



# INNOVATION IN WATER SINGAPORE



Water for All: Conserve, Value, Enjoy



Thank you for picking up the latest print edition of *Innovation in Water | Singapore*. We hope you will enjoy reading all about some of the latest, most cutting-edge water research carried out in Singapore.

PUB, Singapore's national water agency welcomes research collaborations that are in line with our mission: to ensure an adequate, efficient and sustainable supply of water.

The opportunities for collaborative research abound for partners in the water and related industries, universities and research institutions (locally and overseas) and creative individuals who share our objective of improving water supply management through use-inspired fundamental research, application and technological development, as well as investment in process improvement, knowledge management and implementation.

To support this endeavour, PUB offers many opportunities for the collaborative development of new water technologies. If you are interested in finding out more about collaboration opportunities with PUB, please visit <http://www.pub.gov.sg/RESEARCH>



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# Towards Water Innovation



At the **Environment and Water Industry Programme Office (EWI)**, our mission is to nurture and grow the water industry in Singapore. Through EWI's multi-agency efforts, Singapore has been transformed into a Global Hydrohub supporting a vibrant water eco-system. We believe that technology is the key to continued growth in the water industry and we pave the way by offering a variety of avenues to support research and development in water technologies. These range from research funding and PhD scholarships, to offering facilities for companies to test-bed potential breakthrough technologies and solutions.

Let us help bring your innovations to fruition. Visit [www.pub.gov.sg/ewi](http://www.pub.gov.sg/ewi) today to find out more about our schemes.



# Message from the Executive Director



Welcome to the third issue of *Innovation in Water | Singapore*.

Continuing from the first two issues, we are pleased to present the progressive evolution of water research in Singapore. In the first issue, we featured our innovative membrane bio-reactor technology, focusing on how this technology offers a cleaner, more energy-efficient and cost-effective method of water reclamation and illustrating our commitment to taking the lead in the early adoption of new technologies. The second issue showcased the award-winning Variable Salinity Plant (VSP) technology — a unique innovation locally developed in Singapore that can increase our water catchment to 90% in the long term. The VSP technology forms an integral part of our endeavour to harvest every drop of water from smaller rivulets and streams near the shoreline, thereby overcoming the challenges of developing conventional reservoirs from these smaller streams. In this current issue, we explore how, as a member of our water community, Siemens Singapore, is addressing the challenge of halving energy demand for seawater desalination, one of our Four National Taps.

In this issue, we are also delighted to present two new sections titled 'Facilities Focus' and 'People in Water Research'; the former introduces key facilities that are used for research and test-bedding of water technologies in Singapore, while the latter features individuals who have made notable contributions to our water sector. In the first issue of 'Facilities Focus', we provide an inside look at the range of facilities across the entire water value chain managed by PUB, Singapore's national water agency. In 'People in Water Research', Mr. Tan Gee Paw, Chairman of PUB, shares his views on leveraging technology in water management and how this is a key enabling factor in ensuring an efficient, adequate and sustainable supply of water for Singapore.

Our efforts in water research continue to yield substantial results. Together with partnering agencies comprising International Enterprise (IE) Singapore, the Singapore Economic Development Board (EDB) and SPRING Singapore, PUB leads the Environment & Water Industry Programme Office (EWI) in developing initiatives that advance Singapore's position as a global hydrohub for innovative and sustainable water solutions. The water R&D ecosystem in Singapore has been steadily growing, and it now consists of 25 research institutes and corporate laboratories, which, together with the local research community, have carried out 348 R&D projects valued at S\$221 million.

These latest results of our R&D efforts are highlighted in this issue of *Innovation in Water | Singapore*. We welcome anyone with an idea for water R&D to come forward to collaborate with us and join us on this journey to ensure a sustainable supply of water.

## **Chew Men Leong**

Chief Executive, PUB, Singapore's national water agency

Executive Director, Environment & Water Industry Programme Office



# Driving innovation: Singapore's 'hydrohub' for water resources research

Singapore has a vibrant water eco-system supported by the development of innovative water solutions that are integral to the nation. Taking the lead role in the management of Singapore's water resources is the national water agency, PUB Singapore. Together with numerous government agencies and partners in industry and academia, PUB Singapore plays a key role in nurturing the development of a world-class innovation-driven water industry. Through its many R&D initiatives and by making its extensive water infrastructure available to industrial and academic partners for trialling new technologies, PUB Singapore is driving the innovation in water technologies needed to secure a safe and sustainable water supply for the future.



Water is of utmost importance in Singapore. With limited land area, high level of urbanisation and a lack of natural freshwater lakes, Singapore faces challenges to meet its domestic and industrial water demands — needs that are expected to double over the next half century. Improving the nation's water self-sufficiency through the development of a robust, diversified and sustainable water supply is a key strategic goal of the Singapore government with comprehensive water R&D programmes.

Singapore's challenging water resource environment requires innovative water resource management solutions. Over the past five decades, Singapore's water R&D programme has resulted in the introduction of a number of new technologies that have considerably bolstered the nation's water resources and improved its water management system. Driving technological advances is essential for the development of more efficient water resources management into the future and finding new ways to capture, reclaim and save water.

NEWater is an example of such innovation. NEWater, a Singapore-developed technology for the production of high-grade reclaimed water using state-of-the-art membrane filtration technologies, is a major breakthrough. The NEWater initiative has garnered international acclaim and elevated Singapore as a world leader in the application of recycled water and sustainable water management solutions.

As the national water agency, PUB Singapore leads water R&D in Singapore through the Environment and Water Industry Programme Office (EWI), an inter-agency body that also includes the Economic Development Board (EDB), International Enterprise Singapore (IES), enterprise development agency SPRING Singapore, as well academic partners including the National University of Singapore, Nanyang Technological University and A\*STAR. This whole-of-government strategy implemented through the EWI integrates policy and implementation frameworks across the various agencies involved in the development of the water industry. Although the EWI was established just slightly more than five years ago, the initiative has already raised the international profile of the water industry in Singapore as a global 'hydrohub', attracting large-scale investments and high-calibre researchers to the nation's shores.

### Comprehensive R&D coverage

Singapore's water R&D programme is aimed at developing more efficient solutions to ensure a secure, safe and sustainable supply of water. It encompasses the entire water cycle, from rainfall to reclaimed water and desalinated water. The primary goals of the program are to expand and diversify Singapore's water resources, reduce costs of producing clean water, enhance water quality and security, and through this, develop the water industry in Singapore. These goals are pursued through R&D that encompasses all parts of the R&D value chain, from idea conceptualisation and basic research to applied research, demonstration, test-bedding and commercialisation.

Through the EWI, PUB Singapore works closely with research institutions and the private sector. Its in-house research arm, the Centre for Advanced Water Technology, conducts its own research on water analytics, advanced water technologies and water resources management as well. In this way, PUB Singapore

acts as a bridge between upstream research and downstream application, adding value to its collaborative partnerships.

The Environment and Water Research Programme (EWRP) also accelerates this process of transforming new ideas and technology into innovative applications that can be brought to market faster by ensuring a coordinated national approach to project funding.

Grooming talent and human resources to meet the fast-growing needs of industry and research institutions is also an important area of focus at the EWI. In addition to training research personnel and engineers, PUB Singapore supports various graduate scholarship programmes and is active in developing local knowledge capacity by inviting internationally renowned experts to collaborate with researchers in Singapore.

One of the biggest drawcards for water R&D in Singapore is the availability of PUB's extensive network of waterworks, water reclamation plants, NEWater plants, reservoirs and stormwater canals for testing new technologies. The opportunity to conduct on-site testing under actual conditions is crucial for the development of commercialisable technologies. To coordinate activities with the private sector, PUB has more than 150 officers in six technology groups — Intelligent Water Management, Membrane, Network Management, Used Water Management, Water Treatment, and Water Quality — to facilitate the transition from fundamental research to test-bedding and pilot- or demonstration-scale studies.

### Partnerships in water research

PUB Singapore's commitment to fostering research partnerships with local and international research organisations, water utilities and technology solution providers has resulted in a number of major collaborative R&D projects. With its depth of expertise in the water industry and willingness to share its facilities for research, PUB welcomes collaboration with both industrial partners and even individuals on research that supports the provision of a high-quality, sustainable water supply for Singapore.

Breakthrough innovations often arise from research that transcends the boundaries of scientific and engineering disciplines. Advancements in polymeric membrane materials, which have led to significant progress in seawater desalination and water reuse, are an excellent example. PUB encourages such cross-disciplinary research with the potential to result in high-impact innovations and applications for the water industry.

Partnering allows collaborating parties to share the costs of R&D, while reducing associated risks. The funding schemes available in Singapore to support environmental and water research include the EWI's Incentive for Research and Innovation Scheme and Tech-Pioneer Scheme and the EDB's Innovation Development Scheme.

Singapore's long-standing commitment to developing innovative water technologies has recently been recognised by the World Health Organisation (WHO), which has designated the PUB's Water Quality Office as a WHO Collaborating Centre for safe drinking-water management and integrated urban water management. It is yet another example of how Singapore's water industry is driving technological change for better water resource management, contributing to the development of a robust and sustainable water supply for Singapore and helping the global community address water supply challenges posed by population growth and urbanisation.

# Searching for a more cost-effective desalination solution

Each day, millions of people struggle to obtain safe and affordable drinking water. With the global population topping seven billion, water-stressed regions around the world continue to grow. However, since late 2008, Siemens has engaged heavily in research and development (R&D) in an attempt to solve one of the world's most pressing problems — clean water for all.



The cost of treating seawater for potable uses has long been the roadblock towards utilizing a resource that covers over 70% of our planet. Electrical energy to power desalting systems makes up a significant portion of overall water treatment expenses. With the support of Singapore's Environment and Water Industry Programme Office (EWI), Siemens set out to see just how low energy consumption could be driven while desalinating seawater to drinking water standards.

### Siemens' seawater savvy

Research scientists and engineers based at the Siemens Global Water R&D Center in Singapore led the effort in this. In conjunction with some of their colleagues in the United States, researchers took an alternate approach to desalination. While best available technology surrounds thermal processes or pressure-driven membrane filtration such as reverse osmosis, Siemens looked to leverage its expertise in electrochemical processes.

Siemens set out to push the limits of a well-known technology, electrodialysis, and use the desalting approach in ways that had not been attempted previously. An electrodialysis system is an example of a complex electrolysis cell where a voltage is applied across an electrode pair to produce a corresponding oxidation-reduction reaction of the electrolytes in the electrode compartments. In an electrodialysis module, electrical current is carried by the transport of ions through ion-permeable membranes. These so-called ion exchange membranes are arranged so that there are alternating diluting (product) cells and concentrating

(reject) cells that form cell pairs. The arrangement of ion exchange membranes is such that cations (positive ions such as sodium) transport through a cation exchange membrane in the direction of the cathode from the diluting cell into the concentrating cell. The cation's transport is blocked in the concentrating cell by an anion exchange membrane. Anions such as chloride transfer in the same manner as cations, but through an anion exchange membrane.

The net result is that the ions making up salt in our oceans are channelled in one direction or another and ultimately removed. By performing this process electrochemically, Siemens is able to operate at very low pressures, and hence reduce energy consumption. The Siemens approach does not force water through tiny pores under application of high hydraulic pressure as is the case with some processes. Rather, it works on an electrochemical technology that pushes salt ions in opposing directions under a low pressure environment. Such a low pressure solution offers other customer benefits such as a system that can be built with conventional, low-cost plastic piping materials, and standard valves and fittings. Such a system also operates with low noise and vibration — an operational value that is often not quantified.

### Singapore's EWI project

In 2008, out of 35 submitted proposals, Siemens won a challenge grant from the EWI. The goal of the project was to develop an innovative technological solution that could halve desalination's energy demand. During the initial phase of the project, Siemens attempted to validate its assumptions and verify its scientific



Fig. 1: Laboratory electrodialysis units used to study low-energy desalination solutions

approach. Through a series of laboratory-sized units (Figure 1) and prototype modules, Siemens continued to obtain test results confirming that a low-energy desalination solution was possible.

The EWI project culminated with a 50 m<sup>3</sup>/d demonstration unit built in Singapore (Figure 2) and put into service at PUB's Variable Salinity Plant located in Pasir Ris. The unit has been in operation since December 2010, and continues to desalt actual seawater at an energy value less than half that of a typical installation. Siemens continues to operate the demonstration unit although the early R&D work is completed. By pushing this unit to extremes, Siemens scientists have learned how to take their technology to the next step — commercialisation.

While Siemens is satisfied with its technical accomplishments during the EWI project, the overall objective has not yet been realised. Siemens understands that the true measurement of applied R&D success is success in the marketplace. To this end, Siemens has been working to lower costs.

Removing system costs has meant re-designs, new materials of construction, and a keen awareness of the desalting markets (Figure 3). Following commissioning of the demonstration unit, Siemens embarked on designing and building its next-generation prototype modules. In late 2011, a new design was unveiled at a fraction of the cost of the demonstration unit, and with a greater operating efficiency.

### Applying lessons learned

One of the lessons learned during the development phase is that the true value of a desalting system is not exclusively the amount of energy needed to operate the system. Electrical rates throughout the world vary greatly and, in many instances, electrical costs are supplemented by the government. As an example, Trinidad enjoys power costs in the region of 3 cents per kWh, while a neighbouring island, Barbados, has costs exceeding 20 cents per

kWh. The true value to the marketplace is measured by the combination of operational costs and initial capital costs. Using the Net Present Value (NPV) of a potential installation gives a more realistic view of the value of the system for the community.

Siemens has determined that the electro dialysis system being developed is much more flexible than other desalting processes. Changes in operating settings can have a dramatic effect on both the amount of energy necessary to desalt certain waters as well as the amount of membranes necessary for the system. Capital costs are inversely proportional to the amount of energy necessary to meet drinking water standards. In certain cases where electricity is relatively inexpensive, the system can be designed to minimise capital costs. Where electrical costs are high, the amount of capital can be increased to minimise electrical requirements.

Measuring the economics of a system design by NPV allows an engineer to tailor the electro dialysis system for the specific needs of the proposed installation. Relationships between flow rate, number of modules necessary for desalting and the amount of energy employed across the cell are being developed to help engineers determine the best option for the commercial needs of the marketplace.

### Looking Ahead

At present, Siemens is in the process of building a set of first commercial modules that will be used for piloting in Singapore in late 2012. Siemens is also preparing to build additional pilots in Singapore in 2013 to fully test its latest advancements.

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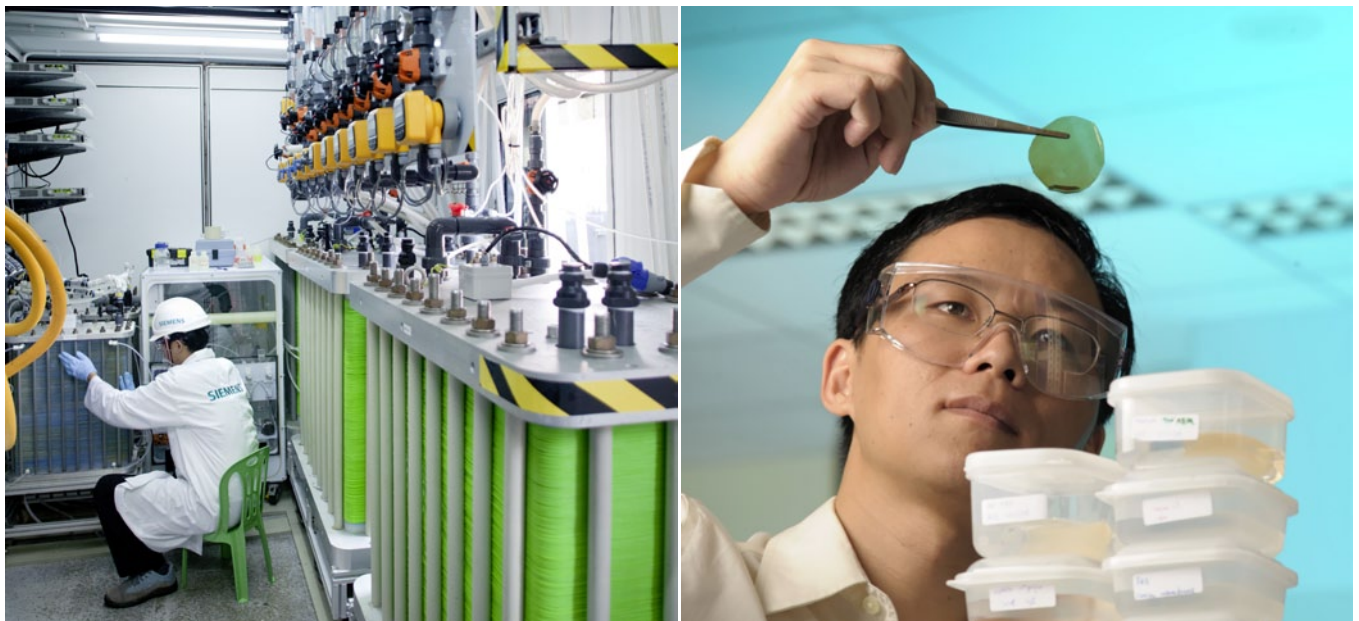


Fig. 2: Demonstration unit at PUB's Variable Salinity Plant in Pasir Ris (left) and new material development (right)





# PEOPLE IN WATER RESEARCH

**Tan Gee Paw**

*Chairman of PUB Singapore*

Mr Tan Gee Paw was appointed Chairman of PUB Singapore in April 2001. He graduated with First Class Honours in Bachelor of Engineering (Civil) from the University of Malaya in 1967, and obtained a Master of Science in Systems Engineering from the University of Singapore in 1971. He was conferred an Honorary Degree of Doctor of Science from the University of Westminster, UK in 1993, and an Honorary Doctorate in Engineering from Sheffield University, UK in 1995. Mr Tan received the Public Administration Medal (Silver) (1978), a Special Award (Gold Medal) for Clean River Commemoration (1987) and the Meritorious Service Medal (2001). He received the Medal of Commendation at the NTUC May Day Award in 2005, and the President's Award for the Environment in 2007. Mr Tan was also bestowed the Distinguished Service Order in 2010. In 2011, Mr Tan was conferred the Distinguished Engineering Alumni Award by the National University of Singapore, and elected an Honorary Fellow of the Institution of Engineers, Singapore. Mr Tan was also elected a Fellow of the Academy of Engineering, Singapore in 2012.

*Throughout your career you have taken a leading role in dealing with important environmental issues. How has your experience influenced your views on the water industry?*

As a young engineer, I was privileged to be involved in the team that drew up Singapore's first Water Master Plan in 1972. If the past four decades have taught me anything, it is that the government alone does not have all the answers or indeed the ability to deal with every aspect of water. We work closely with the community to instil a sense of ownership of our water resources, and constantly strive to cultivate the best human resources — not only to staff PUB, but also to provide the necessary human capital for Singapore's booming water industry.

*What were the technological challenges you encountered at the start of your career?*

Our first challenge was to diversify our water resources. By investing in water R&D and taking an integrated approach to water management, we found answers in the form of NEWater and desalination, as well as expanding our local catchment areas. Together with imported water, they form the Four National Taps.

*Would you consider NEWater as the most important technological development at PUB thus far?*

Yes, NEWater is the result of decades of relentless R&D to find alternative sources of

water for Singapore. Unlike conventional water sources, NEWater is less dependent upon weather, and is therefore, more reliable and sustainable. It has put Singapore on the world map for innovative water management, including winning for PUB the 2007 Stockholm Industry Water Award. NEWater now meets 30% of Singapore's total water demand, and we plan to triple this to meet 50% of our future water demand by 2060.

*How has Singapore's water industry changed over the years?*

In investing in research and technology to meet Singapore's water challenges, we have turned our vulnerability into a strategic asset. Water was identified as a strategic growth sector in Singapore in 2006 with technology development as the key driver, and the Environment and Water Industry Programme Office (EWI), which spearheads the growth of Singapore's water industry, is investing \$470million from Singapore's National Research Foundation in water R&D. Through funding promising research projects, EWI aims to foster leading-edge technologies and create a thriving and vibrant research community in Singapore. Singapore today is home to a thriving cluster of about 100 water companies and 25 public and private research centres. We also facilitate opportunities for water companies to test-bed their new technologies and solutions at our installations under actual site conditions. More than 120 projects involving the test bedding of water

solutions have been facilitated at PUB's installations, and more than 20 test-bedding projects are currently on-going.

*Looking to the future, what do you see as being the main challenges in water research facing Singapore and how does PUB plan to use its leverage on technology to overcome them?*

Going forward, we will continue to invest in R&D to find more economical and efficient ways to produce and treat water. Current technologies have enabled us to develop reliable and sustainable water sources like NEWater. With rising global energy costs, the challenge now is to develop new water technologies that are more energy-efficient and sustainable. For example, we are currently partnering Siemens Water Technologies to experiment with an electrically-driven process to desalt seawater, with the aim of halving the current energy levels.

PUB has also pioneered a new water treatment technology called the Variable Salinity Plant that integrates desalination and NEWater processes to treat water of varying salinity into potable water. This technology has the potential to increase our water catchment from two-thirds to 90% of Singapore's land area.

There is an ancient proverb that states: "We do not inherit the earth from our ancestors, we borrow it from our children." Understanding that what we do today will impact future generations is instrumental in overcoming any challenges we may face.





# Testing the waters

Transforming promising ideas into commercial technologies for water resource management



PUB's Water Reclamation Plants, such as Ulu Pandan WRP (top) and Changi WRP (bottom), offer test-bedding sites for used water treatment projects



The development of new technologies for securing an adequate, efficient and sustainable supply of water at an affordable cost is of paramount importance for Singapore. Although incremental increases in water harvesting efficiency and water conservation are essential components of efforts to optimise the nation's water reserves, it is through the development and application of innovative technologies that the most significant advances in water resource management have been achieved. Innovations such as NEWater — a world-leading technology developed in Singapore for the production of high-quality potable water from treated used water — have been instrumental in diversifying and expanding the nation's water sources.

Developing new ideas for water management into practical solutions, however, is particularly challenging due to the need to ensure the absolute safety of our water supply at all times. Yet, without using real infrastructure to trial new technologies under actual operating conditions, technology developers will not be able to obtain the operational data necessary to assure such

Water Treatment and Water Quality and Security projects such as the Fish Activity Monitoring System are conducted at Chestnut Avenue Waterworks



safety. It is a catch-22 situation that has held back the implementation of many promising water technologies around the world.

In Singapore, PUB, through the Technology Department and the Environment and Water Industry Programme Office (EWI), have established a technology development framework and hands-on consultative team of over 150 experts that allow prospective technology developers to test new technologies using PUB's extensive network of water reclamation plants, waterworks, NEWater factories and reservoirs.

### Pioneering water technology

The mission of EWI is to encourage the early adoption of new and innovative water technologies and develop Singapore as a global test bed for water resources research. The EWI's TechPioneer scheme is a key pillar of the programme's technology development strategy. The TechPioneer scheme aims to accelerate the commercialisation of new environment and water technologies by encouraging demonstration and pilot studies using PUB Singapore's water infrastructure and by bringing together technology developers and end users. This framework provides incentives for users to adopt new technologies and at the same time, provides opportunities for technology developers to establish successful case references in Singapore — a prerequisite for the large-scale adoption of any new water technology. The TechPioneer scheme provides funding of up to S\$10

million for technology users to introduce new environment and water technologies into their existing operational processes.

This allows PUB to fast-track the introduction of new, proven technologies to uphold its mission of ensuring a secure and sustainable water supply. At the same time, technology developers benefit by having the opportunity to establish a successful track record under real operation conditions for their new technologies, accelerating commercialisation and facilitating their entry into the market.

### PUB Singapore's test bed sites

Test-bedding opportunities at PUB Singapore are made available to both private technology developers and academic institutions to encourage innovation and facilitate the testing of new water technologies. In 2011, 35 R&D projects and 20 test bed projects were approved for testing using PUB Singapore's facilities. These facilities include water reclamation plants, waterworks, NEWater factories, and Singapore's catchments and waterways.

For projects related to used water treatment, testing can be conducted at PUB's water reclamation plants (WRPs). The Changi WRP is the largest used water treatment plant in Singapore with a treatment capacity of 800,000 cubic metres per day. A number of technology development projects are currently being conducted at the Changi WRP, including Annamox — a prospective high-speed treatment technology for ammonium rich used water



Bedok NEWater Factory houses a number of projects related to Membrane Technology, such as the Membrane integrity sensors



Real-time water quality monitoring and modelling are conducted at Kranji reservoir

using anaerobic ammonium oxidation — and a membrane bioreactor (MBR) system that is undergoing validation. At the Ulu Pandan WRP, projects currently being undertaken include a pilot study on minimising the life cycle cost of the MBR-reverse osmosis process, the development of used water treatment plants as urban ‘eco’ power stations, and a pilot project for a biological filter using exhausted activated carbon media for hydrogen sulphide removal in odour control. The Jurong WRP is the site for an industrial used water pilot plant demonstrating upflow anaerobic sludge blanket technology for used water treatment.

Projects dealing with potable water can be conducted at PUB Waterworks and NEWater factories. Facilities for conducting research and test-bedding new technologies are available at most of PUB’s potable water plants. Chestnut Avenue Waterworks and Choa Chu Kang Waterworks, the two largest waterworks in Singapore with a combined treatment capacity of over 900,000 cubic metres per day, offer their grounds for technology test-bedding.

At Chestnut Avenue Waterworks, a fish activity monitoring system is being demonstrated as a means of monitoring treated water quality at lower cost compared to other toxicity monitoring systems. Under demonstration at the Choa Chu Kang Waterworks is a project assessing the application of ceramic membrane filtration technology. The project aims to evaluate the performance of the ceramic membrane system used with the current polymeric membrane system implemented at the Choa Chu Kang Waterworks. The ceramic membrane has a range of potential advantages over polymeric membrane systems, including a longer lifespan, a wider range of options for chemical cleaning of membranes, and the ability to withstand much higher backwash pressures due to the robustness of the ceramic membrane structures.

Singapore’s NEWater factories also provide facilities for research and test-bedding, mainly in the area of membrane technology. Research projects undertaken at NEWater factories include studies on 16-inch reverse osmosis modules, direct osmosis high-salinity systems, and membrane integrity sensors.

Singapore’s catchments and waterways are also available as sites for research and test-bedding. The Marina Catchment is Singapore’s largest and most urbanised catchment with a catchment area approximately one-sixth the size of Singapore. It is a popular site for testing new technologies, particularly those related to intelligent watershed management.

The Marina Barrage built across the mouth of the Marina Channel to form Marina Reservoir is a key piece of Singapore’s infrastructure and its operational control is crucial for managing floods in the low-lying city areas. The barrage is controlled using a predictive control system that anticipates storms, surface runoff and downstream tidal levels in a holistic and integrated manner, informed by models for atmospheric processes, rainfall and runoff, reservoir dynamics and coastal hydrodynamics. The predictive control system is an example of an intelligent watershed management system that was successfully trialled at the Marina Reservoir and subsequently implemented.

Other projects that have been carried out in Singapore’s catchments include reservoir embankment greening projects, solar-driven water desalination, and the use of a shallow arm vector frame to conduct extensive field surveys of physical processes in the reservoir.

These are just a few examples of the many active technology projects currently being researched and tested at PUB’s facilities. PUB welcomes enquiries from interested parties. For further information, visit [www.pub.gov.sg](http://www.pub.gov.sg).





# Intelligent Watershed Management

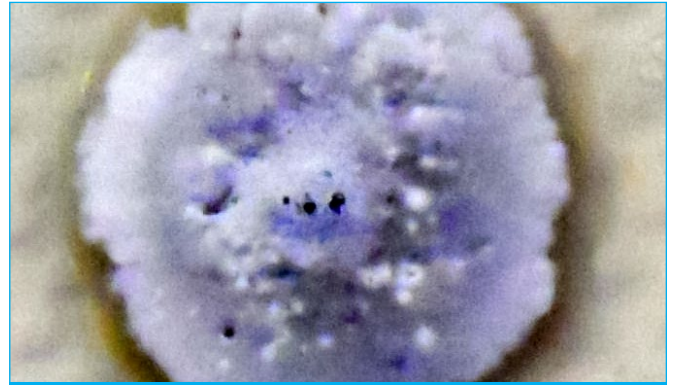
The Intelligent Watershed Management programme aims to leverage on developments in instrumentation, controls and innovative information technology solutions as modelling tools for hydraulics and hydrology research. These enhance Singapore's capability in managing its water resources and controlling floods. Using high-level simulations, water researchers in Singapore can forecast future events and plan efficient counter-measures.

# Bringing musty bacteria to light

Genetic profiling of off-flavour and odour-producing bacteria in the bottom sediments of Singapore's reservoirs aids water-quality management



**Fig. 1:** Reservoirs may harbour bacteria that can affect the taste and smell of the water supply



**Fig. 2:** An example of actinomycetes bacteria isolated from the bottom sediments of a reservoir

Communities of bottom-dwelling bacteria in Singapore's reservoirs contain species known as actinomycetes that produce substances with an earthy and musty odour. Understanding the composition and dynamics of these communities as environmental factors is critical to managing water quality. A custom-designed, genetics-based approach is now available to profile and monitor these communities as conditions vary. A research team from the Interactive Micro-organisms Laboratories (IMO Labs), PUB Singapore and the National University of Singapore developed the microbial community profiling strategy.

The team's strategy is relatively new to the bacteriological analysis of water. Angelito Abaoag of IMO Labs explains the ability to monitor community compositional changes — as a result of variations in environmental conditions — will shed light on the occurrence and dynamics of actinomycetes. This provides valuable insight for the creation of an early detection system of off-flavour and odour compounds in the water. Abaoag adds that this approach has been applied previously to anticipate viral outbreaks in aquaculture, in response to reactions of

bacterial communities, and could prove useful in water quality management.

The researchers isolated actinomycetes from the bottom sediments of different reservoirs (Fig. 1) to identify the genes responsible for the biosynthesis of two unpleasant-tasting and malodorous compounds: geosmin and 2-methylisoborneol. They also grew and compared laboratory-grown cultures grown of these isolates (Fig. 2). Initial tests revealed common structural and growth characteristics between the cultures from different reservoirs. Moreover, cultures of actinomycetes originating from geosmin-and 2-methylisoborneol-containing sediments emitted a strong odour in the laboratory. "We can see correlations on how the suspected microorganisms survive and function amidst the microbial diversity of reservoir bottoms," adds Abaoag.

To identify and quantify the microbial species present in the sediments, the team used a combination of well-established techniques: real-time polymerase chain reaction (RT-PCR) with DNA sequencing. "RT-PCR provides a comparative measurement of the abundance of selected microbial groups, while sequencing gives an accurate

identification of these groups," explains Abaoag. After characterising the genetic changes within the community over one year, the researchers correlated these profiles to understand bacterial function and biochemical reactivity.

Since environmental factors alter microbial community profiles, and therefore the emission of unpleasant-tasting and -smelling substances, the researchers are investigating the impact of these factors on the growth of the isolated bacteria. The resulting data will facilitate the development of an early warning device that specifically targets odour-emitting microorganisms. "Such a device can provide a more flexible option for water reservoir management in understanding impending outbreaks," says Abaoag.

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# Healthy wetlands, cleaner water

By restoring Singapore's wetlands, an all-natural approach to improving water quality is within reach



Image courtesy of Michelle Sim

**Fig. 1:** The first pilot project on plant selection at Kranji



Image courtesy of Mendis Iani

**Fig. 2:** A sunbird at the Sengkang Floating Wetland demonstrates the multiple benefits of a wetland

The accumulation of nutrients such as phosphorus and nitrogen poses a major problem in surface water reclamation, as these compounds allow algae populations to flourish. Thriving wetland ecosystems can help keep this problem in check. "Wetland plants compete with algae for nutrients," explains Michelle Sim, senior manager of Catchment & Waterways at PUB Singapore. "This nutrient reduction lowers risks from algae by-products, and can reduce treatment costs by producing better quality raw water."

Urbanisation has eliminated much of Singapore's native wetlands, but Sim and her colleagues are restoring these environmental niches as part of PUB Singapore's Active, Beautiful, Clean Waters (ABC Waters) Programme. Several pilot studies already underway indicate that Singapore can achieve the dual goals of more efficient water reclamation and improved environmental health.

Determining the plant species that maximise nutrient removal is a key challenge in wetland creation. In the pilot projects, the team members are monitoring changes in nitrogen and phosphorus

levels at wetland sites where they have transplanted different species of plants. In the first project, they re-introduced 6,000 plants representing four different species of rushes and reeds at a wetland site in Kranji (Fig. 1). A few years later, they launched a second project and began cultivating five different wetland species in a set of ponds at Sungei Buloh Wetland Reserve.

In parallel, Sim in collaboration with local research institutions, are examining the water quality improvement by wetland plants on floating mats. The dangling root systems of these plants can provide a home for microbes that help in water quality improvement and act as a natural filtration system by trapping organic matter suspended in the water. This pilot project, also being conducted at Kranji, is focused on the extent to which these floating wetland uptake nutrients from reservoir water during the dry season, when inflows may contain particularly high nutrient concentrations.

Findings from Kranji and Sungei Buloh have identified a subset of species that are particularly effective at nutrient removal,

due in part to their rapid growth and relatively large size. "The plants maintained at these pilot sites will also serve as both a habitat for biodiversity and a plant bank for other projects," says Sim.

The researchers will now couple these findings with data gathered from already completed ABC Waters projects, such as the floating wetlands at Sengkang in north-eastern Singapore (Fig. 2). "We have finalised a list of species with optimal nutrient removal for future wetland projects," says Sim. She notes that these efforts will prove a boon to both environmental advocates and nature-lovers in general.

## Researchers and affiliations

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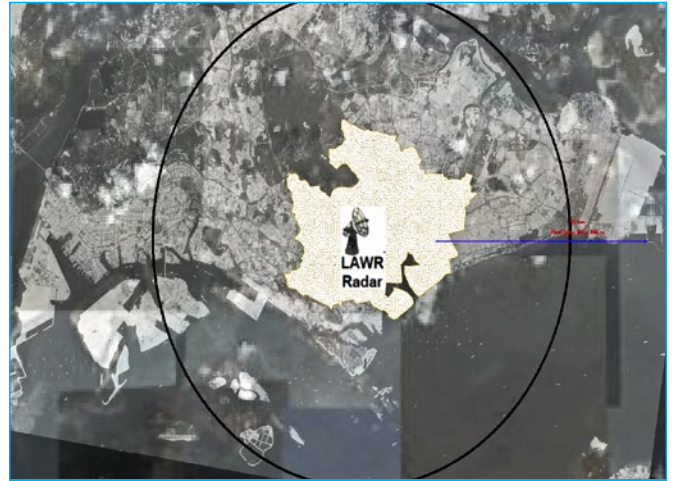
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# Keeping a closer watch on the weather

High-resolution, short-range weather radar systems may help Singapore stay a step ahead of potential flood risks



**Fig. 1:** A typical installation of the LAW system, which provides high-resolution radar scanning over a small geographic region |



**Fig. 2:** As a pilot project, a single LAW unit will be installed with the capacity to monitor flood risk within a 15-kilometre circle encompassing the Marina Barrage

Heavy rains in 2009 and 2010 saw Singapore experiencing some of its worst flooding in decades. The damage was relatively limited, but these incidents have motivated PUB Singapore to identify better mechanisms for tracking the effects of extreme weather and predicting flood risk in order to enable a more rapid and effective response.

Singapore currently performs comprehensive weather analysis with advanced radar systems put in place by the National Environment Agency. However, the current system does not have sufficient spatial and temporal resolution to track rapidly emerging crises such as urban flooding events. "PUB needs a system specifically geared towards hydrological analysis at the scale of catchments and sub-catchments, with sufficient lead time and reasonably accurate rainfall forecasts for their daily flood operations and management activity," says P. Suresh Babu, a researcher with the DHI Group, an environmental consulting agency.

Babu and DHI colleague Ole Larsen have partnered with experts at PUB Singapore to test an alternative system that employs a small-scale radar platform known as Local Area Weather Radar (LAWR). Standard radar generates images with pixels sized 1–2 kilometre square that refresh every five to 15 minutes, but LAWR provides far greater detail for short-range imaging, visualising rainfall patterns within a 60-kilometre radius at 100-metre resolution every one to five minutes. Larsen points out that LAWR already has a proven track record, and is a core component of equivalent weather management infrastructure in flood-prone El Salvador. "At present, 28 LAWR systems have been installed worldwide," he says.

As a pilot study, the researchers will install an LAWR system (Fig. 1) on the roof of the PUB Singapore headquarters, in the vicinity of the city. This represents a central site for flood risk management in the city. PUB Singapore has provided Babu and colleagues with essential data related to water management in this region so

that they can program the LAWR system to accurately recognise potential flood risks at this specific site (Fig. 2). "It may be desirable to have an 'online' flood modelling system that can integrate radar data, rainfall forecasting models and urban drainage networks," says Babu.

The current pilot project is slated to continue until November 2012, after which point the feasibility of implementing the technology will be examined. Larsen predicts that only three additional LAWR systems would be needed. "This [project] could be expanded to cover the whole of Singapore, with all of these systems integrated into a real-time flood prediction model," he says.

## Researchers and affiliations

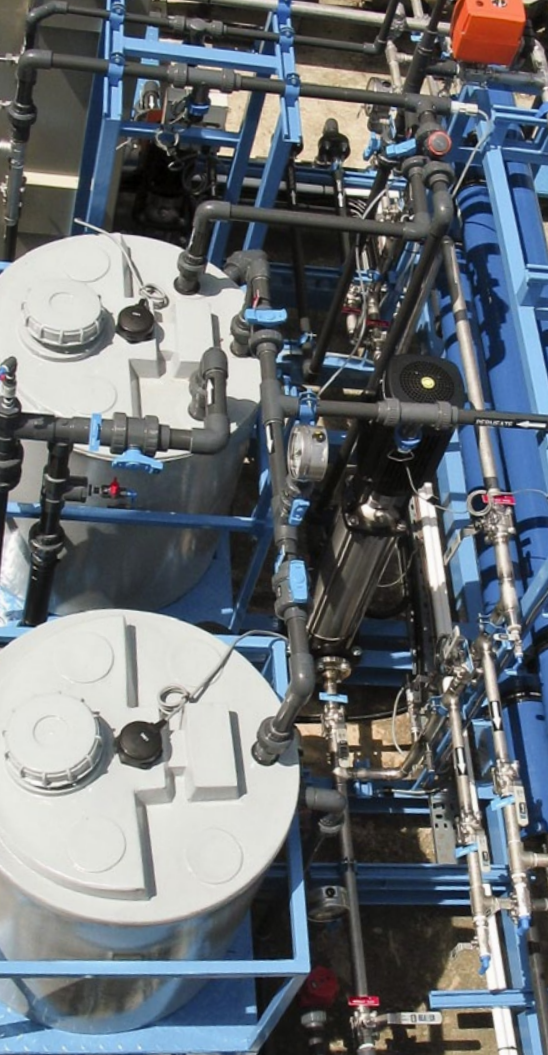
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# Membrane Technology

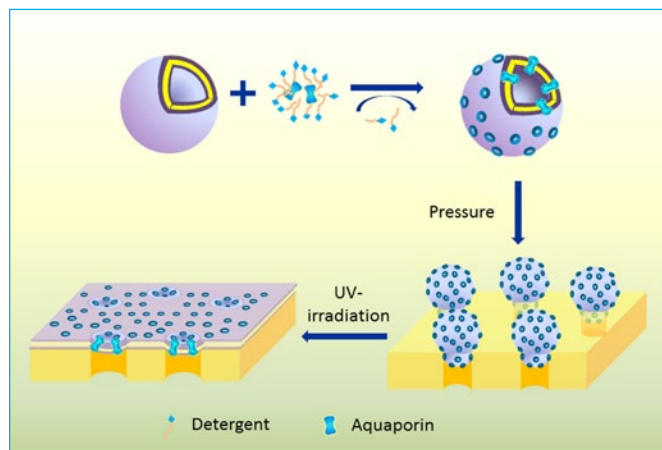
Membrane technology has played a vital role in the development of NEWater in Singapore. Dating back to 1974 when a demonstration plant was set up to study the feasibility of reclaiming used water using physico-chemical processes, the technology has since grown and developed, and is now a key pillar of Singapore's water strategy.

The NEWater demonstration plant, commissioned in May 2000, used microfiltration, reverse osmosis and ultraviolet disinfection to produce reclaimed water from secondary effluent. The quality of the reclaimed water—branded 'NEWater'—surpasses the drinking-water standards laid down by the US Environmental Protection Agency and the World Health Organization.

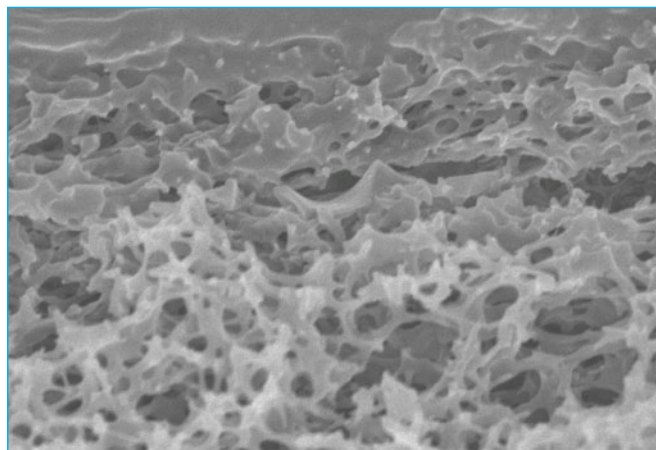
Backed by almost 40 years of experience, Singapore's water researchers continue to explore innovative ways of applying and optimising membrane processes for water treatment and used water treatment processes.

# Mimicking nature's water filters

A biomimetic desalination membrane promises to cut the energy cost of converting seawater into drinking water



**Fig. 1:** A three-step process creates a high-performance desalination membrane based on aquaporin proteins



**Fig. 2:** Electron microscopy reveals the surface structure of an aquaporin (AqpZ) membrane for water purification applications based on nanofiltration

As the global population grows, so does pressure on freshwater resources. Many countries — including Singapore — are therefore turning to seawater desalination to supplement their supplies. Today's desalination technologies are energy-hungry, so PUB Singapore is working with Neal Tai-Shung Chung, a membrane specialist, and his colleagues at the National University of Singapore to develop more energy-efficient alternatives.

Chung is pioneering an approach to harness a highly efficient water filtration system used by nature. Desalination typically involves either forcing or drawing seawater across a salt-rejecting membrane — a process similar to the one that our own cells use to control water levels. The body uses specialised water channel proteins called aquaporins to draw water through cell membranes. These proteins form selectively permeable pores in the cell membrane that allow water molecules to pass through while salts are left behind.

Chung and his colleagues have demonstrated how aquaporins can be successfully incorporated into a

high-performance desalination membrane. Aquaporins are fragile structures, prone to damage and loss of function when incorporated into a synthetic surface. The researchers therefore devised a three-step process to gently manoeuvre them into place (Fig. 1).

At step one, the researchers mixed aquaporin with small polymer spheres called amphiphilic block copolymer vesicles. The resultant material mimics the properties of a natural membrane, ensuring that the aquaporin assumes its natural shape once incorporated into the vesicle matrix. They then applied pressure to evenly dot these spheres onto a pore-filled support layer that was pre-coated with a light-reactive surface. Finally, using ultraviolet (UV) light, Chung and colleagues triggered a chemical reaction that drew the aquaporin-embedded vesicles onto the support-layer surface, converting the spheres into a uniform flat layer.

Critically, the aquaporins retain their activity, and the performance of the resulting membrane for a desalination process called forward osmosis (FO) is high, says Honglei Wang, a member

of Chung's team. "Compared to commercially available FO membrane[s], the biomimetic membrane shows an order-of-magnitude higher water flux with [a] remarkably high salt rejection of 99.8%." The team has also produced similar membranes for nano-filtration water purification applications (Fig. 2).

Having shown that functional aquaporin membranes can be made, Chung and his colleagues are now refining the process. "There are still several challenges," says Wang. The three-step process must be adapted for larger-scale production, and [the] thin aquaporin-polymer layer must be made more robust. "An FO process needs to be designed to enhance the long term stability of the membrane," she says.

## Researchers and affiliations

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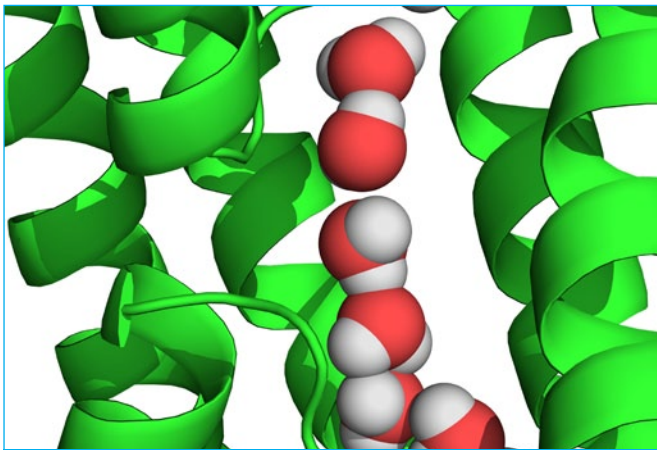
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# Maximising membrane strength

Strengthening next-generation membranes to help them survive the high-pressure desalination environment



**Fig. 1:** The aquaporin protein (green) is perfectly shaped for water molecules (red and white) to traverse



**Fig. 2:** A bioreactor generates aquaporins ready to be incorporated into a desalination membrane

Developing novel membranes that can cut the cost- and energy-demands of desalination is an ongoing challenge. Out-performing existing membranes in the laboratory, however, is only the first step in the process. With support from PUB Singapore, Chuyang Tang at Nanyang Technological University and his colleagues are researching ways to make high-performance membranes that are robust enough for real-world applications. They are using fabrication techniques that should be simple to scale up for full production.

The researchers are developing desalination membranes suitable for reverse osmosis (RO), a process in which salt water is forced at high pressure through a salt-rejecting membrane. Since RO is an energy-intensive way to generate potable water, they are developing membranes that allow the water to flow through more rapidly while still stopping the salt.

The researchers' membrane prototypes are based on aquaporins, the water-channel proteins that nature uses to selectively shuttle water in and out of cells with minimal resistance while

blocking salts (Fig. 1). Finding ways to incorporate the fairly delicate structures of aquaporins into the membrane without destroying their function was a challenge that has now been met, says Tony Fane, the principal investigator of the project. The team's most recent breakthrough is to ensure that the resulting membrane is robust enough to withstand the high water pressures required for RO.

"We invented a novel way of incorporating functional aquaporins in the active layer with excellent mechanical stability," explains Tang. "The trick was to design a scaffolding to support aquaporins properly."

Although the researchers are still optimising the membranes to maximise performance, the results with current prototypes are already impressive.

"At this moment, the biomimetic membranes developed in our lab are about 40% more permeable compared to commercial brackish water RO membranes, with similar or better salt rejection," Tang says. In saltier water, the performance gap is even better, he adds. "They are about an order of magnitude

more permeable than typical seawater RO membranes."

The team is now facing its greatest hurdle. "The biggest challenge for the technology to reach the market is scale up," Tang explains. "Instead of producing membranes with areas of a few hundred square centimetres, we are hoping to producing hundreds of square metres of membrane." He estimates that production scale-up will take one to two years. If they are successful, production at this scale will allow them to pack the membrane into standard modules, meaning that they can be used in existing desalination facilities.

## Researchers and affiliations

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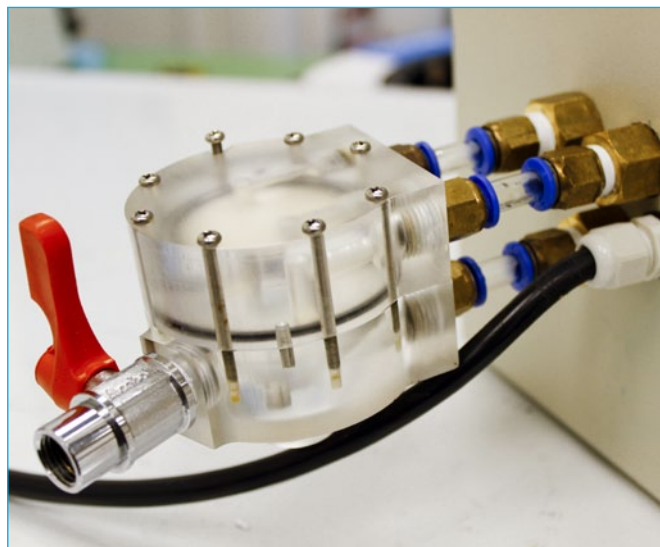
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# Gaining finer control of water treatment

Sensitive, real-time monitoring for ruptures in hollow-fibre-filtration membranes saves energy, money and resources



**Fig. 1:** Monitoring the integrity of filtration membranes used in water treatment is a key area of research at MINT



**Fig. 2:** The membrane integrity sensor developed by MINT

Engineers at the Singapore-based company called Membrane Instruments and Technology (MINT) have developed a sensitive, fast, and economical automated system to monitor the integrity of filtration membranes used in water treatment. The patented system (Figs 1 and 2), known as the Membrane Integrity Sensor (MIS), can rapidly detect and isolate membranes with small tears or holes in them, which may compromise operations.

Researchers at MINT tested and validated the MIS at two PUB Singapore facilities — the Bedok NEWater Factory and the Chestnut Avenue WaterWorks. They found that the MIS is sensitive enough to detect one broken fibre in a million. The MIS is also cheaper than current monitoring systems, such as particle counters or turbidity meters.

“It provides a real-time measure of the how the membrane is performing,” says Adrian Yeo, the project leader. “This is critical information that is hard to get when operating water plants.”

Micro- and ultra-filtration membranes can remove particles and microorganisms down to diameters of less than a micrometer. These membranes are used for water treatment, where they can eliminate high levels of microbial pathogens. They are also employed in water reclamation and desalination plants as a pre-treatment step, where their performance is critical to prevent fouling and maintain efficient operation of the system. Fouling can lead to increased energy use, higher maintenance costs and even shutdown and replacement of parts.

The working principle of the MIS is that it compares the resistance due to water flowing across an operated membrane to that of a reference resistance — a tuneable valve. These resistances are calculated from the difference in pressure on each side of the membrane and the valve, which are measured by highly sensitive pressure sensors within the MIS. A series of tests at both PUB Singapore plants showed that the MIS was far more

sensitive at detecting changes in membrane integrity than its competitors.

The developers estimate that the final cost of the MIS will be about US\$5,000, compared with US\$7,000 for a turbidity meter or US\$12,000 for a particle counter. As such, more units can be installed for the same cost, allowing faster detection of faulty membranes. Furthermore, since the overall increase in sensitivity, speed and reliability of detecting membrane tears reduce the potential level of any resulting contamination, lower levels of chlorination are needed.

“We are now creating a sensor that will be able to predict what will happen in a membrane-based water treatment plant, as opposed to just monitoring it,” Yeo says.

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# Network Management

Singapore's water strategy focuses on the management of water resources in an integrated manner across all points of the water loop. In the field of network management, a key aim of water research and development in Singapore is to ensure the delivery of high-quality water from the waterworks to consumers while ensuring the collection and reclamation of used water in an effective and efficient manner.

The management and maintenance of Singapore's water networks is therefore a critical function, as well as a responsibility that spurs Singapore's water researchers to even greater technological innovation.

# Getting smarter about residential water

‘Smart’ meters that provide consumers with detailed information on their water usage hold promise for targeted conservation efforts

Water bills, simply stating the amount owed, are a familiar sight to most households. But in the near future, these statements could also point to the culprits of high water usage, such as an inefficient washing machine or an over-enthusiastic shower taker. A pilot project now underway at PUB Singapore is putting this approach into action through a ‘Smart Water Meter’ system designed to analyse residential water-flow data and present it using interactive applications for display units or smartphones.

Understanding the factors behind daily water use could be a powerful motivator for residents to reduce water usage and save money. However, attaching measuring instruments to every single household water appliance is impractical and inconvenient. Researchers at PUB Singapore therefore teamed up with iWOW Connections and its partners, Telematics Wireless and Aquacraft, to develop a wireless interface unit that attaches to a single automated meter (Fig. 1). This device logs water flow rates at high frequencies,

and then uses a sophisticated software algorithm called ‘Trace Wizard, to compartmentalise this data into various consumption categories, such as kitchen faucets, toilet flushing, clothes washing, and leaks (Fig. 2).

In Phase 1 of the pilot study, a team led by Wai Cheng Wong tested the flow analysis concept in 20 Singapore households. At the volunteers’ homes, they installed the ‘Automated Meter Reading’ (AMR) devices that contain high-accuracy water-movement sensors. Then, they connected a battery-powered meter interfacing unit to each AMR to record the flow data at ten-second intervals. Finally, at weekly intervals, the researchers downloaded this information for scrutiny with the Trace Wizard smart meter software.

Analysis of the Phase 1 data is ongoing, and a database containing Singapore household water usage information is under construction. If this system successfully generates useful and detailed measurements about the individual’s water usage, Phase 2 of the Smart Water

Meter system will commence in the near future. This phase will use advanced wireless technology to monitor a larger enrolment of volunteer dwellings.

Information portals that enable customers to view their water-usage statistics at their fingertips form a key part of the researchers’ strategy. Interactive features — such as timely reminders about overlong showers — could make saving water as easy as tapping a touch screen. “We hope that by enabling customers with more meaningful information, they can make informed choices and undergo behavioural changes toward water conservation,” says Wong.

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Fig. 1: An automated water meter that monitors residential water use in Singapore

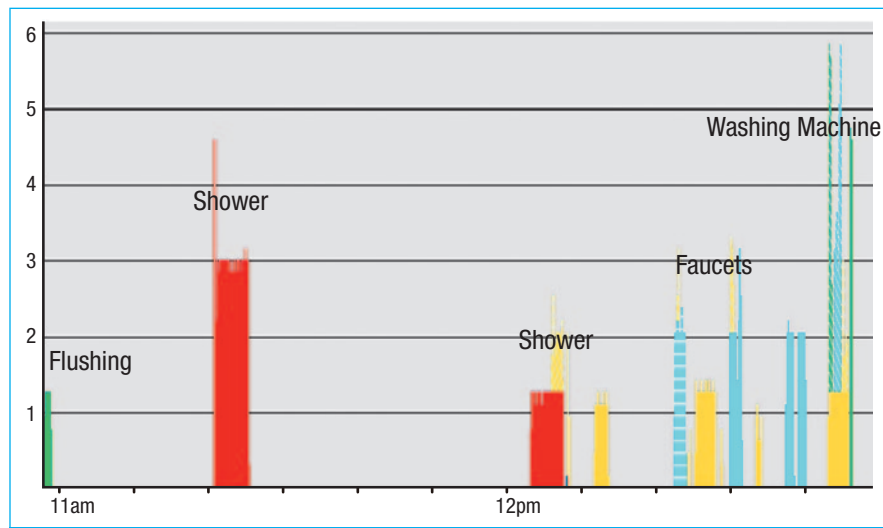


Fig. 2: A display of water use generated by the Trace Wizard software over a two-hour period

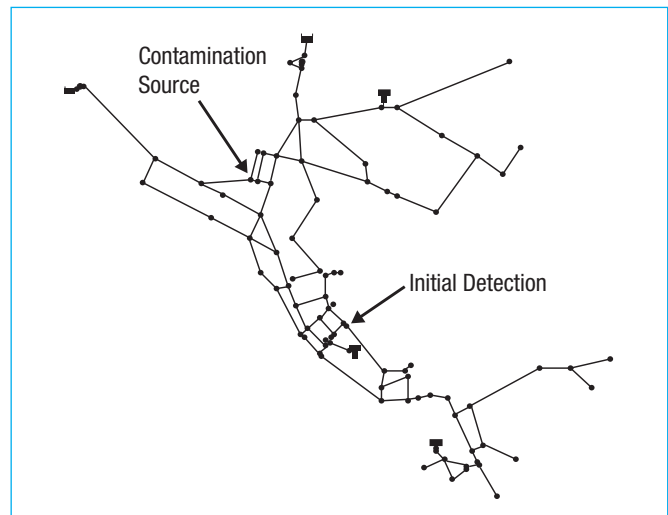


# Keeping a watchful eye on water quality

Sensor software alerts operators at the first sign of a contaminant in Singapore's water distribution network



**Fig. 1:** Officers at PUB use the Canary system to monitor water quality



**Fig. 2:** Municipal water supply networks are large and complex, adding to the challenge of pinpointing the source of a contamination event

Suppliers go to great lengths to keep drinking water safe and secure (Fig. 1), but contamination accidents can and do happen. PUB Singapore uses a sophisticated early warning system to detect chemical or biological contaminants in its water supply. The system is powered by software developed by Sean McKenna and his colleagues at the Sandia National Laboratories in New Mexico, USA. Singapore is currently at the forefront of efforts to deploy the latest improvements to the Sandia software.

Hardware is typically the foundation of a contaminant warning system: the sensors distributed throughout the network to monitor various water quality parameters, such as salinity and chlorine levels. This torrent of data is of little use, however, without interpretation by a software-based 'event detection system' (EDS), McKenna explains. "It is the EDS that makes sense of the raw data coming from the water-quality sensors and determines when a water-quality event occurs," he says.

Sandia's own EDS is called Canary. As part of their recent research, McKenna and his colleagues developed new algorithms to cut the number of false-positive alerts that Canary generates. Genuine contamination events are rare, but water-quality parameters constantly fluctuate slightly, such as when valves in the system are opened and closed through everyday operation of the network (Fig. 2). The researchers found that by adapting Canary to monitor sensor data changes over time, rather than treating each sensor reading as a single data point, patterns emerge that Canary can recognise as regular network operations. Using this mechanism, the team was able to reduce false-positive alerts by 91% without affecting the detection of genuine contamination events.

If a real contamination event occurs, swift action is essential. To this end, the Sandia team, working with researchers at Texas A&M University, recently developed a process called real-time inversion to efficiently pinpoint the source of

a contaminant. Water-quality data, sourced from grab samples collected by water engineers around the network, is 'inverted' by the program to generate a list of possible contaminant entry points to the system. By repeating the process with new sample data taken at different points in the network, operators can use the program to whittle down the list until they identify a single source.

Over the next 12 months, PUB and Sandia will be testing the tracking program to identify contaminant sources and adapt their process to be able to handle multiple concurrent contamination events.

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# Probing the Deep Tunnel Sewerage System

A robotic inspection system that helps to keep a close eye on Singapore’s central used-water collection system



**Fig. 1:** The six-meter Deep Tunnel Sewerage System where the RMSI is employed for inspection

Beneath Singapore, a 48-kilometer tunnel stretches from Kranji to Changi, collecting used water from the municipal sewerage system and delivering it for treatment and water reclamation at the Changi Water Reclamation Plant. This structure represents Phase I of the Deep Tunnel Sewerage System (DTSS), a multi-billion dollar initiative by PUB Singapore to

streamline the nation’s used water management processes (Fig. 1).

Monitoring the operating condition of the DTSS is a monumental and ongoing challenge. “In addition to structural issues such as corrosion protection and lining integrity, sediment accumulation, depth and volume within the DTSS are other areas of concern,” explains Alvin Leong, an engineer at PUB Singapore. The tunnel system at up to 55m deep with high flows can be dangerous for human inspectors, and so Leong and his colleague Eric Liau have turned to robotics as an alternative.

They selected the Redzone Robotics Multi-Sensor Inspection (RMSI) system (Fig. 2), a heavy-duty platform that can effectively manoeuvre both on land (via tank-like tracks) and on water (using a flotation platform). “RMSI was used previously in inspections for PUB’s trunk sewers, where the robot collected quantitative data from more than 50 kilometres of these large diameter sewers,” says Leong.

The PUB team made numerous refinements to better prepare the RMSI

to handle the various conditions within the DTSS. For example, they added additional weights at strategic locations to stabilise the robot amidst heavy water flow, and adjusted the positioning of the camera so that it would consistently remain above-water.

After some preliminary testing, the RMSI was able to perform its data collection tasks while travelling downstream for more than one kilometre. This maximum operating distance was limited only by the length of the tether connecting the robot to its control centre.

These results support further development of RMSI as a tool for facilitating DTSS inspection.



**Fig. 2:** Modified Raft Inspection Platform is used for inspection when the water level in DTSS is high

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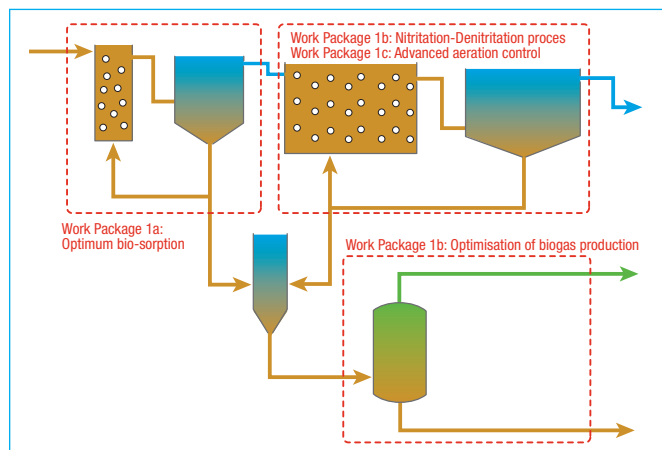
# Used Water Treatment

Singapore's research and development in used water treatment focuses on closing the water loop to short-circuit the water cycle. Instead of discharging treated used water into the sea and relying on the natural hydrologic cycle of evaporation, cloud formation and rainfall to recycle the water, Singapore's water scientists intervene to close the water loop by reclaiming used water and distributing it for large-scale non-potable use by industry as well as indirect potable use.

To do this, Singapore's water scientists work to develop innovative, cost-effective and efficient processes using innovative technologies for sludge minimisation, biogas utilisation and odour destruction that can achieve high effluent standards.

# Putting the power of used water to work

Used water treatment plants could become energy self-sufficient by simple conceptual changes to plant layout which are being tested in Singapore



**Fig. 1:** Schematic of the Energy+ concept. Organic matter and nutrients are removed from the water through biosorption and a nitritation–denitritation cycle, and excess sludge used to produce biogas for power generation.



**Fig. 2:** The 50 m<sup>3</sup>/d pilot plant installed at the Kranji Water Reclamation Plant

Electricity demand of used water treatment constitutes up to 2% of total worldwide consumption. Increasing the energy efficiency of used water treatment plants is required to reduce this electricity demand; and harnessing the energy inherent within the water itself is one way to achieve this reduction.

Martin Andersen of the DHI-NTU Water and Environment Research Centre, Singapore, in collaboration with scientists at Singapore's Nanyang Technological University, and Suez Environnement, France, have developed Energy+, a new design for used water treatment plants capable of generating power from the biological matter present in the water.

“Used water actually contains large amounts of energy — mainly bound in organic matter,” explains Andersen. “The conventional approach is to use external energy to remove the organic matter. Instead, we want to capture the energy from the used water and utilise it.”

The Energy+ concept comprises a two-stage process (Fig. 1). Firstly, organic matter is removed from the water using

only small amounts of external energy. Then, a purification step ensures that discharge limitations are met under low power consumption. The concept secures an increase in biogas production that is then burned in a generator to run the plant.

“The key to the energy balance is in the first biosorption stage of the plant, where small particles are captured by adsorption in an activated sludge system,” explains Andersen. “Here approximately 60% of the organic loading to the plant can be removed.” This energy-rich sludge is then processed by anaerobic digesters, producing significant amounts of biogas.

The researchers have built a pilot-scale plant at PUB Singapore's Kranji Water Reclamation Plant (Fig. 2) to test the Energy+ concept. New sensor technology optimises process operations such that the energy consumption is minimised while outputs, such as energy from biogas and outgoing water quality, are maximised. The sensors also monitor levels of nitrous oxide, a by-product of the process that could escape from the plant.

“Nitrous oxide — also known as laughing gas — is a potent greenhouse gas,” Andersen notes. “Monitoring and controlling it is crucial as we do not want to substitute energy savings with the release of a greenhouse gas stronger than CO<sub>2</sub>.”

The goal of the research team is for the pilot plant to demonstrate energy self-sufficiency by 2012. “When it comes to full-scale operations, we hope to integrate an intelligent system that analyses the large amount of sensor data,” Andersen says. “This system would automatically adjust operations in order to meet water quality discharge requirements at the lowest possible [level of] energy consumption.”

## Researchers and affiliations

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# Extracting energy from unlikely places

An alternative processing step can turn used water treatment plants into eco-power stations



**Fig. 1:** Sludge from used water can be converted to fuel using micro-organisms



**Fig. 2:** The sludge biodigestion pilot plant

Researchers in Singapore are showing that used water should be considered an energy-rich resource. By adjusting the conditions under which used water sludge is processed, significant amounts of methane-rich biogas can be generated and used as fuel. Leading the research to maximise methane production is Ng Wun Jern and his colleagues at Nanyang Technological University, Keppel Seghers, an international environmental engineering company, and PUB Singapore.

Sludge is the semi-solid material remaining after used water treatment. Typically, sludge is either incinerated or sent to the landfill, but neither option is particularly attractive, says Ng. “Incineration has an energy cost, while land filling in Singapore cannot be a long-term solution since we are land constrained,” he says.

An alternative is to use micro-organisms to break down, or ‘biodigest’, the sludge (Fig. 1). This process not only reduces the volume of sludge requiring disposal, but the biogas it generates can supply energy for processing the

remaining sludge. “It may even have uses beyond that,” Ng notes. This form of sludge digestion is already used in Singapore and currently generates enough biogas to provide a quarter of the energy consumed by the country’s used water treatment plants. However, as energy prices are rising, the aim is to have these plants generate 80% of their own energy by 2030.

Ng and his team are working to improve sludge biodigestion by separating it into two distinct phases, since the phases have different optimal conditions that can be fine-tuned. Phase one involves using a suite of micro-organisms in the initial breakdown of the organic matter in sludge. The second phase involves using different microbes to gradually convert the breakdown products to biogas. The team’s early efforts at phase separation have already increased biogas production by 7% (Fig. 2).

“Preliminary results suggest that the phase-separated system performed better than the state-of-the-art, single-stage digestion process, and there are

indications the phase-separated system can be modified for possibly even better performance,” says Ng. Adding a third phase is one possible option, he adds.

Investigating how pre-treating the sludge prior to biodigestion will improve biogas production further is the team’s next step. Ng suspects that the overall rate-limiting step in the process is the initial breakdown of organic matter in the sludge. By pre-treating the sludge with blasts of ultrasound, the team hopes to kick-start the whole breakdown process — by breaking up the sludge before the micro-organisms get to work. This pre-treatment may also accelerate the process, and ultimately generate more methane.

## Researchers and affiliations

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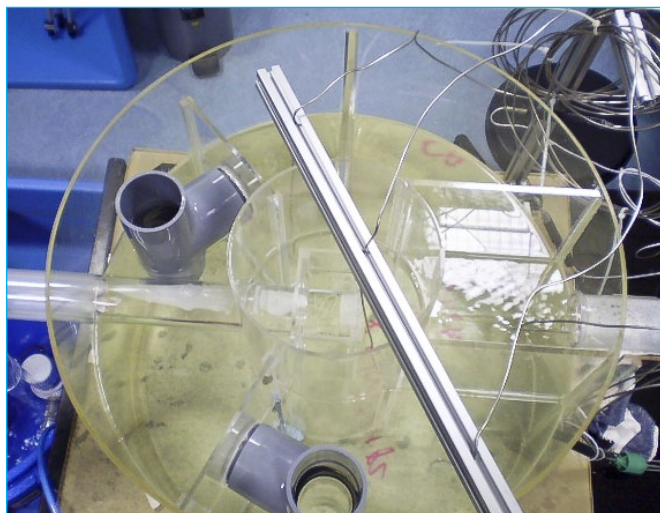
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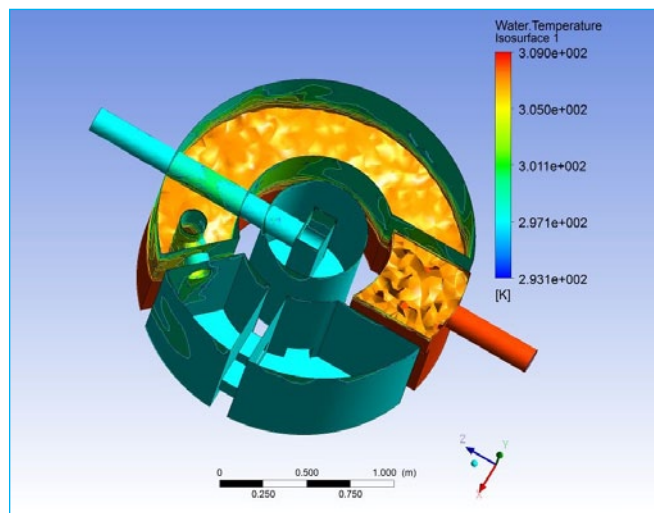
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# Computer modelling of grease traps

Using computer model simulations to study grease trap design and performance



**Fig. 1:** A small-scale prototype of a grease trap



**Fig. 2:** Modelling results showing the movement of the temperature interface over time within a grease trap

In Singapore and many other countries, eating establishments that produce liquid waste containing fat, oil and grease must install grease traps to pre-treat the culinary used water before discharging it into sewers. This is because fat, oil and grease (FOG) often cause blockages in private and public sewers, obstructing the smooth flow of used water. It is therefore important to remove FOG from used water at the first opportunity. Under the Sewerage and Drainage (Trade Effluent) Regulations, eating establishments must ensure that the trade effluent discharged into a public sewer does not contain grease and oil (non-hydrocarbon) at concentrations exceeding 100 mg/L.

Grease traps are designed to keep used water inside them for long enough to allow the oil and grease to float to the top and be separated. Different eating establishments produce varying levels of oil and grease loadings in their culinary water — those with higher loadings may require frequent clearing in order to comply with stipulated discharge limits.

Lack of regular maintenance is a key contributing factor that adversely affects the performance of a grease trap.

Using computer models alongside a small-scale (Fig. 1) prototype, Khee Yang Ng from Singapore Polytechnic studied fixtures that could be installed to improve the grease trap's performance and reduce the cleaning frequency of the grease trap. Multi-component flow analysis was adopted in the simulation to simulate the free surface flow coupled with convective and diffusive heat transfer. The computational fluid dynamics model of the grease trap was calibrated using measurements from the small-scale prototype. Fixture designs such as the addition of baffle plates with T-section at different locations were then simulated and the results were compared with the typical design to assess the effectiveness of the modifications. Baffle plates with T-section were observed in the model simulations to lengthen the flow path of water and provide a non-turbulent environment that facilitates efficient separation.

“We simulated retrofitting of existing grease traps with fixtures at various angles within each grease trap,” says Ng. “The installation of the fixture achieved a better performance as indicated by the delay of temperature rise at the inner core of a grease trap.” This would translate into better oil and grease capture by the grease trap.

As part of the same study, probe systems within grease traps that are able to send text messages to operators for attention were also designed. “When a preset oil and grease depth is reached, a signal triggers an alarm with a GSM message system that sends an SMS to alert the grease trap operator,” explains Ng.

## Researchers and affiliations

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# Water Quality and Security

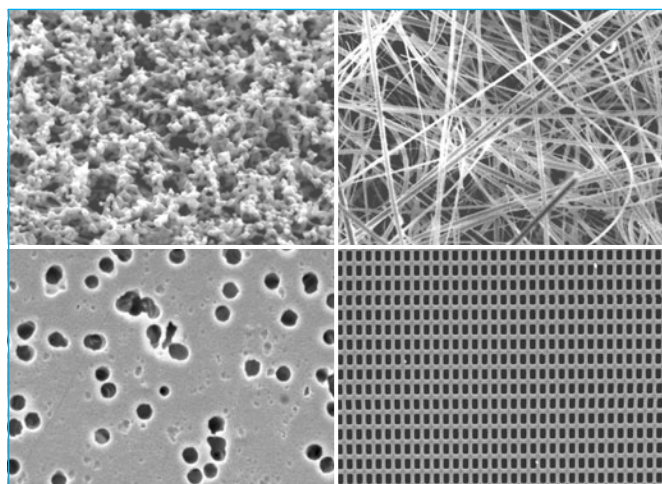


As in any country, the quality and security of water supply is of utmost importance. In order to deal with sources of contamination, Singapore's water scientists constantly strive to improve water quality sampling methodologies through continual innovation in biological and chemical detection methods with one goal in mind: to achieve better, safer and more secure water for the nation's needs.

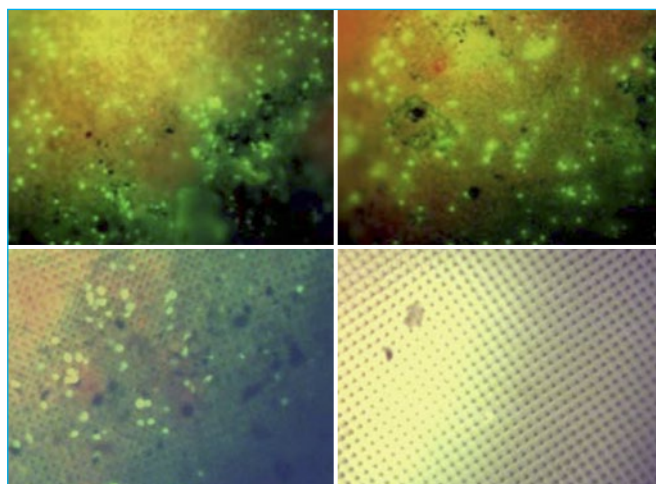


# Capturing pathogens in a tailor-made trap

A carefully fabricated filter is the key to enhancing the sensitivity of water monitoring devices



**Fig. 1:** Electron microscope images show that the microfabricated filter (bottom right) has a more regular and even pore pattern than typical commercial filters (top left, top right, bottom left)



**Fig. 2:** Fluorescence microscopy reveals that captured pathogens are much harder to wash out for analysis from a commercial filter (top row, before (left) and after (right) back-flushing) than a microfabricated one (bottom row, before (left) and after (right) back-flushing)

Microscopic pathogens lurking in potable water supplies must be trapped and identified so that appropriate management steps can be implemented. To detect such contaminants efficiently, Thomas Haiqing Gong at the Nanyang Technological University and his colleagues, in collaboration with PUB Singapore, are developing a lab-in-a-box water monitoring technology. They have designed their autonomous, field-deployable device to be much more sensitive at detecting pathogens than the current technology.

By passing large quantities of water through a pathogen-trapping filter, Gong and his team's water sampling device concentrates any pathogens present in the sample. Once filtration is complete, the pathogens can be washed out of the filter and into a detector for identification. Since conventional filters are prone to clog up with non-pathogenic material suspended in the water, their utility is limited. The researchers therefore

developed a carefully designed, and precisely micro-fabricated, alternative.

Whereas conventional filters have pores with a broad range of sizes, the micro-fabricated material has evenly spaced and uniform pore sizes, tailored exactly to capture any waterborne pathogens (Fig. 1). This approach means that the filter is much less likely to clog up, and it allows the captured pathogens to be released more efficiently for analysis.

"To achieve the mono-pore size for all the pores on the membrane, we used a process that is used in semiconductor industry," Gong explains. The researchers used a technique called photolithography, using specifically aimed UV light to etch an even pattern across a template, which they then used to stamp additional filters.

Gong and his colleagues assessed the performance of their technology using a filter tailored to trap cryptosporidium oocysts. These organisms are particularly dangerous to water supplies because they survive many chemical water treatment

processes, such as chlorination. The researchers found that their filter was able to handle sample water flows up to ten times that of the clog-prone commercial filters, meaning that a much larger volume of water can be sifted for pathogens. They could then flush out up to 95% of the captured pathogens for analysis, much higher than the 30–50% pathogen recovery of conventional filters (Fig. 2).

"Our next step is to develop a mass production process to make the membrane in large quantity," says Gong. The team is aiming to incorporate the filter into disposable microfluidic cards that can be simply slotted in and out of their portable, self-contained water sampling device.

## Researchers and affiliations

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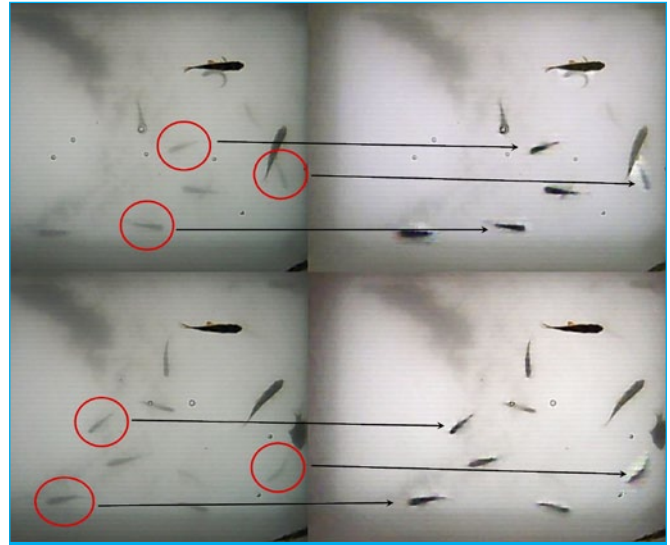


# Fish sentinels of Singapore's water supply

An automated system that monitors fish for unusual behaviour alerts operators if there are changes in water quality



**Fig. 1:** Researchers install a Fish Activity Monitoring System (FAMS) to monitor raw water quality at the Johor River Waterworks



**Fig. 2:** Video enhancement software improves image quality (right) to ensure that fish monitoring is possible in cloudy water

A tank full of fish can make an excellent early warning system for contaminants in the water supply, researchers in Singapore have shown. Like the canaries once carried by miners to warn of dangerous gases in coal mines, fish change their behaviour at the first sign of chemical or biological contamination in water being passed through their tank. By carefully observing the fish, contaminants can quickly be detected.

PUB Singapore exploits this fish behaviour using the Fish Activity Monitoring System (FAMS), a device that combines video cameras with image analysis software to automate the fish-monitoring process. FAMS is now being further developed by Kok Eng Liaw, CEO of ZWEEC Analytics, Singapore, How Lung Eng, a scientist at Singapore's A\*STAR Institute for Infocomm Research, and their colleagues.

"FAMS is a first line of defence, an early warning detection system," Liaw explains. "The moment the fish start to deviate from normal behaviour, the software can

recognise that, and give an early warning." As the fish become sicker, the level of alert escalates. The software can track up to 20 individual fish in a tank, and if they start to die, it will alert the operator to respond accordingly—shutting off the water supply, if necessary.

Liaw and Eng have developed the technology into a stand-alone unit that can operate in remote places and send data to operators in a centralised control centre. PUB Singapore already has 35 FAMS units in place to monitor treated water supplies, and the researchers are now pilot-testing a device that can monitor raw water supplies. This system will allow operators to detect contamination events even before the water enters the water treatment plant (Fig. 1).

The cloudiness of raw water, however, makes it more challenging to use the video technology. As a workaround, the researchers developed low-maintenance filters to remove some particles from the water before it enters the fish tank. They

have also enhanced the video analytics software to handle water with much higher levels of suspended solids (Fig. 2). Roll-out of the enhanced FAMS for raw water monitoring in Singapore is due to begin in 2013.

"We are already moving into the next phase of R&D for the next-generation system," Liaw adds. The researchers have been assessing whether specific contaminants trigger particular, recognizable behaviours from the fish. The early results look promising, Liaw says. "We are looking to identify around 10 of the most common contaminants through the behaviour of the fish."

## Researchers and affiliations

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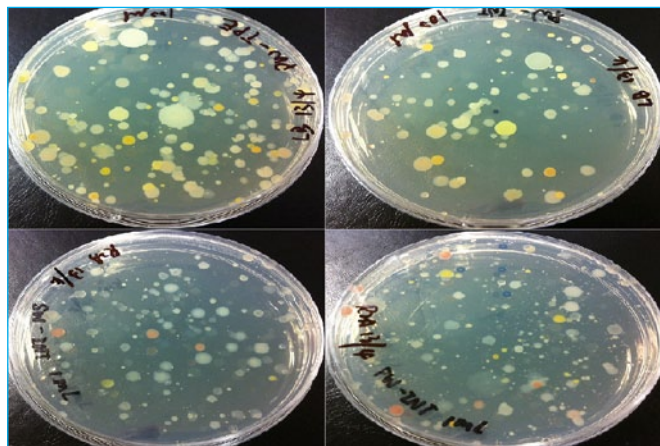
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# Rapidly identifying water-borne pathogens

Using DNA sequencing to identify microbes in drinking water proves quicker and more accurate than traditional culture-based tests



**Fig. 1:** Identification of bacteria, viruses and other waterborne microbes in drinking water is a crucial part of water management, particularly in vastly urban areas such as in Singapore



**Fig. 2:** Colonies isolated from reservoir water and sediment samples

The rapid and accurate identification of bacteria, viruses and other disease-causing microbes in drinking water is vitally important for public health. Traditional testing involves the use of cultures, a time-consuming and, at times, erroneous method of microbial detection. Viruses and bacteria continuously mutate and produce new forms. They also adopt slightly different structures in different environments, so getting accurate results from culture tests is often difficult. Scientists are therefore searching for better methods to identify dangerous microbes in drinking water.

H. B. Zhang and colleagues at PUB Singapore recently developed a new technique for analysing and identifying waterborne microbes using DNA-sequencing. They successfully tested their method in analysing water samples (Fig. 1), collected from six different reservoirs in Singapore.

“Many microbes are now emerging as potential health concerns in terms of drinking water quality,” explains Zhang. “However, traditional methods are unable

to accurately differentiate them. DNA sequencing technology has progressed tremendously, offering an accurate way of identifying pathogens of interest and thus enhancing our capabilities in water-quality monitoring.”

The same species of virus or bacteria can differ slightly in its molecular structure according to the levels of nutrients and oxygen present in the water supply. As a result, samples collected from the same reservoir at different depths contain a multitude of microbes, each subtly different from the next. Singapore, with its vast network of reservoirs, therefore poses a challenge for the scientists responsible for identifying waterborne pathogens.

Zhang and his team began by painstakingly extracting DNA from thousands of water and sediment samples from the six reservoirs. They then amplified and cloned the DNA using polymerase chain reaction (PCR) technology (Fig. 2). At the same time, the team conducted traditional culture-based tests for comparison. They found that the DNA sequencing added significant variations

in terms of numbers and strain diversity within the microbes.

“We have been able to differentiate harmful strains within the same species based on the DNA sequences,” explains Zhang. “In addition, the new method can be integrated into our routine methods in pathogen detection and greatly enhance overall accuracy.”

The only drawback of the new method is the use of large quantities of sequencing reagents during analysis of numerous samples, which can be costly. Zhang hopes that the new technique will be used primarily to support PUB Singapore’s operational departments. “For example, in the case of customer complaints of diarrheal cases, this method could accurately verify if there is any harmful pathogen present in drinking water,” he says.

## Researchers and affiliations

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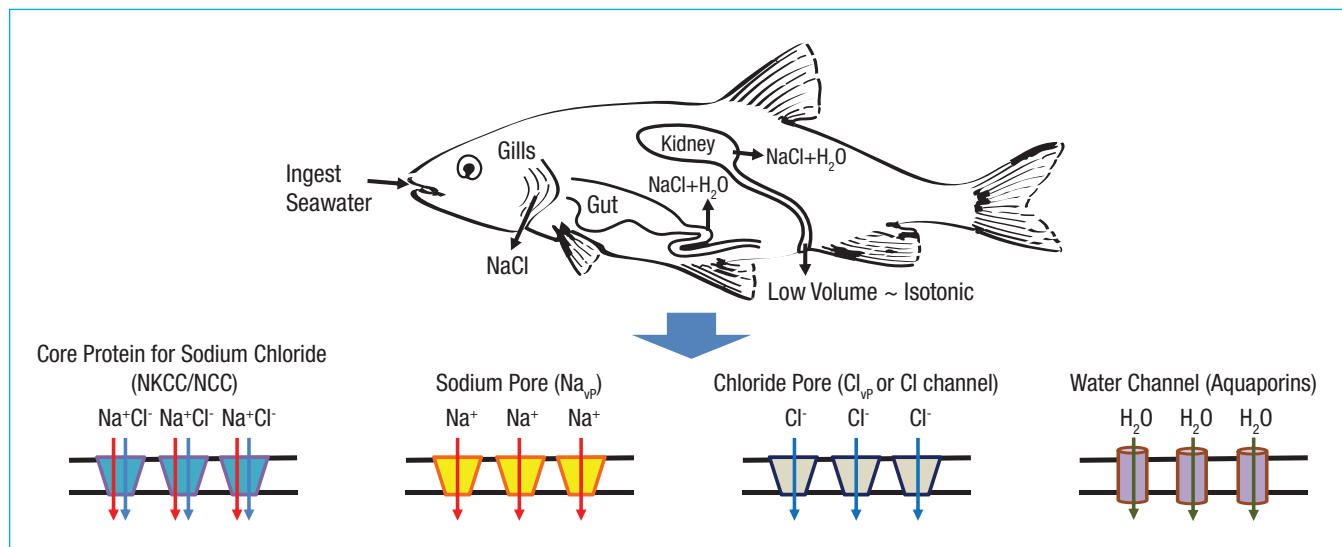
# Water Treatment

For an island nation like Singapore, the development of innovative technologies to optimise water treatment processes for the production of drinking water from seawater is a key element of its water research programme.

However, desalination is a high energy demand process and energy cost is the biggest impediment to viable commercial development. Singapore carries out innovative research and development aimed at reducing energy consumption for step-wise desalination and finding alternatives to reverse osmosis technology that can further reduce energy requirements. For this, we draw inspiration from natural systems such as the human kidney and systems that allow marine plants and fish to survive in high-salinity environments.

# Fish reveal their desalination secrets

Understanding how certain fish process salt water could inspire new ways to turn seawater into drinking water



**Fig. 1:** Several forms of ion and water channel proteins (bottom row) found in euryhaline fish could inspire membranes to remove salt from seawater in desalination plants

An adaptable group of fish species that can happily swim between seawater and freshwater environments could provide the blueprint for the next generation of water desalination systems. Siew Hong Lam and his colleagues at the National University of Singapore, with financial support from the Singapore Environment and Water Industry Programme Office (EWI), are studying the mechanisms by which these ‘euryhaline’ fish deal with the dramatic swings in salinity that they experience. The researchers hope that their work will lead to the development of new biomaterials that mimic these processes.

In particular, the researchers are studying the mechanisms that euryhaline fish use when swimming into seawater from fresh water. As the fish switch to ingesting seawater, they activate processes to selectively uptake salt and water in the gut. Then they secrete the excess salt via their gills, while retaining the water within their body.

Industrial water desalination would greatly benefit from the development of a method to similarly process the salt and water in seawater separately. Lam and his colleagues are therefore looking for the protein-based pores in the fishes’ cell membranes that they use for this process (Fig. 1).

As a first step, the team established a water recirculating system in the laboratory that was capable of challenging the fish with salt water up to double the typical salinity of seawater. Using RNA sequencing, they then compared the gene expression profile of euryhaline fish being kept in these high-salt conditions with individuals being kept in freshwater tanks. The comparisons allowed the team to identify which genes encode proteins that are likely to be involved in facilitating salt and water movements in the gut and gills.

Several promising candidates have already come to light. “We have identified and cloned several genes encoding the protein components that are involved

in facilitating ion and water movements across the cell membrane,” Lam says. “We are still in the process of cloning several others.” The next step will be to express and purify the proteins that these genes encode. This will allow the researchers to study their structure, understand how they work and test their potential as biomaterials for novel synthetic desalination membranes.

The researchers are also studying how these proteins are arranged within the unique architecture of the fishes’ guts and gills. Their aim is to gather more general structural and functional insights that might also inspire efficiency gains in industrial desalination plants.

### Researchers and affiliations

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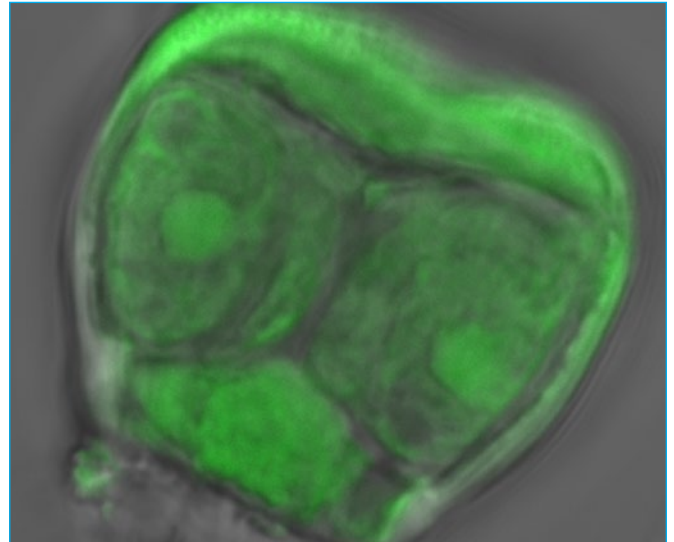


# An 'all-natural' approach to desalination

Future desalination systems may gain efficiency from lessons learned from living plants that naturally process seawater



**Fig. 1:** Salt crystals accumulate on the leaf surfaces of mangrove plants with salt glands



**Fig. 2:** Microscopic image of a salt gland isolated from the leaves of an *Avicennia* mangrove plant

For a densely populated island nation such as Singapore, desalination technology would appear to be an ideal solution for ensuring that its citizens have uninterrupted access to fresh water. Unfortunately, conventional methods for generating fresh water from salt water, which typically entail large-scale distillation or filtration through specially designed membranes, come at a cost. "Existing technologies are energy intensive," explains Chiang Shiong Loh of the National University of Singapore (NUS), "and these facilities may also face problems such as membrane fouling."

Seeking an alternative, Loh has teamed up with NUS colleagues Prakash Kumar, Lin Qingsong and Lim Tit Meng to investigate whether nature can provide some answers. Loh and team were especially interested in plants that manage to thrive in mangrove forests, which are situated near the coast and fed by water from the sea. "The observation of salt crystals on the leaf surfaces of some mangrove plants (Fig. 1) inspired us to investigate

the mechanism of salt secretion by salt glands," says Loh.

Many mangrove plants employ such specialised, microscopic salt glands situated at the surfaces of their leaves, which extract the remaining salt from water that has been taken up by the plants after an initial round of filtration at the root level. However, scientists know remarkably little about how these glands actually function or the specific proteins that participate in the salt removal process.

Loh and colleagues have thus embarked on a project to characterise this mechanism in depth, using salt glands isolated from plants belonging to the mangrove genus *Avicennia*. The team has established a standard protocol for extracting hundreds of glands within a few hours' time, enabling them to perform microscopic analysis of the structure of the intact salt gland (Fig. 2).

To understand the secretion process, however, the team will have to dig far deeper, and plans are underway to begin

a detailed molecular and physiological analysis of gland function. In particular, Loh and team are keen to examine gland-specific membrane proteins, which are positioned at the boundary between the leaf interior and the exterior environment. This makes the proteins obvious candidates for involvement in the secretion process.

This study has only begun, and the goal of low-cost, biologically inspired desalination remains at the horizon for the time being, but Loh is hopeful that steady progress will be made in the months ahead. "We anticipate being able to publish some of our findings in another year or so," he says.

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# Virtual waterworks for real improvements

A detailed computer model of water treatment processes is helping engineers optimise the performance of PUB Singapore's facilities



Fig. 1: A section of the Johor River Waterworks

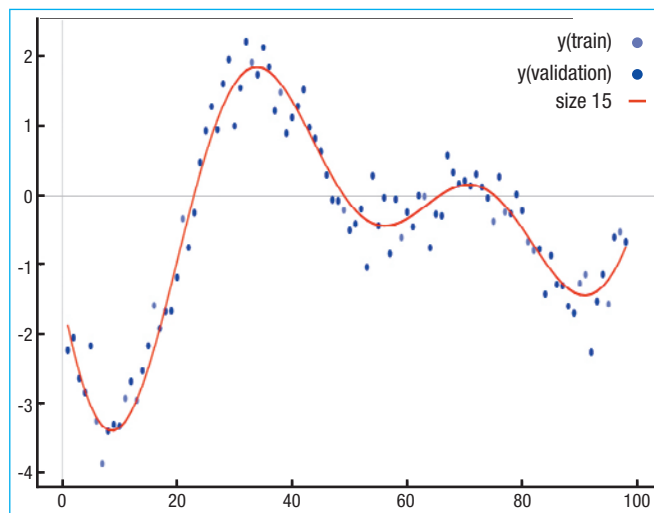


Fig. 2: Development of empirical water quality relationships

Good engineers are constantly adjusting their designs or operating procedures to improve the performance, cost efficiency and safety of their equipment. The staff at PUB Singapore's many waterworks facilities are no exception; they are also committed to assessing the effects of proposed changes to their working practices before implementation.

Water treatment plants consist of complex networks of machinery that operate around the clock to serve the public, so it is difficult or impossible for engineers to perform tests on the real equipment. Instead, computer simulations can provide valuable insight into how the system will perform under new circumstances.

PUB Singapore is working with engineering company CH2M HILL to develop an advanced computer model of water treatment processes at the Johor River Waterworks (Fig. 1). The model is being developed using software called Replica, a dynamic simulation tool that was first created by CH2M HILL in 2001.

"Replica is unique in that it can dynamically simulate hydraulics, control

strategies and water quality functionality simultaneously in the same model," says Jared Thorpe, who is leading the work at CH2M HILL. "It provides a 'flight simulator-like' environment for operator training, and has also been used to optimise energy consumption, chemical usage and operating performance."

The model simulates many complex processes including water intake, water screening, pumping and chemical dosing. To do this, it includes the physics of all the separate components in the system, such as pipes, pumps, valves and tanks (Fig. 2).

Most importantly, the researchers have collected large amounts of historical operational data from the waterworks. They have used this data to calibrate the model and identify empirical relationships between water quality variables. Because of these efforts, Thorpe says that: "The Johor River Waterworks Replica model may be the world's most complete simulation of an operating water treatment facility."

By increasing their understanding of water treatment processes in

Replica, Thorpe and his colleagues are working to optimise the design and performance of PUB Singapore's facilities. The software also provides a safe environment in which to predict a system's response to new demands, or emergency situations. Finally, Replica is providing a unique virtual training tool for PUB Singapore's staff to become more familiar with the machinery they are operating.

"In the future, this Johor River Waterworks Replica model could be expanded to simulate the entire facility and become an online operations support tool," says Thorpe.

## Researchers and affiliations

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# Water research institutions and organisations

## Universities, Research Centres and International Organisations

Advanced Environmental Biotechnology Centre	Singapore
Agency for Science Technology and Research	Singapore
American Water Works Association	USA
Aqua Research Centre	Singapore
Black & Veatch Global Design Centre for Water and Centre of Excellence for Desalination	Singapore
CDM's Neysadurai Technical Centre	Singapore
Central South University	China
Deltares	Netherlands
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Hyflux Global R&D Centre	Singapore
IBM Centre for Intelligent Water Optimization and Control	Singapore
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Memstar Technology	Singapore
Memsys Clearwater	Singapore
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Mitsubishi Rayon	Japan
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Pall Corporation	USA
Pan Asian Water Solutions	Singapore
PUB	Singapore
PulverDryer	USA
PWN Technologies	Netherlands
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Rehau Unlimited Polymer Solutions	Germany
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Siemens Water Technologies	Germany
SIF Eco Engineering	Singapore
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