Preliminary Hydrodynamic Modelling for Coorong Temporary Saline Discharge

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aurecon

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Executive Summary

The Coorong is a long narrow estuarine and freshwater wetlands complex extending some 80 kilometres south east of the Murray River mouth that is separated from the Southern Ocean by a narrow sand peninsula. The ecological viability of the Coorong has been threatened by the prolonged drought and lack of freshwater flow in the Murray-Darling system. The primary threat to the ecosystem has arisen from the steady increase, beyond natural variability in the salt concentration of Coorong waters.

To alleviate the potential damage to the Coorong ecosystem the Murray-Darling Basin Natural Resource Management Board (MDBNRM Board) propose to establish a "temporary" pumping system to discharge high salinity water from the Southern Lake of the Coorong to the adjacent ocean beach. The pumped water would be replaced by lower salinity water from near the Murray mouth thereby gradually reducing the salinity concentrations within the Coorong.

Aurecon was commissioned by the MDBNRM Board to establish a broad scale far-field hydrodynamic model of the ocean waters adjacent the proposed discharge location. The aim of the modelling was to provide a basic understanding of the likely plume footprint of the discharged hypersaline water under the 'worst case' conditions for tides and winds. These conditions include the neap tides with very low waves and either low winds or shore-parallel winds conditions.

Preliminary modelling results for a discharge of 250 ML/day at salinity 150 ppt into the ocean with salinity 36 ppt, indicate that the saline discharge is likely to rapidly disperse into the high energy Southern Ocean marine environment. Results suggest the 3 ppt excess salinity (38 fold dilution) is likely to be confined within a distance of less than 200 m of the discharge and the 1 ppt excess salinity (100 fold dilution) extends around 2 km offshore under the worst case scenarios. Under a condition of prolonged SE shore-parallel winds the footprint extends along the shoreline toward the northwest and the 1 ppt excess salinity (100 fold dilution) extends to around 2 km from the discharge location.

Contents

1. Introduction

The ecological viability of the Coorong has been threatened by the prolonged drought and lack of flow in the Murray-Darling River system. To alleviate the potential damage to the Coorong ecosystem the Murray-Darling Basin Natural Resource Management Board (MDBNRM Board) propose to enhance the exchange of water between the lower Murray River and Coorong Lakes by installing a pumping system that would discharge high salinity water from the Southern Lake of the Coorong to the adjacent ocean via a pipeline discharge system.

It is proposed to establish a "temporary" pumping system to discharge up to 250 ML/day of hypersaline water (salinity range 120 - 150 ppt) from the Coorong at a location near Policeman Point/Woods Well via a pipeline from the Coorong inlet to an outlet on the adjacent ocean beach.

To date, investigations have focused on identifying options that would benefit the Coorong lagoons and have identified the enhanced flushing option as the preferred solution (Webster, 2007). The possible impact of the hypersaline discharge on Southern Ocean receiving waters, however, also requires assessment. Salinity within the Southern Ocean adjacent to the lagoons is usually within the range of 35 to 36 ppt, a factor of 4 less than the proposed discharge.

Preliminary discussion with the Department of Environment, Water, Heritage and Arts (DEWHA) suggested that the proposal may require referral to the department under the federal Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). To support this referral it has been considered necessary to include hydrodynamic modelling of the proposed discharge to the marine environment to provide a more detailed understanding of the likely footprint of the discharging plume. In addition to the preliminary “desktop” review Aurecon were also commissioned to commence this preliminary hydrodynamic modelling exercise.

This document describes a brief review of the oceanographic processes operating in the Southern Ocean and hydrodynamics and dispersion modelling of the proposed saline discharge to the ocean. Results of this report are to be used to assist a preliminary assessment of the potential environmental effects of the proposed discharge (Aurecon, 2009).

Table 1 below outlines a number of key factors that will require consideration during the preliminary works. Each will require information to inform the process and to adequately satisfy regulatory requirements.

Table 1 Key factors during preliminary works

Consideration	Aspect
Pipeline	Pump connection to shore Type of connection Route through sand dune
Discharge plume dispersion	Dispersion of saline concentrate Hydrodynamics of nearshore surf zone Shelf waves Type of outlet/diffuser location on beach (top of beach or below MWL) beach stability/erosion Seasonal water level variability Tide patterns Prevailing winds and wave climate Dodge tides Bathymetry
Marine and coastal communities	Marine and coastal species – rare, scarce, feral, iconic, recreational and commercial fishery species Habitats – marine and sand dune Ecotoxicology of saline concentrate

Consideration	Aspect
	Water quality (origin and receiving waters)
Cultural impacts	Aboriginal heritage Recreational fisheries Commercial fisheries
Site selection	Pump facility footprint Maintenance requirements (especially access) Energy and ETSA connection

1.1 Scope of Works

1.1.1 Preliminary Hydrodynamic Modelling Far-Field Impact Assessment

The scope of works for the preliminary hydrodynamic modelling component of the study was to establish a broad scale far-field 3D hydrodynamic model of the ocean waters adjacent the proposed discharge location using the Delft3D software package. The aim was to provide a basic understanding of the likely plume footprint as defined by the 1 ppt excess salinity and possibly other salinity levels of ecological relevance. The model set-up provides sufficient resolution to incorporate dispersion in both the nearshore zone and in deeper waters beyond the surf zone. Specific tasks within the DELFT3D hydrodynamic modeling component included:

- Set up model bathymetry for the chosen domain utilizing the best available data
- Establish boundary conditions for tides, winds and saline discharge
- Undertake initial model simulations examining dispersion of the dense saline water for ambient conditions of minimal natural dispersion.

In general the 'worst case' conditions were deemed to be comprised of a prolonged period of low winds during neap tides and low waves that together, lead to minimal natural dispersion and hence the largest footprint of the saline plume. In terms of the potential shoreline inundation it was considered that the worst case conditions are likely to consist of prolonged shore parallel winds that cause the plume to be swept along the shoreline.

For the purpose of modeling the discharge characteristics are assumed to comprise a shore-based or surf zone outfall of between 150 ML/day (1.74 m^3s^{-1}) and 250 ML/day (2.9 m^3s^{-1}), with salinity 150 ppt and water temperature of 20 °C discharging into an ocean with constant salinity of 36 ppt and temperature of 20 °C. While it is acknowledged that the discharge and ocean temperatures vary between summer and winter the density difference between the discharge and ocean water will be controlled by the large salinity difference and hence these preliminary model runs focus on salinity only.

Significant seasonal variations in the South Lake salinity from its highest values in late summer/autumn (following the long dry period of high evaporation) and lower values in winter, following freshwater input and greater flushing from the Murray mouth. In terms of the salinity of the discharge to the ocean the highest salinities will occur during late summer of the first 18-24 months of the project after which it is anticipated South Lake salinity will decrease due to the effects of the pumping programme and natural flushing processes. As the salinity levels of the south lagoon decrease the footprint of the dispersing saline plume in the ocean will also reduce.

The results of the modelling are included in this report and utilised within the preliminary environmental effects assessment (Aurecon, 2009).

1.1.2 Nutrient Effects in the Coastal Zone

During the study, the steering committee raised concerns about the possible effects on the marine environment oh high nutrient concentrations in the discharge of Coorong Lakes water.
Using the results of the dispersion modeling and existing nutrient data concentrations an assessment of nutrient dispersion in the coastal zone as carried out. This assessment is included in Appendix E.

2. Existing Environment

The Coorong is a long narrow estuarine and freshwater wetlands complex extending some 80 km south east of the Murray Mouth parallel to the coastal dunes of the Younghusband Peninsula that separate the system from the Southern Ocean. The Coorong consists of the north and south estuarine lakes, saline marshes, freshwater soaks and hypersaline areas at the southern end. The area also contains a number of ephemeral salt lakes and examples of ephemeral carbonate lakes of national and international significance.

The proposed project site extends from the proposed inlet in the south lagoon, across the sand dunes to the proposed ocean discharge area located on the seaward side of the Coorong opposite Policeman's Point south of Lake Alexandrina. It is proposed to pump saline water from the southern lagoon via a pipeline over sand dune system and discharge this water from an outlet to the Southern Ocean.

2.1 Physical Habitat

2.1.1 Environmental Flows

The Murray River is a significant source of fresh water and sediment input to the Coorong coastal area and hence the flow of the Murray is integral to the ecosystem functioning of the Coorong bioregion as a whole. Murray River flows to the Lower Lakes, including the Coorong and through the Murray Mouth to the ocean, have decreased dramatically since water flow control measures were introduced throughout the Murray-Darling Basin. On average, the annual flow through the Murray Mouth is limited to about 27% of the natural median flow recorded before water flow regulation (MDBC, 2002). Prior to flow regulation, flows through the Murray Mouth ceased about every twenty years. This now occurs every two years on average (Jensen, *et al.,* 2000). Reduced river flows and less frequent flooding have changed the morphology of the Mouth, causing sand to build up in and around the Mouth. The Murray Mouth closed in 1981 during a period of extended drought and is now maintained through dredging.

Changes to Murray River flow rates can have significant impacts on the surrounding coastal areas. Recruitment of the species such as the Goolwa cockle is considered to be strongly linked to phytoplankton blooms, which are in turn triggered by flows from the Murray (Murray-Jones and Johnston, 2003). Recent studies commissioned by MDB NRM have examined different scenarios and methods for keeping the Murray Mouth open.

2.1.2 Water Quality

Nitrogen and nutrient levels have been shown to decline in the southern ocean from south to north of the study area which has been attributed to the Bonney upwelling near Robe, which brings nutrient-rich waters from below the continental shelf to the surface waters of the southern Coorong. These higher levels of total nitrogen in the south do not appear to have a knock-on effect on plankton levels however, as chlorophyll *a* levels have been shown to remain similar within the area (Murray-Jones and Johnston, 2003).

The South Australian Departments of Environment and Heritage, and of Water, Land and Biodiversity Conservation have been collecting data on water column chemistry at multiple stations in the Coorong since 1997 although not on the ocean side (Ford, 2007). For most of the study period, the study showed strong seasonal gradients of salinity increasing southward along both lagoons of the Coorong. These gradients vary seasonally and arise from the combination of low rainfall and high evaporation together with limited inputs of freshwater from the Lower Lakes. The concentration of chlorophyll a showed a pronounced spatial variation increasing from the northern end to the southern end where concentrations exceed 100 μgL^{-1} for most of the observations. The study also showed that the concentrations of dissolved organic carbon (DOC), dissolved organic nitrogen (DON), and dissolved organic phosphorus (DOP) all increase southwards along the Coorong faster than the salinity increases indicating that there are sources of these materials in the southern lagoon. This leads to the paradoxical situation of having a high phytoplankton biomass but low dissolved nutrient concentrations which appear insufficient to support the biomass production.

2.1.3 Offshore Salinity, Temperature and Stratification

The CSIRO CARS database indicates the salinity and temperature in the ocean waters adjacent the Coorong vary from 35.7 ppt and 19 °C in April to 35.6 ppt and 15 °C in September. Nearshore waters are likely to be influenced by the Murray River discharge that would lead to decrease in salinity during periods of high River flows. When compared to offshore water temperatures heating of near shore waters during summer is likely to lead to slightly higher temperatures at the shoreline and during winter colder water temperatures than offshore. For preliminary modelling purposes the ocean temperature and salinity have been assumed to be constant at 36 ppt and 20 °C. These values are not likely to affect the general dispersion patterns of the discharge.

2.1.4 Hydrodynamics

The likely footprint of the dense saline discharge within the marine waters will be determined by the oceanographic dispersion processes within the receiving environment. The dispersion characteristics are in turn determined by the hydrodynamics or oceanographic processes. The dispersion processes in the nearshore zone are determined by a range of complex interactions between the dominant energy inputs from wind, astronomical tides and surface waves density gradients and their interaction with the topography and the earth's rotation (Coriolis effect). The first component of the assessment of dispersion involved collating the available data that could be used to gain an understanding of relative magnitudes of the key mixing processes in the receiving waters. The generalized concept and key processes are indicated in the schematic diagram below (Figure 2.1).The concentration of saline water introduced into the ocean is determined by the dispersion and mixing processes within the ambient ocean waters.

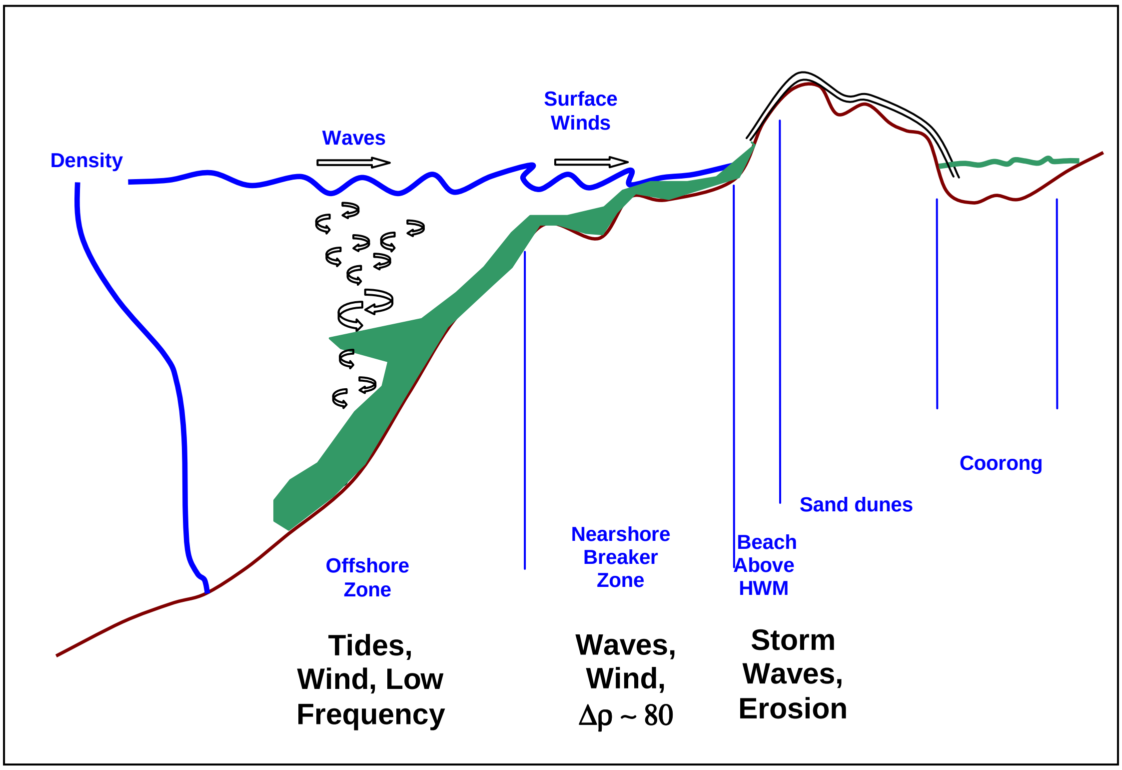


Figure 2.1 General concept diagram for pumping system from Coorong to ocean discharge**.**

2.1.5 Bathymetry

Bathymetric data for the coastal zone was obtained from 3 sources

- Cross shore profiles (east of Coorong to ~20m water depth) each 10 km between Cape Jaffa and Murray mouth, (some nearshore zones missing) (provided by DEH)
- Naval Charts available from the Naval Hydrographic Office
- Murray mouth survey (soundings horizontal resolution ~10m, 500m either side of mouth and offshore to ~10 m depth) provided by DEH

These data (Figure 2.2) were compiled into a database for use in a terrain modelling package.

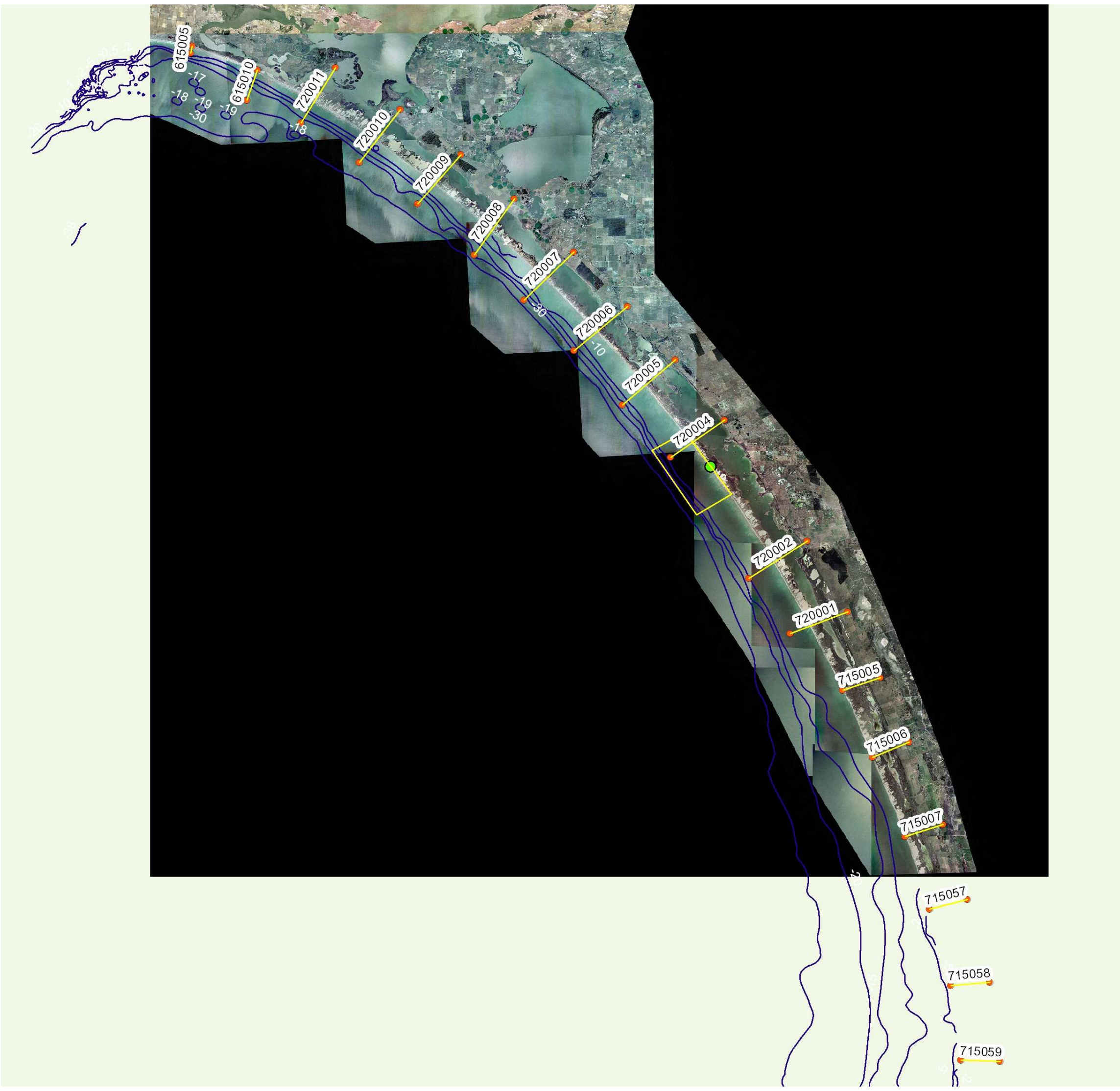


Figure 2.2 Model domain (yellow box), bathymetry contours and locations of cross-shore profiles.

The model bathymetry was derived from the high resolution bathymetry collected near the Murray mouth, the cross shore profiles provided DEH with a surf-zone topography assumed to comprise of troughs (or gutters) and bars with a cross-shore and longshore amplitude variation. The assumed cross shore profile was based on discussions with Dr Peter Cowell of the University of Sydney who along with colleagues from the University have conducted several surf-zone experiments in the region and is currently investigating beach morphology changes associated with climate change scenarios.

These sand waves are about 0.5m height nearshore and diminish offshore as a 2/3 beach equilibrium profile with an exponentially modulated sinusoidal bar system given by:

$$z(x) \;=\; 0.04\,x^{2/3} \;+\; 1.1\;e^{-0.001\,x}\,\sin\!\left(\frac{2\,\pi\,x}{500} - \frac{\pi}{2}\right)$$

where z(x) is the depth at distance, x, from the shore. This generalised offshore bar topography is shown in Figure 2.3 and was merged with the cross shore profile nearest the proposed discharge location.

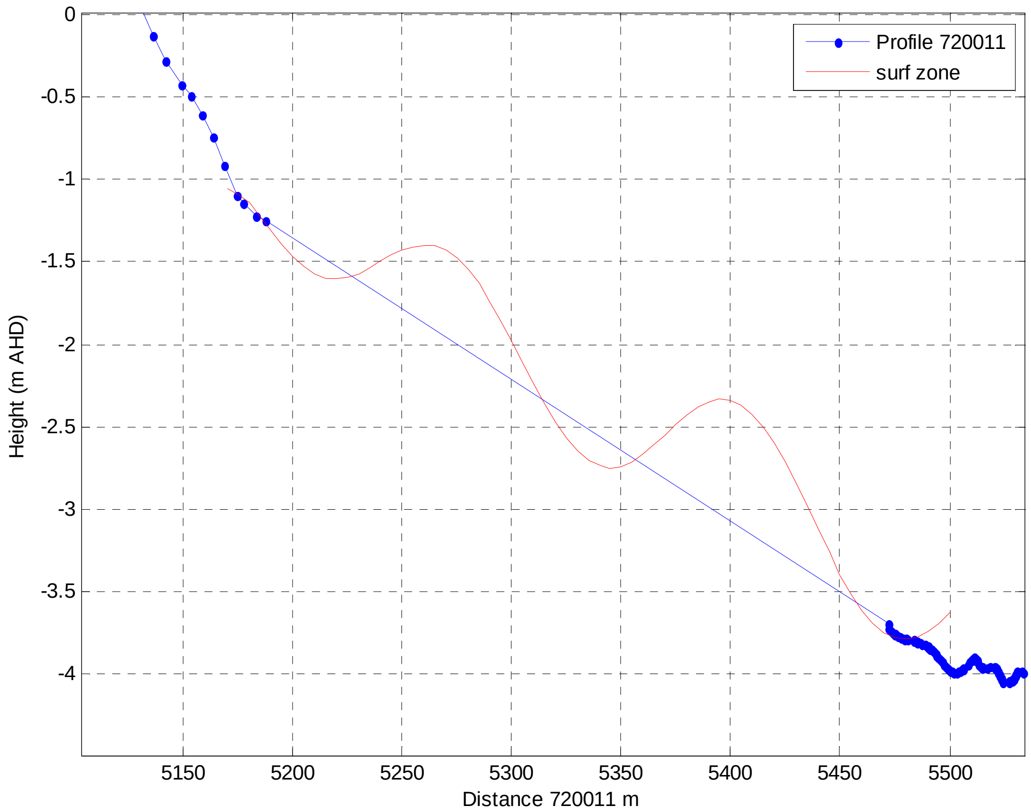


Figure 2.3 Offshore beach profile used in the model domain to fill the missing data within the surf zone**.**

2.1.6 Aerial Photo

The available aerial photography comprised a photo-mosaic of vertical aerial photography provided by the MDBNRM Board (Figure 2.2) and the image available on the GoogleEarth web site. These images were inspected to assess site access, a possible pipeline alignment and the nearshore wave zone.

Given the diameter of the pipe is likely to be around 1 m and the cost of such pipe the shortest route between the southern lake of the Coorong and the ocean is about 800 m to 1 km near Parnka Point. The cross section profiles through the Coorong and ocean suggest the sand dunes are about 20 m high with significant undulations. Given the large pipe diameter required it is likely that the pipe will require trenching to form suitable bedding and thrust blocks and anchor points to ensure the integrity of the system operation.

The aerial photos also indicate the relatively smooth characteristics of the shoreline which is aligned with the predominant swell direction. The regular pattern of waves and white-water zones suggests a few bars (as discussed in the preceding section) exist between the deeper water and the shore line.

2.1.7 Winds, Water Level and Waves

Hindmarsh Island wind data statistics (1 year of data) were obtained from the Bureau of Meteorology (BoM) and are included in Appendix A. Twice daily (9 am and 3 pm) wind observations were interpolated to hourly data for input to the hydrodynamic model.

Wind statistics derived from 14 years of data indicate that the lowest mean monthly wind speed occurs during May. Time series data for the period May 2007 are presented in Figure 2.4. The dashed line shows the hourly interpolated winds derived from the wind vectors. Cubic spline interpolation of the North and East wind vectors were converted to the wind speed and direction shown in the figure. Wind direction uses the meteorological convention of winds blowing from. Between 1 and 6 May winds were blowing from the northwest at an average e wind speed of about 25 km/hr (~7 ms^{-1}) and correlate well the in increased water levels during this period. Winds decreased between 8 and 16 May to around 12 - 15 km/hr (3.3 - 4.2 ms^{-1}) with variable direction blowing from the east and south quadrants.

The water level at Victor Harbour decreased during this period consistent with the effects of the earth's rotation (Coriolis effect) causes water movement to defect to the left. When coupled with the effect of the topography northwest to southwesterly wind-driven currents and the associated Coriolis effect causes water to "pile up" on the coast and by contrast southeasterly to northeasterly winds cause nearshore water to move offshore decreasing coastal water levels. These effects lead to the production of coastal trapped waves (CTW) that propagate from west to east across the southern Australian coastline (Middleton & Bye, 2004). This wave-like pattern associated with CTW activity is clearly shown in the tidal residual plot below. This example shows a relatively large wave with amplitude of about 0.4 m that peaks at around 0.6 m on 3 May and as the wave propagates eastward the trough of -0.3 m arrives at the Victor Harbour site around 12 May.

Wave data for Cape Sorell (west Coast Tasmania) and Cape de Couedic off Kangaroo Island were obtained from BoM. Basic wave height statistics are shown in the Table 2. The data series are not continuous, but the gaps do not appear to coincide with periods of low wave climate, and typically no more than 12hrs. One of the issues with wave riders is they are not especially reliable at measuring low wave energy nevertheless, it would appear that low wave climate conditions are rare – low waves being defined as periods of significant wave height <1m, which occurs less than 10% of the time.

Table 2 Basic wave height statistics for Cape de Couedic (data from 29/11/2000 to 12/12/2007) and Cape Sorell (data from 07/01/1998 to 21/12/2008).

Cape de Couedic				Cape Sorell		
Hs	count	%		Hs	count	%
0.25	0	0.00		0.25	94	0.05
0.50	1604	1.34		0.50	1295	0.71
1.00	11159	9.31		1.00	11914	6.50
1.50	24292	20.26		1.50	26921	14.69
2.00	25245	21.06		2.00	34791	18.98
2.50	20936	17.46		2.50	31310	17.08
3.00	24740	20.64		3.00	45445	24.79
4.00	8847	7.38		4.00	19868	10.84
5.00	3047	2.54		5.00	11242	6.13
7.50	22	0.02		7.50	415	0.23
10.00	0	0.00		10.00	3	0.00
12.50	0	0.00		12.50	0	0.00
Max Hs	8.45 on 04/09/2002				10.41 on 03/09/2003	
Min Hs	0.51 on 02/02/2001				0.04 on 08/11/1999	

Wave data from the period May 2007 are shown above in Figure 2.4. The wave characteristics presented include the significant wave height, Hs, maximum wave height, Hmax, and zero crossing period, Tz, derived from the hourly burst sampling and provided by the BoM. Wave heights show a general correlation with the wind speed. The mean significant wave height during May 2007 is about 3.5 m demonstrating the high energy coast. Minimum wave heights of around Hs = 2-3 m occurred around 12 to 14 May.

2.1.8 Currents

There are very few current measurements in the region and estimates of nearshore water velocities associated with littoral drift and wind driven flows of between 0.5 to 1 m/s are deemed reasonable for this high energy wind and wave coastline.

Modelled tidal currents for a period of dodge and spring tides (discussed below in Chapter 4) are shown in Figure 2.5. The depth averaged current speeds at a location some 200 m offshore from the proposed discharge in 2 metres depth vary from peak flows of around 0.1 m/s during dodge tides to 0.2 m/s during springs. At this near shore location the currents direction is parallel to the shoreline. Model simulations with constant SE winds indicate the wind driven currents of between 0.3 to 0.9 m/s maintaining constant flow direction toward the NW.

2.1.9 Mixing

The tide generating forces affect the whole water column resulting in constant flows across the water depth. The interaction of tidal currents with the sea bed results in turbulence with mixing focussed near the bed. In contrast wind driven forcing applies to the ocean surface and energy is transferred from the surface to the deeper layers resulting in velocity shear and turbulent mixing focussed in the surface zone. In very shallow waters the turbulent boundary layers extend over the whole depth and mixing tends to homogenise the water column.

Surface waves and swell enhance bottom mixing in deeper waters and cascade significant mixing energy at breaking and in the near shore zone.

In the modelling described below the effects of surface waves are neglected and hence the model simulations provide conservative estimates of the likely dispersion near the shore.

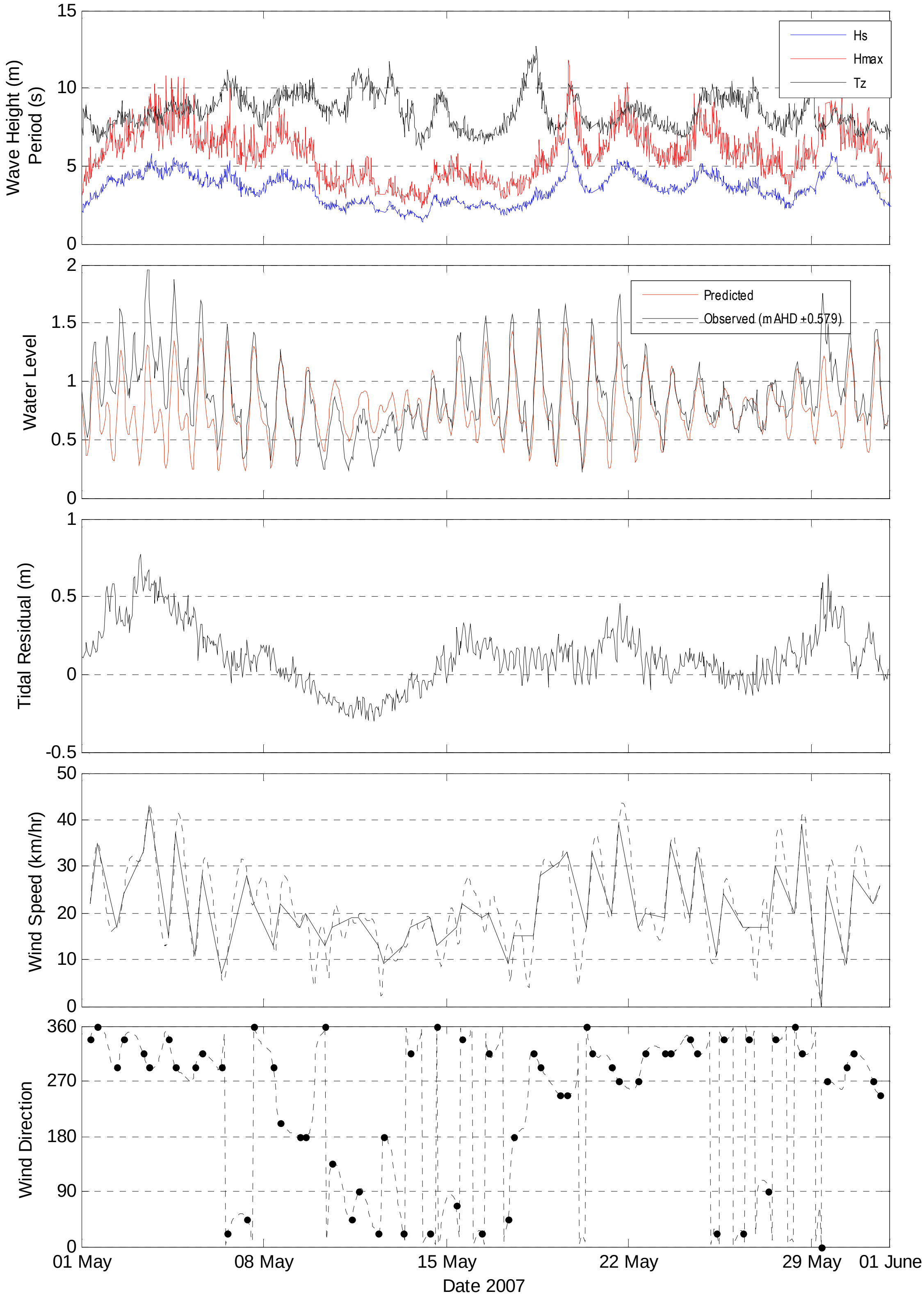
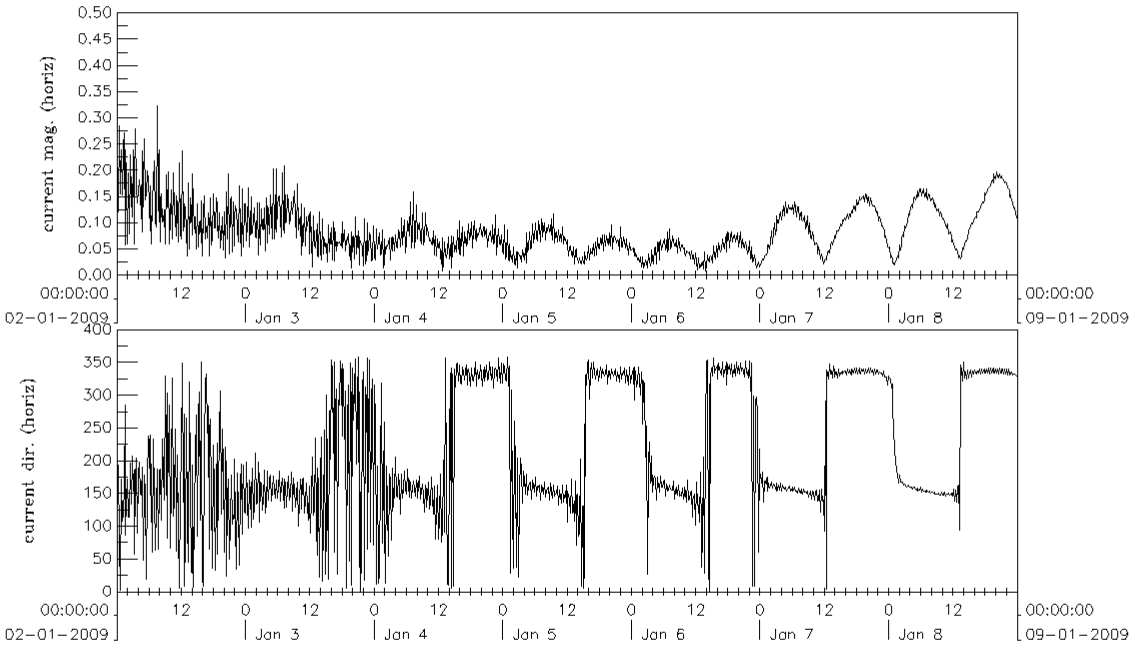


Figure 2.4 Hindmarsh Island winds, Victor Harbour Water Levels and tidal residual and Cape de Couedic wave data for May 2007.

a)



b)

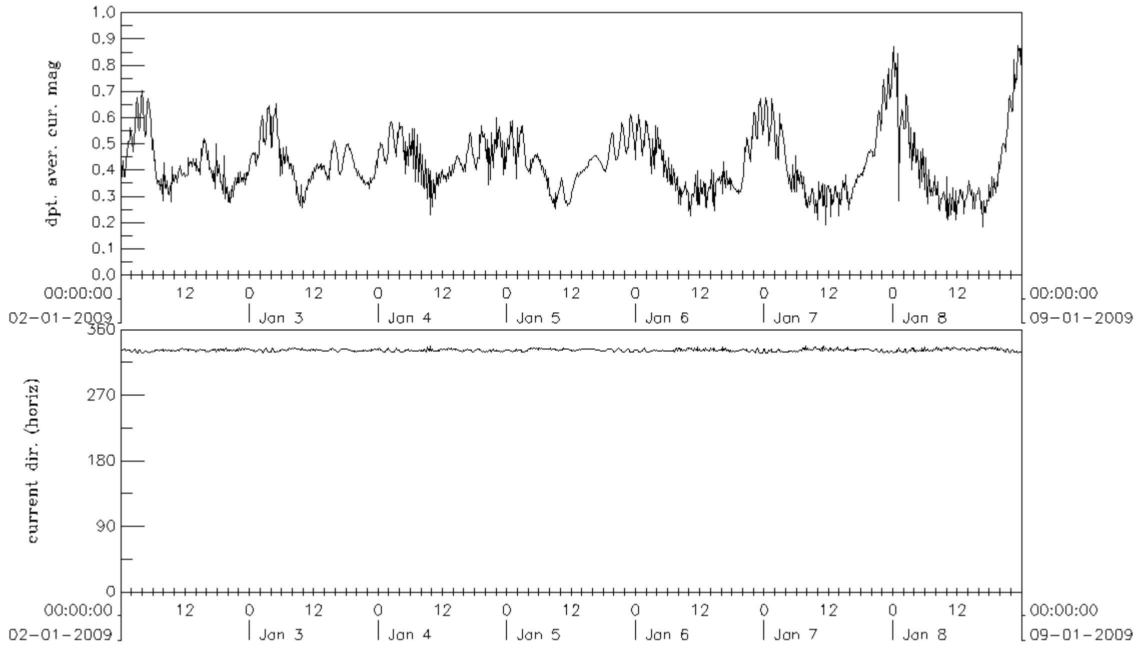


Figure 2.5 Modelled depth-average current 200m offshore the proposed discharge for cases of Tidal forcing only: a), and Tides plus constant SE wind, b).

3. Conceptual Design of Discharge System

3.1 Engineering Constraints

There a number engineering constraints affecting the development of this proposal. The general criteria for the design are that it be flexible, readily constructed and removed after about 3 years of use.

3.2 General Concept

The key components of the concept (indicated in Figure 3.1) include:

- Inlet - Intake and Pump system installed at Coorong south lake (presently being designed by SA Water)
- Pipeline from Coorong South Lake across sand dunes to Ocean (~ 1km minimum length)
- Ocean Outlet - Discharge either to back of beach onto apron, dissipater, flow spreader or to the surf zone via an outlet pipe

The inlet in the South Lake will require a suitable depth of water for the pump(s) intake(s) and it is likely the system would be mounted on a barge moored at some distance from the shore.

The pipeline will need to extend from the inlet (barge), across the water to the shoreline of the South Lake then across the sand dunes of Younghusband Peninsula to the ocean outlet. For a flow requirement of 250 ML/day (2.9 m^3s^{-1}) a pipe diameter (inside) of around 1.9 m (or 2 x 1.4 m diameter pipes) is required to deliver the flow at an average velocity in the pipe of 1 ms^{-1}. Higher pipe velocities could be accommodated allowing smaller pipe diameter to be used at the expense of additional driving head and pumping costs. A pipe of this diameter will require significant anchoring within the sand dunes and particularly at the Ocean Outlet.

The pipeline would most likely need to be seated on a stable bed and hence require a trench to be graded through the dunes to smooth any surface undulations and provide access for pipe laying and removal operations. The sand dunes are around 20 m high in places and a detailed survey along the pipeline route will be required to facilitate assessment of the optimal route that could minimise disturbance to the dunes and reduce cut and fill volumes required to create a smooth bed profile for the pipeline. A construction footprint of around 10 m wide across the (~1 km) dunes may be needed for depending upon the pipe size, number of pipes and laying/removal procedures. The pipeline will be delivering high salinity water of possibly low dissolved oxygen content and hence the pipeline material will need to be carefully selected. As the life of the system is only 3 years some level of corrosion may be tolerable provided the system lifetime exceeds the three year period. Polyethylene or coated concrete or concrete lined mild steel may be suitable.

Preliminary concept designs for a discharge outlet at the back of the beach and for a surf zone discharge are shown in Appendices B and C, respectively. These designs indicate that a significant volume of rock or geotextile bags would be required for the outlet. In addition significant anchoring of the pipe into the beach is likely required to ensure integrity of the system is maintained during storms.

3.3 Issues

Issues to be considered in the preliminary design include:

- Constructability and removal
- Inlet Location selection
- Pipeline route selection
- Access to site
- Environmental and heritage issues in the lake, dunes and coastal areas
- On site work staging and storage areas
- Scour protection and armouring requirements
- Discharge configuration

- Dispersion in near shore and offshore zones
- Plume footprint to say 1 ppt salinity excess in the receiving waters
- Potential Acid Sulfate Soils

In terms of the discharge plume dispersion perspective worst case conditions are thought to comprise low winds and waves during neap tides when the natural turbulent mixing is low and hence the plume identity is retained over longer distances. Conversely, under strong shore parallel winds the plume may hug the shoreline for some distance thereby exposing inter-tidal habitats to the higher salinity waters. The worst case will depend upon the benthic habitat, flora and fauna that may be affected and its tolerance to high salinity water.

Outlet Pipe Discharge to back of beach

- Pipeline (constructability and discharge configuration)
- Need to split to (say) 4 discharges (feedback from beach scour assessment)
- Apron and Dissipater – Rock armour size required to withstand storm bite
- Need for vehicle access along the beach may require additional structure
- Potential scour of flow across beach (mitigate through apron and more outlets)

Outlet Pipe Discharge to surf zone

- Pipeline (constructability and discharge configuration) trenched under beach and shoreline
- Need to split to (say) 2 discharges
- Geotextile bags used to armour required to withstand storm bite
- Need for vehicle access along the beach may require additional structure
- Potential scour of immediately downstream of outlet may require sand bag apron protection

3.4 Cost Estimates

Cost estimates for the supply and installation of 1500 m of pipe across the sand dune vary widely. Approximate costs for supply and installation of 1500 m of 1.353 m id PE pipe are around $2,200 per m or $3.3M supply and $5,500 per m or $8.25M installed. This is a standard PE pipe size and would result in a velocity in the pipe of 2.1 ms^{-1} for a flow of 250 ML/day (2.9 m^3s^{-1}) which is probably a little higher than a preferred velocity of around 1 ms^{-1}. Mild steel cement lined pipe is significantly cheaper and available in larger diameters. For example a 1.92 m id concrete lined steel pipe would cost approximately $2000 per m or $3M for supply of 1500 m. Instalation costs would be additional to this supply cost and likely to be around $2500 per m or $3.75M.

The concept design for a beach outlet installed at the back of the beach with rock apron to allow water flow energy to dissipate and flow as a smooth sheet flow across the beach to the surf zone has been costed at approximately $4.5M.

The concept of a pipe extending into the surf zone with concrete pile anchoring and covered by 3.7 m^3 geofabric bags filled with local sand has been costed at around $3.5M to $4M. This includes a 200 m long pipe section extending from the berm at the back of the beach to out to about 1 m water depth. About 2000 3.7 m^3 bags would be required for the construction and armouring of the pipe.

An approximate cost for the pipeline from the Inlet at South Lake to the Ocean discharge is between $8M and $12M.

These costs do not include the pumping and intake system, detailed design and procurement expenses, project management, pipeline route survey and selection, environmental surveys and approvals.

4. Hydrodynamics and Dispersion Modelling

To investigate the nearshore dispersion a model domain of 10 km longshore by 5 km cross-shore was generated. The model cell size near the shoreline outfall is 10 m longshore by 5 m cross-shore and incorporates 10 vertical sigma layers to adequately resolve the density gradients and shear. Initially a preliminary hydrodynamic model has been established with a view to provide some understanding of the system dynamics. This preliminary phase comprised setting up the model, developing the forcing boundary conditions and preliminary runs to establish that the model performs in manner consistent with general understanding of oceanographic processes.

4.1 Model Setup

To investigate the nearshore dispersion a model domain of 10 km longshore by 5 km cross-shore was generated as shown Figure 4.1 below. The model cell size near the shoreline outfall is 10 m longshore by 5 m cross-shore and incorporates 10 vertical sigma layers. Bathymetry was derived from the available data as described above (section 2.1.5) and is shown in Figure 4.2.

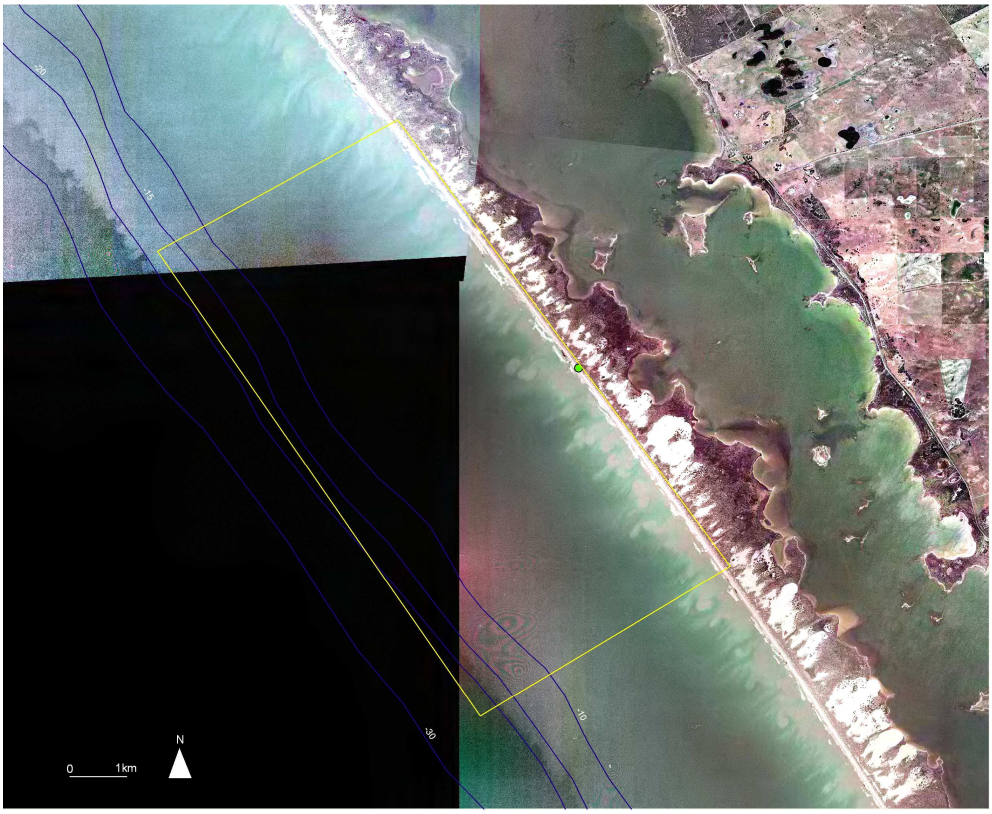


Figure 4.1 Photomosaic of the Coorong showing the model domain and proposed discharge location (green dot).

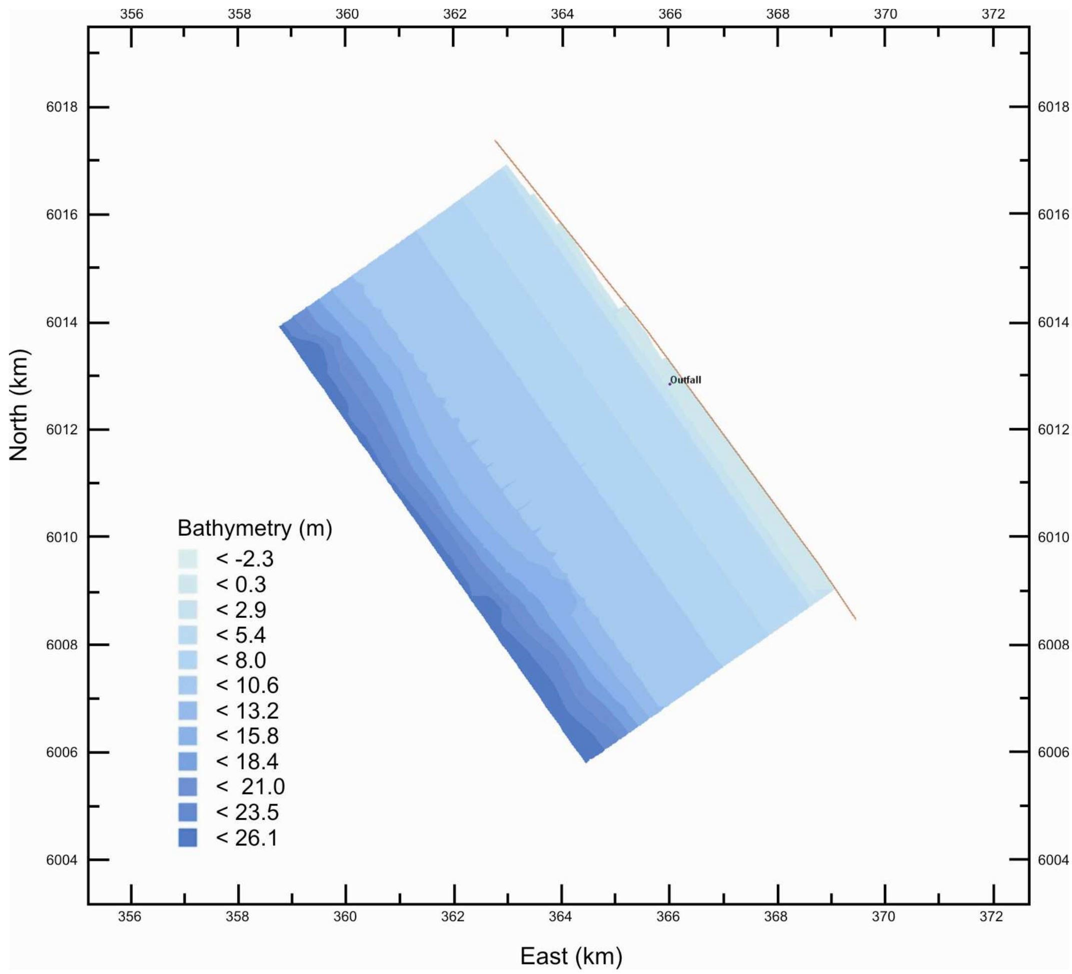


Figure 4.2 Model bathymetry and shoreline outfall.

4.2 Model Forcing, Boundary Conditions and Model Runs

A preliminary tidal forcing was generated by computing the astronomical tide from the 4 major constituents for Victor Harbour (Table 3, reproduced from ANTT, 2000) for the northwest open boundary. The constituents at Kingston show very similar amplitudes and slight phase shift phase to Victor Harbour suggesting this assumption is reasonable for the preliminary modelling exercise. The tidal constants for Victor Harbour and Kingston are provided in Table 3. The longshore distance from Victor Harbour to Kingston is 180 km and the distance from Victor Harbour to the 10 km long model site 100 km. To accommodate an alongshore tidal variability the south east open boundary tide was generated by adding the interpolated phase shift between Victor Harbour and Kingston to each of the tidal constituents (Table 3). The offshore open boundary tide was interpolated between the boundary end points. The model time step is 0.5 minutes and 2 days of neap tides were simulated. Salinity of the ambient seawater was assumed be 36 ppt for all model runs

Table 3 Tidal Constants for Victor Harbour and Kingston (reproduced from Australian National Tide Tables, 2000)

Constituent	M2	S2	K1	O1	P1	K2	M4
Phase speed (°/hour)	28.984	30	15.041	13.943	14.958	30.082	57.968
Victor Harbour							
Amplitude (mm)	131	151	201	140	61	43	34
Phase (° UT)	349.8	46.8	31.8	2.6	28.2	48.4	356.8
Kingston							
Amplitude (mm)	144	166	186	128	54	50	19
Phase (° UT)	338	43	40	9	37	39	13

Amplitude Ratio Victor Habour/Kingston	0.9	0.9	1.1	1.1	1.1	0.9	1.8
Phase difference Victor Harbour - Kingston (°)	11.8	3.8	-8.2	-6.4	-8.8	9.4	343.8
Phase lag across model domain 10 km (minutes)	1.36	0.42	-1.82	-1.53	-1.96	1.04	19.77

Initially the saline discharge of 150 ML/day (1.8 m^3/s) and salinity 150 ppt was input at the beach into the bottom layer of the outfall shoreline cell. Following a series of initial model runs with the 150 ML/day discharge at the back of the beach the discharge was relocated to the surf zone at a depth of -1 m AHD. Additional runs were undertaken with a 250 ML/day discharge located at the back of the beach and within the surf zone. A more realistic situation was modelled by forcing the model with the water level data at Victor Harbour and winds from Hindmarsh Island for the period 15 to 17 May 2007 as shown above in Figure 4.3. Note the wind speed was ramped during the first day to avoid model instabilities in the initial start up phase.

A series of runs using shore parallel winds was also undertaken to assess the likely plume footprint under the potential "worst case" wind conditions. Constant winds from the SE and NW were deemed to represent worst case in terms of the dispersion of the saline discharge. Winds from the SE and NW with a constant speed of 5 ms^{-1} blowing for two days were used to force the model, along with the water level data at Victor Harbour.

Subsequent to the constant shore parallel wind runs, further discussion with the model reviewers suggested that the worst case in terms of the potential saline footprint along the beach may occur at larger tides and longer periods of SE winds.

Hence an additional 9-day model run has been undertaken to simulate constant SE winds with a period of larger tidal range. The astronomical tidal water level variations used in this simulation are show in Figure 4.4 and the wind was held constant at 5 m/s from the SE for the whole simulation period.

The constant wind direction was adopted as a worst possible case and previous analyses of wind data highlighted the variable wind direction along the SE coast. The longest period of winds blowing from the SE quadrant over the past 10 years was shown to be 48 hours and more common events rarely last more than 24 hours.

A summary of the model results presented in this report is provided in Table 4.

Table 4 Summary of Model Runs

Scenario	Saline Discharge	Discharge Location	Wind Forcing	Simulation Length	Results
1	150 ML/d	Offshore	Winds from Hindmarsh Island	3 days	Section 4.3.1
2	250 ML/d	Nearshore	Winds from Hindmarsh Island	3 days	Section 4.3.2
3	250 ML/d	Offshore	Winds from Hindmarsh Island	3 days	Section 4.3.2
4	250 ML/d	Offshore	Constant shore parallel SE winds	3 days	Section 4.3.3
5	250 ML/d	Offshore	Constant shore parallel NW winds	3 days	Section 4.3.3
6	250 ML/d	Offshore	Constant shore parallel SE winds	9 days	Section 4.3.4
7	250 ML/d	Offshore	No winds	9 days	Section 4.3.5

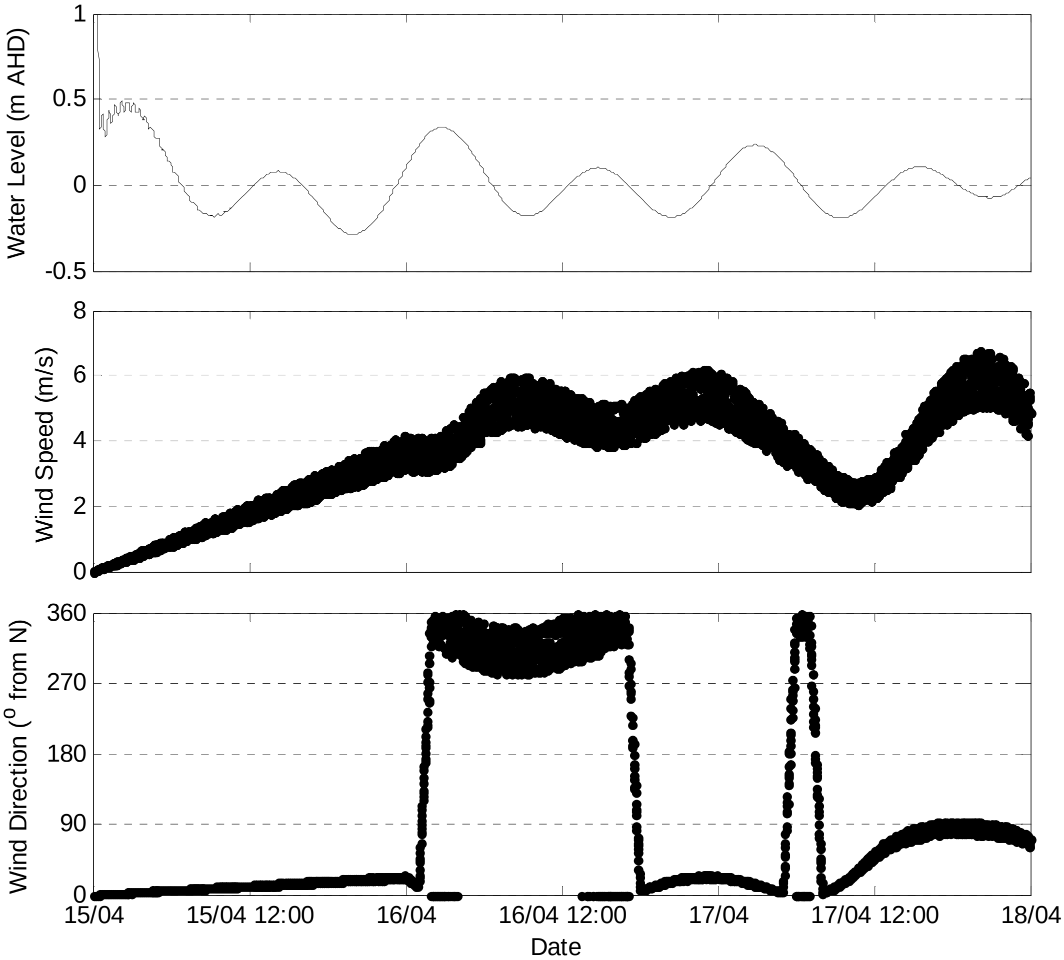


Figure 4.3 Sea level, wind speed and direction used as the model forcing.

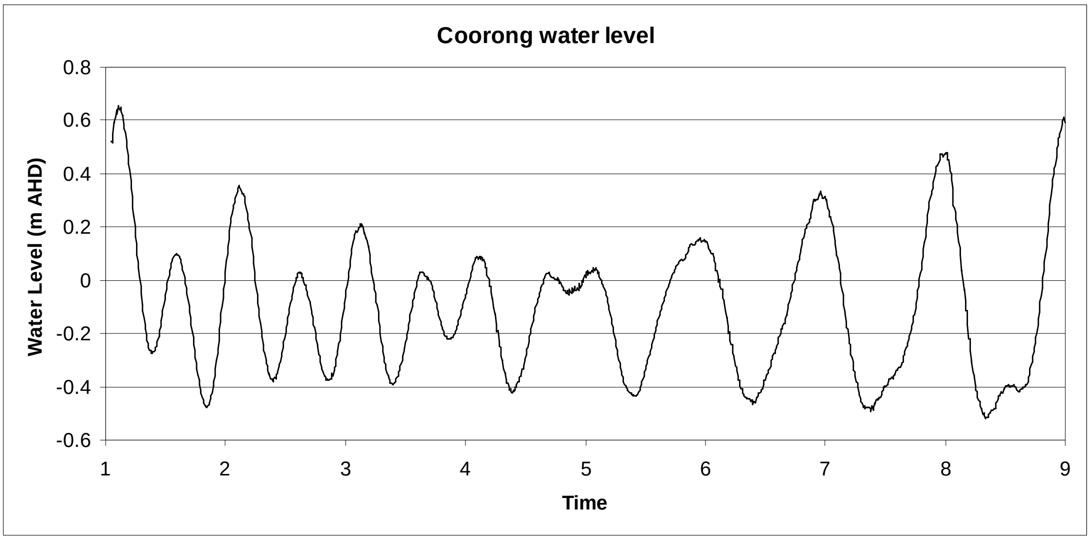


Figure 4.4 Water Level variations for long term (9 days) runs

The *k-e* turbulence closure model is used with the momentum equations and an eddy diffusivity of 5 m^2/s was adopted for the transport and dispersion. The Manning's n bottom roughness parameter was set at 0.01 which is common for sandy beaches with sand waves and ripples.

To establish a working model a number of model runs was undertaken for a range of test cases (see Table 5) to assess the sensitivity of the model to different parameters (refer Appendix D).

Table 5 Model runs undertaken for a range of test cases

Model Run Identifier	Forcing Condition	Dispersion Algorithm	Eddy Diffusivity m^2s^{-1}	Comment on model results and subsequent action
A01	tide only	k-e turbulence closure model	5	
A02	tide only	k-L model	1	
A03	tide only	k-L model	5	
A04	tide only	k-e model	1	
A05	tide and wind	k-e model	5	
A051	tide and wind	k-e model	5	Unstable! suggest adopt 4 day runtime (to force release in steady conditions)
A052	tide and wind	k-e model	5	Unstable! suggest revise bathymetry near boundaries and adopt randomised instantaneous wind to fit a quasi Normal Central Law (4day runtime)
A053	tide and wind	k-e model	5	Strong near shore wind driven currents suggest bottom friction too low.
A06	tide and wind			changed nearshore roughness to n=0.03

4.3 Model Results

4.3.1 Tide and Wind Forcing 150 ML/day (Scenario 1)

Results for the run with tidal and wind forcing are shown below in Figures 4.5 and 4.6. Comparing these results with the tide only case (not shown) indicated the plume disperses more rapidly for the case with winds. The 1 ppt salinity excess isohaline (37 ppt) extends about 2 km offshore for the tide and winds and roughly 1.5 km in longshore extent beyond the 2 m isobath.

The images presented in the figures provide a snapshot of the plume footprint at one instant in time. The shape of the plume will change with the ambient conditions and in particular the long shore component of the wind field that forces long shore currents. Under shore parallel winds the currents within the plume will most likely be swept along the shallower near shore waters and other plume shapes will emerge. The envelope of plume shapes requires a longer period of model run to assess the impact of winds from a range of directions.

Due to the complexity of the model domain and equations being solved the ratio of model simulation time to real time is about 1:5. Hence a 9 days simulation takes about 2 days of computing time and thus only short term simulations were undertaken.

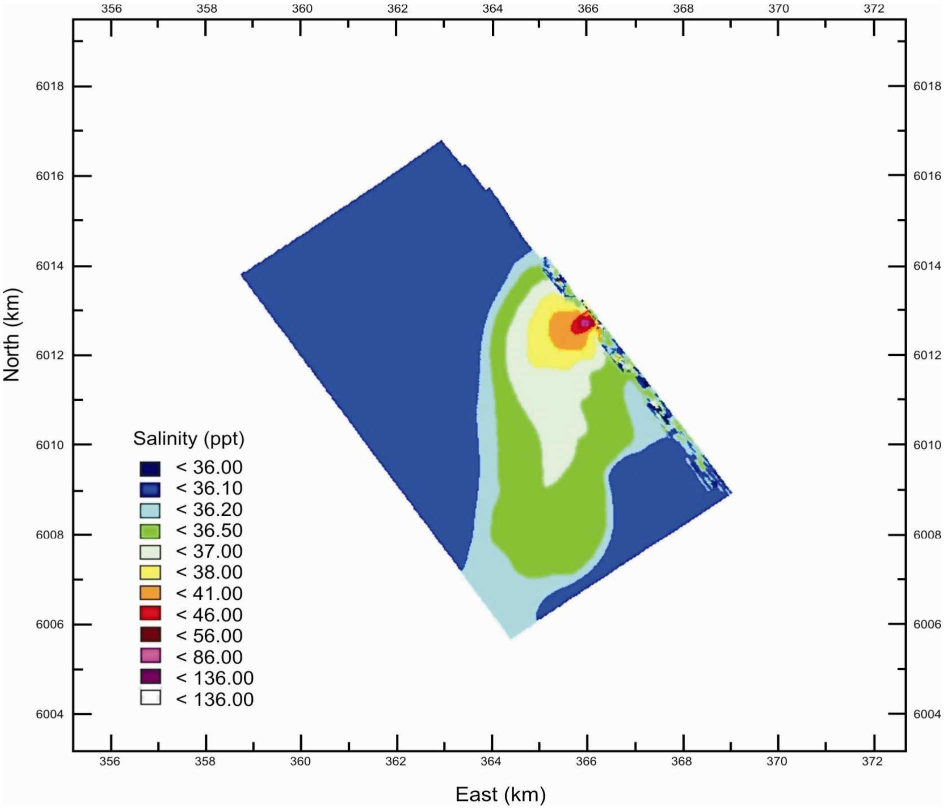


Figure 4.5 Plan view of bottom salinity for the tide and wind case after 2 days of simulation.

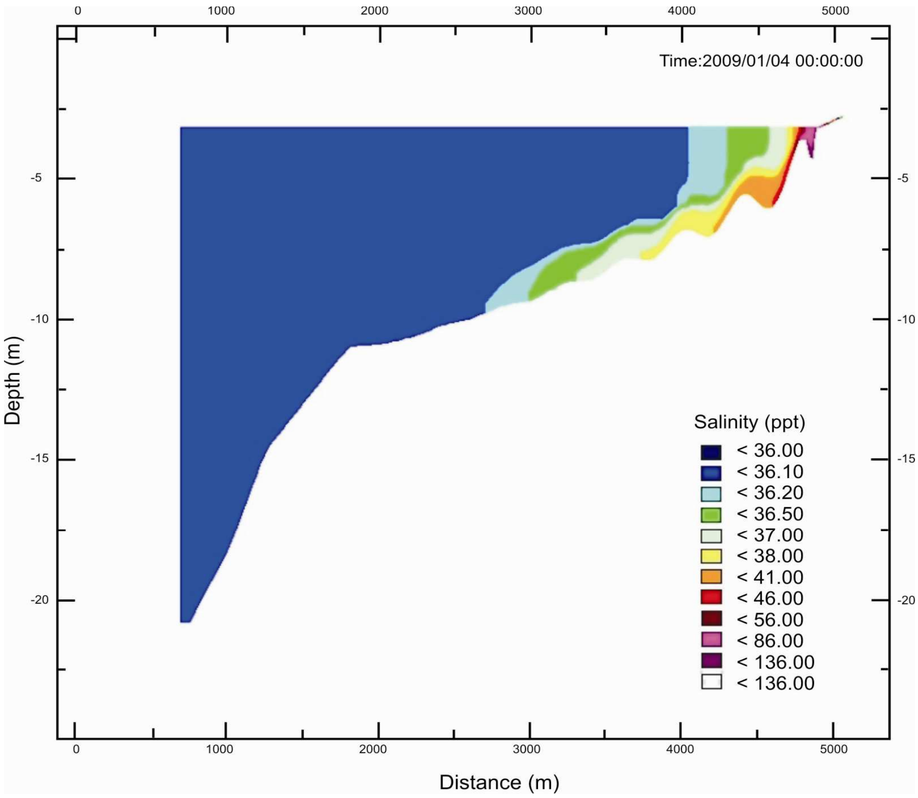


Figure 4.6 Cross section view of salinity for the tide and wind case after 2 days of simulation.

4.3.2 Tide and Wind Forcing 250 ML/day (Scenario 2 & 3)

Results for the runs with 250 ML/day discharge to the beach and surf zone with tidal and wind forcing are shown below in Figures 4.7 and 4.8, respectively. Discharging to the beach creates a larger footprint area at the shoreline (Figure 4.7). The 1 ppt salinity excess isohaline extends about 1.5 km along the shore for the beach discharge while moving the discharge to the surf zone results in more rapid dispersion and a smaller length of affected shoreline.

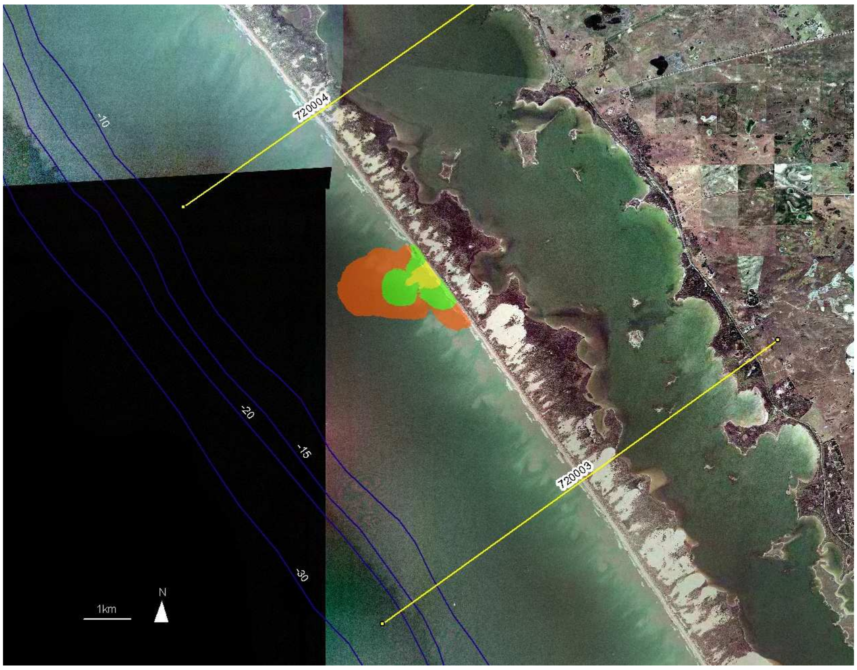


Figure 4.7 Plan view of bottom salinity for the 250 ML/day beach discharge with tide and wind forcing after 2 days of simulation (orange area > 37 ppt, green 39 to 45 ppt and yellow > 45 ppt).

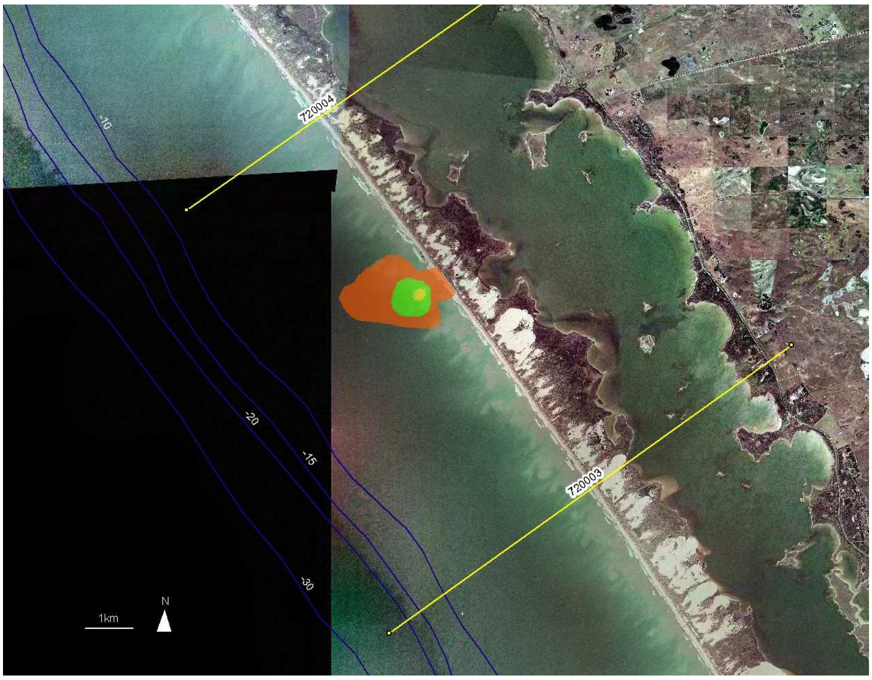


Figure 4.8 Plan view of bottom salinity for the 250 ML/day surfzone discharge with tide and wind forcing after 2 days of simulation.

4.3.3 Tide with Constant Shore-parallel Winds 250 ML/day (Scenarios 4 & 5)

Results for the run with tidal and constant shore parallel wind forcing from both the SE and NW directions are shown below in Figure 4.9 and Figure 4.10 respectively. Interestingly the results from the two directions are quite different due primarily to the effects of the earth's rotation. The deep water upwelling favourable SE winds produce the longest shoreline footprint with the plume extending some 1.5 km alongshore to the 1 ppt excess salinity (37 ppt). For the NW shore-parallel winds the plume forms a downwelling favourable flow and extends offshore with a shoreline footprint of around 1.5 km to the 1 ppt excess value.

The near bottom plume footprint area under the SE winds is considerably smaller than the NW results because of the greater wind driven mixing in shallower waters. These conditions of winds blowing for 2 days from the same shore parallel direction and no waves occur very infrequently and most of the time the plume footprint for the conditions of dodge tide with constant shore parallel winds is likely to be considerably smaller than indicated here.

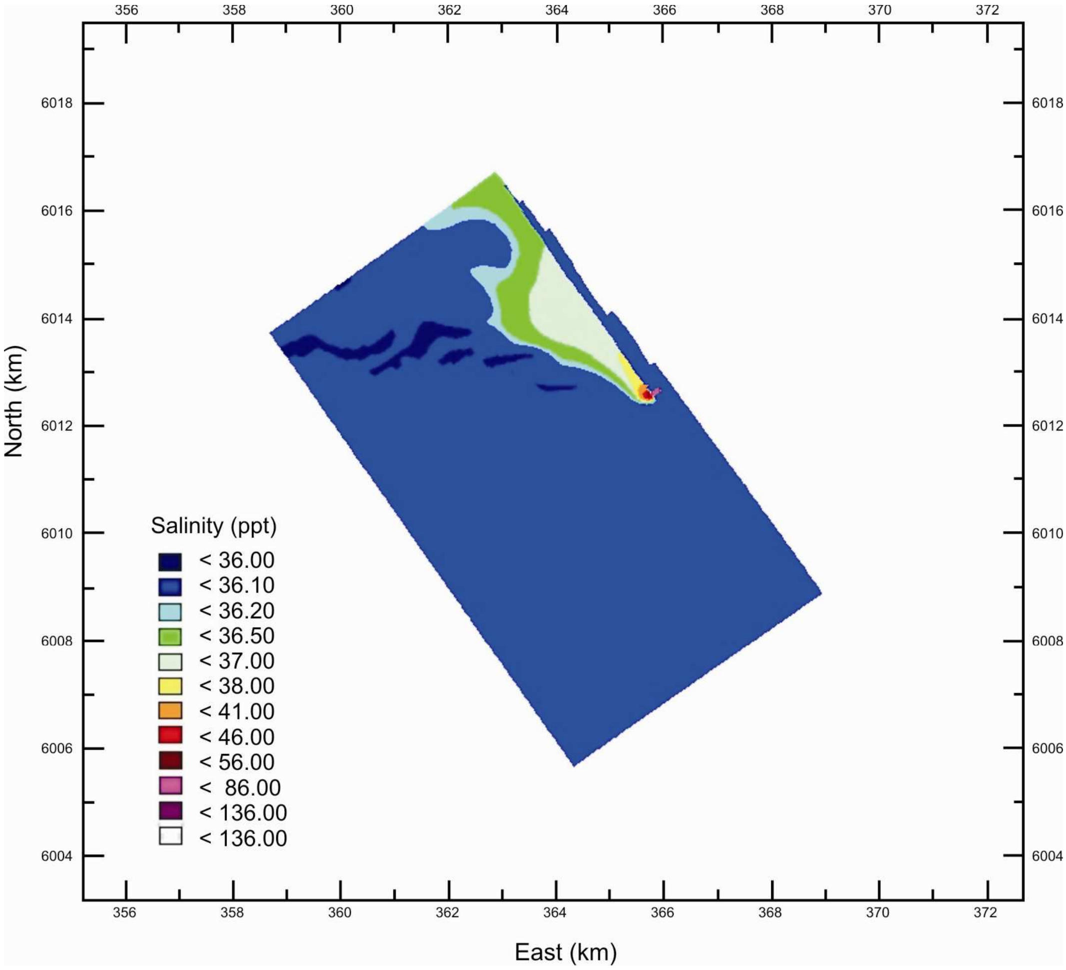


Figure 4.9 Plan view of bottom salinity for the tide and constant shore parallel SE wind case after 2 days

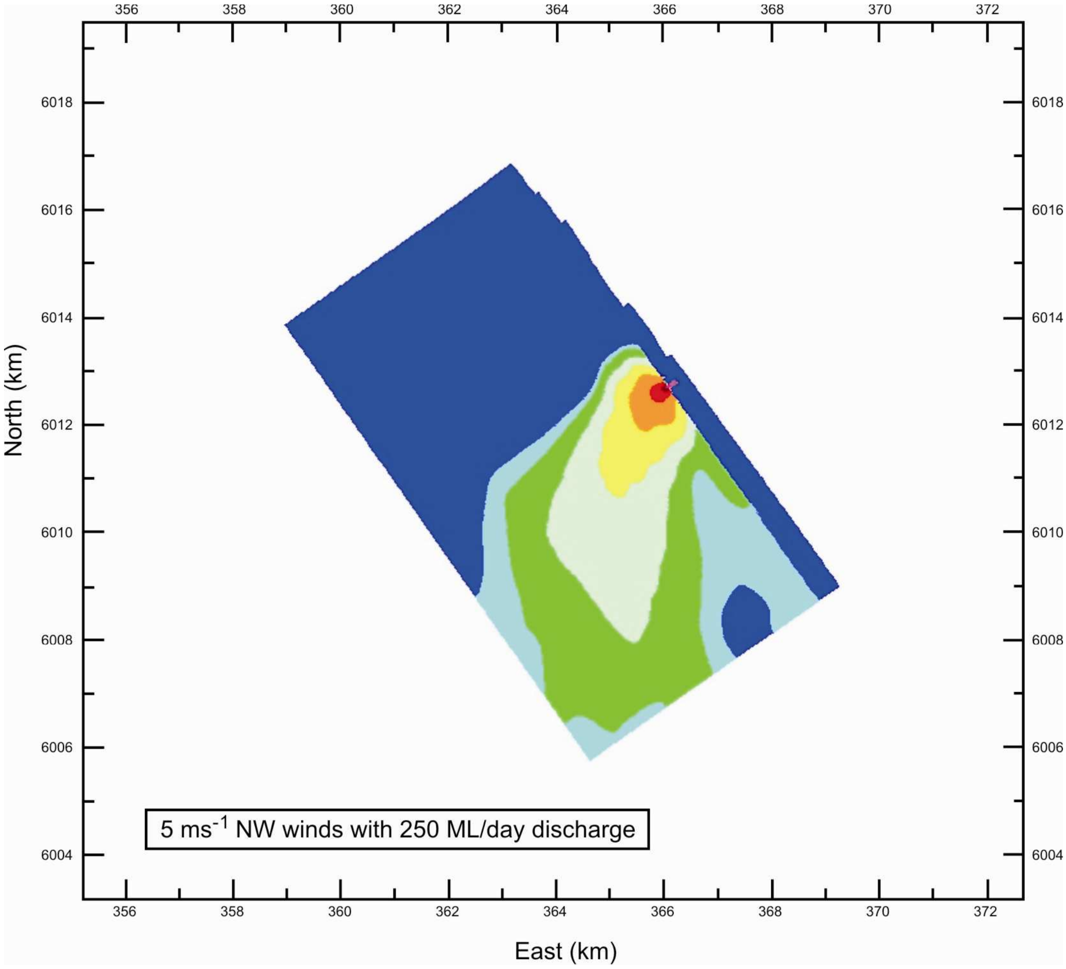


Figure 4.10 Plan view of bottom salinity for the tide and constant shore parallel SE wind case after 2 days

4.3.4 Tide with Constant Shore-parallel Winds 250 ML/day – 9 days (Scenario 6)

Results are presented in the plan view (Figure 4.11) showing the bottom layer salinity at the end of the model run (~ 9 days) during slack water. The saline plume is clearly swept alongshore toward the NW and the results are similar to the previous 2 day run described in the previous section. Following the longer exposure to the SE winds and larger tidal range the plume extends a little further to the NW.

The time series of bottom salinity at a series of locations 200 m from the discharge are shown in Figure 4.12. The plume is clearly swept to the NW and superposed by tidal oscillations as indicated by the trace at the NW location.

At 200m NW of the discharge (red line in figure 4.12) the general salinity has increased from the ocean salinity of 36 ppt to about 38 ppt with tidal oscillations of about 1.25 ppt. At 200m SW and SE of the discharge the tidal oscillations are much weaker and general salinity increase is around 0.25 ppt above the ocean salinity of 36 ppt.

The results suggest that running the model for the longer period of SE winds does not significantly affect the saline plume dispersion.

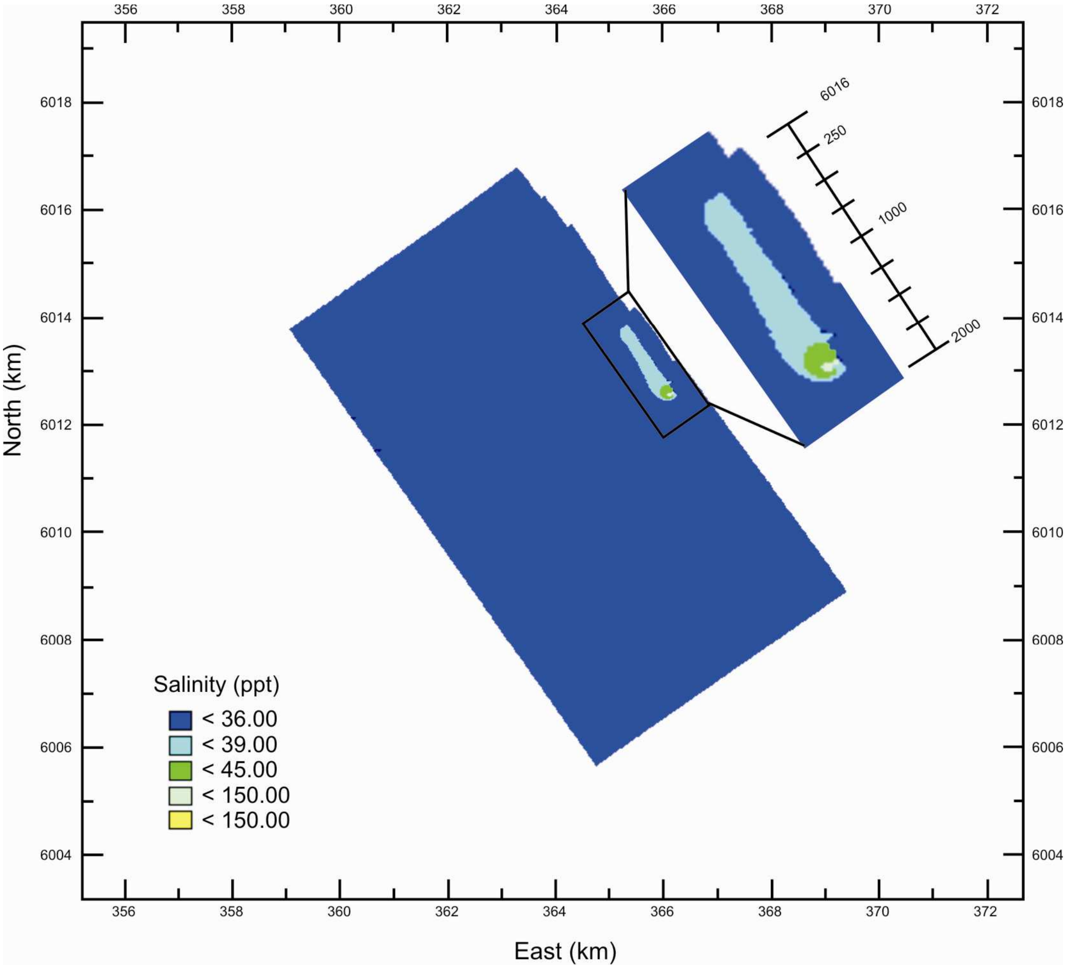


Figure 4.11 Bottom Layer Salinity for Tides with SE wind 5 m/s after 9 days simulation

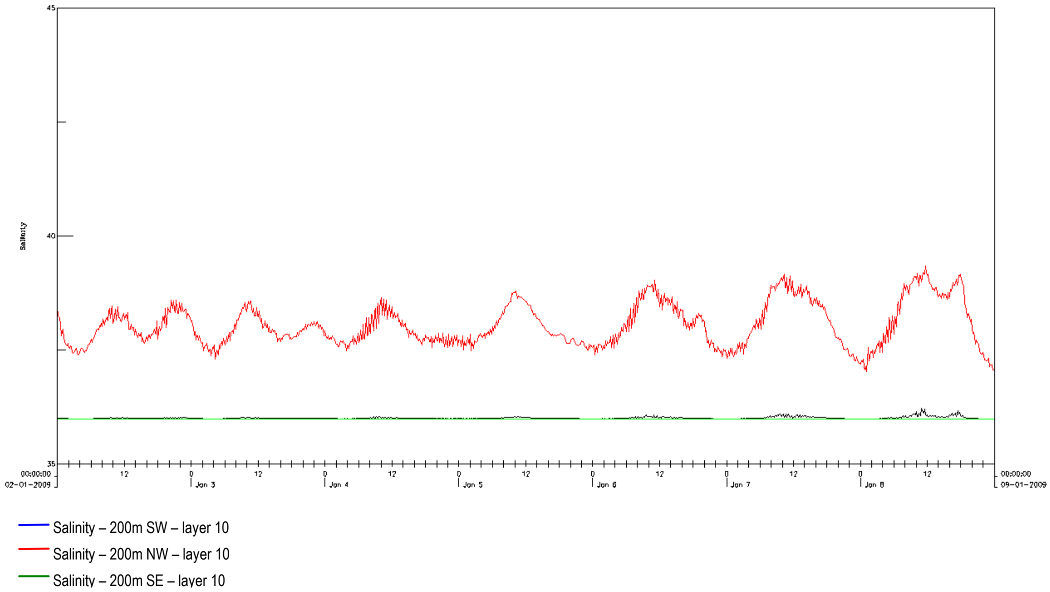


Figure 4.12 Bottom Layer Salinity time series for case of Tides with constant SE Wind at selected locations from the discharge (SE, 200m SW, 200m NW and 200m SE of the discharge).

4.3.5 Tide with No Winds 250 ML/day – 9 days (Scenario 7)

Results for the case of tide with no winds long term model run are presented in Figures 4.13 and 4.14. Comparing the results with the worst case winds (constant shore parallel SE winds) presented in Section 4.3.4 shows that the plume covers a slightly larger area with reasonably symmetric distribution around the discharge. With no wind the dispersive mixing is reduced and hence the saline footprint is slightly larger than the case with winds and tidal currents.

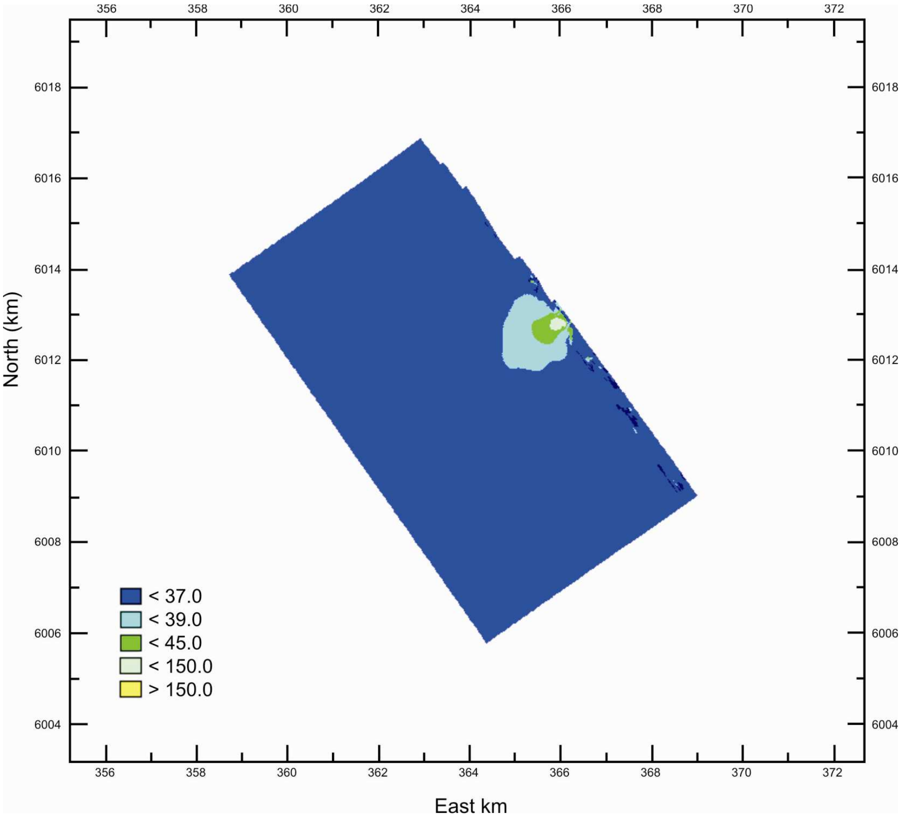


Figure 4.13 Bottom Layer Salinity for Tides and no winds after 9 days simulation

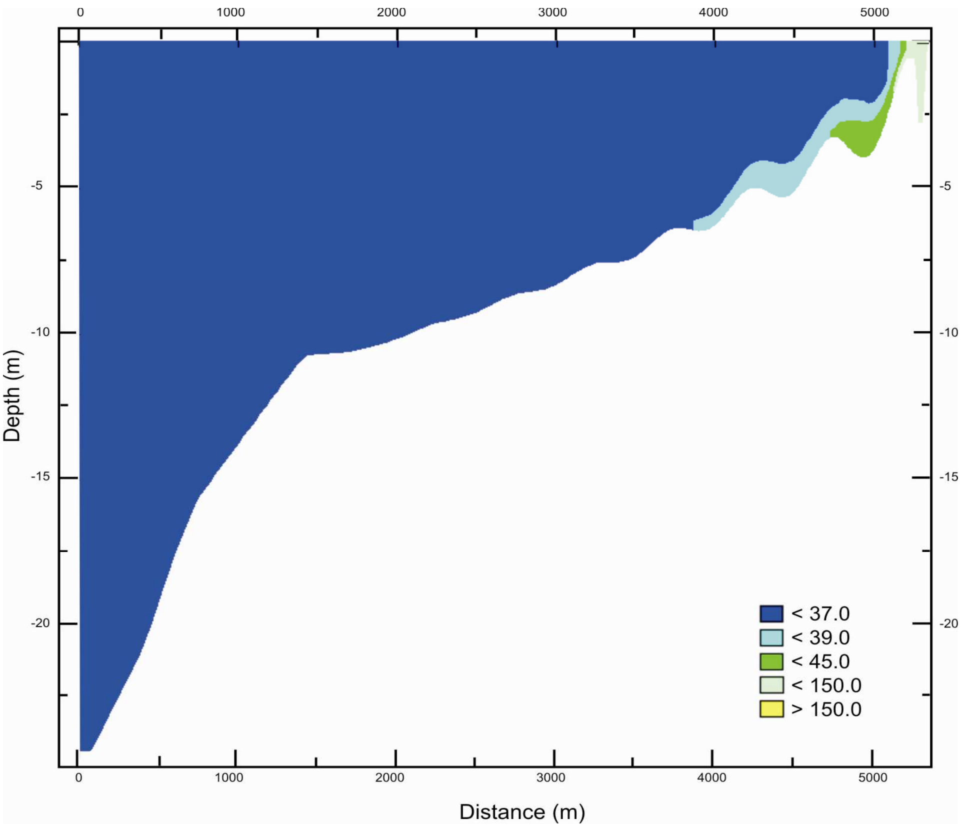


Figure 4.14 Cross section view of Salinity for Tides and no winds after 9 days simulation

5. Conclusions

On the basis of the findings of this preliminary hydrodynamics and dispersion assessment, it may be concluded that the saline discharge is likely to rapidly disperse into the high energy Southern Ocean marine environment. The natural dispersion processes in the coastal ocean are highly dynamic fluctuating with the weather and tidal conditions. The results presented have focused on the worst case conditions that produce the largest plume footprint. These conditions include the neap tides with very low waves and either low winds or shore-parallel winds situations. Analyses of wind records indicate that these worst case conditions are likely to persist less than 1 % of the time and hence most of the time the plume footprint will be smaller than indicated by these results. The 3 ppt excess salinity (39 ppt and 38 fold dilution) is likely to be confined within a distance of less than 200 m of the discharge during the worst case conditions. The 1 ppt excess salinity (37 ppt and 100 fold dilution) extends around 2 km offshore under the worst case scenarios and is within a similar distance alongshore under the influence of the SE shore-parallel winds.

5.1 Recommendations for Baseline Studies

Results presented above provide a reasonable overview of the dispersion of the proposed discharge plume and discuss the possible engineering constraints on the construction of the proposed system. Assuming that the project were to receive approval to proceed then additional information is required to provide a basic information for the preparation of concept design engineering hydraulic assessment and drawings to enable further refinement of the concept presented here. Further studies include

- Pipeline route
  - Detailed terrain survey
  - Identification of potential ASS areas
- Hydrodynamic modelling calibration/verification data
  - Littoral currents in the surf zone
  - near bottom currents (in say 10 m depth)
  - sediment transport estimates

The data collection exercise of at least 3 months deployment would likely take up to 5 months and cost around $80,000. These data would then be suitable to further refine the hydrodynamic model or assist to define a monitoring regime to test the performance of the system when installed.

6. References

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Appendix A

Monthly Climate Statistics for Goolwa

Monthly Climate Statistics for Goolwa (Hindmarsh Island Marina)

Created on [26 Mar 2009 07:18:33 GMT]

023849 GOOLWA (HINDMARSH ISLAND MARINA)
Commenced: 1989
Last Record: 2003
Latitude: 35.51 Degrees South
Longitude: 138.80 Degrees East
Elevation: 3 m
State: SA

Statistic Element	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Number of Years	Start Year	End Year
Mean maximum temperature (Degrees C)	23.6	24.4	22.1	20.6	18.1	15.8	15.4	16	18	19.9	21.2	21.9	19.7	14	1989	2003
Highest temperature (Degrees C)	43	41.3	39.1	35.4	28.9	25.5	22.9	27	31.4	34.7	41.5	41.2	43	14	1989	2003
Date of Highest temperature	14-Jan-96	2-Feb-00	17-Mar-00	3-Apr-92	7-May-02	5-Jun-98	27-Jul-02	24-Aug-95	28-Sep-99	17-Oct-98	30-Nov-93	11-Dec-98	14-Jan-96	N/A	1989	2003
Lowest maximum temperature (Degrees C)	16.5	16.5	13.5	14.5	12.6	9.5	9.8	11.5	12	12.5	13.5	15.5	9.5	14	1989	2003
Date of Lowest maximum temperature	8-Jan-92	21-Feb-93	14-Mar-90	27-Apr-99	16-May-92	1-Jun-89	8-Jul-91	26-Aug-89	5-Sep-95	10-Oct-93	1-Nov-94	9-Dec-90	1-Jun-89	N/A	1989	2003
Decile 1 maximum temperature (Degrees C) for years 1989 to 2003	18.3	18.5	17.9	16.4	14.5	13.3	12.7	13	13.8	14.9	15.9	17.1		14	1989	2003
Decile 9 maximum temperature (Degrees C) for years 1989 to 2003	34.5	36.4	31.2	27.4	22.8	18.5	18.3	20	23.8	27.5	30.2	31.3		14	1989	2003
Mean number of days >= 30 Degrees C	5.6	6.2	4	1.2	0	0	0	0	0.1	1.6	3.4	3.9	26	14	1989	2003
Mean number of days >= 35 Degrees C	2.9	3.5	0.8	0.1	0	0	0	0	0	0	0.8	1.1	9.2	14	1989	2003
Mean number of days >= 40 Degrees C	0.4	0.5	0	0	0	0	0	0	0	0	0.1	0.1	1.1	14	1989	2003
Mean minimum temperature (Degrees C)	15.4	15.5	13.9	11.8	9.7	8.4	7.7	7.7	9	10.7	12.4	13.9	11.3	14	1989	2003
Lowest temperature (Degrees C)	7.8	9.1	7.4	5	1.2	0.6	2	1	3.4	4.3	5.8	7	0.6	14	1989	2003
Date of Lowest temperature	8-Jan-95	26-Feb-92	16-Mar-95	26-Apr-00	12-May-94	18-Jun-98	14-Jul-98	31-Aug-94	11-Sep-02	7-Oct-90	1-Nov-98	1-Dec-94	18-Jun-98	N/A	1989	2003
Highest minimum temperature (Degrees C)	25.7	25	22.6	19.3	18.7	15	13	14	16	20.5	25	22.6	25.7	14	1989	2003
Date of Highest minimum temperature	21-Jan-97	8-Feb-01	2-Mar-00	24-Apr-02	3-May-99	24-Jun-91	8-Jul-94	16-Aug-01	30-Sep-01	26-Oct-97	26-Nov-97	12-Dec-98	21-Jan-97	N/A	1989	2003
Decile 1 minimum temperature (Degrees C) for years 1989 to 2003	12	11.9	10	7.9	5.6	4.5	4.6	4.5	5.8	6.9	8.9	10.8		14	1989	2003
Decile 9 minimum temperature (Degrees C) for years 1989 to 2003	18.6	19.1	17.1	15.3	13	11.5	10.4	10.5	12	14.1	15.5	17		14	1989	2003
Mean number of days <= 2 Degrees C	0	0	0	0	0.2	0.3	0.1	0.4	0	0	0	0	1	14	1989	2003
Mean number of days <= 0 Degrees C	0	0	0	0	0	0	0	0	0	0	0	0	0	14	1989	2003
Mean daily ground minimum temperature Degrees C																
Lowest ground temperature Degrees C																
Date of Lowest ground temperature														N/A		
Mean number of days ground min. temp. <= -1 Degrees C																
Mean rainfall (mm)	12.8	14.4	18.6	27.7	41	59.8	60.5	53	50.6	40.6	27.8	30.4	442.2	14	1989	2002
Highest rainfall (mm)	30.6	63.4	58.8	83.4	63.4	108	98	79.3	99	82.7	63.1	185.4	755.5	14	1989	2002
Date of Highest rainfall	1997	2000	1992	1992	1995	1991	1995	1996	1992	2000	1997	1992	1992	N/A	1989	2002
Lowest rainfall (mm)	2	0	0.2	2.1	12.7	26.8	25.2	21.4	21.5	8.2	1.4	2.8	355.4	14	1989	2002
Date of Lowest rainfall	1992	1991	1994	1993	1990	1997	1997	1995	1994	1991	1990	2000	1994	N/A	1989	2002
Decile 1 monthly rainfall (mm) for years 1989 to 2002	3.2	4.4	2.4	5.4	24.7	40	39.9	41.2	23.6	18.6	4.8	4.7	360.7	14	1989	2002
Decile 5 (median) monthly rainfall (mm) for years 1989 to 2002	11.7	10.8	12.6	22.4	42.6	54.8	60.5	48	46	41.4	28.3	14.7	423.6	14	1989	2002
Decile 9 monthly rainfall (mm) for years 1989 to 2002	24.2	22.4	49.5	62.5	52.3	78.4	86.1	74.9	78.2	61.8	56.4	40.7	450.7	14	1989	2002
Highest daily rainfall (mm)	19	24.4	24.4	43	37	38.3	36	19.8	30.6	45	45.6	90.4	90.4	14	1989	2003
Date of Highest daily rainfall	22-Jan-97	20-Feb-00	1-Mar-92	6-Apr-92	3-May-95	7-Jun-94	8-Jul-93	26-Aug-01	25-Sep-92	31-Oct-97	1-Nov-97	19-Dec-92	19-Dec-92	N/A	1989	2003
Mean number of days of rain	5.2	4.5	7.4	10	15.8	18.1	19.8	17.8	14.9	12.7	9.9	8.1	144.2	14	1989	2002
Mean number of days of rain >= 1 mm	2.6	2.8	4.1	6.3	9.2	11.7	11.2	11.3	8.5	8.1	5.5	4.5	85.8	14	1989	2003
Mean number of days of rain >= 10 mm	0.2	0.4	0.5	0.5	0.7	1.2	1.4	0.8	1.3	0.8	0.6	0.7	9.1	14	1989	2003
Mean number of days of rain >= 25 mm	0	0	0	0.2	0.2	0.1	0.1	0	0.1	0.1	0.1	0.1		14	1989	2003
Mean daily wind run (km)																
Maximum wind gust speed (km/h)														0	2002	2002
Date of Maximum wind gust speed														N/A	2002	2002
Mean daily sunshine (hours)																
Mean daily solar exposure (MJ/(m*m))	26.7	23.7	19.2	13.2	9.2	7.6	8.5	11.8	16	20.2	24.3	25.8	17.2	19	1990	2009
Mean number of clear days	4.3	6.8	5.8	4	2.3	1.6	2.5	4.4	3.5	3.6	3.9	3.6	46.3	14	1989	2003
Mean number of cloudy days	13.4	11.5	13.5	15.3	19.2	17.1	14.7	15.4	15.2	15.7	15.1	15.4	181.5	14	1989	2003

Mean daily evaporation (mm)																
Mean 9am temperature (Degrees C)	19.2	19.3	17.5	16.1	13.5	11.5	10.8	11.7	13.8	15.9	16.6	17.9	15.3	14	1989	2003
Mean 9am wet bulb temperature (Degrees C)	15.7	16.2	14.8	13.4	11.6	10.1	9.5	9.7	11.4	12.4	13.3	14.7	12.7	13	1989	2002
Mean 9am dew point temperature (Degrees C)	13.1	13.5	12.6	10.9	9.8	8.7	7.9	7.5	8.9	9.1	10.3	11.9	10.4	13	1989	2002
Mean 9am relative humidity (%)	70	71	74	74	80	84	83	77	74	67	68	70	74	13	1989	2002
Mean 9am cloud cover (okas)	5.4	5	5.2	5.5	5.8	5.6	5.4	5.1	5.4	5.4	5.7	5.8	5.4	14	1989	2003
Mean 9am wind speed (km/h) for years 1989 to 2003	15.5	13.8	13.1	13	11	12.4	11.7	14.5	14.8	16.7	15.3	15.7	14	13	1989	2003
Mean 3pm temperature (Degrees C)	21.4	22.1	20.4	18.9	16.8	14.6	14.2	14.7	16.4	17.6	19.2	20	18	14	1989	2003
Mean 3pm wet bulb temperature (Degrees C)	17.1	17.5	16.2	14.7	13.2	11.9	11.5	11.2	12.7	13.4	14.7	15.8	14.2	13	1989	2002
Mean 3pm dew point temperature (Degrees C)	13.9	13.9	12.8	11.1	9.9	9.1	8.6	7.6	9.2	9.3	10.8	12.4	10.7	13	1989	2002
Mean 3pm relative humidity (%)	67	65	65	64	66	71	71	64	65	62	63	65	66	13	1989	2002
Mean 3pm cloud cover (oktas)	4.5	4.2	4.7	5.2	6	5.9	5.7	5.4	5.4	5.1	5.1	5.1	5.2	14	1989	2003
Mean 3pm wind speed (km/h) for years 1989 to 2003	21.7	20.8	18.9	16.9	15.2	15.5	16.6	18.9	17.9	19.7	21	21.5	18.7	13	1989	2003

Appendix B

Beach Discharge Concept

Appendix B

Appendix C

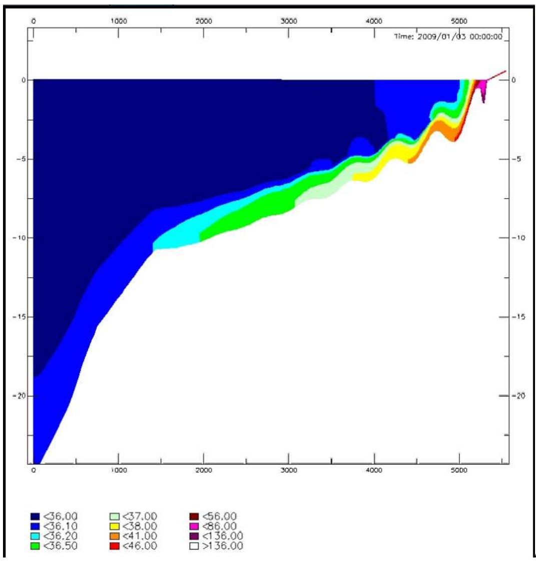
Surf Zone Discharge Concept

Appendix C

Appendix D

Sensitivity to Dispersion Parameterisation

The model forcing for tide only condition was run with different parameterisations of the dispersion ranging from a constant diffusivity approach to the more sophisticated mixing algorithms, the so-called *k-ε* and *k-l* algorithms. Results are shown in Figure D.1 below and indicate subtle differences between the various methods.



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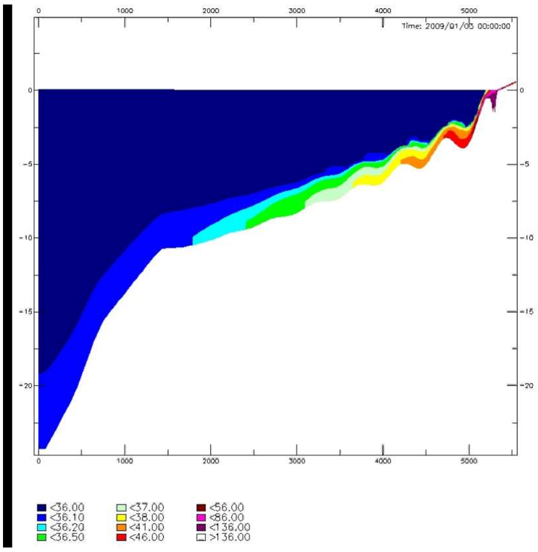

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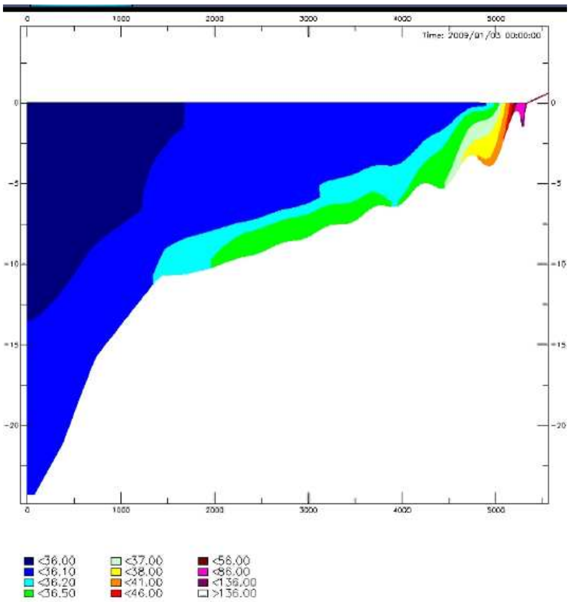
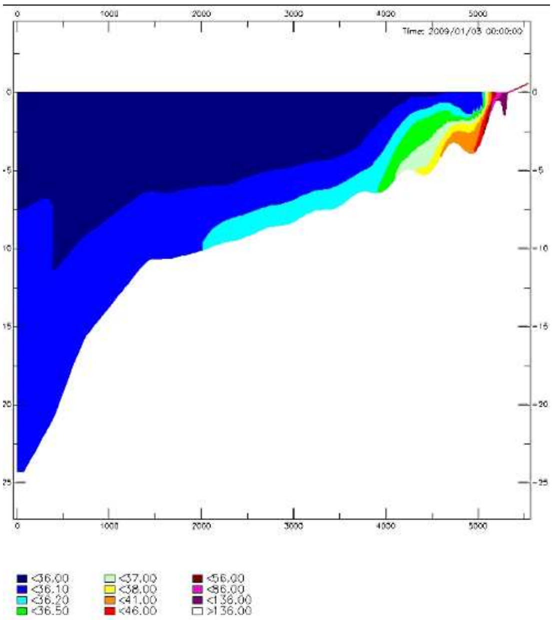


A03 k=L D=5



A02 k-L D=1

Figure D.1 Sensitivity runs showing the effects of different diffusion formulations.

The preliminary run with astronomical tidal forcing only represents a theoretical situation with no wind driven or wave driven flow. This is unlikely to occur in nature as the winds and waves are rarely absent in these waters and hence is referred to as an extremely low mixing scenario. For the purpose of demonstration the preliminary run provides a useful starting point to assess the likely dispersion characteristics.

Tidal forcing results for the bottom layer salinity at the end of the 2 day run show a broad plume area where salinity exceeds the background salinity shown in Figure D.2. Note the sigma coordinate system is a bottom following system.

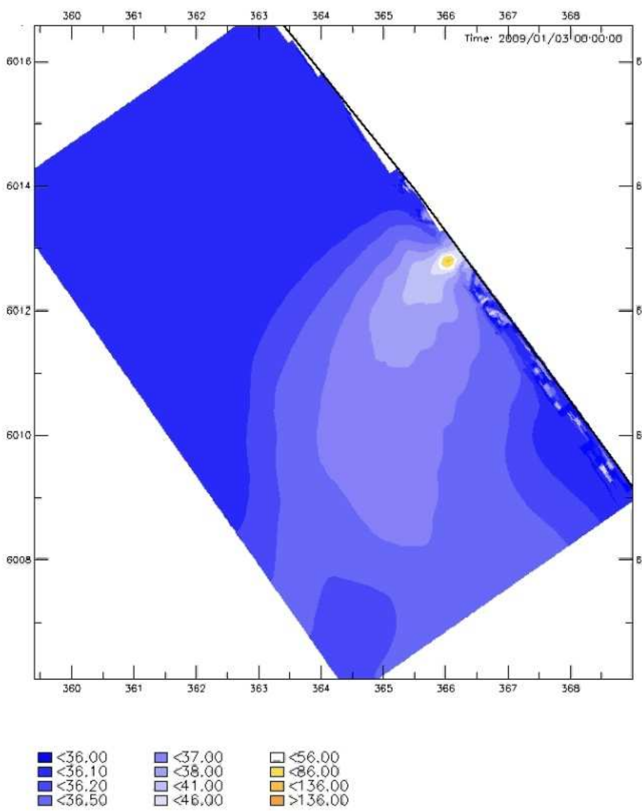


Figure D.2 Plan view of bottom salinity for the tide only run case after 2 days of simulation.

The cross-section out from the outlet site (Figure D.3) shows the heavy saline plume water mixes over the full depth at the shore and then plunges beneath the surface at about 5 m water depth, or around 400 m offshore, then flows offshore down the sloping bottom. The longshore extent is shown in the surface plan view and indicates that near the shore (for this extremely low mixing scenario) in about 2 m water depth the plume extends about 1 km along the shore.

The bottom plan view shows that the plume spreads rapidly both alongshore and offshore and the influence of the earths rotation, the Coriolis effect, causes the plume to vear toward the south. A quasi steady state is achieved within about 1.5 days. The plume area defined by the 1 ppt above ambient salinity contour extends over an area of roughly 8 km offshore by 2 km wide. The extreme low mixing scenario provides estimate of the extent that is unlikely to occur. It is expected that under natural forcing the plume footprint will be significantly smaller than indicated in these figures.

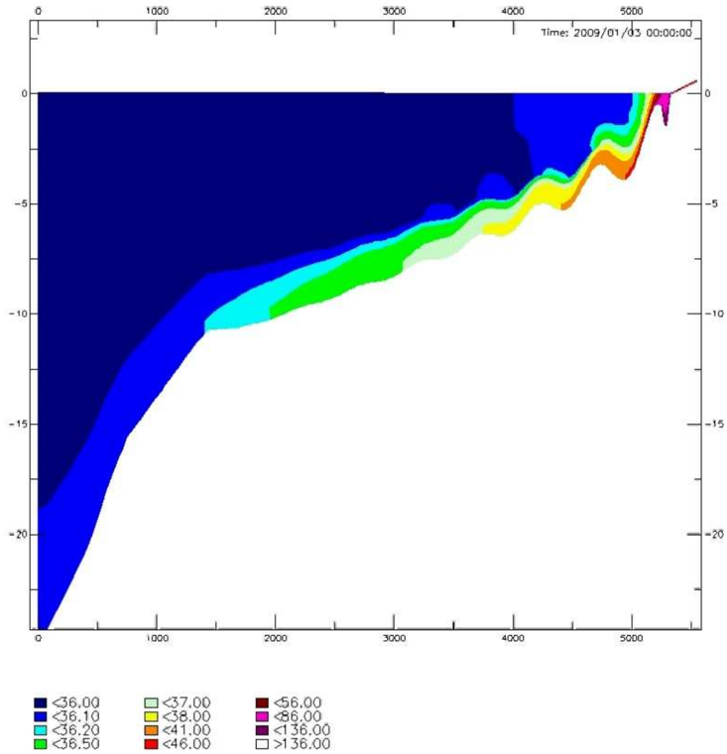


Figure D.3 Cross section view of salinity for the tide only case after 2 days of simulation.

Appendix E

Nutrients dispersion on Coastal Region

Aurecon Australia Pty Ltd
ABN 54 005 139 873
55 Grenfell Street
Adelaide South Australia 5000
Australia

T +61 8 8237 9777
F +61 8 8237 9778
E adelaide@ap.aurecongroup.com
W aurecongroup.com

Appendix E

03 March 2010

Glynn Ricketts
SA Murray-Darling Basin NRM Board
Level 4, 111 Gawler Place
Adelaide SA 5000

Dear Glynn

Following our meeting of November 3, 2009, Aurecon are pleased to provide this letter report on the possible dispersion of nutrients with the proposed discharge of saline Coorong waters to the ocean near Policeman Pt. This assessment has utilised the available data and dispersion modelling results (Aurecon, 2009a) to provide an interpretation of the likely effect of the nutrient loads to the coastal ocean, associated with the discharge. The main issue to be addressed concerns the potential for eutrophication (enhanced algal growth associated with nutrient enrichment) of the near-shore ocean receiving waters.

The following discussion provides an overview of the primary production system, the nitrogen cycle, current nutrient and chlorophyll-*a* (measure of phytoplankton biomass) concentrations in the Coorong and adjacent marine waters. The immediate dilution of the nutrients is estimated by applying the dilutions obtained from the previous dispersion modelling and the potential influence of the complex nitrogen transformation processes on algal production are discussed.

Overview of Primary Production

The review of information and ecological assessment (Aurecon, 2009b) describes the available information and interpretation of the relationship between nutrient sources, primary production and the abundance of cockles on the high-energy Coorong coast. A simplified overview of the system is shown in the schematic diagram (Figure 1). Enhanced nutrients concentrations adjacent to the Coorong are thought to be attributed to freshwater outflows from the Murray River, the upwelling of nutrient-rich waters from below the continental shelf to the surface waters (Bonney upwelling near Robe) and local resuspension of decomposed organic mater. The enhanced nutrient concentrations elevate primary production which provides a more abundant food supply of phytoplankton for filter feeding species such as cockles (*Donax deltoides)*.

The abundance of cockles is affected by environmental variations and is subject to large fluctuations from year to year. Cockles in South Australia are typically greatest in numbers just below the lowest tide levels with juveniles typically living at higher levels on the shore than adults. The Goolwa cockles are filter feeders, and surf diatoms such as *Asterionella* on South Australian beaches form their major food source.

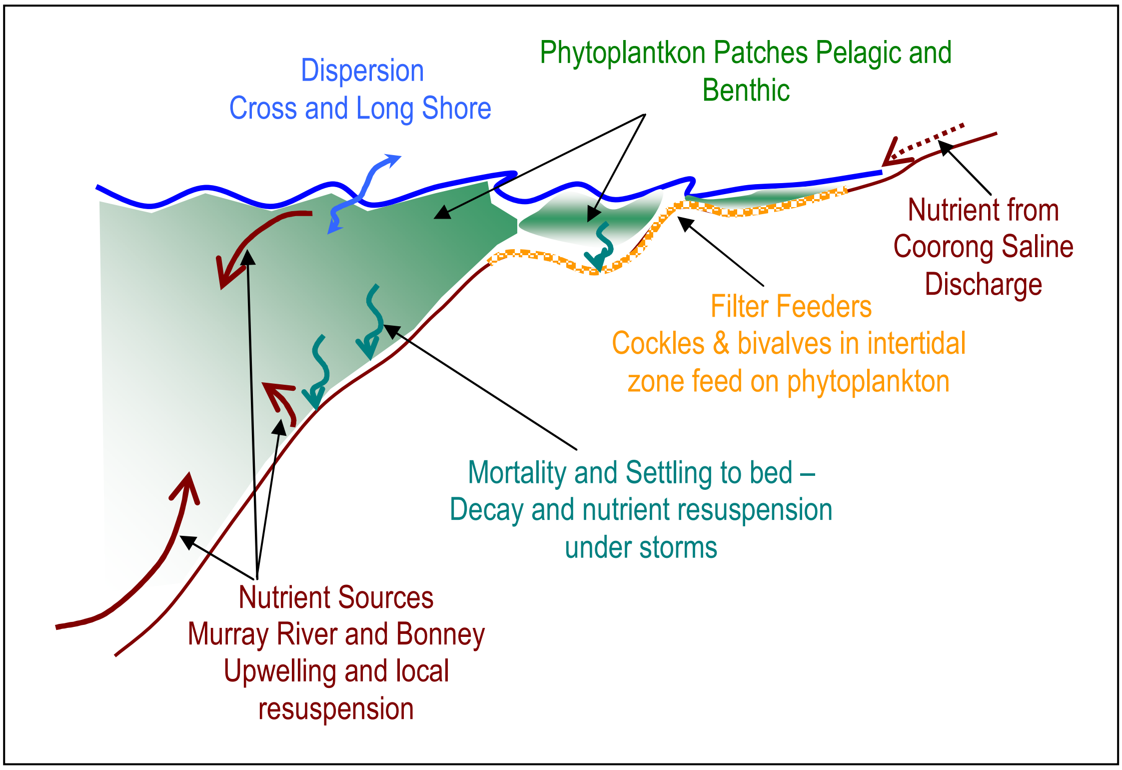


Figure 1 General concept diagram shoeing the relationship between nutrient supplies, primary production and filter feeders such as cockles on the high-energy Coorong coast.

The Nitrogen Cycle

Primary production in the oceans is affected by a range of physical and chemical processes and is generally limited by the availability of nitrogen in its forms that can be readily assimilated by marine phytoplankton. The processes that lead to the conversion of nitrogen into bio-available forms are complex and have been summarised schematically in the nitrogen cycle diagram below (Figure 2).

The bio-available forms of nitrogen (NH_4^+ and NO_3^-) required to stimulate marine phytoplankton growth are produced by the decay of organic matter and nitrogen fixing bacteria or cyano-bacteria (blue-green algae). At the Coorong ocean beaches the main sources of organic matter comprise phytoplankton, macro-algae and seagrass. As shown in Figure 1 primary production in the marine waters adjacent the Coorong is stimulated by nutrient sources including the Murray outflow, upwelling of deep ocean nutrient-rich water onto the shelf and coastal areas and recycling from deposition and decay of organic matter in the coastal zone. The discharge of water from the Coorong will provide an additional source of nitrogen (both in the inorganic and organic forms) to the coastal waters that could lead to enhanced algal growth within some distance of the discharge. The secondary processes of biological uptake followed by mortality, sedimentation, decay and release back into the water column is another mechanism that may result in enhanced algal growth for some period following the initial discharge of nutrient rich water to the ocean.

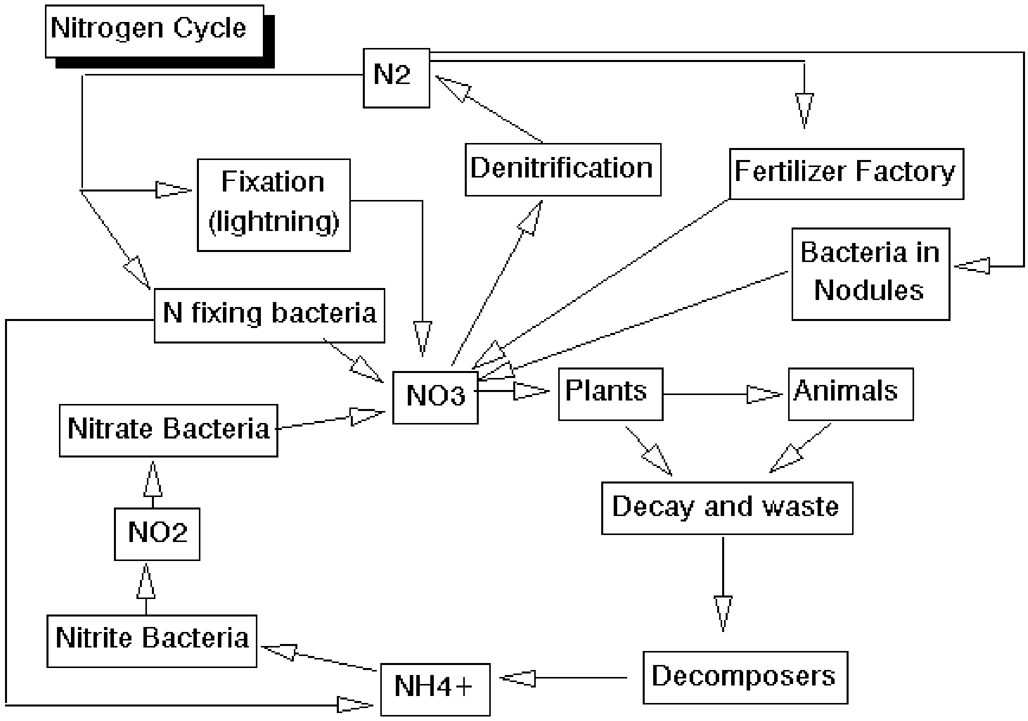


Figure 2 The nitrogen cycle (reproduced from Environmental Biology Sequence - Ecosystems www.marietta.edu/~biol/102/ecosystem.html).

ANZECC Water quality trigger values for Estuarine and Marine Waters

The ANZECC guidelines (2000) for the protection of slightly disturbed estuarine and marine waters of South Central Australian, low rainfall areas are reproduced in Table 1 below. The guidelines recommend that where available local data be used to define more appropriate trigger values. The guidelines also suggest that higher values are likely to occur in near shore coastal waters. The South Australian Environmental Protection Authority (SA EPA) lists water quality criteria for achieving or maintaining a designated environmental value (EPA 2003). The values listed for protecting marine aquatic ecosystems are provided in Table 1. These values will be compared with available data to provide an assessment as to the status of the existing system and likely nutrient status following introduction of the proposed discharge.

Table 1 Default trigger values for physical and chemical stressors for south-east Australia for slightly disturbed ecosystems. Trigger values are used to assess risk of adverse effects due to nutrients, biodegradable organic matter and pH in various ecosystem types. Data derived from trigger values supplied by South Australia. Chl *a* = chlorophyll-*a*, TP = total phosphorus, FRP = filterable reactive phosphate, TN = total nitrogen, NOx = oxides of nitrogen, $NH4^{+}$ = ammonium, DO = dissolved oxygen.

	Chl a	TP	FRP	TN	NOx	NH4+	DO (% saturation)		pH	
	µg /L	µg P /L	µg P /L	µg N /L	µg N /L	µg N /L	Lower limit	Upper limit	Lower limit	Upper limit
ANZECC	1	100	10	1000	50	50	No data	No data	8.0	8.5
SA EPA	-	500	100	5000	200	-	>6 mg/L		-	-

Water quality concentrations in Marine Waters off Younghusband Peninsula

Investigations of the marine ecosystem in the ocean waters offshore the Coorong were carried out in 2005 for the SA MDB NRM Board (Haig *et al*, 2006) to assist with providing information on the environmental assets of the Coorong Marine Bioregion. Samples were collected in 5 to 20 m water depth from waters offshore the Coorong between Cape Jaffa in the southeast and Victor Harbour. The results indicated a maxima in Chlorophyll-*a* near the Murray mouth of about 2.5 μg Chl-*a*/L decreasing both northward and southward of this location. Near the proposed discharge location typical values of between 0.7 and 1 μg Chl-*a*/L were found. Total nitrogen concentrations generally decreased towards the southeast from around 120 μg N/L near the Murray mouth to around 80 μg N/L near the proposed discharge site. Concentrations of ammonia and phosphate (1 μg N/L and 20 μg P/L, respectively) showed little variability with longshore distance.

Assuming it is appropriate to compare the ANZECC trigger values for filtered reactive phosphorus and ammonium (NH_4^+) with the measured phosphate and ammonia concentrations then the measured concentrations are generally well below the ANZECC trigger levels for marine waters (offshore). The chlorophyll-*a* levels, however, show similar levels to the ANZECC guideline values and on occasion exceed the guidelines. This may be explained by the spatial distributions in the sources of nutrients from near-shore and Murray mouth areas that are assimilated by phytoplankton (thereby reducing concentrations of dissolved nutrients) and subsequent dispersion of the phytoplankton biomass to areas depauperate of nutrients. The data indicate an area where primary production is limited by nutrient availability.

The nutrient loads from the Murray Mouth to the ocean have been estimated recently by Brookes et al. (2009). They conducted an analysis of available data on nutrient inflows to the lower lakes, assimilation of nutrients within the lakes and export from the lower lakes (Alexandrina and Albert) to the ocean and to the Coorong. The average annual discharge from the Murray to the ocean is around 25 000 ML/day with significant interannual variability related to wet/dry and drought cycles. Total nitrogen and total phosphorus export loads from the Murray to the ocean for low and high Murray River inflow years are estimated as:

- 172 – 3245 Tonnes N/year and
- 94 – 540 Tonnes P/year.

In essence the loads from the lower lakes to the Coorong lakes are concentrated by the evaporation processes leading to higher concentration waters in the Coorong lakes. Under extended periods low or (as in recent years) no flow periods the Coorong lakes concentrations have increased beyond their natural variability.

Water quality concentrations in Coorong lake waters

Water sampling in the Coorong over the past 10 years has been summarized in Appendix A. The results indicate significant gradients along the Coorong lakes from the near the Murray mouth at the Tauwitchere site to the south eastern extremity as represented by results for the site at Policemans Pt (Tables 2 and 3). The Policemans Pt site provides a reasonable representation of the likely water quality near the intake for the proposed pumping system. Results indicate a mean total nitrogen concentration of 6000 μg N/L and total phosphorus of 260 μg P/L near the intake. Chlorophyll-*a* concentrations are significantly higher in the south lake with a mean value around 80 μg Chl *a*/L. The conductivity indicates the strong saline gradient increasing from 50 mS/cm, a typical seawater concentration near the Murray mouth to a hypersaline value around 120 mS/cm at Policemans Pt in the south lake due the strong evaporative effects.

Soluble phosphorus, ammonia nitrogen and oxidised nitrogen concentrations are similar at both the sites. Total phosphorus and total nitrogen concentrations are considerably higher in the south lake than near the Murray mouth due to the high organic components associated with the high phytoplankton biomass at the Policemans Pt site. This is indicated by the high chlorophyll-*a* concentrations that also comprise nitrogen and phosphorus that contribute to the total nutrient concentrations.

The loads of nutrients associated with the proposed discharge may be estimated by multiplying the Coorong discharge, Q = 250 ML/day, by the median nutrient concentrations. Assuming the pumps and discharge operate for the full 365 days per year and applying the above formula yields the following maximal annual nutrient loads estimates from the Coorong via the proposed pipe discharge:

- 520 Tonnes N/year and
- 23 Tonnes P/year.

These estimates are the maximal that could be exported assuming the pumps operate for the full 365 days per year and in addition assume the median nutrient concentrations will continue to persist after pumping commences. Both of these assumptions are conservative in that pump maintenance and operational constraints will require some shutdown periods. Further, the aim of the pumping system is to ultimately reduce the salt concentrations and this process will also lead to reductions in the nutrient concentrations. Hence the above estimates are considered to be conservative and somewhat higher than would likely occur.

Effectively the proposed discharge will redistribute the existing point source Murray River export load to a second point source some 70-80 km south to the proposed discharge location. In terms of the total combined Murray River and discharge pipe nutrient export to the ocean there will be little change in the long term and it is likely to less than historical loads from the Murray.

Table 2 Mean and median values of water quality variables at the Tauwitchere (near Murray Mouth) and Policemans Pt sites in the Coorong lakes.

	Conductivity (at 25 °C)	Turbidity	pH	Chlorophyll-*a*
	mS/cm	NTU	pH units	µg Chl *a*/L
Tauwitchere				
Mean	47.7	18.5	8.2	17.0
Median	50.0	5.2	8.2	11.1
Maximum	87.4	152.0	9.0	106.0
Policemans Pt				
Mean	121.5	12.0	8.0	78.8
Median	117.9	11.8	8.0	79.4
Maximum	163.0	20.5	8.5	134.7

Table 3 Mean and median values of water quality variables at the Tauwitchere (near Murray Mouth) and Policemans Pt sites in the Coorong lakes.

	Soluble Phosphorus	Total Phosphorus (Total as P)	Ammonia (as N)	Oxidised N (as N)	TKN (as N)	Total N
	µg P/L	µg P/L	µg N/L	µg N/L	µg N/L	µg N/L
Tauwitchere						
Mean	11	115	91	12	1063	1075
Median	7	76	48	6	775	780
Maximum	50	510	804	130	3400	3405
Policemans Pt						
Mean	13	264	88	12	6064	6076
Median	7	255	50	5	5735	5740
Maximum	50	532	343	167	14030	14035

Dilution

Results of the dispersion modelling (Aurecon 2009a) may be used to estimate the dilution of the discharge water with ambient marine water as a function of distance from the discharge source. Saline discharge dispersion modelling indicates when considering the 'worst case' scenario a dilution of 100 fold (~1 ppt excess salinity) occurs within about 2km of the source and the 3 ppt excess salinity (38 fold dilution) occurs within some 200 m of the discharge.

Assuming the nutrients may be treated as a passive tracer (like salt) then the concentrations at some distance, x, from the discharge may be estimated by the dilution formula:

$$C_x = \frac{C_d + D_x C_b}{D_x + 1}$$

where C_x, C_d and C_b are the nutrient concentrations at a distance x from the source, in the discharge (subscript d) and background (subscript b) ocean, D_x is the dilution at distance x from the source.

Passive tracer estimates of the concentrations at the 38 fold (<200m from the source) and 100 fold (< 2km from the source) are listed in Table 4.

Table 4 Estimates of nutrient concentrations dispersion assuming passive tracer dilution. Values for the background (ocean) concentrations from Haig *et al* (2006) and values in italics assumed. Values for source waters taken from the Policeman's Pt monitoring site concentrations.

		$C_{d(mean)}$	$C_{d\,(max)}$	C_b	$C_{x(mean)}$ (D_x=38)	$C_{x(max)}$ (D_x=38)	ANZECC Trigger	SA EPA Guideline
Salinity	ppt	150	150	36	39	39	-	-
Turbidity	NTU	12	20.5	30	29.5	29.8	10	-
pH	pH units	8.01	8.5	*8.1*	8.1	8.1	8 – 8.5	-
Chlorophyll-*a*	ug/L	79.0	134.7	1.0	3.0	4.4	1	-
Soluble phosphorus	ug/L	13	50	20	20	21	10	100
Total phosphorus	ug/L	264	532	*30*	*36*	43	100	500
Ammonia (As N)	ug/L	88	343	1	3	10	50	-
Oxidised N (As N)	ug/L	12	167	*5*	*5*	9	50	200
Tkn (As N)	ug/L	6064	14030	*20*	*175*	379	N/A	-
Total N (mg/L)	ug/L	6076	14035	80	234	438	1000	5000

These estimates indicate that the nutrient concentrations will rapidly disperse into the environment such that the ANZECC and SA EPA guideline trigger values for nutrients will be met within 200 m of the source for the mean and maximum discharge concentrations as indicated in Figure 3. As the soluble phosphorus concentration in the ocean already exceeds the ANZECC guideline it is suggested that the ANZECC trigger value is not appropriate to this area.

Figure 3 Approximate locations of the inlet and discharge points and the 200 m radius indicating approximate extent of the 38-fold dilution.

The chlorophyll-*a* concentrations in the source waters are comprised of phytoplankton species likely to be adapted to the hypersaline conditions. It is unlikely that these species will survive firstly; the passage through the pumping system in which algal cells will be exposed to vigorous turbulence and a rapid pressure increase (~25 m head of water) and; secondly as high salinity tolerant species they will be exposed to lower salinity marine waters and as such are likely to denature, suffer cell damage and eventually settle to the sea bed.

Discussion

Salt tolerant phytoplankton from the Coorong waters are not likely to survive through the discharge pipe and subsequent rapid exposure (shock) to lower salinity ocean waters. Phytoplankton biomass as indicated by the chlorophyll-*a* concentrations of Coorong waters are therefore likely to contribute to the organic nitrogen pool in the coastal waters through the process of die-off, settling, decay and release of previously bound nitrogen.

The pathway of nutrient enrichment is likely to be through the decay of organic nitrogen at the bed and under the right conditions release to the water column becoming available to stimulate localised enhanced algal growth. However, the modelling results indicate that the nutrient concentrations will rapidly disperse into the environment such that the ANZECC and SA EPA guideline trigger values for nutrients will be met within 200 m of the source for the mean and maximum discharge concentrations.

The nutrient loads to the ocean from the combined Murray mouth and proposed Coorong discharge will not increase beyond the historic loads from the Murray mouth. In the short term, the redistribution of loads from the introduction of another discharge location some 70-80 south of the Murray mouth may lead to localised effects within a short distance of the discharge.

The current species composition of the near-shore phytoplankton biomass is not well documented. It is known that some species of blue-green algae occur within these waters but their possible effects on the higher order filter feeders such as cockles are equally unknown. The locally enhanced availability of nutrients associated with the discharge may stimulate blooms of algae of a variety of species, including the possibility of harmful species. As the historic loads from the Murray mouth are not known to have stimulated harmful algal blooms it is suggested that the redistribution of the total ocean load to the combined Murray mouth and the proposed discharge location will have similar effect on the ocean waters off the Coorong.

While it is not possible to quantify the processes in a predictive sense nor the probability of occurrence of a harmful algal bloom that may be attributed to the discharge as opposed to a natural occurrence, it is suggested that a precautionary approach be adopted. It is recommended that algal species be monitored and results provide feedback to the pumping program. The proposed monitoring and feedback process is viewed to provide sufficient management tool to mitigate any adverse conditions. This monitoring could incorporate the chlorophyll-*a* satellite processing capability available within the DEH as a first stage to identifying potential bloom conditions that would trigger more detailed sampling of waters around the discharge site.

References

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Yours sincerely

DCvan Senden

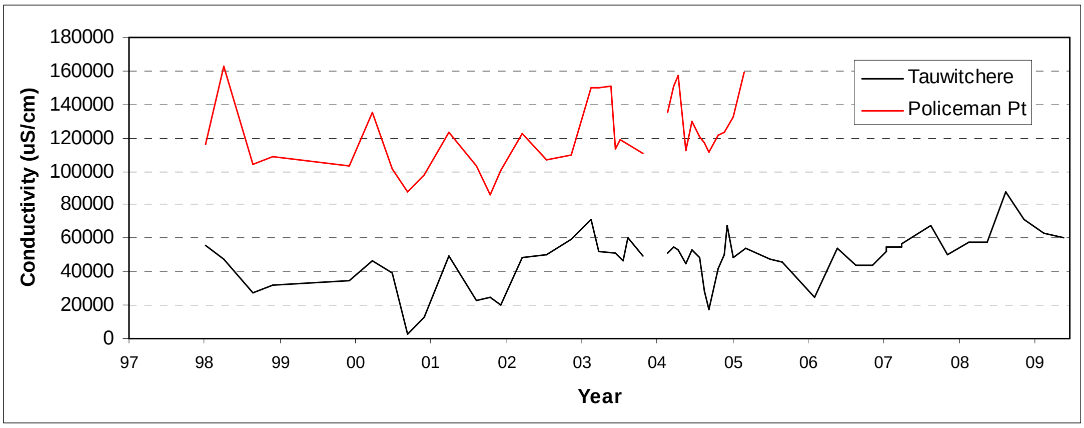
David van Senden
Executive Water
Ph: (02) 9465 5431
Email: vanSendenD@ap.aurecongroup.com

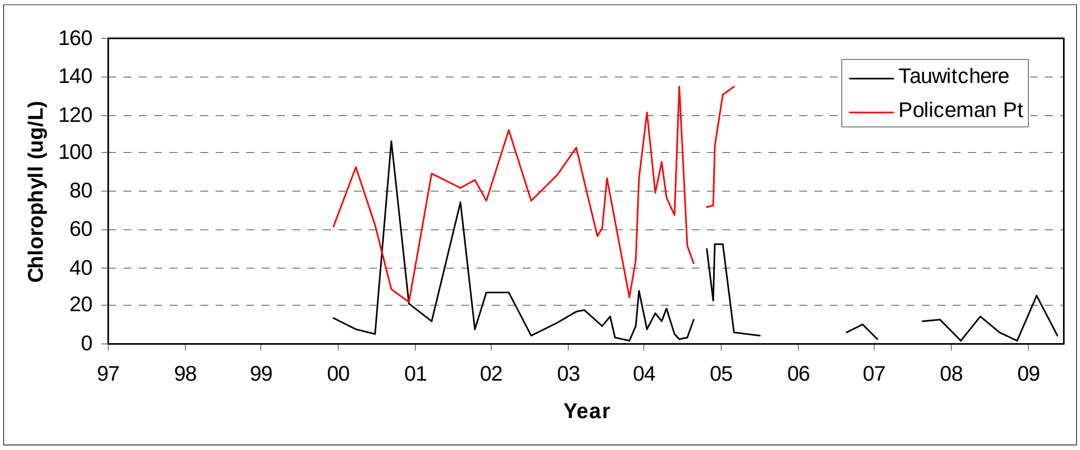
Appendix A

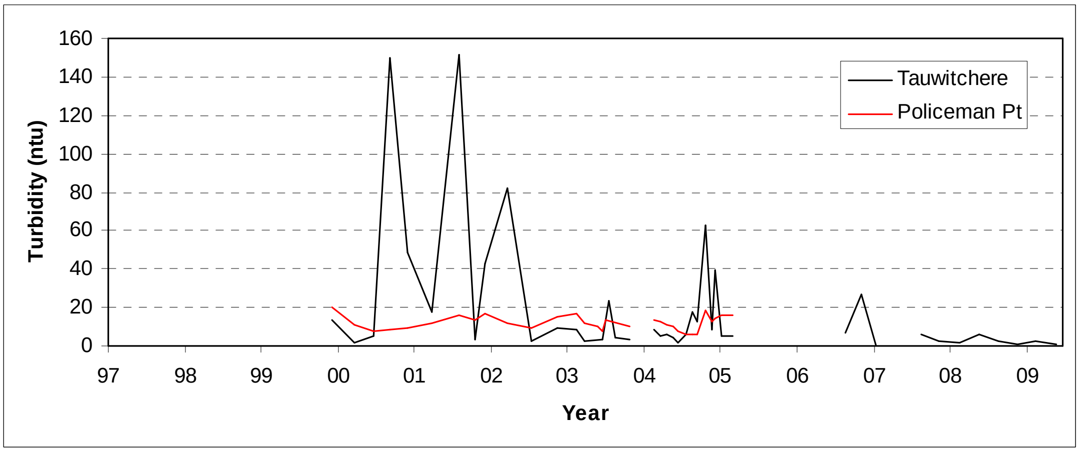
Coorong Water Quality Data (Provided by SA NRM Board.) Sites located near Murray mouth.

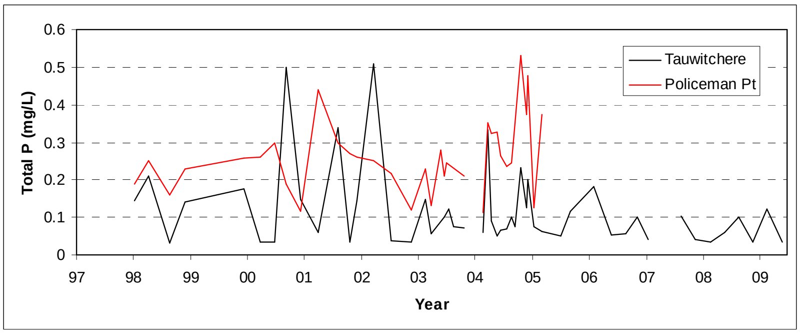
	Ammonia	Chlorophyll-a	Conductivity	Oxidised N	Ph	Phosphorus	Phosphorus	TKN	Total N	Turbidity
	(As N) mg/L	ug/L	(25c) uS/cm	(As N) mg/L	pH units	(Sol As P) mg/L	(Total As P) mg/L	(As N) mg/L	mg/L	NTU
Tauwitchere	Data from 7-Jan-98 to 1-Jun-09									
Number of Samples	52	46	54	52	54	52	52	52	52	44
Number of Non-Detect	19	0	0	21	0	21	1	1		0
Mean	0.091	17.0	47.7	0.012	8.191	0.011	0.115	1.063	1.1	18.5
Median	0.048	11.1	50.0	0.006	8.210	0.007	0.076	0.775	0.8	5.2
Policemans Pt	Data from 7-Jan-98 to 7-Mar-05									
Number of Samples	36	33	36	36	36	36	36	36	36	32
Number of Non-Detect	14	0	0	32	0	19	0	0		0
Mean	0.088	78.8	121.5	0.012	8.006	0.013	0.264	6.064	6.1	12.0
Median	0.050	79.4	117.9	0.005	8.005	0.007	0.255	5.735	5.7	11.8

Figures showing the monthly measurements at Tauwitchere and Policeman Point.

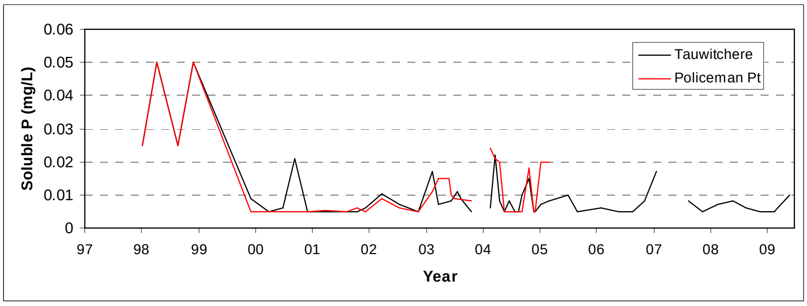




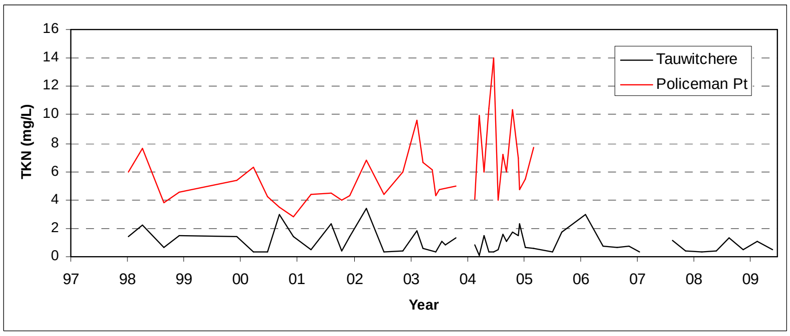




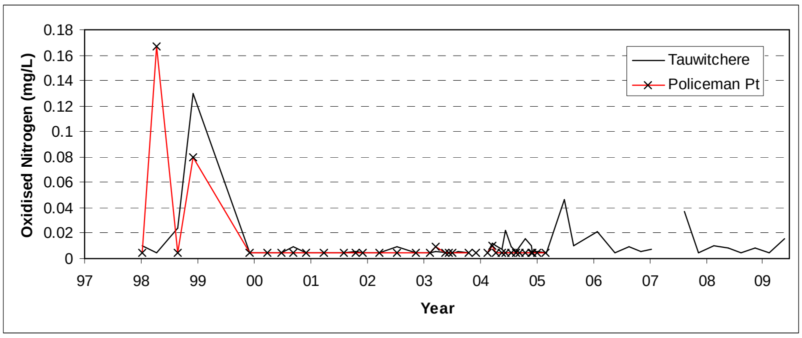
Total P (mg/L)
Year
Tauwitchere
Policeman Pt



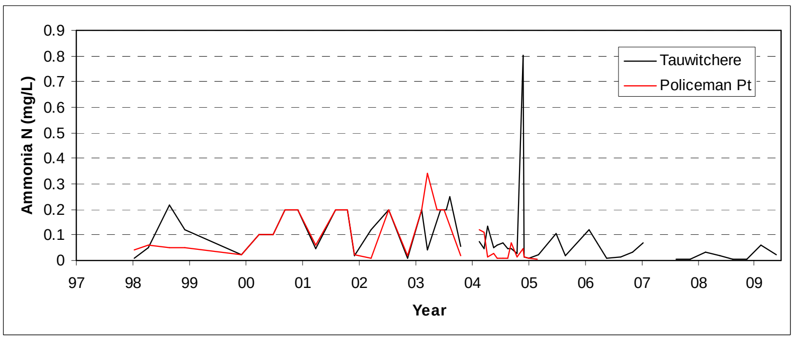
Soluble P (mg/L)
Year
Tauwitchere
Policeman Pt



TKN (mg/L)
Year
Tauwitchere
Policeman Pt



Oxidised Nitrogen (mg/L)
Year
Tauwitchere
Policeman Pt



Ammonia N (mg/L)
Year
Tauwitchere
Policeman Pt