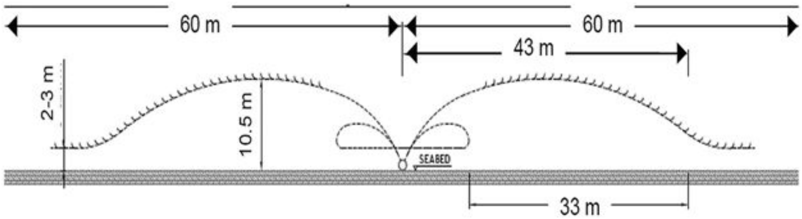

Figure A1-3. Discharge of gold coast seawater desalination plant.

Source: Mickley and Voutchkov (2016), permission from Water Environment Reuse Foundation, now part of the Water Research Foundation.

Permitting and Regulatory Overview and Procedure

Table A1-2 summarizes the key discharge permit requirements of the Gold Coast SWRO Desalination Plant.

Analyses of Plant Concentrate (Mickley and Voutchkov 2016)

The actual dilution ratio at the end of the mixing zone is typically 16:1 or more [as compared to the regulatory target of 10:1 to meet whole effluent toxicity (WET) requirements]. For 18 months prior to the beginning of the desalination plant

Table A1-2. Gold Coast SWRO Desalination Plant—Key Discharge Permit Requirements—Permit No. EPPR00881713.

Permit discharge parameter	*95th percentile*	*Maximum*	*Minimum*
Discharge volume	—	360,000 m^3/day (95 mgd)	—
Distance from diffusers to edge of mixing zone	—	200 ft (60 m)	—
Salinity of plant discharge	$<$67 ppt if BG $<$38; otherwise 67 $\times$ BG/38	$\leq$75 ppt if BG $<$38: otherwise 75 $\times$ BG/38	—
Turbidity of plant discharge	BG + 5 NTU	BG + 20 NTU	—
Dissolved oxygen concentration of plant discharge	—	—	3.4 mg/L
pH of plant discharge, standard units	8.5	9.5	5.5
Total chlorine	0.12 mg/L	0.70 mg/L	—

Source: Mickley and Voutchkov (2016), permission from Water Environment Reuse Foundation, now part of the Water Research Foundation.

Note: BG = background concentration in the ocean for sample collected at the plant intake.

operations, the project team has completed the baseline monitoring to document the original existing environmental conditions, flora, and fauna in the area of the discharge.

Once the plant began operations in November 2008, the project team completed marine monitoring at four sites around the discharge diffuser area at the edge of the mixing zone and at two reference locations 1,640 ft (500 m) away from the edge of the mixing zone to determine environmental impacts and verify salinity projections.

On the basis of these data, the plant staff completed Marine Contamination Risk Assessment (MCRA). The objective of the MCRA was to assess the ecological risk posed by each of the chemical additives used in the desalination treatment process that are likely to be retained in the effluent stream and discharged into the receiving environment.

This MCRA identified the toxicological risks posed by all known compounds in the desalination effluent from the GCDP that could be considered as contaminants to the receiving marine environment in the vicinity of the discharge location. The MCRA was based on a review of the existing information and a limited number of assumptions regarding the operational performance of the desalination plant. The data obtained from the toxicity tests, in conjunction with the data obtained from the Perth Seawater Desalination Plant, demonstrated a lowest observed effect concentration of concentrate which was higher than the expected maximum concentration of brine at the edge of the mixing zone at sea [200 ft (60.0 m) from any of the 14 diffuser nozzles].

As a part of MCRA, the water quality and benthic in-fauna abundance and diversity results after the start of the Gold Coast plant operations were compared with the baseline monitoring results as well as with the results of the monitoring sites. The results of pre- and post-plant commissioning clearly indicate that the desalination plant operations did not have measurable impact on the marine habitat in the area of the discharge—the aquatic fauna practically remained the same in terms of both abundance and diversity. The Gold Coast plant has been in operation for more than 6 years, and monitoring to date has confirmed that the plant's discharge is environmentally safe.

The results from the concentrate discharge monitoring completed at the Gold Coast SWRO desalination plant between March 2009 and February 2010 (Vargas et al. 2011) for the control and impact sites are shown in Table A1-3. As shown in this table, the 12 month median values for temperature, dissolved oxygen (DO), salinity, and turbidity were within the plant discharge permit requirements.

Key Project Lessons Learned

According to the Mickley and Voutchkov (2016) information aforementioned:

> … the water quality and the benthic in-fauna abundance and diversity results after the start of Gold Coast plant operations were compared

Table A1-3. Gold Coast Discharge Water Quality for Permit Regulated Compounds for the Period of March 2009 to February 2010.

		Median value		Discharge limit	
Depth	*Parameter*	*Control*	*Impact*	*Min*	*Max*
0–26 ft (0–8 m)	Salinity, psu	36.6	36.3	35.1	37.1
	Temperature, °C	21.2	21.2	19.9	24.0
	Dissolved oxygen, mg/L	8.0	8.1	6.8	9.1
	Turbidity, NTU	0.9	1.0	None	3.2
	pH	8.1	8.0	8.2	8.4
40–66 ft (12–20 m)	Salinity, psu	36.9	36.8	35.0	37.2
	Temperature, °C	20.4	21.0	19.6	22.7
	Dissolved oxygen, mg/L	8.0	8.1	6.8	9.1
	Turbidity, NTU	0.9	0.9	None	4.1
	pH	8.1	8.0	8.1	8.3

Source: Mickley and Voutchkov (2016), permission from Water Environment Reuse Foundation, now part of the Water Research Foundation.

with the baseline monitoring results as well as with the results of the monitoring sites. The results of pre- and post-plant-commissioning clearly indicate that the desalination plant operations did not have a measurable impact on the marine habitat in the area of the discharge – the aquatic fauna practically remained the same in terms of both abundance and diversity. The Gold Coast Desalination Plant has been in operation for more than six years and monitoring to date has confirmed that the plant's discharge is environmentally safe.

References

Mickley, M., and N. Voutchkov. 2016. *Database of permitting practices for seawater concentrate disposal*, 133–138. WRRF-13-07. Section 10.2. Alexandria, VA: Water Environment and Reuse Foundation.

Vargas, C., P. Viskovich, H. Gordon, and T. Walker. 2011. "The Challenge of Managing Reverse Osmosis Brine disposal: Experience at QLD." In *Int. Desalination Association's World Cong. IDAWC/PER11–075*. September 4-9, Perth, Australia.

3. PERTH I, AUSTRALIA

2019 Case Study

Mickley and Voutchkov (2016)

Management Approach: Ocean Discharge—Open Ocean Outfall

Committee Members: Nikolay Voutchkov (provided from source) and Berrin Tansel (SI units)

Project Contact: Sjoerd Sibma, The Water Corporation Sjoerd.Sibma@watercorporation.com.au

Project Name: Perth I Desalination Plant

Project Location: Perth, Australia

Desalination Process: Intake from open intake, pressure dual media filtration, cartridge filtration, two-pass SWRO system

WTP INFORMATION

- Rated Capacity: 38 mgd (144 × 10^3 m^3/day)
- Max. Concentrate Flow: 45 mgd (170 × 10^3 m^3/day)
- Typical Production: 38 mgd (144 × 10^3 m^3/day)
- Typical Concentrate Flow: 40 mgd (151 × 10^3 m^3/day)

Abstract

The 38 mgd (144 × 10^3 m^3/day) Perth Seawater Desalination Plant has been in continuous operation since November 2006. This plant supplies more than 17% of the drinking water for the City of Perth, Australia, which has more than 1.6 million inhabitants.

Process Design and Configuration

The treatment facilities of the Perth seawater desalination plant (Figure A1-4) are very typical of the state-of-the-art seawater desalination plants worldwide. Since its construction, the Water Corporation of Western Australia (Water Corporation) has built a second desalination plant, Perth II, to provide drought-proof and reliable water supply to the City of Perth (Mickley and Voutchkov 2016).

This plant has a velocity-cap-type open intake structure extending 660 ft (200 m) from the shore. Source seawater is treated using 24 single-stage dual granular media pressure filters, 14 5 μm cartridge filters, and 12 two-pass RO membrane system with pressure exchangers (16 ERI PX 220 per RO train) for energy recovery. The RO permeate is posttreated by lime stabilization and sodium hypochlorite disinfection.

Figure A1-5 provides a general schematic of the Perth I SWRO desalination plant.

Figure A1-4. Perth I seawater desalination plant.

Source: Mickley and Voutchkov (2016), permission from Water Environment and Reuse Foundation, now part of the Water Research Foundation.

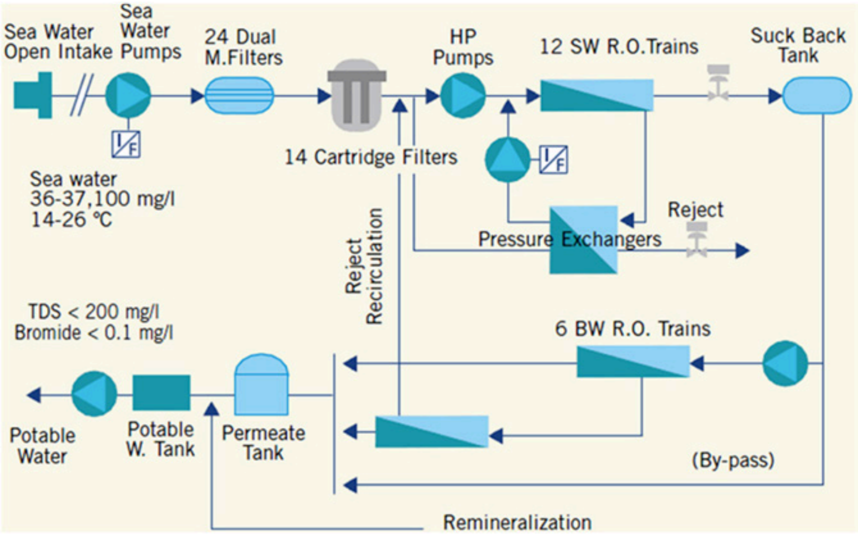

Figure A1-5. Desalination plant schematic.

Source: Mickley and Voutchkov (2016), permission from Water Environment and Reuse Foundation, now part of the Water Research Foundation.

The desalination plant concentrate is discharged to the ocean via an offshore outfall with diffusers. Plant source water salinity varies from 30,000 to 39,000 mg/L (avg. 37,000 mg/L) and intake temperature is between 54 F and 77 °F (15 °C and 25 °C), and averages 68 °F (20 °C).

Project Background

Perth I was the first large SWRO desalination project in Australia. This project was built in response to a prolonged drought period along the west coast of Australia with a span of more than 10 years (Mickley and Voutchkov 2016).

Perth I SWRO plant discharge is located in Cockburn Sound, which is a shallow and enclosed water body with a very limited water circulation and an average salinity of 37,000 mg/L. Cockburn Sound frequently experiences naturally occurring low oxygen levels during periods of low current velocity/low wind intensity. This water body is connected to the Pacific Ocean. Cockburn Sound is characterized by relatively limited access to the Pacific Ocean and a variable offshore current. This sound consists of 33 ft (10 m) shelf near the shore location of the desalination plant, which becomes 66 ft (20 m) basin at its deepest part, which is enclosed by the Garden Island further west. The main areas of environmental concern related to the desalination plant and its discharge included the following:

- Dilution of the concentrate discharge at the edge of the *mixing zone*—150 ft (50.0 m) in all directions of the diffuser,
- Potential toxicity of the concentrate and its effect on the surrounding ecosystem,
- Perceived threat to DO levels in Cockburn Sound by the environmental regulator and the Cockburn Sound Management Council (who monitor the environmental *health* of Cockburn Sound),
- Discharge of other waste products such as sludge from the dual media backwash water.

The desalination plant discharge to the ocean consists of concentrate and spent pretreatment filter backwash water. The concentrate is discharged from the RO system under pressure and after conveyance to a small retention chamber is discharged to the plant ocean outfall.

The spent filter backwash water is pretreated in lamella settlers and equalized prior to discharge with the concentrate. Sludge generated in the lamella settlers is dewatered in a belt filter press and disposed off-site to a sanitary landfill. Neutralized membrane cleaning solution generated from the RO membrane clean-in-place is discharged to the sanitary sewer.

Because the Perth I SWRO plant discharge area has very limited natural mixing, the desalination plant project team constructed a diffuser-based outfall which is located approximately 1,640 ft (500 m) offshore and has 40 ports along the final 660 ft (200 m) at about 1.6 ft (0.5 m) from the seabed surface at a 60° angle. The diffuser was designed to provide a dilution ratio of 45:1 within the

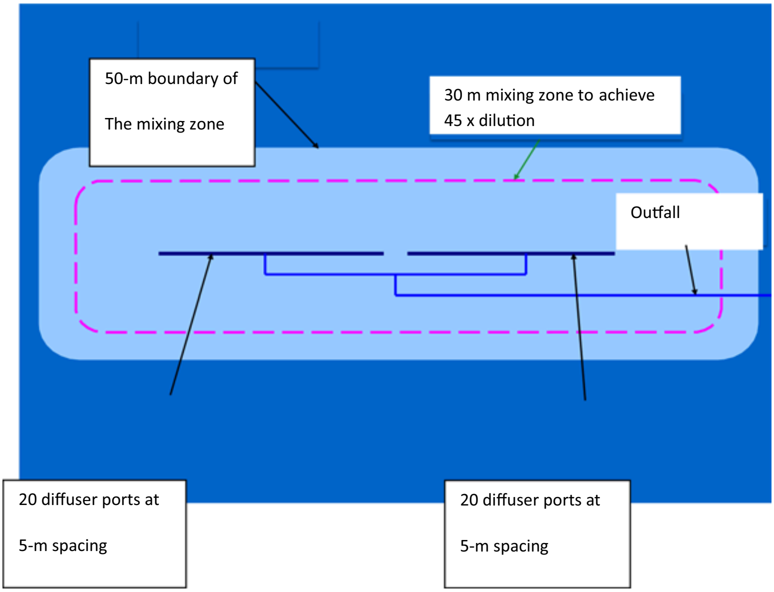

Figure A1-6. Perth I SWRO Plant discharge configuration.

Source: Mickley and Voutchkov (2016), permission from Water Environment and Reuse Foundation, now part of the Water Research Foundation.

mixing zone. The diffuser ports are spaced at 16 ft (5.0 m) intervals with 9 in. (220 mm) nominal port diameter at a depth of 33 ft (10 m) (Figure A1-6). Diffuser length is 520 ft (160 m). The outfall is a single glass-reinforced plastic pipeline with a diameter of 60 in. (1.6×10^3 mm).

This diffuser design was adopted with the expectation that the plume would rise to a height of 28 ft (8.5 m) before beginning to sink because of its elevated density. It was designed to achieve a plume thickness at the edge of the mixing zone of 8 ft (2.5 m) and, in the absence of ambient cross flow, to extent to approximately 160 ft (50 m) laterally from the diffuser to the edge of the mixing zone (Figure A1-7).

Plant operations data (Christine and Bonnelye 2009) show that the actual dilution ratios achieved with this design were between 50 and 120 (measured at the edge of the mixing zone) depending on the actual direction of local currents,which is well above the plant permit dilution ratio requirement of 45:1.

It should be noted that the plant has provision (which is allowed by the permit) to recirculate the intake seawater into the plant concentrate discharge during periods of reduced plant capacity to increase the discharge velocity and improve the dilution and oxygen content, if needed, for compliance with the minimum dilution ratio defined in the permit.

The diffuser design was optimized using computer fluid dynamic models based on the Roberts equation, which allowed for optimizing the diameter and angle of discharge. During the design phase, studies were performed at the University of New South Wales using a hydraulic calculation model as well as physical 1:15 scale

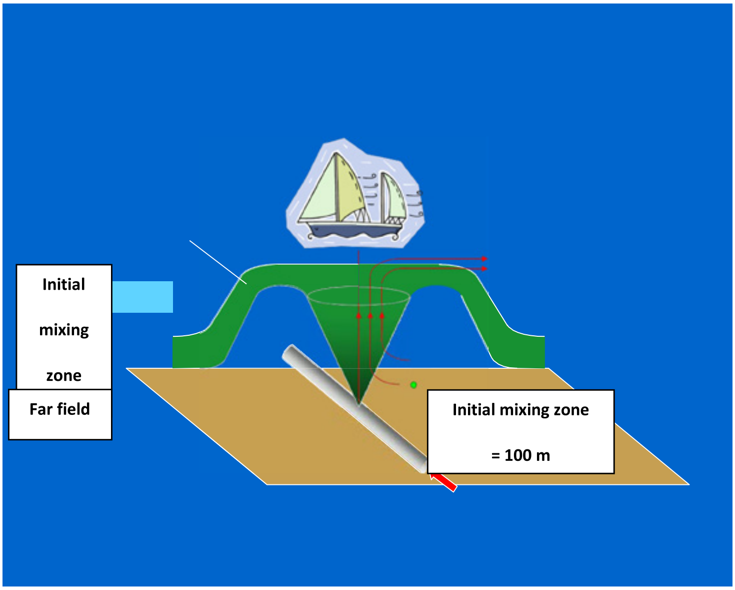

Figure A1-7. Perth I Desalination Plant mixing zone.

Source: Mickley and Voutchkov (2016), permission from Water Environment and Reuse Foundation, now part of the Water Research Foundation.

modeling for the confirmation of the design of the outfall [plume thickness and height, impact, ultimate dilution (<1.2 ppt at 156 ft (50.0 m) objective)].

Permitting and Regulatory Overview and Procedure (Mickley and Voutchkov 2016)

Table A1-4 presents a summary of key requirements included in the plant discharge permit.

The plant discharge permit (referred to as *operational environmental license*) is issued by the Department of Environment and Conservation of Western Australia. The permit prescribes that the discharge should achieve a dilution factor of 45:1, at a distance of 165 ft (50.0 m) in all directions of the diffuser (the edge of the defined mixing zone). The dilution factor is calculated based on the salinity concentrations of concentrate and ambient seawater, which is measured in practical salinity units (psu) as follows:

$$\text{Dilution Factor} = (SB - SS)/(SD - SS)$$

where

SB = Salinity of the discharged seawater concentrate in psu,
SD = Salinity at 165 ft (50 m) from the diffuser (average of the concentrate plume—see explanation of the average below) in psu, and
SS = Salinity of intake seawater in psu.

Table A1-4. Perth I SWRO Desalination Plant—Key Discharge Permit Requirements—Permit No. L8108/2004/4.

Permit discharge parameter	*Average*	*Maximum*	*Minimum*
Distance factor at the edge of mixing zone	—	—	1:45
Distance from diffusers to edge of mixing zone	—	165 ft (50 m)	—
Salinity increment above average at the edge of mixing zone	0.8 ppt	1.2 ppt	—
Turbidity	—	8 NTU	—
Oxygen concentration	—	—	5 mg/L
pH units	—	8.3	7.0
Conductivity of undiluted concentrate	—	92,999 μS/cm	—

Source: Mickley and Voutchkov (2016), reprinted with permission from Water Environment and Reuse Foundation, now part of the Water Research Foundation.

The seawater salinity at the edge of the mixing zone is measured as close as practicable to 1.65 ft (0.50 m) intervals in the bottom 16.4 ft (5.00 m) of the water column. The pycnocline because of the diffuser discharge is identified and only those depths below the pycnocline are averaged to determine the diffuser performance. Salinity is required to be measured for at least 3 minutes at each depth then time averaged prior to the determination of the pycnocline depth and any depth averaging.

The discharge permit requires salinity monitoring to be completed 12 times per year during the first year to obtain data representative for seasonal salinity variations. The frequency of salinity measurement is reduced to two times per year after the first year.

In addition to the requirements of the discharge permit issued by the Department of Environmental Conservation, the Western Australian Environmental Protection Authority has also added a permit condition to complete WET testing at the time of plant commissioning and after 12 months of operation. These tests aim to confirm that the actual plant dilution is adequate to prevent chronic toxicity of the marine flora and fauna.

One of the key concerns of the regulators was that the concentrate, which is denser than the ambient seawater, would sink to the deeper (66 ft/20 m) basin of Cockburn sound and will cause the formation of hypoxic layer and DO suppression. Hypoxia would in turn cause potential fish kills. Therefore, the plant permit requires the operator to monitor DO levels in the deeper basin of Cockburn Sound and the plant is required to limit production to one-sixth of its capacity when the oxygen concentration decreases under certain prescribed levels.

Analyses of Plant Concentrate (Mickley and Voutchkov 2016)

Extensive real-time monitoring was undertaken in Cockburn Sound for 12 months before and after the plant began operation in November 2006 to ensure that the marine habitat and fauna are protected. This monitoring included continuous measurement of DO levels via sensors located on the sandy bed of the Sound.

Visual confirmation of the plume dispersion was achieved by using 14 gal. (52 L) of Rhodamine dye added to the plant discharge. The dye was reported to have billowed to within approximately 10 ft (3.0 m) of the water surface before falling to the seabed and spilling along a shallow sill of the Sound toward the ocean. The experiment showed that the dye had dispersed beyond what could be visually detected within approximately 0.9 mi (1.5 km)—well within the protected deeper region of Cockburn Sound, which is located approximately 3 mi (5 km) from the diffusers. The environmentally benign dye experiment was first commissioned in December 2006 and repeated in April 2007 when the discharge conditions were calm.

In addition to the dye study, the project team has completed a series of toxicity tests with a number of species in the larval phase to verify that the actual mixing ratio of the plant outfall diffusers is higher than the minimum dilution ratio needed to be achieved at the edge of the zone of initial dilution:

- 72 h macro-algal germination assay using the brown kelp *Ecklonia radiata*,
- 48 h mussel larval development using *Mytilus edulis*,
- 72 h algal growth test using the unicellular algae *Isochrysis galbana*,
- 28 day copepod reproduction test using the copepod *Gladioferens imparipes*,
- 7 day larval fish growth test using the marine fish pink snapper *Pagrus auratus*.

The results of the toxicity tests indicate that the plant concentrate dilution needed to be achieved at the edge of the mixing zone to protect the sensitive species listed above is 9.2:1 to 15.1:1, which is within the actual design diffuser system mixing ratio of 45:1.

In addition to the toxicity testing, the Perth desalination project team has also completed two environmental surveys of the desalination plant discharge area in terms of macro-faunal community and sediment (benthic) habitat (Okely et al. 2007a,b, Oceanica Consulting 2009). The March 2006 baseline survey covered 77 sites to determine the spatial pattern of the benthic macro-faunal communities, while the repeat survey in 2008 covered 41 sites originally sampled in 2006 and 5 new reference sites. Some of the benthic community survey locations were in immediate vicinity of the discharge diffusers, while others were in various locations throughout the bay. The two surveys have shown no changes in benthic communities that can be attributed to the desalination plant discharge.

Water quality sampling completed in the discharge area has shown no observable effect of ocean water quality, except that the salinity at the ocean bottom increased with up to 1 ppt, and this salinity level is well within the naturally occurring salinity variation (Christie and Bonnelye 2009).