ENVIRONMENTAL PROTECTION AND SUSTAINABILITY: PERTH SEAWATER DESALINATION PLANT EXPERIENCE

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Abstract

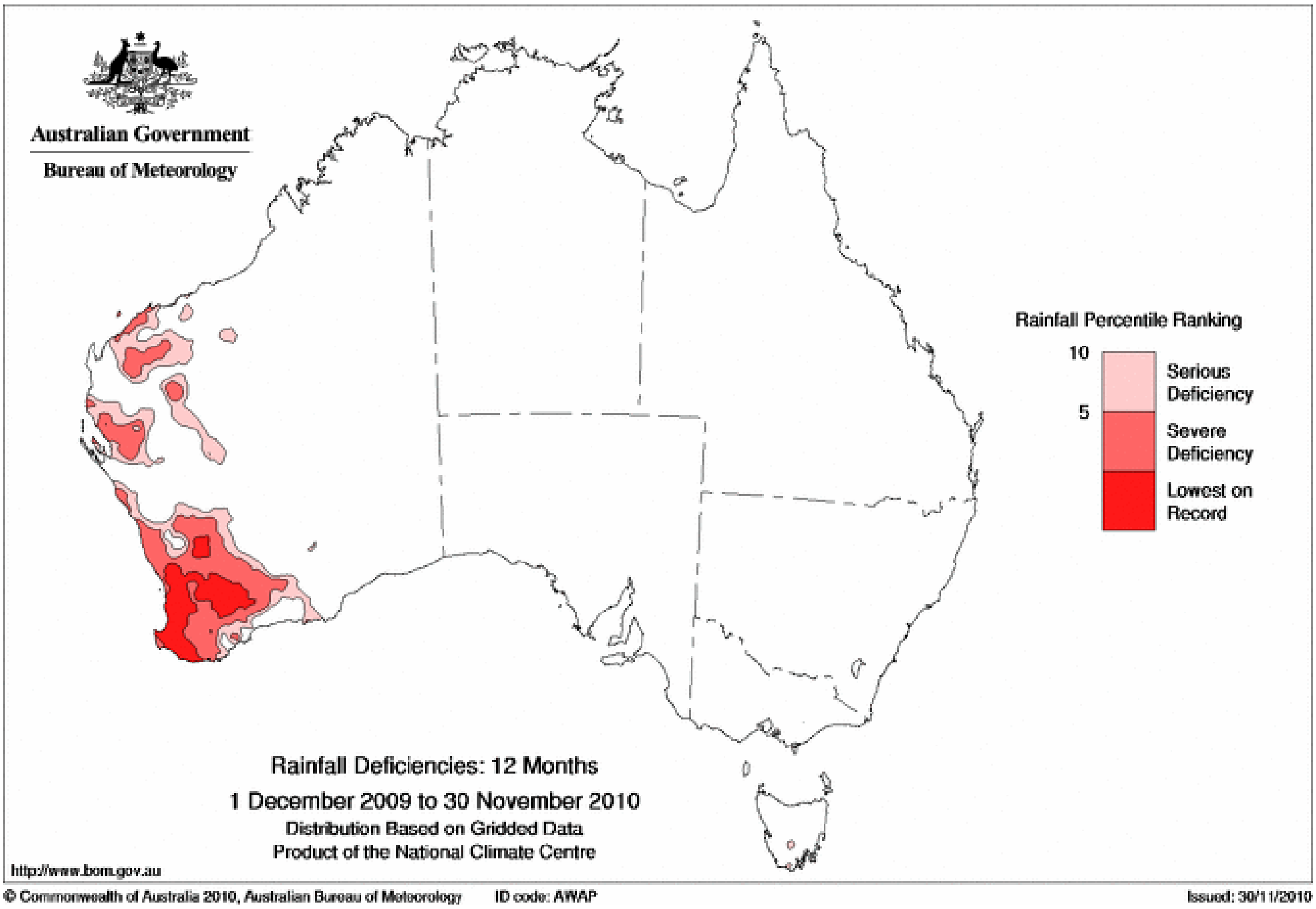
Seawater desalination development in Australia has been strongly influenced by environmental protection and sustainability. The Perth Seawater Desalination Plant (PSDP), as the first large seawater desalination project based on reverse osmosis in this part of the world, had to demonstrate its sustainability with regard to energy and environmental impact. Both subjects were treated with care during the plant design and build (DB) phase and is also subject to very stringent control during its operation and maintenance phase (25 years O&M). This paper outlines how the operational environmental concerns had been addressed, supported by operational data.

The PSDP with a production of 143 700 cubic meters per day (45GL/yr) has been implemented to produce 17% of the total potable water demand for the Perth Integrated Water Supply System (IWSS). The plant forms a key part of the Water Corporation's strategy of "security through diversity" taking into account Perth's growing population and the limitation of the supplies.

The main areas of environmental concern faced at the PSDP consist of dilution of the brine discharge, toxicity of the brine, a perceived threat to dissolved oxygen levels in Cockburn Sound, waste products, and energy consumption.

I. INTRODUCTION

Western Australia has been subjected to repetitive drought in the last decade, impacting the drinking water supply reliability. In this context, seawater desalination appeared to be a key alternative resource as part of the whole water management scheme. The Perth Seawater Desalination Plant (PSDP) project commenced construction in May 2005 and was a fast track project [1]. The plant is located to the south of Perth, the capital and largest city of the Australian state of Western Australia. With a Mediterranean climate (850 mm average rain fall), and a population of more than 1.6 million inhabitants, Perth is experiencing rapid growth and is expected to nearly double in population to 2.9 million by 2060 [2].



Source: www.bom.com.auNovember 2010

Diagram 1: Australian Context: 2010 – 12 months [3]

The PSDP with a production of 143 700 cubic meters per day (45GL/yr) has been implemented to produce 17% of the total potable water demand for the Perth Integrated Water Supply System (IWSS). The plant forms a key part of the Water Corporation's strategy of "security through diversity" taking into account Perth's growing population and the limitation of current dam and groundwater supplies.

Water Corporation 50 years plan (Water forever) [3] and [4]:

- 2010 ~290 gigalitres reticulated drinking water supply for Perth and connected towns
- 2030 -additional 120 gigalitres
- 2060 -additional 365 gigalitres

Seawater desalination development in Australia is strongly related to environmental impact reflection as well as sustainability. The PSDP as the first large seawater desalination project, based on reverse osmosis in this part of the world, had to demonstrate its sustainability with regard to energy and environmental impact. Both subjects were treated with care during the bid preparation as well as during the plant design and construction phases. Sustainability remains a key focus area of the plant into operations.

The main areas of environmental concern faced at the PSDP and its sustainability focus consist of:

- Dilution of the brine discharge at the edge of the 'mixing zone' – 50m in all directions of the diffuser,
- Toxicity of the brine and its effect on the surrounding ecosystem,
- A perceived threat to dissolved oxygen levels in Cockburn Sound by the environmental regulator and the Cockburn Sound Management Council (who monitor the environmental 'health' of Cockburn Sound),
- Other waste products such as sludge from the dual media backwash water and sludge from lime system, and
- Energy consumption.

These items will be addressed below in more detail [5].

II. ENVIRONMENTAL APPROVALS

Considerable time and effort is required to obtain environmental approvals in Australia for large construction projects, sometimes taking upwards of 2 years. The Water Corporation re-activated the project in April 2004 (after being on hold), when some early hydrodynamic modeling work was also undertaken to support the application. A project timeline is listed below, which shows that even though environmental approval was given in July 2004, the environmental operating license was not issued until less than one month before operations began:

- 2002 The Water Corporation begins to investigate desalination plants as a realistic source of water (Initially looking at a 30GL/yr plant),
- 2003 Project put on hold due to increasing rainfalls 2001-2003,
- April 2004 Project Re-Activated (and increased to 45GL/yr) due to low rainfall after being on hold since 2003,
- July 2004 Government Announcement,
- July 2004 Environmental Approval (Section 46 approval) by the Environmental Protection Authority,
- September 2004 Contract awarded for Project Definition Phase (Tender),
- February 2005 Tenders submitted,
- May 2005 Contract awarded to Multiplex Degrémont Joint Venture (MDJV), construction begins,
- August 2006 Pre-commissioning begins,
- October 2006 Environmental License issued by the Department of Environment and Conservation,
- November 2006 First Water,
- April 2007 Practical Completion awarded.

2006 Global Water Awards – Desalination Plant of the Year

Photo 1: Perth Seawater Desalination Plant – General View

The environmental operating license has since been amended 3 times but only for minor operational changes to make the license more practicable. The main monitoring requirements have remained the same.

For further details on the PSDP process, see Appendix 1 "Process Flow Diagram", in section VIII. The Appendix 2, in section VIII, gives details on the Intake Structure.

III. BRINE MANAGEMENT

3.1 Brine dilution

Brine discharge to the environment was raised as a main constraint for the development of seawater desalination. It was perceived by some areas of the public and environmental bodies that the high salt content of the brine could impact the sensitive ecosystem of Cockburn Sound. The issue was evaluated at different levels during the project development, plant construction and into operation.

The PSDP is restricted in operations by its operational environmental license, issued by the Department of Environment and Conservation (DEC). The license prescribes that the PSDP's brine discharge will meet a dilution factor of 45, at a distance 50m in all directions of the diffuser (the edge of the defined mixing zone).

Where: Dilution Factor = (SB – SS) / (SD – SS)

SB (psu) = Salinity of the seawater concentrate being discharged

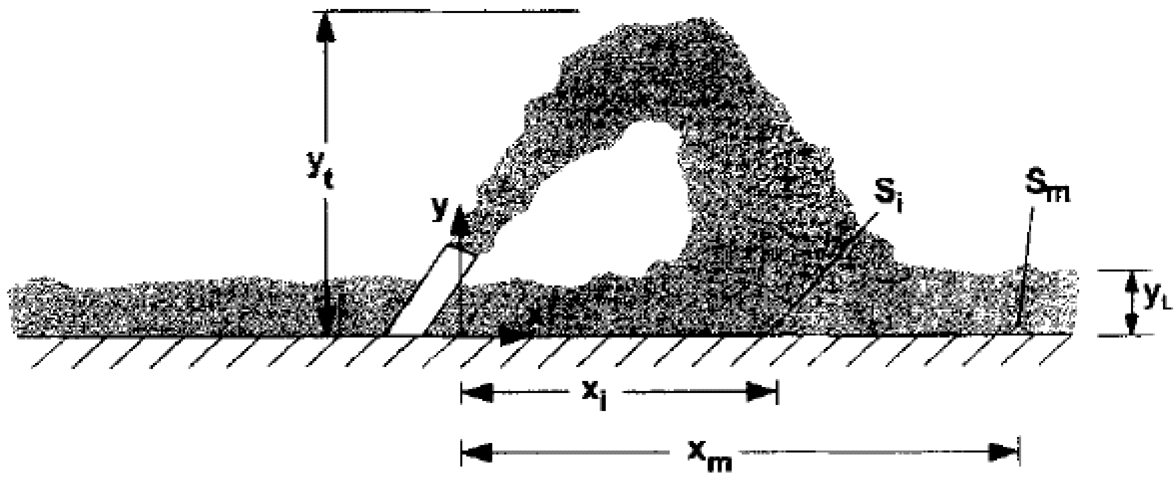
SD (psu) = Salinity at 50m from the diffuser (average of the brine plume – see explanation of the average below)

SS (psu) = Salinity of the seawater (at inlet)

For further details on the design of the outfall system, see Appendix 3 "Outfall Diffusers Configuration", in section VIII.

The seawater salinity at the edge of the mixing zone is measured as close as practicable to 0.5m intervals in the bottom 5m of the water column. The pycnocline due to the diffuser discharge is identified and only those depths below the pycnocline are averaged to determine the diffuser performance. Salinity is measured for at least 3 minutes at each depth then time averaged prior to the determination of the pycnocline depth and any depth averaging. A Seabird CTD instrument is used for all measurements. It was a requirement of the Environmental Operating License to carry out salinity monitoring 12 times over the first year to get an appropriate spread over the seasons, then once every 2 years thereafter. The dilution factors being achieved range from 50 up to 120 at the edge of the mixing zone, depending on which direction the current is flowing, well in excess of the prescribed limitations in the environmental license which requires a dilution of 45 times [6]. The PSDP also has the option to re-circulate seawater into the brine stream. This can be done during periods of reduced PSDP capacity in order to increase dilution, and ensure sufficient volume and velocity of the discharge in order for the diffusion to work.

The diffuser design was optimized using computer fluid dynamic models based on Roberts Equation, which allowed for the optimization of diameter and angle of discharge.



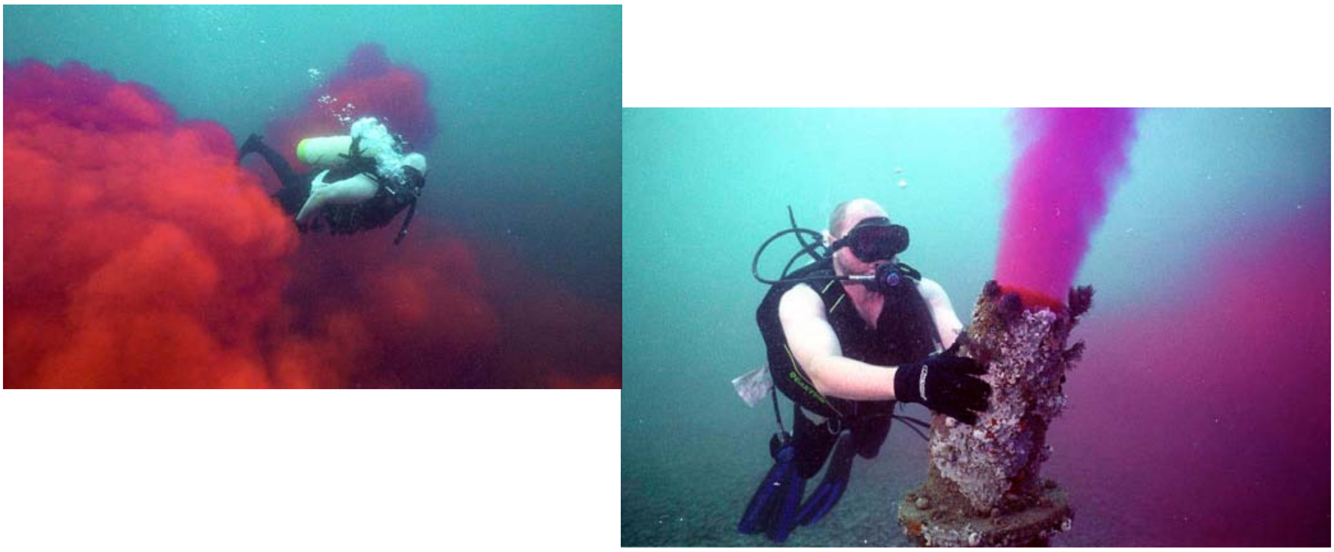
Source: Roberts et al 1997

Diagram 2: Elevated Salinity causes the water to be heavier than ambient water; jet reaches a terminal height and then falls back to the seabed [7]

During the design phase, studies were performed at the University of New South Wales using hydraulic calculation code as well as physical 1:15 scale modeling for the confirmation of the design of the outfall (Plume thickness and height, impact, ultimate dilution (<1.2 ppt at 50m objective)). The final design consists of a 1.6m diameter pipe running 500m offshore under the seabed. The terminal diffuser consists of 40 ports along the final 200 m, at about 0.5m from the seabed surface at a 60 degree angle. Later ELCOM (Estuary, Lake and Coastal Ocean Monitoring) computer modeling undertaken by the University of Western Australia (UWA) verified the model using seasonal data collected from real time monitoring sites (such as current data, salinity and temperature). This modeling was also run under a number of "worst case scenarios", the results of this modeling is discussed in Section 3.3. Diagram 3 shows the diffuser location compared to the shoreline and intake. The intake is located 200m offshore in 10m depth of water (intake screens are at mid-depth (5m)).

Diagram 3: PSDP Diffusers, Intake and shoreline

The performance of the diffuser system was also validated at full scale by the University of Western Australia [8] using salinity measurements around the discharge points as well as hydraulic tests using a rhodamine dye tracer shown in Photo 2 and Photo 3. The experiments consisted of high-resolution profiling of temperature, conductivity, pH, dissolved oxygen, and turbidity under calm conditions over several days in December 2006 and April 2007. The time periods were chosen in an attempt to simulate calm conditions (i.e. a worst case scenario).



Photos 2 and 3: Rhodamine Dye tracer test

The PSDP's discharge is not affected by surrounding industry. There is a large warmer plume to the North of the PSDP which is discharged from the neighboring power station, and although picked up in more extensive salinity and temperature sampling, it does not affect the PSDP's immediate mixing zone.

3.2 Brine toxicity

Toxicity tests were also performed to quantify the impact of the brine discharge on the most sensitive species present in Cockburn Sound [9]. Whole Effluent Toxicity (WET) testing was carried out at commissioning and after 12 months of operation. This was a ministerial condition as set by the Environmental Protection Authority (EPA). A selection of species was subject to long term contact (time frames below) with different concentration of brine and monitored to identify the dilution required for minimal environmental impact.

The toxicity of the brine samples was assessed using the following tests which are all NATA accredited (NATA - National Association of Testing Authorities is Australia's national laboratory accreditation authority):

- — 72 hour macroalgal germination assay using the brown kelp Ecklonia radiate,
- — 48 hour mussel larval development using Mytilis edulis,
- — 72 hour 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.

All toxicity tests were undertaken at Geotechnical Services (Geotech) Ecotoxicology Laboratory at Fremantle using filtered seawater obtained from Cockburn Sound as the dilution water, and brine from the PSDP. The brine sample represents typical brine discharge during normal operations, hence did not include any CIP chemicals (Note that sludge from lime system along with the dual media filter backwash water is sent through a de-sludging system before being discharged with the brine plume so would have been included in the PSDP discharge. This is discussed further in Section 5).

Table 1 summarizes the outcome, expressed as the degrees of dilution necessary to protect the most susceptible species at varying levels.

Protection Level with 50% confidence	Protection Value % Brine	Dilution Factor
99	6.64	15.1
95	8.15	12.3
90	9.23	10.8
80	10.93	9.2

Table 1: Dilution Factor required for different protection levels

Results show dilution rates much lower than those selected during the design phase of the project (45 times dilution), which was also verified by the dilution testing. Hence the PSDP is meeting all of its environmental commitments.

The actual diffusers themselves, after a year of operation, are heavily populated by marine growth, mussels and surrounded by feeding fish, Photo 4.

Photo 4: Marine growth around diffuser

3.3 Environmental Survey

Cockburn Sound is a sensitive area as it is characterized by relatively closed access and a variable off shore current. Cockburn Sound is formed by the presence of Garden Island to the west which is joined onto the mainland at the south by a mostly rock groyne bridge (shown later in diagram 5). Only a small opening in the bridge allows minimal mixing with the ocean at the South, most mixing comes from the North. Hence Cockburn Sound consists of a 10m shelf at the front of the PSDP, moving into a 20m basin at its deepest part, and enclosed by Garden Island further west: the bathymetry data show a deep basin, which is naturally subjected to oxygen drop during low current/wind periods.

During the PSDP's environmental approvals phase, the DEC was concerned that the brine, being denser than seawater, would sink to the deeper basin of Cockburn Sound causing a hypoxic layer and cause dissolved oxygen (DO) levels to drop at the seabed floor. The hypothesis is represented in diagram 4 below. Under extreme hypoxic conditions fish kills can occur which was the DEC's main concern.

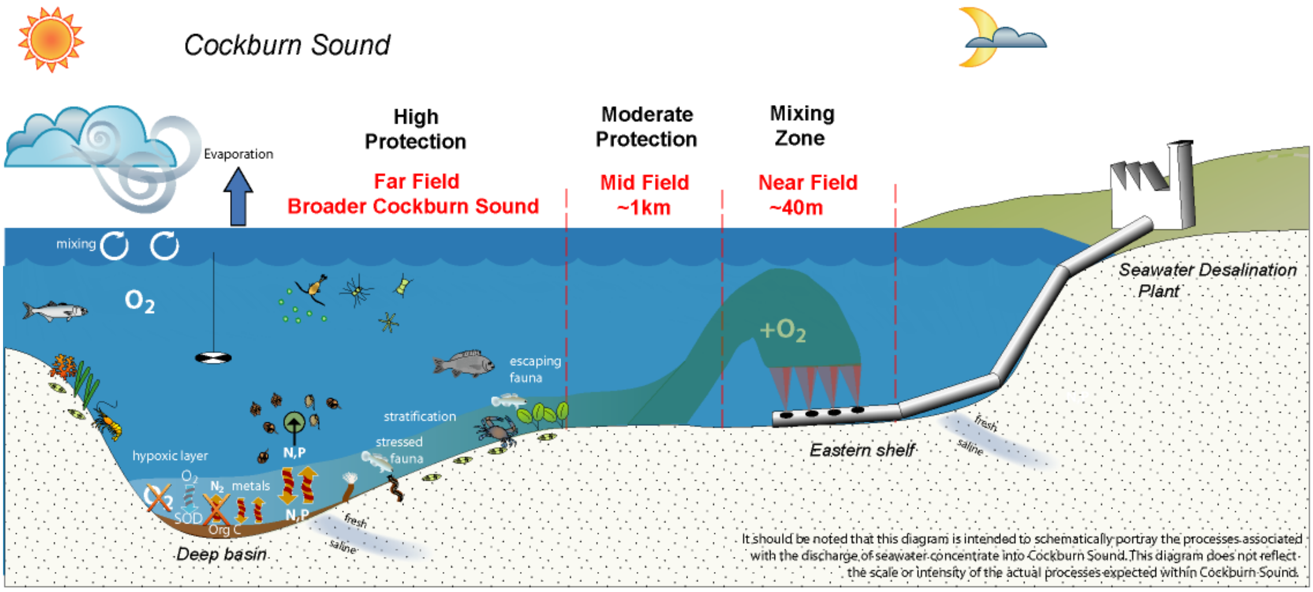


Diagram 4: Hypothesis – Brine would sink to the deep basin

The concern had been expressed that under certain meteorological conditions, the brine, despite the mixing from the diffusers, would form a higher density plume which could flow over a seabed ridge into the deep basin of Cockburn Sound.

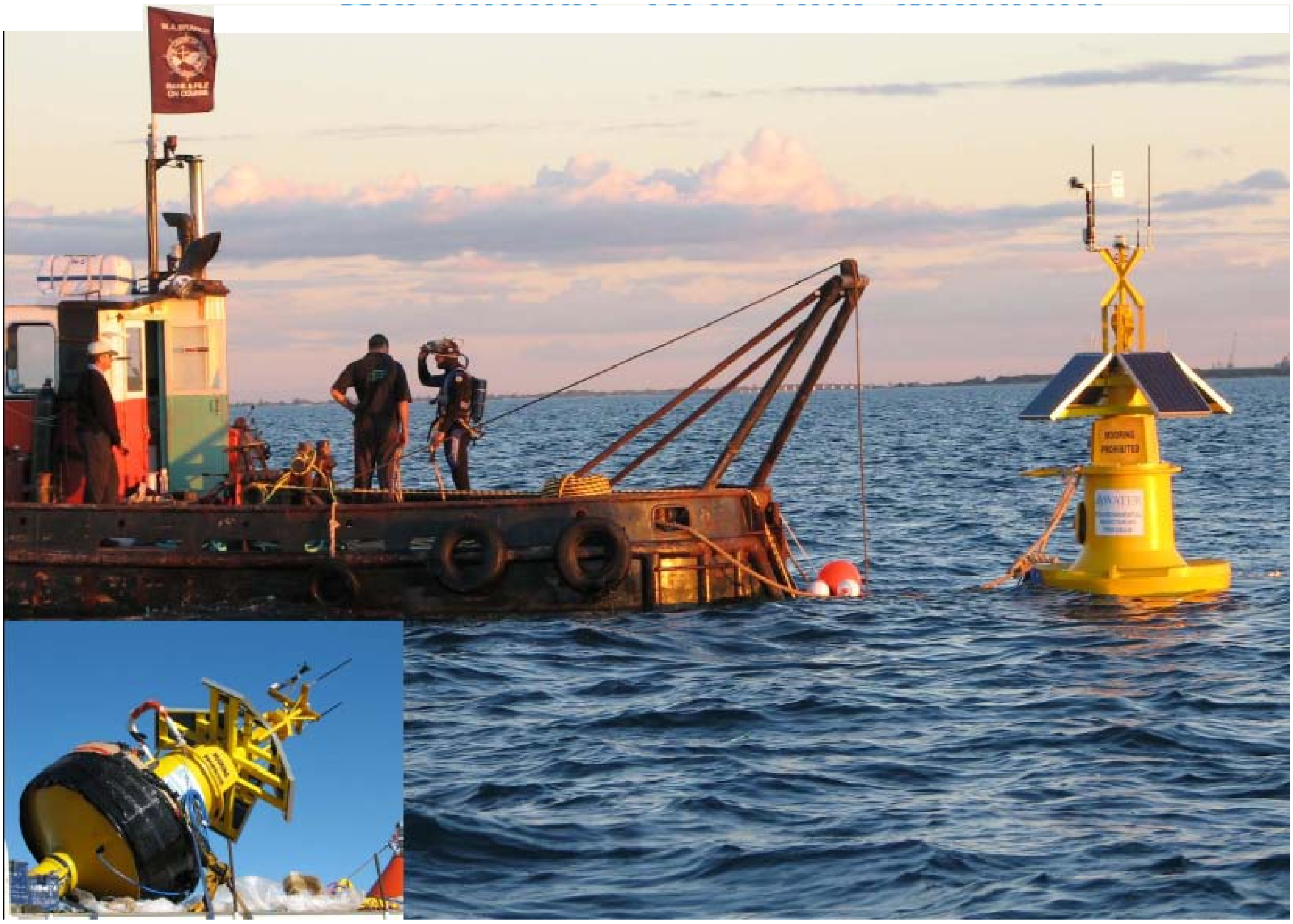


Photo 5: Operations – Real Time Monitors

The PSDP is therefore required to monitor DO levels (a requirement of the environmental operating license) in the deeper basin of Cockburn Sound (at 0.5m from the seabed floor), and is required to “shutdown” to 1/6th capacity when these levels fall to certain prescribed levels. This has occurred twice during 2008 (over 15 days in April and 12 days in May). The Water Corporation has 3 Real Time Monitoring Stations (RTMS) in the deeper basin of Cockburn sound, taking half hourly measurements of dissolved oxygen, temperature and salinity, and transmitting this data back to head office. A map of Cockburn Sound showing the location of the PSDP, Garden Island and the 3 RTMS is shown in Diagram 5. The RTMS are located at the ‘North’, ‘Central’ and ‘South’ locations. Stirling Channel runs in a North-South location directly in front of the PSDP.

Since the environmental license was prescribed, UWA’s rhodamine dye test has proven that the PSDP’s brine discharge is mixing well on the shelf at the front of the PSDP, and cannot even be traced in the deeper basin of Cockburn Sound [10]. Diagram 6 shows UWA’s ELCOM model highlighting the density of the PSDP’s brine plume. The plume (shown as red at the PSDP outlet) can be traced on the 10m shelf and entering into the basin through Stirling Channel getting smaller in size and becoming less dense. The plume, at the end of Stirling Channel is shown to be completely mixed with the surrounding seawater, hence can not even be traced in the deeper basin of the Sound. The plume is shown as red (at the PSDP outlet) at its strongest, then becoming more and more dilute as it transgresses across the 10m shelf of the Sound. As it exits into the 20m basin, the tracer can no longer be tracked.

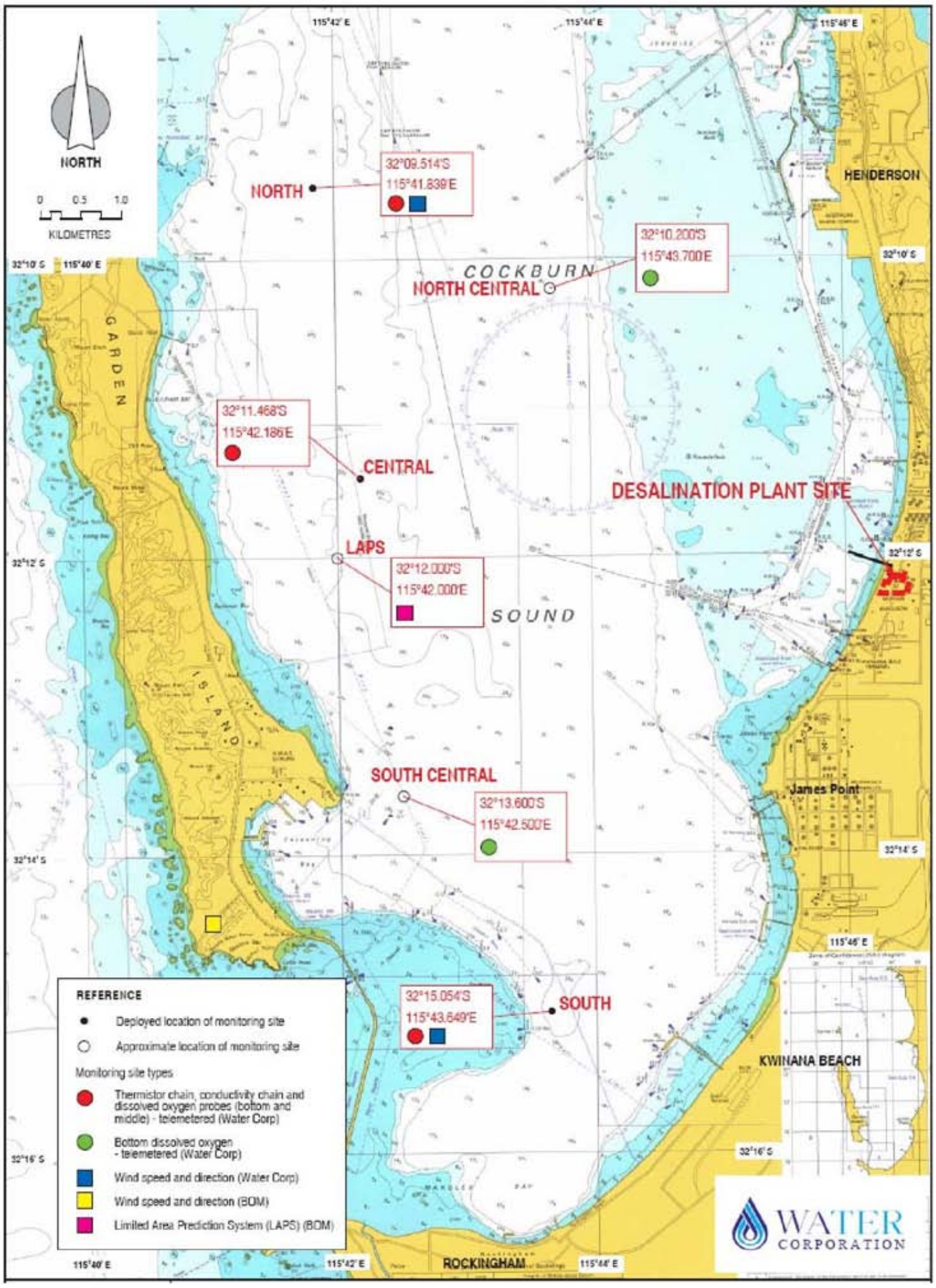


Diagram 5: Diagram of Cockburn Sound showing the 3 Real Time Monitoring Stations at 'North','Central' and 'South' locations.

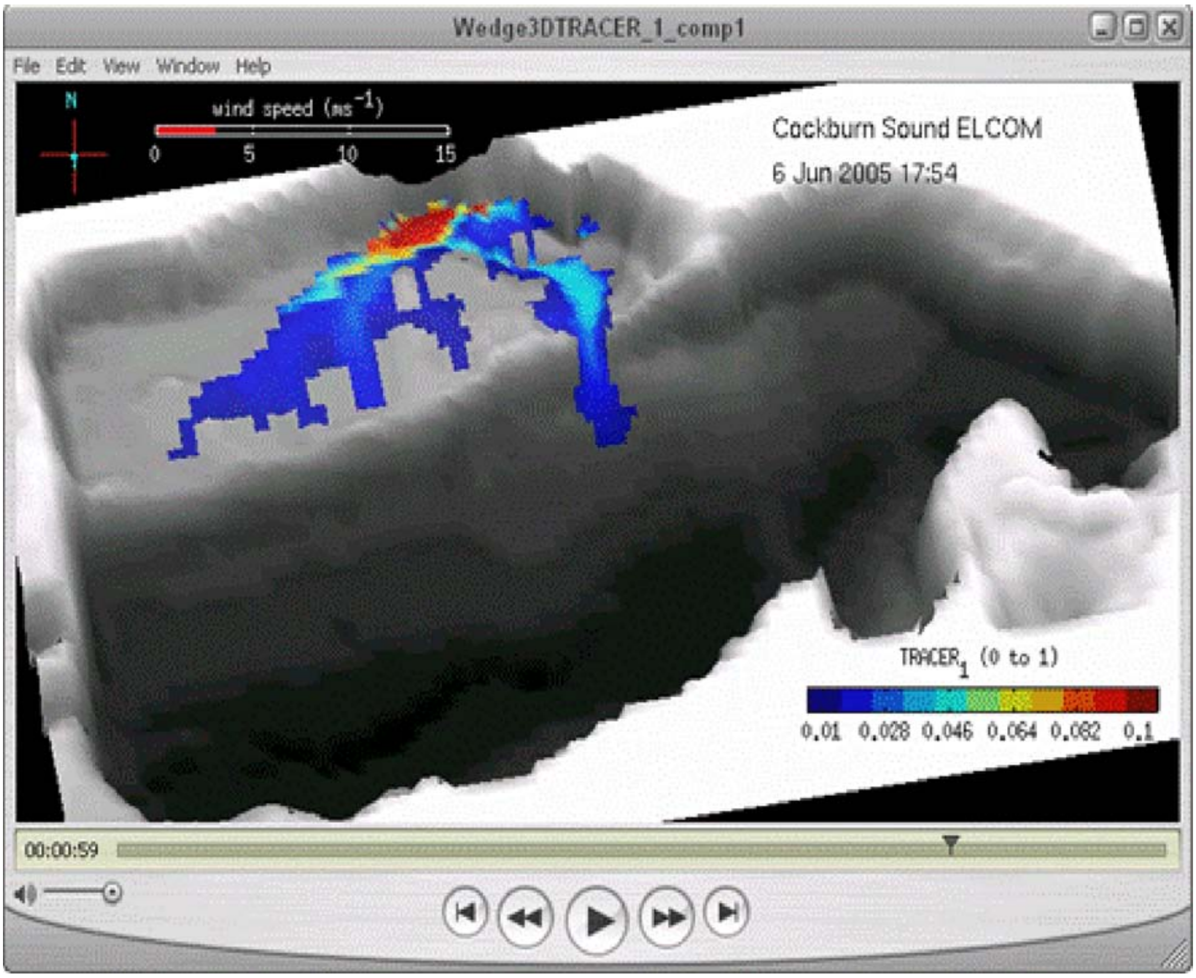


Diagram 6: Field results of the Rhodamine Dye tracer test conducted by the Centre for Water Research at the University of Western Australia

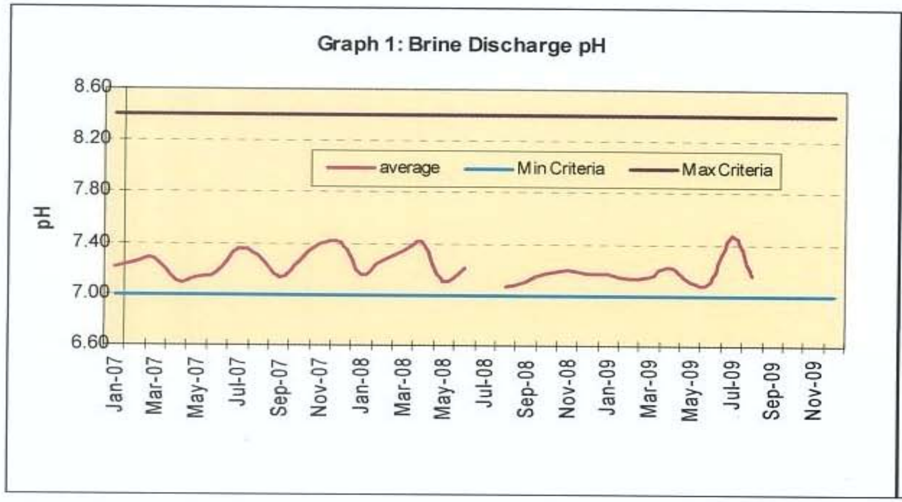
If the brine plume is completely mixed at the end of the Channel, and cannot be traced in the deeper basin of Cockburn Sound (as shown in Diagram 6), the PSDP can not be having any measurable effect on dissolved oxygen levels in the deeper basin of Cockburn Sound [11]. Despite this, the DEC is hesitant to remove any of the dissolved oxygen plant "shutdown" conditions, perhaps due to public perception rather than science.

The PSDP was "shutdown" to 1/6th capacity twice in 2008 due to dissolved oxygen levels at the seabed floor dropping below those required under the environmental operating license. The two periods in April and May 2008 occurred during autumn, most likely caused by the fact that Cockburn Sound stratifies naturally particularly when long periods of calm whether can occur [12]. Cockburn Sound is generally a well mixed environment. The main cause of mixing is wind; however tides also have an effect. During autumn a number of consecutive days can occur with very little wind mixing causing Cockburn Sound to stratify and dissolved oxygen levels at the seabed floor to fall.

For further details see Appendices 4 "Limited Area Prediction System" and 5 "Dissolved Oxygen Trigger Levels – Section 46 of Part IV EP Act. 1986".

3.4. On-line Brine Discharge Monitoring

24 hour real time on-line monitoring of the brine discharge is also a requirement of the PSDP's Water Quality Management Plan, approved by the DEC. The discharge limits were prescribed in accordance with the Cockburn Sound Environmental Quality Criteria taking into consideration the dilution effect of the diffusers. Graphs 1 – 4 show the trends of pH, Conductivity, Dissolved Oxygen and Turbidity from more than 2 years of operations. Note the dilution effect on conductivity of re-circulating seawater through the brine discharge in April/May 2008 when the PSDP had to reduce production to 1/6th capacity due to DO levels. All results have been compliant in part due to the steady state nature of the desalination process.


Graph 1: Brine Discharge pH
pH
8.60
8.20
7.80
7.40
7.00
6.60
average
Min Criteria
Max Criteria
Jan-07
Mar-07
May-07
Jul-07
Sep-07
Nov-07
Jan-08
Mar-08
May-08
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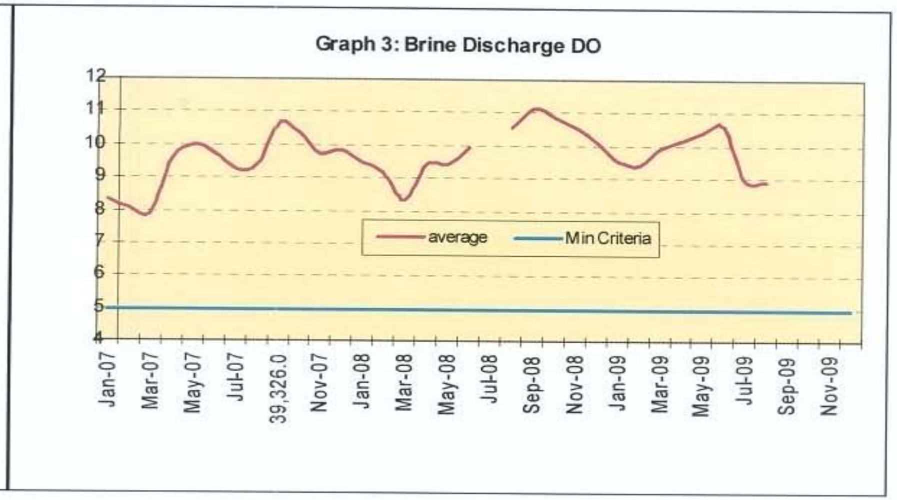
Graph 3: Brine Discharge DO
12
11
10
9
8
7
6
5
4
average
Min Criteria
Jan-07
Mar-07
May-07
Jul-07
39,326.0
Nov-07
Jan-08
Mar-08
May-08
Jul-08
Sep-08
Nov-08
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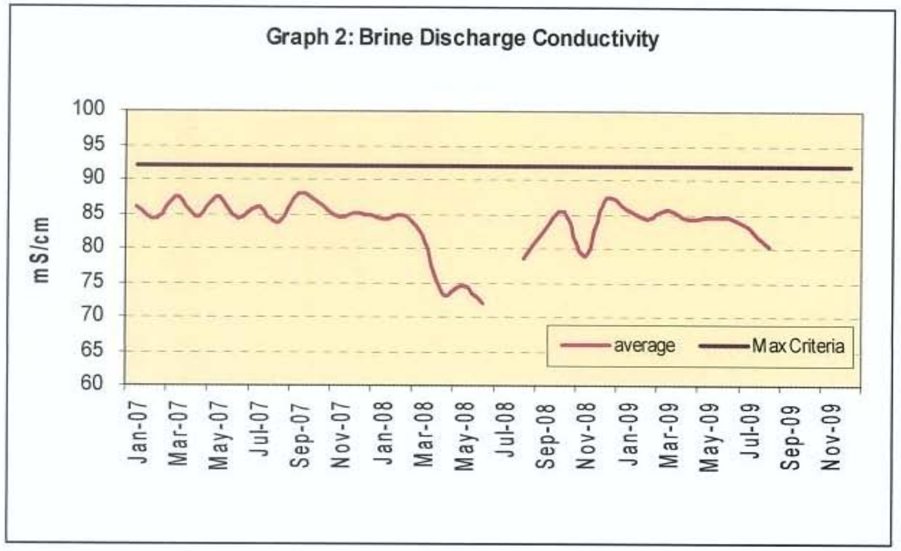
Jul-09
Sep-09
Nov-09


Graph 2: Brine Discharge Conductivity
m S/cm
100
95
90
85
80
75
70
65
60
average
Max Criteria
Jan-07
Mar-07
May-07
Jul-07
Sep-07
Nov-07
Jan-08
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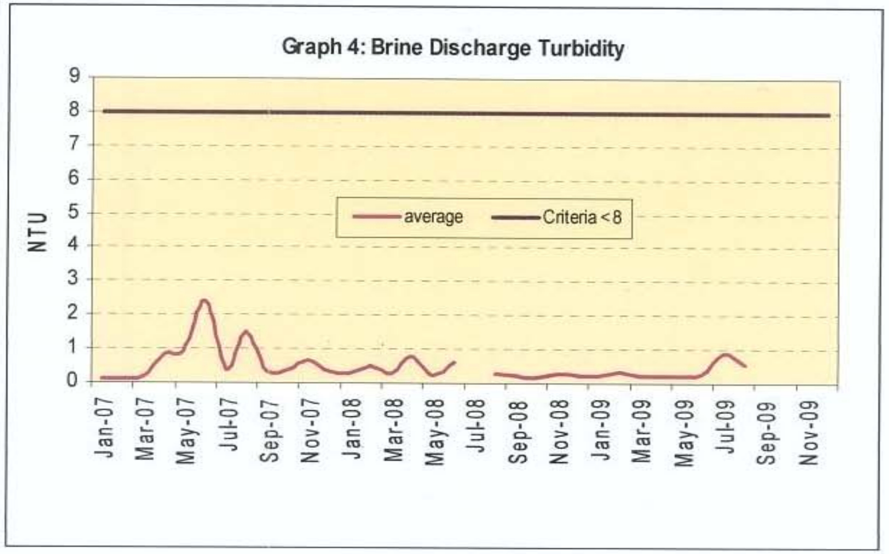
Jul-09
Sep-09
Nov-09


Graph 4: Brine Discharge Turbidity
NTU
9
8
7
6
5
4
3
2
1
0
average
Criteria <8
Jan-07
Mar-07
May-07
Jul-07
Sep-07
Nov-07
Jan-08
Mar-08
May-08
Jul-08
Sep-08
Nov-08
Jan-09
Mar-09
May-09
Jul-09
Sep-09
Nov-09

IV. OTHER MARINE MONITORING

In addition to the Rhodamine dye testing, dissolved oxygen monitoring and brine monitoring, an extensive Macrofauna community, sediment habitat and water quality study was undertaken. These studies were undertaken by consultants Oceanica – Marine and Estuarine Specialists. Two Macrobenthic (see Photos 6 to 10) surveys were undertaken, one in March 2006 before PSDP start up and one in March 2008 as part of the PSDP's Ministerial Conditions. The March 2006 baseline survey covered 77 sites to determine the spatial pattern in benthic macrofauna communities (grab sampling) and benthic habitat and epibenthic fauna (towed video) in the deep waters of Cockburn Sound. The repeat survey used the same methods as the 2006 survey to sample 41 of the 77 sites sampled in 2006, plus 5 new sites, in order to gain a view of some areas impacted by the PSDP, and other areas not impacted by the PSDP. The results showed that there has been a marked shift in sediment characteristics and benthic macrofaunal communities throughout the deep basin of Cockburn Sound between 2006 and 2008, however the changes are due to a regional effect, not the result of the operation of the PSDP [13]. The shift in characteristics was generally more pronounced in the northern basin than the central and southern basin. There was also no significant difference between the west or 'control' sites and the 'potential impact' sites, hence it can be deduced that a regional effect is the cause. The results highlight a requirement for a greater understanding of factors contributing to the temporal variation in the benthic communities of Cockburn Sound, however as the changes are shown to be regional (not due to the PSDP), future surveys should be conducted by the greater community, not solely the PSDP.

Photos 6 to 10: Macrobenthic fauna

The water quality sampling program began in February 2005 more than one year before PSDP operations and concluded in May 2008, some two years after operations began. The monitoring program consisted of 8 water quality sites and 6 transect sites which were sampled twice per season. Overall a total of 28 water quality samples were carried out. The findings of the monitoring program support the findings of the modeling studies carried out during the development phase of the PSDP [14]. In particular the salinity impact was only evident on the eastern shelf of the Sound which was slightly higher than the ambient salinity of the receiving waters (up to 1ppt at the seabed floor), however all readings were well within the range of natural salinity variation (variable by up to 4ppt seasonally). All other parameters showed no observable effect following commissioning of the PSDP (except for TDS, which is closely linked to salinity).

V. OTHER WASTE PRODUCT MANAGEMENT

The desalination plant is equipped with a conventional pre-treatment system including screening, coagulation using ferric sulphate (with pH correction using sulphuric acid), filtration on dual media filters (see Photo 11) and safety filtration through cartridge filters [15]. The coagulation – filtration step removes suspended solids, particles and part of the organics naturally present in the seawater, that are then concentrated in the backwash water.

Photo 11: Dual Media Filters of the PSDP

For further details, see Appendix 1 “Process Flow Diagram” in section VIII.

A clarification and sludge dewatering system was implemented on the PSDP to clarify the pre-treatment reject before discharge. This reduces the turbidity impact on the environment which could have had a significant negative effect on photosynthesis.

The backwash waste water from the Dual Media Filters (DMF’s), the first filtration used at PSDP as the seawater enters the site, is settled out using a Densadeg – a settling tank consisting of lamellas and clear water channels at the top to allow the clear water to exit to the outfall tank (see Photo 12 and Diagram 7). The sludge (taken from the bottom of the tank) is mixed with the sludge produced by the lime system then sent to a centrifuge to spin the solids out. The clear water is returned to the brine outfall tank; the solids after centrifugation are removed from site to a landfill facility. The dewatered sludge consists of 20% solids. It is collected and mixed with mineral or organic waste and disposed to landfill at 40% solids. It was decided to install the sludge treatment facility in order to achieve minimal turbidity of the brine discharge, and to prevent any visible impact of the effluent in the surrounding waters. To date, no other use has been found for the sludge other than landfill due to the high saline content.

Photo 12: 'Densadeg' – Clarifier of backwash waste water

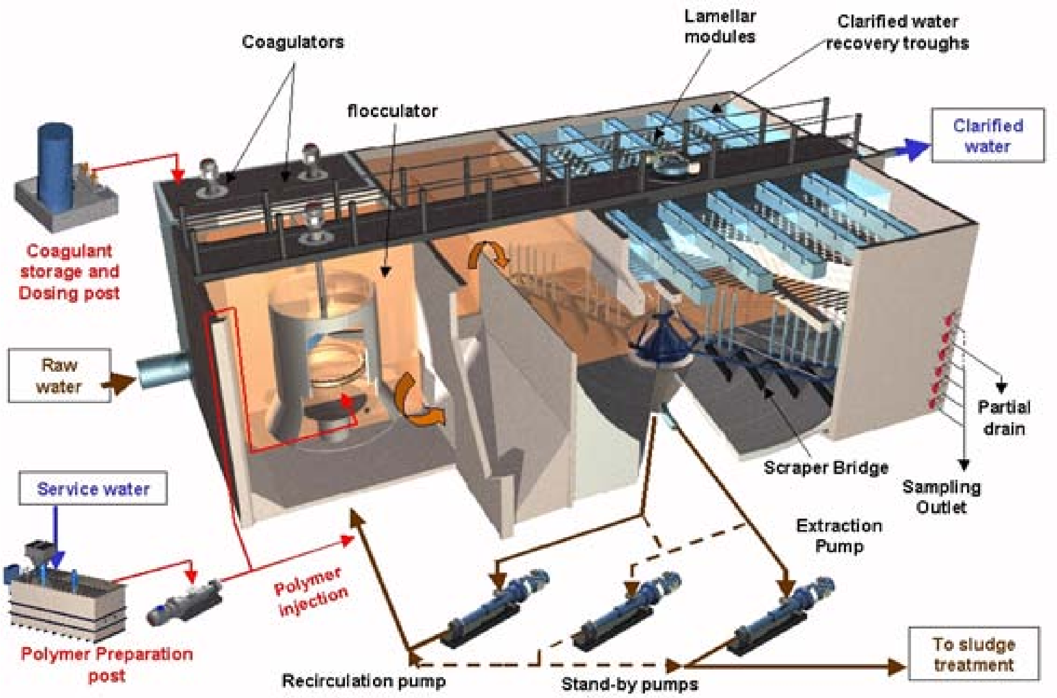


Diagram 7: "Densadeg" - Clarifier of backwash waste water

An additional benefit of desludging is that very little suspended solids are returned to Cockburn Sound, thus the brine plume is a clear water and will not discolour any of the surrounding white sands. This was also a major factor in the decision to install the desludging system during construction.

VI. ENERGY

Desalination is an energy consuming process. In terms of energy management, and in keeping with the sustainability strategy, the Water Corporation decided to purchase "green energy" to power the desalination plant. The Corporation has signed an agreement which led to the development of the Emu Downs Wind Farm located 30 km east of Cervantes in Western Australia's Midwest region. This wind farm [16], which includes 48 wind turbines 1.8 MW unitary capacity has a maximal power production of 83 MW supplying 272 GWh/year into the grid, more than three times the maximum consumption of the desalination plant. All of the energy required to power the PSDP is purchased from the Emu Downs Wind Farm.

A high efficiency energy recovery system was also selected on the first reverse osmosis pass to reduce the plants energy consumption. Energy Recovery Inc - ERI PX 220 installed on the 12 first pass racks exceeds the energy recovery efficiency expected. The 16 PX 220 installed per rack have an efficiency exceeding 96%. The plant energy consumption remains below the design value of 4.1 kWh/m^3, and is operated between 3.2 and 3.8 kWh/m^3 on this rather cold seawater (ranging from 15 degrees in winter to 24 degrees in summer).

Reverse osmosis energy consumption is the lowest energy consumption technology to date, and can be easily powered by renewable energies. Energy recovery systems such as that used at the PSDP (ERI) are now extremely efficient at recovering energy from the brine waste water (greater than

96% efficiency). Sourcing power from renewable energy (albeit offset) is an important sustainability principal employed by the PSDP, which is also now being applied by other large scale Australian desalination plants.

VII. CONCLUSION

The unprecedented marine monitoring programme has included computer modelling for diffuser design and validation, rhodamine dye tracer tests, extensive far field dissolved oxygen tests, a water quality monitoring programme, diffuser performance monitoring programme, WET testing and Macrobenthic surveys. All studies have proven that the PSDP is having negligible impact on the surrounding environment. Impacts on seawater habitat are limited by a validated diffuser design and treatment of suspended solids has led to ensure:

- **No effect of desalination discharge on stratification in the deep waters of the Cockburn Sound,**
- **No impact of desalination discharge on dissolved oxygen in the Cockburn Sound.**

Four (4) years after initial commercial operation date no adverse environmental impacts has been monitored in the Cockburn Sound.

360 Environmental and MDJV staff Water Sampling in Cockburn Sound
Reproduced with approval of Water Corporation

Photo 13: Biannual salinity monitoring for the diffusers

In conclusion, desalination has an important role in Western Australia, as a new source of water, with a constant and reliable availability compared to natural resources. Reverse osmosis appears as a sustainable technology as its possible impacts on the environment can be managed. The PSDP was the first large scale reverse osmosis desalination plant built in Australia, which has now spurned other plants being built in Queensland (operational Dec 2008), Sydney, Melbourne and Adelaide. As the PSDP was at the forefront of large scale desalination plants in Australia, it has lead the way in gaining environmental approvals, and is a leading model for sustainable desalination.

VIII. APPENDICES

Appendix 1 Process Flow Diagram

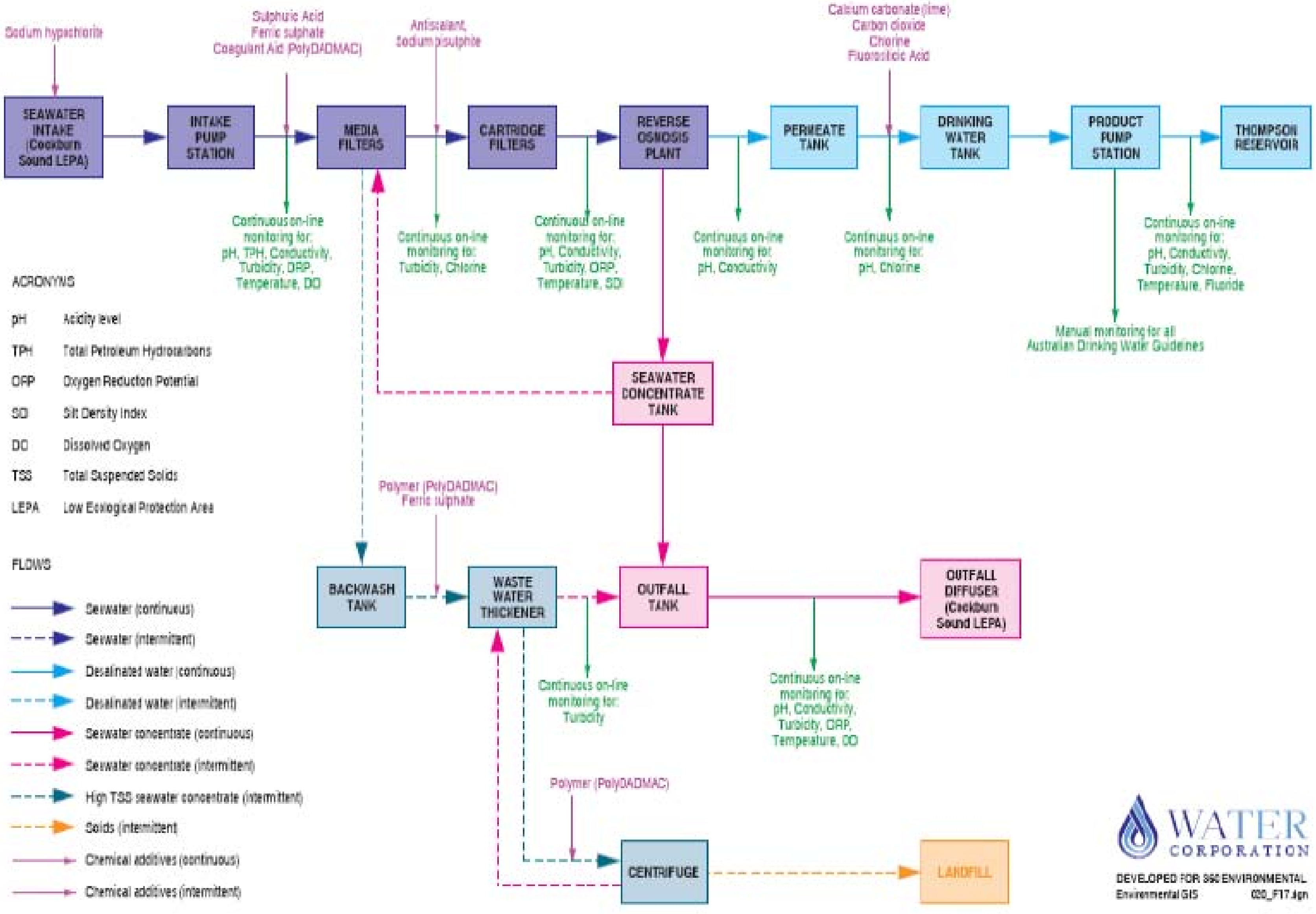
Appendix 2 Intake structure

Appendix 3 Outfall diffusers configuration

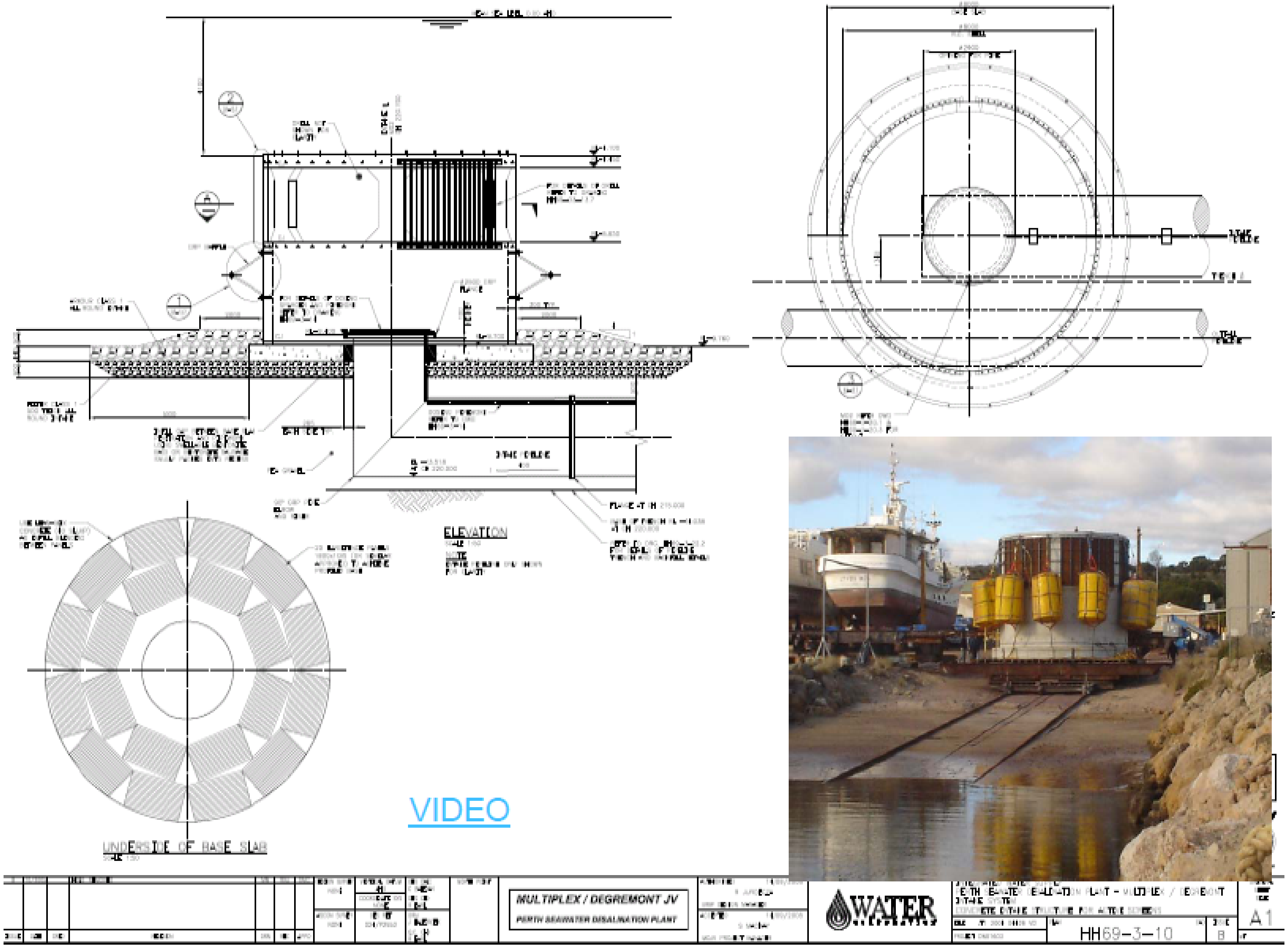
Appendix 4 Limited Area Prediction System

Appendix 5 Dissolved Oxygen Trigger Levels, Section 46 of Part IV EP Act 1986

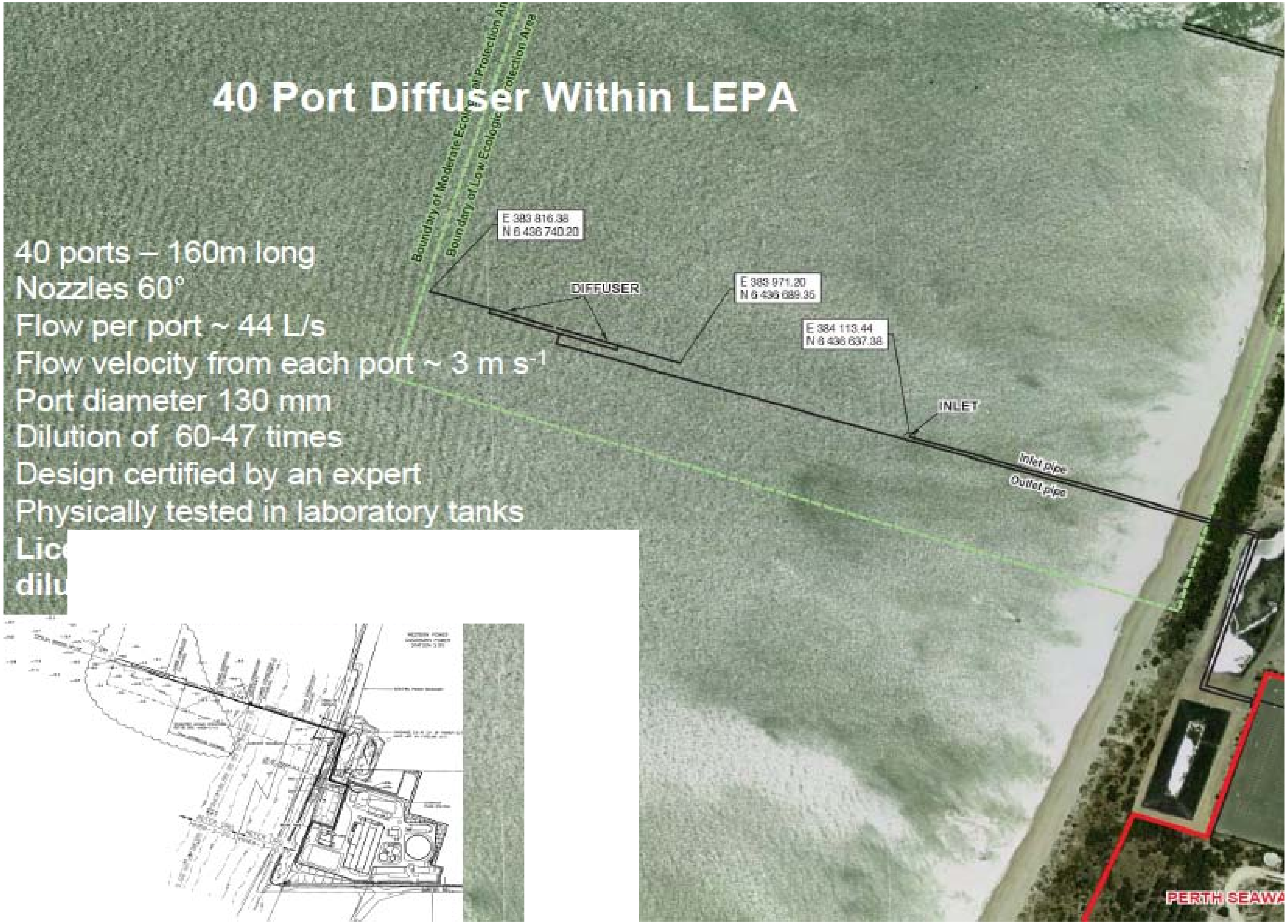
Appendix 1: Process Flow Diagram



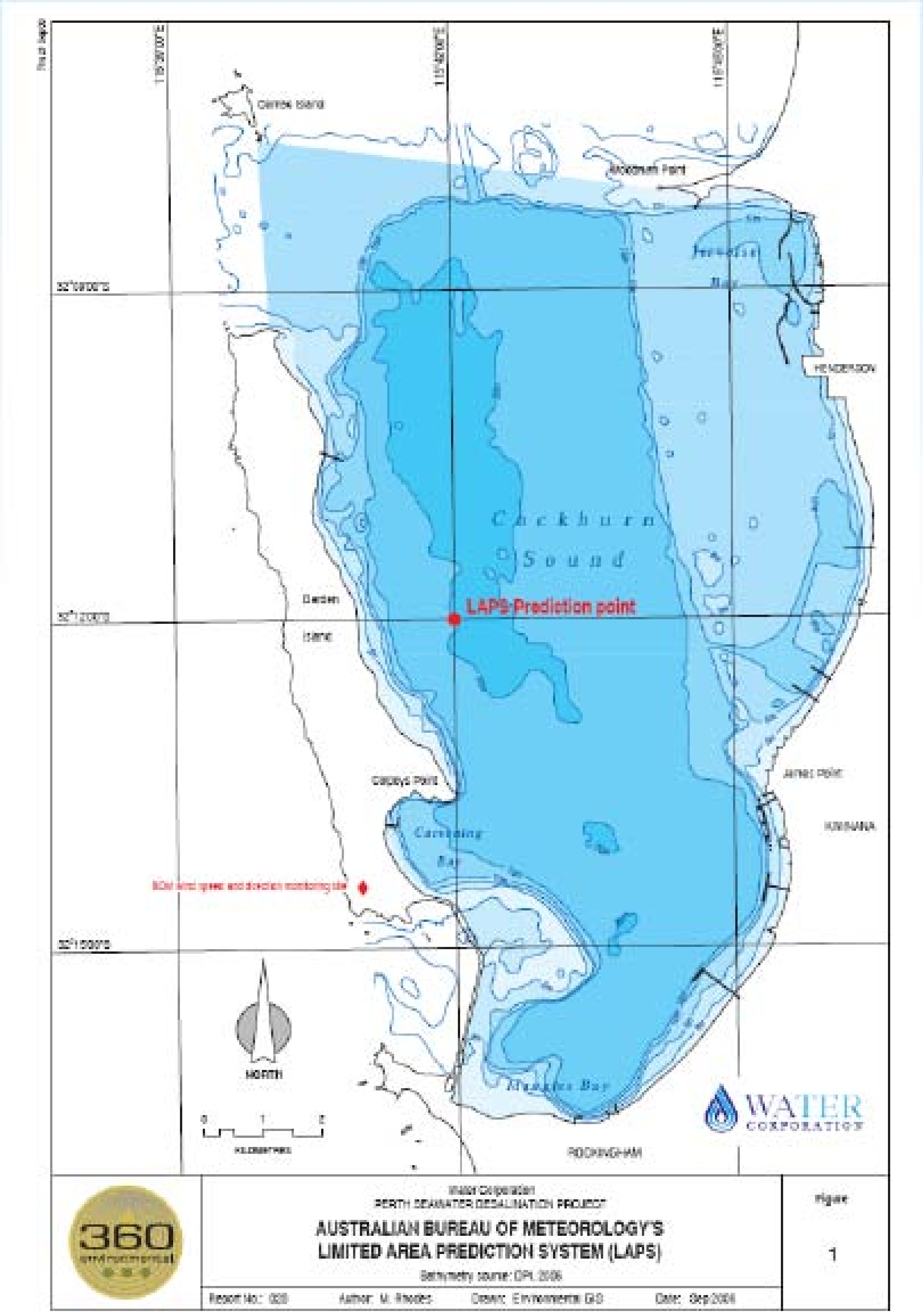
Appendix 2: Intake Structure



Appendix 3: Outfall Diffusers Configuration


40 Port Diffuser Within LEPA
40 ports – 160m long
Nozzles 60°
Flow per port ~ 44 L/s
Flow velocity from each port ~ 3 m s-1
Port diameter 130 mm
Dilution of 60-47 times
Design certified by an expert
Physically tested in laboratory tanks
Lic
dilu
Boundary of Moderate Ecological Protection Area
Boundary of Low Ecological Protection Area
E 383 816.38
N 6 436 740.20
DIFFUSER
E 383 971.20
N 6 436 689.35
E 384 113.44
N 6 436 637.38
INLET
Inlet pipe
Outlet pipe
PERTH SEAWA

Appendix 4: Limited Area Prediction System



Appendix 5: Dissolved Oxygen Trigger Levels, Section 46 of Part IV EP Act 1986

Dissolved oxygen range	ALERT LEVEL: No of consecutive days that triggers a management response	TRIGGER LEVEL: No of consecutive days that must not be exceeded
4.5–5.0 mg/L	15 days and forecast absence of a suitable mixing event for the following 5 days	21
4.0–4.5 mg/L	5 days and forecast absence of a suitable mixing event for the following 5 days	11
3.5–4.0 mg/L	2 days below 4.0 mg/L and forecast absence of a suitable mixing event for the following 2 days	5

Note:	DO>4 mg/L:	No known long-term toxic effect
	4>DO>2 mg/L:	Avoidance reactions commence - localised nutrient/metal release
	2>DO>0 mg/L:	Toxic effects on sessile organisms and an increase rate of release nutrients/metals

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