

# Chapter 2

## Design Considerations for Tunnelled Seawater Intakes

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**Abstract** As a result of prolonged drought conditions and declining raw water storages, six large capacity seawater reverse osmosis (SWRO) desalination plants were constructed to secure the water supplies of the five major Australian state capital cities. For a variety of reasons including capacity, local geology, site topography, environmental concerns as well as the construction programme and construction risk mitigation considerations associated with hostile marine conditions, tunnels were adopted for five of the SWRO plants, connecting the desalination plants with their open intakes and brine concentrate outfall systems. The tunnel system is a relatively new concept for SWRO intake and outfall design. The design of marine intake and outfall works is very complex because of the wide range of constraints that must be accommodated as well as the hydraulic interactions among the intake system, pre-treatment facilities, desalination plant, and outfall system over a wide range of possible climatic, physical, and operational conditions. The challenges posed in the design and construction of tunnel and marine structures in high-energy open ocean environments are presented. These challenges include those associated with waves and currents, short- and long-term hydraulic considerations, durability and corrosion, biofouling control, and ongoing operation and maintenance. Different intake design approaches at two of the Australian SWRO plants are discussed.

### 2.1 Introduction

Between 2004 and 2012 six major seawater reverse osmosis (SWRO) desalination plants were constructed to serve Australia's largest coastal cities—two for Perth and one each for Brisbane-Gold Coast, Sydney, Melbourne and Adelaide (Fig. 2.1). The plants range in production capacity from 45 to 150 GL/a, with their intakes and brine return outfalls designed for flows as high as 18.5 m<sup>3</sup>/s. Five of the plants have

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Fig. 2.1 Location of major Australian SWRO desalination plants

had tunnelled intakes and outfalls. The marine works are located in relatively hostile wave climate environments in the South Pacific, Southern and Indian Oceans.

The intake and outfall tunnels are up to 65 m below sea level, 2500 m in length, 4 m in internal diameter and of both incline and decline configurations. As well as the tunnels, there are marine intake structures, brine return diffusers, connective risers through the seabed floor, shore based seawater pump stations and fine screens. The tunnel and associated marine works are major engineering undertakings in their own right, forming a significant proportion of the project capital cost, and may also be the area of greatest project risk.

This chapter presents technical challenges associated with the design and construction of seawater tunnels and marine works in hostile marine climates with a focus on intakes. As many of these issues and challenges also apply to brine concentrate return systems only a few considerations specifically related to brine concentrate return tunnel and marine works are discussed. This chapter covers:

- Site-specific onshore and offshore topographic, geotechnical and geological conditions
- Marine wave climate and oceanography

- Risk, environmental and cost drivers for tunnelled intake and brine concentrate return conduits
- General hydraulic and environmental performance requirements
- Hydraulic considerations
- Operability, fouling, sedimentation, maintenance, and durability considerations
- Tunnel profile issues
- Intake pumping station and screen configurations.

## 2.2 Background

Australia is a highly urbanized country and though equal to mainland USA in land area, it is relatively sparsely populated. Over 80 % of the 22 million people live near the coast, with some 65 % in the major state capital cities. Increasing population accompanied by the longest recorded drought and limited alternative water resources led to the construction of major desalination plants around Australia to provide strategic diversification of water sources and drought security (Alspach et al. 2009). Most of the desalination plants were delivered through fast-track design-build contracts combined with an operational and maintenance contract (DBOM).

One of the disadvantages of a high coastal population density is the lack of available sites for large desalination plants with sufficient land area and/or suitable zoning classification. In the Australian context of rapid implementation of these desalination projects (as a drought response measure), this was a significant issue.

Consequently, the sites chosen may not have been ideal due to some or all of the following reasons:

1. Sites not located immediately adjacent to the ocean
2. Intakes and outfall in oceans with hostile wave climates with marine construction potentially at risk from large swells, rogue waves, or seasonally unfavourable climatic conditions
3. Unfavourable geotechnical conditions
4. Not close to the center of demand and thus having high connective product water infrastructure costs
5. Potential impacts on coastal and marine environments

The first three factors in conjunction with the large plant capacities, specific environmental constraints, cost effectiveness as well as the assessment of construction risk and delivery time frame, led to the use of tunnelled intakes and outfalls as the selected solution in Australia for the seawater intakes and brine concentrate returns for all but the first major desalination plant (Table 2.1).

**Table 2.1** Seawater intake and outfall configuration

SWRO plant location (city served)	Conduit details <sup>a</sup>	Marine conditions	Launch <sup>b</sup> depth	Seabed depth
Kwinana (Perth)	1 × 2.4 m, 1 × 1.6 m dia. GRP ~ 350 m	Quiescent—Cockburn Sound	NA	8 m
Tugun (Brisbane—Gold Coast)	2 × 2.8 m dia. Tunnels ~ 2200 m long	Hostile (8 m Hsig <sup>c</sup> ) and cyclone risk	70 m	22 m
Kurnell (Sydney)	2 × 2500 m long 3.4 m dia. tunnels	Hostile (7 m Hsig) and wave reflection	18 m	25 m
Binningup (Perth)	3 × ~ 960 m, 2.4/2.0 m dia. tunnel and bored	Moderate (4 m Hsig), protected reef	NA	10 m
Port Stanvac (Adelaide)	2 × ~ 1250 m long 2.8 m dia. tunnels	Moderate (4 m Hsig)	50 m	30 m
Wonthaggi, Melbourne	2 × 1200 m, 4.0 m dia. tunnels	Hostile (8 m) + Bass Strait	18 m	20 m

For descriptions of site geotechnical, environmental and oceanographic at each location refer Baudish et al. (2011)

<sup>a</sup>Lengths of intakes and brine outfalls are indicative

<sup>b</sup>Tunnel depth below ground level at launch shaft

<sup>c</sup>Hsig significant wave height

## 2.3 Intake Design and Construction Considerations

Open sea water inlet conduits are prone to marine organism ingress and colonization as well as sediment accumulation from sand and shell matter. Long, large diameter conduits, such as tunnels, amplify these issues as they cannot be readily taken out of service. They are difficult to inspect because of their depth and length. They are also likely to have internal conduits for maintenance purposes or bio-fouling control and therefore, are not suitable for pigging. They have a number of specific design considerations and issues that are not common with open shore based intakes.

### 2.3.1 Marine and Geomorphological Information Requirements

General marine issues and information requirements for the design of seabed structures and conduits include:

- Seabed geomorphology and bathymetric profile information is required for construction and siting seabed assets ideally being on relatively flat terrain clear of reefs and large boulders so as to minimise underwater preparation works



**Fig. 2.2** Surge and wave conditions—Sydney desalination plant inlet

- Seabed surface sediment particle size distribution data is required for the consideration of scour as well as height of sediment suspended by currents, particularly by storm-wave induced orbital currents in the water column
- Extreme sea levels driven by tide and climatic conditions are of particular importance for pump stations, outlet shafts and gravity brine drains and overflow systems. These conditions include potential long-term sea level rise and drive hydraulic performance criteria as well as onshore ground and structure levels
- Currents induce loading on both permanent seabed structures and temporary marine construction equipment, such as jack-up barges and associated construction plant and equipment. Prevailing currents may be used to advantage in the design of brine diffusers to maximize dispersion and dilution as well as to optimize the relative positioning of intake and brine return systems to each other
- Long term wave climate data is unlikely to be available specific to the selected site. Regional data may have to be calibrated, modelled and interpreted taking into account the specific bathymetry, shore features and wave reflectance issues (Fig. 2.2)
- Site-specific wave climate data is necessary to derive wave-induced currents and loads on seabed structures—this data can be used to optimize positioning of structures in water deep enough to minimize loading on marine structures, but at the same time shallow enough to minimize length of tunnels for economic (cost) and construction timing reasons

- Environmental conditions need to be well understood. These include salinity and temperature, the range of marine flora, fauna and biofouling organisms. Their considerations may impact the design of intake screens, antifouling measures and operation as well as maintenance of offshore works.

### ***2.3.2 Marine and Tunnel Construction and Operation***

The detailed design of the tunnel and marine structures must take into account the construction methodology and type of equipment likely to be employed. Tunnel boring machines (TBMs) and jack-up barges for marine works and drilling risers are highly specialized equipment and both are likely to be long lead items. Jack-up barges in particular must be selected and potentially modified to suit the site-specific marine works, depths and oceanographic conditions.

Construction and operational issues to be addressed during the design include the following:

- In a fast track environment, TBM and jack-up barges will be on the critical path for construction, requiring early decisions on intake riser style and diameter, tunnel diameter and profile.
- Seabed structures should be deep enough to avoid being a navigation hazard, to avoid the effects of extreme waves and at a depth where good seawater quality is expected. They also need to be shallow enough to be constructed from jack-up barges. Intakes also should be positioned high enough off the seabed to minimize sediment entrainment.
- Jack-up barges must be able to be raised during storms to provide clearance for maximum swells caused by inclement weather. Weather causes wave intensity variations and storm surges which can limit marine construction activities. The occurrence of intense storms dictates the need for accurate forecasts and early warning systems.
- Stable and accurate positioning requirements for drilling, for the installation of riser liners, riser caps and screen and diffuser structures as well as accurate intersection with tunnels.
- Timing of marine (riser construction) and tunnelling construction operations also impacts the marine structures design. Tunnel risers may be constructed before or after the tunnelling and this needs to be considered, as risers may be connected to the tunnel through the crown or offset and connected via a lateral.
- Pressure differential limits for segmented liner construction impact on bolting and grouting design.

For large remote intakes that use HDPE pipelines on the seabed, a duplicate intake line may be installed to allow one intake to be taken out of service, while the other is pigged or its screen maintained. This “luxury” does not apply to large tunnel intakes. It is only a marginal cost difference to construct tunnels and marine

works to suit an ultimate capacity. Due to the size and cost of tunnels, and in particular their construction risk, a single intake tunnel (and outfall) is typical. Thus future operation and maintenance requirements associated with a single intake in deep water needs to be addressed in the design development. Consideration needs to be made for the:

- inspection (and maintenance) provisions for the tunnels which are typically 20 m below sea bed and 40 m below sea level
- potential dewatering and safely carrying out inspection and maintenance
- limitations on diver access and ROV technology.

Of note is that since the long seawater intake tunnels in Australia have entered into service (i.e. from 2008 onwards) there have been advances in monitoring technology. ROV video cameras are now employed for regular monitoring of tunnel condition, in particular, for signs of sediment ingress and marine growth.

### ***2.3.3 Intake Design***

Intakes need to operate in a way that minimizes marine impacts, particularly impingement and entrainment of marine life. Key environmental performance criteria for intakes include limitations on maximum intake screen aperture and associated screen velocities. Similarly, outfall systems are now required to achieve stringent environmental performance objectives even when running at reduced capacity.

The upper limit to velocity through the intake screen bars is typically specified as an average of 0.10 or 0.15 m/s. While this limit on velocity may have the objective of protecting marine life or to avoid the intake of sediment, it is a major factor impacting on the size and weight of the seabed intake structure.

Typical screen bar/aperture spacings are in the range of 50–300 mm and, in combination with an allowance for marine growth on the bars, can have a significant impact on the overall size of the intake structure. Thus design needs to balance the size, constructability (in hostile marine environments) and cost factors versus long-term operation and maintenance. Considerations include:

- providing an allowance for marine growth, and interpreting any flow-on effects in the context of meeting project performance specifications, ambient ocean currents, the specified bar spacing and determining resultant impacts on the structure size
- use of anti-fouling copper-nickel alloys to suppress marine growth
- planning in situ maintenance regimes and/or design of removable screens
- the prevention or control of marine growth inside the riser and tunnels.

### ***2.3.4 Hydraulic Design***

Typically the tunnelled intakes and outfalls in Australia have been designed and constructed as segmented precast concrete lined tunnels. Minimum practical diameters for tunneling by TBM are about 2.8 m internal diameter. Diameters larger than 2.8 m are only constructed if required to suit the hydraulic requirements of an intake.

Large diameter HDPE pipeline style intakes are typically installed by floating, sinking and anchoring on the ocean floor. These HDPE pipelines are often designed to be cleaned by pigging, so that their internal condition can be restored. Piping provided for biofouling control or for other types of maintenance can be located external to the pipe. For tunnels small diameter piping is usually installed internal to the tunnel. Thus, the tunnel is not suited to mechanical cleaning or pigging. Due to their length and depth and internal fixings, tunnels are likely to be difficult to clean once in service.

Whilst there is published information on friction co-efficients for segmented tunnels, these co-efficients are not reflective of long-term friction over the 50 or 100 year tunnel design life of a seawater intake. Even if seawater tunnels have been designed to enable their dewatering and cleaning, the intention is not to do so. Thus, the designer must take a view as to the potential long-term changes in hydraulic characteristics due to marine growth and related performance alteration including:

- potential long term loss of diameter in some or all of the intake conduit components
- long term roughness factors to be adopted.

These are significant issues as they affect the choice of tunnel diameter, long term pumping heads, intake pump selection and screen design. Long-term data on marine growth in long conduits where biocide control is practiced is lacking, but it is clear that some growth will still occur. The highest rates of growth will occur at the intake screen, riser and tunnel entry, and then decreasing along the tunnel length where there is less light.

Intake screens require particular attention for the design of cleaning provisions. Ideally screens should be removable so that they can be mechanically cleaned above water. Biocides cannot be used for biofouling control on the screen proper due to risk of escape into the marine environment. They should be applied at the entry to the intake riser, with particular attention given to achieving effective mixing.

Other factors that need to be considered in design include:

- effect of tidal variations, swells and storm surges, as well as the potential long term impacts of climate change
- hydraulic limitations caused by fixed brine nozzles which are quite sensitive to flow rate and with some flow combinations potentially resulting in overflows of seawater within the site proper. This may require design mitigation measures such as spill provision from the brine outlet to the seawater intake
- temperature and salinity.



Dynamic surge impacts associated with sudden stoppage of the seawater pumps must also be considered, as this can lead to significant surges of over 5 m at intakes and potentially overflow onto the site. These effects can be mitigated by reducing momentum by increasing tunnel diameter or providing a large volume in the intake wet well to absorb the surge. Surge is a factor to be taken into account in deciding on the internal diameter of the tunnel.

### ***2.3.5 Durability Aspects***

Durability issues for tunnelled infrastructure and associated connective works should not be underestimated. Tunnel and marine works may be specified to have design lives of 50 or even 100 years. Achieving such design lives needs careful control through design, fabrication, construction and operational stages. The use of fibre reinforced concrete for tunnel segments has greatly extended the expected design life of the tunnel lining compared to conventional reinforcement.

When estimating expected design life of tunnel segments, it is also important to consider the accelerated ingress and corrosion rates expected to result from the occasional exposure of the concrete segments to air during tunnel dewatering. This requires chloride ingress modelling.

Coarse intake bar screens and metal fittings are typically composed of a super-duplex or copper nickel alloy. The latter is preferred due to its natural inhibition properties against marine growth. Coated steel with anodic protection may be appropriate for accessible shore-based equipment, such as screens.

Within intake tunnels there are additional considerations, such as when chlorine is used for control of marine growth, injected at the mouth of the intake risers. While this requires transport of diluted chlorine solution in piping within the tunnel, consideration of the impact of chlorine needs to be taken into account in materials selection of tunnel fixings and chlorine piping. Metals may not be appropriate, while plastics must also be selected for permanent installation to meet the 100-year design life of each component. Chlorine is typically delivered to the injection point as diluted sodium hypochlorite or gaseous chlorine in solution. Scaling risk needs to be addressed with the former, and the more aggressive nature of chlorine in the latter.

## **2.4 Integration of Design**

The intake tunnel is inextricably linked to the design of the intake pump station and intake screens. Almost invariably site-specific solutions are required. Traditionally, fine 3 mm screens are placed upstream of the pumps. These screens capture any material that may pass through the coarse ocean intake screens, including filamentous algae and non-motile marine life such as jellyfish, and also protect the

pumps from damage. This following section outlines alternative design solutions developed for the Sydney and Gold Coast desalination intakes (and outfalls), largely due to geotechnical conditions, tunnel drive method, and specific site limitations.

### 2.4.1 Gold Coast SWRO Desalination Plant

The GCD site is located about 700 m inland on a former municipal waste landfill site adjacent to the north west corner of the Gold Coast airport at Tugun (Fig. 2.3).

The on-site geotechnical conditions show deep consolidated sand both onshore and offshore overlaying sedimentary bedrock. Sound rock is found at depths around  $-55$  to  $-60$  m AHD. The plant site is approximately RL +7 m AHD grading gently seawards down to developed coastal dunes at about RL +5 to 6 m.

Marine climate issues include a summer cyclone season with ocean maximum currents up to 0.5 m/s. During high wave storm events (8 m height at ARI 1000 years) seabed orbital currents can reach 3 m/s or greater. The 6-month summer cyclone season precluded marine construction in this period. There is littoral sediment drift of some 500,000 m<sup>3</sup> per annum northward. The required siting of the intake to achieve stability required seabed depths below 18 m of depth to minimize sand and sediment entry into the intake. This also allows it to be located clear of the



Fig. 2.3 Gold Coast desalination plant—tunnel and marine structures locations



**Fig. 2.4** Tunnel access shaft and TBM components/TBM segment being lowered for assembly below ground

more active near-coastal zone which could have otherwise resulted in undermining or covering the intake or outfall structures.

As outlined in Chap. 3, although there is little marine vegetation on the sandy seabed, the area is regarded as having a high environmental value. Tunnels were selected on the basis of program, environmental factors and visual impact during construction, as well as to minimize marine construction risk. Tunnelling also eliminated the need for an intake pump station remote from the plant site. This simplified the design and greatly reduced local impacts, as a suitable site for such a pump station was not readily available.

Specific features of the Gold Coast intake and outfall tunnel, and the seawater intake pumping arrangement were:

- Deep intake and outfall shafts. Tunnel boring machines (TBMs) work most effectively in rock or hard ground conditions. At the Gold Coast site, this meant that 70 m deep launch shafts were required to locate the TBM's in suitable rock (Fig. 2.4). This necessitated that the shafts be used for all construction activities including lowering and raising of TBM components, shift personnel, tunnel segments and also for removal of tunnel spoil.
- The depth at which sound rock was located was very consistent and did not favour an incline or decline arrangement. Both the intake and brine concentrate return tunnels were therefore graded upwards from land to sea in a slight incline (Fig. 2.5). This ensured any water entering the tunnels during construction drained back to the shaft by gravity, where it was easy to manage. This also resulted in the tunnel being slightly higher and closer to the seabed at the distal end, reducing the time to construct the riser connecting the tunnel to the sea floor.
- The single intake screen is approximately 4.4 m high, 5.8 m in diameter and with 2 m high copper nickel screens with a bar spacing of 140 mm (Fig. 2.6).
- The four 1.33 m<sup>3</sup>/s vertical turbine seawater intake pumps were located within the 9.6 m dia. tunnel intake shaft (Fig. 2.7). This simplified the intake arrangement and reduced both costs and construction time for this element of the project, which was on the critical path for the overall project. However, this also

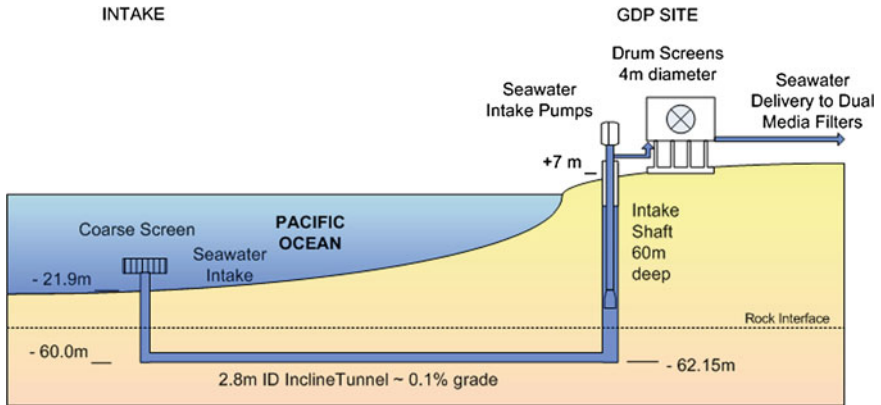


Fig. 2.5 Schematic of the GCD seawater intake arrangement



Fig. 2.6 Intake coarse screen being installed from the jack-up barge

meant that it was not feasible to locate fine screens upstream of the pumps, introducing a potential risk of pump fouling under very poor water quality conditions. Given the good intake conditions afforded by locating the intake far enough offshore in deeper water, and through the use of high clearance pumps, this risk was considered acceptable. Both numerical and physical modelling of the intake/pump suction were carried out to optimize pump inlet design to avoid the development of unfavourable pumping conditions (unbalanced flows/vortexes) for these large capacity pumps (Mould and Sprengel 2010).

- Seawater is delivered from the intake pumps to the two (duty/standby) 4 m diameter, 3 mm mesh dual entry drum screens (Fig. 2.8). The screens are housed in an above ground structure enabling gravity flow to the pre-treatment filters. During operation of the plant to date, there has been very little trash collected by the fine screens, demonstrating the advantages of careful location of the intake structure to ensure good intake water quality.

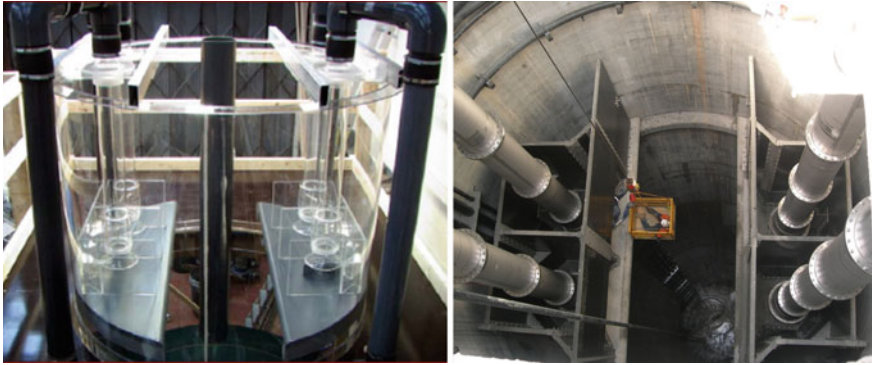


Fig. 2.7 Intake physical model and as-installed seawater pumps



Fig. 2.8 Intake pumps and elevated screen structure 4 m diameter drum screen

### 2.4.2 Sydney SWRO Desalination Plant

The Sydney desalination plant (SDP) is located at Kurnell, to the south of the Sydney airport (Fig. 2.9). Site constraints included a conservation area to the north and a freshwater ecosystem that leads to the Towra Point wetlands adjoining Botany Bay. The plant site geotechnical conditions included shallow loose sands with a high water table interspersed with peaty lenses, underlain by firm sandstone that ranges from  $-6$  to  $-30$  m AHD and undulates underground across the site. This relief is caused by the buried remnants of former drowned river valleys.

Though closer to the sheltered waters of Botany Bay, the intake and brine outfall are located eastwards to the Tasman Sea (Pacific Ocean).

The desalination plant site itself is located at a relatively low elevation (5–6 m ASL finished level), but the ground and rock profile rises seawards to nearly 35 m before sloping down to the 20–25 m high sandstone cliffs at the edge of the Tasman Sea. The sea floor below the cliffs is rocky, and descends to 25 m below sea level

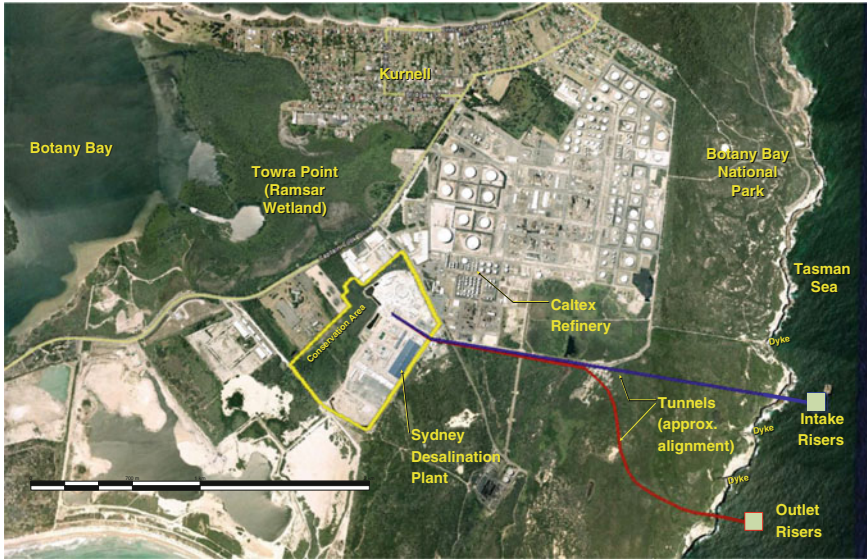


Fig. 2.9 Tunnel and marine structures location—Sydney desalination plant

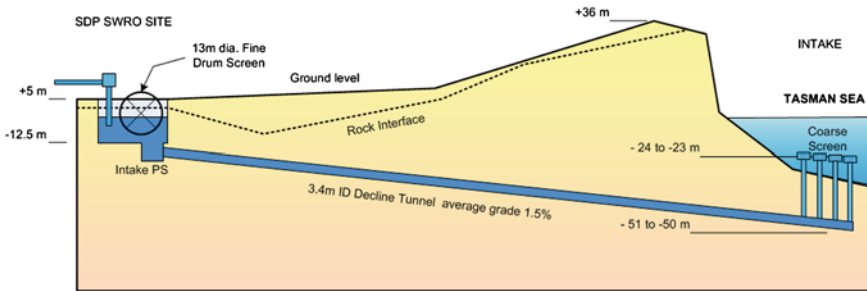


Fig. 2.10 Schematic of the SDP seawater intake arrangement

within a few hundred metres of the cliffs, a depth at which both the intake and concentrate return structures are located (Fig. 2.10).

The coastline bordering the Tasman Ocean is within Botany Bay National Park. There is a wide range of marine flora and fauna associated with reefs and rocky seabed. Migrating whales are frequently observed in the area between April and December. Restrictions to riser construction activity were required when whales were in close proximity.

Specific marine conditions at the intake and outlet site included continuous high energy incident and reflected waves with 1:10 year Hsig of 7.3 m and estimated extreme waves heights of approximately 12 m. Currents typically range between 0.1 and 0.4 m/s. Modelling of the specific local wave climate (as distinct from regional data) was required to assess the influences of the steeply rising floor and

**Table 2.2** Key design issues for incline and decline tunnels

Issue	Incline tunnel	Decline tunnel
Tunnel dewatering	At the landside shaft	Sea side (or landside by progressive movement of pump)
Sediments	May be transported towards seawater pump station	Likely to accumulate at intake end of tunnel
Floating matter	Likely to be remain near the intake marine riser	Likely to be transported towards the seawater pump station
Air entrainment (brine return)	Air will flow along the tunnel crown to the brine outlet	Air must be released before entering the tunnel

cliff face on extreme wave heights as well as frequencies and influences of reflected waves.

Trenched pipelines were never considered for the intake and outlet because of the cliff profile, marine conditions and sandstone geology (both onshore and seabed). Tunnels were adopted. Though primarily in hard sandstone, the tunnel routes crossed near vertical fault lines (weathered dykes). Due to location within the national park, extensive exploratory drilling was not possible. Thus, geotechnical information related to dyke strike and dip and expected condition at the dyke-tunnel route intersections was limited. Igneous dykes had measured widths of 1.3–2.7 m. A limited joint swarm was present at mid length of the route for both tunnels.

The shallow sound rock available at one end of the desalination plant site opened up the possibility of a decline tunnel. This approach was adopted after careful consideration of the technical and operational advantages and disadvantages of a decline arrangement (Table 2.2).

In terms of construction, the decline tunnel offered significant advantages in construction efficiency, including ease of assembly/disassembly of the TBM within a “box-cut”, and transport of tunnel segments and removal of tunnel spoil which did not have to be lowered or raised via a shaft (Fig. 2.11).

A decline tunnel was adopted for both the intake and brine return tunnels, connected directly to an intake pump station. Compared to the Gold Coast plant this resulted in a more conventional arrangement of the fine screens upstream of the sea water inlet pumps (Fig. 2.12).

There are two 12.7 m diameter ( $2 \times 100\%$ ) capacity drum screens for the 250 ML/d Sydney plant (Fig. 2.13). When the plant is augmented to 500 ML/d, two additional screens will be added, resulting in four 33% capacity screens. The large screen diameter was required to accommodate the tidal range as well as ultimate friction effects through the long intake tunnel. There are five  $2 \text{ m}^3/\text{s}$  seawater intake pumps, two for each 125 ML/d SWRO module and a common standby. An additional five pumps will be installed when the plant is augmented. As for the Gold Coast plant, modelling of the inlets to the pump suction was required to ensure optimum flow and performance of the pumps.

Marine construction was extremely difficult due the prevalent swells and the reflected wave waves from the nearby cliff face. Originally, the risers to tunnel were







**Fig. 2.13** SDP intake pump/fine screen during installation

### ***2.4.3 Construction Scale***

A few details from the Sydney desalination project give some idea of the magnitude of the tunnel and marine works. The intake and outlet structures were positioned within a contract prescribed area. The areas are located approximately 300–350 m offshore from the headland at Cape Solander and approximately 700 m apart as shown in Fig. 2.9.

The intake system comprises:

- Four cylindrical, precast concrete intake structures 8.5 m in diameter and 5.2 m high (Fig. 2.14)
- 32 screens (8 per intake structure) 1.9 m high  $\times$  3.0 m long with copper-nickel alloy bars at 340 mm spacing
- Four fibreglass lined ‘risers’ each with a 1.5 m ID, located approximately 20 m apart and extending from the seabed down to tunnel level; fibreglass lined connective stub cross tunnels with a 1.4 m ID approximately 6.0 m in length, connecting the risers to the tunnel



**Fig. 2.14** Pre-cast intake coarse screen structure/screen base being lowered

- A 3.4 m ID tunnel approximately 2.5 km in length, sloping downwards at up to a 2.5 % decline from on-shore and lined with fibre reinforced precast concrete segments
- Eight chlorine solution pipes mounted within the tunnel (one duty and one standby pipe per intake riser)
- A reinforced concrete pumping station structure approximately 35 m<sup>2</sup> and 20 m deep with a distribution channel and bays for four drum screens
- Two drum screens 12.7 m in diameter
- Five 2 m<sup>3</sup>/s vertical pumps.

The brine concentrate return outlet system comprises:

- Two cylindrical, precast concrete outlet structures 6.8 m in diameter and 3.7 m high located on the seabed in more than 20 m of water
- Eight tapered super duplex UNS32750 brine nozzles, (four per outlet structure) with an exit ID of 370 mm for a plant capacity of 250 ML/d. The nozzles will be changed when the plant is expanded to 500 ML/d
- Two fibreglass lined risers each with a 1.4 m ID extending up from tunnel level to the seabed
- Two 1.8 m diameter stub cross tunnels approximately 6.0 m long connecting the risers to the main tunnel
- A 3.4 m ID decline tunnel approximately 2.5 km long
- A reinforced concrete deaeration—air release structure approximately 40 m × 5 m wide and 12 m deep
- A 900 mm diameter raw seawater pump discharge cross-connection and control valve to supplement flows and achieve specified brine dispersion requirements over the full operating range of SWRO plant flows.

Major construction equipment included:

- A jack-up barge (self elevating marine construction platform) from which the riser shafts were drilled and constructed. When elevated the barge was 10 m above the mean sea surface level. The barge had a displacement of 2820 t and had 66 m long legs

- Two double shielded hard rock tunnelling machines, one each for the inlet tunnel and one for the outlet tunnel. The cutting face was 4165 mm in diameter and the TBM body 4100 mm in diameter. The TBM cutting face weighed 33 t, and there were 16 trailers with a total length 123 m
- The tunnel lining erected behind the TBM was a six segment configuration. A total of 22,800 segments were required for the 5.0 km combined length of tunnels. Each segment is 225 mm thick and weighs 1.5 t.

## 2.5 Conclusions

Where desalination plants are constructed on coastlines exposed to hostile open ocean conditions, and tunnels are adopted as intake and brine concentrate return conduits, the tunnel and marine infrastructure become a significant proportion of the overall capital cost of the project. The marine works are an area of the project where a large part of the overall project risk lies, usually being on the critical path and potentially subject to extremes of weather and ocean conditions.

The design of the marine intake and outfall works is very complex because of the wide range of constraints that must be accommodated as well as the hydraulic interactions between the intake system, pre-treatment, desalination plant and outfall system over a wide range of possible climatic, physical and operational conditions.

As each desalination site has a unique combination of physical, environmental and social constraints, the solutions developed for the seawater intake and brine return systems may well be quite different even if they have similar performance requirements.

**Acknowledgments** The information presented in this chapter has largely been derived from experiences gained by Jacobs staff during siting and environmental studies and tender and detail designs related to the six major Australian SWRO plants, in particular the Gold Coast and Sydney SWRO plants. I would like to acknowledge the valuable contributions and insights of Darryl Pain, Phil Banks, Ralph Burch and Doug Franklin.

The Gold Coast Desalination Plant was designed and constructed by the Gold Coast Desalination Alliance comprising alliance partners SureSmart Water, John Holland, Veolia Water; Jacobs (SKM), Halcrow and Cardno.

The plant is operated by Veolia Water for SureSmart Water. The Sydney Desalination Plant was designed and constructed by John Holland and Veolia Water (the Bluewater construction JV) and the Jacobs (SKM)–Mansell design JV. The plant is operated by Veolia Water.

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