SINGAPORE

WATER RECLAMATION STUDY

EXPERT PANEL REVIEW

AND

FINDINGS

JUNE 2002

1. INTRODUCTION

1.1 Project Overview

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. NEWater is treated used water that has undergone stringent purification and treatment process using advanced dual-membrane (microfiltration and reverse osmosis) and ultraviolet technologies. NEWater could be mixed and blended with reservoir water and then undergo conventional water treatment to produce drinking water (defined here as Planned Indirect Potable Reuse or Planned IPR).

Planned IPR as a source of water supply is not new. It has been practised in several parts of the United States for more than 20 years. At Water Factory 21, Orange County Water District, Southern California, high quality water reclaimed from treated used water has been injected into ground water since 1976. Similarly, at Upper Occoquan Sewage Authority (UOSA), Virginia, high quality reclaimed water is discharged into Occoquan Reservoir since 1978. Occoquan Reservoir is a source of water supply for more than one million people located in the vicinity of Washington DC.

Water reclamation is a growing trend in the U.S. and around the world. In the U.S., there are several other water reclamation projects in the municipal scale that are either being planned or under construction. Two of them are at Gwinnett near Atlanta, Georgia and Scottsdale near Phoenix, Arizona.

Figure 1.1 shows the locations of potable water reuse facilities in the United States.

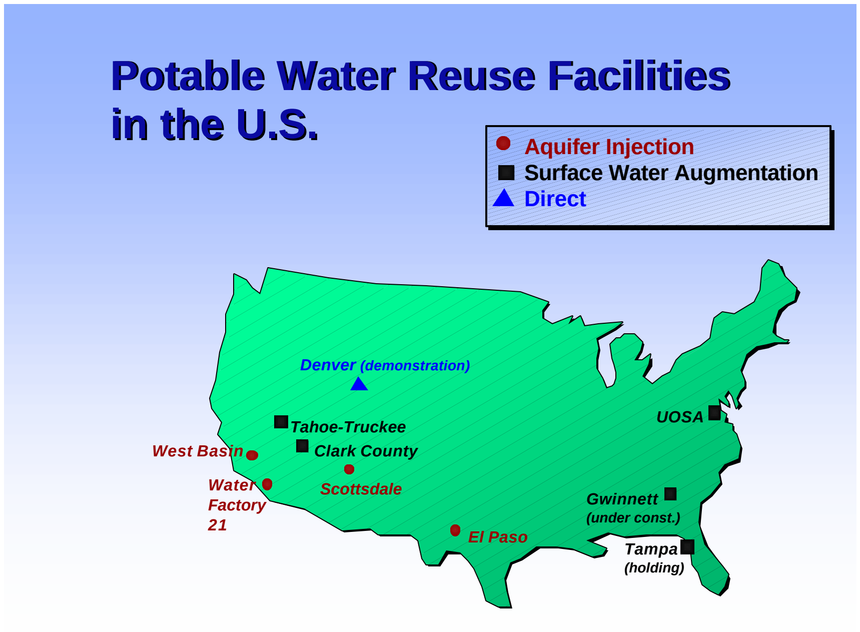

Figure 1.1 – Potable water reuse facilities in the U.S.

1.2 NEWater Study

To achieve the objective of Planned IPR, the NEWater Study was designed to include the following three major activities:

- the design, construction, commissioning and operation of a 10,000 m^3/day advanced water reclamation demonstration plant using state-of-the-art dual-membrane (microfiltration and reverse osmosis) and ultraviolet light technologies. The membrane and UV technology is tested for its robustness and reliability to consistently produce high quality NEWater;

- a *Sampling and Monitoring Programme* (SAMP) where a comprehensive physical, chemical and microbiological sampling and analysis of water samples is conducted to determine the suitability of NEWater as a source of raw water for potable use. The *USEPA National Primary and Secondary Drinking Water Standards* and *WHO Drinking Water Quality Guidelines* are the benchmarks for NEWater quality. Other parameters of potential concern, but not listed in these standards/guidelines are also routinely tested for; and

- a *Health Effects Testing Programme* (HETP) to complement the comprehensive SAMP to determine the safety of NEWater. The HETP is ongoing. It involves the toxicological assessment of NEWater against PUB source water from Bedok Reservoir. The HETP covering both short and long term health effects is carried out using two animal species i.e. mice and fish. The fish are also being used for estrogenic (reproductive and developmental) assessment.

1.3 Expert Panel

The ***Expert Panel*** consisting of both local and foreign experts in engineering, biomedical science, chemistry and water technology was formed in January 1999 to provide independent advice to PUB and ENV on the NEWater Study. The scope of the Expert Panel is defined as follows:

- review and advise on the planning and implementation of the NEWater Study;

- review and advise on the sampling and analysis of water, toxicological and carcinogenic risk assessment, and other relevant health studies;

- review the findings for the Study; and

- evaluate the findings and make recommendations with regard to the suitability of NEWater as a source of raw water for potable use.

Table 1.1 is a summary of the Expert Panel members' names, date of appointment, area of expertise and institution where they practice.

Table 1.1 – Expert Panel

Name	Year of Appointment	Expertise	Institution
Professor Ong Choon Nam (Chairman)	1999	Human Health and Toxicology	National University of Singapore (NUS)
Professor Joan Rose	1999	Microbiology	University of South Florida, U.S.
Mr. William (Bill) Lauer	1999	Water Reclamation Studies	American Water Works Association, U.S.
Professor Ng Wun Jern	1999	Engineering and Water Technology	NUS
Dr. Chew Suok Kai	1999	Human Health and Epidemiology	Ministry of Health (MOH)
Professor James P. Tam	2001	Life/Biological Sciences	Nanyang Technological University (NTU)
Associate Professor Mulkit Singh	1999	Microbiology	NUS
Dr. Bosco Chen Bloodworth	1999	Water Quality and Analysis	MOH/Health Sciences Authority of Singapore (HSA)
Professor Lee Hian Kee	2001	Environmental Chemistry	NUS

1.4 Description of NEWater Factory

The NEWater Factory is a 10,000 m^3/d advanced water reclamation plant employing dual-membrane and UV disinfection treatment process train. The plant is located on a compact site downstream of the Bedok Water Reclamation Plant (formerly known as Bedok Sewage Treatment Works). The NEWater Factory treatment process train is shown in **Figure 1.2**.

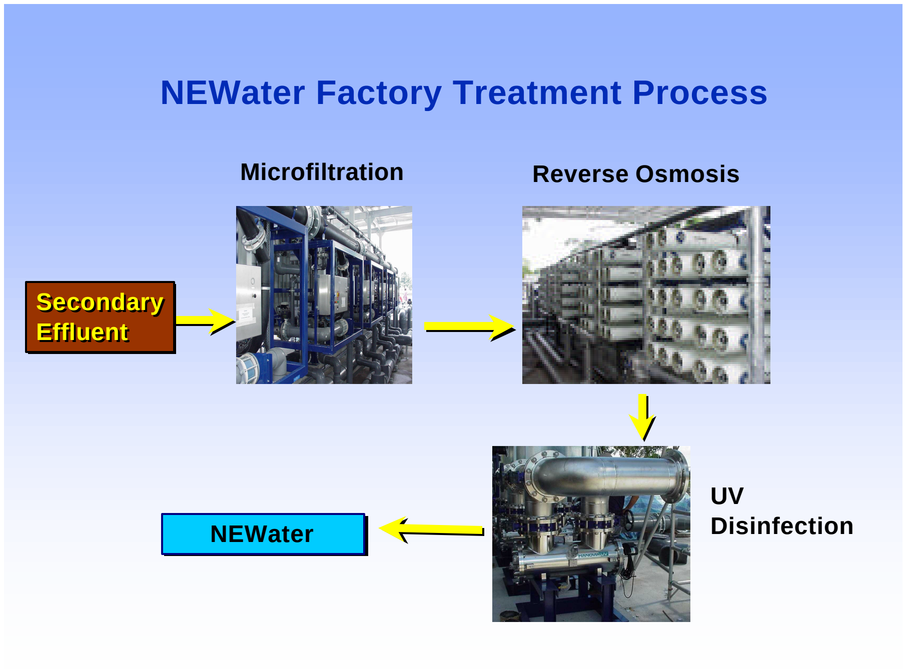

Figure 1.2 – Treatment process flow diagram

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* in its report[1] 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 Bedok WRP 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 1.3** illustrates the multiple barrier approach incorporated in the NEWater Factory process design.

[1] Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies with Reclaimed Water, National Research Council, 1998.

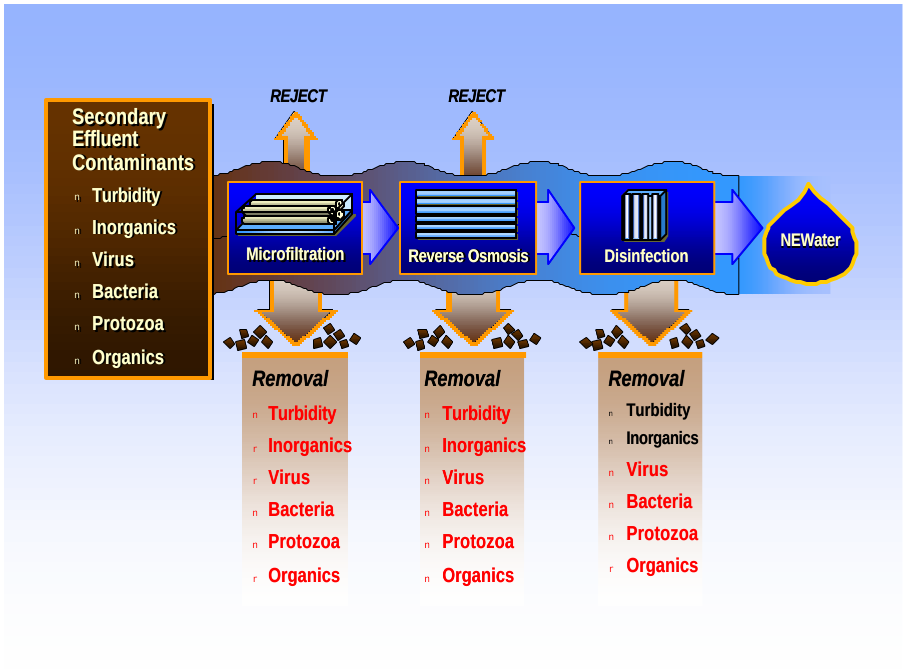

Figure 1.3 – Multiple barrier approach for microbial and chemical contaminant removal

Feed water to the demonstration plant is clarified secondary effluent from an activated sludge treatment process, that typically contains: 10 mg/L BOD_5, 10 mg/L TSS, 6 mg/L ammonia-nitrogen and 400 to 1,600 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 microfiltration (MF) to 0.2 µm to remove fine solids and particles, and then demineralised with reverse osmosis (RO). For the final step, the RO permeate is disinfected by ultraviolet irradiation. Chlorine is added at two points before and after MF to control the rate of biofouling in the membrane systems.

Two parallel 5,000 m^3/d (5 ML/d) reverse osmosis trains are provided, each fitted with thin-film aromatic polyamide composite membranes configured for 80 to 85% recovery in a three-stage array. This is followed by three UV units in series equipped with broad-spectrum medium pressure UV lamps delivering a minimum design total UV dosage of 60 mJ/cm^2. The end product is called NEWater.

1.5 Indirect Potable Reuse

When discussing the reuse of treated effluent for potable purposes, the following definitions are useful to distinguish between “indirect” and “direct” potable reuse and between “planned” and “unplanned” potable reuse.

Planned Indirect Potable Reuse is the abstraction, treatment, and distribution of water for drinking from a natural source water (river, lake or aquifer) that is intentionally and partially fed by the discharge of treated wastewater effluent (*NRC, 1998*). This type of potable reuse is becoming more common as other viable water sources become scarcer because of population growth and watershed urbanisation. Some U.S. examples are Water Factory 21, Orange County Water District, Southern California and Upper Occoquan Sewage Authority (UOSA), Virginia.

Unplanned Indirect Potable Reuse occurs when a water supply is abstracted for potable purposes from natural source (surface or groundwater) that is fed in part by the discharge/disposal of wastewater effluent (treated or not). The subsequent potable reuse of the wastewater effluent was not an intentional part of the effluent disposal plan. This type of potable reuse occurs whenever an upstream water user discharges wastewater effluent into a water source (river, lake or aquifer) that serves as a water supply for a downstream user. As noted later, many large communities unintentionally have been practising unplanned indirect potable reuse. Some examples are the Rhine and Thames rivers in Europe, Mississippi River in the U.S., Yangtze River in China, and Mekong River in Indo-China.

Direct Potable Reuse is the immediate addition of reclaimed water to the potable water distribution system. This practice has not been adopted by, or approved for, any water system in the U.S. (NRC, 1998), although, it is being practised in Windhoek, Namibia, Africa. Hence, direct potable reuse is not considered a viable option for Singapore and will not be discussed from hereon.

2. PLANT OPERATIONS

2.1 General

The NEWater Factory commenced operation in May 2000, and continues to perform satisfactorily and within design expectations. **Table 2.1** below compares the original plant design criteria against actual plant performance (monthly averages) since operation in May 2000.

Table 2.1 – Design Specification versus actual performance

Parameter	Specified/Design	Actual
pH	None	5.9
TOC Removal (%)	>97	>99
Ammonia Removal (%)	>90	>94
TDS Removal (%)	>97	>97
MF Filtrate Turbidity (NTU)	≤0.1	≤0.1

2.2 Reliability and Safety of Plant Design and Operation

Potable reuse projects require more robust multiple barriers to chemical contaminants and microbial pathogens than conventional water treatment systems (*NRC 1998*). For water systems, the systematic reduction of risk to human health to waterborne contaminants is comprehensively known as "multiple barriers". The provision of independent multiple barriers, or redundant safety measures, as well as a continuous, vigilant monitoring and surveillance programme will ensure the greatest level of safe, reliable operation of a potable reuse water system.

The NEWater Factory is designed with a number of fail-safe features to ensure the NEWater produced is of high quality, as well as protect the plant equipment from adverse operating conditions. Some of the fail-safe features are as follows:

- Routine membrane integrity testing;
- Standby units are provided for all critical equipment;
- Routine calibration and verification of the on-line monitoring instrumentation;
- Provision of automatic warning systems to alert the operator of abnormal plant conditions;

- Automatic shutdown of the plant in the event of adverse operating conditions; and
- Computerised data acquisition and trending of the operational data in real-time.

2.3 Plant Production

The NEWater Factory has been challenge-tested to prove that the constructed plant could meet or better all design specification requirements. The trials proved that the plant is capable of a production capacity of 10,000 CMD (m^3/d).

2.4 Water Recovery Rates

Water recovery for the RO membranes has been deliberately kept within the range of 80 to 82%. Operational experience shows that this water recovery rate is optimal to control organic fouling of the RO membranes and therefore decrease the frequency of membrane cleaning.

The CMF water recovery rate is below the design criteria of $\geq$90%, ranging from 84 to 90%, with an average of 87% ($\pm$1.9 standard deviation).

Despite these challenges, the NEWater Factory has shown itself to be reliable, robust and capable of producing consistently high quality NEWater, under a wide and diverse range of feedwater conditions.

2.5 Unit Power Consumption

To date the average unit power consumption at NEWater Factory has not varied from the range of 0.7 to 0.9 kWh/m^3. This is better than the specification requirement of 1.2 kWh/m^3.

2.6 Plant Feedwater Issues

Conductivity

Higher incoming Plant Feedwater conductivity causes plant production to decrease and the conductivity of NEWater to increase.

The designs of future full-production dual-membrane water reclamation plants have incorporated measures and features to minimise the impact of high variations in the Plant Feedwater conductivity.

Turbidity

Operating experience gained from the NEWater Factory shows that the CMF could tolerate high turbidity up to 20 NTU without adversely affecting plant production. At turbidity below 2 NTU, the water recovery would be at least 90%, while at turbidity >10 NTU, the water recovery could be as low as 84%.

2.7 CMF Operations

The average CMF membrane cleaning frequency at 13.4 days betters the specified design requirement of 10 days per clean per unit.

2.8 RO Operations

A greater than six months RO membrane cleaning interval was achieved for the first stage of RO recovery, while a more than three months RO membrane cleaning interval was achieved for the second and third stages. These are much better than the 60 days design criteria.

2.9 UV Operations

Viruses, bacteria and parasites are removed after the RO process treatment. UV disinfection is provided as an added safeguard against microbial contaminants. UV light works by inactivating viruses, bacteria and parasites. The UV Disinfection System at NEWater Factory was designed for 4-log (99.99%) inactivation of microbes. Testing has shown that better than 7-log (99.99999%) is being achieved by the UV System.

2.10 Summary

After two years of operation, the NEWater Factory has demonstrated that NEWater can be consistently and reliably produced on a large scale.

3. SAMPLING AND MONITORING PROGRAMME (SAMP)

3.1 Overview

The Sampling and Monitoring Programme (SAMP) involves a comprehensive set of physical, chemical and microbiological tests.

The water samples are 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*. In total, some 190 physical, chemical and microbiological parameters related to water quality have been measured.

Table 3.1 summarises the number of physical, chemical and microbiological parameters related to water quality with the sampling location.

Table 3.1 – Total number of parameters measured versus sampling location

		Sample Location						
	Water Quality Parameter	**Plant Feedwater (1)**	**MF Filtrate (2)**	**RO Permeate (3)**	**UV Effluent (4)**	**NEWater (5)**	**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	**Inorganic - Other**	39	2	32		39	38	39
Organic	**Disinfection By-products**	22		22		22	22	22
Organic	**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
	Totals	**191**	**18**	**69**	**3**	**189**	**187**	**177**

3.2 Physical and Chemical Analysis Results

Overall, some 20,000 test results from seven sampling locations, including over 4,500 for NEWater have been measured.

Table 3.2 summarises the total number of physical and chemical measurements, including the sampling period.

Table 3.2 – Total number of physical and chemical analytical results

		Sampling Period	
Sample Location	**Total Results Count**	**From**	**To**
Plant Feed Water (1)	7,282	9-Nov-99	30-Apr-02
MF Filtrate (2)	407	8-Aug-00	30-Apr-02
RO Permeate (3)	2,082	8-Aug-00	30-Apr-02
UV Effluent (4)	114	5-Sep-00	30-Apr-02
NEWater (5)	4,741	9-May-00	30-Apr-02
PUB Raw Water	4,165	9-Nov-99	30-Apr-02
PUB Drinking Water	1,142	6-Jun-00	30-Apr-02
Total	**19,933**		

Below Detection Limit Data

Owing to the extremely low concentrations of various parameters present in the NEWater and/or limitations of the analytical technique, an absolute value thus could not be determined. In fact, the majority of the NEWater test results are below the detection limit. This is also known as not detectable (ND), and is reported at the "estimated quantitation limit" or EQL, which is the lowest practical reportable concentration within a specified confidence limit.

For the NEWater Study we have adopted the following approach:

- If the number of non-detectable results is more than 50% of the number of test results, the mean is not calculated because the result would not be meaningful. In such cases, the mean is stated as "Not Calculated" or "NC".
- If the number of detectable results is more than 50% of the number of test results, the mean is computed using the detected values plus the detection limit for the non-detectable results.

- A mean will not be computed if the number of test results is fewer than seven. Some of the newer tests may fall into this category.

It should be noted that this method of handling non-detectable data will tend to slightly overestimate the arithmetic mean.

It is necessary to stress that the lowest or more stringent of either the current *USEPA National Primary and Secondary Drinking Water Standards* or *WHO Guidelines for Drinking Water Quality* has been used in these comparisons.

Physical Characteristics

Overall data have demonstrated that NEWater achieves the current drinking water quality standards and guidelines for all physical water quality parameters, with the minor exception of pH that averages around pH 5.9. The pH of USEPA and WHO standard/guideline are set at a range 6.5 to 8.5 for aesthetics and corrosion protection reasons.

However, the pH increases to seven upon standing and exposure to open air for two to three hours. This is due to the release of dissolved carbon dioxide present in NEWater after RO treatment.

Table 3.3 is a summary of the physical water quality results for NEWater. True colour in NEWater was not detectable in any of the 96 samples collected and tested.

Table 3.3 – Summary of NEWater physical water quality parameters with detectable results

		Standard/Guideline					Number of Results		
Parameter	**Units**	**USEPA**	**WHO**	**Mean***	**Min.***	**Max.***	**Total**	**Detectable**	**Not Detectable**
pH	Units	6.5-8.5	6.5-8.5	5.9	5.3	6.7	96	96	0
Temperature	°C	-	-	29.6	26.4	30.9	7	7	0
Total dissolved solids (TDS)	mg/L	500	1,000	48.3	11	118	95	95	0
Turbidity	NTU	5	5	NC	ND	0.4	96	15	81
Conductivity	µS/cm	-	-	92.2	28.6	256	96	96	0
Suspended Solids	mg/L	-	-	NC	ND	0.6	94	1	93
UV 254 Absorbance	cm^{-1}	-	-	NC	ND	0.011	96	6	90

**Notes:*

1. *NC – Not calculated.*
2. *ND – Not detectable (below detectable concentration).*

Inorganics

The quality of NEWater achieves the drinking water quality standards and guidelines set by USEPA and WHO, respectively, for inorganic parameters including disinfection by-products. Below is a list of NEWater inorganic parameters found at non-detectable concentrations (not detectable in any of the samples).

- Chlorate
- Bromate
- Perchlorate
- Arsenic
- Beryllium
- Chromium
- Cyanide
- Hydrogen Sulphide (H_2S)
- Manganese
- Mercury
- Selenium
- Silver
- Bromide
- Antimony

Table 3.4 is a summary of the NEWater inorganic water quality results that had detectable concentrations. All of the values are within the USEPA and WHO standards/guidelines.

Table 3.4 – Summary of NEWater inorganic water quality parameters with detectable results

		Standard/Guideline					Number of Results		
Parameter	**Units**	**USEPA**	**WHO**	**Mean***	**Min.***	**Max.***	**Total**	**Detectable**	**Not Detectable**
Chlorine (Total as Cl_2)	mg/L	-	5	1.39	0.01	2.6	96	96	0
Chlorite	mg/L	-	0.2	NC	ND	0.15	87	1	86
Iodine	mg/L	-	-	0.06	0.01	0.15	60	60	0
Monochlor-amine (as Cl_2)	mg/L	-	3	0.9	ND	2	87	80	7
Aluminium (total)	mg/L	0.05-0.2	0.2	NC	ND	0.12	21	5	16
Ammonia (as N)	mg/L	-	1.5	0.51	ND	2.14[a]	83	71	12
Asbestos	fibres/L	7 million	-	NC	ND	210,000	7	1	6
Barium	mg/L	2	0.7	NC	ND	0.017	21	1	20
Boron	mg/L	-	0.5	0.06	ND	0.149	23	20	3
Cadmium	mg/L	0.005	0.003	NC	ND	0.0002	21	1	20
Chloride	mg/L	250	250	14.34	2.57	47.8	28	28	0

Copper	mg/L	1.3	2	NC	ND	0.003	21	1	20
Fluoride	mg/L	4	1.5	0.16	0.04	0.41	28	28	0
Iron	mg/L	0.3	0.3	NC	ND	0.009	28	5	23
Lead	mg/L	0.015	0.01	NC	ND	0.002	21	4	17
Molybdenum	mg/L	-	0.07	NC	ND	0.018	21	1	20
Nickel	mg/L	-	0.02	NC	ND	0.013	21	1	20
Nitrate (as N)	mg/L	10	11.3	2.01	0.02	5.4	44	44	0
Nitrite (as N)	mg/L	1	0.91	NC	ND	0.38	28	8	20
Sodium	mg/L	-	200	13.35	3.16	42.1	28	28	0
Sulphate	mg/L	250	250	0.15	ND	0.54	28	22	6
Thallium	mg/L	0.002	-	NC	ND	0.0018	21	3	18
Zinc	mg/L	5	3	NC	ND	0.041	21	2	19
Calcium	mg/L	-	-	0.17	0.044	0.514	21	21	0
Potassium	mg/L	-	-	1.08	0.504	3.07	10	10	0
Silica (SiO_2)	mg/L	-	-	0.88	ND	4.95	17	15	2
Strontium (Sr^{2+})	mg/L	-	-	NC	ND	0.021	21	3	18
Total Alkalinity	mg/L	-	-	8.63	5	16	21	21	0
Total Nitrogen	mg/L	-	-	3.28	ND	11	20	19	1
Total Phosphorous	mg/L	-	-	0.03	ND	0.084	21	19	2
Magnesium	mg/L	-	-	0.13	0.03	0.45	10	10	0

[a] *An outlier one out of 83 determinations. Not statistically significant.*

**Notes:*

1. *NC – Not calculated.*
2. *ND – Not detectable (below detectable concentration).*
3. *Original monochloramine values have been converted to mg/L as chlorine.*

Organic Compounds

Below is a list of the NEWater organic compounds that had non-detectable concentrations (not detectable in any of the samples).

- Chloropicrin
- Cyanogen chloride (as cyanide)
- Chloral Hydrate (trichloroacetaldehyde)
- Chloroacetic acid
- Dichloroacetic acid (DCAA)
- Trichloroacetic acid (TCAA)
- 1,3-Dichlorobenzene
- 1,4-Dichlorobenzene
- 1,2,4-Trichlorobenzene
- Trichlorobenzenes (total)
- Carbon Tetrachloride
- Dichloromethane (methylene chloride)

- 2-chlorophenol
- 2,4-dichlorophenol
- 2,4,6-Trichlorophenol
- Dichloroacetonitrile
- Trichloroacetonitrile
- Dibromoacetonitrile
- Bromochloroacetonitrile
- Acrylamide
- Epichlorohydrin
- Hexachlorobutadiene
- Microcystin-LR
- Polychlorinated biphenyls (PCBs)
- Benzene
- Ethylbenzene
- Styrene
- Toluene
- Xylenes (total)
- Chlorobenzene
- 1,2-Dichlorobenzene
- 1,1-Dichloroethane
- 1,2-Dichloroethane
- 1,1,1-Trichloroethane
- 1,1,2-Trichloroethane
- 1,1-Dichloroethene
- 1,2-Dichloroethene (cis & trans)
- Tetrachloroethene
- Vinyl Chloride
- Tributyltin oxide
- Di(2-ethylhexyl) phthalate
- Di(2-ethylhexyl) adipate
- Benzo(a)pyrene
- Dioxin (2,3,7,8-TCDD)
- Haloacetic Acids (HAA5)
- MTBE
- Mirex
- Furan (2,3,7,8-TCDF)
- Haloacetic Acids (HAA7)

Table 3.5 is a summary of the NEWater organic compounds that had occasionally been detected, but these concentrations are within the USEPA and WHO standards/guidelines or considered insignificant because of rarity and/or low concentrations.

Table 3.5 – Summary of NEWater organic compounds with detectable results

		Standard/Guideline					Number of Results		
Parameter	**Units**	**USEPA**	**WHO**	**Mean***	**Min.***	**Max.***	**Total**	**Detectable**	**Not Detectable**
Total Trihalomethanes (THM's)	µg/L	80	R<1 (see notes below)	NC	ND	86.5[a]	53	1	52
Bromodichloro-methane	µg/L	-	60	NC	ND	7.9	53	4	49
Bromoform ($CHBr_3$)	µg/L	-	100	NC	ND	48.3	53	1	52
Chloroform ($CHC1_3$)	µg/L	-	200	NC	ND	5	53	1	52
Dibromochloro-methane	µg/L	-	100	NC	ND	25	53	4	49

Chlorinated furanones (MX)	ng/L	-	-	NC	ND	8	41	10	31
Formaldehyde	µg/L	-	900	18.45	ND	75.9	87	73	14
Trichloroethene	µg/L	5	70	NC	ND	46.72[b]	16	1	15
Dialkyltins	ng/L	-	-	NC	ND	6.5	14	1	13
Total Organic Carbon (TOC)	mg/L	-	-	0.19	ND	0.74	96	71	25
Dissolved Organic Carbon (DOC)	mg/L	-	-	0.16	ND	0.59	96	71	25
Biodegradable Organic Carbon (BDOC)	mg/L	-	-	NC	ND	0.19	11	4	7
COD	mg/L	-	-	NC	ND	5	96	1	95
Organic Nitrogen	mg/L	-	-	1.08	ND	2.4	20	14	6

[a] An outlier one out of 53 determinations. Not statistically significant.

[b] An outlier one out of 16 determinations. Not statistically significant.

**Notes:*

1. *NC – Not calculated.*
2. *ND – Not detectable (below detectable concentration).*
3. *WHO defines "R" as the sum of the ratios of five organic compounds with their respective guideline limits.*

Pesticides/Herbicides

NEWater is analysed for 50 types of pesticide/herbicide compounds. The values achieve the drinking water quality standards and guidelines set by USEPA and WHO, respectively, for pesticide/herbicide compounds.

Below is a list of the pesticide/herbicide compounds found at non-detectable concentrations (not detectable in any of the samples):

- 2,4,5-T
- 2,4-Dichlorophenoxyacetic acid (2,4D)
- 2,4-DB
- 1,2-Dichloropropane
- 1,2-dibromoethane
- 1,3-dichloropropene
- Alachlor
- Aldicarb
- Aldrin
- Atrazine
- Glyphosphate
- Heptachlor
- Heptachlor epoxide
- Hexachlorobenzene
- Hexachlorocyclopentadiene
- Isoproturon
- Lindane (HCH)
- MCPA
- Mecoprop
- Methoxychlor

- Bentazone
- Carbofuran
- Chlorotoluron
- Cynazine
- DDT and derivatives (total isomers)
- Dalapon
- Dinoseb
- Dichlorprop
- Dieldrin
- Diquat
- Endothall
- Endrin
- Ethylene dibromide
- Fenoprop
- Metolachlor
- Molinate
- Oxamyl
- Pendimethalin
- Pentachlorophenol
- Permethrin
- Picloram
- Propanil
- Pyridate
- Silvex (2,4,5-TP)
- Simazine
- Terbuthylazine (TBA)
- Tifluralin

Table 3.6 is a summary of the NEWater pesticide/herbicide compounds that had occasional detectable concentrations, but these concentrations are within the USEPA and WHO standards/guidelines or consider insignificant because of rarity and/or low concentrations.

Table 3.6 – Summary of NEWater pesticide/herbicide compounds with detectable results

		Standard/Guideline					Number of Results		
Parameter	**Units**	**USEPA**	**WHO**	**Mean***	**Min.***	**Max.***	**Total**	**Detectable**	**Not Detectable**
1,2-Dibromo-3-chloropropane (DBCP)	µg/L	0.2	1	NC	ND	0.57[a]	23	1	22
Chlordane (total isomers)	µg/L	2	0.2	NC	ND	0.02	18	3	15
Toxaphene	µg/L	3	-	NC	ND	0.1	11	2	9

[a] *An outlier one of 23 determinations. Not statistically significant.*

**Notes:*

1. *NC – Not calculated.*
2. *ND – Not detectable (below detectable concentration).*

Radionuclides

The radionuclide concentrations in NEWater are within the drinking water quality standards/guidelines stipulated by USEPA and WHO. Six radionuclides have been tested and all of them were at below detectable concentrations, except for gross beta. However, the value was well within the USEPA and WHO standards/guidelines.

Wastewater Signature Compounds

Four wastewater signature compounds have been tested and all of them were found at below detectable concentrations, except for ethylenediamine tetraacetic acid (EDTA). Again, the value was well within the WHO guideline.

Synthetic and Natural Hormones

Concentrations of the three human hormones: estrogen, ethinyl estradiol and 17β-estradiol have so far not been detected in NEWater.

3.3 Microbiological Water Quality

The microbiological quality of NEWater consistently meets the standards/guidelines set by USEPA and WHO. Six of these parameters are required by the USEPA and WHO standards/guidelines. The remaining four are potential microbial parameters for future drinking water standards/guidelines.

Table 3.7 summarises the total number of microbiological test results, including the sampling period.

Table 3.7 – Total number of microbiological analytical results

		Sampling Period	
Location	**Total Results Count**	**From**	**To**
Plant Feed Water (1)	802	5-Oct-99	30-Apr-02
MF Filtrate (2)	335	3-Jan-01	30-Apr-02
RO Permeate (3)	278	26-Dec-00	30-Apr-02
NEWater (5)	713	9-May-00	30-Apr-02
PUB Raw Water	196	5-Oct-99	30-Apr-02
PUB Drinking Water	20	8-Aug-00	30-Apr-02
Totals	**2,344**		

Table 3.8 is the summary of the SAMP microbiological results for NEWater.

Table 3.8 – Summary of NEWater microbiological results

Parameter	Units	Mean	Min.	Max.	No. Samples	No. Detectable	No. Not Detectable
Faecal Coliforms	CFU/100 mL	NC	ND	ND	99	0	99
Total Coliforms	CFU/100 mL	NC	ND	ND	99	0	99
HPC	CFU/mL	5.2	1.1	80	97	80	17
Coliphage-Somatic*	PFU/100 mL	NC	ND	ND	87	0	87
Coliphage-Male Specific*	PFU/100 mL	NC	ND	ND	87	0	87
Enterococcus*	CFU/100 mL	NC	ND	2.00E-01	99	1	98
*Clostridium perfringens**	CFU/100 mL	NC	ND	ND	91	0	91
Giardia	cysts/100 L	NC	ND	ND	16	0	16
Cryptosporidium	oocysts/100 L	NC	ND	ND	17	0	17
Enterovirus	Present/Absent	Absent	-	-	21	0	21

** These parameters are additional to those listed in the USEPA and WHO standards/guidelines.*

Note:

1. *ND = Not Detectable. NC = Not Calculated*
2. *Arithmetic means are shown.*

Out of the 10 microbiological water quality parameters, only HPC (heterotrophic plate counts) are consistently detected in NEWater. The HPC concentration is well within the USEPA Drinking Water Standards. NEWater HPC concentration (5.2 CFU/mL) is lower than those observed for PUB Drinking Water (15.2 CFU/mL) and PUB Raw Water (3,850 CFU/mL)

Figure 3.1 plots the arithmetic means of total coliforms and faecal coliforms against sampling locations. The microfiltration, reverse osmosis and UV disinfection systems provides effective “multiple barriers” to microbial pathogens. The microfiltration process demonstrates a 4 to 5-log removal (99.99 to 99.999%) of faecal coliforms and total coliforms. The results for PUB Raw Water and PUB Drinking Water are shown for comparison purposes.

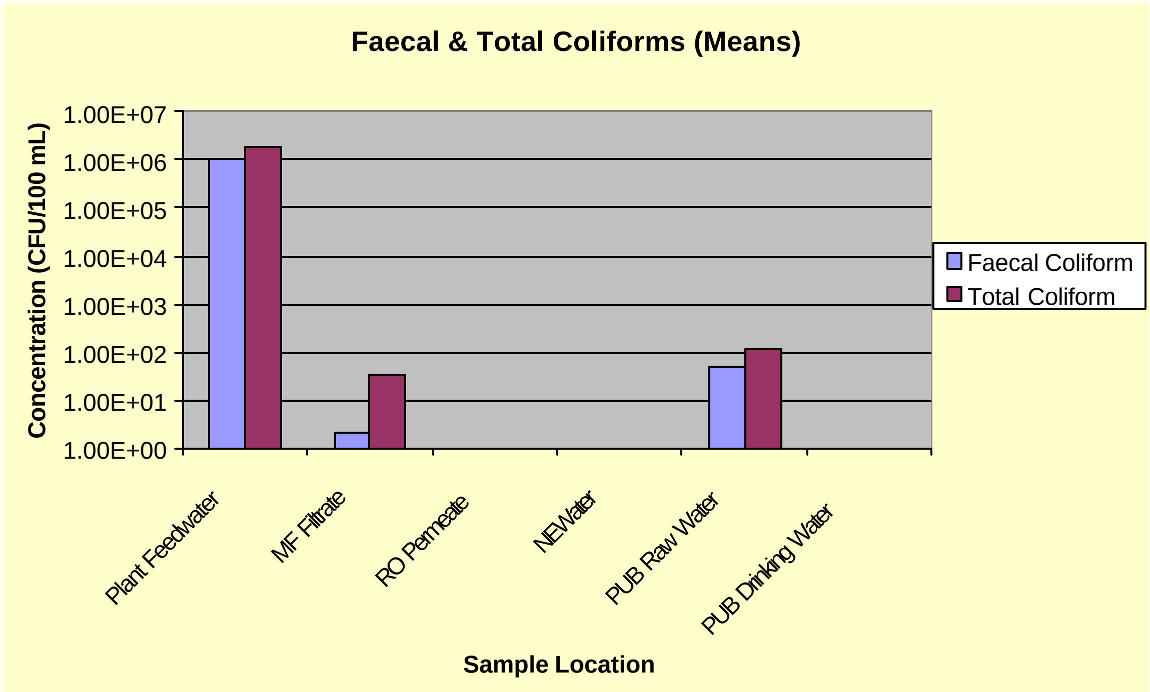

Figure 3.1 – Mean total and faecal coliforms at various treatment stages

3.4 Summary

The physical, chemical and microbiological data for NEWater are well within the latest requirements of the *USEPA National Primary and Secondary Drinking Water Standards* and *WHO Drinking Water Quality Guidelines*.

4. HEALTH EFFECTS STUDY

4.1 Overview

The Health Effects Testing Programme (HETP) involves the evaluation of the long-term chronic toxicity and estrogenic effects of the NEWater product in comparison to PUB Raw Water (reservoir water); the latter is drawn from the Bedok Reservoir. The HETP is complementary to the comprehensive physical, chemical and microbiological SAMP discussed in Section 3 earlier and is ongoing.

The HETP is based on the use of mice and fish toxicological assessment. The mice test started in October 2000 and the final sacrifice is scheduled for October 2002, after 24 months of life-long exposure. The final pathological report will be due six months later in April 2003.

The fish toxicological and estrogenic study commenced in January 2001 and is ongoing. This study is expected to be completed by mid-2003.

4.2 Mice Study Results

The long-term chronic toxicity and carcinogenicity potential of NEWater compared to PUB Raw Water is being tested by the mice study. The test mouse is the B6C3F1 strain, one of the most sensitive mouse strains used for toxicological and carcinogenicity assessment. It is widely used for conducting long-term health effects studies of new pharmaceuticals.

Groups of mice are fed NEWater and PUB Raw Water concentrates at 500 and 150 times, over a period of 24 months, with sacrifices taking place after three, 12 and 24 months of exposure.

The mice study is scheduled for completion in October 2002, after 24 months of life-long exposure. Pathology reports received for the short- and long-term mice study at 3-month and 12-month exposure times show that the exposure to concentrated NEWater at 500 and 150 times does not cause any tissue abnormalities or health effects attributable to its consumption.

The final (life-long at 24-month exposure) sacrifice is scheduled for October 2002.

4.3 Fish Study Results

Fish has been used in recent years as a model for human disease studies. The U.S. National Institute of Health (NIH) and National Research Council (NRC) have also recommended using this model for toxicological assessment.

The orange-red strain of the Japanese medaka fish (*Oryzias latipes*) is the test animal selected for the study because of its extensive biological database. The long-term chronic toxicity, as well as the estrogenic potential (reproductive and developmental) are currently being assessed.

The fish testing is conducted over a 12-month period with two generations of fish. The fish study commenced in January 2001. The pathology reports for the first and second fish generations showed no evidence of carcinogenic or estrogenic effects from exposure to NEWater.

However, the fish study is being repeated owing to design deficiencies of the aquarium system, fish husbandry issues and weaknesses in the study protocols. The Expert Panel requested the fish study be repeated with improvements to the study protocol. An extensive review of the fish study was completed with the collaboration of *Agri-food and Veterinary Authority of Singapore* (AVA). The repeat fish study commenced in late-April 2002 using the improved protocol, and is expected to be completed in mid-2003.

4.4 Summary

The HETP complements the comprehensive physical, chemical and microbiological SAMP. The ongoing HETP will provide further information on the safety of NEWater. The parallel use of mice and fish in long-term (carcinogenic and estrogenic potential) testing is unique and more sophisticated than previously reported health effects studies of water reclamation.

To date, the findings of the NEWater Study's HETP show that exposure to or consumption of NEWater does not have carcinogenic (cancer causing) effect on the mice and fish, or estrogenic (reproductive or developmental interference) effect on the fish.

5. EXPERT PANEL FINDINGS AND RECOMMENDATIONS

After evaluating the data and reports presented during the reviews, the Expert Panel has arrived at the following conclusions:

(a) NEWater is considered safe for potable use, based on the comprehensive physical, chemical and microbiological analysis of NEWater conducted over two years. The quality of NEWater consistently meets the latest requirements of the *U.S. Environmental Protection Agency's National Primary and Secondary Drinking Water Standards* and *World Health Organisation's Drinking Water Quality Guidelines*;

(b) Singapore should adopt the approach of indirect potable reuse (IPR) based on the following reasons:

- Blending with reservoir water will provide trace minerals, which have been removed in the reverse osmosis process, necessary for health and taste;
- Storage provides additional safety beyond the advanced technologies used to produce safe high quality NEWater;
- Public acceptance.

This approach is similar to the precedent practice in the U.S. with planned indirect potable reuse;

(c) The Singapore Government should consider the use of NEWater for indirect potable reuse, as it is a safe supplement to the existing water supply; and

(d) A vigilant and continuous monitoring and testing programme be carried out if a Planned IPR scheme is implemented.

*** End of Report ***