Technical Memorandum

To: Dr Gisela Kaiser, Informal Settlements, Water & Waste
cc: Rolfe Eberhard, Chris Heymans
From: Tom Pankratz
Date: 21 June 2018
Subject: Seawater Desalination in Cape Town, South Africa

Executive Summary

This report summarizes its author's comments and recommendations following an assignment by the World Bank to support the City of Cape Town as it prepares for a world-class procurement of a permanent desalination project as part of Cape Town's wider water augmentation strategy.

Background – Cape Town has recognized that seawater desalination could increase the reliability of its water supply for more than 15 years. Several studies have been undertaken in this regard, including a 2015 feasibility study conducted by WorleyParsons. The pursuit of a permanent, 'optimal scale' seawater desalination plant has repeatedly been mentioned in the City's *Water Outlook 2018 Reports*.

Earlier this month, I met with City executives, staff members and consultants to discuss the global seawater desalination market and the lessons learned when implementing permanent, large-scale projects. During this trip to Cape Town, I also visited seven of the prospective coastal sites at which a desalination plant may be located.

These site visits include two of the three locations at which temporary seawater desalination plants have been constructed and now demonstrating—albeit at a relatively small scale—that seawater desalination is a viable water supply alternative for Cape Town.

The May update to the City's *Water Outlook 2018 Reports* suggests that, "decisions around desalination must not be delayed." This is sound advice.

Recommendations –

- It is recommended that the City move ahead with plans to develop a permanent seawater desalination plant that employs reverse osmosis (RO) technology.
- It is further recommended that the plant have a production capacity of no less than 50 ML/day, with a preferred capacity range of 100-150 ML/d.
- Based on the preliminary information available, the Cape Town Harbour site appears to be an appropriate, relatively 'low-risk' site to host such a plant.
- A design-build-operate (DBO) procurement is the recommended approach for the City's initial desalination project.
- The City should initiate a feasibility study on the Harbour site, and begin the process of obtaining a 25+ year lease commitment from the site's owner.

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Implementing Large-scale Seawater Desalination in Cape Town

Desalination has been taking place on earth since its formation. Distillation and osmosis—the two concepts embodied in most of today's desalination facilities—are natural phenomena that have only recently been adapted by humans. Although the idea of separating salt from water is not new, the concept required an understanding of physical chemistry before it could be commercially exploited.

While distillation was first identified as a method of seawater desalination as early as the fourth century BC, osmosis was first identified in 1748, when French physicist Jean-Antoine Nollet found that a pig's bladder filled with ethanol and submerged in a trough of water would expand until it burst. He correctly reasoned that pure water would diffuse through the semipermeable bladder in order to dilute the ethanol until the solutions inside and outside the bladder were at equilibrium.

However, it wasn't until 1960 that scientists at the University of California at Los Angeles developed a synthetic membrane that would allow the natural osmosis process to be reversed to produce fresh water. Within a few years, a brackish water membrane was introduced commercially, and by 1974, membrane technology had developed to the point that seawater desalination was commercially viable.

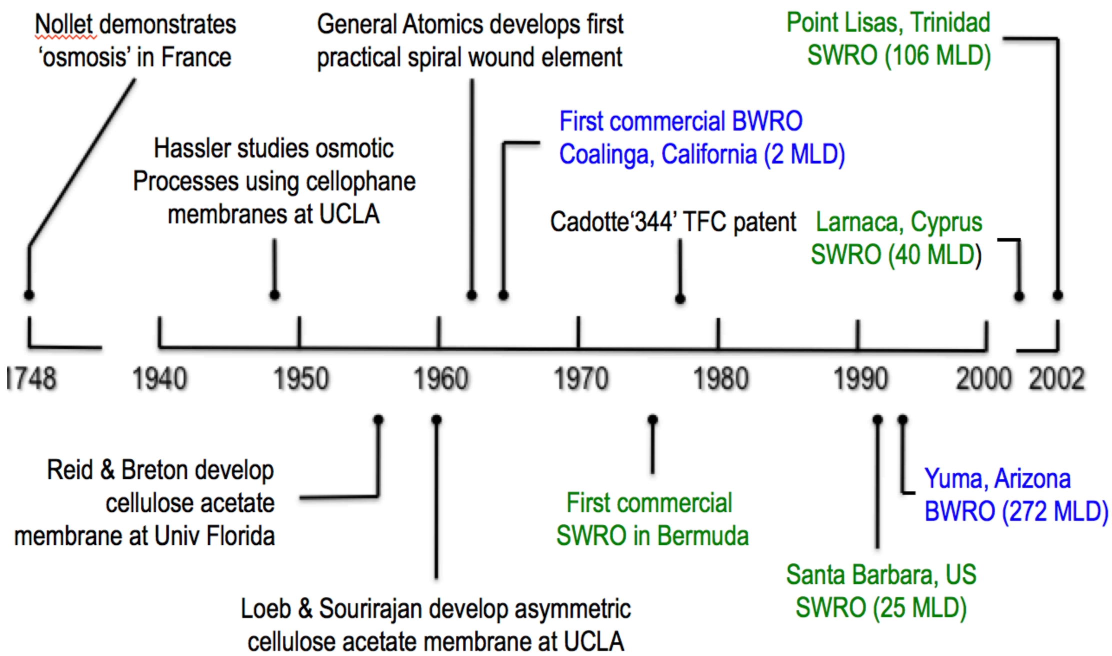

Figure 1. Membrane desalination's first 270 years

Membrane desalination had some inherent advantages over evaporative technologies. Most notably, reverse osmosis (RO) required a fraction of the energy consumed by thermal desalination processes. Thermal processes also had large cooling water requirements, necessitating huge seawater intakes, along with their resulting impact on local marine life.

For these reasons, the size and number of RO desalination installations grew quickly, and RO plants soon began to replace existing thermal capacity. Through 2002, 15,000 ML/day of brackish and seawater was desalinated using RO technology. And, in the last 15 years, over 7,800 RO plants have been installed producing an additional 50,600 ML/day of desalted water, 55% of which is desalted seawater.

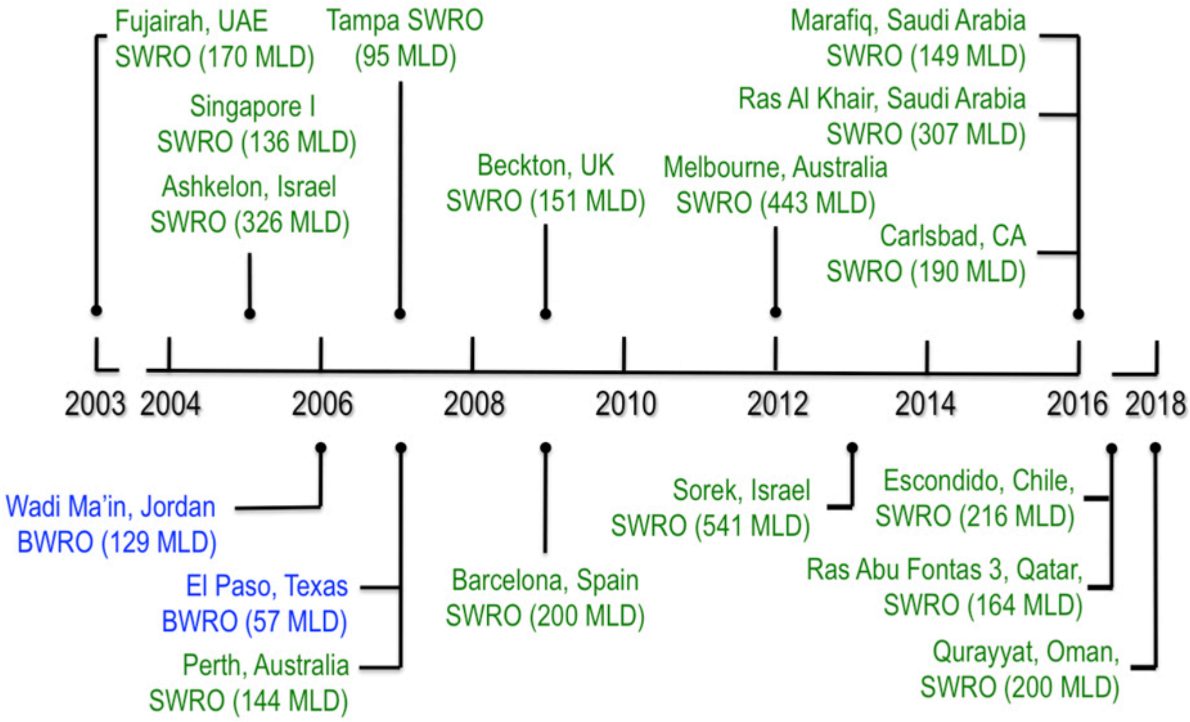

Figure 2. Selected RO Projects 2003-2015

What's Changed?

RO membrane systems may now be the fastest growing segment of the water industry, as well as an integral part of almost every potable reuse project. Technological advances have improved performance and reduced capital and operating costs to the point that RO desalination is now a viable, weather-independent alternative to conventional treatment and/or water importation in many water supply situations.

Some of the most notable technological advances are:

RO membrane technology – Membranes are the heart of the desalting process, and advances in membrane science have resulted in lower pressure operation with 99.75% salt rejection, with both increased reliability and longer operational life.

Pretreatment advances – Although RO membranes are able to prevent the passage of dissolved solids, they are highly susceptible to fouling by suspended solids and organics. It is therefore important to remove these solids ahead of the RO membrane to maintain performance and prevent irreversible damage.

In fact, most RO failures are more accurately described as "pretreatment failures". The use of technologies such as dissolved air flotation (DAF) and ultrafiltration (UF) have demonstrated the ability to consistently deliver high-quality feedwater to RO systems, even when faced with deteriorating water quality or high solids conditions such as those encountered during algal blooms.

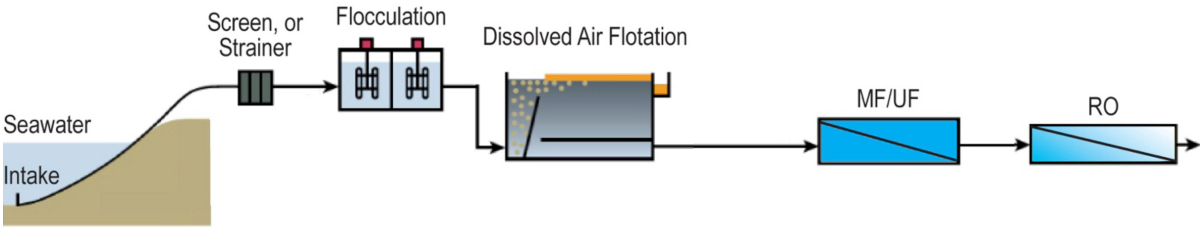

Figure 3. Typical seawater RO system with pretreatment

Energy consumption – RO system energy requirements are directly related to feedwater salinity, and depending on local electricity rates, the energy costs may represent 33% to over 50% of an installation's operating cost. New pumping strategies, high-efficiency energy recovery devices and improvements in membrane design and system configurations have reduced energy consumption to a point that is within 25% of its theoretical limit. Seawater desalination's specific energy consumption now averages about 3.5 to 4.0 kWh/m^3 of water produced.

Plant size – The design complexity and operational requirements of a large-scale RO plant are not significantly different from that of a smaller plant, and development and permitting costs are much more dependent on siting-related issues than they are to a plant's production capacity. Economies-of-scale can therefore contribute to a considerable reduction in the unit cost of fresh water production.

The inherent modularity of RO systems is an important planning consideration, as is the recognition that the economies-of-scale begin to have a noticible impact at a production capacity of about 50-55 ML/day. An optimal plant size is often 100-150 ML/d, and space permitting, plants are usually readily expandible.

Commodification – The growth in the RO market has meant that many key components, products, sub-systems and even entire plant designs have been standardized. Most notably, the membrane itself has been standardized to the point that one supplier's product is virtually interchangeable with its competitors.

Project Development Challenges

Alternative project delivery – Changes in project procurement methods have become one of the biggest drivers in the growth of new, large-scale municipal seawater desal projccts. Because of the cost and complexity of developing new projects, a whole host of alternative project delivery methods may be considered.

These range from fairly straightforward design-build-operate (DBO) contracts to public-private partnerships (PPP), some of which include the private sector participant assuming everything from permitting risk, to project financing and asset ownership for 20 to 35 years.

In some years, over 50% of the contracted capacity involves a non-traditional procurement with increased private sector involvement.

Project justification – The decision to move forward with a permanent, large-scale desalination project may be one of the most politically sensitive decisions that City leaders must make. A desalination project's cost and complexity will have long-term budget, environmental and social impacts, which must be weighed against the prospects of doing nothing, which may be even more damaging, and unpredictable.

Fortunately, there are new design tools that may help urban planners make these decisions. There is also a growing body of knowledge surrounding the cost and challenges of developing desalination projects.

Coastal cities around the world are addressing the seawater desalination challenge in their long-term water plans. With the exception of Middle East and many island countries, seawater desalination is usually considered for only a portion of a community's overall water supply, which also may include water importation, groundwater abstraction, water reuse and conservation/demand management.

The City of Perth, Australia, is a widely lauded example of a city with a diversified water portfolio that followed a pragmatic approach when implementing seawater desalination. The Water Authority of Western Australia made the decision to move ahead with development of a 137 ML/day seawater desalination plant in midst of its Millennial Drought in 2002, and the resulting plant was fast-tracked and fully operational by 2006.

When the drought conditions continued, the Water Authority moved forward with a second 137 ML/d project at another site, further from the city. On the same August 2011 day that the new plant was commissioned, it was announced that the construction crews would remain onsite and work would immediately begin to double the plant's production. Sixteen months later, the expanded plant began delivering a total of 274 ML/day. Nearly 50 percent of Perth's water supply can now be provided through seawater desalination.

San Diego, California is an example of another coastal city that has diversified its water supply portfolio to adapt to an increasing population, and growing water scarcity. In 1991, 95% of the regional water supply was imported from far northern California. Following long and protracted studies, the San Diego County Water Authority contracted with a private sector participant to build the Carlsbad Seawater Desalination Plant, which now produces 190 ML/day of desalted seawater under a 30-year take-or-pay contract.

While the Carlsbad project is not without its detractors, it is widely viewed as a success, and is doing precisely what it was intended to do: provide a locally-controlled, weather independent supply of up to 10% of the area's needs with a nominal melded rate increase. Other seawater desalination plants are being considered, with new locations being identified and studied, but no decision to move forward will be made until it is necessary.

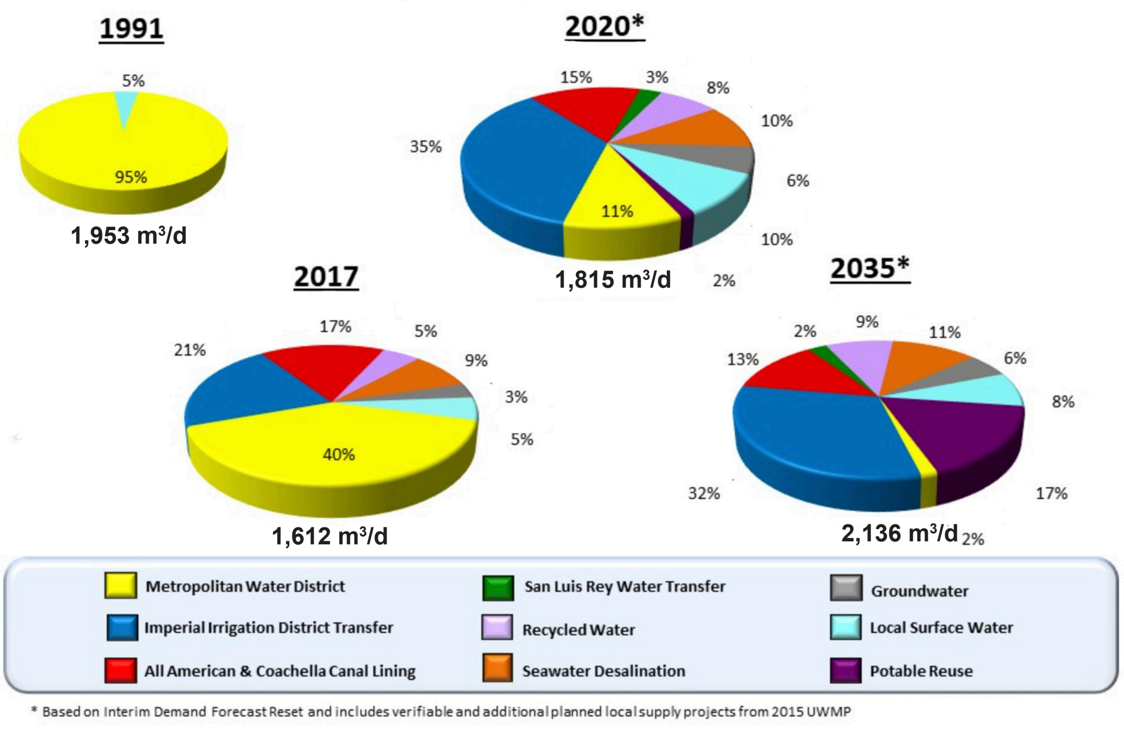

Figure 5.Increasing San Diego's Water Reliability through Supply Diversification

A planning tool developed by an MIT researcher is an example of how urban planners can model the challenges they face when developing new infrastructure. According to researcher Sarah Fletcher (Attachment 1), the planning tool is able to analyze multiple uncertainty, risk and capital planning scenarios involving both existing reservoirs and new supply infrastructure, i.e. desalination plants. By evaluating tens of thousands of simulations, planners can evaluate various frameworks, ranging from doing nothing to various combinations of small and large-scale desalination.

Siting Challenges – Despite the large number of plants installed, and the growing level of process standardization that exists, there are two elements of a seawater desalination plant that are unique to each project and represent its largest cost variables: the seawater intake and concentrate (brine) outfall. Together, the identification of the technical, environmental and commercial challenges of these two related issues must be considered as the first step of any project 'fatal flaw' analysis.

Whereas, seawater intakes/outfalls have historically represented 4% to 12% of an entire facility's capital cost, some intake arrangements may now cost 25% to 50% or more of a project's capital cost.

Although co-locating a seawater desalination plant at an electric power generating plant with once-through cooling was once considered desirable, the high flows of once-through power plants and the resulting *impingement*—which refers to trapping fish and other larger marine organisms against the intake screen, and *entrainment*—which occurs when smaller organisms pass through the screen and into the process equipment—are now looked upon unfavorably.

For this reason, desalination plants in the United States are now required to be permitted as standalone facilities, so as not to justify the continued operation and prolonged life of a large, once-through cooling system.

Finding a site that is convenient to the seashore, environmentally and socially acceptable, convenient to the existing water reticulation system and electric power supply, and with sufficient land to construct a plant of the desired production capacity will be one of a planner's first challenges.

Other challenges – A seawater desalination project is not just one project, it is a collection of independent projects integrated into a single facility. Aside from the intake and outfall, pretreatment system and the desalination process itself, a seawater RO plant also includes a post-treatment component and a product water conveyance component that are significant, and often underestimated engineering and construction projects unto themselves.

Cape Town's Challenge

The idea of seawater desalination in South Africa, and Cape Town specifically, is not new. The first edition of South Africa's September 2004 *National Water Resource Strategy* recognized the possibilities of seawater desalination as a coastal water supply, noting:

> "Desalination of seawater offers particular opportunities for coastal users. Although generally still more expensive than developing (and transferring) surface resources, the technology is tending to become more competitive as a

result of advances in the field, particularly through the introduction of more cost-efficient membrane technologies."

Three months later, a Cape Town mayoral committee recommended that a study be conduced to investigate the most appropriate site for a pilot plant. It said that a smaller project would provide pertinent lessons for large-scale desalination and recommended that a pilot project with a production capacity of 0.5 to 5 ML/d be undertaken. The resulting September 2005 report noted:

> "To avoid severe restrictions it is essential that alternative water sources are investigated further and responsibly and timeously developed. Desalinated seawater represents a virtually unlimited resource to which Cape Town, as a coastal city, has easy access. Unlike in the case of other water resources the supply assurance of desalinated seawater is highly unlikely to be affected by climatic variations."

The 7 ML/d temporary seawater RO plants at Monwabisi and Strandfontein, and the 2 ML/d project at V&A Waterfront should provide valuable lessons that may be applied to the decision-making process necessary for a permanent large-scale project to serve Cape Town.

As part of the second edition of its May 2011 *National Water Resources Strategy*, South Africa's Department of Water Affairs (DWA) said that the "National government recognizes that desalination will play a critical role in the country's future water security." It listed seawater desalination as one of six key challenge saying:

> "Desalination should be considered as an option to increase supply of water, especially in coastal areas with limited sources of supply," and, "Large metropolitan municipalities and water boards with a proven track record in the implementation of large water treatment projects must be positioned to implement desalination projects."

Embarking on the region's first permanent large-scale seawater desalination plant will be an enlightening experience. If there is one lesson that can be learned from the past 15 years of global desalination project development, it is to avoid building a plant too big, too soon. Furthermore, and particularly for an inaugural plant, it is better to select a low-risk site with as few unknowns as possible.

While these suggestions may sound intuitive, there have been numerous examples where a community waited too long to decide to move forward, and when the decision to do so was finally made, they felt they needed to rush ahead with a large and expensive 'drought-buster' project, only to find themselves with an oversized and underutilized asset.

Recommendations

Plant Siting – Based on visits to potential project sites on False Bay, the West Coast and Cape Town Harbour, the Cape Town Harbour site seems to represent the least-risk option in terms of technical, economic, environmental and social challenges.

There appears to be sufficient area available to site a 100 to 150 ML/day seawater RO plant, there are reasonable existing intake and outfall options, relatively convenient access to both a power supply and the City's water reticulation system.

There are numerous examples of successful seawater RO plants and pilot plants that have been sited in harbour locations or on navigable waterways with significant ship traffic.

Preliminary indications are that pretreatment risks related to a harbour location could be mitigated with an appropriate pretreatment system.

Plant Costs – Using GWI's DesalData.com Cost Estimator, the costs of a 100 ML/d seawater RO plant have been estimated for three different plant scenarios in Figure 6, below: a 'basic' plant to provide a baseline comparison, a plant located at the Cape Town Harbour site, and a plant located at a site requiring an offshore, non-tunnelled intake and outfall.

This analysis does not account for product water storage or distribution costs.

	Basic	Harbor	Non-Harbor
Pretreatment	129	413	413
Civil Costs	170	270	270
Pumps & energy recovery	145	173	173
Equipment & mat'ls	338	436	436
Design costs	87	255	437
Legal & professional	15	44	76
Installation services	122	122	122
Membranes	80	96	96
Pressure vessels	23	27	27
Piping (high alloy)	198	198	198
Intake/outfall	114	105	342
Total (ZARx10^6)	1,520	2,139	2,589
CapEx: ZAR m/ML/d	15.2	21.4	25.9
Water Cost* : ZAR/m^3	n/a	12.32	13.71

* all values in ZAR, 20-yr term, 75/25 D:E, 6% int, 94% availability, ZAR 0.85/kWh

Figure 6. Estimated RO plant Capital Cost

Project delivery – A permanent, large-scale seawater RO plant requires significant design, execution and operational expertise, and is usually one of the most complex infrastructure projects that a municipality can undertake. It is therefore recommended that a design-build-operate (DBO) procurement model be considered to deliver such a project, particularly when project is the first of its type undertaken by the municipality.

The DBO project delivery process generally offers benefits that include a shortened project schedule, reduced owner risks, construction and operational cost savings and increased access to new and innovative technology.

Build-operate-transfer (BOT), build-own-operate-transfer (BOOT) or independent water project (IWP) procurement models have been successfully employed for seawater desalination projects by some public entities. However, employing public-private partnerships (PPP) such as these may require new legislation, which may significantly increase a project timeline. It may be premature to recommend this approach for the City of Cape Town's first project.

However, a BOT/BOOT/IWP may be considered if project funding or additional risk shedding is necessary. A draft term sheet for a pending seawater RO project at Huntington Beach, California, is attached as a reference (Attachment 2). The term sheet outlines the division of project participant responsibilities for a large-scale seawater RO project, which will include non-recourse financing for a 30-year term.

Project timeline It is estimated that it will take five to seven years to complete a large-scale seawater RO project in Cape Town. This estimate includes preparation and approval of an environmental impact assessment/report, and securing all necessary permits and approvals.

(Note that the project schedule for the project delineated in the attached term sheet shows that the resulting plant will have a Commercial Operation Date (COD) that is no later than 48 months from financial close.)