcomes in the control of cyanobacterial cells and associated toxins. On average, 60% of cells were completely lysed post-treatment, indicating a substantial disruption of cellular integrity and a significant reduction in the potential for regrowth or secondary toxin release. In parallel, a 70% reduction in total microcystins concentration was observed, underscoring the capability of O_3-NBs to not only inactivate cells but also degrade the toxins already present in the water. These findings affirm the potential of O_3-NB technology as an effective oxidative treatment strategy for managing cyanobacterial risks. Detailed site-specific results, operational insights, and treatment optimization parameters are further discussed during the presentation.

One key result comes from a recent real reservoir trial targeting an extreme *Microcystis* bloom. Initial concentrations of cyanobacteria were over 276 million cells/mL, with corresponding microcystin toxin levels of 5,600 µg/L. Following O_3-NB treatment, cell counts dropped to 650,000 cells/mL and toxin levels to 32 µg/L within hours. Over two days, these fell further to 383,000 cells/mL and 6 µg/L, confirming both rapid and sustained impact. However, this trial was conducted under extreme bloom conditions localised in a small area of the target waterbody; scaling up this trial is a challenging task that is currently under investigation. Despite scaling-up challenges, cell viability assays showed that while total counts remained elevated at some depths, viability was reduced to ~20%, indicating that O_3-NBs not only reduce biomass but critically damage the surviving populations. This mitigates regrowth risk and downstream toxin release. Laboratory, pilot and full-scale trial exploring fate of epibiont associated with these blooms including ARGs is ongoing.

In parallel, PFAS removal trials using O_3-NB and GAC have shown promising results in laboratory tests. O_3-NBs create a high surface area for PFAS capture, enabling a 15-20% improvement in PFAS removal efficiency compared to GAC alone. Importantly, the process uses lower ozone concentrations than traditional ozonation, reducing energy consumption and safety risks. Pilot trial at a full-scale wastewater treatment plant is ongoing.

Collectively, these results validate the application of ozone nanobubble technology as a powerful oxidative treatment for cyanobacterial control. The dual action of O_3-NBs—rapid reduction of toxin concentrations and disruption of cell viability—offers an effective strategy for mitigating bloom impacts and enhancing overall water safety. Furthermore, these outcomes support the integration of O_3-NB treatment as a complementary process within existing multi-barrier water treatment frameworks, providing both immediate and residual protection against cyanobacterial hazards. However, challenges such as footprint, dosing points, and long-term system stability are being addressed through ongoing pilot studies.

CONCLUSIONS

Ozone nanobubble technology is emerging as a transformative, sustainable treatment option for modern water utilities. It offers multiple advantages over conventional methods: enhanced contaminant removal, lower chemical demand, reduced DBP formation, and compatibility with advanced monitoring and AI-based control.

Early lessons from both cyanobacterial control and PFAS removal applications at small scale demonstrate that O_3-NBs can serve as an effective complementary treatment within multi-barrier frameworks. Their ability to deliver immediate and residual protection aligns well with the challenges of managing dynamic, climate-impacted water systems. However, scaling-up process and challenges associated with long term applications require further investigation.

WHAT’S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

The next phase of this work will focus on several fronts:

- Exploring and addressing scalability barriers and long-term real-world applications (Figure 1). Scalability barriers, such as system integration, energy optimisation, and cost-effectiveness, must be carefully addressed to enable the successful translation of ozone nanobubble technology from promising pilot studies to long-term, reliable applications in diverse real-world water treatment settings.
- Explore the potential impact of O_3-NB on secondary biological control agents, such as cyanophages and free-living protozoa.
- Expanding trials to address other emerging contaminants, including antimicrobial resistance genes (ARGs).
- Continue PFAS treatment with O_3-NB and GAC, moving from laboratory to pilot implementation in Victorian wastewater systems.
- Developing portable nanobubble systems for site-specific applications (e.g., temporary deployments during bloom events or emergency PFAS incidents).
- Enhancing AI-driven adaptive dosing to optimise performance across variable water qualities.
- These advancements will directly enhance utility resilience in several ways:
- Water quality security: O_3-NB enables proactive management of HABs and chemical contaminants under increasingly variable conditions.

Figure 1. Exploring challenges associated with long-term applications in Victoria.

- Sustainability: Lower chemical and energy use supports climate adaptation goals.
- Public health protection: Potential improved removal of difficult contaminants like PFAS and ARGs ensures safe water reuse for agriculture and communities.
- Operational flexibility: Portable systems will allow utilities to respond faster and more cost-effectively to changing risks.

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Harmful algal blooms in water supply and recovery systems: Investigating accumulation phenomenon and management strategies

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Title of Full Paper

Harmful algal blooms in water supply and recovery systems: Investigating accumulation phenomenon and management strategies

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Conference Topic

Please, specify the Next Water 2025 topic

INTRODUCTION

Blue-green algae (cyanobacteria) present escalating challenges for water management, particularly during droughts when water security is most fragile. Harmful algal blooms (HABs) can produce potent toxins (cyanotoxins) that pose health risks to humans and animals, while nuisance blooms generate taste and odour (T&O) compounds like geosmin and MIB that affect public perception of water quality. With the intensifying impact of climate change—through droughts, floods, bushfires—Victoria's regional water supplies are increasingly vulnerable to HABs, which can restrict water availability, hinder recycling processes, and degrade water quality.

Current water treatment processes (coagulation, clarification, filtration) can effectively remove intact cyanobacterial cells. However, cell breakthrough into treated water, metabolite persistence, and cell accumulation in treatment residuals (sludge, washwater) are emerging operational challenges. Importantly, accumulation of cells in sludge can promote ongoing metabolite production, raising risks of recontamination and inefficient treatment cycles.

Given the basin-wide scale of these issues in the Murray-Darling system, this study brought together three Victorian water corporations (Lower Murray Water, Coliban Water, Goulburn Valley Water) and the Mallee Regional Innovation Centre, with academic partners from Monash University and University of Melbourne, to collaboratively investigate:

- The factors driving cyanobacterial cell accumulation in clarification and sludge processes.
- Feasible interventions to disrupt these cycles and improve resilience in drinking water systems.

The work aligns with the Victorian Drought, Resilience, Adoption and Innovation Hub's goal of co-designed, demand-driven research to support drought resilience.

METHOD/EXPERIMENTAL DESIGN

Three drinking water treatment plants (DWTPs)—DWTP-K, DWTP-E, and DWTP-C—were selected based on prior evidence of in-plant algal growth or accumulation. A phased sampling program was deployed:

- Phase 1: Baseline sampling across critical control points—raw water, clarified water, sludge, filtered water, distributed water, and washwater supernatant—during major T&O events.
- Phase 2: Targeted sampling during active bloom periods, with enhanced genetic analysis (qPCR) for total cyanobacteria and key toxin genes.

- Phase 3 (planned): Post-intervention sampling to assess treatment improvements.

Sampling parameters included:

- Cyanobacterial/algal speciation and cell counts.
- T&O compounds (geosmin, MIB).
- Cyanotoxins (anatoxin-a, cylindrospermopsin, microcystins, nodularin, saxitoxins).
- Genetic profiling (NGS).

OUTCOMES / RESULTS

Phases 1 and 2 of the study demonstrated that clarification remains one of the most effective processes for the removal of cyanobacterial cells across all participating drinking water treatment plants (DWTPs). Post-clarification water samples consistently showed significant reductions in cell counts compared to raw water, confirming the robustness of this treatment step. However, despite this overall success, some breakthrough of cyanobacterial cells was observed, with filamentous forms and floc forming species proving particularly resilient. These filamentous cyanobacteria, due to their structural complexity and propensity for aggregation, are more challenging to remove and pose an ongoing risk of entering downstream processes.

In addition to breakthrough concerns, the study identified backwash water management as a critical vulnerability in the treatment train. High concentrations of cyanobacteria were consistently detected in washwater supernatant across all DWTPs, raising concerns about the potential for recontamination, particularly in facilities where supernatants are recycled back into the treatment process. This highlights the need for improved management and possible additional treatment of washwater streams to mitigate the risk of introducing viable cyanobacterial cells into clarified water. Parallel to this, sludge samples revealed significant microbial accumulation. Next-Generation Sequencing (NGS) analyses uncovered diverse microbial communities (Figure 1) within the sludge, enriched with taxa involved in nitrogen cycling and organic matter degradation. Such nutrient-rich environments within the sludge are likely to favour the survival and even regrowth of cyanobacteria, adding another layer of complexity to their control.

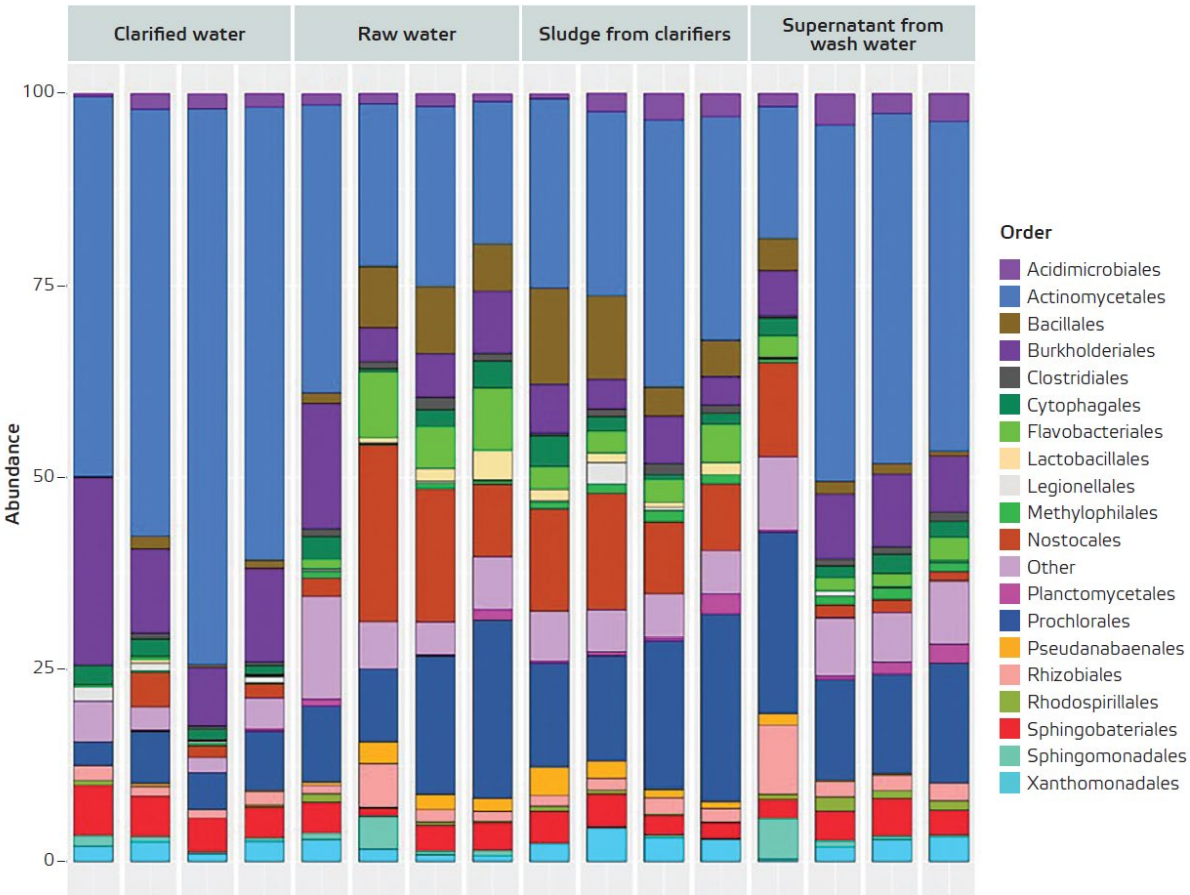

Figure 1. Bar plot comparison of taxa at the rank of Order across DWTP-C samples

The study further revealed pronounced spatial variability in microbial communities across different treatment stages, influenced by the characteristics of the source water, site-specific operational conditions, and the configuration of treatment processes. Notably, filamentous and floc forming cyanobacteria remained the most problematic forms due to their robust morphology and resistance to removal. A key methodological insight from the study was the discrepancy between genetic data and traditional microscopy. NGS consistently detected cyanobacterial presence even in samples where microscopy failed to identify them, illustrating the limitations of conventional cell counting methods when applied to complex water matrices. This finding underscores the importance of incorporating advanced molecular techniques into routine monitoring frameworks to provide a more accurate and comprehensive assessment of cyanobacterial risks in water treatment systems.

Key Discoveries:

1. Safe Drinking Water: Despite breakthrough risks, distributed water remained safe across all utilities.
2. Advanced Monitoring Need: Real time monitoring tools are necessary for robust monitoring and risk management.
3. Operational Challenges: Management of sludge and washwater remains an unresolved vulnerability.
4. Research Gaps: The behaviour of cyanobacterial cells and metabolites within sludge and spent water recycling streams requires deeper study.

CONCLUSIONS

This project delivered critical insights into how cyanobacteria behave within full-scale treatment plants, particularly their potential to accumulate and persist in residual streams. It demonstrated the value of combining molecular, chemical, and imaging methods for comprehensive risk assessment and monitoring.

The advanced genomic analyses provided a window into microbial processes previously invisible with conventional techniques. NGS profiling of sludge revealed complex networks of organisms driving key biogeochemical functions, offering opportunities for more targeted treatment and sludge management strategies.

Ultimately, the project reinforced that addressing HABs is vital for building drought resilience. The risks posed by climate-driven blooms will only grow, making it imperative for utilities to adopt more proactive, data-driven approaches to protect water security.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Future directions include:

1. Phase 3 Implementation: Conducting targeted treatment trials using advanced oxidation, activated carbon, and other technologies, guided by data from Phases 1 & 2.
2. AI Integration: Exploring AI-driven image recognition and machine learning for real-time bloom detection and adaptive process control.
3. Optimising Sludge Management: Developing best practices to limit metabolite accumulation and prevent reintroduction to the treatment cycle.
4. Collaborative Research: A broader program of follow-on studies, now funded by the Australian Research Council, Intelligent Water Networks, Water Research Foundation (USA), and other partners, is underway. This will focus on advanced oxidation (e.g. ozone nanobubbles) to remove multiple contaminants—cyanobacteria, antimicrobial resistance genes, organic micropollutants—in both drinking and recycled water systems.

Resilience Benefits:

This work directly supports drought resilience by:

- Preserving scarce water resources through more effective treatment and recycling.
- Reducing operational risks during extreme events (blooms, floods, droughts).
- Enhancing treatment reliability with modern monitoring and AI-optimised control.

- Providing scalable models that can be adopted across the Murray-Darling Basin and beyond.

Ultimately, the insights from this project will help Victorian and Australian water utilities future-proof their treatment systems against an evolving climate and safeguard public health under increasingly challenging water management conditions.

Reference:

Arash Zamyadi, Linda Blackall (2024) Harmful and nuisance blue-green algae in water supply and sludge/washwater recovery systems: Investigating accumulation phenomenon and management strategies. Mallee Regional Innovation Centre, Mildura, Australia.

Performance of Stormwater Treatment Systems for Heavy Metals and Organic Chemicals: A Comprehensive Review

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Performance of Stormwater Treatment Systems for Heavy Metals and Organic Chemicals: A Comprehensive Review

Optimising Resilient Water Supply Systems

INTRODUCTION

Stormwater is increasingly recognised as an alternative water resource, but its safe reuse requires effective treatment. Nature-Based Solutions (NBS)—such as biofilters, constructed wetlands, porous pavements, ponds, and swales—have been widely adopted to treat stormwater runoff and reduce pollutant loads (Philp et al., 2008).

However, their performance in removing refractory pollutants, especially heavy metals and organic chemicals, remains poorly understood. These contaminants pose significant health risks (Ma et al., 2016), and treatment efficiency is often influenced by design and operational parameters, which have not been systematically reviewed.

This study addresses this gap by synthesising current evidence on NBS treatment performance and identifying the key factors affecting removal outcomes. The findings aim to inform the optimisation of stormwater harvesting systems and support safe water reuse practices.

METHOD/EXPERIMENTAL DESIGN

Data Collection

Systematic literature review - A systematic literature review was conducted to identify relevant studies on the treatment performance of Nature-Based Solutions (NBS) for stormwater contaminants (only focusing on heavy metals and organic chemicals; pathogens review can be found in our previous report (Zhang et al., 2023)). The search was performed using two major scientific databases: Scopus and Web of Science. A three-stage screening process was applied to remove duplicates and exclude irrelevant publications based on titles, abstracts, and full-text reviews. The detailed review protocol is illustrated in **Figure** 1.

Following screening, a total of 163 publications addressing heavy metals and 67 publications focusing on organic chemicals were selected for analysis. These studies formed the evidence base for evaluating the treatment performance of NBS technologies.

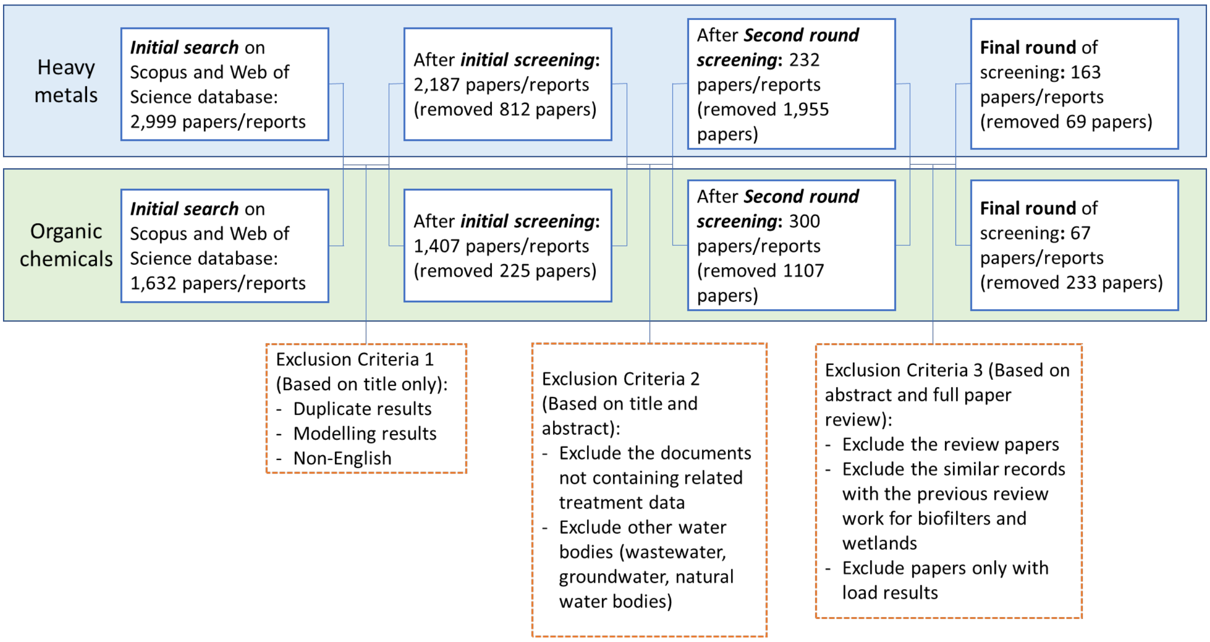

Figure 21 *Key steps and exclusion criteria of the systematic review of stormwater treatment performance data for heavy metals and organic chemicals.*

Overview of collected data - Data were extracted on the performance of stormwater systems in removing both heavy metals and organic chemicals. A summary of the number of studies, pollutants, and system designs included is provided in **Table 1**.

Table 9 *Overview of data collected for different treatment technologies.*

Technology	No. of papers	No. of pollutants	No. of sites (designs)
Heavy metals			
Biofilters	68	22	454
Constructed wetlands	44	20	54
Porous pavements	23	18	52
Stormwater ponds	21	19	47
Swales	7	5	23
Sub-total	**163**	**25**	**630**
Organic chemicals			
Biofilters	32	168	67
Constructed wetlands	10	43	15
Porous pavements	3	8	5
Stormwater Pond	4	11	5
Swales	8	41	19
Advanced technologies	10	19	10
Sub-total	**67**	**181**	**121**

Among the technologies, biofilters were the most frequently investigated for both pollutant categories. Constructed wetlands were also widely studied, with more data available for heavy metal removal (54 sites) than for organic chemicals (15 sites). In contrast, porous pavements, ponds, and swales had comparatively fewer studies, particularly for organic chemical removal. Due to the complex nature of organic contaminants, some studies also evaluated advanced treatment technologies (*e.g.*, ozonation, photo-chemical oxidation, and UV/H_2O_2) in conjunction with NBS systems.

Data Analysis

A statistical summary of influent and effluent concentrations, along with calculated removal efficiencies, was undertaken for each study. Effluent concentrations were compared to relevant health-based guideline values from the Australian Drinking Water Guidelines (ADWG) (Nhmrc, 2011) to assess the residual risk posed by pollutants.

To investigate the influence of design and operational parameters on treatment performance, non-parametric *Kruskal-Wallis tests* and *Pearson and Spearman correlation analyses* were applied, depending on the data distribution characteristics.

OUTCOMES / RESULTS

Overview

Among the NBS reviewed, biofilters demonstrated the most consistent and effective removal of both heavy metals and organic chemicals. The majority of effluent concentrations remained below the Australian Drinking Water Guideline (ADWG) values, indicating a high level of treatment reliability. As illustrated in **Figure 2**, which presents inflow and outflow concentrations for 12 representative organic chemicals (varying in properties, not all tested chemicals are shown), biofilters achieved notable pollutant reductions across a range of contaminants.

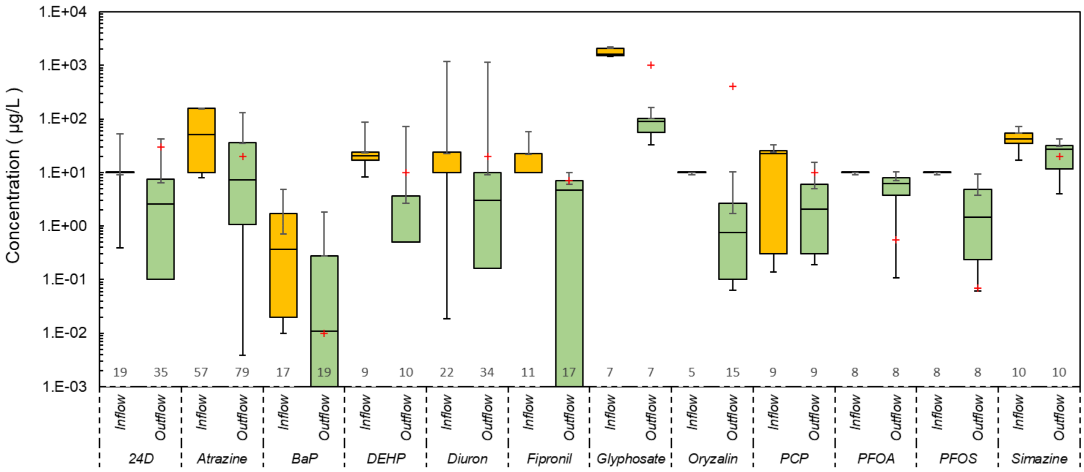

Figure 22 Boxplot of inflow and outflow concentrations of organic chemicals in stormwater biofilters. Red plus symbols stand for ADWG values - PFOS used "PFOS+PFHxS" values in ADWG. Numbers next to the x-axis stand for the number of data points used for each boxplot

Constructed wetlands, the second most studied system, also showed strong treatment potential. Median removal rates exceeded 50% for most assessed chemicals, including both metals and organics. In contrast, porous pavements, ponds, and swales exhibited more variable and generally lower performance. Notably, Ni removal in some porous pavement studies indicated net leaching, suggesting potential pollutant mobilisation under certain conditions.

Studies investigating advanced treatment technologies—such as ozonation, UV/H_2O_2, and photo-chemical oxidation—reported removal efficiencies exceeding 80% for most organic chemicals. These technologies may serve as effective post-treatment options, complementing NBS systems to achieve higher water quality suitable for reuse applications.

Influence of System Design and Operational Parameters

The performance of biofilters was significantly influenced by a range of design and operational parameters. Plant presence, submerged zone inclusion, media type, and infiltration rate were all found to have statistically significant effects on removal outcomes for both metals and organic chemicals ($p < 0.05$, *Kruskal-Wallis test*; *Pearson and Spearman correlation analyses*).

The presence of vegetation and a submerged zone consistently enhanced pollutant removal, likely by promoting microbial activity and prolonged contact times. While no single media type proved universally optimal for all contaminants, performance was pollutant-specific, highlighting the need for specific design based on target pollutants. A similar chemical-dependent trend was observed for pavement material types in porous pavement systems, indicating that material selection plays a critical role in pollutant attenuation.

For constructed wetlands, vertical flow designs outperformed horizontal configurations in heavy metal removal, particularly for Pb and Fe, as shown in **Figure 3.** The vertical infiltration enhances adsorption and filtration processes, improving removal efficiencies.

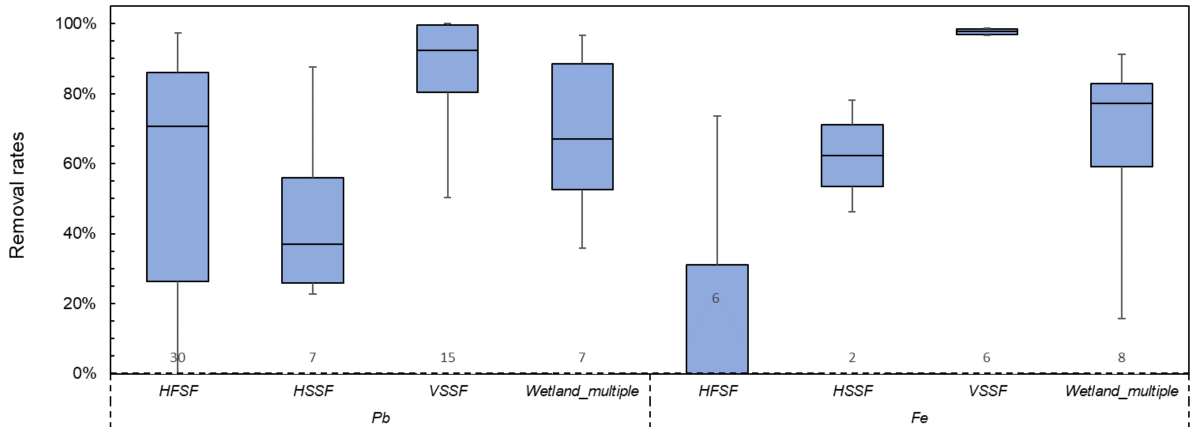

***Figure 23** Removal of Pb and Fe in different constructed wetland designs. Number next to the x-axis stands for the number of data points used for each boxplot (HFSF- horizontal free surface flow wetlands; HSSF- horizontal subsurface flow wetlands; VSSF- vertical subsurface flow wetlands; wetland multiple - wetlands in series)*

These findings indicate the importance of design adaption in stormwater treatment systems. Based on the evidence, planting and submerged zones are recommended features for biofilters, while vertical flow configurations are encouraged for constructed wetlands. However, design decisions should also account for local constraints, including available footprint, target pollutants, and intended reuse applications, to ensure optimal system performance and feasibility.

CONCLUSIONS

This review highlights the current knowledge gaps in understanding the performance of stormwater treatment technologies in removing heavy metals and organic contaminants. By systematically analysing a broad range of studies, this work provides a consolidated assessment of treatment effectiveness across different NBS types and identifies key design and operational factors influencing performance.

The findings offer practical insights for improving system configurations, including the use of vegetation and submerged zones in biofilters, and vertical flow design in constructed wetlands. These recommendations can support the development of more effective and targeted stormwater harvesting practices, targeting on specific pollutant profiles and local reuse objectives.

WHAT’S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

This review provides a knowledge base to support more resilient stormwater harvesting practices by clarifying how NBS performance is influenced by system design and operational factors. The findings can guide the development of fit-for-purpose systems that deliver safe, sustainable water reuse while reducing reliance on conventional supplies.

To further build resiliency, future work should focus on the development of integrated treatment trains that combine NBS with advanced technologies for enhanced removal of emerging contaminants. There is also a need for translating performance evidence into design tools and implementation guidelines. Long-term monitoring and modelling studies will be essential to assess system durability under changing climate and urbanization pressures.

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Wastewater Network Performance Benefits from Rolling Out Derived Flow at Hunter Water

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Wastewater Network Performance Benefits from Rolling Out Derived Flow at Hunter Water

Authors: Chris Farragher, Daniel Livingston

Conference Topic

Smart Solutions for Resilient Service Delivery

INTRODUCTION

Hunter Water is the water and wastewater services provider for over 600,000 people in the Lower Hunter region of New South Wales, based in Newcastle. Hunter Water owns and operates over 500 wastewater pump stations. Due to the relatively small size but high number of stations, as well as the frequency of fouling of equipment, wastewater pump stations are not typically fitted with flow meters. However, knowledge of flow performance of pumps and flow volumes through each wastewater pump station presents desirable benefits and opportunities. So, Hunter Water has used existing monitoring and control equipment to calculate each pump's flow performance, and in turn calculate a flow measurement through each wastewater pump station simply through modification of the control logic code installed at each site, all at minimal cost. This paper outlines how that was done and the resulting benefits.

"Derived Flow" is the term Hunter Water uses for an onsite calculation of pump flow performance derived from monitoring data available at the station from the Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA). The existing monitoring data comes from level sensors that are used to control the operation of the pump station (Burgess, 2008). Pump flow performance is used to measure hourly station inflow, by multiplying a pump's assessed flow rate by that pump's run time in that hour to derive a mass flow through that pump. The mass flow through each pump is totalled to obtain a station hourly outflow volume. A comparison of well level at the beginning of the hour to the level at the end of the hour is used to convert that outflow volume into an inflow volume for the hour. This secondary measurement is the basis of a Hunter Water system that systematically monitors pump station mass inflow, allowing the calculation of a 24-hour moving total of inflow from a station's own gravity catchment. Flows from upstream catchments are netted off the measured flow through the station – a process Hunter Water refers to as "Mass Balance". That moving 24-hour total allows for an early warning of sewage building up in the network, or of sewage leaving the network.

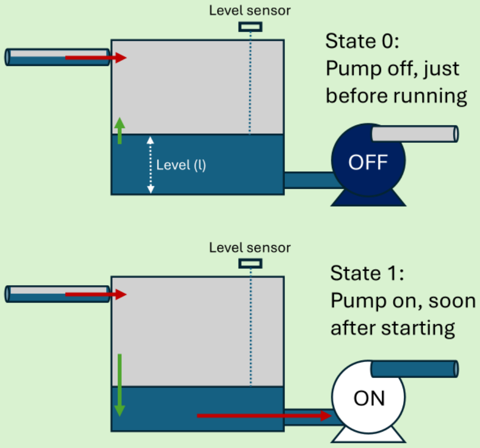
METHOD/EXPERIMENTAL DESIGN

Flow meters are the natural go-to for measuring flow; but they are costly (Salguero, Deatrick, & Johnson, 2015). Flow meters have been installed on the discharge pipework of some wastewater pumping stations throughout Hunter Water's area of operations, but they have a poor service history when used on the sewer network.

Hunter Water had previously successfully measured what it terms depletion flows, the flow rate in and out of a water reservoir. The method involves using high resolution storage level measurement data combined with the known cross-sectional area of the reservoir tank to calculate a depletion flow. It was noticed that step changes in inflow/outflow were from pumps in the network starting and stopping, and that the quantum of the step change revealed the flow performance of the pump in question. Hunter Water identified that this was an opportunity to assess the pump performance at wastewater pump stations. Existing level sensors determine pump cut-in and cut-out levels. Combining this existing data (i.e., the change in level against time) with the known cross-sectional area of the pump well, makes deriving a pump's flow rate performance possible through calculation.

There are a number of possible approaches to calculating a Derived Flow. The one used by Hunter Water could be described as an automatic drop test. Given that there is always some amount of inflow, the change in level due to the operation of the pump can best be estimated by calculating the difference in the rate of change of the well level before and after a pump state transition from off to on, and likewise, before and after a pump state transition from on to off.

The calculation is the difference between dl/dt (where l = level of liquid in well in mm, t = time in minutes) multiplied by the cross-sectional area (in m2), divided by 60 to get the flow (in Litres/second). See Figure 1 below for a description of the calculation of the pump flow rate as derived via the transition of the pump state from off to on. A corresponding derivation of the pump flow rate can be made associated with the transition of the pump state from on to off.



Level sensor measures well level. Flow calculation is derived from that measurement as follows:

$l = level\ in\ mm, \qquad t = time\ in\ \mathrm{min}$

$\left(\frac{dl}{dt}\right)_0 = rate\ at\ which\ well\ is\ filling\ with\ pump\ on\ *$

$\left(\frac{dl}{dt}\right)_1 = rate\ at\ which\ well\ is\ filling\ with\ pump\ on\ *$

$A = known\ cross\ sectional\ area\ of\ well\ in\ m^2$

$$Derived\ pump\ flow = \left\{\left(\frac{dl}{dt}\right)_0 - \left(\frac{dl}{dt}\right)_1\right\} \times \frac{A}{60}$$

Units: $\left({}^{mm}/_{min} \times m^2\right) / \left({}^{s}/_{min}\right) = L/s$

* Note that dl/dt is negative when the well level is falling. Hence the derived pump flow rate is typically based on the rate at which the well level was rising prior to the pump starting being added to the rate at which the well level is falling once the pump is turned on.

Figure 1: How pumped flow calculation is derived (for initial pump flow performance) from existing level sensor equipment

OUTCOMES / RESULTS

The implementation of Derived Flow calculations has enabled Hunter Water to begin to transition from time-based pump maintenance to condition based pump maintenance. This has resulted in a shift to more proactive maintenance that is better targeted to the pumps that need maintenance based on their condition. The current strategy is to use Derived Flow to improve the in-service performance of the pump fleet, without increasing costs, by progressively shifting from time-based maintenance schedules. Ultimately, it is hoped that Derived Flow will allow both better performance of the pump fleet, and a reduction in maintenance costs. In addition to the cost savings associated with more appropriately targeted pump maintenance scheduling, several secondary "bonus" or unexpected benefits have also been observed. Derived Flow and Mass Balance also provide additional clues regarding the condition of non-return valves. The shape of the rate of change signal reveals when a rising main is draining in between pump runs and the relative overnight flow rate can also be used as supportive evidence, as backflow from the rising main appears as inflow in the station inflow measurement.

Mass Balance has provided earlier detection of blockages, and Mass Balance as well as Derived Flow has given notification of rising main breaks, leading to less environmental pollution from wastewater overflows. Note that Derived Flow can detect rising main breaks via the subsequent jump in pump flow performance. At times, the scheme has allowed Hunter Water to intervene before an environmental release occurs. This is when a network blockage results in a sufficient drop in inflow at a station to be detected, before the blockage results in flow to the environment. Other times, an overflow still happens, but the volume of release is much less, due to SCADA alarms bringing attention to abnormal pump flowrates or flow mass balance anomalies.

Capital upgrades have been deferred in some cases through realisation that capacity issues were the result of pump condition-based performance issues rather than inherent design limitations. Planning decisions are generally improved because base assumptions can be cross checked with measured pump flow rates and network flow volumes reported by the system.

Operating costs for electricity have also been reduced by more prompt maintenance when pumps have been poorly performing or failing reflux valves have caused excessive pumping.

Pump performance monitoring also provides insights into design principles for wastewater pump stations. A principle of design is to ensure minimum velocities in the station pipework and rising main. Flow velocity in a station's pipework is a critical element in pump service life and maintaining good performance, as too low a velocity will allow dense solids, such as rocks, to accumulate at the pump. Derived Flow has shown a loose correlation between stations with low pipework velocities and stations with rapid pump performance loss. Figure 2 is a screen capture from SCADA which shows the rapid drop in flow performance at a station with low sewage velocity in its station pipework (from oversized pipes).

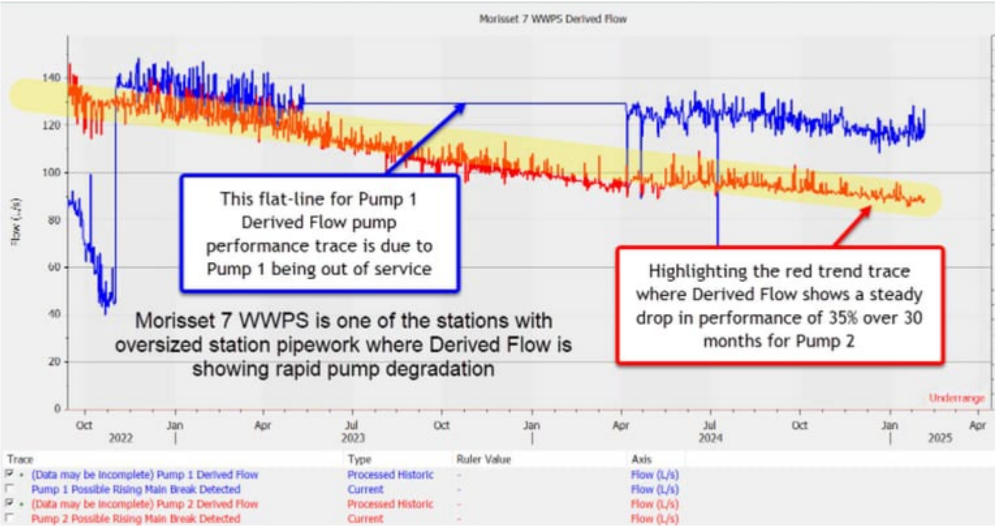


Figure 2: Morisset 7 pump station is an example where Derived Flow has shown accelerated rates of pump wear, evidenced by the drop in flow performance

CONCLUSIONS

The roll-out of PLC/SCADA changes to enable measurement of wastewater pump station flows has been a cost-effective initiative for Hunter Water. The Derived Flow method described can achieve high levels of accuracy with careful implementation. All that is required is software changes. There are multiple significant benefits for a relatively low-cost initiative that can be replicated in any water or wastewater storage application that has level sensors and PLCs. The benefits described will help managers and operators to make more informed decisions regarding pump asset management.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Implementation of Derived Flow and Mass Balance has profoundly increased Hunter Water's knowledge of the operation of its wastewater network. There are myriad decisions that are made in the planning, maintenance and operation space that were previously based on assumptions about the pump performance. Derived Flow has simultaneously removed the need for such assumptions and shown that those assumptions were very often degrading decisions in the planning, maintenance and operation of Hunter Water's wastewater network. Access to live and historical pump performance data is leading to better responses to operational incidents, such as major leaks, and better-informed planning decisions, each of which makes for a more resilient network, and a more resilient community. Derived Flow and Mass Balance has shortened Hunter Water's response time to incidents in the network.

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Satellite remote sensing for improving the WaterNSW Integrated Water Quality Model

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Satellite remote sensing for improving the WaterNSW Integrated Water Quality Model

Conference Topic

Smart Solutions for Resilient Service Delivery

INTRODUCTION

Satellite remote sensing has enormous potential to supplement *in situ* data for calibrating water resources system models. Many remote sensing products are freely available in near real time and long-term records now exist to allow methods to be developed to use this data to calibrate models and supplement *in situ* data. As a result, remote sensing techniques have become increasingly popular for understanding water quality and detecting algal blooms in large lakes and reservoirs.

WaterNSW is currently developing the Integrated Water Quality Model, a new tool designed to predict water quality in Lake Burragorang, to facilitate proactive water management for Sydney's largest water source. The main component of the Integrated Water Quality Model is an AEM3D numerical model of Lake Burragorang which has been calibrated based on field data from multiple sites. This study explores the effectiveness of satellite remote sensing to evaluate and improve the skill of the AEM3D component of the WaterNSW Integrated Water Quality Model. In a separate component of the project, detailed multispectral data was collected using an Unmanned Aerial Vehicle to better understand spatial variability of one algal bloom event and how this was represented in the corresponding satellite data.

METHOD/EXPERIMENTAL DESIGN

The project compared the performance of the AEM3D model of Lake Burragorang and remotely sensed estimates of surface temperature and chlorophyll-a (Chla). Both the model simulations and remotely sensed data were compared to *in situ* data at point locations. The model simulations and remotely sensed data were also compared for their spatial agreement.

Case study location

Located in the lower Blue Mountains of New South Wales, Lake Burragorang spans an area of 75 km^2 and provides nearly 80% of the water supply for the Sydney region. The lake reaches a maximum depth of 105 m. Water quality data were gathered from four profilers and eight sampling sites operated by WaterNSW (Figure 1).

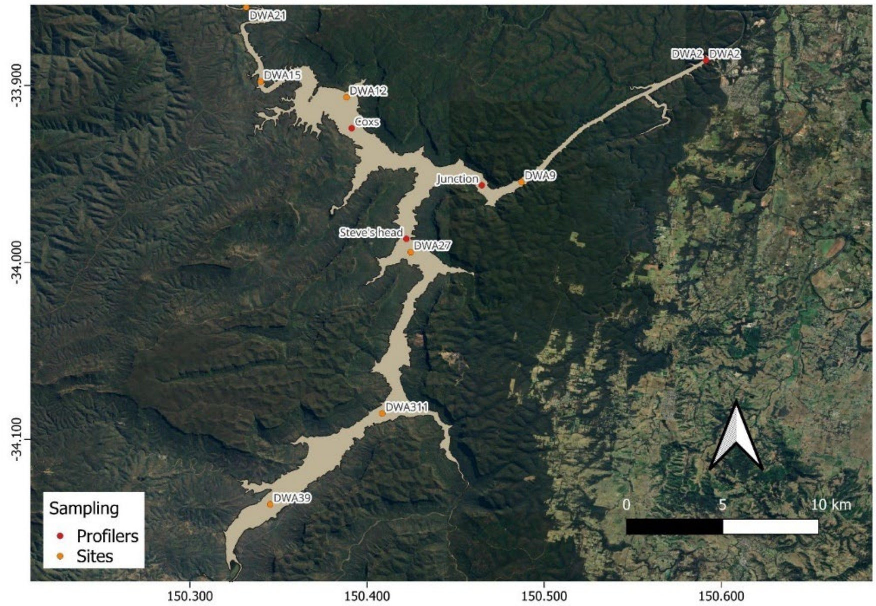

Figure 24 Sampling site locations within Lake Burragorang

Remotely sensed data

Remotely sensed data was obtained from the Sentinel 2 and Landsat series. Sentinel 2, comprising Sentinel-2A and Sentinel-2B, has operated since 2015. Sentinel 2 offers a relatively high spatial resolution of 10m and a frequent revisit rate, with a temporal resolution of 5 days (Spoto et al., 2012). The DEA (Digital Earth Australia) surface reflectance Sentinel 2 Collection 3 ARD (Analysis Ready Data) was used as it incorporates a number of required corrections and cloud masking.

The Landsat series consists of the Thematic Mapper onboard Landsat 5, the Enhanced Thematic Mapper onboard Landsat 7, and the Operational Land Imager and Thermal Infrared Sensor onboard Landsat 8. It has been providing imagery since 1984. Landsat has a spatial resolution of 30m and a temporal resolution of 16-day. In our study, the Landsat DEA surface reflectance NBART (Nadir-corrected Bi-directional Reflectance Distribution Function Adjusted Reflectance) Collection3 ARD were obtained from Geoscience Australia products. These images have been validated, calibrated and adjusted for Australian conditions. Cloud masking was then applied.

Three periods of increased algal activity were identified after 2015 when Sentinel 2 was launched. These periods were September 2016 – December 2017, September – December 2020, and July – December 2022. We acquired satellite imagery from Landsat and Sentinel 2 for each of these periods. Subsequently, we estimated water temperature and chlorophyll-a (Chla) from the images. A suite of different algorithms was identified for estimating Chla, with the Normalised Difference Chlorophyll Index (Mishra and Mishra, 2012) and the Green/Red methods (Brezonik et al., 2005) providing the best matches to *in situ* data.

Integrated Water Quality Model

WaterNSW are developing the Integrated Water Quality Model, which includes a hydrodynamic model of Lake Burragorang using AEM3D. The AEM3D model has a spatial resolution of 180m x 60m, and the simulation time step can be defined from 1 hour to one day. The model has temporal boundary conditions defined using observed data of solar radiation, wind speed, air temperature, and relative humidity. The version of the AEM3D model used for this project was calibrated using observed time series of catchment inflows and water quality data. In our study, the simulation was setup based using a 3-hour simulation interval and run for three separate periods in 2017, 2020 and 2022 periods.

High resolution algal tracking

Field work was completed tracking algal blooms in two WaterNSW-managed lakes, Lake Cargelligo and Lake Brewster. These two lakes were selected because visible algal blooms and elevated algal levels were reported in February 2025 and Lake Burragorang had not had any algal activity. We conducted Remotely Piloted Aircraft Systems (i.e., drone) flights to capture ultra-high-resolution multispectral imagery over the lakes in March 2025. The drone was equipped with an Altum-PT Sensor, which features five spectral bands, including

Blue, Green, Red, Red Edge and NIR. A spatial resolution of 3 cm was achieved. Satellite imagery from Planetscope SuperDove was acquired from January to March 2025 to compare to the drone data.

OUTCOMES / RESULTS

Model and remotely sensed data

The remotely sensed data compared well to the AEM3D model simulations at the sampling locations with results for surface temperature shown in Figure 2.

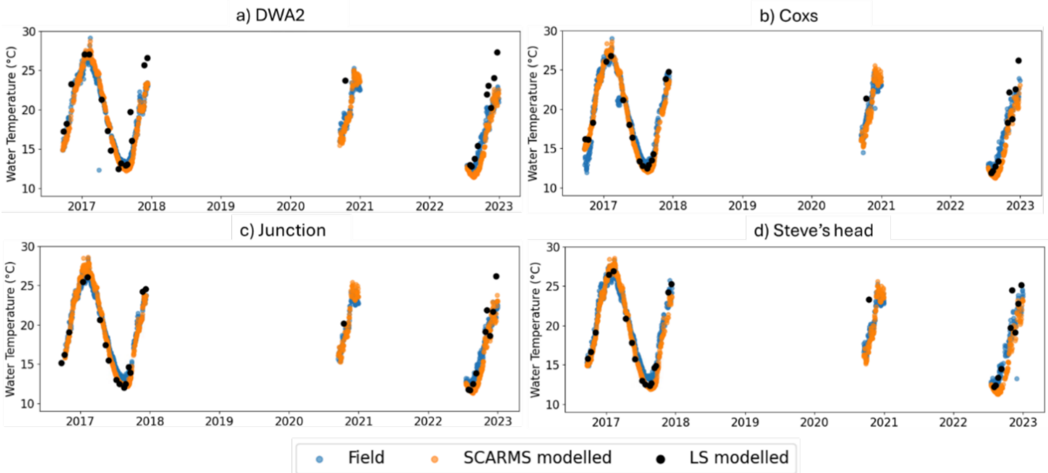

Figure 25 Surface temperature time series from in situ data, AEM3D model and Landsat (LS) remotely sensed data

The value of remotely sensed data is the spatially distributed information that is available. Thus the model spatial fields were compared to the AEM3D model simulations for surface temperature (Figure 3) and Chla (Figure 4). They were compared using correlation (R), root mean square error (RMSE) and bias (mean difference between the remotely sensed data and AEM3D). There was strong agreement in the correlations of the temperature data which is influenced by the strong seasonal cycle. The model tended to be cooler than the remotely sensed estimates of temperature.

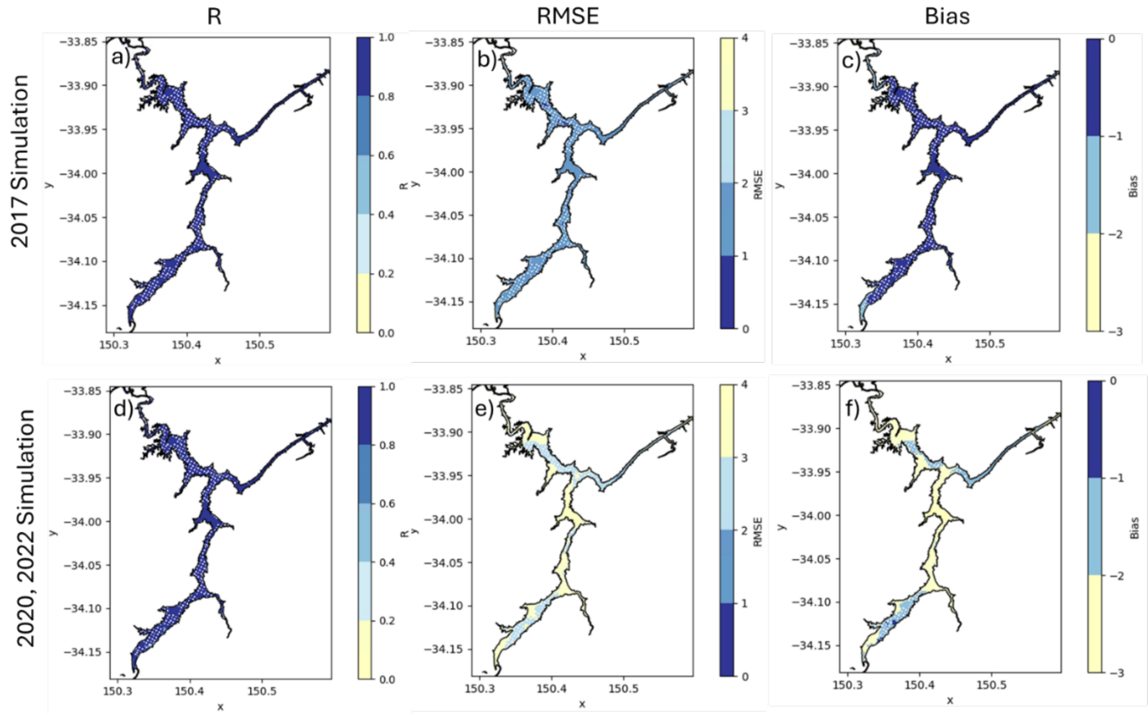

Figure 26 Spatial performance of between Landsat derived and AEM3D modelled water temperature in a) R, b) RMSE, and c) BIAS on clear days for 2017 simulation, the same for d-f) but for 2020, 2022 simulation.

Correlations between model and remotely sensed data were lower for Chla than temperature. There were some strong spatial patterns in the errors with the southern arm of Lake Burragorang tending to have larger differences between the model and the remotely sensed data. Neither the remotely sensed data nor the model simulations had a good match with the *in situ* Chla data. Further investigations were carried out to test input data quality to the AEM3D model and implications for the simulations.

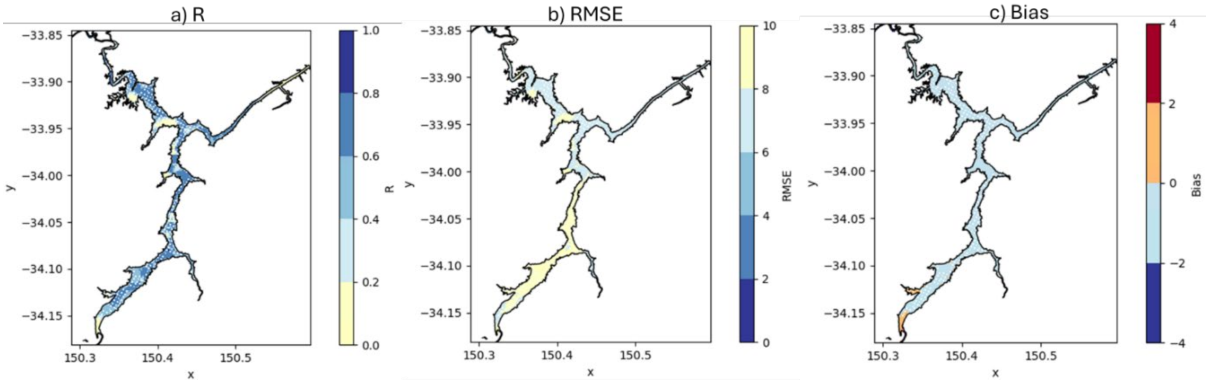

Figure 27 Spatial performance of between Sentinel 2 derived and AEM3D modelled Chlorophyll A with a) R, b) RMSE, and c) BIAS on clear days for all years.

High resolution algal tracking

The high resolution drone imagery provides excellent delineation of water body features as shown in Figure 5. It was found however that while there were differences in the magnitude of the estimated indices, the overall spatial patterns were very similar. This suggests that high resolution satellite products such as Planet Scope are likely to be as useful for remotely monitoring algal blooms as field-based drone data.

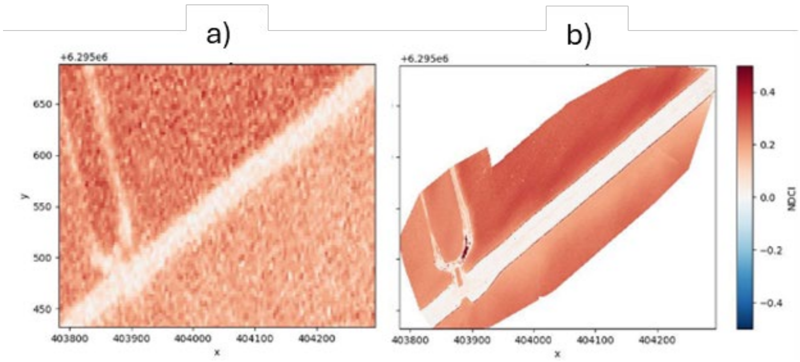

Figure 28 NDCI derived from a) Planet Scope and b) drone for Lake Brewster in March 2025.

CONCLUSIONS

This project has investigated the utility of remotely sensed data for improving a three-dimensional hydrodynamic model of Lake Burragorang. We found that there were large uncertainties in both the model simulations and the remotely sensed data. Comparing the spatial patterns of discrepancies in the two estimates was useful for indicating areas of the model to focus calibration and validation efforts on. Matching dates between the remote sensing and *in situ* data was challenging due to the impacts of cloud and the time between overpasses of the satellite. Higher temporal resolution products such as Planet Scope may help to increase the number of days with available data. However, given the uncertainties in remotely sensed estimates of water quality parameters, further work is required to best leverage these data sources.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Resilient water supplies require fit for purpose tools to understand threats to water quality both under present conditions and also future conditions with a changing climate. Calibrating and constraining detailed hydrodynamic models under non-stationary catchment conditions is challenging and spatially distributed data will continue to be vital to understand the overall model skill.

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A robust solid-state reference electrode and its application in environmental monitoring

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A robust solid-state reference electrode and its application in environmental monitoring

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Conference Topic

Smart Solutions for Resilient Service Delivery

INTRODUCTION

Reference electrodes which demonstrate long-term potential stability are essential for many continuous monitoring applications and are commonly based on Ag|AgCl (silver chloride) electrodes; however, these electrodes are susceptible to poisoning from aqueous sulphide species present in wastewater and natural groundwater. Reference electrodes are often a limiting factor in continuous monitoring applications of potentiometric sensors as the cell voltage between indicator and reference electrodes is directly used to determine analyte concentration. Consequently, regular sensor maintenance and recalibration are needed to mitigate reference electrode drift.

Here, we present a sulphide resistant solid-state reference electrode (SSRE) based on a composite material using suspended KCl electrolyte and sacrificial AgCl in a cross-linked polyvinyl acetate polymer matrix. Sulphidation of the sacrificial AgCl produces a stable Ag_2S precipitate and prevents further ingress of the poisoning sulphide species through the composite material. A novel SSRE using this material was compared to a control SSRE without suspended AgCl and a typical liquid filled reference electrode.

This reference electrode has also been paired with other electrodes to create the Vesi™ sensor pack. These sensors measured oxidation-reduction potential (ORP), pH, conductivity, and temperature continuously. The measurements were stored on a cloud database, allowing the user to monitor their solution chemistry remotely. This sensor pack was tested in a field trial measuring water quality in a creek contaminated with acid mine drainage.

This work should be of interest to researchers trying to develop new potentiometric sensors for continuous monitoring applications, and workers in industry that need to regularly monitor water quality using manual sampling or commercial sensors.

METHOD/EXPERIMENTAL DESIGN

Long-term stability in presence of sulphide

All tests measuring open circuit potential were maintained at ca. 25 °C using an incubator. Tests were conducted in 12.8 mM (1 g L^{-1}) Na_2S solution buffered at pH 9 to avoid sulphide losses as H_2S. The potential of each SSRE was measured simultaneously against the same SCE reference electrode (1001 Series, Koslow Scientific) by connecting the reference electrode cables from each potentiostat channel (VMP3, BioLogic). A double junction was used to protect the SCE and periodic maintenance was performed, however the SCE still drifted due to poisoning several times during the trials. The SSREs remained immersed in solution for the entire duration of the test.

Application in environmental monitoring

The KCl/AgCl SSRE was paired with a Pt electrode for ORP, a ceramic pH electrode, and a conductivity/temperature probe. This sensor pack was calibrated once when the sensor was deployed, and pH measurements were compared to typical manual sampling measurements.

OUTCOMES / RESULTS

Long-term stability in presence of sulphide

To demonstrate the benefits of AgCl additive in the composite matrix, KCl SSREs and KCl/AgCl SSREs were immersed in a pH 9 buffer solution with 1 g L^{-1} Na_2S and left to condition in situ while their potentials were monitored vs. a SCE reference electrode, as seen in Figure 1.

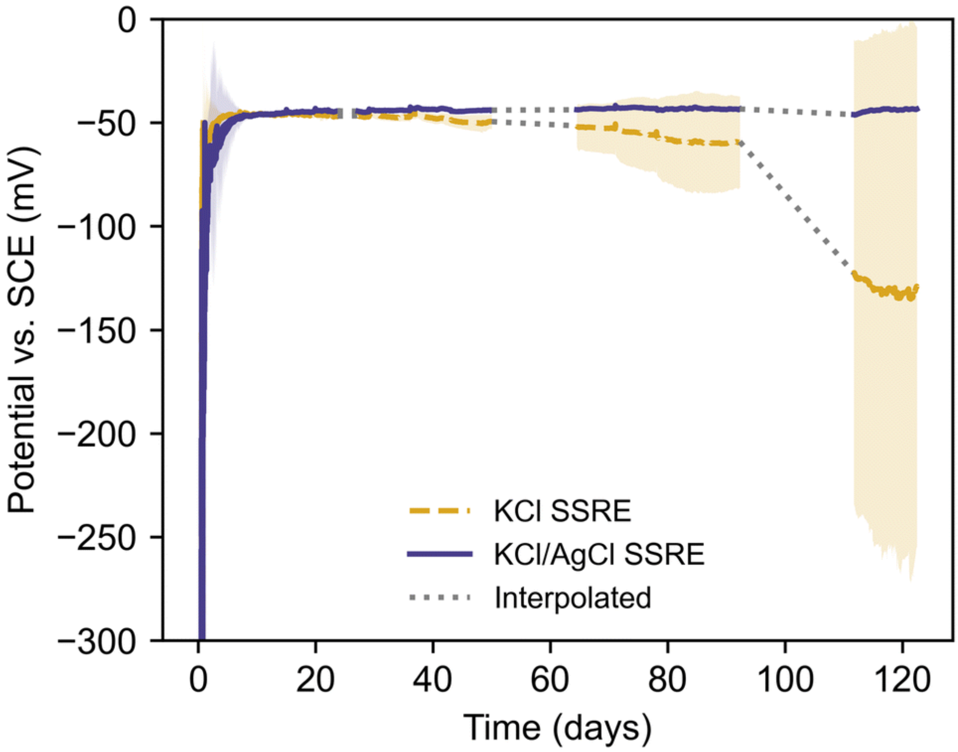

Figure 1: *long term potential monitoring of KCl SSRE and KCl/AgCl SSREs in 1 g L^{-1} Na_2S solution in pH 9 buffer. Mean potentials (n = 5) are reported with the coloured shading indicating the 95% confidence interval. Interpolated sections indicate periods where the conventional SCE reference suffered sulphide poisoning.*

SSREs without sacrificial AgCl were used as a control and only exhibited a mean working time of 69 days, although some samples demonstrated negative drift before 20 days. In contrast the KCl/AgCl SSREs demonstrated great stability, all maintaining a potential agreeing with theory after 119 days of continuous immersion. These results demonstrate the suitability of these electrodes for long term monitoring applications, even in the presence of a known reference electrode poison.

Application in environmental monitoring

Sensor packs incorporating this novel KCl/AgCl SSRE have been manufactured and tested in continuous monitoring applications. This prototype featured ORP, pH, conductivity, and temperature measurements, as seen in Figure 2.

Figure 2: *Vesi^{TM} sensor pack using solid-state reference electrode with ORP, pH, conductivity, and temperature sensors.*

This sensor pack was continuously monitoring and saving measurements in a cloud database, enabling remote monitoring of water quality in real-time. The pH sensor was calibrated at initial deployment, and these pH measurements were also compared to manual sampling using a typical glass pH electrode. After 6 months of continuous use the reference electrode still provided a stable reference potential, and thus a stable pH calibration as seen by the strong agreement with manual sampling results in Figure 3.

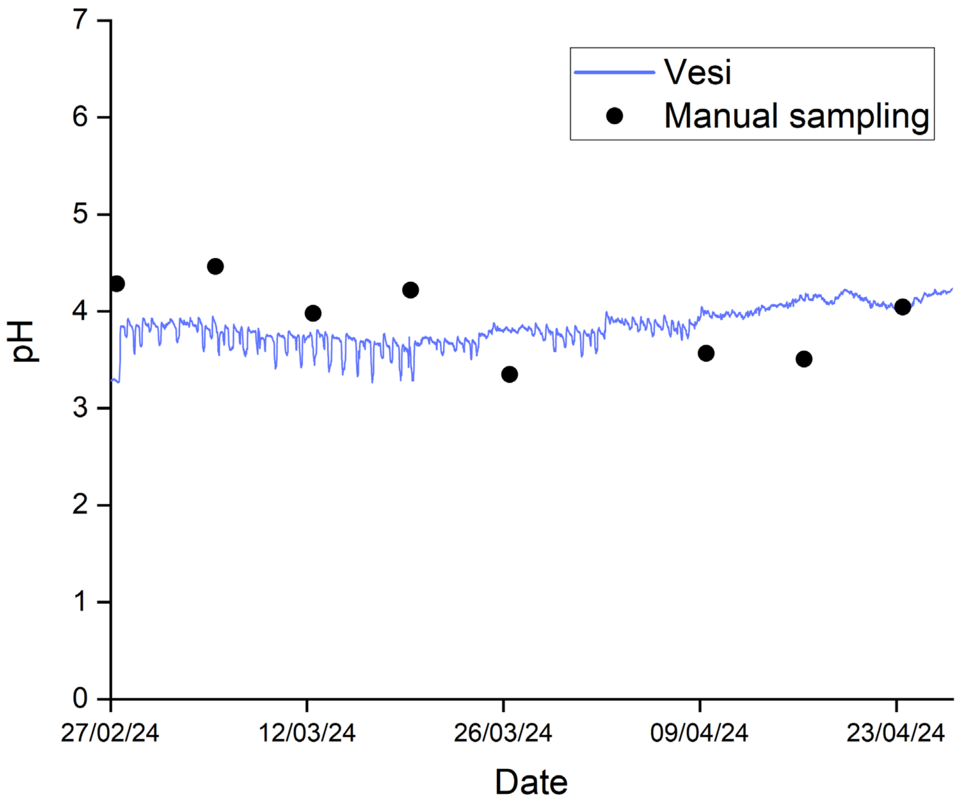

Figure 3: *pH measurement comparison between Vesi^{TM} sensor pack and manual sampling after 6 months without recalibration.*

These results demonstrate that even in challenging environments with acid mine drainage contamination, this reference electrode is a suitable solution for continuous monitoring, enabling ongoing measurements with other electrochemical sensors.

CONCLUSIONS

SSREs using suspended sacrificial AgCl demonstrate remarkable potential stability in the presence of sulphide species which usually poison reference electrodes, demonstrating greater than 119 days of continuous stability. This design has also demonstrated great stability in a continuous monitoring application of acid mine drainage, providing accurate pH measurements that matched well with manual sampling after 5 months without any recalibration. This reference electrode should enable the use of electrochemical sensors in new, challenging applications, and also highlights a new approach for preventing reference electrode drift which could be more widely explored.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

This novel design highlights a new way to customise reference electrodes and improve their resilience in otherwise challenging media. This work also enables continuous monitoring with electrochemical sensors in systems with little calibration or maintenance, allowing for more frequent measurements of water quality, and enabling faster remediation should action be necessary.

Evaluating Electrolysis-Derived Oxygen for Aeration in Wastewater Treatment: Lessons learnt

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Title: Evaluating Electrolysis-Derived Oxygen for Aeration in Wastewater Treatment: Lessons learnt
Conference Theme: Smart Solutions for Resilient Service Delivery

ABSTRACT

Aeration is one of the most energy-intensive processes in wastewater treatment, traditionally reliant on atmospheric air (~21% oxygen) to sustain biological treatment processes. This study investigates the feasibility of utilizing high-purity oxygen, generated as a byproduct of hydrogen electrolysis, to enhance aeration efficiency, reduce energy consumption, and lower emissions. In collaboration with Viva Energy, Barwon Water is conducting an early-stage Front-End Engineering Design (FEED) study at the Northern Water Plant (NWP) to assess the technical integration and commercial viability of electrolysis-derived oxygen in wastewater treatment.

Key engineering considerations include oxygen capture, compression, storage, transportation, and controlled delivery through supersaturation technologies, along with retrofitting constraints, safety risks, and system compatibility. A critical aspect of this study is optimizing the oxygen transfer and delivery system while ensuring seamless integration with existing wastewater treatment infrastructure. This requires evaluating storage and transport logistics, as well as developing an operational framework that aligns with process control and safety standards. The oral presentation will share lessons learned from early-stage evaluations, key technical and operational insights, and next steps toward a full-scale trial. This study provides a foundation for advancing cross-sector collaboration between hydrogen production and wastewater treatment, potentially unlocking new pathways for enhanced energy efficiency and decarbonisation in the water industry.

Introduction

Aeration is one of the most energy-intensive operations in wastewater treatment plants (WWTPs), often accounting for 50–60% of total energy consumption. Conventionally, WWTPs rely on atmospheric air (~21% oxygen) to sustain aerobic biological processes that break down organic matter and nutrients. Due to the low oxygen content of air, large blower systems and extensive mixing infrastructure are required to maintain adequate dissolved oxygen concentrations, leading to high operational costs and significant greenhouse gas emissions.

Globally, several pilot and full-scale studies dating back to the 1970s have explored high-purity oxygen (HPO) and enriched oxygen-based systems, demonstrating benefits such as improved oxygen transfer efficiency, enhanced biokinetics, faster treatment rates at higher mixed liquor suspended solids (MLSS) concentrations, and reduced hydraulic residence times. However, widespread adoption was limited not only by the capital and operational costs of oxygen generation (e.g., cryogenic separation or pressure swing adsorption systems), but also by operational challenges, including process instability, sludge bulking, and increased foaming. These legacy issues led to cautious industry uptake, despite the performance benefits demonstrated under controlled conditions.

The emergence of renewable hydrogen production presents an opportunity to integrate electrolyser-generated oxygen into wastewater aeration, offering a cost-effective, scalable, and cross-sector solution for the water industry. Barwon Water's Northern Water Plant (NWP) in Geelong provides a unique test site for trialing this approach, given its proximity (~1 km) to Viva Energy Hub, where a 2.5 MW Nel (PEM) electrolyser will produce hydrogen using recycled water from Barwon Water, generating oxygen as a byproduct. Under typical operation, this oxygen is vented to atmosphere, representing a missed opportunity for resource integration.

The Green Oxygen for Wastewater Treatment Project, supported by ARENA funding, aims to evaluate the feasibility of repurposing electrolyser-generated oxygen for wastewater aeration. By leveraging oxygen byproduct from Viva Energy, the initiative seeks to enhance aeration efficiency, reduce energy costs and emissions, and validate new treatment strategies through full-scale trials. A key focus is to assess the direct impact of oxygen enrichment on wastewater treatment outcomes, enabling industry-wide learning that could support replication across other WWTPs. The findings will provide critical operational and economic insights, potentially unlocking new sustainability pathways for both the hydrogen and water sectors.

Beyond its technical advantages, this collaboration redefines infrastructure planning, demonstrating how co-location of complementary industries can drive cost-effective sustainability solutions. The NWP and Viva Energy Hub serve as a real-world testbed for integrating renewable energy, water recycling, and emissions reduction into a single system, strengthening regional sustainability efforts while providing a scalable blueprint for similar initiatives worldwide. This project underscores the importance of circular resource utilisation in achieving net-zero environmental goals as depicted in Figure 1.

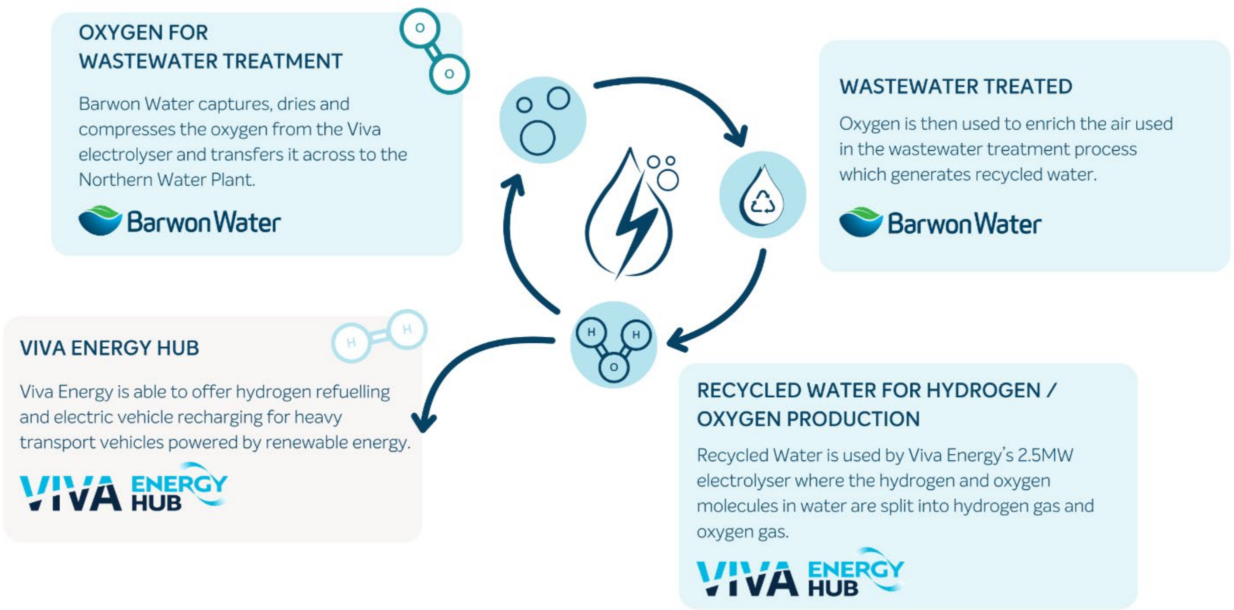

Figure 29 Closed-loop integration between Viva Energy's hydrogen production and Barwon Water's wastewater treatment process.

While this paper outlines key lessons and insights from the early stages of the Green Oxygen for Wastewater Treatment project, the final submission will include further findings from the ongoing FEED study, including detailed engineering modelling outcomes and quantified benefits. These additional results will offer a clearer picture of the feasibility, operational gains, and decarbonisation potential of electrolysis-derived oxygen in wastewater treatment. This continued evaluation will strengthen the business case and support sector-wide efforts to build more resilient, energy-efficient wastewater infrastructure.

METHODOLOGY

This project is being delivered by Barwon Water in collaboration with Viva Energy, RMIT University, Jacobs, Kandls Engineering, and Nel Hydrogen, integrating expertise in water treatment, hydrogen production, infrastructure design, and regulatory compliance. The project follows a structured, staged approach, ensuring technical validation and commercial feasibility before full-scale implementation

The project, currently in Stage 1, centers on the Front-End Engineering and Design (FEED) study, evaluating oxygen capture, compression, transport mechanisms and delivery of oxygen to the BNR tank at the NWP, while establishing key techno-economic benchmarks for integrating electrolyser-derived oxygen into wastewater aeration. A crucial aspect of this stage is the development of the demonstration trial protocol, which defines the specific objectives, monitoring parameters, operational framework, and contingency planning for a two-year validation phase. This trial protocol outlines the sampling methodologies, specialist equipment needs, performance assessment criteria, safety and budget considerations required to systematically measure aeration efficiency, microbial activity, and emissions reductions. If Stage 1 confirms feasibility, Stage 2 will move forward with real-world infrastructure deployment, including the conversion of one biological reactors at NWP to oxygen-enriched aeration, integrating oxygen transport systems, and executing the full-scale demonstration trial. This structured progression ensures risk mitigation, optimised resource allocation, and industry-wide learning, paving the way for scalable adoption across wastewater treatment facilities.

LESSONS LEARNT

1. Enriched oxygen aeration advantages and unknows:

Oxygen enrichment in aeration systems presents a promising opportunity to improve wastewater treatment performance compared to conventional air-based systems. These systems achieve higher oxygen transfer efficiency (OTE), enabling faster removal of pollutants such as BOD, COD, and ammonia. Literature and modelling studies report potential energy savings of 30–50%, alongside additional benefits like improved sludge settling, reduced sludge production, and enhanced sludge dewaterability. Enriched oxygen conditions have also been linked to reduced formation of extracellular polymeric substances (EPS), promoting better floc formation and settling behaviour. Moreover, enriched aeration enhances mixing conditions, helping to eliminate dead zones and improve the overall stability of biological nutrient removal (BNR) processes all while offering opportunities to optimise performance within existing infrastructure.

While enriched oxygen aeration offers clear advantages over conventional air-based systems, several uncertainties must be carefully explored before widespread adoption. The integration of supplemental oxygen into existing aeration systems can enhance process efficiency and pollutant removal, but its full impact on microbial dynamics, effluent quality, and operational stability is not yet fully understood. Unlike traditional aeration, where performance is well characterised, enriched aeration introduces new variables including oxygen blending methods, control strategies, and dosing precision that require site-specific validation. At the Northern Water Plant, a phased demonstration is underway to evaluate the effectiveness of different oxygen delivery approaches and assess potential trade-offs. These findings will be critical in confirming whether the theoretical benefits translate reliably at full scale.

2. Capital deferral benefits

Another key lesson emerging from the project is the potential of oxygen enrichment to defer or avoid large-scale capital upgrades, particularly the expansion of biological treatment infrastructure. By enhancing oxygen transfer and process performance within existing bioreactor footprints, enriched aeration can alleviate capacity constraints without the need for costly and time-intensive civil works. A preliminary business case model compared the NPV of two options: expanding the biological treatment infrastructure versus investing in oxygen enrichment systems. The value generated from deferring capital expenditure (the difference between the two NPVs) forms the basis for a commercially viable pathway, where a portion of this value can be allocated to an oxygen supplier. This shared value model incentivises both parties, the water utility and the oxygen provider and supports the circular economy by valorising what would otherwise be a byproduct. These insights suggest that enriched aeration, beyond its operational merits, also opens up innovative financing and partnership models to deliver infrastructure resilience in a cost-effective and scalable way.

3. Managing Oxygen Production vs Wastewater Demand

A key operational challenge in enriched aeration is aligning oxygen supply from external electrolysis with the variable oxygen demand of wastewater treatment processes. Electrolysers are typically operated based on hydrogen market requirements, which are influenced by electricity pricing and industrial demand. As a result, oxygen is generated as a secondary product, and its availability may not always coincide with the needs of the aeration system. To manage this mismatch, utilities should consider buffer storage options or blending strategies that maintain aeration performance during periods of low oxygen production. Real-time monitoring and control systems can also support stable operation by responding to fluctuations in supply. In the longer term, as hydrogen production scales and becomes more consistent, wastewater facilities may benefit from more reliable oxygen availability. However, this will depend on external market development and proactive coordination between water utilities and hydrogen producers.

4. Infrastructure Compatibility and Integration Challenges

Integrating electrolyser-derived oxygen into wastewater treatment requires careful consideration of both technical and regulatory challenges, especially when retrofitting an offtake system from existing infrastructure. In our case, the oxygen supply is being captured from Viva Energy's Nel MC500 electrolyser, which is designed primarily for hydrogen production. Since oxygen is a secondary product, offtake must be carefully managed to avoid back-pressure or flow disturbances that could impact electrolyser stability. Flow control and buffer vessels are being considered to safely extract oxygen without interfering with hydrogen generation. It is worth noting that not all electrolyser vendors offer standardised oxygen offtake options, and proprietary designs may influence how easily oxygen can be recovered for reuse. Once extracted, transporting and delivering the high-purity oxygen introduces additional integration challenges. Compression systems must maintain stable pressure to avoid fluctuations in aeration performance, while pipeline materials and storage vessels must meet stringent safety and compatibility requirements for oxygen handling. These infrastructure decisions also have implications for regulatory approvals, including potential licensing requirements for gas pipelines and pressure equipment.

In this project, two main oxygen delivery approaches are being explored: (1) direct injection of electrolyser-derived oxygen into the blower line for distribution through existing fine-bubble diffusers, and (2) external supersaturation of the mixed liquor using technologies such as the Speece Cone or SDOX, with the oxygen-rich liquor then recirculated into the BNR tanks. Each method presents different integration and safety considerations. For direct injection, oxygen enrichment levels must be carefully controlled, typically kept below 35% by volume, to avoid elevated fire risks, material degradation, or unintended process disturbances. This approach benefits from using existing diffuser systems but requires careful airflow and control adjustments. However, it may not fully utilise the high transfer efficiency potential of pure oxygen, and some losses to the atmosphere are expected due to dilution and limited bubble contact time.

In contrast, supersaturation technologies offer a more controlled and isolated method of oxygen delivery. By dissolving high levels of oxygen outside the bioreactor and then pumping the oxygenated liquor back in, these systems avoid over-pressurising the blower network and reduce the risk of oxygen accumulation in confined equipment. Supersaturation methods can also achieve higher oxygen transfer efficiencies and provide better control over dissolved oxygen distribution. However, they may involve additional capital investment and integration effort. The most suitable delivery strategy depends on site-specific factors such as tank configuration, safety constraints, operational flexibility, and existing infrastructure.

5. Evaluating Supersaturation Delivery Technologies and Selection Considerations

For wastewater utilities considering oxygen enrichment, understanding the performance trade-offs between conventional diffuser-based aeration and supersaturation technologies is essential. Selecting the most suitable delivery method requires evaluation of oxygen utilisation efficiency, infrastructure compatibility, capital deferral benefits and long-term operational cost-effectiveness, ensuring process stability is maintained without introducing excessive complexity.

Initial modelling indicated that introducing oxygen at 35% concentration downstream of blowers resulted in only marginal improvements in aeration efficiency. This method offered limited benefits due to the reduced effectiveness of conventional fine-bubble diffusers in handling enriched oxygen streams. In contrast, supersaturation technologies demonstrated significantly higher oxygen transfer efficiencies by enabling near-complete oxygen dissolution prior to entering the biological reactor.

Among the technologies assessed, Speece Cone Aeration offered high transfer efficiency (approaching 100 %) by using a pressurised cone system to fully dissolve oxygen before reintroducing the mixed liquor into the treatment process. SDOX® (Supersaturated Dissolved Oxygen) operates on similar principles but at higher pressures, which may affect energy requirements and scalability depending on plant configuration. Other approaches, such as nanobubbles and Membrane Aerated Biofilm Reactor (MABR), and VorTech systems present potential in specialised applications but lack the scale, maturity, or practical integration pathways needed for current trials. These options were therefore considered out of scope for demonstration at this stage. Figure 2 shows the evaluated oxygen delivery technologies for this project.

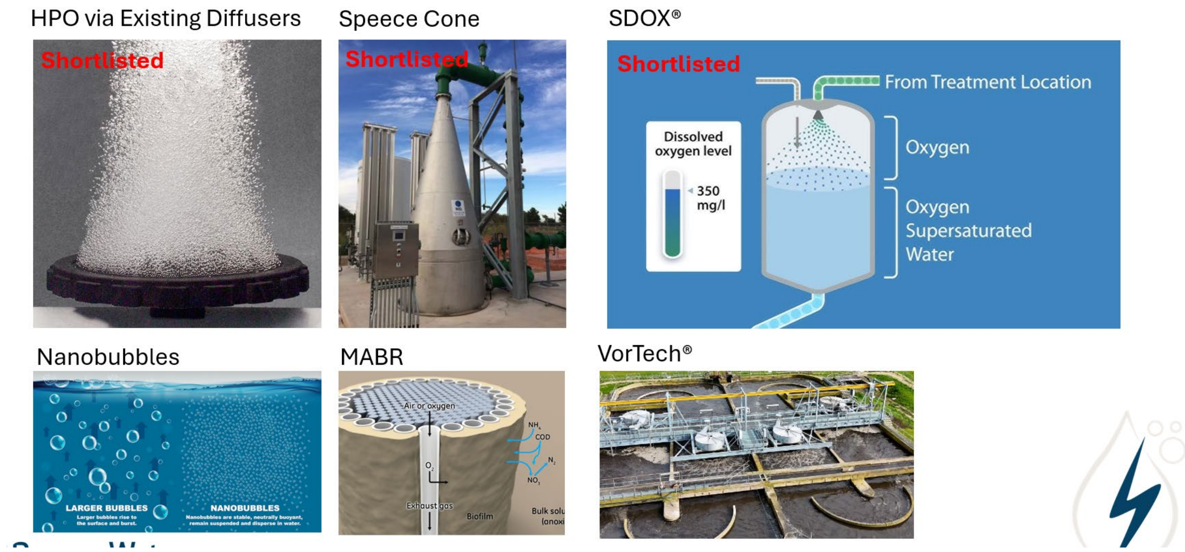

Figure 30 Evaluated oxygen delivery technologies, with shortlisted options including direct injection, Speece Cone, and SDOX®

6. Risks and Safety Considerations

Oxygen-enriched aeration introduces specific safety and operational risks that must be carefully managed. Unlike conventional air-based systems, handling concentrated oxygen requires stringent controls to address hazards related to pressurisation, material compatibility, fire prevention, and long-term system integrity. A key risk area is pipeline pressurisation and oxygen transfer. Delivery systems must operate under controlled pressures to avoid overstressing pipelines and to minimise leakage risks. Components such as compressors, valves, and diffusers must be assessed for oxygen compatibility, as standard materials may degrade or pose ignition hazards under high oxygen exposure.

Fire safety is a critical consideration, as enriched oxygen significantly increases the risk of combustion. System designs must incorporate non-flammable materials, reliable ventilation, and automated shutoff mechanisms to prevent oxygen accumulation. Adherence to standards such as those provided by the European Industrial Gases Association (EIGA) can guide safe integration. In addition, oxygen enrichment alters the dynamics of biological treatment, potentially affecting microbial performance and reactor stability. Control systems must be adapted to deliver precise oxygen dosing, supported by automated monitoring to track transfer efficiency and maintain safe operating limits.

For utilities adopting oxygen enrichment, a multi-layered approach to safety is essential. This includes conducting detailed risk assessments for all infrastructure modifications, implementing robust control systems, and ensuring regulatory compliance throughout design, commissioning, and operation phases.

Conclusion

The Green Oxygen for Wastewater Treatment Project has yielded valuable insights into the technical, operational, and commercial feasibility of integrating electrolysis-derived oxygen into wastewater aeration systems. Key lessons from this study emphasize the importance of oxygen extraction protocols, infrastructure compatibility, system integration challenges, and treatment efficiency impacts. Findings indicate that high-purity oxygen aeration offers significant potential for energy savings, improved microbial activity, and enhanced treatment stability, but successful implementation depends on supply consistency, aeration system adaptability, and safety management protocols.

The project is currently nearing the end of Stage 1, which has focused on developing critical feasibility assessments and supporting documentation. This phase has delivered a comprehensive Functional Design Report, a user-customisable Techno-Economic Model (TEM), a structured Demonstration Trial Protocol, and a replicability report on co-locating electrolysers with wastewater treatment plants (WWTPs) in the Barwon South West region. The study also highlights the potential of oxygen enrichment to defer major capital upgrades by increasing the capacity of existing biological treatment assets, offering a cost-effective alternative to traditional infrastructure expansion. Additionally, key lessons learned have been compiled, capturing insights from the front-end engineering design (FEED) study, informing broader industry applications for wastewater utilities exploring oxygen enrichment strategies.

HARMFUL ALGAL BLOOM MANAGEMENT FOR DRINKING WATER SAFETY: A GLOBAL PERSPECTIVE

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HARMFUL ALGAL BLOOM MANAGEMENT FOR DRINKING WATER SAFETY: A GLOBAL PERSPECTIVE

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Conference Topic

Smart Solutions for Resilient Service Delivery

KEYWORDS

Algal bloom, risk assessment, monitoring, early warning, climate change

INTRODUCTION

Harmful Algal Blooms (HABs) present a critical challenge to drinking water supplies worldwide. Such rapid proliferation of algae can produce biomass that causes process fouling and sludge management issues, and can generate taste and odour compounds and/or toxins that contaminate water making it unsafe for human and animal consumption. With climate change, the frequency, intensity, and geographical spread of HABs are likely to increase and to continue posing a significant risk for drinking water supplies worldwide.

As HABs become more frequent and severe due to nutrient pollution and climate change, ensuring safe drinking water requires comprehensive and innovative approaches. HAB management strategies generally rely on a combination of risk assessment, monitoring, and risk mitigation activities from source catchment to drinking water production plants. Technologies and mitigation measures used include monitoring systems, in-lake control solutions, advanced treatment technologies, and dealing with the root causes of bloom formation (Figure 1).

This paper presents the results of an internal survey conducted in 2023 among Veolia's Business Units worldwide on management strategies to deal with HABs. Best practices and innovative approaches are drawn from 13 countries across the globe, reviewed and discussed in this paper from the perspective of a water supply operator.

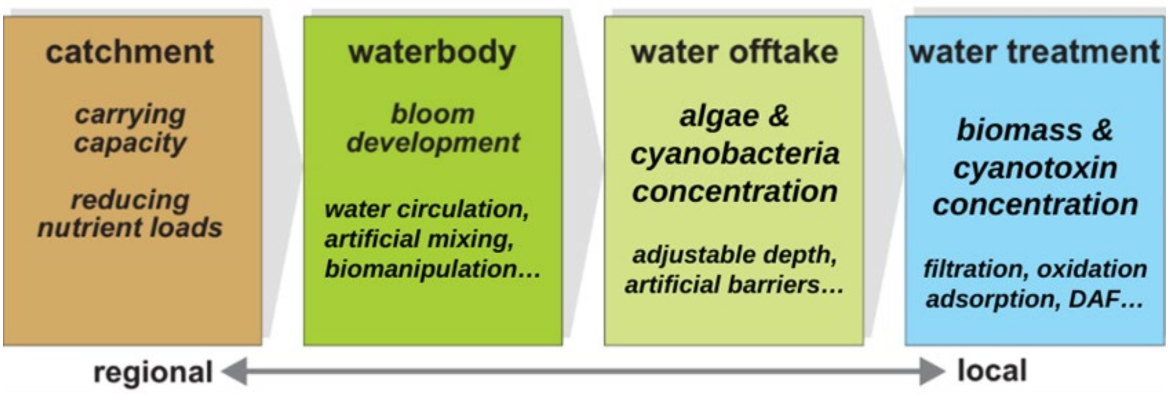

Figure 1: Levels and scales of measures for controlling algae occurrence (adapted from [WHO, 2021)](#)

METHOD/EXPERIMENTAL DESIGN

This paper is based on an analysis of the information collected through an internal survey conducted in 2023 among Veolia's Business Units (BUs) worldwide. The survey requested operators to share their return on experience on encountered algae types and management issues, monitoring strategies, in-situ control measures, treatment solutions & operational procedures. Responses to the survey were obtained from 13 countries representing over 50 drinking water sources. Table 1 provides a summary of the global survey responses.

OUTCOMES / RESULTS

The survey confirms HAB management is a major issue for Veolia's BUs worldwide, that tends to intensify and expand in duration in many places. Process fouling and sludge management are the main operational issues, while taste and odour (T&O) events and algal toxins are the primary water quality concerns. While planktonic algae are the primary cause, benthic algae are of increasing concern, especially for T&O issues.

In most Veolia BUs, algal bloom monitoring commonly relies on water sample microscopic analysis and continuous monitoring sensors of algal pigments and relevant water quality parameters. Smart buoys, vertical profilers and satellite imagery coupled with data driven models are increasingly being used by Veolia's BUs to provide early warning of bloom events (Figure 2 for example). Innovative technologies such as genetic biosensors and flow imaging microscopy are also being tested and showing promising results for early warning and automatic detection of algae species respectively.

A vast array of solutions has been implemented or tested by Veolia's BUs to control HAB at the catchment scale, in the waterbody, at the water offtake (Figure 3), or in the drinking water treatment plant (DWTP). There is no quick fix nor one-fits-all solution, as each waterbody is specific and different factors drive HAB occurrence. Curative solutions such as algicides are being used as a short-term answer to algal bloom events, but there is significant effort to optimize dosing and seek low toxicity alternatives. In-lake control solutions such as aeration/mixing systems, ultrasound technologies and the dosing of phosphorous binding material are also commonly implemented to reduce the occurrence and intensity of blooms. As for preventive solutions, some BUs do implement catchment nutrient control or in-lake physical control, although they require long term efforts and investments to succeed.

Source catchment responsibilities and contractual scope largely determine the type of solutions that Veolia can implement. For example, in China, source catchment protection and raw water supply is the responsibility of public administration, so Veolia's operators focus their effort on raw water monitoring and drinking water treatment. In the US, conversely, Veolia has greater responsibilities for source water protection and can implement a wide range of solutions such as nutrient control.

In all the BUs surveyed, Veolia has responsibility for drinking water quality and therefore implements treatment adjustments and optimization procedures to ensure safe drinking water. In Australia notably, Veolia has developed management plans that include specific treatment procedures according to algae types.

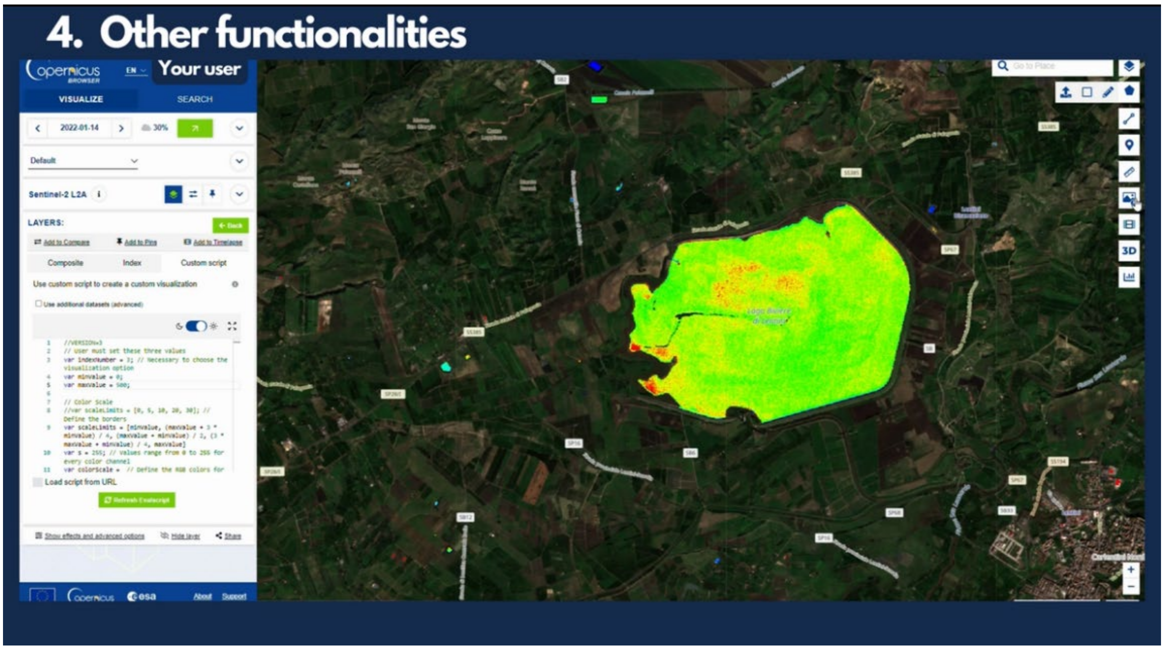

Figure 2: Early warning with the [MAGO Water Monitoring Tool (EU Collaborative Research Project)]() - Water quality parameters in lakes, reservoirs, and irrigation ponds using Sentinel-2 satellite images

RECOMMENDATIONS

Waterbody diagnosis is recommended prior to any medium- or long-term action. It consists in identifying algae and algal bloom drivers (nutrient sources, waterbody shape and hydrology, climate) from information and data on the catchment and the reservoir system. This includes monitoring of cyanobacteria, T&O and toxins if relevant locally. Emerging cyanotoxins should be investigated when potential producers are detected (e.g. *Planktothrix rubescens, Nostocales*…). Investigating drivers is necessary to determine the right combination of measures within the scope of an overall HAB management strategy.

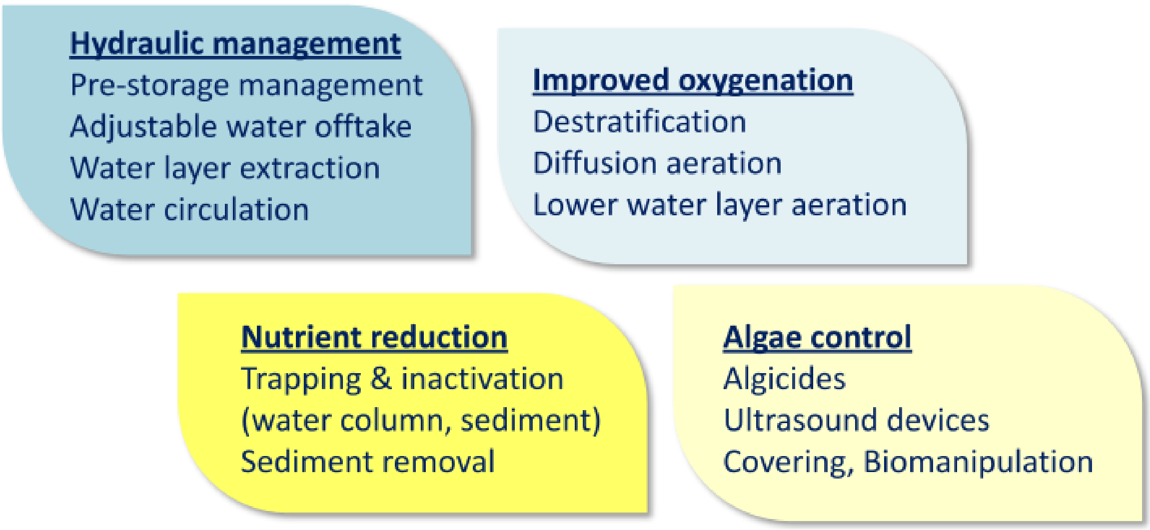

Figure 3: Overview of in-situ control solutions classified according to HAB factors.

CONCLUSIONS

The complexity of HAB management in drinking water contexts requires a multifaceted strategy involving prevention, early detection, and rapid response to protect public health and maintain water security. The survey results also highlighted the need for strong stakeholder cooperation and alignment for successful and long-term management of HABs, as water supply operators rarely have full control on the underlying drivers of HABs and can often only manage bloom events when they occur rather than prevent them in the long term.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY?

Key HAB management areas that have been identified in this study and shared across the global business, as important ways to ensure resiliency and security of water supplies:

- Risk assessment is necessary for designing successful HAB management strategies.
- Early detection of bloom events is key for efficient response to HAB events.
- Effective management strategies rely on a combination of mitigation measures.
- Long-term management of HAB requires stakeholder cooperation and alignment.

Table 1: Responses to survey questions from 13 Veolia Business Units worldwide.

	Algae types, water sources and issues	Solutions for monitoring, early warning and/or prediction	On-site control solutions	Treatment solutions & operational procedures	Other challenges & needs
Australia	Mostly freshwater Cyanobacteria, Pelagic / benthic algae Process fouling, Sludge management, Chlorine/ozone demand, DBPs, T&O, Health risk	Raw water monitoring for early warning In-lake buoys* with online sensors Grab samples + lab analysis**	Not managed by Veolia	Treatment adjusted to algae types: T&O: Ozone and PAC Algal cells: Optimisation of coagulation and settling Toxin removal: Add filtration and disinfection **DAF investigated for event response**	Cyanobacteria increasing during 'cooler' months Multiple stakeholders for catchment-scale actions
Bulgaria	Freshwater, Diatoms, Cyanobacteria Microcystins once	In-lake buoys* with online sensors Grab samples + lab analysis**	Adjustable water intake depth	Treatment process adjustments	Water Safety Plan approach for cyanotoxin risk assessment
Chile	Freshwater, Algal blooms, Green algae, Cyanobacteria, T&O	In-lake buoys* with online sensors Grab samples (surface and depth) + lab analysis**	In-lake ultrasound buoys Water circulation management	PAC dosing	
China	Freshwater, Golden-brown algae, Green algae, T&O, Process fouling	Regular grab samples + lab analysis** Online sensor***	Not managed by Veolia	Pre-oxidation, sometimes pre-chlorination PAC dosing frequently Some KMNO4, One DAF	Effect of climate change: earlier blooms Keeping process functional before algae season
Colombia	Freshwater, Green algae, Cyanobacteria T&O, Turbidity, Reduced water production, Process fouling	Grab samples + lab analysis** **Satellite imagery**	1 in-lake ultrasound buoy Water circulation management	Pre-oxidation Coagulation (aluminum polychloride) PAC dosing	Risk of vandalism
Czech Republic	Freshwater Algal blooms, T&O Process fouling	Not managed by Veolia	Not managed by Veolia	Coagulation (aluminium sulphate) Flocculation (organic polymer) DAF, Filtration UV disinfection or chlorine-based disinfection Positive tests for ultra & nanofiltration	
Ecuador	Freshwater, Diatoms, Cyanobacteria T&O, Filter clogging	Multi-sensor probes for different algae types, Organoleptics		PAC dosing	
France	Freshwater, Algal blooms, Cyanobacteria, Benthic, T&O, Microcystins, 1st Anatoxin in 2023, Process fouling	Grab samples + lab analysis** Online sensor*** **Genetic biosensors, Satellite imagery**	Adjustable water intake depth Aeration systems	Treatment process adjustments PAC dosing	Algal bloom management for bathing water
Japan	Freshwater, Algal blooms T&O Filter clogging	Grab samples + lab analysis** Online sensor*** and vertical profiling Continuous GCMS for MIB & geosmin **Flow imaging microscopy**	Adjustable water intake depth Water circulation management Surface shading	Reduce or stop pre-chlorination PAC dosing GAC filtration basin Coagulation (polyaluminium chloride)	Lack of skilled staff Under consideration: basin shading, algae mechanical removal
Mexico	Freshwater Green algae	In-lake buoys* Rapid test kits for cyanotoxins	1 ultrasound buoy in raw water storage Algicide: Copper sulphate		Invasive species
Oman	Seawater with seasonal red tides Reduced water production	Grab samples + lab analysis** Online sensor*** **Satellite imagery**		Pre-chlorination at intake pipe Coagulation (with coagulant aid dosing) DAF	
Spain	Freshwater Algal blooms, Cyanobacteria Turbidity, OM (DBPs), Toxins Clogging of micro-irrigation systems Eutrophication of recreational waters	Grab samples + lab analysis** Online sensor*** **Satellite imagery: MAGO Water Monitoring Tool (see Figure 1)** **Risk prediction with statistical models**	Some in-lake ultrasound buoys Aeration systems Bactericide: Hypochlorous acid for irrigation ponds and recreational waters	Treatment process adjustments Raw water dilution with advanced treatment of wastewater	Invasive species
USA	Freshwater, Algal blooms, Cyanobacteria & toxins, T&O, Nutrient and sediment loading	Grab samples + lab analysis** Online sensors*** at intake + profiler **Risk prediction tool based on water quality, weather forecast, satellite imagery, reservoir outflow**	Aeration system Algicide: Copper sulphate **H_2O_2 pilot** **Nutrient offset scheme**	Ozone PAC dosing DAF	

* In-lake buoys with online sensors: chlorophyll-a, phycocyanin, turbidity, pH, O_2, temperature ; ** Lab analysis: algae count and identification, physico-chemistry plus sometimes, nutrients, metals, MIB, Geosmin, cyanotoxins (Microcystin-LR, Total Microcystins, Anatoxin-a, Saxitoxins…) ; *** Online sensors: chlorophyll-a, phycocyanin ; PAC: Powder Activated Carbon ; GAC: Granular Activated Carbon ; DAF: Dissolved Air Flotation

Empowering water utilities: Crafting an end-user-friendly reliability ranking for evaluating satellite remote sensing advances

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Title of Full Paper

Empowering water utilities: Crafting an end-user-friendly reliability ranking for evaluating satellite remote sensing advances

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Conference Topic

Smart solutions for resilient service delivery

INTRODUCTION

Water is an essential resource underpinning environmental sustainability, economic development, and social well-being. Its management is becoming increasingly complex in the face of climate change, extreme weather events, population growth, land use changes, and natural disasters. These challenges threaten the availability and quality of water, making it harder for utilities and agencies worldwide to ensure safe, sufficient water supplies. To support adaptive management, modern water utilities are turning to advanced monitoring technologies—among them, satellite remote sensing (Earth Observation, EO) is emerging as a particularly promising solution.

EO technologies provide continuous, spatially extensive measurements of hydrological and environmental variables, complementing traditional ground-based systems. Over the past decade, satellite capabilities have advanced considerably in resolution, frequency, and data accessibility. Public sector missions (Landsat, Sentinel), commercial constellations (Planet, Maxar), and new sensors (hyperspectral, radar, LiDAR) offer a wealth of data, now processed with sophisticated analytics, artificial intelligence (AI), and machine learning (ML) techniques. However, despite this progress, water utilities lack an accessible framework for assessing the reliability of satellite-derived data for operational needs. This paper addresses this gap by developing an end-user-friendly reliability ranking, designed to help utilities evaluate and adopt EO technologies for critical water management applications.

METHOD/EXPERIMENTAL DESIGN

The authors employed a rigorous, PRISMA-guided systematic review of satellite EO literature relevant to water utility operations. Searches were conducted across Web of Science, Scopus, IEEE Xplore, and Google Scholar, targeting studies published mainly after 2016. The review focused on original research involving remote sensing applications in operational contexts such as catchment monitoring, water demand estimation, flood mapping, water quality monitoring, farm dam surveillance, urbanisation trends, drought forecasting, fire spotting, and post-fire water quality management.

In parallel, the team systematically catalogued the technical capabilities of key satellite platforms—optical, thermal, microwave (passive and active), hyperspectral, LiDAR, and altimetry—mapping their spatial, temporal, spectral, and radiometric resolutions against water-related operational needs. The review also considered data delivery pathways, cloud-based processing, emerging analytical tools (including AI/ML), and complementary technologies such as in situ sensor networks and drone-based platforms. The resulting synthesis informed the development of the reliability ranking framework, which classifies sensors' suitability for various water utility applications based on empirical evidence from the literature, technical performance, and operational considerations.

OUTCOMES / RESULTS

The review confirmed that satellite EO offers broad potential to support utility operations across multiple domains. For catchment and flood monitoring, SAR (Synthetic Aperture Radar) and multispectral optical sensors (Sentinel-1, Sentinel-2, Landsat) provide high-confidence data for mapping land cover, soil moisture, vegetation dynamics, surface water extent, and floodplain inundation. These datasets can enhance hydrologic modelling, support disaster response, and inform catchment-scale water resource management.

In water quality monitoring, EO is increasingly used to track parameters such as turbidity, suspended solids, coloured dissolved organic matter, and harmful algal blooms (HABs), particularly in large surface waters. Optical sensors (Sentinel-2, Sentinel-3, MODIS, VIIRS) can detect proxies like chlorophyll-a and cyanobacterial pigments, offering early warning of HAB risks. However, direct measurement of chemical parameters (e.g., nutrients, toxins) remains beyond current EO capabilities, necessitating integration with ground-based monitoring.

Farm dam monitoring, water demand estimation, and post-fire water quality assessments benefit from time-series EO data that track changes in surface water extent, evaporation rates, vegetation condition, and soil degradation. Similarly, EO aids urbanisation monitoring by mapping impervious surfaces, vegetation loss, and urban heat islands. In drought forecasting, satellites contribute valuable inputs—precipitation deficits, evapotranspiration, soil moisture anomalies—that inform predictive models.

A major enabler of these applications is the growing ecosystem of data access platforms (e.g., Open Data Cube, Google Earth Engine, Digital Earth Australia), which democratise EO data and lower technical barriers for utilities. AI/ML techniques further enhance EO value by improving image classification, anomaly detection, and the creation of “virtual sensors” that estimate parameters not directly measurable from space. For instance, neural networks have been used to reconstruct nutrient distributions or generate four-dimensional datasets of water properties.

However, challenges remain. Cloud cover limits optical observations; temporal resolution varies across sensors; and integrating EO with utility workflows requires data interoperability, user training, and ongoing validation. Importantly, the paper highlights the need for ground-truthing and complementary sensing. Ground sensor networks, while limited in spatial extent, provide critical calibration and validation for EO products. Drones (UAS) offer flexible, high-resolution, local-scale surveys that bridge the gap between satellite and field measurements.

The resulting reliability ranking framework offers a practical tool for water utilities. It evaluates each sensor’s suitability for specific applications on a 1–4 scale, informed by both literature evidence and sensor characteristics. For example, Sentinel-2 is highly suitable for catchment monitoring and urbanisation trends, while SAR excels in flood mapping and drought monitoring. No current satellite system is “ideal” for all applications, underscoring the need for multi-sensor integration.

CONCLUSIONS

Satellite EO has matured into a powerful and versatile asset for water utilities, providing scalable, repeatable observations that complement traditional monitoring and modelling. Optical, thermal, microwave, and hyperspectral satellites collectively enable improved understanding of surface water dynamics, catchment processes, and water quality trends. EO-derived insights can guide operational decisions, from optimizing treatment plant operations to managing water allocations and responding to climate-driven events.

That said, EO is not a standalone solution. Some water quality parameters (e.g., toxins, pathogens) cannot yet be directly sensed from space. Field data remain essential for calibration and validation. Additionally, integrating EO into operational workflows requires attention to data compatibility, sensor limitations, and capacity building within utilities.

The open-access model adopted by public space agencies (Sentinel, Landsat) has been critical in driving EO adoption. Public-private partnerships and standardisation efforts (e.g., Analysis Ready Data, Open Data Cubes) further lower barriers. AI/ML integration, combined with cloud-based platforms, is accelerating the transformation of raw EO data into actionable intelligence.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

The next frontier lies in enhancing the operational utility of EO for water management. Key priorities include:

- Integration of EO with advanced models to improve forecasting and early warning systems for floods, droughts, HABs, and fire impacts.
- Development of robust data assimilation frameworks that blend EO, in situ, and modelled data into unified decision-support tools.
- Expansion of multi-sensor approaches, leveraging synergies between optical, SAR, hyperspectral, thermal, and altimetry data to fill observational gaps.
- Upskilling utility personnel to interpret EO products and integrate them into routine operations.

In terms of building resilience, EO provides water utilities with unprecedented capability to monitor changing conditions in near-real time, across entire catchments and water supply networks. This enhances situational awareness, supports adaptive management, and enables more proactive responses to emerging threats—from flash floods to HABs to wildfire-induced contamination events. Over time, EO-supported decision-making can help safeguard water security, improve resource efficiency, and reduce vulnerability to climate variability (Figure 1).

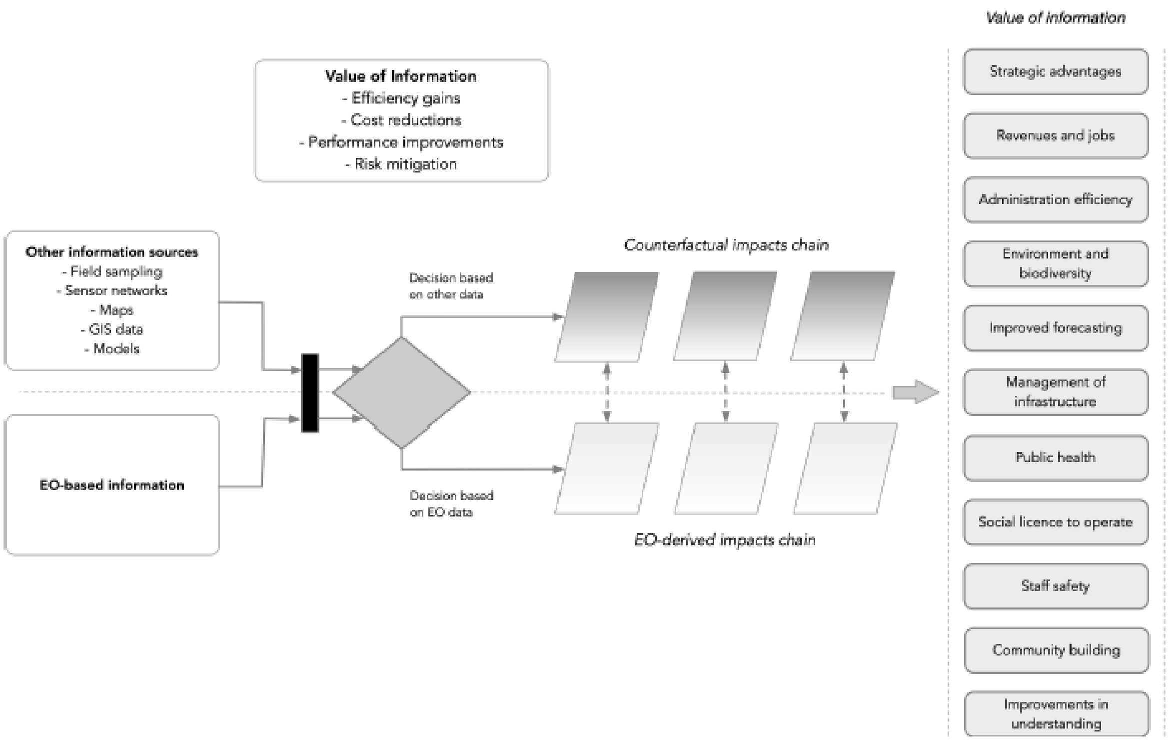

Figure 1. Representation of the means by which water utilities and agencies may assess the possible benefits of Earth observation technologies and the potential indicators against which they can be assessed, made on the basis of the value of information and downstream impacts on the right. Linking arrows between the EO-derived impacts chain and the counterfactual impacts chain indicate the value of key datasets when combined

Ultimately, the end-user-friendly reliability ranking proposed in this paper offers a practical bridge between cutting-edge EO technology and the operational realities of water utilities. By empowering utilities to make informed choices about EO adoption, this framework contributes directly to the development of more agile, data-driven, and resilient water management systems for the future.

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Optimising Autosampler Use for Enhanced Event-Based Monitoring and Decision-Making

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Optimising Autosampler Use for Enhanced Event-Based Monitoring and Decision-Making

Smart Solutions for Resilient Service Delivery

INTRODUCTION

Event-based water quality monitoring is critical for understanding pollutant transport, catchment dynamics, and the impacts of extreme weather on waterway health (Bartley et al., 2012). Autosamplers—automated devices that collect water samples during hydrological events—enable the capture of high flow event data that is often missed by manual grab sampling. This data supports water quality modelling, informs catchment management decisions, and contributes to long-term monitoring programs (Khamis et al., 2023).

WaterNSW operates autosamplers in the Greater Sydney drinking water catchment. These devices are primarily deployed to monitor runoff during significant rainfall events, providing pollute-graph data essential for assessing the impacts of land use, rainfall intensity, and other drivers of water quality degradation. However, the utility of autosampler data has been limited by several factors, including remote access challenges, insufficient sample coverage during peak flows, inconsistent maintenance, and fragmented data systems.

This project reviewed autosampler deployment, management, and data integration practices within WaterNSW. The aim was to identify how these systems can be optimised to enhance data quality, support event-based pollutant load estimation, and better align with internal stakeholder needs. Key focus areas included: stakeholder engagement, evaluation of historical autosampler data, operational challenges in sample collection, and recommendations for improving data management and sampling protocols.

METHOD/EXPERIMENTAL DESIGN

A multi-pronged methodology was used to evaluate how autosamplers deployed across the Greater Sydney drinking water catchment meet business needs and support event-based water quality monitoring. The approach focused on operational effectiveness, data suitability for assessment, and internal stakeholder perspectives.

Document and Literature Review:

Historical documents were reviewed to understand the original rationale, deployment strategy, and evolving operational procedures for autosamplers. In parallel, a targeted literature review was conducted to identify best practices in autosampler deployment and maintenance, including approaches to trigger setting, wet-weather sampling, and data integration. These reviews provided context for evaluating local practices and highlighted potential areas for improvement.

Stakeholder Workshops:

Two rounds of internal workshops were held to capture both strategic and operational insights. The first round engaged data end-users from multiple business units to identify data quality needs, current limitations, and integration challenges. The second round involved Water Monitoring personnel and focused on field-level challenges such as site access, maintenance routines, and equipment reliability. Feedback from these sessions informed key gaps in communication, expectations, and operational clarity.

Autosampler Data Analysis:

A case study analysis was conducted on historical autosampler datasets from selected sites. Key analyses included:

- **Hydrograph Alignment**: Sample timestamps were overlaid on flow hydrographs to evaluate coverage across event phases (rising limb, peak, falling limb).
- **Polluto-graph Trends**: Pollutant concentration profiles were constructed and compared with hydrographs to assess representativeness.

This methodology enabled an assessment of current autosampler practices, grounded in technical review and informed by stakeholder engagement, to identify actionable opportunities for improving data quality and operational effectiveness.

OUTCOMES / RESULTS

Analysis of historical autosampler data revealed performance inconsistencies that significantly impact the utility of event-based monitoring across catchments. While autosamplers are designed to provide high-resolution water quality data during storm events, loss of corporate knowledge to prioritise the optimisation of trigger management, sample pacing, and maintenance has undermined their effectiveness.

Trigger Level Sensitivity: A Case from Coxs River

At site of Coxs River at Kelpie Point, data from 2010 illustrated the intended performance of autosamplers under appropriate trigger settings. With the trigger set at 0.5 m, the system captured five major events, producing 88 aluminium concentration samples aligned with flow peaks (**Figure 1**). This enabled robust analysis of pollutant dynamics during storm events.

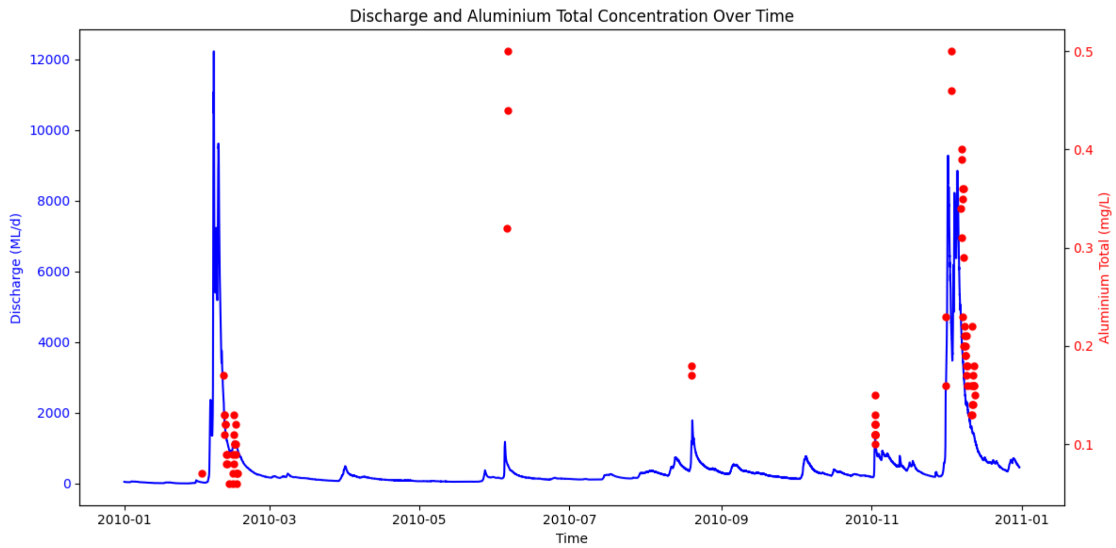

***Figure 31** Aluminium autosampler data points collected at Coxs River at Kelpie Point in 2010 with respect to discharge rate*

However, in 2018, despite similar flow activity, only one event was captured, generating just seven samples (**Figure 2**). This mismatch occurred because most storm events failed to exceed the outdated 0.5 m trigger threshold. The comparison underscores the need for regular recalibration of triggers in response to evolving hydrological conditions.

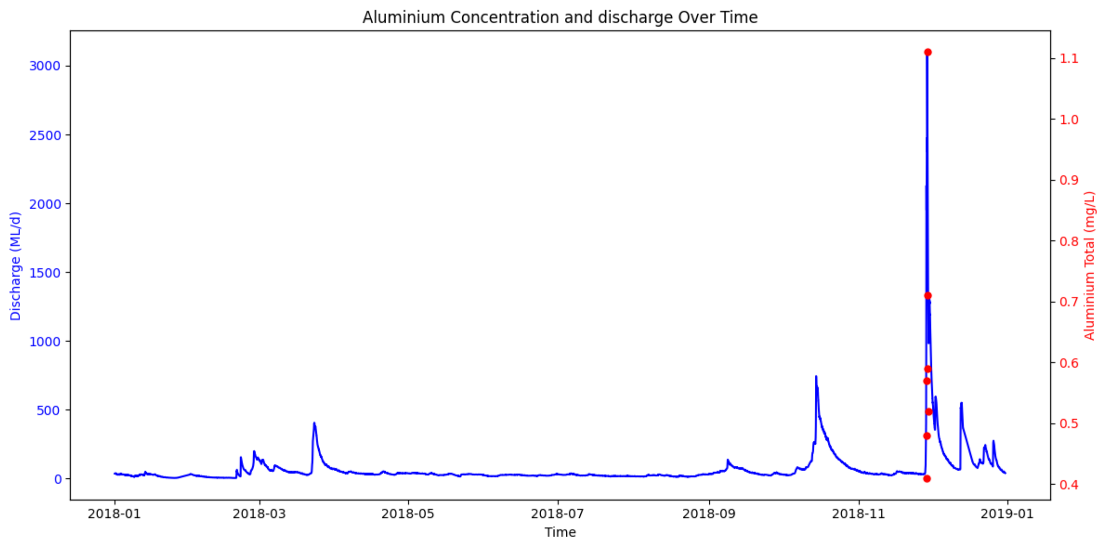

Figure 32 Aluminium autosampler data points collected at Coxs River at Kelpie Point in 2018 with respect to discharge rate

Data Relevance: Autosamplers and Pollutant Loads

To assess the value of autosampler data, pollute-graphs were constructed correlating pollutant concentration with flow. At Coxs River at Kelpie Point, a strong positive relationship was observed between aluminium and discharge (Figure 3), confirming that high flows mobilise greater pollutant loads—a critical insight for catchment modelling and regulatory compliance. This event-based detail is rarely captured by routine sampling, highlighting the unique role autosamplers play in load estimation.

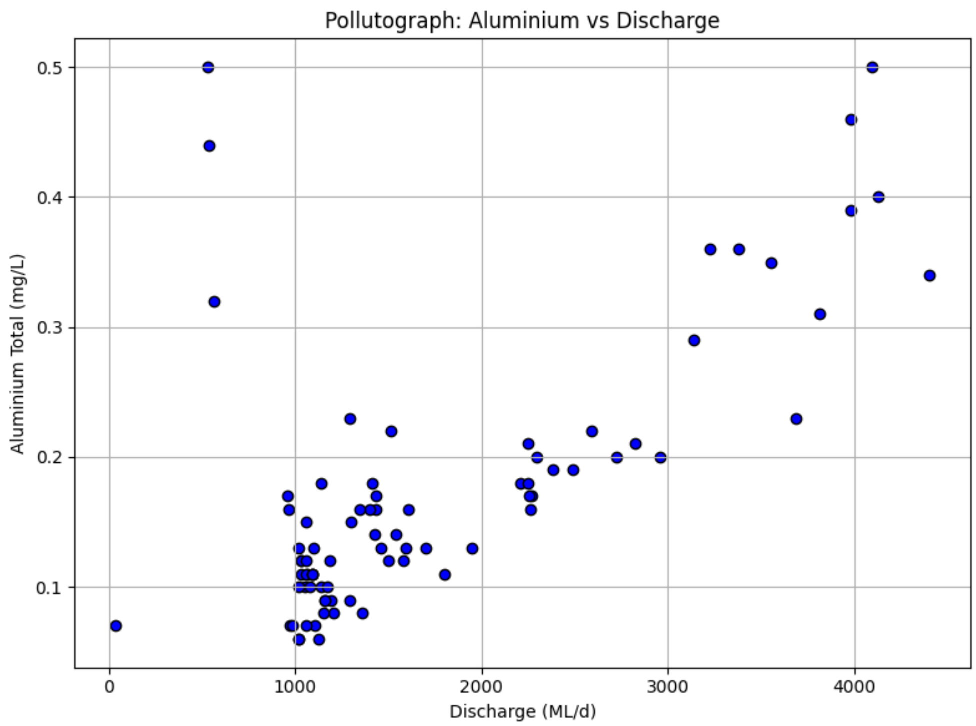

Figure 33 Pollutograph for aluminium vs discharge at Coxs River at Kelpie Point in 2010

Stakeholder Perspectives and Operational Gaps

Stakeholder workshops revealed consistent concerns: sampling gaps during key events, data inaccessible for modelling, and lack of QA/QC protocols. Operational staff cited poor access to sites during storms, safety risks, and unclear program ownership. These insights point to challenges in field operations, and also in governance and strategic alignment that need to be addressed.

Collectively, the findings confirm that autosamplers have significant potential when properly configured, but also that their current deployment is inconsistent and underutilised. With appropriate reprogramming, maintenance, and integration, they can provide critical pollutant data during high-risk hydrological conditions. However, changes in expectations around worker field safety make it difficult to operationalise.

CONCLUSIONS

This review confirmed that autosamplers are a powerful but underutilised asset within WaterNSW's water quality monitoring framework. When properly triggered and maintained, they can capture high-resolution, event-based data critical for understanding pollutant transport dynamics and informing catchment-scale modelling. However, case studies and stakeholder consultations revealed systemic issues—ranging from outdated trigger levels and incomplete storm event coverage to fragmented data systems.

Operational challenges leading to missed events, have led to incomplete pollute-graphs, reducing the reliability of pollutant load estimates. At the same time, data integration challenges and inconsistent QA/QC protocols limit the usability of collected samples for regulatory reporting or strategic planning. Despite these limitations, strong stakeholder interest and recent analytical trials (e.g., machine learning for load estimation) indicate that the program retains high potential value, but alternative delivery models need to be considered for operational viability.

To restore functionality and improve resilience, autosampler practices need to be reassessed with current hydrological realities, business needs, and technical capabilities. This includes modernising infrastructure, refining operational protocols, and proper evaluation and prioritisation of the sites and analytes for monitoring.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Optimising autosampler operations will directly enhance WaterNSW's capacity to manage water quality risks under increasingly variable climate conditions. However alternative monitoring methodology may provide more operationally viable methods of capturing event-based data. By improving the spatial and temporal resolution of data captured during high-flow events, WaterNSW can:

- Strengthen catchment modelling and scenario forecasting;
- Reduce uncertainty in pollutant load estimates for regulatory compliance;
- Support targeted catchment interventions and investment planning.

Looking forward, a reinvigorated event-based water quality monitoring network can act as a backbone for broader digital monitoring initiatives, complementing in-situ sensors and emerging technologies like passive samplers. This will position WaterNSW to build a more resilient and adaptive monitoring system—one capable of responding proactively to extreme weather events and long-term environmental change.

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The Urgent Molecular Shift: A Paradigm Change for Water Quality and Public Health through Multi-Omics

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The Urgent Molecular Shift: A Paradigm Change for Water Quality and Public Health through Multi-Omics

Nicholas J. Ashbolt & Claire Hayward, SAAFE[CRC], Future Industries Institute, University of South Australia

Theme: Water for One Health: Integrating ecosystems, people, and policy

INTRODUCTION

Traditional microbial monitoring for water quality management in Australia, as in many other countries, relies heavily on culture-based detection of *Escherichia coli* and enterococci as indicators of faecal contamination, and hence potential presence of enteric pathogens. However, this approach fails to indicate the full spectrum of microbial risks in water systems, owing to two fundamental limitations [1,2]:

1. Faecal indicators do not reliably mirror the fate and behaviour of key enteric pathogens—particularly viruses and protozoa—during treatment or in the environment, due to marked differences in their persistence and removal profiles.
2. Faecal indicators provide no insight into the vast array of *environmental pathogens* that thrive independently of faecal contamination and predominantly impact those more vulnerable in society — hence described as opportunistic pathogens (OPs). Such pathogens are primarily associated with free-living protozoa (FLP) in biofilms, both in natural and engineered water systems. These are broadly categorized as saprophytic pathogens (those deriving nutrients from decaying plant matter) or saprozoic pathogens (those exploiting living animal-derived organic matter, often via FLP hosts).

Notable examples of saprozoic OPs include *Legionella pneumophila*, non-tuberculous mycobacteria (NTMs), and *Pseudomonas aeruginosa.* These organisms are of increasing public health concern and are adapted to engineered water systems and can also contribute to the dissemination of antimicrobial resistance (AMR) [3].

This paper outlines the scale and complexity of this challenge, and highlights how modern microbiological approaches, including omics-based technologies and bioinformatics can offer a more robust and risk-relevant framework for water quality assessment. Just as the water sector has successfully integrated advanced analytics into routine chemical monitoring, it is well over time to embrace a comparable transformation in microbial surveillance. This paradigm shift must be reflected in the next generation of water quality guidelines to improve public health outcomes. Our goal is to stimulate this critical conversation and bring together stakeholders across the drinking water, recreational, environmental, and reuse sectors to help drive this transition from legacy indicators to science-based, system-relevant microbial monitoring.

METHODS – RATIONAL FOR THE SHIFT

Health basis for different targets

OPs flourish in engineered infrastructures, independent of faecal contamination [4]. These organisms are increasingly recognised as major contributors (by an order of magnitude) to the burden of waterborne disease, as well documented in Europe and the USA [5,6]. In contrast, Australia has relatively few documented outbreaks, but this reflects a lack of comprehensive surveillance rather than a lower actual burden [7]. Underreporting is especially acute for OPs, with an estimated 70% of cases resulting from sporadic community acquired infections [8] that typically go undocumented, since most health reporting focuses only on outbreaks and healthcare associated infections.

Opportunistic waterborne pathogens such as *L. pneumophila*, NTMs, and *P. aeruginosa* are known contributors to community-acquired pneumonia (CAP), which has a mortality rate of 11.8% for hospitalised patients over 65, with a cost burden of over $500 million annually [9]. While national data are limited, New Zealand provides a useful benchmark, where *L. pneumophila* accounted for a mean 4.6% of CAP cases and direct healthcare costs of $2.1 million per year between 2016 and 2020 [10,11]. Scaled to Australia [12], this suggests direct costs of $20–50 million annually due to OPs' contributions to CAP alone. When indirect costs such as loss of wages and productivity are included, the total health burden is likely far greater and surpasses those associated with waterborne enteric diseases. Although still costly to manage, these enteric pathogens are well managed in urban centres though the current Australian Drinking Water Guideline framework [13]. In contrast, waterborne enteric risks are under-managed in regional and remote communities [14], reflecting a need for fit-for-purpose microbial management approaches.

Compounding the need to address both enteric and OPs is the escalating challenge of AMR which is a priority concern globally [15,16] and increasingly in Australia [17]. The role of water systems in the dissemination and amplification of AMR is a central focus of SAAFE[CRC] research [18], particularly within distribution system biofilms, which support horizontal gene transfer [19,20]. Emerging findings suggest that corrosion control chemicals may stimulate these resistance processes [21], as do pipe materials [22], and that extracellular DNA which may evade removal by conventional disinfection, can persist and potentially amplify within downstream biofilm communities [23]. These factors underscore the urgent need for risk frameworks that move beyond faecal indicators to include OPs and AMR dynamics within engineered water systems.

Molecular tools and their evolution

Molecular methods for water microbiology have been pioneered in Australia in collaboration with international partners since the 1990's [24], and more recently reviewed by RMIT researchers [25]. Despite this early leadership, widespread transition away from traditional culture-based methods towards modern alternatives has been slow, largely due to institutional inertia and the longstanding reliance on culturable *E. coli* as a proxy for recent faecal contamination. While *E. coli* remains a practical and historically validated indicator, it is increasingly recognised as insufficient for capturing the broader spectrum of microbial risks especially for disinfectant-resistant viruses and protozoa, and for OPs not associated with faecal sources.

One commonly cited limitation of molecular approaches, particularly quantitative polymerase chain reaction (qPCR), has been their inability to distinguish between viable and non-viable organisms, as DNA or RNA from dead cells or inactivated virions is also detected. However, this barrier is being addressed by cell or capsid integrity pre-treatments, such as propidium monoazide or ethidium monoazide, which selectively bind nucleic acids in compromised cells or virions, thereby blocking their amplification during PCR [26,27]. More recently, this viability-based approach has been extended to metagenomic sequencing, enabling more ecologically and epidemiologically relevant insights into active, microbial communities in the environment [28].

Advances in sequencing technologies have dramatically lowered costs (<$100 per sample) for sequencing and basic bioinformatic analysis, making high-resolution microbial community profiling accessible beyond academic labs. Coupled with simplified and portable molecular tools such as loop-mediated isothermal amplification and lateral flow assays (akin to COVID-19 rapid antigen tests), these technologies support flexible deployment of multi-targeted molecular indicators (multi-omics) for laboratory and field settings. Together, these innovations pave the way for a new generation of rapid, affordable, and informative microbial diagnostics that can move water microbiology beyond the limitations of culture-based paradigms, and closer to real-time management systems that address the breath of microbial water quality risks.

Molecular tools for source discrimination and understanding pathogen ecology

Molecular tools are increasingly vital for identifying sources of faecal pollution (and hence likely pathogen attributions) and the environmental origin of OPs and genes. Techniques such as microbial source tracking and molecular-based quantitative microbial risk assessment have shown that the origin of faecal contamination is critical to determining risk, particularly from enteric viruses, which are far more prevalent and persistent in human faecal waste compared to animal sources and zoonotic pathogens [29,30]. As such, moving beyond general faecal indicators to include source-specific molecular markers significantly enhances risk resolution and supports more targeted and efficient public health interventions [31,32]. Among the most promising developments is the use of the human sewage marker plasmid pBI143 [33], although new ones will continue to be identified to further improve specificity and stability for tracking human/zoonotic inputs.

Complementary advances in metagenomic profiling are also emerging, enabling broad-spectrum analysis of microbial communities, functional and pathogen-related gene expression and identification of host-specific microbial signatures [34]. These tools together represent a leap forward in our capacity to discriminate contamination sources and better align microbial monitoring with human health risks. Recreational water monitoring in North America was the first to embrace these molecular approaches through direct engagement by Ashbolt with the US EPA [35], Alberta Health Services [36] and Health Canada [37].

In parallel, extracellular vesicles (EVs) are being increasingly recognised as central players in the ecology, transmission, and virulence of pathogens including bacteria, fungi, protozoa, and viruses. EVs are nanoscale, membrane-bound particles that package and protect diverse bioactive molecules (proteins, lipids, nucleic acids, toxins, and signaling compounds) and enable OPs to evade host immune responses, coordinate infection processes, and disseminate AMR [38,39]. In engineered water systems, EVs derived from free-living amoeba (FLA) appear to be key drivers of saprozoic pathogen blooms, especially *L. pneumophila*, by supporting pathogen persistence and proliferation within biofilms, and facilitating aerosol-based transmission [40]. Concerningly, FLA themselves via cysts, trophozoites, and their EVs can shield infectious enteric bacteria, viruses and OPs from disinfection processes, reducing treatment efficacy by at least two $\log_{10}$ units [41,42]. This protection enhances the environmental survival of both faecal and OPs, underscoring the need for molecular surveillance tools that capture these non-culturable, protozoa-associated transmission routes.

Conclusions

Effectively managing microbial risks in water systems requires Australia to move beyond its historical reliance on faecal indicator bacteria and embrace a science-informed, risk-based monitoring paradigm. Traditional culture-based methods and faecal indicators are inadequate for understanding the diversity, persistence, and behaviour of both enteric and OPs, particularly those associated with FLA, biofilms, and EVs. These elements are central to the survival, treatment resistance and transmission of both classic and emerging waterborne pathogens, such as *L. pneumophila*, NTMs, *P. aeruginosa*, and AMR-vectors.

Modern molecular tools, including qPCR with viability pretreatments, metagenomic sequencing, and microbial source tracking markers, offer the specificity, sensitivity, and ecological relevance required for contemporary water quality surveillance. When paired with portable diagnostics such as LAMP and lateral flow assays, they offer scalable solutions that can be applied across both urban and regional water services. Just as the water sector has successfully integrated advanced chemical risk frameworks, now is the time to integrate equivalent sophistication in microbial risk management to ensure health protective and resilient water systems.

WHAT'S NEXT TO HELP BUILD RESILIENCY

To strengthen Australia's ability to manage microbial risks in water, key next steps include:

- Update monitoring frameworks by incorporating source-specific, pathogen-targeted molecular (omic) methods into water quality guidelines and monitoring frameworks, in part as wastewater and environmental surveillance (WES).
- Build national reference datasets quantifying the burden of disease from OPs and their contribution to illnesses such as CAP and their contribution to AMR.
- Standardise and validate molecular assays, including viability-linked detection, to enable regulatory uptake.
- Expand surveillance and risk assessments to include non-faecally derived OPs and FLA-associated transmission pathways, particularly in distribution systems and decentralised or recycled water schemes and for wastewater and environmental surveillance (WES) as part of a One Health-focused approach.

By taking these actions, Australia can lead a new era in water microbiology, one that is more resilient, equitable, and responsive to emerging public health challenges across our communities.

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Conceptual models of risk posed from wet weather overflows to both human health and of adverse ecological effects in urban receiving waterways

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Title of Full Paper

Conceptual models of risk posed from wet weather overflows to both human health and of adverse ecological effects in urban receiving waterways

Conference Topic

Water for One Health: Integrating ecosystems, people, and policy - Examine the interconnectedness of human, animal, and environmental health within water systems.

INTRODUCTION

During rainfall events, the inflow and infiltration of stormwater into the wastewater system through faults, such as cracks and breaks, can increase the flow in wastewater system pipes, causing wet weather overflows (WWOs). Sydney's wastewater system is designed with emergency relief structures (ERS, example shown in Figure 1) to protect public health by allowing excess wastewater to overflow into waterways during wet weather rather than into homes or buildings.

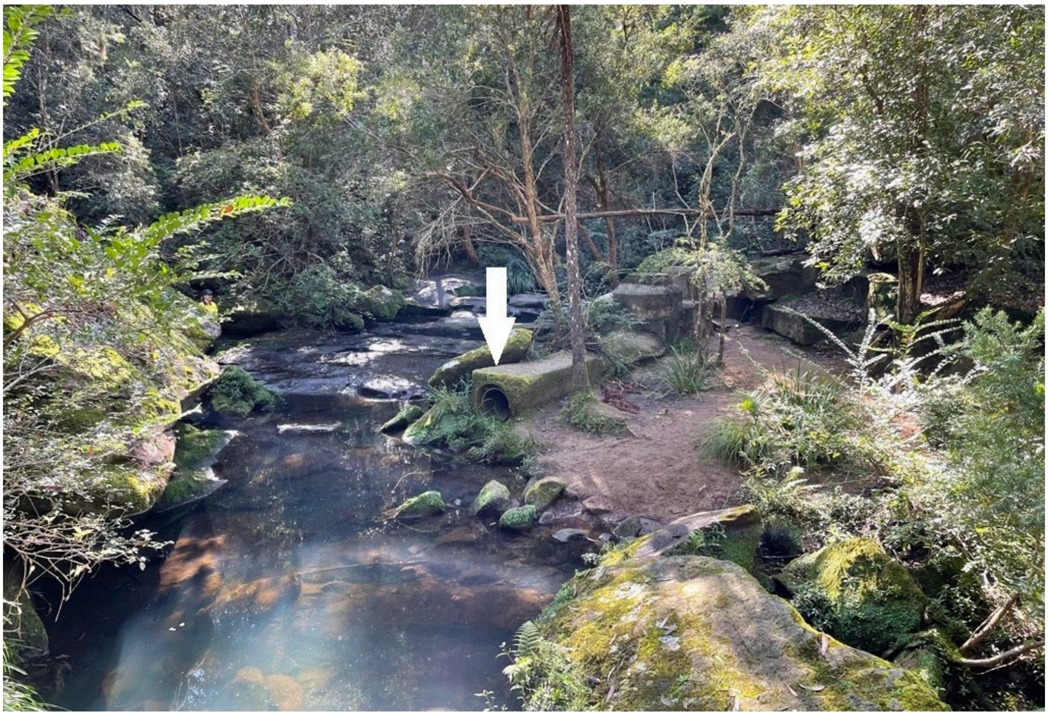

Figure 1. Darling Mills ERS (indicated by the white arrow) in bushland below housing on ridgelines of the Castle Hill/Baulkham Hills area of Sydney Australia

Over the last ten years Sydney Water and the New South Wales, Australia, Environment Protection Authority (NSW EPA) have developed a framework for the improved management of WWOs. This framework enabled a methodology to be developed to prioritise solution planning based on the risk posed from WWOs across the wastewater system. This initial methodology was based on qualitative and modelled inputs. The NSW EPA detailed an obligation for continuous improvement. An obvious area of improvement were the monitoring inputs into this methodology. In response to this obligation, the Wet Weather Overflow Monitoring (WWOM) program (2016-2024) evaluated monitoring tools that had not been previously detailed in the international scientific literature for WWOs from a sanitary wastewater system (that is separate to the stormwater system).

COLLABORATIVE RESEARCH APPROACH

An independent expert peer-review panel provided assurance that the outcomes of the WWOM program were robust and would withstand scrutiny from stakeholders. Under expert panel guidance, Sydney Water's Laboratory Services and Water and Environment Services groups collaborated with university researchers and the Commonwealth Scientific and Industrial Research Organisation to conduct a series of studies across four research areas (Figure 1). Conducting these studies across a range of receiving water sites helped understand potential impacts from overflow points with differing spill frequencies and volumes.

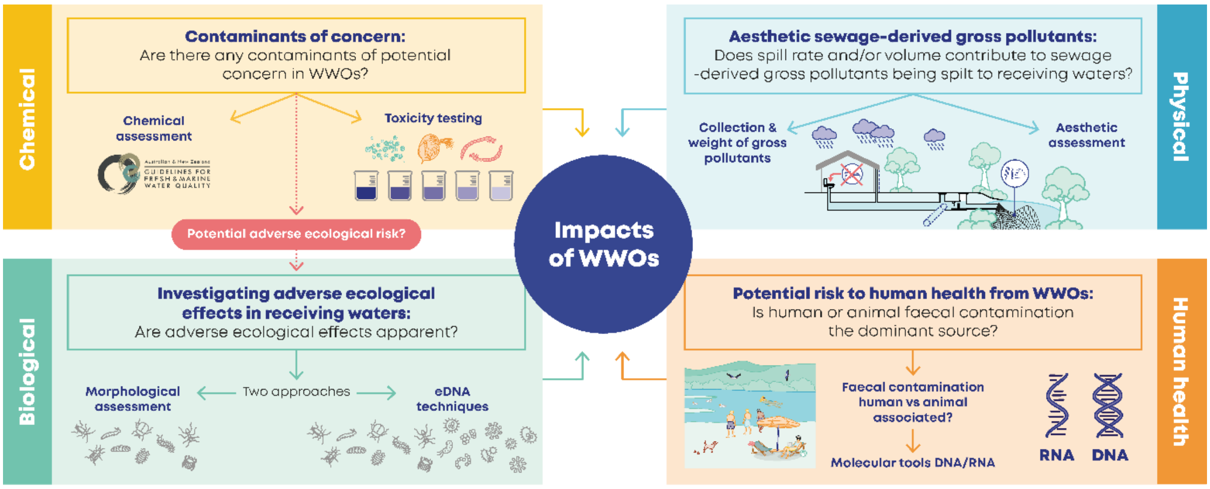

Figure 2. Summary of WWOM program showing components investigated and overarching research questions.

OUTCOMES

This collaborative approach developed an understanding of the impacts of WWOs with the evaluated monitoring tools. Study findings were published in 16 journal articles in high-impact international scientific journals. Another two articles have been submitted, with one since accepted and the other article is under journal review. These findings form the basis of the WWOM 2016 to 2024 Synthesis Report that documents answers to the four overarching research questions (Figure 1) by presenting four conceptual models raised in conjunction with the peer-review panel (Figures 3 to 6). Gravity-fed WWOs that had flow rates in excess of than 150 L/s discharged larger volumes of gross pollutants with the greater volumes spilt from siphonic overflows that had spill rates above 1000 L/s (Figure 3). The dominant gross pollutant documented were wet wipes.

During wet-weather the major faecal contamination comes from humans through WWOs with minor contributions from animals (Figure 4). Risk based thresholds have been developed for four human faecal-associated marker genes to assess the risk to human health from WWOs across 10 days post a spill event (Figure 4). Differing decay rates were documented across marker genes, however, the three enteric viral pathogens assessed decayed similarly irrespective of the study site and exposure to sunlight. The decay of CrAssphage CPQ_056 was the best aligned human faecal-associated marker gene to the viral decay rates and is potentially an adequate surrogate for multiple viral pathogens in the water column.

Companion lines of evidence from chemical and toxicity testing determined ammonia to be the primary toxicant for adverse ecological effects from WWOs (Figure 5). In contrast 18 organic contaminants that included common pharmaceuticals and personal care products were below a level of concern. Toxicity testing also identified the metals of copper and zinc to be contaminants of concern (Figure 5). However, loading from stormwater runoff should be considered. As studies on highly urbanized sub-catchments of the Sydney estuary (Davis and Birch, 2009) have shown that copper, lead, and zinc contamination primarily originates from diffuse sources such as residential areas and roads, contributing between 79% and 87% of the total metal load (Figure 5). This suggests treatment of metals in influent without treatment of stormwater sources is highly unlikely to have an environmental benefit.

Gauging 78 ERSs across a wide range of low, medium and high frequency WWOs provided a real-world insight into functioning of the Sydney sewerage system. We determined that WWO spill durations of less than 6 h comprised just over 60% of WWO spill events while WWO spill durations of 24 h or less comprised over 90% of WWO spill events (Section 4.5.2 of Synthesis Report). These documented WWO durations suggested that seven and eight (multi)-day chronic toxicity tests over estimated effects. Pulsed toxicity tests of 6 h and 24 h were developed that better mimicked WWO durations than multi-day chronic toxicity tests (Figure 5). These pulsed toxicity test outcomes helped determined that dilutions of greater than 1 in 2 were required to remove toxicity and the potential of adverse ecological effects from WWOs (Figures 5 and 6).

Adverse ecological effects were documented in urban streams with low dilution capacity of WWO spill volumes (Figure 6) from studies of freshwater macroinvertebrates at paired sites situated upstream and downstream of a stream reach receiving WWOs. Three urban stream conditions were identified with limited capacity for dilution of spill volumes from WWOs. These stream conditions with low dilution were: scenario one, too many ERSs spilling into the same point in a stream (Figure 6, left hand pane); scenario two, an oversized ERS spilling to a very small urban stream reach (Figure 6, middle pane); and scenario three, too many oversized ERSs spilling to a small urban stream reach (Figure 6, right hand pane).

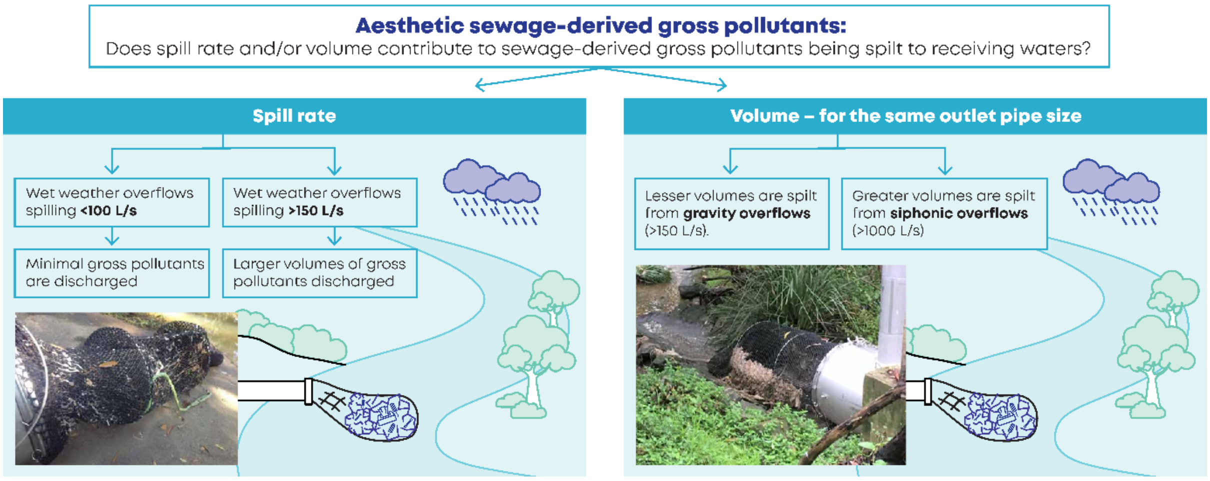

Figure 3. Conceptual model illustrating differing yields of sewage-derived gross pollutants influenced by ERS spill rate

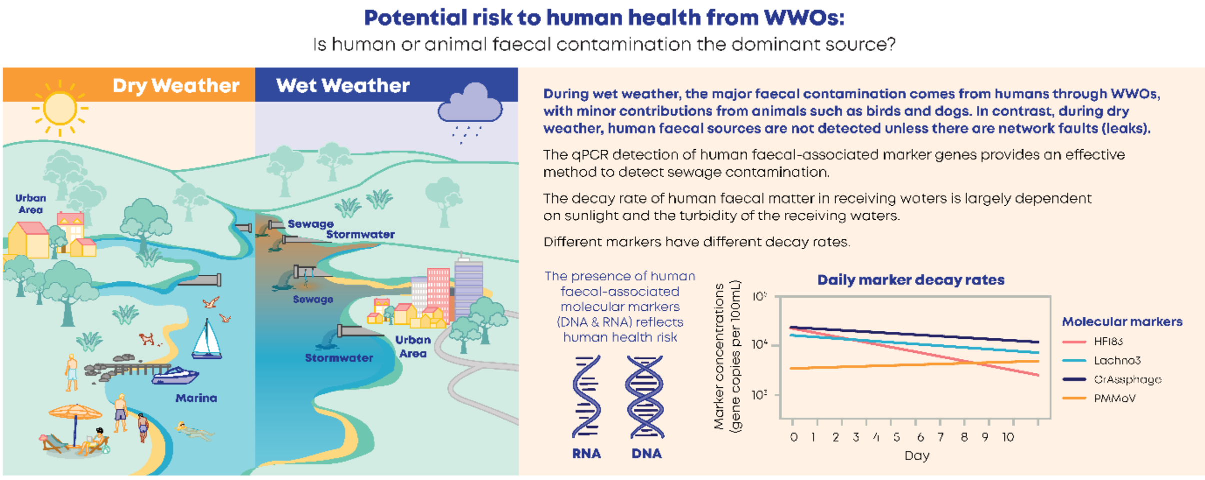

Figure 4. Conceptual model raised from the human health pilot studies

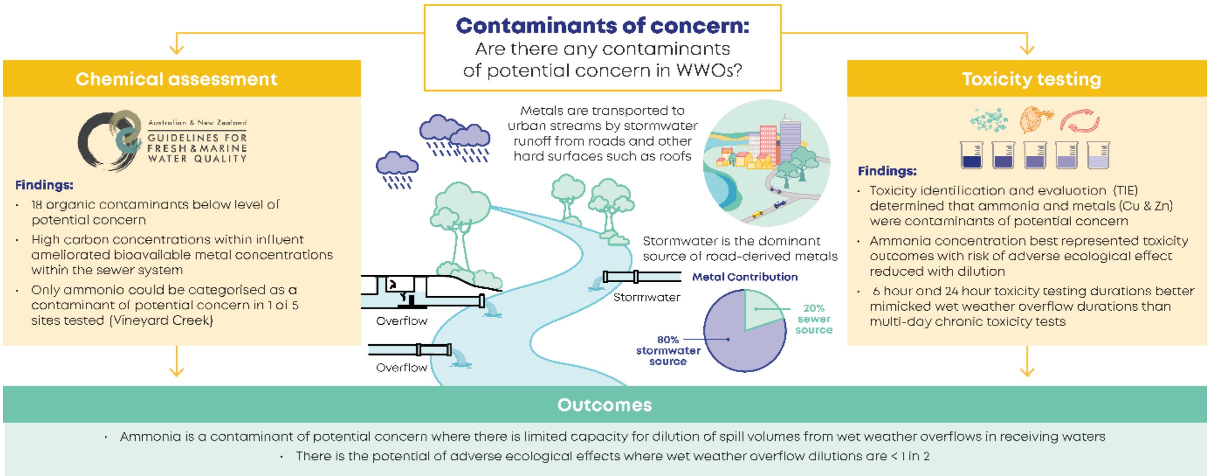

Figure 5. Conceptual model illustrating the contaminants of concern

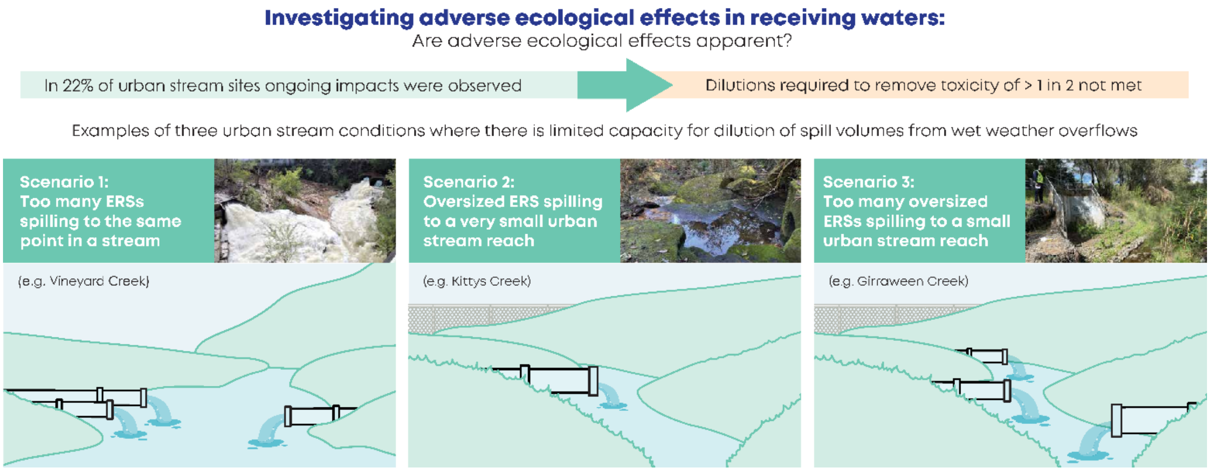

Figure 6. Conceptual model illustrating adverse ecological effects in receiving waters from WWOs

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Recommendations for future monitoring inputs into the risk-prioritisation methodology are detailed in the WWOM 2016-2024 Synthesis Report. Collaboration under the WWOM program enabled capability uplift within Sydney Water Laboratory Services for future application of these recommendations. Applying these recommendations will contribute to improved management of WWOs.

PUBLICATION FROM SUB-STUDIES

DOIs of 16 publications follow with fuller citation details contained in the WWOM 2016-2024 Synthesis Report: https://doi.org/10.1016/j.watres.2018.08.049; https://doi.org/10.1016/j.envint.2019.01.035; https://doi.org/10.1038/s41598-019-48682-4; https://doi.org/10.1016/j.scitotenv.2019.135390; https://doi.org/10.1016/j.watres.2020.116109; https://doi.org/10.1016/j.scitotenv.2020.140071; https://doi.org/10.1016/j.ecolind.2021.107537; https://doi.org/10.1016/j.jenvman.2021.114256; https://doi.org/10.1016/j.watres.2022.119093; https://doi.org/10.1016/j.chemosphere.2022.136997; https://doi.org/10.1016/j.scitotenv.2023.162764; https://doi.org/10.1016/j.scitotenv.2023.165008; https://doi.org/10.1007/s11356-023-29152-x; https://doi.org/10.1016/j.scitotenv.2023.167845; https://doi.org/10.1016/j.scitotenv.2024.171389; https://doi.org/10.1016/j.scitotenv.2024.172448

17th paper accepted after finalising the Sydney Water WWOM 2016-2024 Synthesis Report (Section 4.5.1 of Synthesis Report) https://doi.org/10.1016/j.scitotenv.2024.175924

A National Intelligence System for Water Quality: A Platform Set to Transform Environmental Monitoring

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A National Intelligence System for Water Quality: A Platform Set to Transform Environmental Monitoring

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Conference Topic

Water For Once Health: Integrating Ecosystems, People and Health

INTRODUCTION

Water Quality testing, monitoring and reporting within the Australian water industry is hindered by outdated practices, fragmented workflows, and compliance and threshold incentives that promote conservatism as our primary risk mitigation (Dosemagen & Williams, 2022; Kaufman, 2014). Environmental data from thousands of water samples, collected daily across the country, are trapped in static formats, primarily spreadsheets, behemoth unstructured databases and or historic PDFs reports which limits our agencies from displaying timely, transparent, and actionable behaviours (Lanoue, 2020). Siloed processes have contributed to costly monitoring programs, duplication, and increased environmental risks, undermining the goals of integrated management such as those promoted by this session on 'Water For One Health: Integrating Ecosystems, People and Health.'

Traditional water industry practices reflect disconnected, reactive subsystems – where water agencies, environmental protection authorities and industry cannot readily disseminate data. What is required is a digital system and standardised language, that facilitates an industry where all data across the nation can be viewed, shared, analysed and audited in one place. In doing so it will allow many key goals of government, add predictive capabilities for environmental health, show trends in environmental chemistry all of which lead to a system which will enable preventive actions over than reaction.

This digital innovation overcomes key challenges identified in literature, including rigid threshold-based assessments (Groffman et al., 2006), poor data interoperability, and third party-driven inefficiencies (Bouwmeester, 2023; Dosemagen & Williams, 2022). Findings from stakeholder interviews confirm that implementing a system like this would significantly streamline regulatory compliance, reduce operational costs, enable citizen science and enhance transparency. This positions the water industry toward proactive, adaptive, and resilient management aligned with broader sustainability and One Health objectives.

The Viable Systems Model (VSM) provides a framework for managing complex, decentralised systems, such as national environmental water chemistry (Beer, 1972). It posits that each separate system operates as a unique 'black box'. The environment—particularly water quality—is shaped by distinct geologies, contaminant streams, biodiversity's, hydrologies, and chemical legacies that defy simplistic, standardised assumptions (Ashby, 1956). Drawing on Ashby's Law of Requisite Variety, which holds that only a system with sufficient complexity can effectively understand and manage another complex system, VSM rejects the idea that a single rigid threshold can control whole ecosystems and argues that it will always fail to capture the variability of site behaviours and users. Instead, the need is clear for an adaptive 'System 4', a forward-looking intelligence function capable of interpreting real-time, site-specific data, filtering this information from diverse ecosystems, and enabling timely, proactive decisions to intervene in contamination events before they occur.

This paper applies the Viable Systems Model through two integrated research methods: a critical literature review exploring limitations of threshold-based environmental regulation and opportunities for adaptive governance, and twelve semi-structured interviews with stakeholders across the Australian water sector. Together, these offer a snapshot of how digital systems might support more resilient, real-time environmental management—findings to be expanded in future publications.

LITERATURE REVIEW

Historically, environmental regulation has relied on fixed chemical thresholds to distinguish safe from hazardous conditions. In Australia, frameworks like the National Environmental Protection Measure (NEPM) and drinking water guidelines use chemical limits to define permissible contamination levels (National Environment Protection, 201). While practical, such thresholds carry major limitations. They ignore ecosystem variability dynamics such as hysteresis, where recovery follows a different path than degradation (McPherson et al., 2022), and may activate too late, risking irreversible damage (Groffman et al., 2006). Critically, thresholds often prove overly simplistic once site-specific risk assessments begin incorporating real-world complexity. For example, Van Dijk et al. (2021) show how aquatic risk assessments in the EU initially apply high generic thresholds for chemical pollutants, but these are consistently revised downward-sometimes by orders of magnitude-when ecosystem-specific exposure, sediment behaviour, and food web bioaccumulation data are included. This trend highlights the flaw in setting blanket thresholds: as actual site data emerges, the supposedly “safe” limits are revealed as inadequate, requiring ever-lower benchmarks to remain protective. This process adds cost, delays, and confusion—problems that could be mitigated by systems that support adaptive, data-responsive environmental governance from the outset.

In response, recent literature calls for adaptive thresholds embedded within broader monitoring frameworks (Kelly et al., 2015). Greaves et al. (2025) propose regional Safe Operating Spaces (SOS) based on resilience thinking. These recommend flexible, scenario-driven thresholds reflecting ecosystem connectivity, biodiversity, and integrity, moving beyond static chemical values toward real-time, predictive regulation.

Underlying the call for adaptive systems is the global issue of a fragmented data environment. Lanoue (2020) highlights inconsistencies in terms of format, metadata, unit of measurement, and public access in environmental monitoring. Dosemagen and Williams (2022) call this the “last mile” problem: data is technically available but completely unusable – data that lacks context or interoperability. Even integrated systems like Europe’s SEIS have failed to consistently improve outcomes (Sverdrup et al., 2019).

To resolve this, research advocates for environmental platforms aligned with FAIR principles(Findable, Accessible, Interoperable, Reusable). Bumberger et al. (2024) present a modular sensor management system supporting automated quality control, real-time data sharing, and adaptive governance. These capabilities underpin modern, resilient water management aligned with Water for One Health: integrating ecosystems, people, and health.

OUTCOMES / RESULTS

Methodology

This research involved twelve hour-long, semi-structured interviews with professionals across the Australian water sector, including consultants, regulators, lawyers, and technical leads. Transcripts were thematically coded to identify recurring challenges, inefficiencies, and opportunities for innovation, with reference to the Viable Systems Model. Interviewee anonymity was maintained throughout – a summary of themes and related quotes is available in Table 1.

Table 1: Themes and Quotes from Qualitative Research

Theme	Stakeholder Quotes
Systemic challenges in contamination data management	*"I think there’s a lot of double work in that world — you know, we win a job, and it was a different consultant before us. They hand over the information, and we’re trying to work out what their data actually is."* *"We rebuy that information over and over—BOM data especially. Every project buys it again."* *"People are just used to doing things in Word and Excel and PDFs. That’s the default, and consultants don’t want to change unless they’re made to - The consultant controls the lab data, too—it all flows through them"*
Delays due to consultant reliance	*“Even a basic report, it still takes time. You gotta go through the engagement of a consultant. Obviously. Sometimes they'll go out on field. And then the time it obviously takes them to analyse,*

	write and review the actual reports before they are sent. It will often be months after a sample is taken before we know." *"We collect water quality data pre-contract, through a consultant of course, then the contractor collects their own, using their own consultant. That all gets bundled into separate reports submitted to council, DEECA, and the EPA. Each agency reviews it in isolation, it circles back to us months later, and then it just sits on a shelf. No one reuses the data. No one looks at it again."*
Opportunities through Viable Systems Model (System 4)	*"We need a system that would allow my team to monitor at every stage of a collection process, without physically interfering. A system that allows us to see the data direct from the labs. A tool that skips the 'analysis' stage from a third party and gets me the information quick."* *"Why doesn't every river health monitoring program across the country feed into the same place? Every trade waste sample, every groundwater bore, it's all the same kind of data in the end. If it were centralised, we could see how we're performing and maybe even start to understand issues at a national scale."* *"To be able to log on and see all the moving parts in real time-that is such a significant step forward"*
Need for predictive modelling and visualisation	*"Dynamic, flexible interpretation, not just static thresholds or one-time checks. That would change a lot"* *"Everything that's visual... is easier to describe to other people. You shouldn't need to be a technical expert to understand contamination - other people's capability of visualising what those words mean differs greatly."* *"If you've got this area, and you know you've sampled X, Y, Z here, you're not going to resample that just because it's a different scope. You could use the original data again."*
Financial benefits of improved forecasting	*"Looking at it from a cost point of view for the company, yes, it would be beneficial. It would save money compared to consultants"* *"If you can save eight hours of messing around formatting their data-that's eight hours you can knock off the final price"*

In summary, this snapshot of stakeholder insights highlights some inefficiencies and consultant-dependent data handling across the water sector. However, embedding a System 4 capability via real-time data integration, predictive modelling, and digital standardisation offers a path toward proactive, intelligence-led environmental management. Further detailed publications are forthcoming to present these over 12 hours of interviews – not applicable to this forum

CONCLUSIONS

This research has exposed deep structural inefficiencies and entrenched fragmentation in Australia's environmental contamination reporting systems, particularly across the water sector. Legacy workflows dominated by static PDFs, spreadsheets, and consultant-led silos, continue to impede timely, coordinated, and effective responses. Valuable environmental data is often lost, delayed, or locked within redundant and incompatible systems. This not only results in duplicated costs and diminished accountability but severely limits the capacity for data reuse, longitudinal analysis, or regional comparisons.

Perhaps most critically, regulatory responses remain reactive. Overly conservative, compliance-driven models rely on numerical thresholds (Aven, 2020; Kaufman, 2014), which offer little predictive or preventative capacity. The proposed 3 parts per trillion (ppt) PFAS drinking water threshold (NHMRC, 2024) is a clear example. While well-intentioned, it is unenforceable under current laboratory conditions (SLR, 2024), undermined by wide variability in detection, and unsupported by a national QA/QC framework (PFAS NEMP 3.0, 2023). Worse, this standard activates *after* contamination has already occurred—identifying exposure, rather than helping prevent it or track its source (Van Dijk et al., 2021). It offers no foresight, no early warning, and no mitigation path. In a context of bioaccumulative, persistent chemicals like PFAS, such a paradigm is functionally obsolete.

To build resilience, the sector must move beyond threshold-based reactivity toward real-time, predictive intelligence. It must develop systems that ingest diverse data at speed, retain fidelity across jurisdictions, and present decision-makers with live, contextualised insights—empowering timely intervention before environmental harm escalates. This shift is not merely technical but strategic: it requires infrastructure that unifies environmental data, accelerates interpretation, and enables forecasting with the same rigour applied in meteorological systems.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

The water sector continues to grapple with fragmented, consultant-dependent workflows that rely heavily on static PDFs and siloed datasets. These limitations delay response times, complicate regulatory oversight, and hinder the ability to build a clear, cumulative picture of water quality across regions and timeframes. In particular, the absence of a national standard for chemistry storage, and naming conventions, data collected by different agencies, consultants, or contractors often cannot be reliably compared.

Lithodat offers one possible pathway forward. Originally developed for geochemical research, the platform is now being trialled for broader environmental use, including contamination reporting. Its architecture enables ingestion of disparate datasets, groundwater, surface water, trade waste, stormwater, construction sampling, and even citizen science into a single, spatially coherent interface. This capability could allow agencies to compare multiple data types within the same catchment, revealing trends that might otherwise remain hidden and enabling earlier, more coordinated responses.

As a digital backbone, Lithodat has already proven effective in resolving long-standing data inefficiencies. Adopted by CSIRO, national geoscience agencies in Australia and Canada, and the global research community via the AusScope Geochemistry Network – Earthbank, it offers a robust, cloud-based platform for spatial data integration and management (Boone et al., 2021; Powell et al., 2025). Crucially, it supports metadata capture and QA/QC validation at the point of upload, ensuring traceability, auditability, and cross-jurisdictional comparability, functions that are notably absent in current PFAS and contamination workflows.

In practical terms, this could help reduce duplication of consultant reports, lower compliance costs, and increase trust in data used across agencies. Public-facing modules may also support improved transparency and community engagement by allowing structured environmental datasets to be shared beyond institutional silos.

While no platform alone can solve the sector's systemic issues, Lithodat's technology represents a serious contender for building a more coordinated, intelligence-led environmental data infrastructure. In time, it could contribute to a national environmental forecasting capability, akin to meteorological models, drawing on real-time industry 'sensor' data and validated sampling to flag emerging risks before harm occurs.

This vision underpins the development of Lithodat's next-generation platform: the Diagnostic Environmental Reporting Tool (DERT). Positioned as a transformative, scalable solution for contamination reporting and environmental governance, DERT is designed to go beyond static compliance, enabling agency data harmonisation and standardisation, automated ingestion pipelines from industry and laboratories, and geospatial-temporal analytics at scale.

Its modular architecture opens the door to something far more ambitious: a federated, real-time environmental intelligence system for the nation. Just as meteorological agencies rely on high-performance computing and continuous sensor integration to simulate atmospheric behaviour, DERT sets the foundation for a national-scale ecological nowcasting and forecasting framework where hydrological, geochemical, biological, and climatic data streams converge into continuously updating system models.

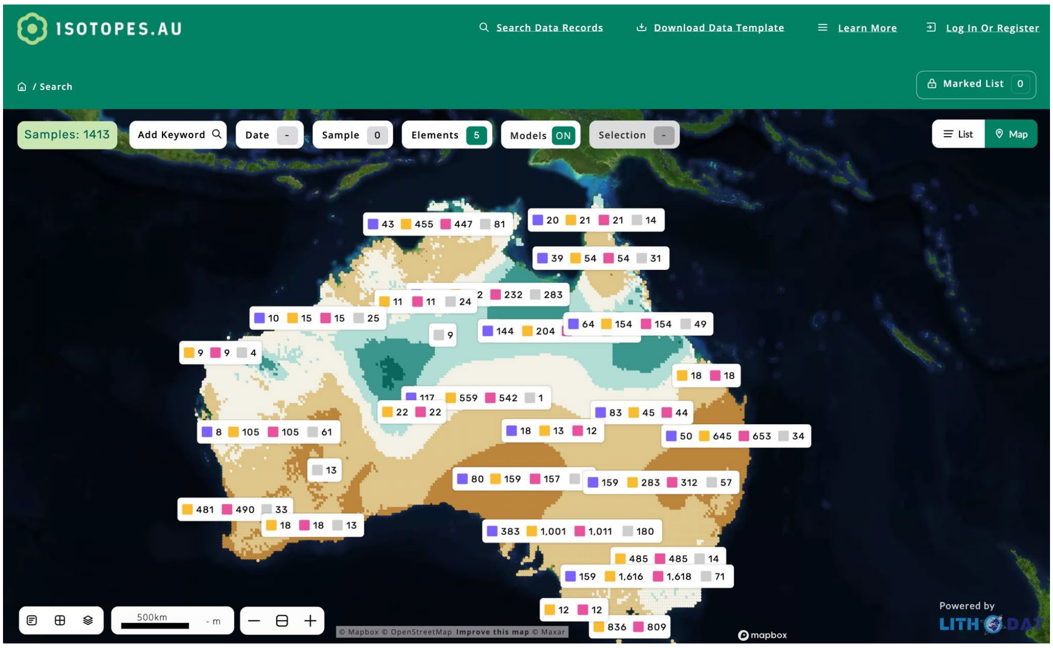

Figure 1: Example from National Realtime and Chemical ANALYSIS – CSIRO - Isotopes.AU

AUTHORS NOTE

For readers interested in a deeper understanding of Stafford Beer's Viable System Model (VSM), we recommend several key resources. A clear and practical introduction is provided in the video *Demystifying the Viable System Model: A Practical Approach* (available on YouTube). Foundational texts include Beer's own works such as *Brain of the Firm*, *The Heart of Enterprise*, and *Platform for Change*, which lay out the core cybernetic principles underpinning VSM. For contemporary analysis, *The Viable System Model: Interpretations and Applications* edited by Roger Harnden and Raúl Espejo offers diverse real-world applications. Additionally, Dan Davies' *The Unaccountability Machine* provides a critical, modern reflection on institutional decision-making that resonates with Beer's original theories.

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Integrating Expert Knowledge and Bayesian Networks for Antimicrobial Resistance Management Related to Water Uses: A Collaborative Approach for Water Resource Resilience

Dr Claire Hayward[1,2], Professor Nicholas Ashbolt[1,2], Dr Steven Mascaro[2,3,4], Dr Owen Woodberry[2,3,4]

[1]University Of South Australia, [2]SAAFE CRC, [3]Bayesian Intelligence, [4]Monash University

Title of the workshop

Integrating Expert Knowledge and Bayesian Networks for Antimicrobial Resistance Management Related to Water Uses: A Collaborative Approach for Water Resource Resilience

Conference Topic

Water for One Health: Integrating ecosystems, people and policy

MODERATOR:

Dr Steven Mascaro, Bayesian Intelligence, University of South Australia and Monash University

WORKSHOP LEADS:

- Prof. Nicholas Ashbolt, CRC SAAFE and University of South Australia
- Dr Claire Hayward, CRC SAAFE and University of South Australia
- Dr Owen Woodberry, Bayesian Intelligence, University of South Australia and Monash University

IDEAS TO BE PRESENTED, DEVELOPED AND DISCUSSED:

Rationale

Antimicrobial resistance (AMR) is an urgent One Health challenge that intersects healthcare, water, agriculture and environmental sectors. Water plays a central role in the movement and amplification of resistant microorganisms and genes, particularly via wastewater and water reuse pathways – but how to separate general microbiological 'noise' from gene-pathogen combinations of likely risk? We are addressing this environmental dimension to AMR through systems thinking and multi-sector collaboration. This workshop introduces a Bayesian Network (BN) model developed using information from existing literature and environmental monitoring programs conducted as part of SAAFE[CRC] and supported by expert elicitation. The model maps causal pathways of AMR emergence, persistence and dispersal related to water use and simulates the impact of various management options across sectors and over time.

In addition to providing an overview of the modelling, this expert elicitation workshop will consider how to address challenges raised in previous discussion forums, challenges that include a lack of AMR awareness in water-related settings and the fragmentation in jurisdiction for water management across a generally siloed system with discrete sectors. With no explicit regulations currently addressing environmental AMR in Australia, we aim to explore what accountability could look like, who might be responsible and how shared responsibility can be supported in the absence of formal policy. Participants will consider both sector-specific and shared responsibilities in AMR mitigation and discuss how government leadership in conjunction with industry best practices may provide cross-sector collaborations and solutions.

Learning Expectations

- Participants will:
- Learn how BNs can model AMR risks and inform management strategies.

- Discuss levels of AMR awareness, behaviour change barriers and accountability within their sectors.
- Identify critical AMR control points in their systems and highlight gaps in existing guidance that, if filled, could enhance AMR management.
- Explore pathways for integrating new policy levers and opportunities for innovative management approaches.

Outcomes

- Greater awareness of AMR risks in environmental and water reuse pathways.
- A refined BN model informed by stakeholder perspectives.
- Sector-mapped AMR control points and identified policy/best practice gaps.
- Insight into systemic barriers and opportunities for cultural or policy change.
- List of cross-sector opportunities for collaborative action, innovation, or policy integration.
- A shared understanding of the importance of government and the water industry for intersectoral engagement.

GENERAL STRUCTURE OF THE WORKSHOP:

Time	Activity	Note
0-5 mins	Presentation: Welcome and workshop overview	Drs Nicholas Ashbolt/Claire Hayward introduces the AMR challenge, objectives of the session and the role of systems thinking.
5-15 mins	Presentation: Using Bayesian networks to model AMR pathways and test interventions	Dr Steven Mascaro & Dr Owen Woodberry introduces the model/concept of BNs
15-20 mins	Open floor for clarification	Questions on the model structure, objectives, and how the group can contribute.
20-65 mins	Sector-based roundtable discussions	Each table discusses: • Current understanding and what they think they need to know for (environmental) AMR • Awareness levels and communication facilitators/barriers around AMR in their fields • What do you think good practices/SOPs would look like for the 3 classes of determinants? • Responsibilities across stakeholders (including gaps in responsibility) • Opportunities for policy integration and innovation (analogues from managing other contaminants)
65-85	Sharing and synthesising insights	Tables report key insights. Moderator identifies shared priorities, challenges, research gaps and overlaps. Further thoughts from all after seeing the summaries.
85-90	Wrap-up	Closing comments on leadership, collaboration and next steps.

LINKS TO RESEARCH

SAAFE[CRC] Project: AMR Risk Management. (SA-EPA/ SAAFE[CRC])
https://www.crcsaafe.com.au/research/projects/amr-management.

Beyond human health: The need for environmental AMR endpoints to manage risks in waters

Dr Claire Hayward[1,2], Professor Nicholas Ashbolt[1,2], Dr Lara Settimio[3]

[1]University Of South Australia, [2]SAAFE CRC, [3]South Australian Environment Protection Authority

Title of Full Paper

Beyond human health: The need for environmental AMR endpoints to manage risks in waters

Conference Topic

Water for One Health: Integrating ecosystems, people and policy.

INTRODUCTION

Antimicrobial resistance (AMR) is one of the greatest public health threats of our time, with the World Health Organisation warning it could cause more deaths than cancers by 2050 [1]. While often framed as a clinical issue, a growing body of research has demonstrated that AMR is fundamentally a One Health crisis than encompasses human, animal and environmental health [2]. Antimicrobial misuse in healthcare, agriculture and aquaculture has accelerated the spread of resistant bacteria and their genetic determinants, yet efforts to monitor and mitigate this dissemination has disproportionately focused on healthcare and veterinary settings [3]. This narrow focus has overlooked the critical role of environmental systems as reservoirs and amplifiers of AMR.

The environment plays a dual role in AMR dynamics. It is both the ancient original of antimicrobial resistance genes (ARGs), and a contemporary pathway by which resistance spreads [4]. Many of the resistance mechanisms found in clinical pathogens have evolved from environmental microbes to combat naturally occurring antibiotics found in their respective niches. Concerningly, these mechanisms are now amplified by anthropogenic activities [1].

Water systems are a critical vector for AMR transmission across multiple One Health domains [1]. Notably, the discharge of antimicrobial compounds and resistant organisms into receiving water systems from wastewater treatment plants (WWTPs), agricultural runoff and storm water events have been highlighted as key drivers [1, 5, 6]. These AMR determinants can disrupt soil and aquatic microbiomes, reduce agricultural productivity and impact ecosystem functioning and health [7]. Despite this, routine environmental AMR surveillance remains fragmented and inconsistent, and environmental endpoints are rarely incorporated into water management or public health planning [8].

METHOD/EXPERIMENTAL DESIGN

This paper explores the case for incorporating environmental AMR endpoints into water system surveillance and public health management. Focusing on aquatic environments, it discusses current scientific evidence on environmental AMR risks, identifies major surveillance gaps, and examines challenges in monitoring antimicrobial resistance outside of clinical contexts. The paper advocates for the development of a conceptual framework to guide future surveillance efforts, one that integrates scientific understanding with policy imperatives and supports a One Health approach. By aligning environmental AMR research, monitoring strategies, and regulatory priorities, this work proposes a pathway for embedding environmental endpoints into national AMR action plans. The aim is to support the development of a resilient and coordinated AMR surveillance system that reflects the complexity of environmental transmission and enables effective cross-sectoral risk mitigation.

OUTCOMES / RESULTS

<u>Key environmental AMR pathways and reservoirs</u>

Environmental pathways contribute significantly to the persistence and spread of AMR, though the nature and significance of these sources vary by country and socioeconomic status [2]. In global contexts, discharges from pharmaceutical manufacturing are a significant concern, with international initiatives such as the AMR Industry Alliances certification scheme attempting to address this contribution [9]. However, Australia does not have a local antimicrobial manufacturing industry and instead, environmental AMR risks stem from a combination of more diverse sources.

Domestic, industrial and hospital wastewater enters treatment facilities not designed to remove antimicrobials or AMR organisms [10]. Agricultural runoff introduces antimicrobials from animal use and fertilisers into surrounding receiving waterways [1]. These discharges can contain concentrations of AMR chemical stressors exceeding the minimum selective concentrations or predicted no-effect concentrations (PNECs) [7]. Environmental surveillance, if appropriately targeted and sufficiently resourced, could serve both as an early warning system and as a mechanism for evaluating the effectiveness of mitigation strategies. Its capacity to detect important AMR pathogens, emerging ARGs and trends in resistance distribution is increasingly recognised through largely unrealised in practice [11].

Impacts on ecosystem functions

Antimicrobial discharges can disrupt microbial communities, impacting broader ecosystem stability and functions. Sub-inhibitory concentrations of antimicrobials exert selective pressures that favour resistant organisms and promotes horizontal gene transfer [12]. This can lead to microbial community shifts, dysbiosis, and reductions in diversity affecting keystone species and ecosystem services [13]. High throughput molecular techniques have revealed shifts in bacterial populations in response to anthropogenic inputs across soil and aquatic ecosystems [14]. Effluent composition can disrupt the balance between heterotrophic bacteria and photoautotrophs (e.g. phytoplankton) in freshwater systems [15]. For example, growth of key bacterial phyla such as *Proteobacteria, Bacteria, Actinobacteria, Firmicutes* and *Deinococcus-Thermus* has been shown to correlate with the abundance of *Cyanobacteria*, suggesting mutualistic relationships established by nutrient availability [16]. However, nutrient and antimicrobial inputs from effluent can disrupt these interactions, altering the community composition and weaken ecosystem functions such as dissolved organic matter processing [17]. Conversely, efforts to target nutrient removal, such as NH_4^+ in wastewater, may shift dominance from *Cyanobacteria* to algae and disturb plankton-benthic coupling [18].

These changes can erode key system properties such as functional redundancy, microbial connectivity and overall ecosystem resilience[13]. Functional redundancy refers to the capacity of multiple microbial taxa to perform similar roles in a community and can act as buffers against disruption., whilst connectivity influences the movement of resistance genes through trophic levels and across niches (i.e. sediment, water and biofilms) [13]. Loss of these properties may accelerate ARG persistence and dissemination. In relatively undisturbed environments, microbial diversity and metabolic competition can act as a natural barrier to AMR proliferation, however, chronic anthropogenic pressures may erode this resilience. This underscores the importance of protecting ecosystem function as a mechanism to limit AMR amplification, an often overlooked but critical component of AMR risk mitigation.

Limitations of current AMR surveillance

Environmental AMR surveillance remains fragmented, lacking coordination across jurisdictions, institutions and methodologies. Approaches very from culture-based methods to genomic analyses, qPCR and metagenomics. Current surveillance largely focuses on human health endpoints, applying interpretive frameworks such as clinical breakpoints that are poorly suited to environmental isolates [19] let alone microbiomes that have their own emergent properties [20]. While epidemiological cut off values may offer some improvement, they are still grounded in clinical datasets and have limited applicability to non-clinical species. The only ecotoxological assay targeting bacteria in a regulatory context is the Activated Sludge Respiration Inhibition Test which does not account for resistance selection or ARG transmission [21].

Baseline data on ARGs or resistant organisms in Australian environments are minimal. Without understanding natural background levels or typical ranges, interpreting surveillance results or associating them with risk becomes difficult [11]. Additionally, limited monitoring of antimicrobial concentrations in discharges from key sectors means environmental exposure remains poorly characterised. For example, the Australian Drinking Water Guidelines do not currently address antimicrobials or other pharmaceuticals, and adopting international guidelines is complicated by differing antibiotic use patterns, regulatory contexts, and environmental conditions [22]. AMR PNECs are emerging internationally as a tool to guide environmental monitoring, but a standardised approach for their derivation and application is still needed [11] that fit with Australia and New Zealand's multispecies approach to deriving fresh and marine water guidelines [23, 24].

Promising tools and methodologies for environmental surveillance

A range of culture-independent tools are being explored to improve AMR surveillance in aquatic environmental matrices, addressing key limitations in traditional clinically focused monitoring systems. Quantitative PCR has been widely used to quantify the abundance of selected ARGs, particularly in studies examining the impacts of wastewater discharges and other anthropogenic activities on freshwater resistomes [25]. However, shotgun metagenomic (SMG) sequences is increasingly favoured for environmental applications due to its ability to capture a broader spectrum of AGRs, including those not typically targeted in clinical surveillance. Critically, SMG can simultaneously profile microbial community structure [26].

Metagenomic and transcriptomic analyses provide insight into the dynamics and activities of ARGs within microbial populations, including identification of ARG hosts that are active [26, 27]. Transcriptomics in particular adds a functional dimension to AMR surveillance by identifying genes that are not only present by actively transcribed. This helps to distinguish between background resistance and genes under active selection or posing a greater ecological or health risk[26, 27]. This is especially important given the limitations of clinical whole genome sequencing datasets, which are biased toward culturable and clinically relevant bacteria, limiting their utility in One Health investigations [19]. While SMG captures DNA/RNA from all microorganisms, regardless of culturability and avoids PCR amplification bias [26], challenges remain in assigning ARGs and transcripts to specific hosts, particularly in complex environmental microbiomes. Improving reference databases and incorporating long-read sequencing approaches may help address this limitation and strengthen the application of these tools in environmental surveillance.

Candidate endpoints and indicators

Several candidate endpoints are being explored to improve risk assessment and regulatory decision-making. These include total ARG load, gene transfer potential, shifts in community structure and functional gene analyses [11]. Importantly, many ARGs are latent in environmental microbes and not yet present in human, animal or plant pathogens [28]. As such, their detection in the environment could indicate emerging risks with potentially severe consequences if mobilised into clinical contexts. The presence of ARGs alone, however, does not imply biological activity or transcription, highlighting the need for future surveillance to distinguish between potential and active resistance [28].

Given that faecal contamination often correlates with ARG abundance, indicator organisms such as *E. coli* and viral markers like crAssphage have been proposed as proxies for AMR pollution [14]. However, this relationship is not always consistent and may be influenced by host origin or microbial community structure. For example, positive associations between ARGs and crAssphage may be obscured at higher taxonomic levels due to offsetting associations at finer scales [14]. Some ARGs, such as *bla*TEM, are considered ubiquitous in soil microbiomes, while other like *bla*OXA or *bla*CTX are more closely associated with anthropogenic inputs [29]. The environmental context is therefore critical to interpreting resistome data. For instance, detection of the *dfr*B gene in riverbed biofilms, but not in the effluent samples, suggests possible environmental origins or diffuse nonpoint sources such as surrounding livestock farming operations [14]. This underscores the importance of integrating landscape and land-use data into resistome studies to accurately trace resistance pathways.

CONCLUSIONS

Environmental AMR remains a significantly understudied and overlooked issue, despite its growing importance in both public and ecological health. A key barrier to progress is the lack of agreed and consistent definitions when referring to AMR and environmental challenges. Establishing a unified language and approach across all stakeholders is crucial to enhance understanding and facilitate productive discussions.

There is an urgent need to establish water-based AMR endpoints and robust monitoring frameworks. Australia can learn valuable lessons from international experiences and global partnerships that have worked toward common standards and best practice [30]. Critical first steps include clearly defining the scope and problem within Australia, understanding the presence and distribution of antimicrobials in the environment, outlining appropriate measurement methodologies, and identifying the most significant sources contributing to environmental AMR. Employing a combination of molecular and culture-based methods will be essential to determine which ARGs are actively being transcribed. Finally, advancing solutions to this complex problem will require strong interdisciplinary collaboration involving engineers, microbiologists, ecologists and policymakers to ensure that scientific insights translate into effective environmental management and regulatory policies.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Looking forward, research priorities must focus on understanding critical knowledge gaps that underpin environmental AMR. To support cost effective monitoring, it is important to assess which combination of methods provides the most comprehensive yet practical picture of AMR in the environment. On the policy front, environmental AMR risk thresholds must be developed and integrated into water safety planning and environmental frameworks. Sampling strategies should target control points where interventions could most effectively reduce the development and spread of resistance. Framing environmental AMR surveillance as a cornerstone for resilient, sustainable food systems, ecological restoration, and human health security will help elevate its priority in policy agendas. Ultimately, the development of robust and predictive endpoints will enable early warning systems that guide timely intervention strategies.

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27. Li, A.D., et al., *Metatranscriptomic time series insight into antibiotic resistance genes and mobile genetic elements in wastewater systems under antibiotic selective pressure.* BMC Microbiology, 2025.
28. Inda-Díaz, J.S., et al., *Latent antibiotic resistance genes are abundant, diverse, and mobile in human, animal, and environmental microbiomes.* Microbiome, 2023.
29. Kampouris, I.D., et al., *Antibiotic resistance gene load and irrigation intensity determine the impact of wastewater irrigation on antimicrobial resistance in the soil microbiome.* Water Research, 2021.
30. Hamilton, K.A., et al., *Quantifying and addressing the contribution of water and wastewater to the emerging risk of antimicrobial resistance. Co-Sponsored by: Global Water Research Coalition*. 2024, Water Research Foundation: Alexandria VA.

Imagining a partnership between the Australian CDC and the Australian Water Sector in wastewater surveillance - wastewater as a resource for public health

Ms Lyn Metcalf[1], Dr Monica Nolan[2,3]

[1]Interim Australian Centre for Disease Control (iCDC), [2]Promoting Health4All , [3]World Health Organization

Title of the workshop/Panel

Imagining a partnership between the Australian Centre for Disease Control and the Australian Water Sector in wastewater surveillance - wastewater as a resource for public health

Conference Topic

Water for One Health: Integrating ecosystems, people, and policy

MODERATOR:

- TBC (Hannah Sassi)

PARTICIPANTS:

- Ms Lyn Metcalf, Interim Australian Centre for Disease Control
- Dr Monica Nolan, Promoting Health4All & WHO Consultant
- Industry Rep – Water Sector (tbc)

IDEAS TO BE PRESENTED, DEVELOPED AND DISCUSSED:

The interim Australian Centre for Disease Control is establishing a National Wastewater Surveillance Program for public health which is expected to be operational in the 2nd half of 2025. This program will monitor priority pathogens and provide capacity for early detection of emerging pathogens with epidemic and pandemic potential. The program aims to contribute novel surveillance data in near-real-time to enhance agile public health response, in line with recommendations from the COVID-19 Response Inquiry Report.

The National Wastewater Surveillance Program is a three-year trial, which will build capability and capacity across the public health, laboratory and water sectors. In a One Health context wastewater is a precious resource, as it contains some of the earliest signals for emerging pathogens that threaten human or animal health. There remain ongoing threats from emerging pathogens, such as monkeypox virus, SARS-CoV-2, and Japanese encephalitis virus (JEV). The threat of a possible outbreak of high pathogenicity avian influenza H5N1 (HPAI) in Australia has seen a significant investment from the Australian Government to enhance national preparedness and response capability.

Partnership and collaboration between the water and health sectors has enabled cost-effective wastewater monitoring for early detection of key human diseases such as polio and COVID-19. Recent innovations in sampling, laboratory methodologies, and data analytics have opened opportunities for the use of wastewater surveillance to inform timely public health actions. This has potential to contain outbreaks early and limit their spread and impact, thus preventing disease and saving costs, lives and livelihoods.

This workshop focuses on the multidisciplinary nature of wastewater surveillance, and the critical need for intersectoral collaboration between the water, health and laboratory sectors – with a particular focus on the role of wastewater utilities.

The workshop will explore the opportunities that exist for strengthening collaboration between the sectors to build a robust, agile and responsive wastewater surveillance system that can respond to emerging pathogenic threats to human health, and how a national approach to wastewater surveillance in Australia, led by the

Australian Centre for Disease Control, can contribute to building capacity, capability, expertise and trust with and across the wastewater utility sector.

GENERAL STRUCTURE OF THE WORKSHOP/PANEL:

1. Welcome and Introduction (Moderator) 5 mins
2. Presentations (30 mins, 10 mins per panel member):
   a. Perspectives from the interim Australian CDC (Lyn Metcalf, 10 mins)
   b. Perspectives from wastewater surveillance expert (Dr Monica Nolan, 10 mins)
   c. Perspectives from water industry (tbc) 10 mins
3. Workshop (60 mins)
   a. Outline of topics 10 mins
   b. Discussion / work by attendees (utilising a combination of Mentimeter and traditional workshop feedback as permitted by venue) 35 mins
   c. Summary / conclusions 15 mins

LINKS TO RESEARCH

Interim CDC role

1. Australian Centre for Disease Control (Interim functions) website Australian Centre for Disease Control (cdc.gov.au).

Pandemic preparedness and One Health

2. World Health Organisation. Adoption of pandemic agreement : World Health Assembly adopts historic Pandemic Agreement to make the world more equitable and safer from future pandemics
3. One Health quadripartite call to action : Quadripartite call to action for One Health for a safer world
4. One Health quadripartite joint plan for action : One health joint plan of action (2022–2026): working together for the health of humans, animals, plants and the environment
5. World Health Organisation, 2023. ('Defining Collaborative Surveillance: A Core Concept for Strengthening the Global Architecture for Health Emergency Preparedness, Response, and Resilience (HEPR)', n.d.) Defining collaborative surveillance (who.int). Accessed 18 June 2024

Global and local wastewater surveillance – normative guidance

6. World Health Organisation (2024). Wastewater and environmental surveillance for one or more pathogens: guidance on prioritization, implementation and integration
7. Polio Surveillance Action Plan, GPEI/World Health Organisation (2025 prepublication version). Global-Polio-Surveillance-Action-Plan-2025-2026.pdf
8. SARS-CoV-2 environmental surveillance. World Health Organization; 2023. Environmental surveillance for SARS-CoV-2 to complement other public health surveillance
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Global consortium for Wastewater Surveillance and European directive

11. GLOWACON : Global Consortium for Wastewater and Environmental Surveillance for Public Health website - EU4S (europa.eu).
12. Directive of the European Parliament and Council, 2024 Urban Wastewater Treatment Directive (recast). (and noting articles 22 and 23 of particular interest). https://data.consilium.europa.eu/doc/document/ST-7108-2024-INIT/en

Seminal Reviews

13. The National Academies Press, National Academies of Sciences, Engineering, and Medicine, 2023. Wastewater-based Disease Surveillance for Public Health Action
14. The National Academies Press, National Academies of Sciences, Engineering, and Medicine, 2024. Increasing the Utility of Wastewater-based Disease Surveillance for Public Health Action: A Phase 2 Report | The National Academies Press

201

Foundations for understanding and managing antimicrobial resistance challenges across the water sector

Dr Hannah Sassi[1], Professor Erica Donner[2], Professor Nicholas Ashbolt[2], Professor Aaron Jex[2], Professor Ricardo Magalhaes[2]

[1]Water Research Australia, [2]CRC SAAFE

Foundations for understanding and managing antimicrobial resistance challenges across the water sector

Conference Topic

Water for One Health: Integrating Ecosystems, People and Policy

MODERATOR:

- Dr Hannah Sassi – Senior Research Manager (WaterRA)

PARTICIPANTS:

- Dr Erica Donner – Research Director (CRC SAAFE, University of South Australia)
- Dr Aaron Jex – Monitoring Program Lead (CRC SAAFE, WEHI)
- Dr Nick Ashbolt – Risk and Living Labs Lead (CRC SAAFE, University of South Australia)
- Dr Ricardo Magalhaes – Data and Analytics Program Lead (CRC SAAFE, University of Queensland)
- Dr Andy Barnes – Solutions Program Lead (CRC SAAFE, University of Queensland)

IDEAS TO BE PRESENTED, DEVELOPED AND DISCUSSED:

Main contents of the workshop/panel. Include:

Rationale

Antimicrobial resistance (AMR), which impacts human, animal and plant disease management, is a challenge that is not confined to a single location, environment or sector – indeed management solutions require cross-sector coordination; therefore, it is a challenge necessitating a systems understanding to address its complexity and dynamic behavioural impacts across multiple fronts. Alongside industry/government partners, SAAFE^CRC aims to address this challenge over the next eight years through cross-sectoral research programs centred on three key themes: monitoring, analytics (including risk assessment), and solutions. The goal of the CRC is to facilitate a deeper understanding of individual sectors that build and grow into a cross-sectoral initiative to develop solutions and strategies to manage the collective challenge posed by AMR. In this panel discussion, SAAFE ^CRC researchers will discuss their research within the water sector to demonstrate how their research fits together to build a multi-faceted strategy for addressing environmental AMR in Australia.

Learning Objectives

- Understand how SAAFE ^CRC shapes their research programs and areas to meet the national and global challenges of AMR cross-sectorally
- Learn about the water research program and how water will intersect with other SAAFE ^CRC partner sectors

Outcomes

- Understanding of how cross-sectoral research can be developed and designed to target shared problems
- Update on the SAAFE ^CRC water research portfolio and program rationale

GENERAL STRUCTURE OF THE WORKSHOP/PANEL:

Presentations (70 min)

Session Introduction – Dr Hannah Sassi (5 min)

Designing a cross-sectoral research portfolio to address the shared global challenges of AMR – Dr Erica Donner – (20 min)

The Water Research Program within SAAFE CRC (45 min):

- Monitoring Research Program – Dr Aaron Jex (15 min)
- Risk and Living Labs Lead – Dr Nick Ashbolt (15 min)
- Data and Analytics Research Program – Dr Ricardo Magalhaes (15 min)

Open Discussion / Q&A (20 min)

Initial discussion questions:

- In your opinion, what does success look like for SAAFE CRC in your program area and for AMR mitigation in general?
- *Open to floor for questions*

LINKS TO RESEARCH

SAAFE CRC • All Projects

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An unconventional stormwater approach for an industrial precinct

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An unconventional stormwater approach for an industrial precinct

Water for One Health: Integrating ecosystems, people, and policy

Introduction

Traditionally stormwater management of a greenfield development is managed by different entities (i.e., council, private developers) and involves conveyance of stormwater away from urban areas and discharged to the nearest waterway. Water considered as an issue or waste product to be managed. This business-as-usual approach neglects key aspects such as stormwater recycling or reuse and neglects the value of the discharging ecosystem, such as improved water quality, human health, biodiversity etc (Brown et al 2009).

Conversely, the Integrated Water Cycle Management (IWCM) approach adopted by Sydney Water as the Regional Stormwater Authority in the Mamre Road Industrial Precinct considers stormwater as a 'resource'. This approach involves harvesting of stormwater through a series of wetlands and basins and combining the stormwater with recycled water (i.e. treated wastewater) to be supplied to customers as non-potable water via a third pipe network ('purple pipes').

This paper elaborates on how this innovative scheme redefines stormwater management, shifting the perspective from a hazardous issue to a vital resource that facilitates the concept of 'water for one health'. This approach yields multiple benefits, including the protection of healthy waterways, enhanced cooling and greening through sustainable water supply practices, alignment with cultural values, and optimized environmental outcomes that foster resilient communities.

Background

The Mamre Road Precinct, located in Western Sydney, was rezoned in 2020 to designate 850 hectares of industrial land, transitioning from rural uses while preserving approximately 95 hectares for environmental conservation. This significant rezoning aims to create employment opportunities closer to the Western Sydney Airport, to be opened in 2026 and will result in large- format industrial warehouse developments. However, the urbanisation of these greenfield areas alters catchment hydrology, resulting in increased volumes of stormwater and higher flow rates.

The immediate receiving waterway, Wianamatta-South Creek, has been identified as impaired yet retains significant ecological value. Therefore, the NSW government adopted a new land-use planning and urban design strategy to realize the vision of Western Parkland City, and new waterway health objectives and targets for the Wianamatta-South Creek catchment have been established. In 2022, Sydney Water (the city's water utility) was appointed by the NSW government as the regional stormwater authority for the Mamre Road and Aerotropolis Initial Precincts to provide an integrated stormwater service (The Scheme) to achieve key elements of the Parkland City Vision.

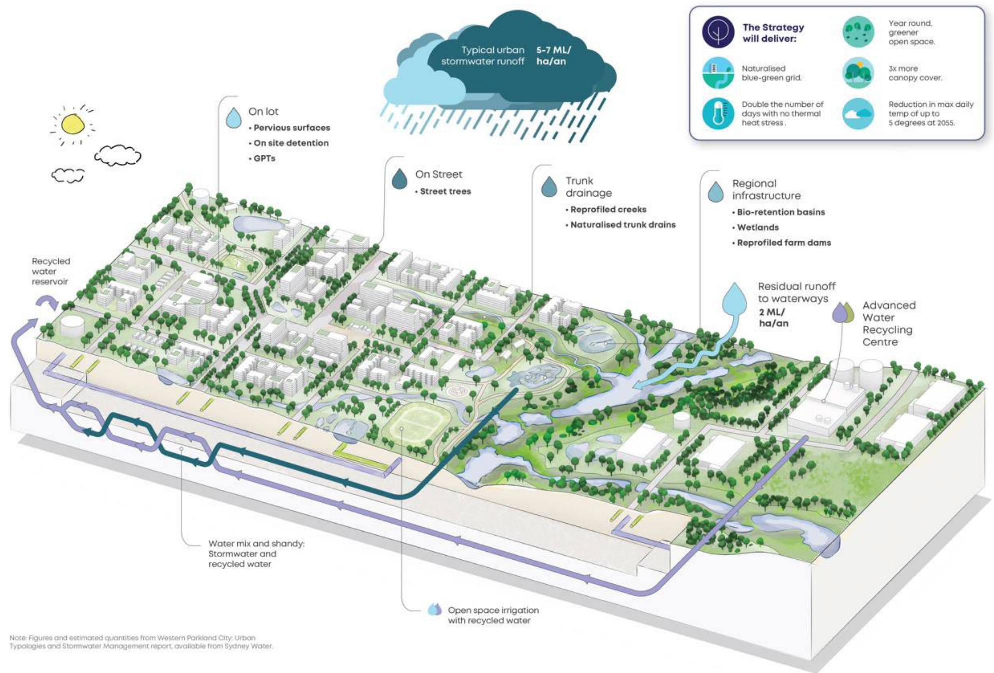

Figure 34: The Mamre Road Integrated Stormwater Scheme

The asset details of the regional stormwater infrastructure are shown in Table 1.

Table 10: The Regional Stormwater Infrastructure components

Asset/component	Objective	Outcomes
Naturalised trunk drainage channels for catchments >15ha and Rehabilitated existing waterways.	Safely convey flow up to 1% AEP, use native vegetation and increase channel sinuosity.	Increase greening/cooling, maintain water in the landscape, and ensure flora and fauna connectivity
Regional Water Sensitive Urban Design Basins including wetlands, bioretention, and harvesting ponds.	Achieve the waterway health objectives for stormwater quality and flow reduction.	Increase greening/cooling, maintain water in landscape, provide a sustainable and climate dependant water source, and protect downstream waterways from bed and bank erosion, loss of native fauna, and poor waterway health.
Recycled water storage and distribution system.	Achieve the waterway health objectives for stormwater flow reduction.	Sustainably transfer stormwater as recycled water to end-users and irrigation of vegetated area.

Principles of the Scheme Design

The Scheme has been developed with design principles that integrates people, policy and ecosystem (Table 2).

Table 11: Scheme Design Principles

Design Principle	Element of One Health	Objectives
Health and Wellbeing	People and Policy	Safe access management
		Urban greening
		Localised cooling
Cultural connection to Country	People and Ecosystem	Design to the existing topography and land features
		Enhance local ecological communities
		Maintain water in the landscape
		Flora and fauna connectivity
		Minimise soil profile disturbance
Waterway Health	Policy and Ecosystem	Achieve waterway health targets at precinct boundaries
		Maximise length of waterways
Wildlife strike management	Animals and Ecosystem	Minimise wildlife strike hazard to Western Sydney Airport

Social amenity	People	Opportunities for active transport Facilitate opportunities for passive recreation Facilitate public access to green, natural places

How does the scheme achieve 'Water for One Health'?

'One health' is an integrative framework that captures the relevant health goals inherent in stormwater management. It is generally defined as an approach to balance and optimize the health of interdependent people, animals, and ecosystems. The One Health concept can be applied to the links between stormwater management and healthy cities (Grigg 2009). Figure 2 shows how stormwater management (the Scheme) is a multifaceted approach to deliver an integrated urban development that supports the health of human, animal and ecosystem.

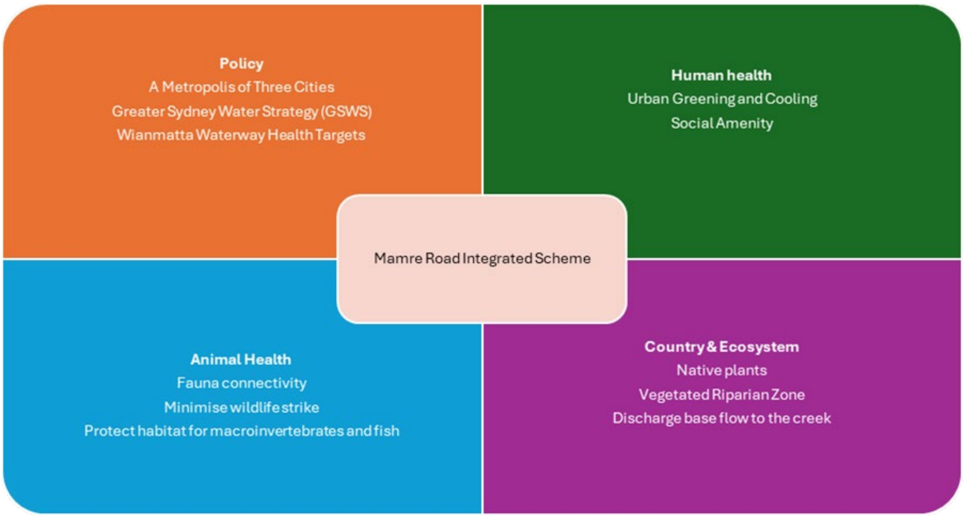

Figure 35: Design elements of the Scheme that utilise stormwater as a resource for 'one health'

Policy:

In 2018, the Greater Sydney Commission introduced the Greater Sydney Region Plan – A Metropolis of Three Cities, envisioning Wianamatta–South Creek as a green corridor within the Western Parkland City to enhance liveability for residents. The NSW Government has launched various initiatives to promote green infrastructure across Greater Sydney, focusing on healthier urban environments. This includes the Greater Sydney Water Strategy, which integrates land use planning to enhance stormwater management and improve waterway health.

In 2017, the NSW Government released The Risk-Based Framework for Considering Waterway Health Outcomes in Strategic Land Use Planning Decisions (the Risk-Based Framework) to enhance the management of waterways throughout the state. The Wianamatta South Creek catchment is a lengthy, ephemeral waterway system, where the volume of flow reaching the waterways is crucial for their long-term health. Reducing the flow of stormwater into these sensitive systems will also decrease pollutant loads and improve water quality.

To preserve the natural values of the Wianamatta South Creek waterways as urbanization progresses, the NSW Government established Waterway Health Objectives and Stormwater Targets. These targets aim to address the additional stormwater generated, which poses a threat to creek ecosystems. The objectives are designed to meet "ambient water quality and stream flow objectives," based on the tipping point at which the health, ecology, and biodiversity of water-dependent ecosystems are expected to decline. The Scheme meets these targets by capturing and treating surplus stormwater from the catchment before it reaches the waterways.

People, Country and Ecosystem:

Sydney Water undertook Aboriginal engagement for the Aerotropolis Stormwater Catchment Scheme Plans including Mamre Road Precinct between 2021- 2022. The outcomes from the engagement were used to inform the design guideline for the Scheme.

The Scheme has been designed in such a way that it performs a variety of functions. Regional basins and trunk drainage channels, whilst providing a stormwater containment and treatment function, will also become green landscape features, accessible to local communities for passive recreation and amenity. The basins are also integrated into the adjacent open space infrastructure such as cycle and walking paths for active transport. The Scheme complements the Parkland City Vision by including dense trees, wetlands, ponds, and irrigation network. The use of recycled wastewater for irrigation to top up harvested stormwater during dry periods also ensures that green spaces can remain green and cool all year round.

The protection, restoration, and maintenance of waterways, riparian corridors form a key part of the scheme and incorporates design elements that better mimic the existing hydrologic characteristics of the catchment. In particular, the design of the naturalised trunk drainage channel incorporates grades based on the typical stream grades in Western Sydney, a sinuous low-flow channel that mimics the natural streams to increase the contact time with vegetation, native planting, greening and cooling of the area through irrigation and increasing canopy/vegetation cover. The riparian zones adjacent to existing waterways are also proposed to be revegetated with native plants. Rehabilitating these waterways protects the health and structure of the receiving waters, mitigates erosion impacts, and restores flows to a more natural state, benefiting the ecological environment.

Challenges and Lessons Learnt

This scheme is one of the largest integrated stormwater initiatives and has undergone thorough scrutiny to ensure efficiency and affordability for developers. Efficiencies were achieved by utilizing flood-affected land for regional stormwater infrastructure, thus minimizing the footprint on expensive industrial land.

The existing topography of the precinct in certain instances was not compatible for large format industrial warehouses requiring extensive cut and fill of the site. Therefore, the low-flow channel in the trunk drainage channel was rock-lined to reduce scour and erosion. However, additional pervious area was provided as offset within those developments. These large warehouses also provide a shadow impact on the vegetated channel. In the circumstances where minimum solar access was not achievable, alternate landscape species were considered.

Wildlife strikes present another significant challenge for this project. The precinct aims to achieve a Parkland City Vision, which includes increasing tree canopy targets to 40%. This goal conflicts with the wildlife strike requirements for the nearby airport. Consequently, the regional infrastructure has been designed to carefully balance these competing objectives. This includes selecting appropriate landscaping species, implementing design interventions such as vertical drops into water bodies with sandstone logs, and excluding features that could provide habitat for wildlife.

Figure 36: Rendered image for the Naturalised Channel and Regional Stormwater Basins (by Thompson Berrill Landscape Design for Sydney Water)

CONCLUSION

Moving away from traditional stormwater practices and implementing sustainable stormwater management practices in urban developments, it's possible to create a more resilient and healthier environment whilst realising significant benefits, including reduced reliance on potable water, improved water quality, and enhanced ecosystem health, all contributing to 'One Health'.

WHAT'S NEXT

The Development Servicing Plan (DSP) for the Mamre Road Scheme was registered by IPART in early May 2025. It outlines charges for integrated stormwater management and recycled water services to be paid to Sydney Water by developers. This approach demonstrates how integrating water cycle management with strategic land use planning can address the needs of Western Sydney while supporting key NSW Government objectives like urban greening, water conservation, and waterway health. It serves as a model for other Australian water utility providers to enhance resilience and liveability.

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Circular Economy Sausage-Making Workshop 101

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Circular Economy Sausage-Making Workshop 101

Conference Topic: Wild Card.

Moderated by Benjamin Bryant (Icon Water) and supported by Nupur Khanna (Icon Water), Jason Mingo (Water Services Association of Australia), Nicola Nelson (Australian Water Association) and Vincent Bianchini (Water Research Australia).

Rationale:

Circular economy (CE) is no longer an emerging concept in the water sector. With notable wins across biosolids and water treatment solids reuse contributing to beneficial reuse, and resource recovery , the challenge now is to build on these successes and accelerate circularity on the ground.

This workshop will test a key assumption: *there are shared principles/guidelines underpinning successful CE initiatives, regardless of context.* We'll bring together participants' real-world experiences (what's worked, what hasn't) and use that to examine whether common ingredients for success can be distilled.

To prompt reflection and debate, we'll introduce a *strawman set of CE success principles* drawn from current industry thinking. These will serve as a scaffold for group discussion: Which principles hold across different settings? Which fall short? What's missing to progress CE? The discussion will help validate or challenge these principles and clarify *where we should focus next* including what barriers need to be overcome, what kind(s) of support and outputs are needed nationally, and where research or collaboration can help integrate and amplify CE delivery in practice.

Objective:

Amplify circular economy delivery on-ground by identifying shared success principles, unlocking key barriers and identifying opportunities for collaborative action or research.

Learning expectations:

- Understand what has made circular economy projects succeed or fail in different utility and broader water industry context.
- Identify shared principles that support circularity by leveraging frameworks and principles being developed at a national level by organisations like Circular Australia and Water Services Association of Australia and how they might be applied in new domains.
- Recognise common pain points across the sector, where support is needed and in which form.

Workshop outcomes:

- A co-created set of principles for successful circularity (and principles for where CE doesn't work out).
- A shortlist of sector-wide challenges and areas for further work.
- Identification of potential research opportunities and project ideas to be further developed post-workshop.
- Contributions toward a post-event paper or opinion piece to position the water sector as a CE catalyst.

Workshop structure:

Time	Session segment	Notes
10 min	Welcome + scene-setting	Moderator opens the sessions. Set the context with a short overview of the CE state-of-play in the sector and key drivers. Share the objective of the workshop and structure. Introduces strawman set of principles to frame discussion.
40 min	Distilling success principles	Breakout group discussions: Participants reflect on their own CE experiences (what worked, what didn't and why) using the strawman principles as a guide. Groups identify lessons learnt and refine success/failure principles, then report back to plenary with key insights and comment threads.
35 min	What's next: unlocking and applying	World cafe format: Groups rotate across discussion stations: 1. What are the common pain points we should collaborate on going forward? 2. What types of outputs or support (e.g. research, policy, guidance) are needed to go further? 3. Where should the sector focus next to amplify impact? Each table captures key points and identifies priority items. Final segment synthesises and refines sector wide priorities and corresponding support mechanisms.
5 min	Wrap up	Facilitator summarises outputs. Confirm immediate next steps (e.g. post-event paper) and thank participants.

Links to research

The workshop outcomes will directly inform WaterRA's research scoping and project development activities. Insights into barriers, knowledge gaps and successful principles with be used to 1) identify and shape sector-wide research priorities in CE, 2) contribute to aligned guidance, industry reports or frameworks in partnership with WSAA and AWA, and 3) highlight where evidence-based work is needed to support regulatory and policy discussions.

Customer acceptability, customer preferences and social license to operate: what does all this mean for the water sector?

A/Prof Bethany Cooper[1,2], Dr Saeideh Khosroshahi[3], Prof Lin Crase[1], Prof Dan Rigby[4], Mr Marcus Crudden[3]

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Customer acceptability, customer preferences and social license to operate: what does all this mean for the water sector?

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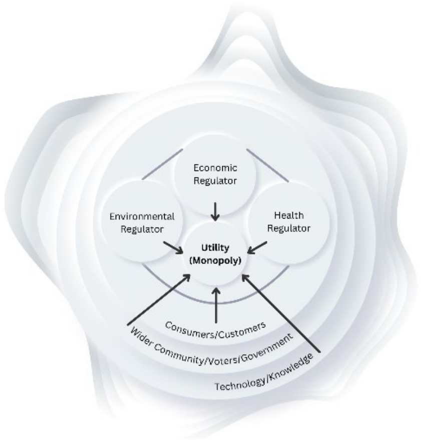
INTRODUCTION

The provision of safe potable water and wastewater services has historically been dominated by technocrats (Turner et al. 2022). On the one hand, this dominance is credited with the widespread containment of water-related human and environmental harm, at least in nations where there has been sufficient capacity to act upon the technical advice on offer. On the other hand, questions arise about the capacity of technical experts to make choices that align with the preferences of the populace. After all, if water and wastewater 'services' are to be 'purchased' by individuals, then some reference to the preferences of those footing the bill is required to at least approximate efficiency.

The prominence of customers in the Australian water sector arguably underwent a significant shift through the economic reforms that attended the 1990s and 2000s. More specifically, the National Water Initiative (NWI) saw widespread acceptance of the notion that customers should face prices that reflect the cost-of-service provision and economic regulation should be on hand to provide the oversight required. Twenty years after the NWI, most states have relatively mature relationships between the regulator and the regulated around the more rudimentary aspects of water and wastewater services and infrastructure. However, customer understanding and acceptance of what constitutes an acceptable service is not definitive; preferences can change over time and there is at least some evidence that this occurs in the case of water and wastewater services. This dynamic is captured in Figure 1.

Figure 1: The dynamic interactions for water businesses



This paper is used to consider if our current approaches to regulation can deal with evolving customer preferences. We specifically explore what constitutes tangible evidence of customer preferences misalignment with expert minimum standards and thus provide a basis for the economic regulator to support pro-active steps by a water business. We contrast this with settings that are more ambiguous and thus caution against the regulator deferring excessively to customer preferences or sentiment when the evidence is not robust.

METHOD/EXPERIMENTAL DESIGN

From an economic perspective, the regulator aims to prevent or limit 'gold plating'. Put differently, the economic regulator's job is to limit technocratic ambition that goes beyond the requirement to deliver the desired outcome. In cases where the economic regulator is not 'the expert' in understanding the 'desired state', they will be keen to defer to others, like health and environmental experts to understand the minimum requirements to be met by water businesses. The task for the economic regulator then reduces to ensuring that those minimum requirements are met at the lowest feasible cost to customers.

However, the overall efficiency of this approach will depend on at least two factors:

a) the extent to which environmental and/or health regulators set standards that reflect community welfare and expectations and
b) the capacity of the economic regulator to gather and interpret alternative data and then influence the water utility to behave efficiently.

In this instance, we invoke a case study method to shed light on these two factors and the potential relationships between water businesses, various regulators and their customers. Accordingly, the aim is to highlight possible scenarios and interactions, while acknowledging that this approach cannot capture all instances a business may need to confront.

Our analysis covers two cases. In the first instance, we scrutinize water aesthetic standards and what customers consider as acceptable potable water. Our second case focuses on a suite of diffuse source pollutants and customers attitudes and preferences to pollution reduction. We compare the two cases to draw out salient lessons.

OUTCOMES / RESULTS

The case of water aesthetics

The Australian Drinking Water Quality Guidelines are "non-mandatory standards, designed using the best available scientific evidence" (DCCEEW 2019). They seek to guide the provision of healthy and aesthetically acceptable drinking water. The guidelines on aesthetics are not as definitive as those applied to health parameters, but they nonetheless offer a basis for what's considered 'good quality' drinking water.

An important parameter that influences the taste of water is the level of total dissolved solids (TDS). As a general rule, lower levels of TDS lead to more acceptance by consumers, but until recently there was limited evidence about (a) what changes in TDS were detectable to laypeople (b) what threshold level of TDS would be adjudged acceptable to consumers.

The Guidelines specify that a TDS level of 600 mg/litre should be considered good quality and thus implicitly sets a target for water utilities. However, meeting this threshold may be difficult in some settings, especially if the source water is a groundwater system. Nonetheless, there are known and proven technologies to achieve this change. Utilities are encouraged to engage with customers on the issue, but the form of that engagement is not clear cut.

In 2024-25, Cooper et al. (2025) systematically collected taste preference data from over 600 water customers in South Australia. The technique used was paired-comparison, supported by a sophisticated statistical design that drew from the latest published research. The data was thus robust and when the statistical models were generated, it revealed that consumers had a threshold acceptance of TDS in their drinking water that was significantly below the TDS expectation for 'good quality' in the guidelines.

What does this mean for the regulator and the utility?

Most water utilities have plans to upgrade water supply infrastructure. At a national level, the industry is set to spend around $11 billion in the coming year (WSAA 2024). Upgrading infrastructure to meet a minimum standard where the customer has a clear preference for an alternative would be economically inefficient. From the perspective of the economic regulator, this case would support a discussion with the utility around the costs of meeting the expectations of customers or avoiding infrastructure spending if it has no positive outcome for those who ultimately bear the cost.

The case of diffuse pollutants in wastewater (e.g. AMR)

Wastewater treatment plants are increasingly being identified as 'hot spots' for a variety of diffuse pollutants. In essence, many of these pollutants are ubiquitous in human consumption and as they pass through to become waste streams they run the risk of becoming more concentrated and evolving to generate increased risks to human health. Concerns about these phenomena are also heightened by the growth in the reuse of treated wastewater for food production, amongst others.

Antimicrobial resistance (AMR) is a case in point. AMR occurs as antimicrobials are used to treat disease, but through that use, harmful microbes targeted become increasingly resistant. Groups of antibiotics for example, simply no longer have the efficacy they once enjoyed. In addition, scientific evidence has emerged showing that wastewater treatment plants can play a major role in the spread and selection of antimicrobial-resistant bacteria and AMR genes.

From a water customer perspective, there is very little empirical evidence about their preferences for dealing with threats that attend AMR in wastewater. There are multiple studies that show consumers are materially concerned about AMR in food animals particularly and a significant willingness to pay more for foods that pose a lower threat (Zhou et al. 2025). However, it has also been noted that "consumers lacked deep understanding of antibiotic use practice and antibiotic stewardship" (p. 1). Arguably, their understanding of 'tangential' AMR impacts through wastewater reuse is even less developed.

A further complicating factor, in this instance, is that any rational response to the AMR threat will be influenced by risk preferences and these can vary markedly across the population. While researchers have established techniques for measuring risk preferences individually, bringing this information into a holistic response is challenging.

On the technical front, there are also major scientific gaps that confront the environmental and health regulators. For example, it has not yet been determined how to apply treatment targets. Moreover, this won't be possible until more is known about the abundances and diversity of antimicrobial resistant bacteria and genes, or the impacts of dosing in treatment plants and the likelihood of infection to humans after exposure to reclaimed water. Put simply, these gaps are limiting the capacity of environmental and health experts to set meaningful targets for wastewater operators.

What does this mean for the utility and the regulator?

There is at least some possibility that customers would prefer less pollutants to transfer through wastewater, especially if it materializes in a subsequent material risk to human health. However, the extent to which those preference might exceed some minimum standard remains an open question, especially as the minimum standard itself is yet to be fully articulated. As with drinking water infrastructure, wastewater infrastructure will require significant investment in the coming years, simply by virtue of the age of this investment. The challenging question is the extent to which any upgrades for wastewater infrastructure are funded to deal with the perceived preferences of water consumers to mitigate risks for diffuse pollution (like AMR) versus meeting the current minimum standard that is largely silent on future impacts of diffuse pollutants.

Importantly, this problem differs markedly with the earlier case because (a) the minimum standard established by experts was already clearly articulated and (b) there was a compelling, rigorous body of evidence that showed the preferences of customers offered social license for the water business to go beyond the minimum. Bringing these contrasting cases together allows us to formulate propositions about how we might deal with instances where consumer preferences exceed the minimum standard imposed on a water business by a health or environmental regulator.

CONCLUSIONS

Consumer preferences are not static, and it is reasonable to expect that they will change over time. There will be instances where customers' expectations run ahead of the science on the safety and acceptability of water and wastewater services. Where the evidence on customer preference is robustly accumulated and interrogated there should be comfort from an economic perspective to support a water business that seeks to meet those preferences. After all, this is efficiency enhancing.

In contrast, where preferences are not fully formed or articulated and where the acceptable minimum standard is still being formulated by experts, the case for supporting early investment is weakened. This is not to say that water businesses can acquiesce. Rather, the case for water businesses using resources to stay abreast of developments in this domain is justified on economic grounds at least.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Most water businesses are regulated on a multi-year cycle. However, customer preferences and knowledge about risks can change rapidly. If water businesses are to be able to adapt to those changes, they need social license to be active participants in (a) increasing understanding of customers and (b) generating scientific research to bridge knowledge gaps around risks and acceptability for water and wastewater management.

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Novel operating strategies for sustainable treatment of regional community wastewater using high rate algal ponds

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Title of Full Paper

Novel operating strategies for sustainable treatment of regional community wastewater using high rate algal ponds

Conference Topic

Wild Card

INTRODUCTION

The objective of this research is to develop sustainable, resilient low CAPEX-OPEX treatment systems for rural and regional communities, which will provide a treated effluent suitable for beneficial reuse.

High rate algal ponds (HRAPs), operated as continuously stirred tank reactors (CSTRs), treat wastewater in shallow, serpentine channels mixed by a paddlewheel at mean surface flow velocities ≃ 0.2m/s. Mixing maintains a native algal-bacterial consortium in suspension. The microalgae provide oxygen for bacterial respiration, which eliminates the need for mechanical aeration, and yields carbon dioxide for photosynthesis. Treatment is achieved by mineralisation and incorporation of nutrients into the biomass. Disinfection is largely due to increased exposure to UVB, a consequence of mixing (Young, et al, 2017). Our research at demonstration scale (Buchanan, et al, 2018), followed by independent winter validation consistent with national reuse guidelines (Fallowfield, et al, 2018), demonstrated that the treated wastewater was suitable for irrigation of non-food crops. HRAPs were accepted as an appropriate treatment for rural and regional communities in South Australia (SA). Furthermore, guidelines were promulgated for their construction and operation (SA LGA, 2020). Subsequently, two, 5000 m^2 HRAPs were constructed at Peterborough, SA to treat wastewater from the township and an abattoir

Although meeting reuse guidelines for irrigation of non-food crops, the treated effluent is high in suspended solids mainly comprising small, neutrally buoyant microalgae, which are difficult to separate (Young, et al, 2021). There is a requirement to improve effluent quality using a low cost, sustainable biosolids removal technology.

Two options, likely to improve biosolids settling were identified. Sabatté et al,(2024) reviewed the potential and status of filamentous algae for wastewater treatment. Denser than microalgae they readily gravity settle, however, in CSTR HRAPs they are often outcompeted by more rapidly growing microalgae. Photogranules are dense microbial aggregates of photosynthetic microalgae and bacteria (Gikonyo, et al. 2022). These photogranules are formed in photobioreactors under anaerobic conditions, occasionally operated as sequencing batch reactors (SBRs; Trebuch, et al. 2023, Sales, et al. 2022), where anaerobic conditions were induced by sparging with N_2. Frequently, activated sludge is combined with microalgae in the presence of mechanical aeration to initiate photogranule formation (Ansari, et al. 2019), although aeration-free systems have been studied. Using microalgal oxygen production rather than energy intensive aeration to create aerobic conditions improves the sustainability of photogranule systems (Smetana, & Grosser, 2023).

Here we consider two SBR HRAP operating strategies to improve biosolids removal and treated effluent quality. The first, selective enrichment of filamentous algae, depends upon independently managing both solids retention time (SRT) and hydraulic retention time (HRT) to enable the denser filamentous algae out compete less dense microalgae.

The second strategy requires feeding the SBR under anaerobic conditions to stimulate production of polyphosphate accumulating organisms (PAOs), which produce and store polyhydroxyalkanoate (PHA; Torresi, et al., 2019). In aerobic conditions the PHA is metabolised by the PAOs for the assimilation of phosphorous. During the anaerobic growth of PAOs extracellular polymeric substances (EPS) are released aggregating and increasing the density of microalgal-bacterial photogranules enhancing settling of the biosolids.

METHOD/EXPERIMENTAL DESIGN

Selective enrichment of filamentous algae

Initial experiments were performed in 4L, paddlewheel mixed SBR HRAPs receiving wastewater pre-treated in septic tanks. Filamentous algae, bio-prospected from environmental waters and wastewater treatment plants, were selected for growth in wastewater and subsequently used in SBR HRAP incubations in controlled laboratory conditions and in a glasshouse (Figure 1(A); Sabatté et al, 2025, *in press*).

In situ photogranule formation in a HRAP

Laboratory studies were conducted in surface irradiated, impeller mixed, 60L perspex tanks fed simulated wastewater with acetate as the carbon source (Figure 1(B)).

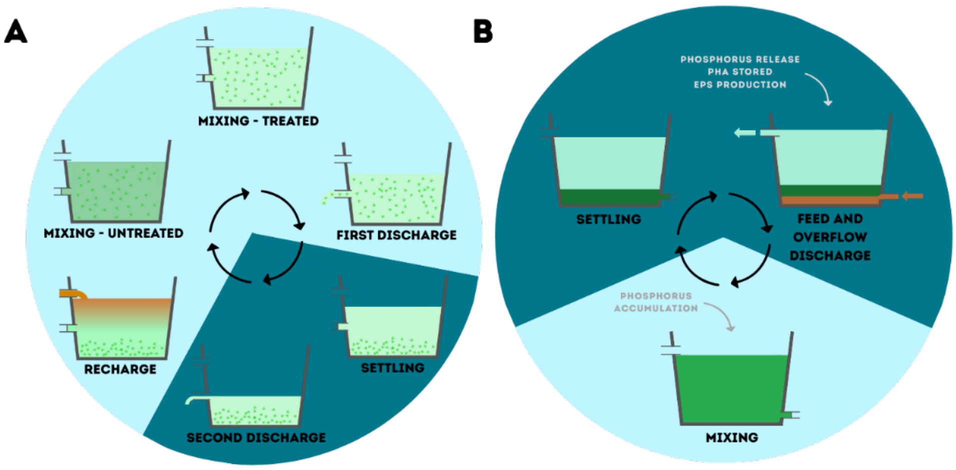

Figure 1 *(A) SBR HRAP operating regime for selective enrichment of filamentous algae grown in wastewater pre-treated in septic tanks, (B) operating regime for selective enrichment of photogranules.*

OUTCOMES / RESULTS

Selective enrichment of filamentous algae

In CSTR HRAPs operated in the laboratory at 1.6 – 10d HRT, 86-96% of the biomass comprised microalgae and 2-32 % filamentous algae, whereas the SBR HRAPs at HRTs between 1.6 and 3.3d and a SRT of 5 d the biomass comprised 93% filamentous algae and 6.2 – 6.9% microalgae. Similarly operated SBR HRAPs in glasshouse incubations removed >80% of the BOD_5, 20 -30% of the phosphorous and between 68-90% of the influent wastewater NH_4-N. These results are 'proof of concept', demonstrating that uncoupling SRT and HRT in a SBR HRAP was able to selectively enrich and maintain filamentous algal populations for wastewater treatment

***In situ* photogranule formation in a SBR HRAP**

Laboratory studies have shown that following cessation of mixing and illumination, anaerobic conditions can be induced in the SBR HRAP. Feeding influent wastewater to the bottom of the HRAP further assists in reducing dissolved oxygen concentrations, conditions favouring the selection of PAOs and photogranule formation via EPS production. Significant phosphorous release occurred in the anaerobic layer when feeding influent, indicative of the development of a PAO population. At recommencement of mixing and illumination, however, the expected uptake of phosphorus in the aerobic phase of SBR operation did not occur. This absence of uptake requires further investigation. Microscopy clearly identified photogranule formation and the biomass readily settled yielding a supernatant low in suspended solids.

CONCLUSIONS

SBR technology is commonly used within wastewater treatment plants; however, we are unaware of the SBR approach being integrated with HRAPs. Laboratory operation of SBR HRAPs, uncoupling STR from HRT, provided a method to selectively enrich more dense, filamentous algae with the aim of improving the quality of treated wastewater. Alternatively, managing mixing and timing of the raw wastewater feeding regime in SBR HRAPs offers the potential to develop populations of PAOs, producing EPS which aggregates algae and bacteria to produce *in situ* readily settleable photogranules, without the need for addition of activated sludge.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Supported by the ARC Centre for Biofilm Research and Innovation and SA Water, we have recently commissioned three, pilot -scale CSTR HRAPs and three, SBR HRAPs at the SA Water Angaston treatment plant in the Barossa Valley. The facility enables comparison of the wastewater treatment performance of SBR HRAP operational strategies with the 'traditional' CSTR HRAP operation. This pilot scale research will provide further data on the performance of filamentous enriched SBR HRAPs and SBR-HRAP operated to develop photogranules. The development of SBR HRAP technology represents a significant advance in low-cost sustainable wastewater treatment. Currently, operational management of HRAP performance is limited to changes in operational depth, which are rarely applied. In contrast, SBR HRAPs offer the potential to independently control SRT and HRT to improve wastewater treatment and the quality of the final effluent. Furthermore, the potential reduction in HRT, decreases evaporative loss, increasing the volume of treated effluent available for beneficial reuse. Shorter HRTs also translate in smaller future treatment plants with lower CAPEX and reduced land requirement.

ACKNOWLEDGEMENT

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Beyond treatment efficacy: Expert-driven modelling for uncovering hidden AMR hazards in potable reuse supply networks

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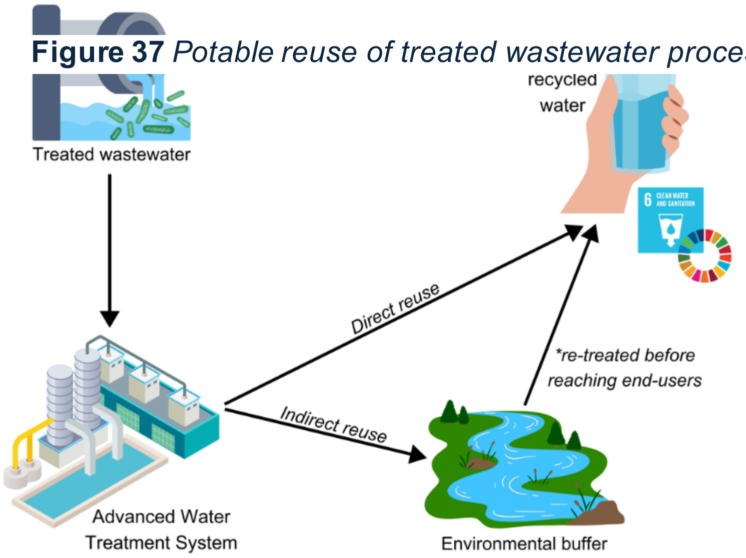
Title of Full Paper: Beyond treatment efficacy: Expert-driven modelling for uncovering hidden AMR hazards in potable reuse supply networks

Introduction

Antimicrobial resistance (AMR) is a critical public health and development crisis requiring urgent global attention and coordinated action (World Health Organization, 2015). AMR is an important consideration for water managers, including those responsible for Advanced Water Treatment systems (AWTS) producing purified recycled water (PRW) for potable reuse. AWTSs purify treated wastewater through an additional series of advanced treatment processes to achieve a quality of water that is considered safe for drinking. The resulting PRW provides a climate-resilient, alternative source of drinking water to supplement traditional water supplies, distributed either directly to end-users or indirectly via an environmental buffer (Figure 1).

Drinking water supplies and aquatic environments have been identified as important sources for the spread of AMR (Xi et al., 2009; Xu et al., 2016). AMROs and ARGs are being detected consistently in treated wastewater, the source water for AWTSs, and within AWTSs themselves (Miller et al., 2022). Advanced treatment technologies are not currently validated for the removal of AMROs and ARGs, nor do Australian Drinking Water Guidelines address AMR. Furthermore, there are increasing public health concerns being expressed about the safety of drinking water contaminated with AMROs/ARGs as multiple studies indicate that it poses negative health impacts (Alawi et al., 2022; Zhou et al., 2024). Building public trust and confidence in the safety of potable reuse schemes is a critical responsibility for water managers in establishing and maintaining their social license to operate (SLO). However, scientific knowledge is limited regarding drivers of AMR in AWTSs and their supply network, empirical data are sparse, and no models have been developed to explore potential risks under different scenarios in Australia.

Figure 37 *Potable reuse of treated wastewater process*

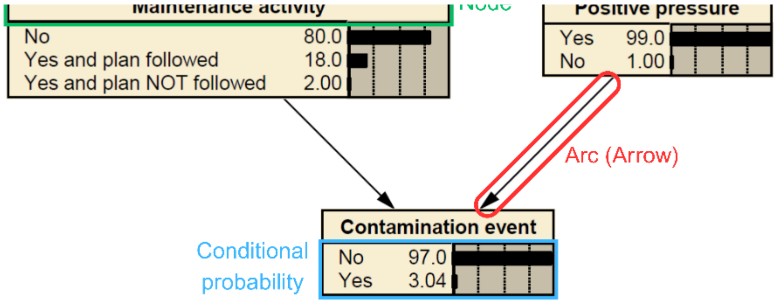


Methods/Experimental design

Given the inherent complexity and dynamic nature of AMR, coupled with a scarcity of empirical data, we chose Bayesian Belief Networks (BBNs) as the modelling approach due to their capacity to handle high levels of uncertainty. The focus of our BBN was to explore the presence and persistence of AMROs and ARGs within a specific AWTS and its supply network. This AWTS produces PRW for future indirect reuse using an advanced treatment chain consisting of microfiltration, reverse osmosis, and advanced oxidation, as detailed in Faulks et al. (2025). Using initiative logic, BBNs explain outcomes based on the hypothesised relationship among variables in a system (McCann et al., 2006). The BBN diagram, shown in Figure 2, is made up circles (nodes) representing variables, (2) arrows (arcs) indicating causal relationships where a child node depends on one or more parent nodes, and (3) tables of probabilities that quantify these dependencies.

Figure 2 shows a causal relationship where maintenance activities, and adherence to maintenance plans (parent), as well as positive system pressure (parent) contributes to or causes a contamination event (child) within the supply network pipeline. The probability tables tell us how likely the child is depending on the parent, e.g., contamination is unlikely when positive pressure is maintained in the network but highly likely when positive pressure is lost.

Figure 38 *Extract of Model 5 showing BBN structure components*



The "Belief" in Bayesian Belief Networks highlights that this style of Bayesian network relies heavily on expert inputs instead of empirical data. We obtained expert input through a formal approach known as "expert elicitation", in three stages: Semi-structured interviews with experts: Two consecutive, full-day, in-person expert elicitation workshops, and subsequently: Six online sessions to continue the elicitation process. Experts were selected for expertise relevant to the knowledge domains highlighted by our literature review. Altogether 18 experts covered a range of disciplines, including microbiologists, civil and process engineers, technologists, water regulators, academics, and health risk modellers.

We designed activities to foster participation by all experts, allowing experts to gradually refine the model. Mixing disciplines seated at each table promoted collaboration. Elicitation focussed on an actual AWTS design and geographic setting, including its supply network. Through these activities, experts identified scenarios where AMROs/ARGs are likely to be affected as water is propagated throughout this system. With careful facilitation, experts then helped develop key scenarios into five main BBN models, which were then combined into an overarching model.

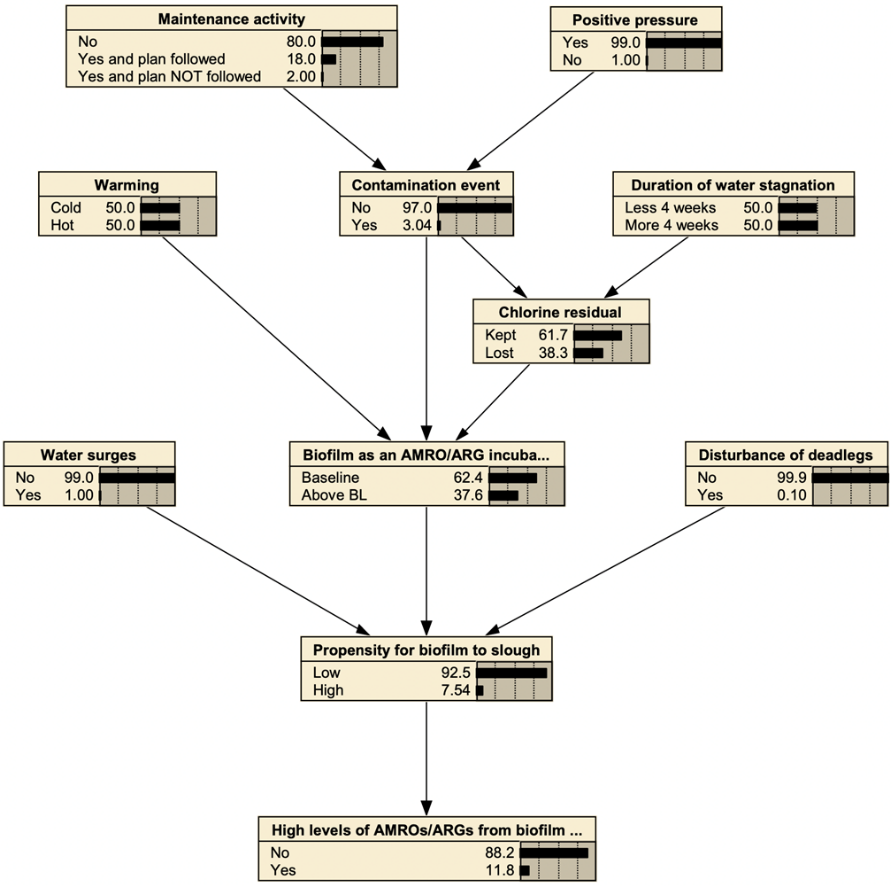
Methods are detailed in Low-Choy et al. (2025).

Results/Outcomes

Expert elicitation informed the development of five individual BBN models, each addressing different aspects of the specific AWTS and its supply network. Here, we focus on BBN Model 5, which describes the interplay of factors influencing AMROs/ARGs within the supply network, particularly the role of biofilms in their attenuation and release into the bulk water. Within the early phases of model building (early Day 1) two scenarios; "Biofilm in supply network as AMR reservoirs" (Scenario 21) and "Water stagnation" (Scenario 22), were identified by experts as impacting AMR within the supply network. Conceptual models were developed to unpack how these might occur (Day 1). Later (Day 1) experts decided to amalgamate these two conceptual models, forming an early iteration of Model 5.

This model describes how operational factors (e.g., chemical dosing, maintenance, positive system pressure), consequences of their disruption (e.g., contamination), environmental factors (e.g., temperature), and human behavioural aspects (e.g., adherence to maintenance plans) can influence the biofilm's capacity to harbour and proliferate AMROs/ARGs. Furthermore, the resulting structure and stability of the biofilm matrix, along with hydraulic conditions such as high shearing stress from water surges, impact the detachment and release of biofilm into the bulk water. This detachment, in turn, determines whether AMROs/ARGs are transferred in high abundance from the biofilm into the bulk water.

Figure 3 *BBN Model 5: Factors influencing AMROs/ARGs in the supply network*



Sensitivity analysis revealed key insights into the factors that most affect the outcomes of interest. In the pipeline, the contribution of biofilms to increasing AMRO/ARG presence in the bulk water, was captured in BBN Model 5, which was most influenced by the propensity of biofilm to slough.

Details on the other four individual BBN models and combined BBN model are provided in Faulks et al. (2025).

Discussion

Water production in this AWTS is demand driven. As such, experts determined that the supply network would be more susceptible to conditions which are favourable for increased AMRO/ARG presence due to biofilm growth. Low or zero demand (i.e., during shut-down periods) results in stagnant water conditions and potential loss of disinfectant residual. Such conditions can promote biofilm growth, which, upon resumption of water production, may release AMROs/ARGs harboured by the biofilm into the bulk water.

Biofilms have the potential to harbour ARGs and serve as AMR incubators (Zhang et al., 2018), however, the specific role of biofilm detachment on AMRO/ARG abundance in the bulk water is currently not well understood. An important finding (from both experts and literature), is that minimising biofilm sloughing presents a potential management strategy to mitigate AMR risks. While biofilm maturation and dispersal are natural processes (Liu et al., 2016), water managers can implement strategies to create environmental conditions within the supply network, that promote a more stable biofilm matrix, thereby reducing sloughing.

Microbial communities in the biofilm take up and use nutrients from the water. Because of this, detached fragments of biofilm from one section of the pipe network may be taken up again by biofilms downstream. Nevertheless, the net effects of biofilm sloughing on water quality generally and AMR specifically, is currently uncertain within the literature. Ultimately, experts determined that biofilm sloughing occurring near the POU, where the potential for biofilm uptake or reabsorption is limited, would be of great concern for water managers.

Conclusion

AWTSs have the potential to achieve exceptional microbial water quality and to reduce the likely presence and persistence of AMROs/ARGs considerably. However, these water quality improvements achieved through treatment can be compromised as water is distributed through the supply network.

Previous research has focused primarily on the efficacy of advanced treatments for AMRO/ARG removal or degradation. However, our expert elicitation reveals that numerous factors interact in complex ways to influence the presence of these contaminants in AWTSs and supply networks. This research highlights the importance of the environmental, biological, and operational aspects of water distribution on reducing microbial water quality and increasing the likely presence of AMROs/ARGs.

This study reveals insights not previously captured within the literature, without the need for extensive data sets, highlighting the value of the BBN modelling approach. The BBN provided a forum for transdisciplinary brainstorming and collaboration to effectively tease out the hidden system vulnerabilities and assessing potentially hazardous events. The role of biofilms in supply networks for AMROs/ARG abundance in bulk water was one of these hidden hazards identified by expert elicitation.

This research also highlights the value of active stakeholder engagement in maintaining the relevance of elicitation discussions to industry, thereby ensuring the developed BBN, our key research output, could practically support informed decision-making and enhanced social license.

What's next – How will this build resiliency

The BBN models developed in our study offer water managers of this specific AWTS and its supply network a practical, expert-informed framework for predicting and explaining AMR occurrence within their system, even when empirical data are limited. Managers can explore "what-if" scenarios, revealing how a variety of operational and environmental conditions likely impact AMRO/ARG fate. This improved system understanding is crucial for informed decision-making, empowering water managers to develop and implement AMR mitigation strategies, and thereby building trust and confidence in potable reuse schemes to secure their social license to operate. The BBNs' adaptive nature means they can be applied to other AWTSs, fostering wider industry benefit. The BBN also provides an interactive visual platform to facilitating effective and transparent communication among stakeholders. This foundational research also highlights key knowledge gaps highlighting directions for future research and revealing major drivers for an outcome to assist in guiding investment to ensure the long-term safety and sustainability of potable reuse.

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WaterNSW Catchment and River Health Research Strategy

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WaterNSW Research Strategy - Next Water conference WaterRA 2025 _Full Paper.DOCX (could not be inserted)

WaterNSW Catchment and River Health Research Strategy

Wild Card

INTRODUCTION

The Science Program is the structured way WaterNSW manages its legislated responsibility to undertake research to deliver outcomes that improve the availability of safe, reliable source water and support the management of Greater Sydney's drinking water catchment. However, recently, the NSW pricing regulator (IPART) included a new requirement in the WaterNSW operating licence to develop a catchment and river health strategy. This requirement broadened the research scope from the Greater Sydney Drinking Water Catchment to WaterNSW's statewide operations. As WaterNSW is the bulk water supplier for two-thirds of the water used in NSW, this expanded research function provides significant challenges and opportunities to enhance our role in river health custodianship and support critical corporate strategic needs around sustainability and operational efficiency.

The new WaterNSW research strategy balances the new operating license requirement alongside its existing legislated function to undertake research on the health of Greater Sydney's drinking water catchment. Further key considerations included the strategy's alignment with the many other agencies and stakeholders across NSW with interests in catchment and river health, the relative significance and geographic priority of specific issues, and opportunities to improve water security, water quality and biodiversity.

METHOD/EXPERIMENTAL DESIGN

Key inputs to the research strategy development included an analysis of external strategic drivers, including the regulatory and water industry landscape. Internal research needs were identified through reviewing corporate risk frameworks and consultation workshops with over 50 internal stakeholders. In parallel, a research benefit and impact assessment was undertaken on the existing Science Program. Informed by this, the research strategy was developed to focus on key challenges and develop a program of impact through targeted research partnerships.

OUTCOMES / RESULTS

The five broad research goals identified were:

1. Sustainable Assets: Understand how WaterNSW assets can be managed to maximise co-benefits and mitigate adverse impacts to customer, community, cultural and ecological values.
2. Effective Monitoring: Accelerate the development and uptake of emerging technologies that can improve the efficiency of water monitoring.
3. Proactive Risk Assessment: Extend the evidence base that informs proactive source water risk assessment and decision making
4. Healthy Sydney Catchment: Understand how catchment interventions can more effectively reduce source water pollution and protect the health of the Sydney Declared Catchment
5. Long-term Resilience: Inform long-term transformation pathways towards a climate-resilient and nature positive business.

CONCLUSIONS

This presentation will provide an overview of the WaterNSW research strategy and provide an opportunity to invite feedback and explore potential collaborations.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Providing clarity on research objectives and pathways to impact will allow for more effective collaboration, leveraging the investment in research and accelerating innovation and transformation.

Like Parent, Like Metabolite: Do Antibiotic Transformation Products Exert Comparable Selective Pressure for Antimicrobial Resistance as Their Parent Antibiotic?

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Like Parent, Like Metabolite: Do Antibiotic Transformation Products Exert Comparable Selective Pressure for Antimicrobial Resistance as Their Parent Antibiotic?

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1. Introduction

Antibiotics are crucial in combating bacterial infections in human and veterinary medicine [1, 2]. However, the rising global consumption of antibiotics—combined with inadequate disposal and incomplete metabolism—has led to their widespread detection in aquatic environments, particularly within wastewater systems [3-6]. Between 2016 and 2023, global antibiotic consumption rose by 16.3%, reaching an estimated 34.3 billion defined daily doses (DDDs), with projections indicating a further 52.3% increase by 2030 [7]. A substantial fraction of these antibiotics is excreted either unchanged or as metabolites, ultimately entering wastewater [8, 9]. There, they can further degrade into structurally diverse TPs that often exhibit environmental persistence [8]. A comprehensive review by Haddad et al. catalogued over 250 antibiotic and cytostatic TPs, highlighting their frequent detection in aquatic environments and, in some cases, their enhanced toxicity compared to parent compounds [10]. Despite their potential to promote antimicrobial resistance (AMR), the behaviour, bioactivity, and ecological impacts of antibiotic TPs remain poorly understood.

Once released into the environment—via effluent discharge or biosolid application—antibiotic TPs can persist and interact with environmental microbial communities [11]. They can exert selective pressure at sub-inhibitory concentrations, potentially enriching antibiotic-resistant bacteria (ARB) and promoting the spread of resistance genes in downstream ecosystems, including sediments and agricultural soils [12]. Some TPs, particularly those derived from macrolides and tetracyclines, have been detected in WWTP-impacted environments and may contribute to ARG enrichment due to their residual bioactivity and persistence [13-15].

Recent studies have shown that antibiotic TPs not only persist in aquatic systems but can also exceed the concentrations of their parent antibiotics. In a high-resolution screening of surface waters in Beijing, Hu et al. reported cumulative TP concentrations up to 5,171 ng/L, accounting for over 60% of total antibiotic-related burdens [16]. Notably, TPs contributed 31.2–54.1% to the predicted risk of resistance selection—surpassing parent antibiotics in both concentration and selective pressure. Similarly, a nationwide survey of Australian wastewater by Li et al found that several antibiotic transformation products—such as amoxicilloic acid, penicilloic V acid, and hydroxy-metronidazole—occurred at higher concentrations than their respective parent compounds, underscoring the environmental persistence and potential significance of TPs in AMR risk assessment [17].

Despite growing evidence and improved techniques for detecting and characterising TPs, relatively little is known about their antimicrobial activity and their role in resistance dynamics. Although their inclusion in AMR risk assessment frameworks is increasingly advocated, empirical data on their resistance-selecting capacity under realistic environmental conditions remain limited. Addressing this gap is essential for the development of science-based environmental quality standards (EQS) and effective mitigation strategies.

In this study, we address this gap by investigating whether antibiotic TPs can exert selective pressure for AMR comparable to their parent compounds. Using wastewater-derived microbial communities, we conducted a growth-based evolution experiment in which cultures were exposed to environmentally relevant concentrations of both parent antibiotics and their TPs. Resistance selection was assessed by qPCR targeting the intI1 and 16S rRNA genes. We hypothesise that certain antibiotic TPs can exert selective pressure comparable to, or even exceeding, that of their parent compound. These findings offer new insights into the overlooked role of antibiotic TPs in resistance dynamics highlight their relevance for environmental risk assessment and regulation.

2. Materials and Methods

2.1 Complex community sample collection

Raw wastewater influent was collected as a grab sample from a wastewater treatment plant in Falmouth, UK, serving a population of approximately 43,000, in October 2024. Samples were aliquoted in 1:1 with 40% glycerol and stored at −80 °C until use.

2.2 Antibiotics and their transformation products

A total of thirty compounds, including antibiotics and their corresponding TPs, were selected from three major antibiotic classes: fluoroquinolones, MLS, and sulfonamides. Compound selection was guided by their widespread clinical and veterinary use, frequent detection in wastewater and aquatic environments, and the environmental persistence or relevance of their TPs [18-20]. The fluoroquinolone group included ciprofloxacin, norfloxacin, ofloxacin, and moxifloxacin, along with their respective TPs: desethylene ciprofloxacin (deCIP), desethylene norfloxacin (deNOR), demethyl ofloxacin (dmOFL), and moxifloxacin sulfate (MOX-SO_4)—all previously reported as either metabolic by-products or photoly tic/hydrolytic degradation products found in aquatic systems [19, 21]. MLS comprised clindamycin (CLI), azithromycin (AZI), clarithromycin (CLA), erythromycin (ERY), and roxithromycin (ROX), each paired with a major transformation product: clindamycin sulfoxide (CSO), N-desmethyl azithromycin (dmAZI), desmethyl clarithromycin (dmCLA), N-desmethyl erythromycin A (dmERY), and descladinose roxithromycin (dcROX), respectively. These TPs have been identified in sewage influents and effluents, as well as surface waters [22-24]. For sulfonamides, six commonly used compounds were included: sulfadiazine (SDZ), sulfamerazine (SMR), sulfamethoxazole (SMX), sulfapyridine (SPY), sulfathiazole (STZ), and sulfamethazine (SMR)—each paired with its corresponding N-acetylated metabolite, which are known to be major human metabolites and have been frequently detected in WWTP effluents and surface waters [25, 26]

2.2 SELECT Assay - Growth-based resistance selection assessment

To investigate whether antibiotics and their TPs influenced bacterial growth dynamics within wastewater microbial communities, we used the SELECT (SELection Endpoints in Communities of bacTeria) assay to monitor changes in optical density during the exponential growth phase [27]. When bacteria develop resistance, they often exhibit reduced growth, and a decline in overall community growth can therefore signal the onset of selection pressure [27-29]. Moreover, reduced growth has been linked to the early enrichment of resistance genes such as *intI1*, with slower growth rates closely associated with the concentrations at which selection begins [29].

2.3 Selection experiment: serial passage

Thawed wastewater sample was centrifuged at 3500 rpm for 10 mins, after which the supernatant was discarded, and the pellet was resuspended in an equal volume of sterile 0.85% NaCl. This washing step was repeated twice to remove residual antibiotics or selective compounds. Iso-Sensitest broth was inoculated with 10% (v/v) of the washed wastewater sample. From the broth-bacteria mixture, 30 mL was added to each Falcon tube pre-labelled with compound names and replicate numbers. The appropriate volume of each antibiotic or TP stock solution was added to reach a final concentration of 250 µg/L, and tubes were kept on ice. This concentration was chosen to provide selective pressure sufficient to enrich resistant populations without causing lethality. Each treatment was then divided into five replicates of 5 mL each. Before incubation, two 1 mL aliquots per replicate were collected into labelled Eppendorf tubes, centrifuged, and resuspended in 1 mL of 20% glycerol for freezing. Cultures were then incubated at 37°C with shaking at 180 rpm for 24 hours. Each day, 50 µL of culture was transferred into fresh broth with the corresponding antibiotic or TP at 250 µg/L, and this serial passage was repeated for seven consecutive days. On Day 7, four 0.5 mL aliquots were collected from each replicate, mixed with 0.5 mL of 40% glycerol, and stored at –80°C.

2.4 DNA extraction

DNA was extracted from day 0 and day 7 frozen sample replicates using the QIAGEN DNeasy UltraClean Microbial Kit (formerly MO BIO UltraClean®) according to manufacturer protocols. DNA was stored at −20°C until further use. Extracted DNA was diluted 5X with 1X TE buffer (10 mM Tris-HCl, 1 mM EDTA, pH 8.0; Sigma-Aldrich), and stored at 4 °C until use in qPCR assays.

2.5 Real-Time Quantitative PCR (qPCR)

Quantitative PCR was performed to quantify the class 1 integrase gene *intI1* and the 16S rRNA gene for normalisation of bacterial abundance. *IntI1* was selected as it is widely recommended as a marker for AMR surveillance [30]. Reactions were performed using SYBR Green Master Mix in 15 µL volumes containing 10 µL of SYBR Master Mix, 1 µL each of forward and reverse primers (16S rRNA primers at 9 µM; intI1 primers at 10 µM), 0.2 µL of BSA, and 2.8 µL of nuclease-free water. Each plate included no-template controls and standard curves. The qPCR thermal cycling conditions included an initial denaturation at 95 °C for 120 s, followed by 40 amplification cycles comprising 10 s at 95 °C and 60 s at 60 °C, during which fluorescence data were collected. Only qPCR runs with a coefficient of determination (R^2) greater than 0.9 and amplification efficiencies between 90–110% were included in the analysis. Molecular prevalence was calculated as the ratio of intI1 copy number to 16S rRNA gene copy number.

2.6 Data analysis

Growth curves were analysed to identify inhibition patterns and determine the lowest observed effect concentration (LOEC) for each compound. Area under the curve (AUC) and maximum OD were also calculated for comparative analysis. For the qPCR data, gene copy numbers for *intI1* and the 16S rRNA gene were determined using standard curves generated from 10-fold serial dilutions of known template DNA. Statistical comparisons between treatments (parent vs. transformation product) and across timepoints (Day 0 vs Day 7) were conducted using linear mixed-effects models, with treatment as a fixed effect and replicate as a random effect. Where appropriate, post-hoc tests (Tukey's or Dunnett's) were applied. All statistical analyses were performed in R (v4.3.1), with significance set at $p < 0.05$.

3. Results

3.1 Growth inhibition by antibiotic and their transformation products

To evaluate the selective potential of antibiotics and their TPs, we employed a growth based SELECT assay to determine the LOEC for each compound. The LOEC was defined as the lowest concentration at which maximum bacterial growth (OD_{600}) declined below 90% of the no-antibiotic control. While LOEC values for several parent antibiotics have been previously reported, this study presents the first systematic determination of LOECs for a broad range of environmentally relevant TPs, enabling direct comparisons between parent compounds and their metabolites. A full summary of LOEC values across all compound pairs is provided in Table 1, and representative growth inhibition curves illustrating dose-dependent reductions in bacterial growth are shown in Figure 1.

Table 1. *LOECs of parent antibiotics and their transformation products: LOECs were determined using the 90% inhibition threshold from maximum density (OD_{600}) measurements in the SELECT assay. Compounds are grouped by antibiotic class and annotated as parent or metabolite. LOECs for several transformation products are reported here for the first time.*

Compound	Abbreviation	Type	Class	LOEC (µg/L)
Ciprofloxacin	CIP	Parent	Fluoroquinolone	0.97
Desethylene ciprofloxacin	deCIP	Metabolite	Fluoroquinolone	3.9
Moxifloxacin	MOX	Parent	Fluoroquinolone	3.9
Moxifloxacin N-sulfate	MOX-SO4	Metabolite	Fluoroquinolone	1.9
Norfloxacin	NOR	Parent	Fluoroquinolone	3.9
Desethylene norfloxacin	deNOR	Metabolite	Fluoroquinolone	3.9

Ofloxacin	OFL	Parent	Fluoroquinolone	3.9
Desmethyl ofloxacin	dmOFL	Metabolite	Fluoroquinolone	3.9
Sulfadiazine	SDZ	Parent	Sulfonamide	125.0
N-acetyl sulfadiazine	aSDZ	Metabolite	Sulfonamide	500.0
Sulfamerazine	SMR	Parent	Sulfonamide	250.0
N-acetyl sulfamerazine	aSMR	Metabolite	Sulfonamide	500.0
Sulfamethazine	SMZ	Parent	Sulfonamide	500.0
N-acetyl sulfamethazine	aSMZ	Metabolite	Sulfonamide	500.0
Sulfamethoxazole	SMX	Parent	Sulfonamide	125.0
N-acetyl sulfamethoxazole	aSMX	Metabolite	Sulfonamide	125.0
Sulfapyridine	SPY	Parent	Sulfonamide	500.0
N-acetyl sulfapyridine	aSPY	Metabolite	Sulfonamide	125.0
Sulfathiazole	STZ	Parent	Sulfonamide	500.0
N-acetyl sulfathiazole	aSTZ	Metabolite	Sulfonamide	250.0
Clindamycin	CLI	Parent	MLS	7.8
Clindamycin sulfoxide	CSO	Metabolite	MLS	7.8
Azithromycin	AZI	Parent	MLS	0.976
N-desmethyl azithromycin	dmAZI	Metabolite	MLS	7.8
Clarithromycin	CLA	Parent	MLS	1.95
Desmethyl Clarithromycin	dmCLA	Metabolite	MLS	62.5
Erythromycin-18	ERY	Parent	MLS	3.9
N-desmethyl erythromycin A	dmERY	Metabolite	MLS	7.8
Roxithromycin	ROX	Parent	MLS	1.95
Descladinose roxithromycin	dcROX	Metabolite	MLS	0.48

3.1.1 Fluoroquinolones

Fluoroquinolone antibiotics exhibited strong growth-inhibitory effects, with LOECs consistently observed at low concentrations. Ciprofloxacin showed a LOEC of 0.97 µg/L, while moxifloxacin, norfloxacin, and ofloxacin each exhibited LOECs at 3.9 µg/L. Among the corresponding transformation products, desethylene ciprofloxacin, desethylene norfloxacin, and desmethyl ofloxacin also exhibited LOECs of 3.9 µg/L, indicating comparable potency. Notably, moxifloxacin N-sulfate displayed a lower LOEC of 1.9 µg/L, suggesting even greater activity than its parent compound.

3.1.2 Sulfonamides

Sulfonamides exhibited higher LOECs, consistent with a weaker impact on microbial growth. Parent compounds such as sulfadiazine, sulfamethoxazole, sulfamerazine, sulfapyridine, sulfathiazole, and sulfamethazine exhibited LOECs ranging from 125 to 500 µg/L. Their acetylated metabolites generally mirrored this profile, with N-acetyl sulfadiazine, sulfamerazine, sulfamethazine, and sulfathiazole all showing LOECs of 250–500 µg/L. A few TPs, such as N-acetyl sulfamethoxazole and N-acetyl sulfapyridine, demonstrated LOECs comparable to their parents (125 µg/L), indicating a retained capacity for exerting growth-based selection pressure.

3.1.3 Macrolides and Lincosamides

The macrolide and lincosamide antibiotics displayed a wider range of LOECs. Clindamycin and its sulfoxide metabolite both showed LOECs of 7.8 µg/L. Azithromycin and its N-desmethyl metabolite exhibited similar potency, with LOECs of 0.976 µg/L and 7.8 µg/L, respectively. Clarithromycin and erythromycin-18 had LOECs of 1.95 and 3.9 µg/L, whereas their metabolites (desmethyl clarithromycin and N-desmethyl erythromycin A) exhibited LOECs of 62.5 and 7.8 µg/L, respectively. Descladinose roxithromycin showed the lowest LOEC observed in this class at 0.48 µg/L, surpassing its parent roxithromycin (LOEC = 1.95 µg/L) in potency.

Together, these results highlight the previously uncharacterised growth-inhibitory capacity of antibiotic TPs. In several cases, TPs displayed LOECs comparable to or even lower than those of their parent compounds, underscoring their potential role in driving resistance selection in microbial communities.

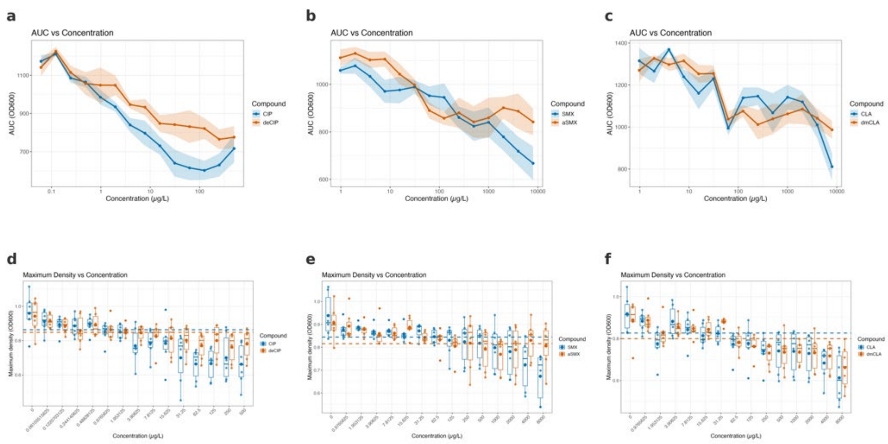
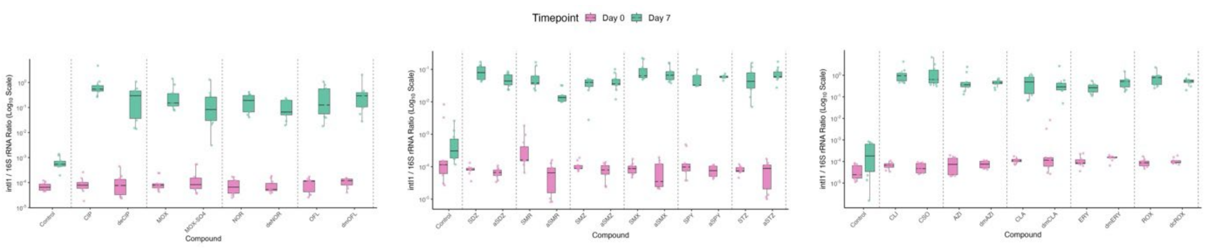


Figure 1. Growth inhibition profiles for representative antibiotic–metabolite pairs based on SELECT assay outputs. *Panels a–c show AUC and panels d–f show maximum OD_{600} for ciprofloxacin (CIP), sulfamethoxazole (SMX), and clarithromycin (CLA) and their transformation products (deCIP, aSMX, dmCLA). Shaded areas and error bars indicate ±SD. Dashed lines denote the 90% threshold for LOEC determination.*

3.2 *IntI1* prevalence across compounds

To further explore the selective effects of antibiotic TPs, we analysed the relative *intI1* abundance, normalised to 16S rRNA gene copies, across individual compound treatments. Boxplots were stratified by timepoint (Day 0 and Day 7) to visualise the prevalence and temporal dynamics of *intI1* under exposure to parent antibiotics and their respective TPs. This analysis builds on the trends reported in section 3.2 and provides a compound-level view of selective pressure.



(a) (b) (c)

Figure 3. *Relative abundance of intI1 normalised to 16S rRNA (intI1/16S) at Day 0 and Day 7 across compound treatments. Boxplots show log_{10}-transformed values for parent antibiotics and their transformation products within (a) fluoroquinolones, (b) sulfonamides, and (c) MLS classes.*

3.3.1 Fluoroquinolones

All fluroquinolones exhibited substantial increases in intI1 prevalence from Day 0 to Day 7, indicating strong selective pressure. Interestingly, several transformation products (TPs)— desethyl-ciprofloxacin, MOX-SO4, and desethyl-norfloxacin—showed comparable final intI1 levels to their respective parent compounds. Most notably, desmethyl-ofloxacin induced slightly higher intI1 enrichment than ofloxacin, suggesting that this TP may retain antimicrobial activity or persist longer in the environment. This interpretation aligns with findings from Löffler et al. , who noted that several fluoroquinolone TPs, including desmethyl-ofloxacin and desethyl-ciprofloxacin, exhibit high structural similarity to their parent compounds and may retain antimicrobial potency [31]. These TPs were predicted to exert selective pressure based on structural similarity-based resistance risk quotients and were flagged as persistent and mobile in aquatic environments, reinforcing their potential to promote integron-associated resistance under continuous exposure scenarios.

3.3.2 Sulfonamides

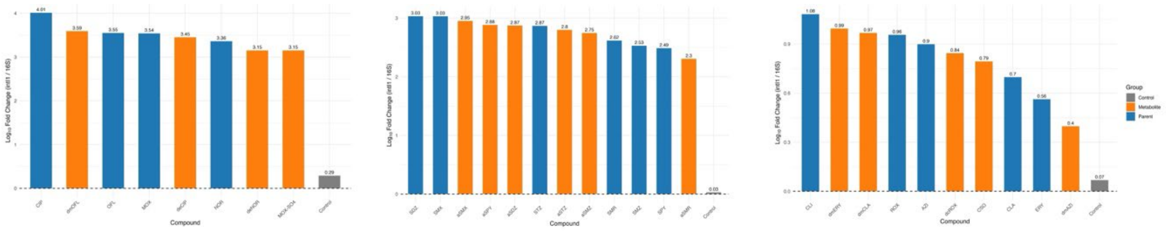
In sulfonamides (Fig. 3b), all parent antibiotics showed marked increases in *intI1* prevalence from Day 0 to Day 7. Similarly, all TPs also reached comparable final *intI1* levels to their parent compounds, with N-acetyl sulfapyridine and N-acetyl sulfathiazole exceeding that of the respective parent compound, suggesting a conserved selection profile. The elevated *intI1* levels observed for N-acetyl sulfamethoxazole is noteworthy, given that this compound has been previously identified as a major transformation product of sulfamethoxazole during chlorination processes. Dodd and Huang demonstrated that N-acetyl sulfamethoxazole forms rapidly via cleavage and substitution at the sulfonamide moiety, resulting in persistent byproducts that retain bioactive structural motifs [32]. While these findings are specific to N-acetyl sulfamethoxazole, it is plausible that other acetylated sulfonamides share similar reactivity and persistence, potentially contributing to their observed selection potential in this study. This is in line with environmental surveillance data showing that acetylated and conjugated sulfonamide TPs often occur at concentrations exceeding those of their parent compounds in WWTP effluents. Hu et al. found that such TPs contributed over 30% of the total sulfonamide burden and displayed increased persistence and mobility [16]. The acetylated TPs, not only persist through treatment but may also revert to active forms or maintain partial antimicrobial activity, exerting prolonged selective pressure on microbial communities [33]. Similarly Li et al, reported that aSPY, occurred at the highest concentrations among all sulfonamide TPs, with a detection frequency of 42 out of 47 WWTPs [34]. Its median concentration even exceeded that of several parent compounds, highlighting its environmental persistence. Given that sulfapyridine itself is no longer in clinical use and likely derives from the hydrolysis of sulfasalazine, this finding underscores the importance of tracking sulfonamide metabolites in AMR frameworks.

3.3.3 MLS

As shown in Figure 3c, nearly all MLS antibiotics and their TPs induced increased *intI1* prevalence by Day 7, with several TPs exhibiting comparable or even stronger effects than their parent compounds. Notably, clindamycin sulfoxide showed one of the highest *intI1*/16S ratios observed in this study, exceeding that of clindamycin and the control group. This suggests that clindamycin sulfoxide, a known human metabolite of clindamycin, may retain sufficient antimicrobial activity or impose other ecological stressors that facilitate *intI1* enrichment. This aligns with reports from Australian WWTPs, where it was detected at median concentrations 6.8 times higher than clindamycin, indicating its persistence and prevalence in effluents [34]. Further supporting its environmental relevance, clindamycin sulfoxide was identified as a TP of concern, citing its high structural similarity to clindamycin, predicted persistence, and moderate AMR risk quotient [33]. Similarly, other macrolide TPs—including desmethyl-clarithromycin and desmethyl-erythromycin—also showed *intI1* increases comparable to their parent compounds.

3.4 Fold change in intI1 prevalence

To assess the magnitude of integron-mediated resistance selection, we calculated the $\log_{10}$-transformed fold change in intI1 relative abundance from Day 0 to Day 7 for each compound across the fluoroquinolone, sulfonamide, and MLS classes. As expected, nearly all parent antibiotics induced substantial increases, with ciprofloxacin and sulfadiazine producing the strongest fold changes within their respective classes. Notably, several transformation products—including desmethyl-ofloxacin, desethyl-ciprofloxacin, and acetylated sulfonamides—also induced comparably high fold changes, suggesting that these compounds exert selective pressure similar in magnitude to their parent antibiotics.



(a) (b) (c)

Figure 4. Log_{10} fold change in *intI1* abundance (Day 7 relative to Day 0) across compound treatments. Bars represent the log-transformed fold change in relative abundance of the class 1 integron gene (intI1/16S) following exposure to parent antibiotics (blue) and their transformation products (orange) within fluoroquinolone (a), sulfonamide (b), and MLS (c). Many transformation products induced comparable or only slightly reduced enrichment relative to their parent compounds, indicating sustained selective potential.

Our results demonstrate that antibiotics with higher LOECs, such as sulfamethoxazole and sulfadiazine, can nonetheless initiate resistance selection earlier than lower-LOEC compounds like ciprofloxacin when applied at a fixed supra-LOEC concentration. This apparent discrepancy highlights that LOEC alone does not fully capture the temporal dynamics of resistance selection. While LOEC identifies the lowest concentration at which selection becomes statistically significant, it does not account for the rate or onset of resistance enrichment once exposure occurs. Prior studies have similarly noted that resistance selection can occur well below minimum inhibitory or selective concentrations and that selection strength and timing are shaped by both compound-specific and community-level factors [27, 35]. Therefore, assessing time to selection onset, as done in our study, provides complementary insight to LOEC-based thresholds and better reflects real-world dynamics where exposure is not static and ecological context matters.

4. Conclusion

This study provides compelling evidence that antibiotic TPs, often overlooked in environmental surveillance, can exert comparable selective pressure to their parent compounds under environmentally relevant exposure conditions. Across three major antibiotic classes—fluoroquinolones, sulfonamides, and macrolide-lincosamide-streptogramin (MLS) agents—several TPs demonstrated significant enrichment of *intI1*, a key marker of horizontal gene transfer and antimicrobial resistance. Notably, compounds such as desmethyl-ofloxacin, clindamycin sulfoxide, and acetylated sulfonamides displayed intI1 increases on par with or exceeding those of their parent molecules. These findings underscore the need to expand AMR risk assessments beyond parent antibiotics to include their bioactive metabolites. By integrating transformation products into both experimental assays and regulatory frameworks, environmental monitoring can more accurately reflect the complex selective landscape shaping resistance dissemination in wastewater systems.

5. What's next?

To build on our findings, we propose a targeted concentration–response experiment to quantify the selective potential of key compounds and their metabolites from each class. Using a 7-day evolution assay, microbial communities will be exposed to a gradient of concentrations (0–1000 μg/L), with samples collected at Day 0 and Day 7 for qPCR quantification of *intI1* and 16S rRNA genes. Fold changes in relative *intI1*/16S abundance will be calculated across doses. Statistical modelling using the same linear mixed-effects framework will enable estimation of the LOECs and facilitate direct comparisons of selection strength between parent antibiotics and their metabolites. This approach will help identify thresholds for resistance selection and refine environmental risk assessments by incorporating transformation products into potency evaluations.

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Feasibility and Viability of Large Floating Solar Electricity Generation at Hunter Water

Mr Daniel Livingston[1]

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Feasibility and Viability of Large Floating Solar Electricity Generation at Hunter Water

Daniel Livingston, Duncan Jinks, Maddison Carbery

Conference Topic

7 Wild card

INTRODUCTION

Early investigations into the feasibility of large scale floating solar electricity generation at Grahamstown Dam have been undertaken covering multiple issues including economics, evaporation impact and water quality impact. Such an installation could offer unique benefits due to high evaporation losses and significant nearby electricity consumption in the Tomago industrial area.

Hunter Water has already implemented roof and ground-mounted solar generation at 15 sites, with over 6 MW installed and an additional 8 MW planned over the next 8 years, including 1-2 MW floating solar installations at wastewater treatment plant ponds.

Hunter Water is a state-owned water utility providing water and wastewater services to over 600,000 people in the Lower Hunter region of NSW.

Hunter Water is not expecting to become self-sufficient for electricity generation, as there are many sites for which onsite generation is not viable, predominantly due to insufficient suitable area for solar. Standalone battery energy storage solutions are being investigated, as well as in conjunction with solar installations.

This overall context triggered investigations of floating solar as an alternative to land-based solar at sites such as wastewater treatment plant ponds as well as Hunter Water's largest raw drinking water reservoir, Grahamstown Dam.

Currently, floating solar costs 20% to 30% more than land-based solar. Thus, investment in large scale floating solar requires co-benefits such as evaporation reduction. This paper documents Hunter Water's economic and other associated analyses undertaken as readiness investigations to facilitate such potential future investment.

METHOD/EXPERIMENTAL DESIGN

An economic analysis for a 1 GW system, covering approximately 50% of the dam's surface area and costing $1.4 billion, was conducted. See Figure 1 for an indicative layout. This was the base case, with several other scenarios also modelled. Economic analysis was performed by Frontier Economics with electricity generation market and regulatory expertise subcontracted. Scenario analysis included testing of key variables such as capital cost, expected asset performance/life, expected electricity pricing (including daytime pricing under saturated solar generation conditions), green certificate pricing, discount rate and evaporation benefit assumptions.

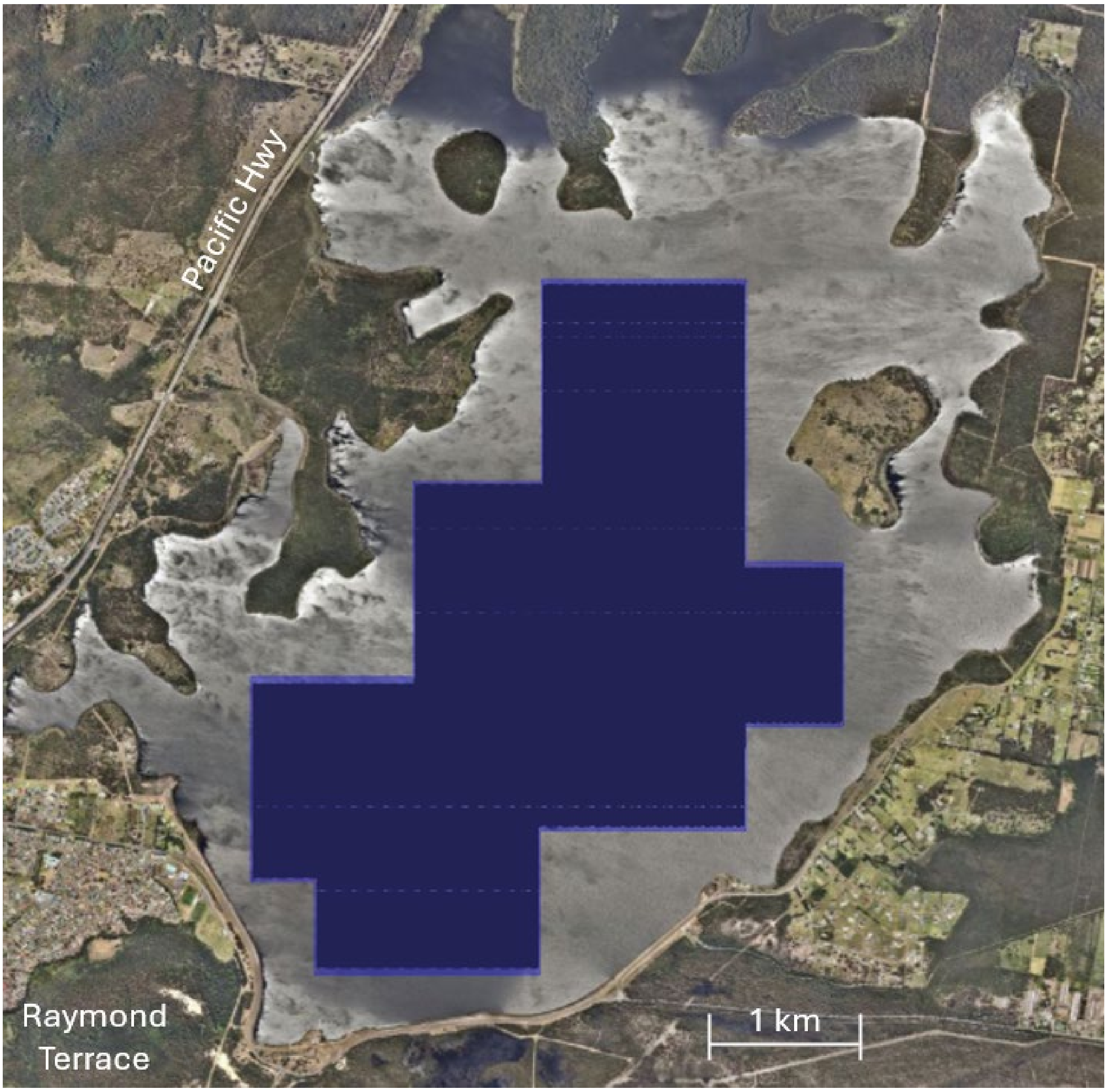

Figure 1: Indicative layout of a 1.3 GW floating solar installation on Grahamstown Dam

Market testing was done by a Request for Information undertaken through Hunter Water's procurement mechanisms, seeking as much information as market participants were willing to provide on technical details, pricing, market and regulatory factors.

Evaporation reduction benefit was examined as an independent objective as well as a co-benefit. Alternative options for evaporation reduction were reviewed that did not have energy generation benefits.

Water quality and ecological impacts were investigated by literature review with expert knowledge and experience applied to the unique characteristics of Grahamstown Dam.

OUTCOMES / RESULTS

Economic Analysis

The economic analysis found the base case and all scenarios where just one input variable was adjusted for sensitivity analysis remained uneconomic. However, favourable changes in multiple variables could make it viable. Potential pathways for improved future viability were identified. Key variables are the construction cost, energy prices, green certificate prices and the evaporation reduction benefit.

A key constraint to floating solar viability is the relatively poor capacity factor (of around 16%). Capacity factor reflects the amount of time that a generator is producing 100% of capacity. See Figure 2 for comparison to ground-mounted solar, which can achieve a capacity factor of around 25%.

Figure 2: Fixed floating panels (BayWa r.e., left image) and active tilting ground-mount panels (NEXTracker, right image). This shows how capacity factor is a fundamental challenge for floating solar. Ground-mount panels can improve capacity factor through active tilting to follow the sun.

Evaporation Benefits

Floating solar reduces evaporation through two primary mechanisms: shading which directly blocks solar radiation, and suppression of wind and wave action. These effects are not strictly linear with surface coverage. While surface area coverage is a strong predictor, studies (e.g. Bontempo Scavo et al., 2021) show that wind suppression can significantly amplify evaporation reduction, especially in large, open reservoirs like Grahamstown. E.g., 30% surface coverage can reduce evaporation by around 50%, and 50% coverage may achieve 70% reduction, depending on design and local climate.

Evaporation reduction benefit was modelled to be around $5 per MWh of electricity produced, compared to a mid-point estimate of $65 per MWh for electricity revenue. However, there is significant uncertainty in calculating evaporation benefit. The analysis made relatively simple assumptions based on surface area coverage, but wind and wave action factors may add significantly to evaporation reduction benefit depending on the solar panel infrastructure configuration.

Additional uncertainty is associated with the assumptions used in determining the economic value of the water saved from evaporation reduction. This can vary depending on several factors including the imminence and relative cost of significant capital investment to augment water sources.

The evaporation benefit from floating solar is compared to other approaches to reducing evaporation in Table 1, following.

Table 1: Comparison of evaporation options identified (in order of decreasing cost)

Technology type	**Examples**	**Evaporation reduction**	**Cost relative to value of water saved**	**Notes**
Floating Solar (FPV)	PV panels on pontoons	40–80%	Much higher (at least an order of magnitude higher, ignoring energy benefit)	Dual benefit: energy + evaporation reduction
Modular Floating Covers	Modular balls, shade structures	70–95%	Much higher (at least an order of magnitude higher)	High cost, potential water quality/ecological impacts
Suspended Covers	Shade cloths	50–90%	Much higher (at least an order of magnitude higher)	Cheaper than modular, but still costly
Chemical Covers	Monolayers (e.g. WaterSavr)	30–60%	Slightly higher	Ecological and water quality risks. Low cost, but performance varies with wind/waves

Biological Covers	Duckweed, aquatic plants	10–55%	Similar cost range	Ecological and water quality risks, uncertain control

Market Analysis

Responses to Hunter Water's confidential market testing from 15 parties with varied experience and expertise demonstrated strong market interest but limited capacity to develop cost-effective floating solar. The market for floating solar is nascent in Australia but maturing in Asia and Europe. International suppliers have partnerships with Australian providers, so building Australian capacity is realistically possible; however, the relative abundance of land in Australia reduces the likelihood of speedy uptake.

Water Quality Impact Analysis

Water quality impacts are likely to be driven by shading and blocking of wind effects, with resulting impacts on temperature, algal growth and dissolved oxygen concentrations. While some of these effects may be beneficial (e.g. reduced sunlight leading to reduced algal growth), there remain several unknowns such as the impacts of floating solar on hydrodynamics and the potential for pockets of varying water quality to make treatment more difficult. Toxicity effects of material breakdown also need to be considered.

Ecological Impact Analysis

Ecological impacts may include impacts on fish, macrophytes, phytoplankton, zooplankton, micro and macroinvertebrates, birds, and other fauna. Impacts on macrophytes may be mitigated by solar panel installation being located away from shorelines to avoid interference with macrophyte growth range near-shore, and such that varying water level does not create anchoring problems.

CONCLUSIONS

The analysis performed to date demonstrates that there are potential co-benefits that may justify investment in large-scale floating solar on Grahamstown Dam if market conditions change favourably. These initial investigations also identify issues that will require specific detailed investigations and risk mitigation.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

In mid-2025 Hunter Water went to the market for 60% design of floating solar generation systems at two of our wastewater treatment plant ponds, each in the order of 1 MW. This will provide significant opportunity for learning and capacity building that can be applied to large-scale floating solar implementations.

Hunter Water is keeping a watching brief on government policy, subsidies, and key market and economic variables, including capital construction cost, energy costs (particularly daytime) and green certificate prices.

There are some key outstanding questions regarding water quality and ecological impacts of any floating solar installation, that will not be able to be answered until the material type and design of the technology is decided. A one-to-two-year lead period is expected to be needed for pilot trials and testing to occur, to understanding material leaching and effect on water quality.

REFERENCES

Bontempo Scavo, F., Tina, G. M., Merlo, L., & Nizetic, S. (2021). *Modeling, experimental analysis and optimization of floating photovoltaic power plants*. PhD research presentation, University of Catania. Available online through the University of Catania.

Building resilience through better collaborations

Dr Ann-Marie Rohlfs[1], Dr Hannah Sassi[2], James Gardner[3], Prof. Yang Liu[4], Monique Binet[5], Dr Mariah Sampson[6]

[1]WaterNSW, [2]Water Research Australia, [3]WSAA, [4]Queensland University of Technology, [5]CSIRO, [6]Barwon Water

Building resilience through better collaborations

Conference Topic

Wild Card

MODERATOR:

- James Gardner – WSAA

PARTICIPANTS:

- Hannah Sassi - WaterRA
- Ann-Marie Rohlfs - WaterNSW
- Mariah Sampson – Barwon Water
- Yang Liu - QUT
- Monique Binet - CSIRO

IDEAS TO BE PRESENTED, DEVELOPED AND DISCUSSED:

Rationale

Collaboration is a key enabler of high-impact research that is crucial to building resilience to Australia's many water challenges. Collaborations offer many benefits; they focus resources on critical issues, develop novel solutions and accelerate the uptake of research into practise. Collaboration also requires significant investment of time and resources, and effective communication between partners. More productive collaborations can be built by understanding who our collaborators are, what drives their research agenda and practises, and where mutual or co-beneficial value can be found. In this panel session, perspectives from across industry, academia and government will be shared to explore what good collaboration looks like and ways to better bridge the gaps between us and our research partners to maximise the value realised from water research collaborations.

Learning Expectations

- Provide an overview of collaboration practises including how to establish collaborations and manage engagement between different research partners.
- Understand the perspectives and needs of different water research collaborators
- Share learnings and improvement opportunities from past collaboration experiences

Outcomes

- Key collaboration and engagement practises can be identified, implemented and valued by partners.
- Collaboration partner needs and perspectives are better understood across the different sectors involved in water research.
- Future collaborations are more productive, effective and positive from incorporating learnings from past experiences.

GENERAL STRUCTURE OF THE WORKSHOP/PANEL:

Presentations (50 mins)

1. Introduction (3 mins) – Introductory remarks on the session theme and importance of collaboration for impactful research. Introduce the Mentimeter. James Gardner
2. Setting up and managing collaborative engagements (5 mins) – Hannah Sassi
3. Learnings from the WaterNSW Science Program (10 mins) – Ann-Marie Rohlfs
4. Regional collaborations (10 mins) – Mariah Sampson
5. Set up for success: Establishing the IOT for Water ARC Research Hub (10 mins) – Yang Liu
6. One Health: collaboration across sectors (10mins) – Monique Binet

Discussion (40 mins)

Initial discussion questions will be answered by each member of the panel with further questions directed to selected panellists.

Initial discussion questions

- What drives your research priorities and how do you identify collaboration opportunities?
- What is a key challenge you have encountered with collaboration and can you share some advice on how to manage these?

Further questions will be drawn from the audience using the Mentimeter and will encompass the following themes:

- Building trust is critical to strong collaborations. What strategies do you employ to establish and maintain trust among diverse research partners?
- Which attributes or qualities do you value in a research collaboration partner?
- How can the water research community collectively foster more effective research collaborations?

12-MONTH OPERATIONAL PERFORMANCE OF A DEMONSTRATION SCALE UASB AND HIGH-RATE ALGAE POND SYSTEM TREATING DOMESTIC REGIONAL SEWAGE

Dr Andrew Ward[1], Dr Jason Dwyer[2], Professor Damien Batstone[1]

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12-MONTH OPERATIONAL PERFORMANCE OF A DEMONSTRATION SCALE UASB AND HIGH-RATE ALGAE POND SYSTEM TREATING DOMESTIC REGIONAL SEWAGE

CONFERENCE TOPIC

Wild Card

INTRODUCTION

There are over 600 regional lagoon-based treatment plants across Australia, and these systems are often overlooked when examining wastewater treatment. Although they may be regional and don't treat a large percentage of the population, they represent a significant portion of the physical treatment plants operated across Australia. Despite the widespread adoption and use of lagoon-based technology, its application in terms of configuration, installation, and operation has not significantly changed over the last 50 years, in contrast to other wastewater treatment technologies. Current lagoon-based operational issues include uncontrolled algae growth, Cyanobacteria blooms, high evaporation rates due to long retention times, sludge accumulation, odour, and high GHG emissions. They are also known to have poor nutrient removal and, when combined with operational challenges, they struggle to meet licence discharge limits.

This paper demonstrates the operational performance of an integrated up-flow anaerobic sludge blanket (UASB) digester and high-rate algae pond (HRAP) treatment process over a 12-month period. The UASB digester is a leading candidate for high-rate anaerobic treatment of domestic wastewater due to its small footprint, relatively low cost to build and operate, low excess sludge production, and good performance on domestic wastewaters. A low hydraulic retention time (HRT) of approximately 24–48 hours can be achieved using a UASB because the solid retention time is independent of the solid retention time (SRT).

The treatment performance of the integrated system over the 12-month period demonstrated that the process significantly outperforms the current lagoon-based treatment system on all treatment metrics tested. The integrated HRAP and UASB system demonstrates and further develops a technology alternative for retrofit or upgrade opportunities for lagoon-based treatment plants. The benefits of this UASB pre-treatment on algae growth and phycoremediation performance are also considered important outcomes from the study.

METHOD/EXPERIMENTAL DESIGN

A demonstration scale integrated UASB and HRAP system was operated for 12 months (28/02/2023 - 29/02/2024) at a subtropical regional treatment plant in Helidon, Lockyer Valley, Queensland, Australia.

The UASB reactor, a stainless-steel vertical unit (4.1m height x 3m diameter) with a $27m^3$ active liquid volume was used. Raw wastewater passed through a 10mm screen before entering the UASB. The system was tested at 72-hour, 48-hour, and 36-hour HRTs for anaerobic digestion and treatment performance. At start up the UASB was fed raw wastewater at a 72-hour HRT, data collection started upon reaching steady state operation. Biogas was treated with an iron-based media scrubber to remove hydrogen sulphide. Effluent digestate from the UASB fed the HRAP as part of the integrated system.

The HRAP, measuring 35.6m in length, 1.9m in width, and operating at a 0.32m depth ($12m^3$ volume and $49m^2$ surface area), was continuously mixed at 0.2 m/s by a paddlewheel assembly (0.25 kW). It was fed UASB digestate from a $1m^3$ buffer tank at a rate of 1200 L/day, equating to a 10-day HRT. Effluent exited via an overflow standpipe, which also regulated the HRAP's operating depth. The HRAP was inoculated with a 20% volume from a pre-existing wastewater-fed algae culture.

Sampling occurred twice weekly, with unfiltered and filtered aliquots taken from UASB and HRAP influent and effluent. Parameters tested included TSS, VSS, TCOD, SCOD, TN, TP, NH_4-N, NO_2-N, NO_3-N, and PO_4-P. Volatile fatty acids and gaseous CH_4, CO_2, N_2, O_2, and H_2S samples were also analysed. Microbial community and pathogen sampling was also undertaken on the system.

OUTCOMES / RESULTS

Over the experimental period, the anaerobic digester operated consistently without issues from fluctuating influent concentrations. UASB influent and effluent characteristics are shown in Table 1. The digester demonstrated consistent solubilisation of organically bound nitrogen, with 90 ± 12% of nitrogen in the effluent being bioavailable for algae uptake. Higher solubilisation was observed in the 72-hour and 48-hour HRT stages. This solubilisation is desirable for algae remediation, as more nitrogen is available for uptake. The UASB pre-treatment also positively impacted TSS removal, with an average decrease of 74 ± 24% over the 12-month period. Longer HRTs resulted in better TSS removal efficacy, with 84% for the 72-hour HRT, decreasing to 60% and 64% for the 48-hour and 36-hour HRT, respectively. This reduction in TSS is crucial for algae biomass production, as high TSS can hinder algae growth (Musa et al., 2020). These results validate the two-step process for optimising wastewater treatment.

The mean UASB temperature over the experimental period was 23.3 ± 3.1°C, with seasonal variations from 18.9°C in winter to 29.2°C in summer. Lower winter temperatures did not affect gas production, and the system continued to perform well during cooler months. The system pH remained stable at 7.42 ± 0.31, with no volatile fatty acid accumulation, indicating efficient methane conversion. Biogas production was highest at 36-hour HRT (2182 L/day), with consistent methane content (>80%) across all HRTs. Stability in methane content indicates a stable anaerobic digestion process.

The biogas daily production rate for the different HRT's was highest for the 36h HRT and decreased from 2182 L/day to 1823 L/day for the 48h HRT and 1203 L/day for the72 hour HRT treatment. This higher daily biogas production demonstrated that a higher loading TCOD loading rate had a greater influence on methane production when compared to the longer retention time. Biogas composition was consistent for all HRT's tested with over 80% methane reported continuously over the full 12-month experimental period Figure 1. The stability in methane content also demonstrates a stable anaerobic digestion process and limited process instability induced via the variable TCOD events that were reported in the influent.

Biogas was passed through a carbon-based scrubber to remove hydrogen sulphide, with Figure 2 showing pre- and post-hydrogen sulphide concentrations. No reduction in scrubber efficiency was noted over the 12-month period. After 12 months of continuous operation, the UASB was sampled, and TSS concentrations were taken from different depths using specific sampling ports designed for sludge bed monitoring. This sampling indicated that the UASB sludge accumulation was less than 750mm, indicating minimal sludge volume buildup. Some sludge at the bottom of the digester is essential for the operation of the up-flow sludge bed reactor. Ongoing monitoring will determine sludge removal frequency and develop a maintenance program to manage sludge volume in the reactor.

The HRAP system demonstrated high treatment performance over the experimental period. An average ammonia removal rate of 93 ± 6% was reported for the 12-month period (Figure 3). Seasonal variation in light intensity and temperature did not significantly affect ammonia removal. Soluble phosphorus and dissolved inorganic nitrogen (DIN) removal over the 12-month period were 36 ± 28% and 44 ± 30%, respectively. Soluble phosphorus and DIN removal showed a strong correlation to seasonal changes, with higher removals in summer and lower removals during winter, correlating with solar intensity and temperature. The temperature over the experimental period varied seasonally, with a maximum average temperature of 30.2 ± 2.0°C in January (summer) and a low of 12 ± 3.4°C in June (winter). Solar radiation levels ranged from 808 MJ/m^2/month in December to 379 MJ/m^2/month in June. Higher DIN concentrations during winter were associated with higher nitrate levels, indicating nitrification from bacterial processes during periods of lower algae activity.

High photosynthetic rates resulted in elevated dissolved oxygen (DO) concentrations and high pH levels (due to CO_2 removal), which, coupled with the shallow HRAP depth and high solar radiation, facilitated pathogen removal. Major bacterial pathogen indicator organisms, thermotolerant coliforms, and E. coli were tested in the influent, feed to the HRAP, and in the HRAP during summer (Nov-Dec) and autumn (Mar-Apr). The combined system achieved 3 Log Removal Values (LRV) Figure 4, substantially exceeding the 1 LRV achieved by lagoon-based systems. This significantly mitigates public health risks compared to lagoon-based treatment and enhances the effectiveness of passive further treatment through sand filtration or active treatment through chemical disinfection.

Microbial profiling of the community showed that the algae biomass was dominated by the species Scenedesmus sp. and Desmodesmus sp. Some seasonal shifts were observed, with Desmodesmus sp. increasing during colder winter months, although the culture remained dominated by Scenedesmus sp. Valuable algae biomass was harvested from the system, with an average algae TSS of 256 ± 138 mg/L. No significant stoppages were reported over the experimental period, demonstrating the system's reliability to operate continuously with minimal operator intervention required.

CONCLUSIONS

The UASB and HRAP system offers an effective wastewater treatment solution for rural and regional communities, demonstrating stable operation and reliability over the 12-month period. Results demonstrated the UASB and HRAP system significantly outperforms current lagoon-based treatment system on all treatment metrics tested. The HRAP system's high ammonia removal rates and pathogen reduction capabilities contribute to improved public health outcomes. Overall, the integrated UASB and HRAP system demonstrates a more sustainable process compared to existing open lagoon-based treatment plants. The system effectively addresses lagoon operational issues such as uncontrolled algae growth, Cyanobacteria blooms, high evaporation rates, poor nutrient removal, sludge accumulation / removal, and GHG and odour emissions.

WHAT'S NEXT – HOW WILL THIS HELP BUILD RESILIENCY

Looking ahead, the adoption of this integrated system can help build resiliency by providing a reliable, low-maintenance solution that meets the needs of regional treatment plants. By reducing operational challenges and enhancing treatment performance, the UASB and HRAP system supports the long-term sustainability and resiliency of wastewater treatment infrastructure, ensuring cleaner effluent and reduced environmental impact.

Table1: Wastewater and UASB digestate characteristics over the 12-month period.

Parameter	UASB Influent	UASB Effluent
DIN (mg/L)	59.44 ± 19.63	79.93 ± 22.25
NO_3 (mg/L)	0.15 ± 0.11	0.14 ± 0.11
NO_2 (mg/L)	0.05 ± 0.21	0.04 ± 0.20
NH4 (mg/L)	60.74 ± 17.41	79.75 ±22.21
TKN (mg/L)	93.49 ± 36.88	85.39 ±15.71
PO_4 (mg/L)	7.12 ± 2.46	10.23 ± 3.14
TP (mg/L)	15.76 ± 9.12	11.68 ± 3.28
TCOD (mg/L)	1339.04 ± 591.16	452.9 ± 112.97
SCOD (mg/L)	301.51 ± 46.14	189.78 ± 24.04
TSS (mg/L)	1209.29 ± 293.04	176.71 ±27.22
VSS (mg/L)	1050.8 ±273.03	165.1 ±24.6

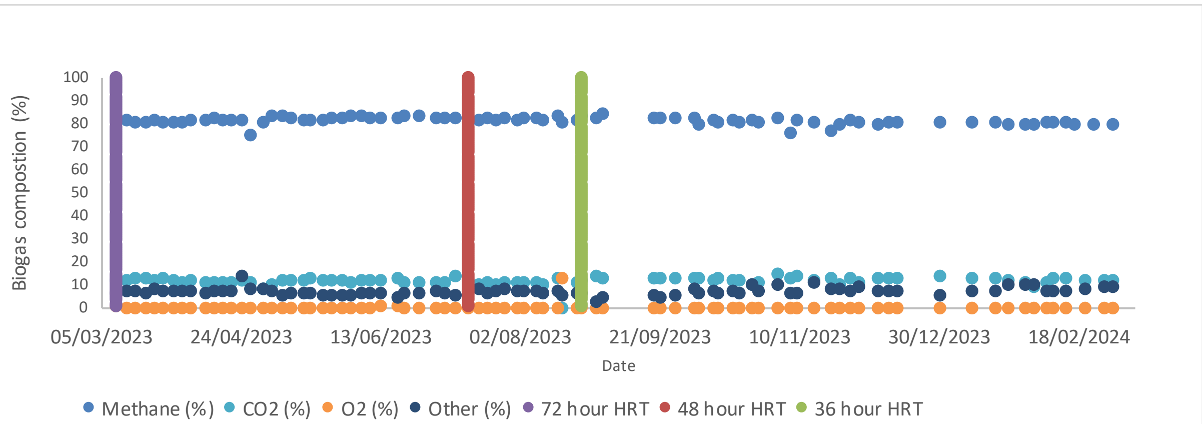

Figure 1: Biogas composition over the 12-month experimental period.

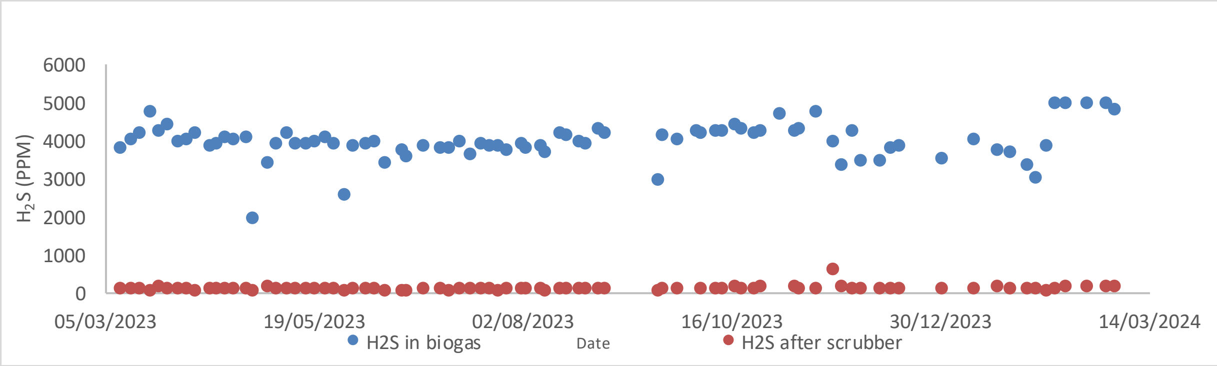

Figure 2: Hydrogen sulphide concentrations pre and post biogas carbon filter.

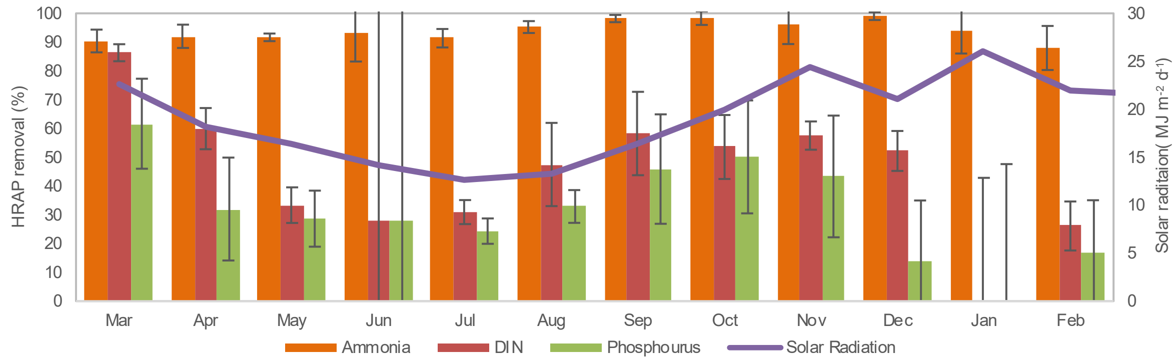

Figure 3: Nutrient removal and solar radiation over the 12-month experimental period.

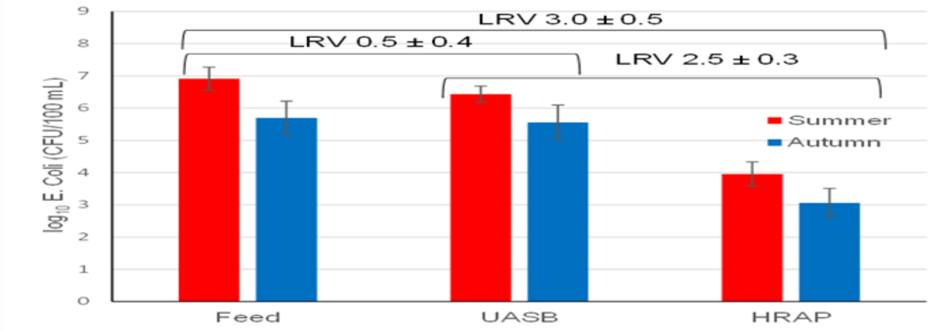

Figure 4: Summer and winter pathogen LRV from feed, UASB and HRAP system.

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