Oakajee Port and Rail

Concept Design for the Oakajee Port Brine Diffuser

December 2010

Consulting Environmental Engineers

Concept Design for the
Oakajee Port Brine Diffuser

Table of Contents

Cover image: Oakajee Development Site
(Source: Department of Transport, Government of Western Australia)

Prepared by:
CEE Pty Ltd
PO Box 201, First Floor, 90 Bridge Road, Richmond, Victoria

Version	*Prepared by*	*Date*	*Reviewed by*
0-draft	Ian Wallis	29 July 2009	KM
1l	Ian Wallis	9 August 2009	KM
2	Ian Wallis	28 Feb 2010	PC
3-final	Ian Wallis	12 March 2010	PC
3-final	Ian Wallis	14 Dec 2010	JR

This report constitutes the professional opinion and judgement of Consulting Environmental Engineers

1. Scope of Work

Oakajee Port and Rail Pty Ltd is investigating options for a proposed desalination plant on the Oakajee Breakwater, at the site of the proposed Oakajee Port, about 20 km north of Geraldton (see Figure 1-1). This new deep water port will serve mining operations in the mid-west region of Western Australia. A small desalination plant will supply potable water for construction and, following the completion of construction works, for the ongoing operations of the port.

A brine discharge outfall off the Oakajee breakwater is proposed as the preferred option for disposal of brine and the trace chemical constituents associated with seawater desalination and treatment. It is planned to site the brine diffuser on the south side of the proposed breakwater.

In June 2009, AECOM engaged Consulting Environmental Engineers (CEE) to develop a concept design for the brine outfall to meet the expected regulatory requirements for discharge of brine to near-shore ocean waters and to predict the performance of the proposed diffuser.

The scope of work was as follows:

- Define the likely regulatory requirements for the discharge of brine;
- Prepare a concept design for a brine outfall that would comply with the expected regulatory requirements; and
- Prepare a performance report for the proposed brine discharge arrangement for submission to the regulator.

Figure 1-1. Location of Proposed Oakajee Port (Source: Oceanica)

2. Design Information

The proposed seawater reverse osmosis desalination plant at Oakajee will have an design capacity of 14 ML/d of fresh water. For the expected recovery rate of freshwater from seawater of 44 per cent, the capacity of 14 ML/d of fresh water corresponds to a seawater intake rate of 31.8 ML/d and a corresponding brine discharge rate of approximately 17.8 ML/d that will be returned to the ocean.

The desalination plant may be developed in stages. However the performance predictions are based on the ultimate capacity, noting that the diffuser ports can be progressively uncapped to correspond to increments in capacity of the plant.

An RO plant with a nominal capacity of 14 ML/d can operate at a higher rate when all the cells are new (up to 18 per cent above the nominal design capacity), at capacity (plus or minus 5 per cent), and at a slightly lower rate (estimated to be 12.6 ML/d) when the cells are fouled. Thus the performance predictions are made taking this range of operational flow into account. Table 2-1 summarises the design conditions.

Table 2-1. Summary of Design Flows for Diffuser Design

Rating to Capacity , per cent	Peak Product Water Demand, ML/d	Assumed RO Recovery, %	Peak Seawater Supply, L/s	Brine Discharge L/s	Seawater Salinity, mg/L	Brine discharge salinity, mg/L
118	16.5	44	434	243	36,000	64,286
100	**14.0**	**44**	**368**	**206**	**36,000**	**64,286**
90	12.6	44	331	186	36,000	64,286

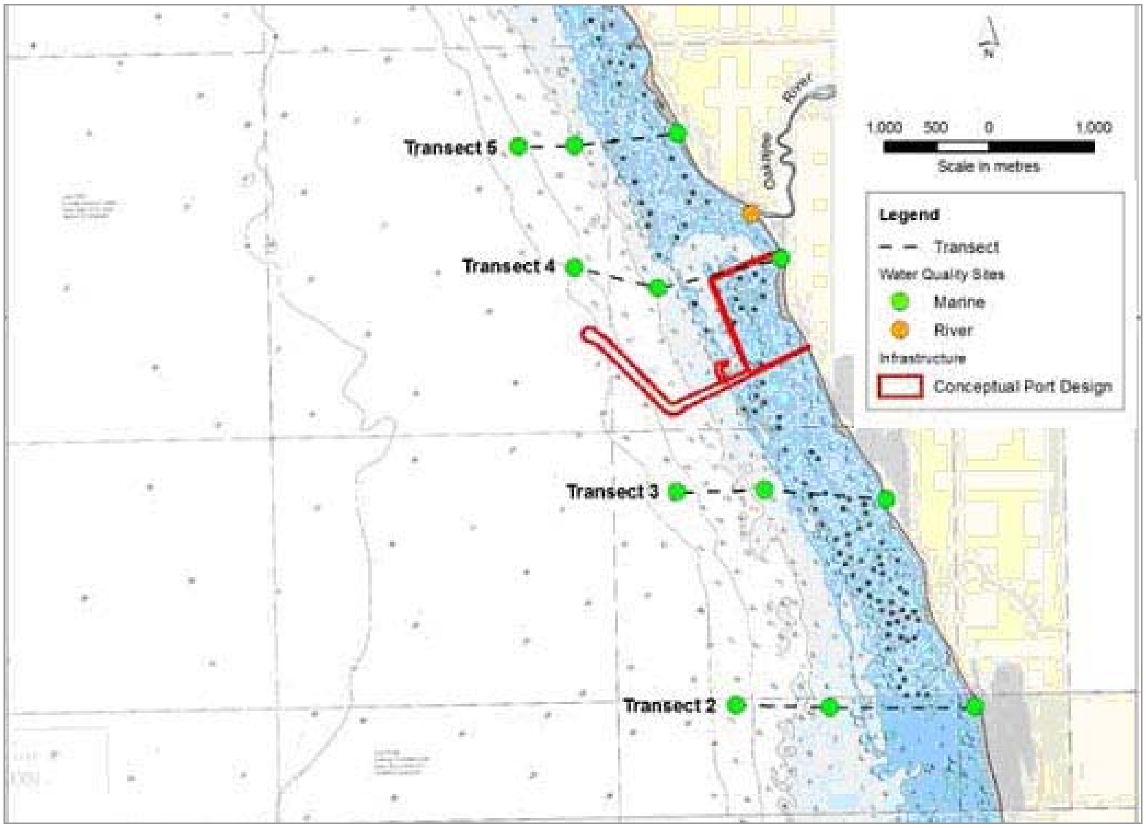
To accommodate the range of operating condition, the brine outfall is to be designed for brine discharges between 192 to 243 L/s, at a brine salinity of 64,286 mg/L.

The temperature of the brine will be 1 degree C above that of the ambient seawater. As by-products of the desalination process, the following contaminants may at times be present in the discharge:

- Coagulants (e.g. ferric chloride) at 1 to 10 mg/L;
- Filter aids at 0.2 to 4 mg/l;
- Anti-scalants at 1 to 2 mg/l;
- Sulphuric acid (pH may be 6 to 7);
- Traces of heavy metals; and
- Alkaline and acidic cleaning compounds.

It is proposed to discharge the brine through a diffuser on the southern side of the breakwater (see Figure 1-2). The location for the diffuser was selected based on the performance requirement, as established in Section 4 of this report.

Figure 1-2. Concept Design of the Proposed Oakajee Port. (Source: Oceanica).



Note: Transect lines and green site locations depict water quality sampling points

Metal salts

The desalination plant will use ferric chloride or ferric sulphate as a coagulant. Ferric salts are used to bind the solids in the seawater into larger particles (flocs) to aid settling and filtration in the pre-treatment processes.

The filter backwash will be discharged with the brine stream. Backwashing the filters will transfer filtered marine life including seaweed and some metal salts into the brine stream.

At peak production for the 14 ML/d capacity plant, seawater would be dosed with between 8 and 15 kg/hr of ferric. Most of the ferric will be retained in the sludge and only a small proportion will be discharged.

Biofouling Control

Occasional shock dosing with biocides may be undertaken to limit build-up of marine growth in the incoming pipeline.

The most likely process would use chlorine (e.g. sodium hypochlorite NaOCl). The chlorine would be neutralised with sodium bisulphite (NaHSO3) prior to the RO plant, and thus prior to discharge to the marine environment. The products of chlorination followed by dechlorination are salts that are non-hazardous (WCI, 2006).

Anti-scalants

The minerals in seawater become more concentrated during the RO process. Ions of calcium, magnesium, barium, strontium, sulphate and carbonate can form sparingly soluble salts (e.g. calcium carbonate, calcium and magnesium sulphate and barium and strontium sulphate) which can precipitate on the membrane surface.

Antiscalant polymers are added to feedwater to prevent membrane scaling. Polymers identified include polyphosphates, phosphonates, polymaleic acids and polyacrylic acids.

In addition to antiscalant, acid is commonly added (e.g. sulphuric acid) to reduce seawater pH and increase the solubility of the various sparingly soluble salts.

Reverse Osmosis (RO) Cleaning Chemicals

In normal operation, RO membranes become fouled by mineral scale, biological matter, colloidal particles, and insoluble organic constituents. RO cleaning typically occurs at three to six months intervals, depending upon the quality of the intake water and efficiency of the pre-treatment scheme (WCI, 2006).

The cleaning procedure chosen depends upon the type of membrane fouling. Alkaline solutions e.g. NaOH (pH of 11-12) are used to remove silt deposits and biofilms from membranes, while acidic solutions (pH 2-3) are applied to dissolve metal oxides or scales. Cleaning solutions can contain additional chemicals to improve membrane cleaning. Common additives in alkaline solution include detergents (e.g. dodecylsulfate, dodecylbenzene sulfonate) or oxidants (e.g. sodium perborate, sodium hypochlorite) (WCI, 2006).

3. Environmental Context

The coastal environment of the Oakajee area is subject to moderate to strong onshore winds throughout the year. Prevailing winds tend from the south-south-west, but also range from easterlies through to north-westerlies and can be particularly strong during summer. The shoreline and inshore waters experience large waves and swell during conditions with strong winds.

The seabed on which the proposed outfall diffuser will be located generally comprises hard limestone substrate, with minimal amounts of sand. Algal beds are found on the shallow limestone reef and a mixture of algae and seagrass are observed from about 15 m depth.

The bathymetric map for the area shows that the sea floor descends on a gradual slope from the shoreline to a depth of only 3 m at 580 m from shore, then to a relatively flat region of 5 m depth between about 750 to 840 m offshore. The offshore face of the reef slopes down to a depth of 8 m at about 920 m from the shore (Oceanica 2008).

The waters at 1,100 m offshore are around 10 m deep and reach 20 m depth at a distance of approximately 2,200 m from shore (EPA 1997). Combined with wind characteristics, this seabed profile generates a high wave energy environment near the shore with almost continuous surf and strong currents (EPA 1997).

Tidal Conditions

Ocean water level is affected by tides, winds and coastal trapped waves. Tides at Oakajee are considered mixed, varying from semi-diurnal (two high and two low tides each day) to diurnal tide cycles (one high and one low tide per day). The tidal range at Oakajee is between 0.4 and 1.4 m.

Water Quality

The baseline marine oceanographic and ecological conditions of the Oakajee region have been most recently characterised by Oceanica Consulting Pty Ltd (Oceanica). Subsequent water quality information is summarised below.

Baseline water quality at the site of the proposed port development is being monitored by Oceanica on an ongoing basis (see *Oakajee Port Baseline Water Quality Monitoring Report (2006-2008)*, Oceanica, 2009). This monitoring has thus far comprised sampling in 2006 and quad-annually in 2007 and 2008. The Oceanica study follows earlier water sampling conducted by Alan Tingay & Associates (2000).

Key Findings of the Oceanica Study

There was considerable spatial and temporal variation for the majority of water quality parameters in the ocean waters at Oakajee. The spatial variation reflected the patchy and heterogeneous water quality conditions in the region. Such variations are common for such an exposed and highly dynamic coastline.

Most water quality parameters also varied temporally: elevated nutrients were detected in summer and lower nutrients in winter, reflecting natural seasonal cycles in water quality conditions.

The water quality conditions at Oakajee were compared to the ANZECC/ARMCANZ (2000) default water quality guidelines, specific for south-west Australian inshore and offshore marine waters. These results showed that for some of the nutrient and physical parameters at Oakajee, background concentrations appeared to be naturally above the ANZECC/ARMCANZ (2000) guideline levels (see Table 3-1). Natural exceedances of guideline values were also reported in previous studies within the Oakajee/Geraldton region (Tingay & Associates 2000; GPA 2006). It would therefore be appropriate to adopt site specific environmental quality guideline values (EQGs), as part of the post-construction monitoring programme.

Potentially harmful and toxic algal species were observed in all seasons at the majority of transects, but did not exceed the WASQAP[1] guideline trigger levels (WASQAP 2007). Similarly, there were no exceedances of enterococci counts or polycyclic aromatic hydrocarbon concentrations above the ANZECC/ARMCANZ[2] (2000) guidelines.

Table 3-1. ANZECC/ARMCANZ (2000) Water Quality Guidelines Values For South-West Australian Waters

Parameter	Default ANZECC/ARMCANZ (2000) Guidelines for Inshore Marine Waters in SW Australia
Total Phosphorus (µg/L)	20
Ortho-phosphate (µg/L)	5
Total Nitrogen (µg/L)	230
Ammonium (µg/L)	5
Nitrate + Nitrite (µg/L)	5
Chlorophyll (µg/L)	0.7
Dissolved Oxygen (% saturation)	>90
pH	8.0-8.4
Turbidity (NTU)	1-2
Light Attenuation Coefficient (log10)/m	0.09-0.13
Enterococci (MPN/100ml)	35 (primary contact) 230 (secondary contact)
PAH (Naphthalene) (µg/L)	50 (99 % protection)

[1] Western Australian Shellfish Quality Assurance Program
[2] Australian and New Zealand Guidelines for Fresh and Marine Water Quality; Agriculture and Resource Management Council of Australia and New Zealand

4. Dilution Requirements

The proposed discharge location for the ocean outfall at Oakajee is on the southern side of the breakwater. The breakwater is located on the high energy coast, with swell and waves creating local surge and mixing for the majority of the time. CEE considers that the regulatory authority will require a diffuser to be installed so there is sufficient initial dispersion of the brine stream to avoid any toxic effect from the discharge on marine flora and fauna, and to avoid a pond of brine forming on the seabed, causing adverse effects in local flora and fauna.

The dilution requirements for the discharge of brine at Oakajee are derived from the ecotoxicity tests carried out for the Perth, Adelaide and Victorian desalination plants. These toxicity tests investigated the impacts of high salinity seawater discharged by desalination plants on marine flora and fauna species in the surrounding environment, and included tests with the suite of residual chemicals from the RO process.

The results are summarised below and represent the data currently available for desalination plants in Australia. Based on current information on desalination processes, intake water quality and anticipated brine characteristics, these data are considered to provide a reasonable data base for assessment of the dilution required for the proposed Oakajee plant.

Perth Seawater Desalination Plant (PSDP)

The Whole Effluent Toxicity (WET) Testing program for the Perth Southern Desalination Plant comprised testing (using simulated brine) on a number of the locally indigenous species. The toxicity tests were conducted at Geotechnical Services Ecotoxicology Laboratory at Fremantle using filtered seawater from Cockburn Sound and brine samples at commissioning (2006) and 12 months later (2007). The results are expressed in terms of the dilution corresponding to the highest concentration in the toxicity tests that causes an effect not significantly different to the control test or NOEC dilution (Geotechnical Services, 2008)

Table 4-1. Summary of 2006 / 2007 Tests for Perth Plant

Species tested	2006 tests NOEC Dilution	2007 tests NOEC Dilution
72 Hour Algal Growth	2:1	10:1
72 Hour Macroalgal Germination	16:1	2:1
48 Hour Mussel Larval Development	17:1	8:1
Copepod Reproduction	220:1 (continuous exposure)	8:1 (24 hr pulse)
7 Day Larval Fish Growth	9:1	8:1

Note that the 2006 copepod reproduction test exposed the copepods to the RO brine for the duration of the test. The concentration causing a toxic response is likely to be over-conservative as these organisms are subject to tidal movements and thus are extremely unlikely to be exposed in the brine for such an extended period.

The 2007 copepod reproduction test exposed the copepod to the RO brine for a more realistic period of 24 hours, at which time the brine was replaced with dilution water for the duration of the test. It can be seen from Table 4-1 that a much lower dilution produced a no effect response by the copepods.

Excluding the 2006 copepod reproduction test, the dilutions calculated using the Burrlioz statistics program to protect the range of the test species are listed in Table 4-2.

Table 4.2. 2007 Species Protection Trigger Values for Perth Plant

Protection Level with 50 % confidence	Dilution based on EC-10	Dilution based on NOEC
95	12:1	11:1
99	15:1	13:1

The results of the Perth tests indicated that the toxicity effects of the brine were generally avoided after a dilution of 15:1.

Adelaide Desalination Plant

A program of toxicity testing was undertaken to examine the environmental effects of the proposed brine discharge from the Adelaide Desalination Plant. Testing accounted for a variable brine concentrate, including an ambient and a pH-adjusted discharge, with and without an additional antiscalant and two backwash products (chemicals that may be present in the brine stream as a result of the treatment process).

The ecotoxicity tests investigated a range of acute, sub-chronic and chronic effects on a suite of relevant species, selected to comply with ANZECC and ARMCANZ (2000) guidelines for the assessment of toxicants in receiving waters. The results are summarised in Table 4-3.

Table 4.3. Results of Direct Toxicity Testing- Adelaide Plant

Test	EC10/NOEC Dilution Values	
	Ambient saline concentrate + antiscalant	Ambient saline concentrate without antiscalant
Microalgal Cell Yield	12:1	18:1
Sea Urchin Fertilisation Success	5:1	5:1
Sea Urchin Larval Development	8:1	8:1
Sea Urchin Metamorphosis	8:1	8:1
Scallop Larval Development	8:1	8:1
Macroalgal Germination	2:1	1:1
Macroalgal Gametophyte Growth	4:1	2:1
Amphipod Survival (96-h)	2:1	2:1
Amphipod Survival (14-d)	2:1	4:1
Amphipod Biomass (14-d)	2:1	4:1
Polychaete Survival (96-h)	4:1	5:1
Polychaete Biomass (14-d)	2:1	2:1
Fish Growth (7-d)	8:1	8:1

Note: Values in brackets are 95% confidence intervals.

The highest dilution requirements corresponded to the case of ambient pH. The dilutions required to protect the range of the test species are listed in Table 4-4. The results of the Adelaide tests indicated that the toxicity effects of the brine concentrate were avoided after a dilution of 23:1.

Table 4.4. Concentrations of Brine and Corresponding Dilution for Protection of 95 % and 99 % of species

PC95 (% sample) and safe dilution factor for ambient pH		
	Ambient saline concentrate + antiscalant	Ambient saline concentrate without antiscalant
PC 95	8.7 %	6.5 %
Dilution Required	12:1	16:1
PC 99	7.3 %	4.5 %
Dilution Required	14:1	23:1

Victorian Desalination Plant

As part of the Victorian Desalination Plant Environmental Effects Statement (2009), Hydrobiology and CSIRO undertook a toxicity assessment for the brine that would be generated by the proposed desalination plant.

The ecotoxicity testing was undertaken to identify the dilution that provides 99 per cent species protection. The results showed that salinity was the primary, but not the only, stressor in the discharge. The tests concluded that the maximum dilution required for any single chemical constituent assessed (including salinity) was 20:1, with most requiring less dilution to meet the requirements of SEPP (WoV).

A "safe dilution" of 30:1 with a salinity variation of 1 psu above ambient levels, was adopted to meet the ecosystem protection requirement under SEPP (WoV)[3]. This assumes a safety factor of 1.5

From an ecological perspective, the initial dilution and the short timeframe in which this dilution occurs indicates that marine organisms in the water column would be exposed to diluted brine for only a short period of time. The tests are based on much longer periods of exposure (24 hours or more) and hence the results are expected to be conservative – short exposure is less likely to result in a toxic reaction, including osmoregulatory shock from salt exposure.

Conclusion

The dilution required to avoid toxic effects for the Oakajee plant can be assessed from the combined results of toxicity tests for the Perth, Adelaide and Victorian desalination plants. The test results indicate that an initial dilution of 30:1 will be sufficient to minimise the toxic effects of the brine discharge from the Oakajee Desalination Plant. Because of the energetic marine environment in which the diffuser is to be located, the initial dilution of 30:1 also should be sufficient to avoid formation of a dense field on the seabed. Further dilution of the brine stream will occur due to ambient mixing as the diluted plume is carried away from the diffuser by the tidal currents.

[3] The Waters of Victoria State Environment Protection Policy

5. Diffuser Design

The basis of design for the Oakajee diffuser is to produce an initial dilution of 30:1 to minimise adverse impacts of the proposed brine discharge on the marine biological environment.

To achieve the required initial dilution of 30:1 at times of low currents, the proposed diffuser will discharge the brine at a relatively high velocity (2 m/s at peak flow) through a series of small ports of 75 mm diameter. The jets will rise a distance of about 3 m above the diffuser and then fall back to the seabed. The dilution achieved within 30 m of the diffuser will be 34:1 for the low flow case, 38:1 for the design capacity of 14 ML/d and 44:1 at the peak production rate of 16.5 ML/d. (see Table 5-1).

To accommodate the rise of the jets within the water column, the diffuser will be located on the 8 m contour (relative to top chart datum). This depth is achieved approximately 920 m from the shoreline. A location at this distance will place the diffuser in a zone of high mixing and strong currents, resulting in high subsequent dilution of the brine discharge.

Table 5-1. Dilution Calculations for Proposed Oakajee Diffuser

Parameter	186 L/s case	206 L/s case	243 L/s case	
Port diameter, m	0.075	0.075	0.075	
No of ports	24	24	24	
Port spacing, m	2	2	2	
Length of diffuser, m	48	48	48	
Discharge vel, m/s	1.8	1.9	2.3	
Height of rise, m	2.4	2.6	3.0	
Froude No	13	16	18	
Head loss, m	0.2	0.2	0.3	
Predicted dilution	34:1	38:1	44:1	

Dilution predictions have been made using the model set out by Roberts with an adjustment to account for the interference between closely spaced jets. This model has been checked against the actual dilution produced by the Kwinana brine diffuser and found to be correct (slightly conservative).

With a dilution of 38:1, the salinity increment is 750 mg/L. This equates to a 2.1 per cent increase in salinity. The diluted brine will have a negligible effect on DO, temperature and pH after this degree of mixing with seawater. It also is noted that the diffuser is located just offshore of the normal zone of breaking waves, in an area with high natural turbulence and dispersion.

6. Diffuser Diameter and Port Arrangement

To achieve even flow distribution from the ports and provide adequate structural strength, the diffuser should be designed with a diameter of 500 mm. Given the high wave forces, the pipeline is likely to be of steel construction with a corrosion protection coating. The diffuser will need to be secured on the seabed.

Figure 6-1 shows the indicative location of the diffuser. Further detailed investigation of the bathymetry and seabed conditions is required to finalise the location. Ideally the diffuser would be located in a natural channel or in an excavated trench in the seabed to protect it from wave and current forces.

It is anticipated that the diffuser and associated pipeline from the breakwater will be fabricated in 12 m lengths, with bolted flanged joints, towed out to position by a workboat, sunk into position and then secured by an appropriate engineering technique.

The ports will be formed by short stub sections of pipe with an internal diameter (after protective coatings) of 75 mm. The stubs will be welded to then diffuser on the seaward side of the pipe, facing offshore, at an angle of 60 degrees above the horizontal.

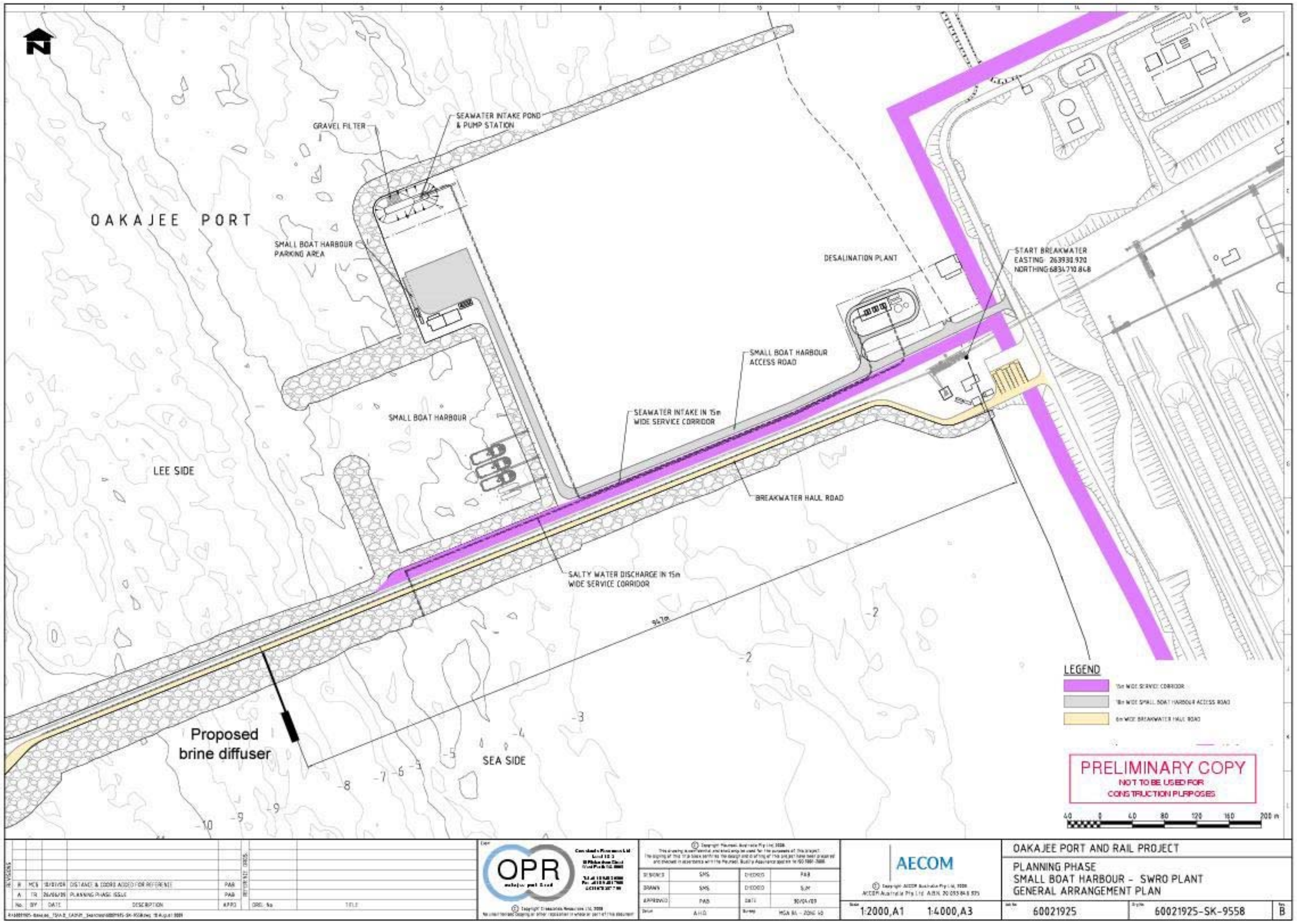


Figure 6-1 Proposed Diffuser Location

7. Conclusion

The conclusions from this assessment for a brine diffuser at the proposed Oakajee desalination plant are as follows:

- Based on the results of ecotoxicity tests carried out for the Perth, Adelaide and Wonthaggi desalination plants, a dilution of 30:1 would be satisfactory to protect the local marine ecosystem from adverse effects of the brine discharge.
- To achieve this dilution and to keep the jets from emerging on the ocean surface, the diffuser should be located at a depth of 8 m.
- At the design discharge rate of 206 L/s, the brine dilution would be 38:1;
- At the minimum discharge rate of 186 L/s, the brine dilution would be 34:1;
- At the peak discharge rate of 243 L/s, the brine dilution would be 44:1;
- The diffuser should be 48 m long with 24 ports at 75 mm diameter at 2 m spacing;
- All port should discharge upwards at 60 degrees above the horizontal, and all ports should be on the offshore side of the pipe;
- The nominal diameter of the diffuser should be 500 mm.
- It would be practical to construct the diffuser to the full length and only a proportion of the ports if the desalination plant is developed in stages;
- The diffuser should commence at about 10 m off the south side of the breakwater at about 920 m from shore.

8. Implementation

We understand that the Oakajee port project has been approved but without the proposed desalination plant. Thus it will be necessary to seek approval for the prosed intake and brine discharge facilities, probably as part of the modified port layout.

The request for approval should include this outfall performance report, engineering drawings on the proposed outfall design and details on the proposed method of construction, an outline of the sections of the Construction Environmental Management Plan addressing installation of the outfall, a commissioning procedure and the proposed environmental monitoring program.

Given the high wave energy at the outfall site, we suggest that an appropriate monitoring program would involve installation and operation of a continuously recording salinity monitor on the seabed about 50 m offshore from the centre of the diffuser. Baseline data on seawater salinity would be collected at the intake to the desalination plant. The seabed monitor would allow calculation of the increment in salinity due to the brine discharge (and hence the brine dilution) as well as the details of the salinity field at the offshore edge of the mixing zone.

References

Alan Tingay & Associates (2000) *Oakajee Deep Water Port : Water and Sediment Quality Baseline Monitoring Report,* No. 99/137, Alan Tingay and Associates, South Perth, Western Australia

Environmental Protection Authority (1997) *Oakajee Deepwater Port – Shire of Chapman Valley*, Bulletin 849, Environmental Protection Authority, Perth, Western Australia

Geotechnical Services (2008) *The Provision of Water Quality Monitoring Services For the Perth Seawater Desalination Plant: WET Testing*, Geotechnical Services, Welshpool, Western Australia

Hydrobiology & CSIRO (2008) *Toxicity Assessment for the Victorian Desalination Plant*, Hydrobiology & CSIRO, Australia

Oceanica Consulting Pty Ltd (2009) *Oakajee Port Baseline Water Quality Monitoring Report*, Oceanica Consulting Pty Ltd, Nedlands, Western Australia