
Executive Summary

**Agreement No. CE 97/2002 (WS) -
Pilot Plant Study on Development of
Desalination Facilities in Hong Kong -
Investigation**



Prepared for
**Water Supplies Department
Government of Hong Kong SAR**



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Introduction

An adequate supply of potable water is of strategic importance to the economic well-being of the HKSAR. As it will take time to develop additional freshwater sources, WSD has started a systematic programme to identify and develop feasible options since late 1990s. It has been concluded in the previous study that reverse osmosis (RO) would be the most cost-competitive and environmentally-friendly desalination technology for municipal-scale application in the HKSAR.

The Consultancy under *Agreement Number CE97/2002 (WS) – Pilot Plant Study on Development of Desalination Facilities in Hong Kong* (this Study) commenced in May 2003 to explore the technical and financial viability of desalination using reverse osmosis technology in Hong Kong.

Objectives

The major study objectives of this Study are:

- To pilot-test performance of different pre-treatment processes and seawater reverse osmosis (SWRO) membranes under Hong Kong conditions;
- To recommend optimal parameters for detailed design and operation of future full-scale SWRO desalination facilities in HKSAR;
- To provide cost estimates for desalinated water production in HKSAR; and
- To recommend the way forward and any further studies with respect to developing the desalination facilities in HKSAR.

Key Tasks and Programme

Since commencement in May 2003, the key tasks undertaken in this Study include:

- Pilot plant studies, comprising site selection, environmental review, contract administration, procurement, supervision, optimisation studies, data analyses, and reporting;
- Process water quality monitoring including compliance tests of product water; and

- Seawater quality monitoring.

The key milestone events and dates are given in Exhibit 1 below. The Pilot Desalination Plant was procured under a design-build-operate (DBO) arrangement. Two separate sites at Tuen Mun and Ap Lei Chau were selected as the piloting locations, as they represent different sources of feed seawater in coastal environs of the HKSAR. The Pilot Desalination Plant was operated for a continuous 12 month period at each of the two sites to capture seasonal variations in seawater quality.

EXHIBIT 1

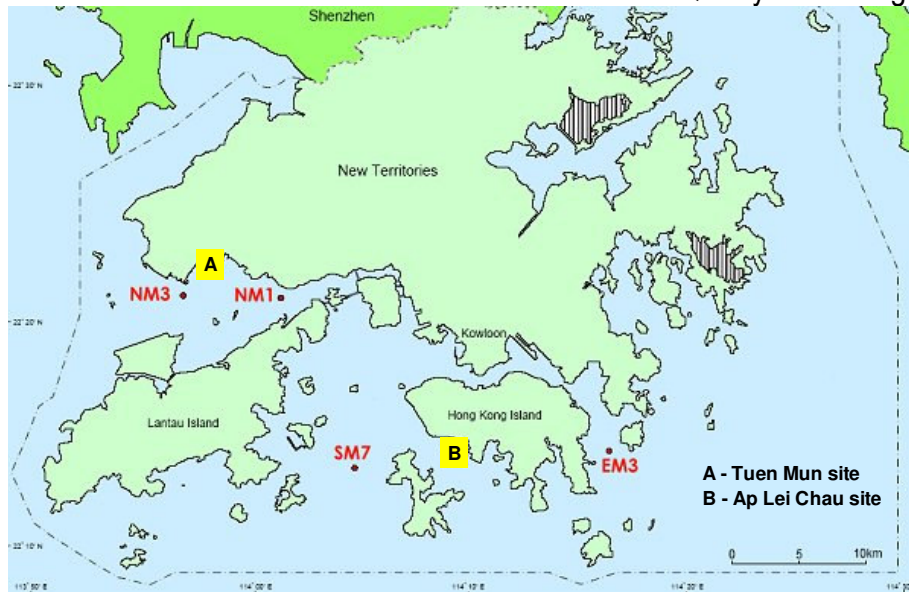
Key Milestone Dates

Task / Deliverable	Date
Commencement of Consultancy Study (Agreement No. CE 97/2002)	2-May-2003
Award of Contract for the Supply, Installation and Operation of Pilot Desalination Plant (Contract No. 9/WSD/03)	12-Feb-2004
Award of Contract for the Seawater Sampling and Laboratory Testing Programme (Contract No. ST/008/03)	22-Mar-2004
Award of Contract for the Raw and Treated Water Sampling and Laboratory Testing Programme at Tuen Mun site (Contract No. SO/WSD 7/2004)	8-Jun-2004
Commencement of Pilot Desalination Plant Operation at Tuen Mun site	7-Dec-2004
Commencement of Raw and Treated Water Laboratory Testing Programme at Tuen Mun site	21-Dec-2004
Completion of Pilot Desalination Plant Operation at Tuen Mun site	7-Dec-2005
Award of Contract for the Raw and Treated Water Sampling and Laboratory Testing Programme at Ap Lei Chau site (Contract No. SO/WSD 132/2005)	3-Feb-2006
Commencement of Pilot Desalination Plant Operation at Ap Lei Chau site	8-Feb-2006
Commencement of Raw and Treated Water Laboratory Testing Programme at Ap Lei Chau site	7-Mar-2006
Completion of Pilot Desalination Plant Operation at Ap Lei Chau site and Contract No. 9/WSD/03	5-Feb-2007

Exhibit 2 below shows the locations of the two sites.

EXHIBIT 2

Pilot Desalination Plant Site Locations and Seawater Quality Monitoring Locations



Process water quality monitoring on the Pilot Desalination Plant was conducted throughout the piloting periods at Tuen Mun and Ap Lei Chau. Compliance tests were conducted, as part of the process water quality monitoring, for Pilot Desalination Plant product water. A total of 113 parameters were tested according to the 2nd edition of the World Health Organization (WHO) Guidelines for Drinking-Water Quality (1993) and WSD objectives for drinking water.

Seawater quality monitoring at four representative locations (namely NM1, NM3, EM3, and SM7) were also conducted for one full year during the piloting period to monitor the feed seawater characteristics for the design of future full-scale SWRO desalination facilities. Also shown in Exhibit 2 are these four monitoring locations.

Technical Performance and Findings

Seawater Quality Monitoring

As shown in the long-term seawater monitoring by the Environmental Protection Department (EPD) and the seawater sampling and monitoring conducted under this Study, the seawater in the western side of HKSAR is typically more turbid and has higher suspended solid (SS) levels compared to that in the eastern side, due to influence of the Pearl River tidal flows. On the other hand, the seawater in the eastern side of HKSAR is less turbid and has lower SS levels, being remote from the influence of the Pearl River flows.

In summary, the western seawater exhibits distinct seasonal variations in salinity. The eastern seawater is oceanic in nature, having relatively

consistent quality throughout the year. The warm seawater temperature is an advantage to RO desalination in HKSAR.

Pilot Desalination Plant and Process Monitoring

The Pilot Desalination Plant was configured to combine different pre-treatment processes¹ with SWRO membranes² for the evaluation under Hong Kong conditions. The process flow diagram is presented in Exhibit 3 below. The performance of the pre-treatment and SWRO processes piloted was closely monitored. Overall, it was demonstrated that SWRO desalination was technically viable under HKSAR conditions.

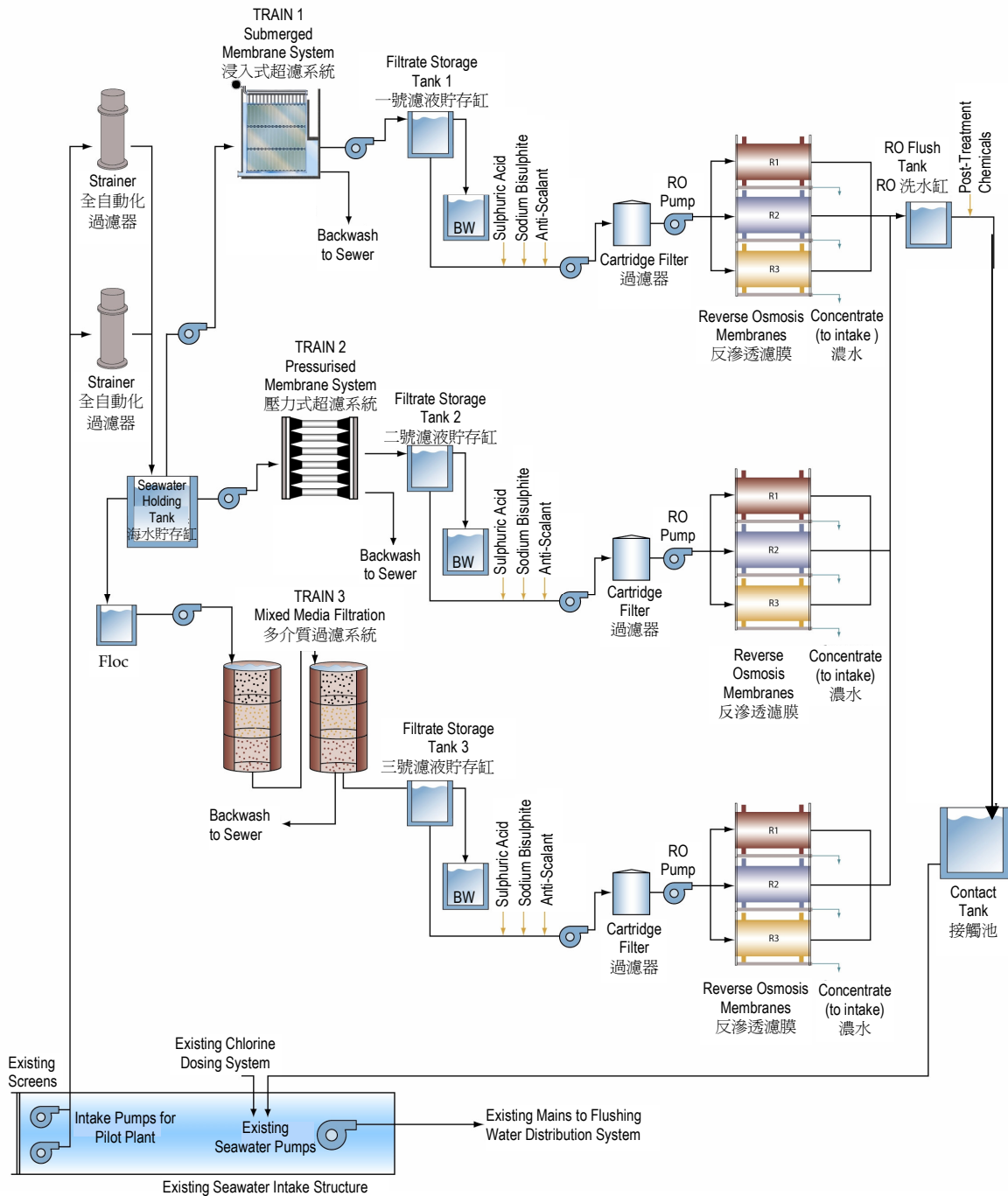
In the first site at Tuen Mun, the feed seawater was under strong seasonal influence from Pearl River estuary in summer wet season, during which the salinity dropped and turbidity rose considerably. The corresponding operational changes of the Pilot Desalination Plant that had been implemented include additional coagulant dosage in pre-treatment systems and reduced feed pressure in SWRO process.

On the other hand, the feed seawater in the second site at Ap Lei Chau was relatively consistent in quality. With relatively less variation in salinity, the Pilot Desalination Plant operation was relatively more stable.

¹ The pre-treatment systems were (1) Zenon ZeeWeed® 1000 Submerged Ultrafiltration System, (2) Norit X-Flow Pressurised Ultrafiltration System, and (3) a 2-stage Granular Media Filtration System.

² The SWRO membrane brands were (1) Hydranautics, (2) Dow, and (3) Toray.

EXHIBIT 3 Pilot Desalination Plant Process Flow Diagram



The performance of all piloted pre-treatment systems in terms of filtrate quality (turbidity and silt density index, (SDI)³) and the respective filtrate

³ Silt Density Index (SDI) is an indication of the quantity of particulate matter in water. It can be used to determine effectiveness of filtration processes in respect of particulate removal and fouling tendency of water treatment equipment based on filtering through a 0.45 µm filter pad for a timed period. Further details available in ASTM D4189.

target goals and objectives⁴ are tabulated in Exhibit 4 below. The filtrate quality from pre-treatment of membrane technologies was comparatively better than that of conventional media filtration.

Conventional GMF was unable to meet the performance objective or target goal of the SDI – this is somewhat surprising, as GMF is a rather conventional technology that has performed well in many overseas applications. It is believed that the performance of the GMF system can be improved by using an optimal mixed filter media.

EXHIBIT 4

Comparison of Pre-treatment Systems for Filtrate SDI and Turbidity⁵

	Ability to Meet Turbidity for 95th percentile		Ability to Meet SDI for 95th percentile	
	Target Goal (0.2 NTU)	Objective (1 NTU)	Target Goal (3.0)	Objective (4.0)
Tuen Mun - Pre-treatment, Submerged UF	No	Yes	No	Yes
Tuen Mun - Pre-treatment, Pressurised UF	Yes	Yes	No	Yes
Tuen Mun - Pre-treatment, Conventional GMF	Yes ⁶	Yes ⁶	No	No ⁷
Ap Lei Chau - Pre-treatment, Pressurised UF	Yes	Yes	No	Yes
Ap Lei Chau - Pre-treatment, Conventional GMF	Yes	Yes	No	No ⁷

On the other hand, all SWRO membranes showed satisfactory rejection of salinity in permeate; the differences of permeate quality among various SWRO membrane brands were not significant.

Recommended Optimal Parameters of SWRO Processes

With reference to the findings and operating conditions during the piloting periods, the recommended optimal parameters for the detailed design and operation of future full-scale SWRO desalination facilities in HKSAR are provided in Exhibit 5 below.

⁴ The filtrate quality shall meet the typical minimum SWRO process requirements (i.e. turbidity of <1 NTU and SDI of <5). For the purpose of this pilot study, two levels namely “Target Goal” and “Objective” are established. “Objective” level is equal to or slightly better than the minimum requirements for SWRO process, while that for “Target Goal” is more stringent.

⁵ It was proposed that only one of the two UF pre-treatment trains (i.e. Pressurised UF Pre-treatment system) would be carried forward to the Pilot Desalination Plant at Ap Lei Chau.

⁶ Only the performance of the GMF pre-treatment system after the rebedding in Oct 2005 is considered.

⁷ The filtrate SDI satisfies the typical minimum requirement of SDI < 5.

EXHIBIT 5

Recommended Optimal Parameters for the Future Full-scale SWRO Desalination Facilities in HKSAR⁸

Site	Tuen Mun representing feed seawater under strong seasonal influence from Pearl River estuary during summer wet seasons	Ap Lei Chau representing feed seawater with oceanic nature and not influenced from any freshwater discharges
General	Pre-treatment recovery – 90% to 95% (or per supplier's recommendations) Pre-treatment filtrate quality fulfilling minimum SWRO process requirements (typical value for turbidity of <1 NTU and SDI of <5) ⁹ Maintain the plant at least 95% of time online Membrane clean-in-place (CIP) requirement – typical filter runtime of several months in between CIPs (or per supplier's specifications)	
Pre-treatment – Ultrafiltration	Coagulant (ferric chloride) dosing – 1.5 to 3 mg/L as ferric	Coagulant (ferric chloride) dosing – 0.5 to 1 mg/L as ferric
Pre-treatment – Granular Media Filtration ¹⁰	Coagulant (ferric chloride) dosing – 6 to 8 mg/L as ferric	Coagulant (ferric chloride) dosing – 3 to 4 mg/L as ferric
General Parameters for SWRO Processes	Flux rate – 16 Lmh ¹¹ Recovery – 45% to 50% (first pass RO), 90% (second pass RO) Anti-scalant dosage – 1 to 2 mg/L (or per supplier's recommendations) Sodium Bisulphite (SBS) dosage – 2 to 4 mg/L (to maintain the feed oxidation-reduction potential (ORP) of below +300 mV) Feed pH ¹² – 6.5 (first pass RO), 10 (second pass RO) Provision of energy recovery devices (ERD) in first pass RO	
Site-specific Parameters for SWRO Processes	Feed pressure range – 45 to 60 bar (dry season), 20 to 30 bar (wet season) Annual variation in feed seawater salinity may offset the efficiency of ERD	Feed pressure range – 45 to 60 bar (year-round) Stable feed seawater salinity would be beneficial to the use of ERD

⁸ The recommended optimal parameters are based on technical performance in the operation of the Pilot Desalination Plant. These shall serve as reference parameters for future full-scale SWRO facilities.

⁹ Reference: Dow Filmtec Technical Manual (July 2005), Section 2.5.1 on page 54.

¹⁰ Gravity Filters are typically designed in full-scale facilities. The optimal parameters presented are for reference purposes.

¹¹ Lmh (litre per hour per square meter) is the unit for flux which is defined as the rate of flow passing through a unit of membrane area.

¹² Further studies are recommended to determine optimal feed pH for future full-scale SWRO facilities.

With reference to the operational experience from the Pilot Desalination Plant, the recommended customisation for site-specific feed seawater characteristics include additional sedimentation (such as gravity filter or dissolved air flotation) for seawater in western side of HKSAR. On the other hand, for seawater with considerable organic content, a pre-chlorination step upstream of pre-treatment process(es) for organics control would be recommended.

Red Tide Event

Red tide occurrence is potentially disrupting to SWRO processes, thus the impact to Pilot Desalination Plant should be studied. Only one such event, however, was encountered on 2nd May 2005 during the Pilot Desalination Plant test. Under the red tide event, all SWRO systems did not show any adverse effect on permeability. It was considered that the pre-treatment systems were able to prevent or suppress impacts of the red tide event. The robustness of the pre-treatment system under such disruption, nevertheless, was inconclusive based on one single event.

Product Water Quality and Boron Mitigation

The product water from the Pilot Desalination Plant showed compliance with the 113 tested parameters under the 2nd edition of WHO Guidelines for Drinking-Water Quality (1993)/WSD objectives for drinking water quality, while the 3rd edition of WHO Guidelines for Drinking-Water Quality (2004) which is currently in force is also compared for reference. Compliance with 2004 WHO guidelines is generally expected except that boron needs special attention. Boron mitigation in SWRO permeate to comply with 2004 WHO guideline value (0.5 mg/L) was a major challenge identified in this Study – and in fact faced by all SWRO facilities worldwide – given that boron in seawater (pre-dominant species of boric acid, H_3BO_3 , which is *non-ionic*) is not readily rejected by SWRO processes.

The key of boron mitigation by SWRO processes is to adjust the process pH towards alkaline range in order to shift the pre-dominant boron species to ionic form. Two approaches namely RO alkalisation and second pass RO system were pilot tested in this Study. It was recommended, based on both technical and economic merits, to adopt the partial second pass RO system for subsequent permeate blending in the future full-scale SWRO facilities for boron mitigation.

Post-treatment Study

A post-treatment study was conducted to evaluate corrosion of the product water from the pilot desalination plant, and to verify compatibility or effect of product water with the existing potable water distribution system in HKSAR. In summary, except for the questionable results for the cement-lined ductile

iron pipe material, the corrosion rates in the other four tested materials¹³ were within allowable ranges. The product water from the pilot desalination plant would be compatible with the selected pipe materials although further evaluation is recommended for confirmation.

Cost Estimation for Full-scale SWRO Facilities

Preliminary cost estimates were conducted with the base case scenario of developing a 50 million cubic metre (mcm) *per annum* SWRO facilities in HKSAR. Depending on the choice of different pre-treatment systems, the estimated capital cost of the SWRO facilities ranged from HK\$2.5 billion to HK\$2.7 billion, while that for the estimated annual recurrent cost ranged from HK\$196 million to HK\$214 million.

At the base case scenario and 4% discount rate, the estimated unit water production cost ranges from \$7.90/m³ to \$8.53/m³, which is very similar among the different pre-treatment and SWRO systems piloted under this Study (difference of about 8 percent).

Sensitivity analyses on the cost estimates showed that unit water production cost would be generally sensitive to electricity tariff, plant capacity, plant service life (especially E&M plant for salt water equipment), required product water boron level (i.e. scale of the second pass RO), and plant utilisation. The level of boron at the raw seawater abstraction point is also an important issue to be considered when developing a full-scale SWRO facilities.

Summary

The Pilot Desalination Plant was successfully completed. It is concluded that desalination using SWRO is technically viable under HKSAR conditions. Changes in local seawater characteristics and corresponding operational adjustments were identified.

Recommendations

Implementation Issues for a Full-scale Facilities

The overall economic costs and benefits to HKSAR of pursuing seawater desalination as a strategic water resource option may worth consideration. It is recommended to resolve the following key issues prior to implementing full-scale SWRO facilities, specifically (1) to seek *public* support to desalination; (2) to determine the *optimal capacities* of the full-scale SWRO facilities; (3) to

¹³ The other four tested materials were bitumen-lined mild steel, unplasticised polyvinyl chloride (UPVC), PVC-lined galvanised steel and medium density polyethylene (MDPE).

attempt to negotiate a more favourable *electricity tariff*; (4) to investigate the *technical and institutional feasibilities* of co-siting the proposed SWRO plant(s) with existing power station(s), given the potential cost savings to desalted water production; and (5) to conduct an *investigation/preliminary design* and an *environmental impact assessment study* under the Environmental Impact Assessment Ordinance (EIAO) for the full-scale SWRO facilities.

Recommendations

To facilitate the ultimate goal of pursuing the full-scale SWRO facilities in HKSAR, the following recommendations are made in this Study:

Demonstration Plant. It is considered prudent to conduct a *medium-sized demonstration desalination plant* to supply a local community to gauge public opinions and allow time to investigate the reliability of water supply due to climate changes and other factors.

Co-location of Desalination Facilities and Power Plant. It is recommended to explore the possibility of the *co-location option* of the desalination facilities and power plant. The mutual benefits include savings in construction of sub-station, avoidance of long transmission lines, desalination facilities as base load for power plant, and sharing common infrastructure of seawater intake and outfall.

Further Study on Renewable Energies. There are opportunities and constraints of using renewable energies in HKSAR to operate the power-driven desalination processes. To fully explore the full potential, a further study on the most appropriate form of renewable technologies and their applications to desalination in HKSAR is recommended.

Further Study on Optimal Parameters for Future Full-scale SWRO Facilities. Further studies are recommended to confirm the overall effectiveness of alkalization and partial second pass system with permeate blending for boron mitigation in the full-scale SWRO facilities. Further evaluation of the corrosivity of product water is also recommended to confirm its compatibility with pipe materials.