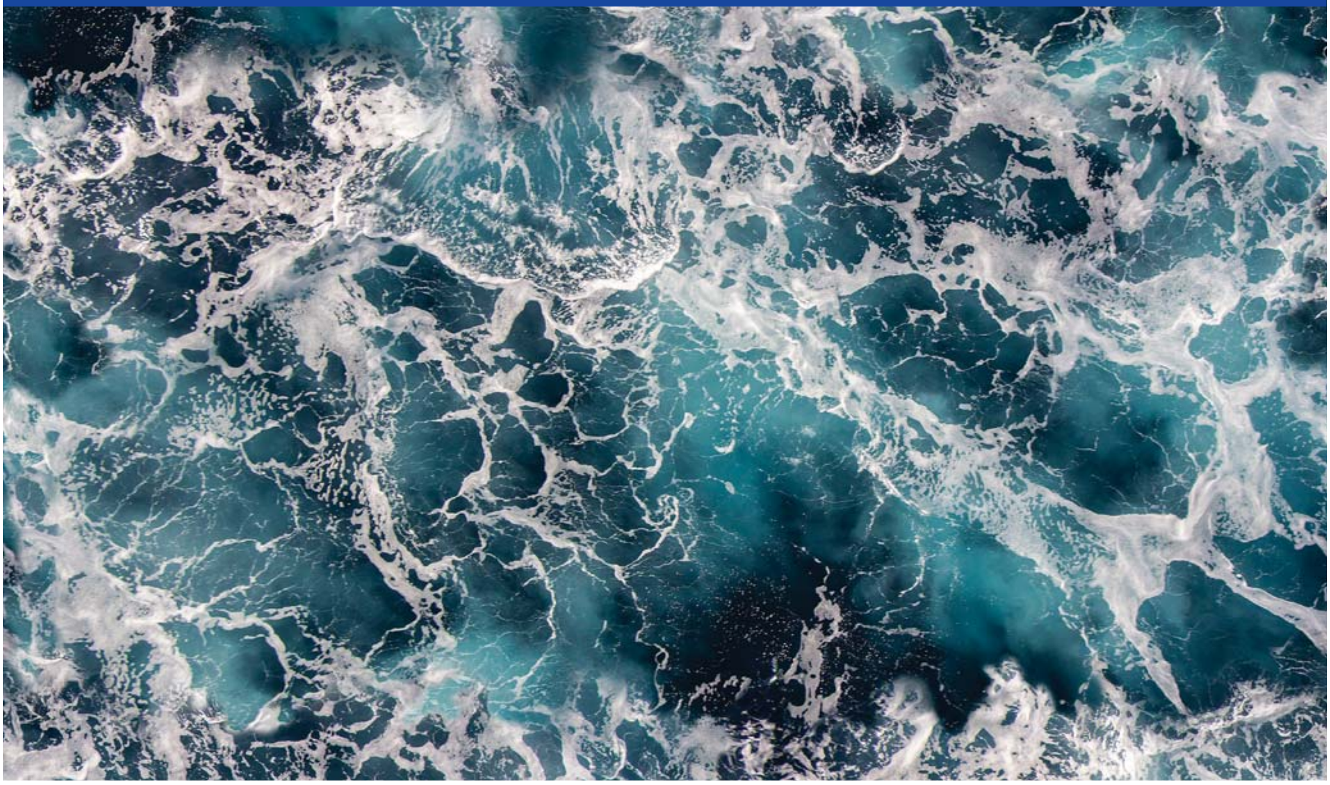
SEAWATER DESALINATION

Seawater desalination – what difference does site choice make to cost?

There are various factors to consider when selecting desalination as an alternative water-supply option. The selection of a suitable site may be the most important contributing factor to the cost of a large-scale seawater desalination plant. This is according to Dawid Bosman of TCTA.



Seawater desalination holds a tantalising value proposition for coastal cities: An infinitely scalable supply of assured water, at a predictable price, which effectively de-couples water security from the climate. Such drought-proofing already serves many cities around the world; more than 160 seawater desalination plants with a capacity beyond 50 Ml/day are on-line, providing assured water to local authorities in Spain, the Middle East, Australia, the USA and others.

Given the extent to which South Africa's natural water resources have already been committed, it is likely that large-scale desalination will be adopted by some of the coastal metros, probably within a five-year timeframe. From a national perspective, it is an opportune time to learn from the project implementation experiences and practices of other nations. The Trans-Caledon Tunnel Authority (TCTA) has, over the past few years, been observing the desalination implementation lessons from abroad, in anticipation of the first desalination mega-project on home ground.

One of the early observations has been that the capital cost of these plants can vary significantly: Among a benchmark group of more than 200 similar projects (all extra-large scale seawater reverse osmosis plants, or XL-SWRO), the specific capital cost ranges from as little as $200 per m^3 per day capacity, to more than $3 600, with the 25th and 75th percentiles spanning from $800 to $1 400. As a general rule of thumb, an XL-SWRO plant should cost in the vicinity of $1 000 for every kl/day capacity. Taking into account operating cost within normal parameters, the product should cost in the vicinity of $0.60 to $1.20 per m^3. The benchmark costs are expressed in US Dollar, for ease of comparison.

This leads one to the question: What are the factors contributing to an XL-SWRO project being relatively more expensive than others, and how can this be managed? Expensive water is a political hot potato, and more so when it could be blamed on the adoption of a new technology, even when a drought made that decision unavoidable; that has been one of the key lessons emanating from the Australian desalination build programme of 2006 to 2012.

While there are multiple factors that influence the capital cost of desalination plants, this analysis suggests that site selection is perhaps the single most important contributing factor, to the extent that it may pre-determine a number of very expensive design options.

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Site considerations for large-scale desalination plants
Large-scale seawater desalination requires the continuous abstraction of a large quantity of consistent quality seawater, the delivery of this feed-water into a high-pressure industrial process plant, where energy will be used to separate some of the volume as freshwater, with the remaining portion returned to the sea as brine. The cost and environmental impact of this endeavour is significant, and can become daunting if it is not planned and executed with great care.

The site chosen to place this operation is extremely important, and the impact of this choice will allow or constrain subsequent design options, construction methods and operational efficiency. If the chosen site will cause construction to infringe upon a pristine beach or a sensitive wetland, or cause a noise or visual disturbance to a residential area, or the abstraction of feed-water and release of brine will exceed regulated limits in the marine environment, then the developer would be compelled to mitigate those impacts, normally through adjustments in the plant design. Invariably, this leads to higher cost.

However, a site that could avoid some or all of these impacts, will usually allow easier permitting, bring less pressure on the developer to select expensive design options, and allow easier integration with pre-existing infrastructure. Considering the XL-SWRO projects completed during the last decade, it would appear that the choice of site determined subsequent capital cost mainly in two areas:

- The **marine works**, where the design options of the intake and outlet structures may be determined by the site topography, the adjacent land use or environmental sensitivity;
- The **plant architecture**, where visual and noise impact on affected parties and nearby settlements, during construction and thereafter, need to be mitigated through design modifications.

Marine works
The marine works is a key element of the capital outlay of a desalination plant. These structures generally appear over-designed, and much larger than one would intuitively estimate they should be. This is due to two reasons, firstly, that the RO process recovers only about 40% by volume of the feed water as permeate or product water, and hence the intake pipe needs to also accommodate the 60% that will return to sea. Secondly, the fluid velocity in the intake pipe must be sufficiently low, in the range of 0.05 to 0.1 m/s, to avoid any marine life entrainment. This requires large-diameter structures, in general.

The marine works is usually either a trenched pipe or a jacked pipe design, which are generally cost-effective, or a tunnel design, which tends to be much more expensive. The choice of site will largely determine which construction method could be followed. The DesalData costing model indicates that by selecting a tunnel design, instead of a trench design, the cost of the marine works increases by 200%, and total plant capital expenditure increases by about 30%; directly through more complex construction, and indirectly through greater legal and design costs (Global Water Intelligence, 2018). Brief descriptions of the two designs will help to illustrate why tunnelling is much more expensive.

A trench design can be usually be followed when the site is not significantly elevated above sea level, and with direct access to a sterile beach. Typical construction comprises a trench dug towards the beach with pile-driven steel sheets as reinforcement, in which large-diameter HDPE pipes are laid. Through the surf-zone and out to sea, the pipe is laid in a sub-surface trench, which may be protected by a temporary steel jetty, as required by local conditions. Figures 1 to 3 shows some of the trench design elements during construction.

Tunnelling is usually required when:

- The site is situated some distance inland from the beach, and other developments block its access to the sea (an example would be the Gold Coast Desalination Project);
- The beach is in recreational use, or ecologically sensitive, which would be impacted by a trench (An example would be the Southern Desalination Project);
- The site is on a raised coastal ledge, which requires an engineering solution to access and lift the water to a higher elevation (An example would be the Adelaide Desalination Project).

Compared to a trench design, a tunnel design is much more complex. Figures 1 and 2 below show cross-sections of the intake and outlet structures, in this instance of the Adelaide Desalination Project (Note the elevation of the plant, some 52 m above sea level). In the first phase of construction, typically, a 10 m diameter shaft will be sunk, about 50-60 m deep, depending on the depth of competent rock found by the geotechnical survey, and the depth required to create a wet well. Then a Tunnel Boring Machine (TBM) will be lowered into the shaft, and commence boring out to sea, lining the tunnel with concrete segments as it progresses. Due to the requirement to abstract seawater at a depth of 20 m or more, and the need to disperse brine over a large area in deep water, the intake and outlet tunnels could extend well beyond a kilometre, depending on the gradient of the sea floor.

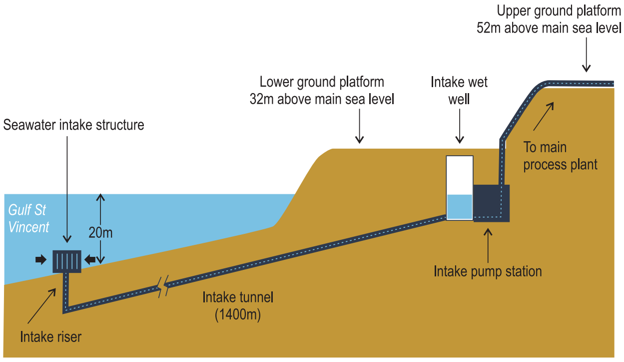

Figure 1: The intake tunnel structure of the ADP. Note that the diagram is not drawn to scale (Aurecon Group).

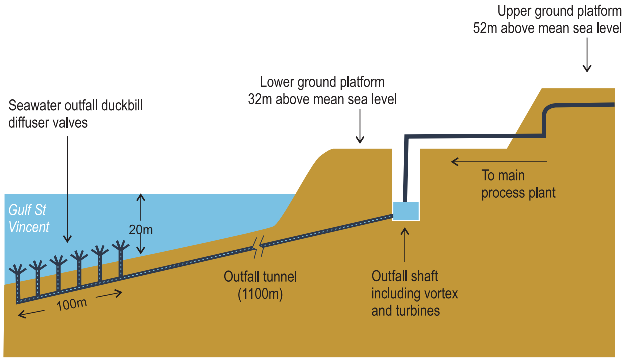

Figure 2: The outfall tunnel structure of the ADP (Aurecon Group).

From the above description and illustrations, one could intuitively deduce that a tunnel design should be significantly more expensive than a trench design, all other aspects being equal.

To determine how the choice of marine works or co-location corresponds with actual outcomes, 16 XL-SWRO projects were randomly selected, and compared in terms of their specific capital cost. Given that each project is unique, the limited sample analysed, and that capital cost is influenced by other factors beyond the marine works, this comparison is largely for illustrative purposes:

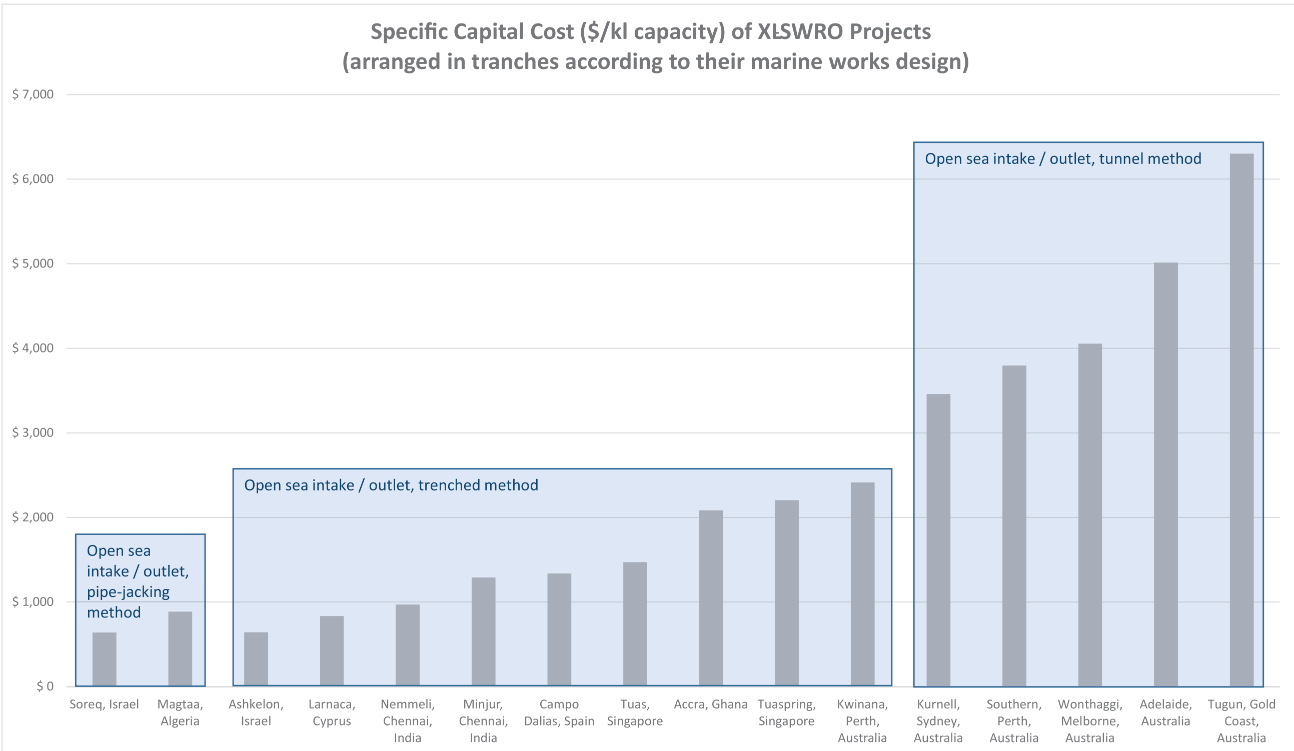

Figure 3: A comparison of the specific capital cost of large-scale seawater desalination projects (Data sourced from www.DesalData.com, www.desalination.biz and www.water-technology.net)

It would appear that XL-SWRO projects with trenched or pipe-jacked marine works are generally more cost-effective than projects with tunnels.

Plant architecture

Desalination plants are more likely to compete with existing land users for space than most other types of infrastructure. It yields a high-value product which is ready to be consumed by the end user, but expensive to convey over distances. Hence, practical and economic considerations argue for these plants' location in close proximity to urban concentrations. Simultaneously, desalination plants require a site at the sea, or very close to it, to be cost-effective. As a result, it is not uncommon for a planned desalination plant to be challenged by other land users on the basis of real or perceived infringement on nearby settlements, or by ad-hoc recreational users of the impacted land. In most instances, the developer will revise the plant architecture to the extent that the impact is sufficiently mitigated, unless the cost of such mitigation brings a secondary site option into consideration.

Co-location with a power plant

Should the option exist of placing an XL-SWRO plant adjacent to a water-cooled coastal power plant, the advantages could be very substantial to the desalination facility, and the viability of this site should be explored. The benefit of such co-location could be much more than the convenience of a close-proximity power supply, provided that the marine infrastructure of the power plant could be shared.

Co-location has several benefits: 1) The desalination plant obtains its entire feed water supply from the condenser cooling cycle of the power plant, thereby eliminating the need for an expensive seawater intake structure. This saves at least 5-20% on capital cost. 2) With no need to construct a seawater inlet structure, disruption of the marine benthic zone during construction is avoided. 3) Since the cooling water from the condenser is about 10ºC warmer than the ambient sea water, having had some heat transferred into it, the RO process requires 5-8% less pressure for salt exclusion, resulting in a commensurate power (and cost) saving (Bear in mind that energy typically comprises about 30% of the product cost). 4) The highly saline brine released from the RO process is diluted by a much larger stream of seawater, before being released into the sea, resulting in highly cost-effective brine dispersal. 5) The thermal impact of the power plant on the marine environment is reduced, due to some of its heated outfall water being converted into potable water.

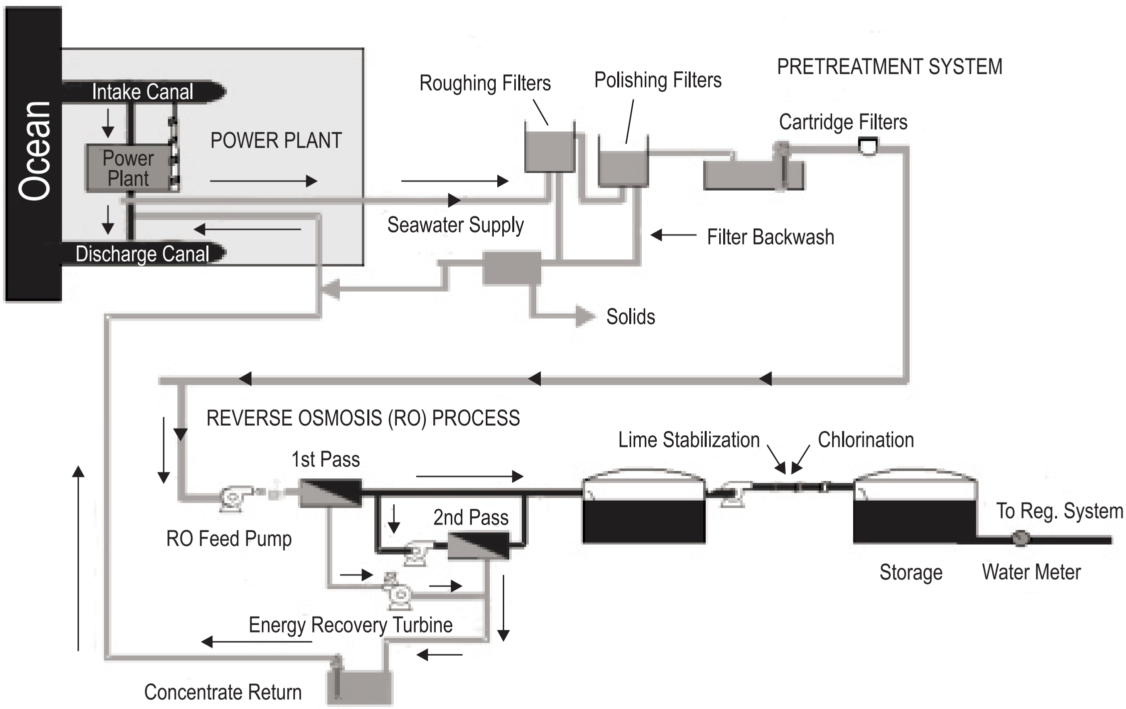

Figure 4: A schematic illustration of co-location of a power plant and a desalination plant (Callahan, N).

Considering the viability of co-location in the long term, there are a few challenges to consider. Foremost is matter of technology lifecycles: Co-location requires two distinct technologies (i.e. thermal power generation and reverse osmosis), which are in different life-cycle phases, to become inter-dependent through shared infrastructure. Should thermal power generation, or simply the design of the pre-existing power plant become redundant, or its cooling technology be replaced, then the desalination plant will lose significant advantages. At a minimum, this would require additional infrastructure to pump and screen the raw seawater, RO process modifications, and the construction of an outlet pipeline and brine diffuser. It is therefore a good practice to require that the feasibility of both plants be demonstrated independently, on a freestanding basis, as a prerequisite for co-location.

Site selection process

The process of selecting a site requires thorough analysis, but it also involves the anticipation of environmental and societal responses, which can make it more iterative than linear in character. Site selection, as a field of study and practice, evolved mainly during the 20th century in the USA, and has remained largely unchanged in its approach and method: Project needs are matched with the merits of potential sites, followed by an elimination process, and in-depth analysis of a short-list of sites.

The site selection for large desalination projects follow the same approach, but the unique criteria and requirements make it a specialised discipline. Once a short-list of perhaps three to five sites have been identified, specialist consultants would typically be retained to conduct a detailed due diligence of each site, which could include study elements such as geotechnical assessments, marine biological assessments, extended environmental screening and seawater characterisation.

For each of the short-listed sites, the following considerations would be explored, and where possible, its impact quantified over the project life cycle:

Logistical considerations:

- The plot size should be adequate to allow for up-scaling of the desalination plant, and for the safe on-site storage of chemicals. A size of 20 ha is usually adequate for an XL-SWRO of 150-300 Ml/day capacity
- Proximity and unobstructed access to the shoreline
- Ease of integration with the existing water grid
- Proximity to the power grid infrastructure. A 150 Ml/d plant typically requires a 132 kV single source supply, and draws 22-25 MW of power under full production
- A site already owned by the implementing agency has a distinct advantage, as it could avoid sensitive and drawn-out purchase negotiations

Sub-surface geotechnical considerations (especially when tunnelling is required):

- Assessment of subsurface conditions, both onshore at the plant site, and offshore along the route of the intake and outlet tunnels

Marine considerations:

- Seabed conditions, as determined by a bathymetric survey
- Seawater currents, from which brine plume dispersal could be modelled. The rapid dispersal of brine in sea water is desirable, from an environmental perspective. Due to the salinity of brine being higher than that of the ambient seawater, and therefore has a higher density, the brine will tend to settle on the sea bed, and cause harm to the marine fauna and flora in the benthic zone. A sustained level of sea current is therefore desirable, to help with the dispersal of brine. A site with restricted or inconsistent ocean currents could encounter permitting delays, onerous monitoring requirements and even periodic plant shut-downs, when brine concentration limits have been exceeded.
- Long-term seawater characterisation: The quality and temperature of feed water has a significant impact on the pre-treatment process design and power consumption in the RO process, and hence influences capital and operational cost. Sampling should continue for at least a year, to allow for seasonal variation. Certain feed water qualities may be site-specific, and determined by the localised impact of storms, sea currents or the proximity of pollutants.

On-shore environmental considerations:

- Prior use of the site: A previously disturbed site can be attractive, as it often presents a lower environmental hurdle.
- Current and future use of the adjacent sites, and the wider precinct. A site within an industrial precinct can be advantageous;
- Ecological sensitivity of the site and adjacent area;
- Proximity and line-of-sight to human settlements;
- Existing recreational utilisation of the beach area.

Once the costs and benefits associated with each of the above considerations have been quantified, as well as the timeframe in which it is likely to occur, the Net Present Value (NPV) of cash flow associated with each can be calculated. Whilst allowing for key considerations that could not be quantified, the site with the lowest NPV would usually be selected.

Concluding remarks

Choosing a site for a large-scale seawater desalination plant is a complex matter, which requires many considerations to be quantified and considered. The cases presented here, suggest an element of causality between the site characteristics, and the subsequent design options and their cost implications. It is therefore advisable to follow a rigorous and systematic approach of short-listing, analysis and selection.

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