



# SINGAPORE'S NEWATER DEMONSTRATION PROJECT

## Another Milestone In Indirect Potable Reuse

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### Executive Summary

The Republic of Singapore has conducted a comprehensive study to evaluate the feasibility of using dual-membrane technology to reliably produce reclaimed water from municipal effluent. The study was conducted at a purpose built 10 ML/d demonstration facility at the Bedok Water Reclamation Plant (WRP). The objective of the study was to show that reclaimed water could meet both the US-EPA and WHO guidelines for drinking water and could be used for either high grade industrial or indirect potable reuse applications. The following is a description of the operational performance of the demonstration plant since its initial commissioning in May 2000 and highlights the lessons that have been incorporated into the design of the subsequent high grade reclamation facilities.

### Introduction

The island republic of Singapore obtains approximately 50% of its water supply from outside its national borders. In 1999, the Singapore Government launched a strategic initiative to discover alternative and renewable sources of water, in an effort to ensure reliability of supply and consistency of quality. This initiative, known as the "Four Tap Strategy" consists of Imported Water, Seawater Desalination, Collection and Treatment of local surface run-off and Water Reuse. Water reuse was always an important component of Singapore's water supply, beginning with the Jurong Industrial Water Works project in the early 1970s, which supplied tertiary quality effluent to industries in the south west of the island. Since 1999, however, the Singapore Government, through the Public Utilities Board, has aggressively developed advance water reclamation facilities, known as NEWater Factories, to supply the high tech semi-conductor manufacturing sector - effectively, substituting traditional water supplies with high-quality reclaimed water - and augmenting the potable water storage reservoirs located on the Island. The first

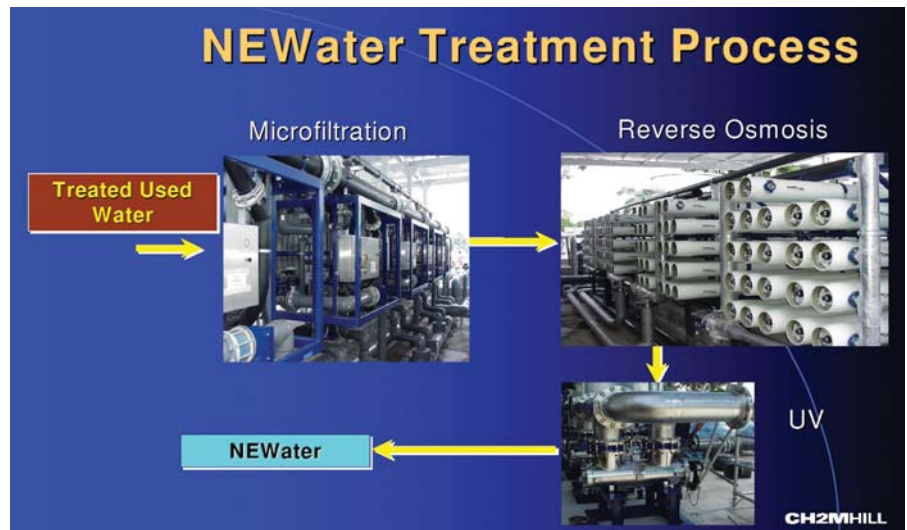


Figure 1. Treatment process flow diagram.

stage of this programme was the decision in 1999 to develop a NEWater demonstration project. The success of this project gave the PUB the confidence to proceed with the programme and introduce NEWater to the surface water reservoirs on February 21, 2003. The following paper chronicles recent milestones in the development of the Islands reclaimed water resources and presents some data from the demonstration project that was used in the design of the NEWater Factories.

### The NEWater Demonstration Study

NEWater is the term coined by the PUB to describe the product from water reclamation using advanced treatment processes of microporous membrane filtration, reverse osmosis and ultraviolet disinfection. The Singapore Water Reclamation Study ("NEWater Study") was first conceptualised in 1998 as a joint initiative between Public Utilities Board (PUB) and Ministry of the Environment (ENV). The primary objective of the joint initiative was to determine the suitability of using NEWater as a source of raw water to supplement Singapore's water supply. The centrepiece of the strategic initiative is the operation of a 10 ML/d dual-membrane water reclamation plant called the "NEWater Factory". The NEWater Factory is a membrane based advanced

water reclamation plant consisting of microfiltration (MF), reverse osmosis (RO) and ultraviolet (UV) disinfection (Figure 1). The plant is located on a compact site downstream of the Bedok Sewage Treatment Plant, recently renamed the Bedok Water Reclamation Plant (WRP).

The design of the NEWater Factory dual-membrane and UV technology process trains are in line with the recommendations of the United States National Research Council (1998) in its report on the use of reclaimed water to supplement water supplies. The first design tenet was to ensure rigorous source control of the raw sewage. The Bedok Water Reclamation Plant (WRP) was selected as the site of the demonstration plant because it receives more than 95% of its wastewater from domestic sources. The second design tenet was the use of multiple physical barriers for the removal of microbial pathogens and chemical contaminants (Figure 2).

Source (feedwater) water to the demonstration plant is a clarified secondary effluent from an activated sludge treatment process, that typically contains: 10 mg/L BOD, 15 mg/L TSS, 6.4 mg/L ammonia-nitrogen and 400-1600 mg/L total dissolved solids (TDS) including 12 mg/L of total organic carbon (TOC). The

secondary effluent is first microscreened (0.3 mm), followed by MF to remove suspended solids, prior to demineralisation with RO.

The MF process consisted of five self contained units operating in parallel. The MF units were fitted with polypropylene hollow fine fibre membranes with a nominal pore size of 0.2 microns. The membranes operated in single pass with a design process water recovery of 90%. Two parallel 5 ML/d reverse osmosis trains are provided, each fitted with thin film aromatic polyamide composite membranes configured for 80-85% recovery in a three stage array. As a last step, the RO permeate is disinfected by three UV units in series equipped with broad spectrum medium pressure lamps at a minimum design dose of 60 mJ/cm<sup>2</sup>.

The NEWater demonstration study was designed to generate information in the areas that were deemed to be critical in any decisions on the expanded use of reclaimed water in Singapore's overall water supply programme. Elements of the NEWater demonstration study commenced with an assessment of technical feasibility and process reliability. The membrane and UV technology was tested over a two year period for robustness and reliability to consistently produce high quality NEWater. NEWater quality and treatment reliability was assessed by a Sampling and Monitoring Programme (SAMP), where a suite of physical, chemical and microbiological parameters was systematically measured across the process train to determine the suitability of NEWater as a source of raw water for potable use (Table 1). The water samples were analysed for all drinking water parameters listed in the current USEPA National Primary and Secondary Drinking Water Standards and WHO Guidelines for Drinking Water Quality. Other parameters of potential concern, but not listed in these standards/guidelines, were added to the list of analytes based on the input of an independent advisory study panel. In total, some 190 physical, chemical and microbiological parameters were monitored and as of April 2002, over 22,000 physical, chemical and microbiological tests had been performed for the NEWater Study.

This comprehensive monitoring program was considered to be adequate to assess the safety of the NEWater and the reliability of the NEWater process. However, a two year Health Effects Testing Programme (HETP) was developed to complement the SAMP, and address the potential health impact of unidentified contaminants in the NEWater. The HETP involved a compar-

**Table 1.** Total number of parameters measured versus sampling location.

Water Quality Parameter	Sample Location						
	Plant Feedwater	MF Filtrate	RO Permeate	UV Effluent	NEWater	PUB Raw Water	PUB Drinking Water
Physical	9	3	3	2	8	8	7
Inorganic Disinfection By-products	6	1	2	1	6	6	6
Inorganic - Other	39	2	32		39	38	39
Organic Disinfection By-products	22		22		22	22	22
Other Compounds	42				41	41	37
Pesticides/Herbicides	50				50	50	50
Radionuclides	6				6	6	6
Wastewater Signature Compounds	4				4	4	4
Synthetic & Natural Hormones	3	3	3		3	3	3
Microbiological	10	9	7		10	9	3
<b>Totals</b>	<b>191</b>	<b>18</b>	<b>69</b>	<b>3</b>	<b>189</b>	<b>187</b>	<b>177</b>

**Table 2.** Health Effects Studies using Live Animals.

Project	Toxicological Assessment	References
Denver Potable Water Reuse Demonstration Project, Colorado, U.S.	Two-year chronic (carcinogenicity) mice and rats study. Reproductive study in rats.	Lauer <i>et al.</i> , 1990
Tampa Water Resources Recovery Project, Florida, U.S.	90-day subchronic assay on mice and rats. Reproductive and developmental study on mice and rats.	CH2M HILL, 1993; Pereira <i>et al.</i> , undated
Total Resources Recovery Project, City of San Diego, California, U.S.	Biomonitoring (28-day bioaccumulation and swimming tests) study.	Western Consortium for Public Health, 1996

**Table 3.** Comparison of Design and Actual Operating Parameters (August 2000).

Parameter	Specified Design	Actual
TOC Removal (%)	>97	>99
Ammonia Removal (%)	>90	96
TDS Removal (%)	>97	96
MF Filtrate Turbidity (NTU)	≤0.1	<0.1
Plant Feedwater (m <sup>3</sup> /d)	13,300	13,850
MF Filtrate (m <sup>3</sup> /d) <sup>1</sup>	11,800 (90%)	12,166 (88%)
Product Water (m <sup>3</sup> /d) <sup>1</sup>	10,000 (85%)	10,136 (83%)

ative toxicological assessment of NEWater with existing raw potable water sourced from Bedok Reservoir. Compared with previous studies, the NEWater demonstration is the first programme to include chronic testing of fish, in parallel with a chronic mice study. Previous studies in the U.S. were conducted using one animal either in a chronic (long-term) or sub-chronic (short-term) test (Table 2).

**NEWater Demonstration Plant Performance**

NEWater Factory was first commissioned in May 2000 and to date plant performance has tracked closely with design requirements (Table 3). Analytical results from 9 May to 2 January 2002 indicate that NEWater is of consistently higher quality than those specified under US-EPA 1998 and WHO 1993 drinking

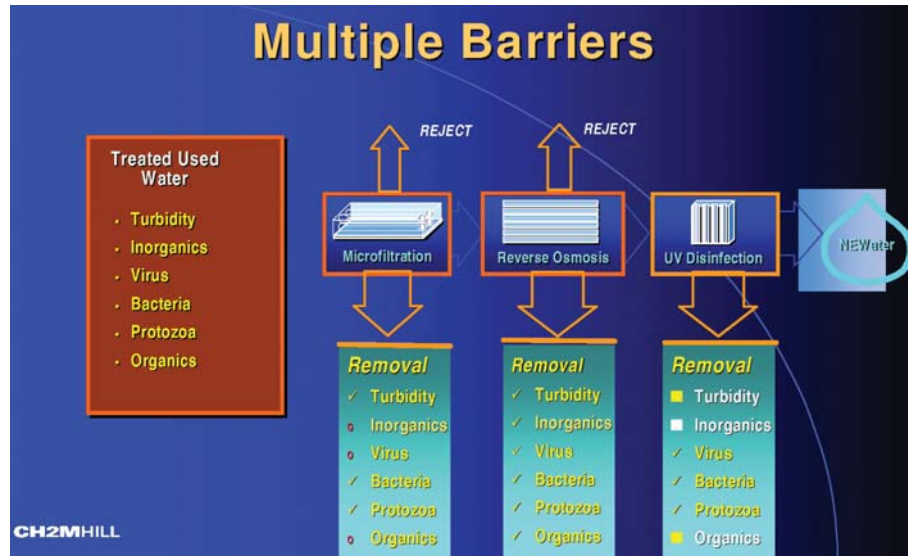
water regulations and guidelines (Table 4).

**Impact of Plant Feedwater Quality on MF Performance**

Perhaps the one of the most important observation from the demonstration study is that the performance of the membranes is closely linked to the quality of the incoming secondary effluent (plant feedwater). In the case of the microporous membranes variations in feed turbidity or suspended solids influenced process recovery and cleaning intervals, while in the case of reverse osmosis membranes, variations in dissolved solids impacted on operating pressure and product water quality.

The MF process provided excellent pre-treatment for the RO system, resulting in stable and robust RO system performance. However, the performance of the MF was affected by the level of suspended solids in the plant feedwater. An increase in the suspended solids increases the solids loading on the MF membranes, which can necessitate more frequent backwash and clean-in-place (CIP) operations, which can vary from 10 to 15 days interval. To accommodate potential variations in feed turbidity, the full scale NEWater plants designed after the NEWater demonstration plant include an additional 20% membrane area, so that that membrane loading rate could be reduced during periods of elevated suspended solids.

Similarly the RO process achieved the design requirements of a 97% reduction of TDS and a 99% reduction in TOC (Table 3). However, RO performance was influenced by variations in the dissolved solids in the plant feedwater. The TDS of the plant feed could vary from 270 to 2,270 mg/L depending on the extent of seawater ingress into the sewers tributary to the Bedok WRP, with the highest levels observed during the Spring tides (high water is higher and low water is lower than usual). Under these conditions the RO feed pressure increased (caused by the higher feed osmotic pressure resulting from the additional dissolved solids) leading to a decrease in the normalised plant product flow (Figure 3). In addition to the decrease in normalised flow, variations in feed water TDS also lead to variable product water TDS. Consequently, the conductivity of the NEWater ranged from 39.6 (µS/cm) at periods of low tide to 71.1 µS/cm under high tide conditions (Table 4). In order to ensure that the NEWater plants produce a consistent quality, including consistent levels of TDS, a recycle step was included into the RO design for the



**Figure 2.** Multiple barrier approach for microbial and chemical contaminant removal.

NEWater plants that have been developed to supply industry. In these larger NEWater plants it is possible to blend the output from the MF process with some RO permeate to lower the TDS of the RO feed. By using this recycle step it is possible to minimise the variations in the

level of dissolved solids in the NEWater.

**Conclusions and Project Milestones**

The NEWater demonstration study has generated important data to guide the PUB in the development and expansion of the use of reclaimed water in the

**Table 4.** Water quality for NEWater Factory product water. All results in mg/L, unless indicated.

Water Quality Parameter	NEWater Factory <sup>1</sup>	US-EPA/WHO <sup>2</sup>
Colour (Hazen Units)	<5	15
PH	5.2 to 6.2	6.5-8.5
Conductivity (µS/cm)	39.6 to 71.1	—
Alkalinity (as CaCO <sub>3</sub> )	8	—
Total Dissolved Solids	22 to 41.3	500
Hardness (as CaCO <sub>3</sub> )	<5	—
Fluoride	0.18 to 0.22	1.5
Nitrite (as N)	0.38	0.91
Nitrate (as N)	0.49 to 1.65	10
Ammonia	0.35 to 0.57	1.5
Chloride	3.6 to 10.9	250
Turbidity (NTU)	<0.1	5
Aluminium	0.09	0.2
Iron	<0.003	0.3
Manganese	<0.003	0.05
Sulphate (as SO <sub>4</sub> )	0.16 to 0.54	250
Zinc	<0.004	3
Silica (as SiO <sub>2</sub> )	0.21 to 0.32	—
Phosphate (as P)	0.011 to 0.044	—
Sodium	5.1 to 9.6	200
TOC (µg/L)	60 to 90	—
Total Coliform (counts/100 mL)	<1	Not Detectable
Fecal Coliform (counts/100 mL)	<1	Not Detectable
Clostridium Perfringens (cfu/100 mL)	<1	—

Notes:

1. Taken from analytical results for the months of June and July 2000.
2. Lowest limit of either the US-EPA 1998 Surface Water Regulations or WHO 1993 Guidelines for Drinking Water.

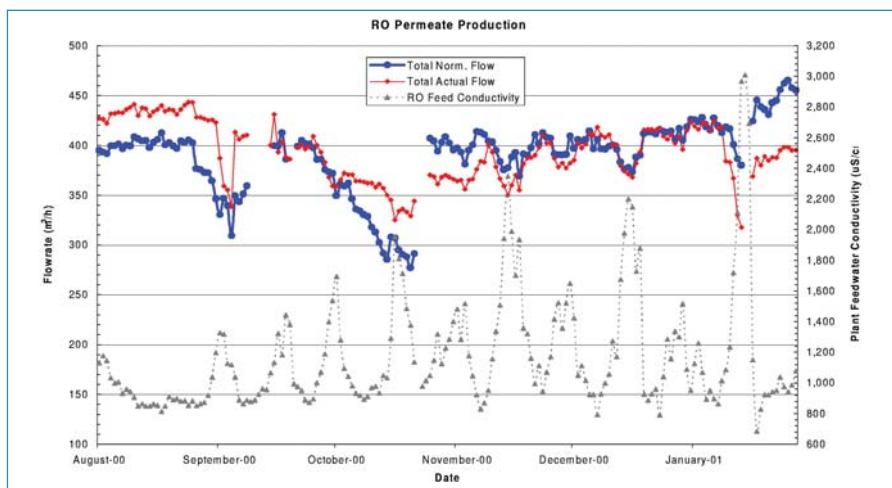
Island's overall water management strategy. These milestones in the use of NEWater are chronicled in table 5. In early-2003 the first full-production NEWater plants went on line at Bedok WRP and Kranji WRP with a combined initial capacity of 72,000 m<sup>3</sup>/d. These plants have the provision to expand to 168,000 m<sup>3</sup>/d in the future. The new Bedok and Kranji NEWater plants will provide water to the microelectronics industry, thereby saving existing drinking water for domestic use. (The micro-electronics industries are far more sensitive to water quality than domestic users). In addition to the industrial use of NEWater, In late-June 2002, a panel of local and overseas experts charged with reviewing the NEWater Study recommended the Singapore Government adopt indirect potable reuse of NEWater with a portion of the production from the Bedok and Kranji NEWater plants being used to augment levels in the surface water reservoirs. On July 11, 2002, the concept of indirect potable reuse of NEWater was formally launched to the public. PUB's goal is to reuse 20% of the used water for industrial and potable use by the end of the decade. NEWater debut at the August 9, 2002, National Day celebrations with some 60,000 bottles of NEWater being given away on the parade day alone. Since then, more than a million bottles of NEWater have been distributed to demonstrate the safety of the water for potable consumption to the public. NEWater began flowing to the Bedok and Kranji surface water reservoirs on February 21, 2003.

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**Figure 3.** RO permeate production, RO feedwater conductivity and RO CIP events.

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**References**

National Research Council (USA) 1998. Issues in Potable re-use: The viability of augmenting drinking water supplies with reclaimed water.

**Major Suppliers**

MF units - US Filter Memcor; RO Units - Hydranautics; UV units - Hannovia

**Table 5.** Water Reclamation Milestones.

Year	Milestone
1998	Water Reclamation Study initiative conceived by PUB and the Ministry of the Environment
February 1999	CH2M HILL commissioned for the engineering design, project delivery and study management of the Singapore Water Reclamation Study
May 2000	Bedok NEWater Factory Demonstration Plant constructed and commissioned within a seven month period. Design capacity of 10,000 m <sup>3</sup> /day
October 2000	Commencement of the most comprehensive and sophisticated study into water reclamation: <ul style="list-style-type: none"> <li>• Sampling and monitoring programme for some 190 water quality parameters</li> <li>• Toxicological assessment using both mice and fish for the first time</li> </ul>
January 2001	PUB announces its goal to recycle 20% of secondary treated used water for industrial use
July 2001	CH2M HILL awarded the engineering design and construction supervision for full-scale Bedok and Kranji NEWater Plants, as well as interactive visitor/public education centre at Bedok. Ultimate design capacity of 168,000 m <sup>3</sup> /day
July 2002	Expert Panel recommends the adoption of Indirect Potable Reuse of NEWater to supplement Singapore existing water supply sources
August 2002	NEWater debuts to wide public acceptance at the National Day Parade and celebrations. Up to 60,000 bottles of NEWater given away at the on parade day.
January 2003	Bedok and Kranji NEWater Plants with an initial capacity of 72,000 m <sup>3</sup> /day
February 2003	The potable and non-potable use of NEWater is officially launched by the Prime Minister of Singapore at a gala event. At the same time a visitor and public education centre was opened to the public. The unique centre is fully integrated with the Bedok NEWater Plant and includes an elevated walk-through of the process area, and a multimedia interactive exhibition/education area with a 120-seat digital audio/video auditorium. The very latest in multimedia interactive learning tools are used extensively throughout the centre.