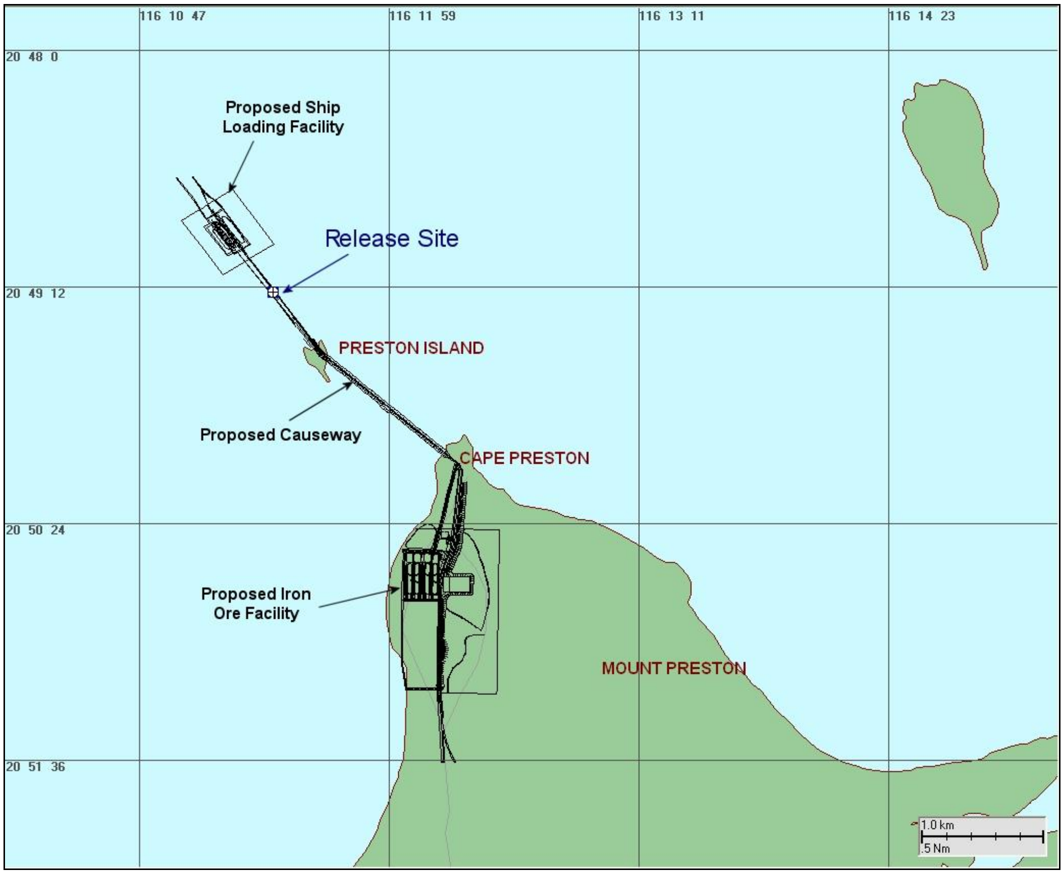
BRINE DISCHARGE MODELLING AT CAPE PRESTON, WESTERN AUSTRALIA



Prepared for:

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1 EXECUTIVE SUMMARY

As part of the proposed International Minerals Pty Ltd (IM) iron ore pellets and iron ore concentrate processing facility at Cape Preston, IM proposes to draw sea water to feed a Desalination plant. The brine water from the IM facility would then be discharged collectively with brine from the adjacent Mineralogy Desalination facility. The discharged stream is expected to be approximately two (2) degrees hotter than the receiving waters and have a salinity of 64ppt (compared with an average of approximately 35.4ppt for the receiving waters). The combined discharge rate is $2.51 m^3/s$, which would be discharged through a 0.9m diameter vertical pipe immediately below the water surface.

To determine the area of effect of the plume, in terms of the salinity anomaly and the chlorine concentrations within the nearby receiving waters, Maunsell Australia (Maunsell) on behalf of IM, commissioned Asia – Pacific Applied Science Associates (APASA) to quantify the likely mixing and dilution of the brine plume using computational simulation techniques.

To carry out this investigation, a validated 3-dimensional plume model (the OOC model) was used to track the dynamics of the salinity anomaly created by the discharged brine water plume and the dilution of sodium hypochlorite (chlorine) concentrations within the plume. Inputs to the OOC model included the intended brine water discharge configurations, local current data and the vertical salinity and temperature structure of the receiving waters. The assessment examined dilution rates and plume behaviour under strong current conditions (being the influence to tides and local winds).

Overall, the OOC model simulations indicated that the plume will tend to sink, chiefly due to the higher density of the discharge relative to the ambient water. Because the plume will be concentrated in the benthic layer, transport is predicted to be primarily due to tidal currents. Hence the plume axis is expected to align with the northeast/southwest with the tidal axis. The initial plunge phase of the discharged plume of the discharged plume is predicted to achieve rapid cooling and dilution rates of at least 10 times within a 5m radial distance, so that salinity should not exceed 42ppt beyond this distance (a change of 22ppt relative to the initial discharge). Further dilution to ambient salinity is predicted to occur over distances of up to 55m radially on either side of the source. Because the tidal ellipse in this area is relatively narrow (i.e. tides do not circle widely) the mixing zone is expected to be relatively narrow (<10m lateral to the tidal axis). Thus the mixing zone is expected to occupy approximately 1000m^2. Allowing for a doubling of the tidal excursion and lateral spread (to account for currents stronger than those represented in the sample conditions as a safety factor), a mixing zone of 4000m^2 would be indicated. Consequently, the mixing zone should not exceed 1ha (10,000m^2), being the compliance threshold for the impact zone, given the specified discharge characteristics.

2 INTRODUCTION

International Minerals Pty Ltd (IM) is developing a facility to process iron ore pellets and iron ore concentrate at Cape Preston, approximately 80 km south of Dampier. IM intends to establish the project on a Greenfield site adjacent to a large magnetite body owned by Mineralogy Pty Ltd (Mineralogy), a sister company of International Minerals.

It is proposed that the International Minerals and Mineralogy seawater intake systems will be located along the jetty at Cape Preston and will provide sufficient seawater feed for the Desalination plants. The brine stream outlet shall be nominally located at the end of the Wharf at Cape Preston (see Table 1; Figure1), northwest of Preston Island.

Current design specifications indicate brine would be discharged at 2.51m^3/sec (1.83m^3/sec from the Mineralogy facility and 0.68m^3/sec from the International Minerals facility) as a continuous discharge. The brine is assumed to be approximately two (2) degrees hotter than the receiving waters and have a salinity of 64ppt (compared with an average of approximately 35.4ppt for the receiving waters). It has also been proposed that the brine stream will be chlorinated (using sodium hypochlorite) to control algae and biofouling. It was estimated that the free residual chlorine concentration in the brine will be approximately 0.5ppm at discharge.

To quantify the mixing, cooling and dispersion of the discharged brine, Maunsell Australia (on behalf of International Minerals) commissioned Asia-Pacific Applied Science Associates (APASA) to carry out a detailed modelling study using a validated three dimensional discharge model (the OOC model). The main objectives of the study are to:

1. Model the mixing and dispersion of the brine plume under the influence of strong current conditions; and
2. Estimate the extent and shape of the mixing zones set up by the salinity anomaly and the chlorine concentrations.

The findings from the study will assist in understanding the mixing zones set up by the brine discharge.

Table 1: Assumed location of the brine release

Latitude and Longitude	Average Depth of Water (m)
20° 49' 13.4" South 116° 11' 26.8" East	10

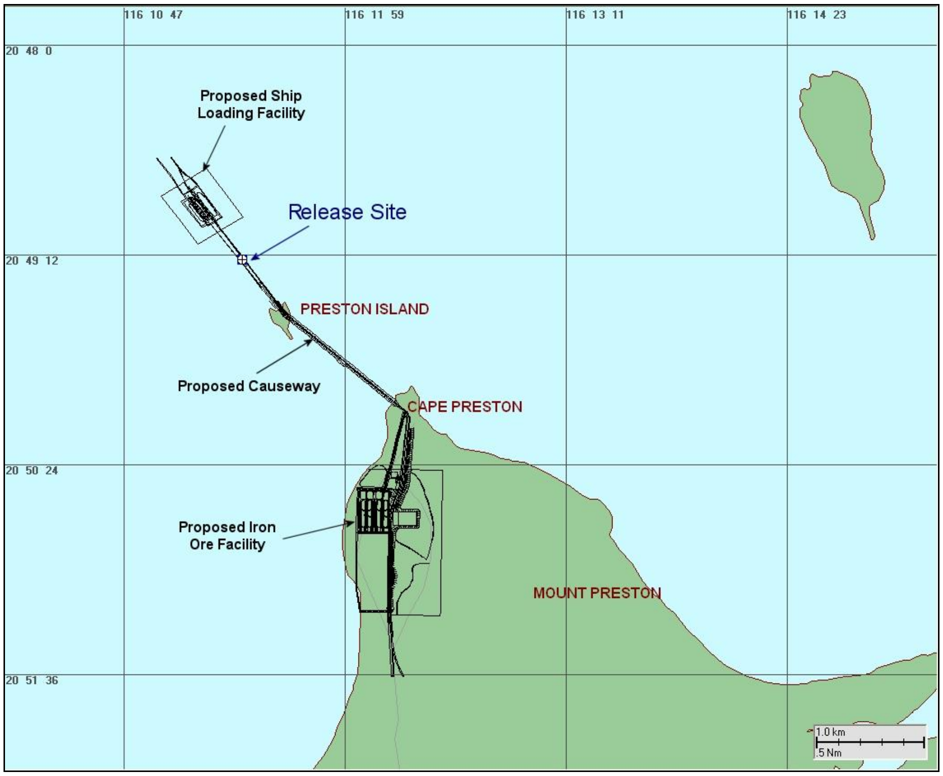


Figure 1: Map showing the proposed brine discharge site (denoted by the blue circle) at Cape Preston, Western Australia.

3 METHODOLOGY

To simulate the mixing, cooling and dispersion of the discharged brine plume, two important processes were considered. Firstly, the hydrodynamics of the receiving waters were generated using a validated hydrodynamic model for the region. Secondly, the generated current data was used as input into a discharge and plume behaviour model, OOC (Offshore Operators Committee), to determine the extent and shape of the discharged brine plume. A description of the environmental data and the OOC model are described in the following sections.

4 ENVIRONMENTAL DATA

The receiving waters are described in terms of current speed and direction, ambient salinity and water temperature profiles. The following sections describe the environmental data used as part of the modelling study.

5 CURRENT DATA

Hydrodynamics of the receiving waters was generated as part of an earlier study using a 3-dimensional circulation model, BFHYDRO (APASA 2004). Data were in the form of a spatial current field for wind and tidal forcing. Figure 2 shows the predicted current speeds at the proposed release site during January 2004 based on derived tidal data and winds measured at Karratha.

Out of the available month-long current data, a 3 ½ day window (22nd – 26th January, 2004) was selected on the basis of the strongest current data observed in the hydrodynamic dataset (see Figure 3) and will produce the maximum transport away from the discharge point, hence quantifying the maximum extent of the mixing zone in the horizontal.

Figure 3 indicates that the major axis of the currents runs approximately north-east to south-west in line with the tides. The wind stress had a marginal influence on the current direction and speed. The average and maximum predicted current speeds for selected dataset were 0.22m/s and 0.42m/s respectively.

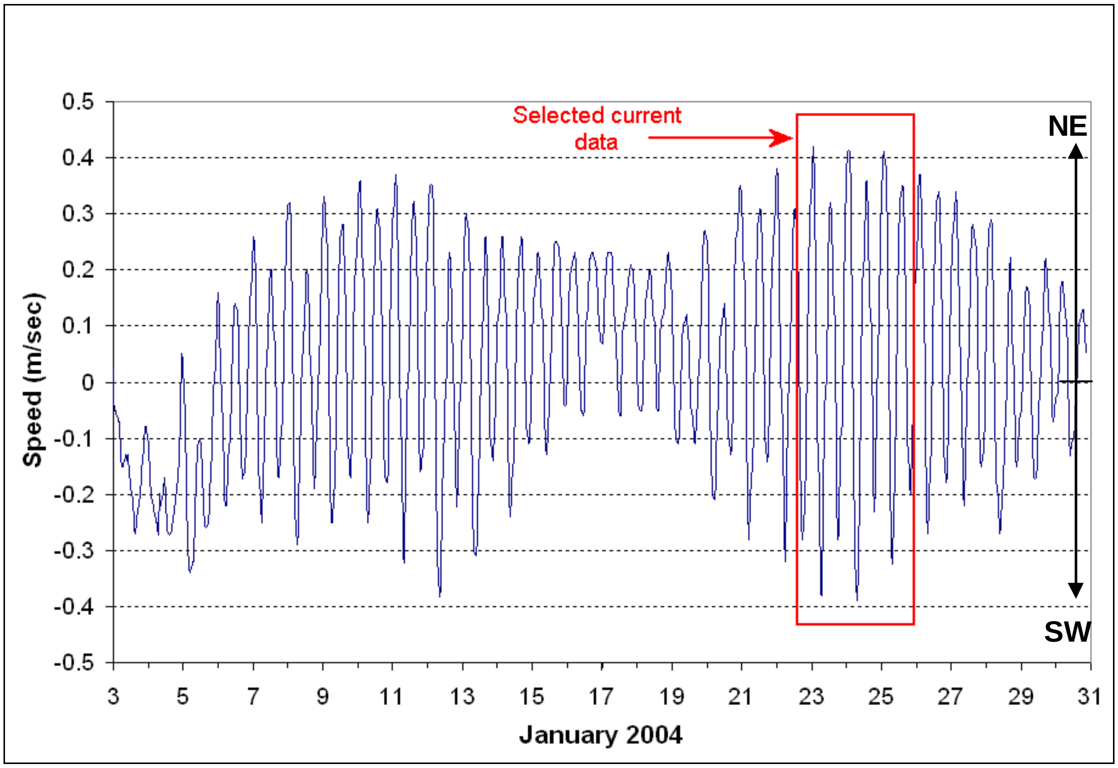


Figure 2: Predicted current velocity relative to the tidal axis at the proposed release site for January 2004.

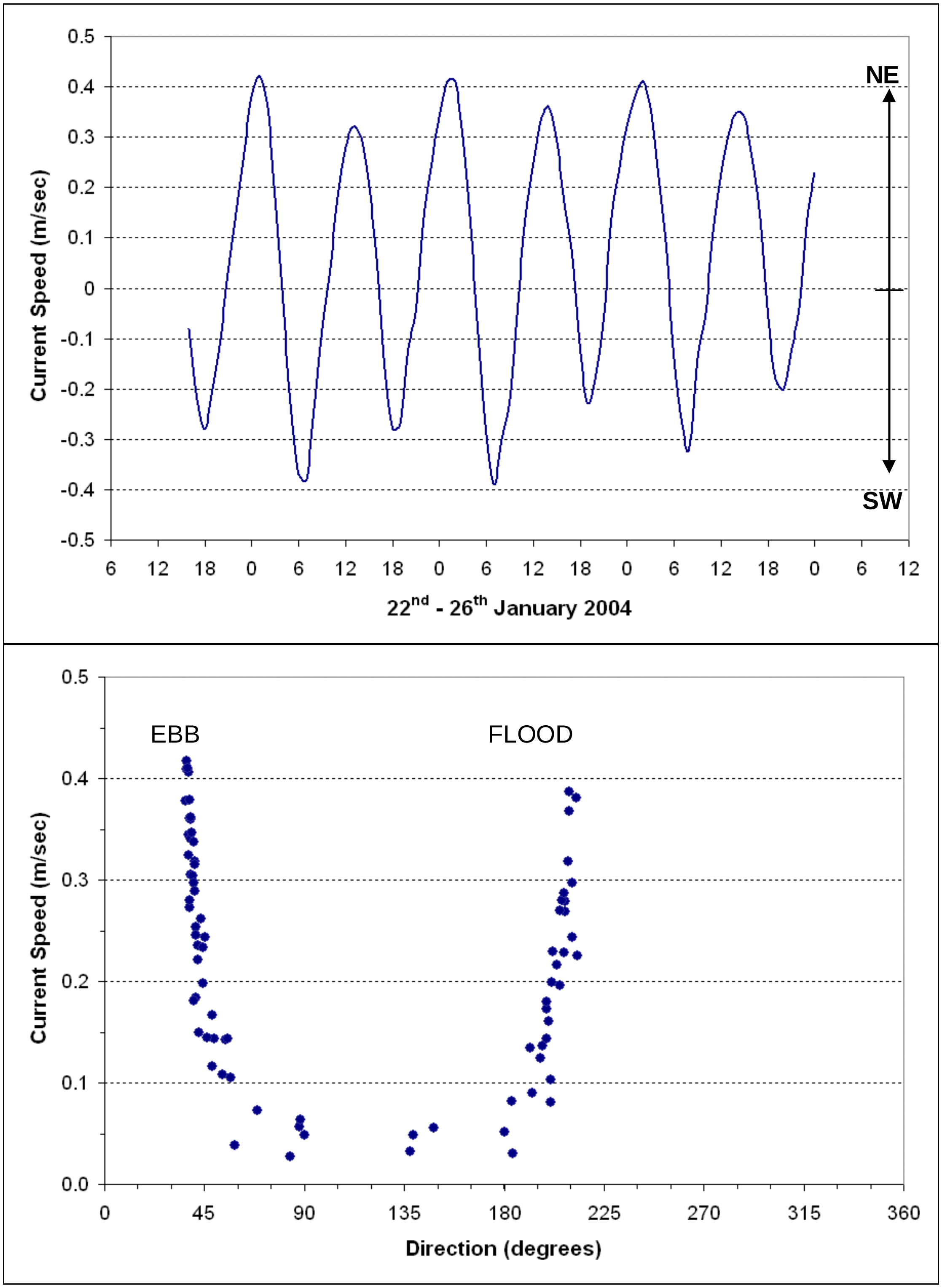


Figure 3: Data plots showing (a) speed versus time plot and (bottom) speed versus direction scatter plot for the predicted currents between 22nd – 26th January 2004, used as input into the dispersion model.

6 HYDROGRAPHIC DATA

Salinity profiled for 7 sites at Cape Preston in November 2002 ranged from 35.42 to 36.48ppt and 9 sites in 2004 ranged from 35.44 to 36.05ppt D. A. Lord (DAL) recorded salinities ranging from 35.40 to 35.44ppt in February 2000. The annual range for area is therefore 35.4 to 36.5ppt.

For the study site, DAL measured temperatures in February 2000 ranging from 29.52 to 30.90ºC. The water column appeared to be relatively well mixed throughout the region with temperatures rarely varying more than 0.1ºC (maximum temperature variation less than 1ºC) from surface to bottom at any one site.

As an input into the dispersion model the ambient salinity and temperature was set to 35.4ppt and 29.5^{o}C, respectively, being “worst case” of the known range.

7 DISPERSION MODEL

The mixing and dispersion of the brine discharge was predicted using the OOC Model, which is a three-dimensional discharge and plume behaviour model that calculates the fate of discharges in both the near-field (immediate discharge zone) and far-field (wider region).

The OOC model has been carefully selected due to its suitability to addressing the complexities of this study. This model is specifically designed for simulating and quantifying the dispersion of discharges of heated and hypersaline water into tidal systems from industry operations and has been applied and validated in many areas around the world including the Gulf of Mexico, the North Sea (Terrens and Tait, 1994) and for Bass Strait platforms such as the Halibut platform (Terrens and Tait, 1996) and the Kingfish B platform (King and McAllister, 1998).

The OOC model predicts the transport and dispersion of the discharged material through three independent, but integrated stages. The stages are:

Stage 1: **The dynamic buoyancy jet phase -** which predicts the initial dilution and spreading of the discharged brine water in the immediate vicinity of the release location.

Stage 2: **The dynamic collapse phase** - which estimates the growth and dilution of the release cloud, if it either impacts the surface or bottom or becomes trapped by a strong density gradient in the water column.

Stage 3: **The dispersive phase** - where the model predicts the 3-D motion and dispersion of the discharged brine water caused by the local current system.

Investigating the mixing due to these three stages is necessary because each process occurs at different time scales. The governing equations and methodology of the OOC model were built on the formulation originally developed by Koh and Chang (1973) and extended by the work of Brandsma and Smith (1995), Smith *et al*., (1994), and Brandsma and Sauer (1983) for the convective phase (stage 1) and dynamic collapse phase (stage 2) of plume motion.

7.1 Input Data

The OOC model requires quantitative data to describe the characteristics of the discharge and the receiving water as well as hydrodynamic data for the receiving waters. Input to the model included:

1. The total daily volume and rate of discharge of the brine water;
2. The temperature and salinity of the brine and the receiving waters;
3. The depth, size and orientation of the discharge pipe;
4. Hydrodynamic data to represent local physical forcing; and
5. The concentration of the chlorine within the brine before discharge;

Reports by D.A. Lord & Associates (2000) and WA EPA (2002) and Maunsell provided detailed information on the anticipated composition of the brine water and the potential volume that would be released (see Table 2). These details were used to configure the hypersaline-plume module of the OOC model. A combined discharge rate of 2.51m^3/sec was defined for the total brine water output, through one outlet pipe. Further since the release depth was unknown, two potential discharge scenarios were examined:

Scenario A: Discharge down a vertical pipe just below the water surface; &
Scenario B: Discharge down a vertical pipe 5 m above the water surface.

A report by D.A. Lord & Associates (2000) proposed that a maximum velocity at the water intake point of 1 m/s was the same discharge velocity assumed for the outlet pipe for Scenario A. However, a lower discharge velocity (approx. 25%) was used for Scenario B, to account for the spread of the plume as it falls through the air and a loss of velocity as it strikes the water surface.

The brine was assumed be about 2^{o}C higher in temperature than ambient (typically 29.3^{o}C during January) and have a salinity of 64 parts per thousand (compared with about 35.4ppt for seawater). Thus, on release, the density of the brine plume would be about 1043.2kg/m^3, which is significantly more dense than the receiving water (typically 1022.7kg/m^3). Hence, it was anticipated that in the initial stages, the higher density of the brine discharge will cause the plume to plunge under the receiving waters and spread as a gravity current.

Table 2 shows a summary of the discharge settings used by the OOC model hypersaline plume module to represent the brine water discharge.

Table 2: Summary of settings used to describe the discharge characteristics of the brine discharge.

Discharge rate	2.51 m^3/sec
Velocity	1 m/s
Period of discharge	Continuous
Orientation of discharge pipe	Downwards
Pipe diameter	0.9 m
Depth of the discharge pipe:	
Scenario A	Near surface
Scenario B	5 m above water surface
Salinity of brine discharge	64 ppt
Temperature of brine discharge	31.2^{o}C
Concentration of chlorine within the brine water	0.5 ppm
Salinity of receiving water	36 ppt
Temperature of receiving water	29.3^{o}C

8 MODEL PREDICTIONS AND RESULTS

The mixing and dispersion of the brine discharge were carried for two discharge configurations: (a) below the water surface; & (b) 5-metres above the water surface. Modelling indicated a marginal difference in the extent, shape and direction of the brine plume resulting from each of the two scenarios. The maximum horizontal distance the brine plume travelled was 54m when discharged below the surface, and 49m when discharged above the surface. This indicates that the chief mechanism for sinking and mixing is the density difference between the discharge and the receiving water, while the velocity of the discharge has limited effect. Consequently, the results presented herein will be based on just one of the discharge scenarios; the discharge below the water surface, which is considered a reasonable representation for both cases.

Table 3 shows the brine plume characteristics for the time step when the maximum migration was predicted. Note the values are shown for the plume centerline.

The model indicated that due to the density differences between the brine and receiving water, the brine plume would collapse to the bottom of the seabed. As the plume is collapsing it is creating a turbulent mixing zone and entraining the receiving waters. Once the plume has collapsed and reached the bottom (approximately 5m in the horizontal) the plume has entrained 4 times its volume of ambient waters during this process. This dilution with ambient waters at 35.4ppt ensured that the salinity of the brine water had reduced to 38.7°C and a predicted chlorine concentration of 0.12ppm by this stage.

Furthermore, the model predicted that the currents would advect the plume, causing it to continually mixing with the ambient waters, though at a slower rate than the downward plunge phase. Figures 4 shows the size and shape of the brine plume for the time step when the maximum migration was predicted.

Table 3: Predictions for the distribution of chlorine, temperature and salinity in the brine plume under peak spring tidal flows (plume centerline values shown).

Distance South (m)	Distance West (m)	Maximum Horizontal Distance (m)	Plunge depth (m)	Chlorine Concentration (ppm)	Temperature (°C)	Salinity (ppt)
0.0	0.0	0.0	-0.4	0.50	31.3	64.0
0.0	0.0	0.0	-0.9	0.48	31.1	60.6
0.0	0.0	0.1	-1.3	0.45	30.9	58.0
-0.1	-0.1	0.1	-1.8	0.42	30.7	55.5
-0.1	-0.1	0.2	-1.9	0.39	30.7	54.9
-0.4	-0.6	0.7	-3.8	0.36	30.2	47.9
-0.6	-0.8	1.0	-4.4	0.31	30.1	46.1
-1.2	-1.6	2.0	-6.1	0.22	29.8	42.7
-1.8	-2.4	3.0	-7.2	0.13	29.5	39.3
-2.4	-3.2	4.0	-7.6	0.12	29.5	38.8
-3.1	-4.1	5.1	-7.8	0.12	29.5	38.7
-9.2	-12.1	15.2	-8.3	0.10	29.4	38.2
-10.0	-13.3	16.6	-8.3	0.10	29.4	38.1
-11.2	-14.8	18.6	-8.3	0.09	29.4	37.9
-11.8	-15.6	19.6	-8.3	0.09	29.4	37.8
-12.4	-16.4	20.6	-8.3	0.09	29.4	37.6
-13.0	-17.2	21.5	-8.3	0.08	29.4	37.5
-13.6	-18.0	22.5	-8.3	0.08	29.4	37.4
-14.2	-18.7	23.5	-8.3	0.08	29.4	37.3
-14.9	-19.7	24.7	-8.3	0.07	29.4	37.1
-15.6	-20.7	25.9	-8.3	0.07	29.3	37.0
-18.6	-24.6	30.8	-8.2	0.06	29.3	36.5
-19.3	-25.5	32.0	-8.2	0.05	29.3	36.4
-21.5	-28.4	35.7	-8.1	0.05	29.3	36.2
-22.3	-29.4	36.9	-8.1	0.04	29.3	36.1
-23.0	-30.4	38.1	-8.0	0.04	29.3	36.0
-23.7	-31.4	39.3	-8.0	0.04	29.2	35.9
-24.5	-32.3	40.5	-8.0	0.04	29.2	35.9
-25.2	-33.3	41.8	-8.0	0.04	29.2	35.8
-25.9	-34.3	43.0	-7.9	0.04	29.2	35.8
-28.2	-37.2	46.6	-7.9	0.03	29.2	35.6
-29.5	-39.0	48.9	-7.9	0.03	29.2	35.6
-31.0	-41.0	51.4	-7.9	0.02	29.2	35.6
-31.8	-42.0	52.7	-7.9	0.02	29.2	35.5

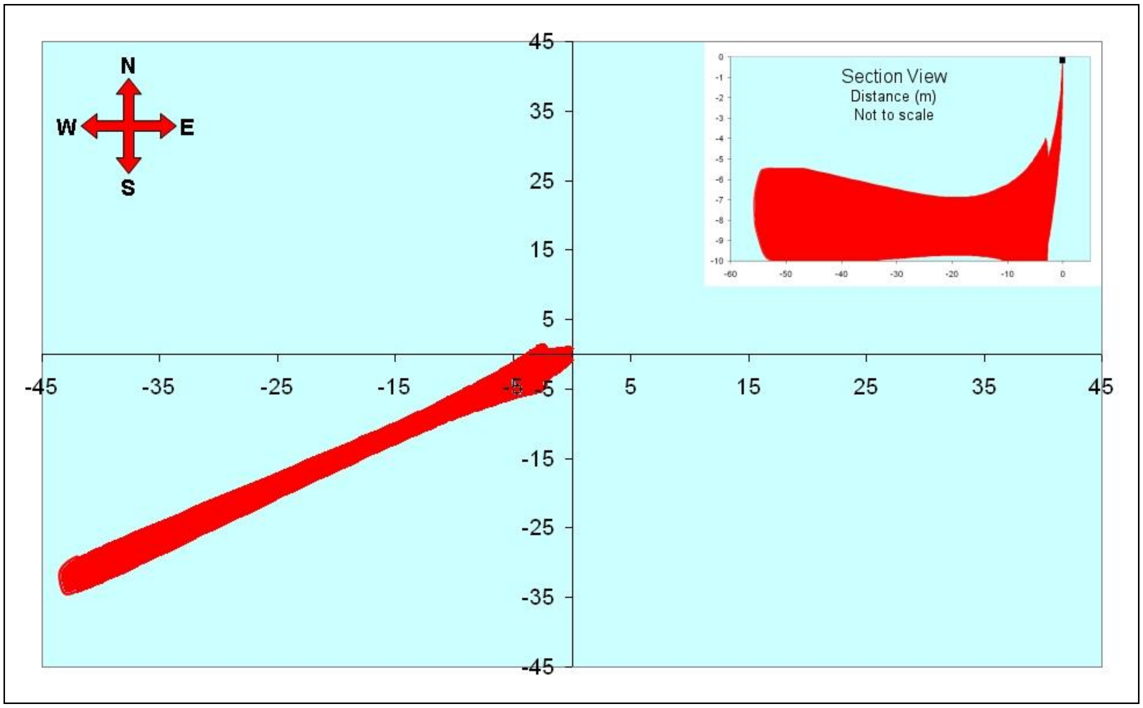


Figure 4: Predictions for the size and shape for the time step when the maximum migration was predicted under a strong currentt. Main figure shows a plan view. Inset shows a cross-sectional view.

Figure 5 shows a scatter plot of the expected salinity anomalies as a function of radial distance from the release location for each of the 80 individual simulations under strong current conditions. The results suggest that the salinity concentrations would decrease rapidly (to within 43ppt of ambient within 5m) on initial mixing with the receiving waters. Further, based on the present planned discharge characteristics, the salinity concentration was predicted to dilute to within 1ppt above ambient (35.4ppt) approximately 40m from the release site. However, the saline water from the discharge is expected to continue mixing with receiving waters and reduce to within 0.3ppt (approximately 1%) above ambient, 55m from the discharge site. Hence, the salinity variation should be no greater than five percent above the ambient level for more than one percent of the time anywhere around Cape Preston (except within the proposed Moderate Protection Mixing Zone – 1 ha).

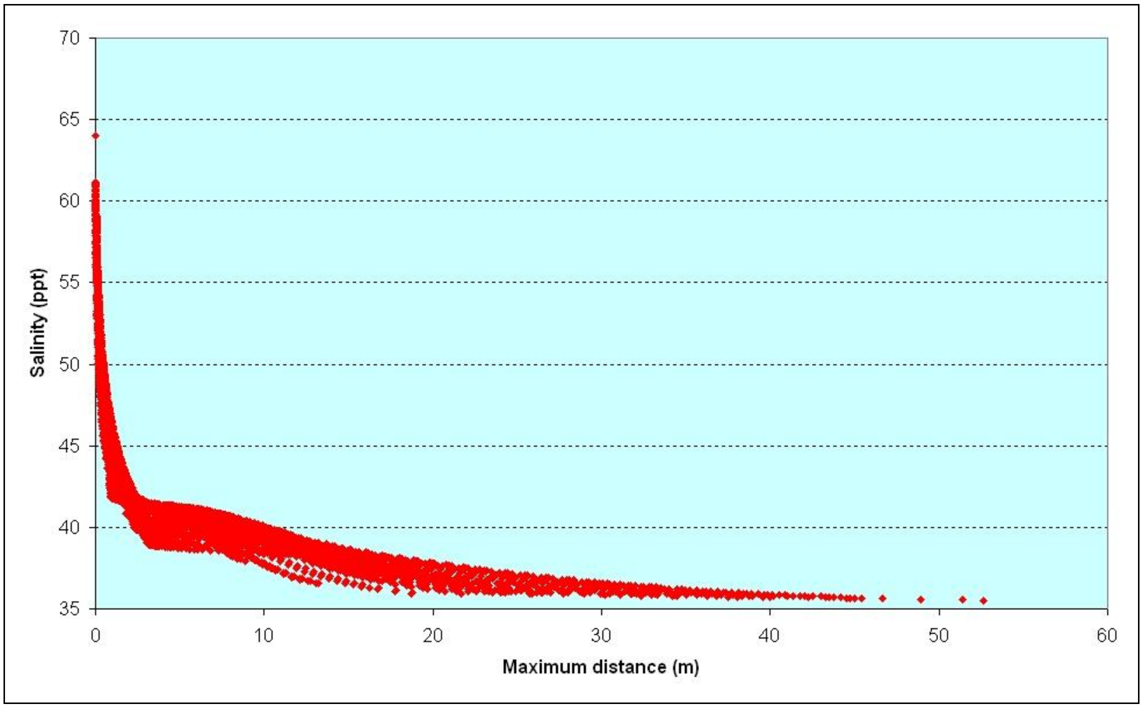


Figure 5: Scatter plot of the salinity anomaly as a function of radial distance from the release. Predictions are from 80 independent subsurface simulations.

Figure 6 shows a scatter plot of chlorine concentration as a function of radial distance from the release location under varying conditions. Chlorine concentrations were expected to drop to 0.1ppm within 20m of the discharge site. This indicates that the most rapid dilution should occur during the initial mixing phase and that slower dilution rates would occur as plumes are transported and dispersed by local currents. However, maximum excursion distances required to achieve dilution from this concentration to below the ANZECC (2000) guideline concentration of 40ppb (0.04ppm) were up to 55m.

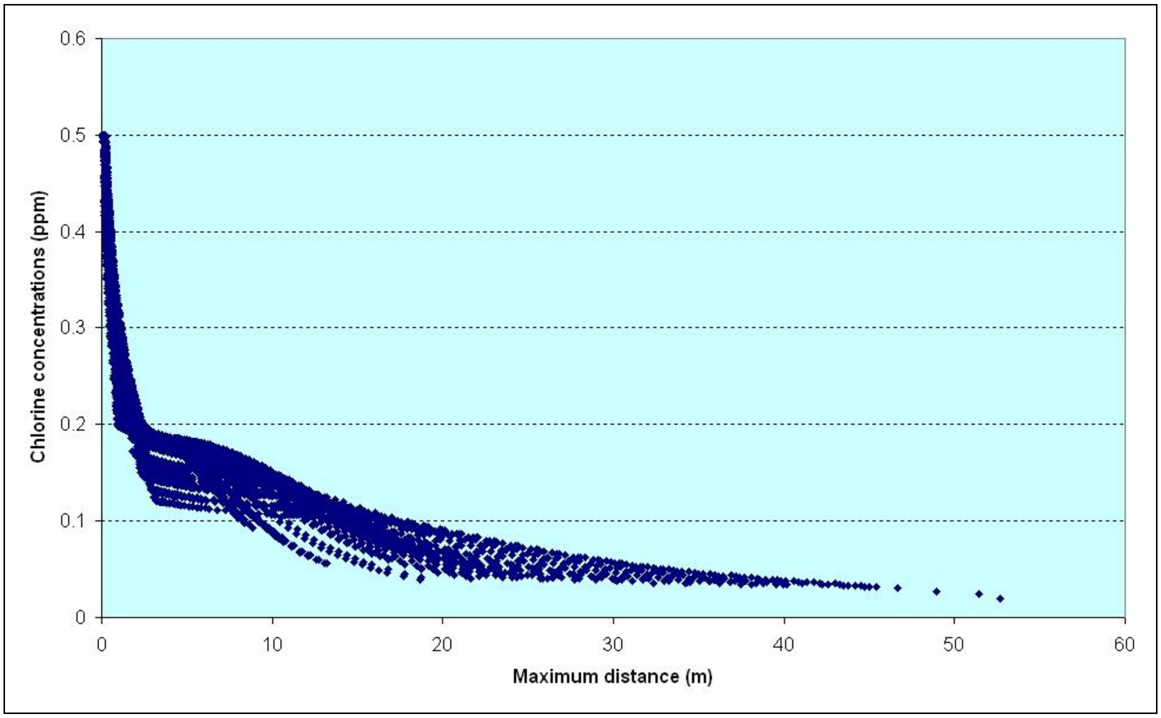


Figure 6: Scatter plot of the chlorine anomaly as a function of radial distance from the release. Predictions are from 80 independent subsurface simulations.

Finally, since the plume will be concentrated in the benthic layer, transport is predicted to be primarily due to tidal currents. Hence the plume axis is expected to align with the NE-SW tidal axis. The initial plunge phase is predicted to achieve rapid cooling and dilution rates of at least 10 times within a 5m radial distance, so that salinity should not exceed 42ppt beyond this distance (changes of 22ppt relative to the discharge). Further dilution to ambient salinity is predicted to occur over distances of up to 50m radially on either side of the source (Figure 7 and 8). Because the tidal ellipse in this area is relatively narrow (i.e. tides do not circle widely) the mixing zone is expected to be relatively narrow (<10m lateral to the tidal axis). Thus the mixing zone is expected to occupy approximately 1000m^2. Allowing for a doubling of the tidal excursion and lateral spread (to account for currents stronger than those represented in the sample conditions as a safety factor), a mixing zone of 4000m^2 would be indicated. Consequently, the mixing zone should not exceed 1ha (10,000m^2), given the specified discharge characteristics.

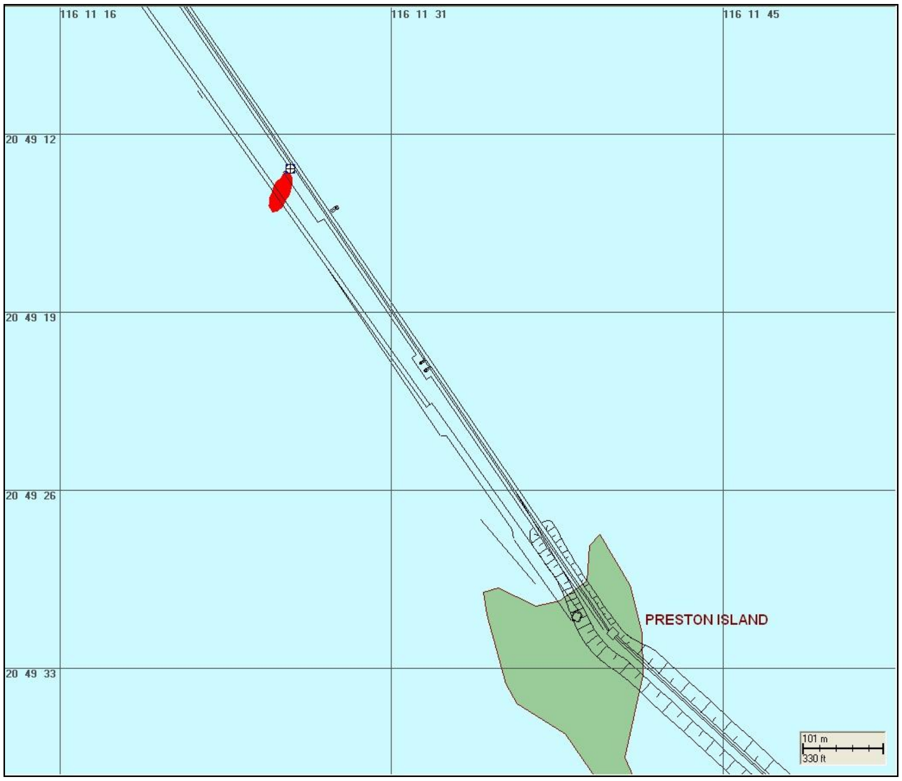


Figure 7: Large scale view of the brine plume at maximum flood tide.

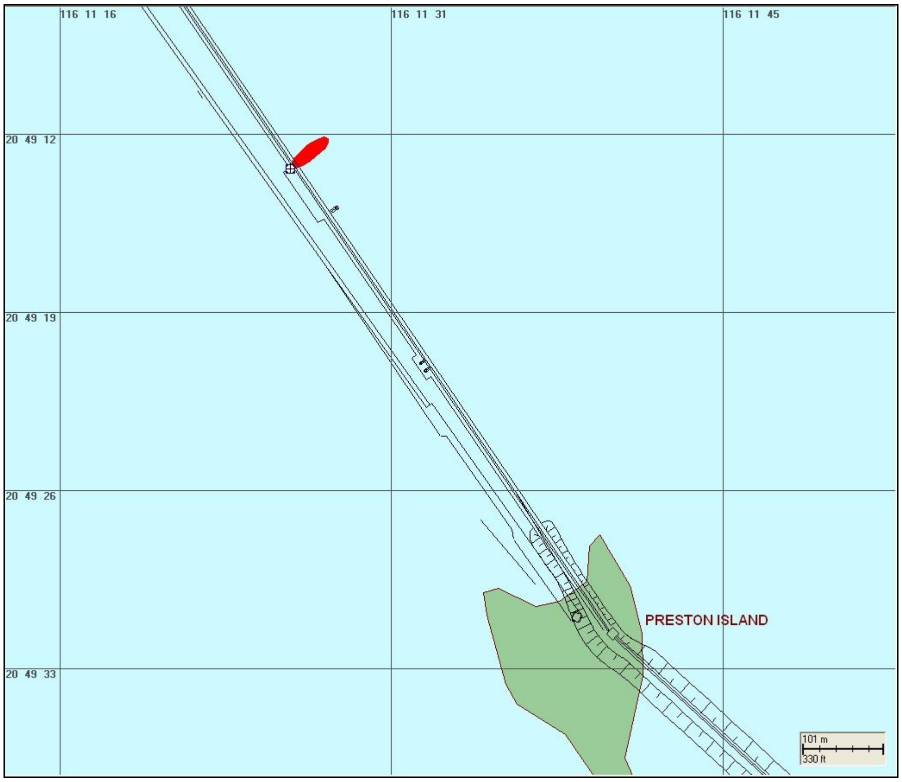
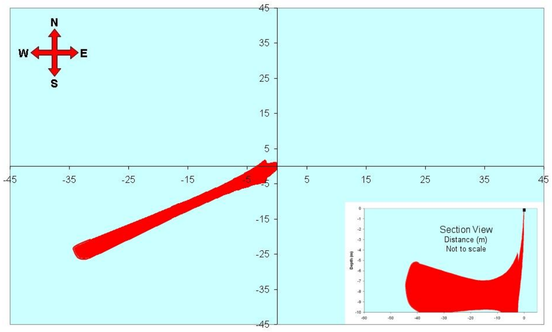


Figure 8: Large scale view of the brine plume at maximum ebb tide.

Figure 9 shows a time series of the predicted brine plume discharge spanning 6 hours. The mixing and dispersion is shown at hourly intervals through half a tidal cycle spanning from the flood current to the start of the ebb current.

(a) 0200hrs 23rd January 2004



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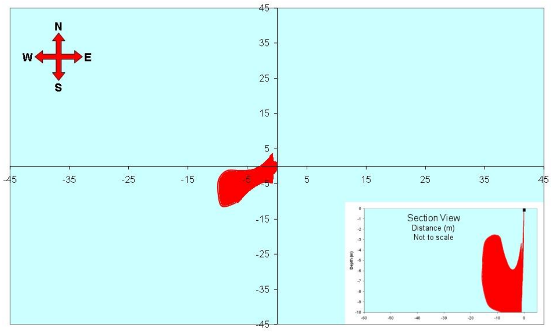

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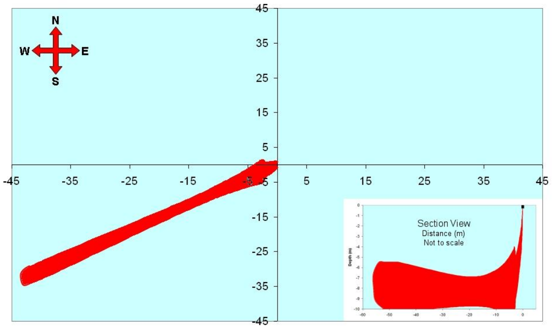

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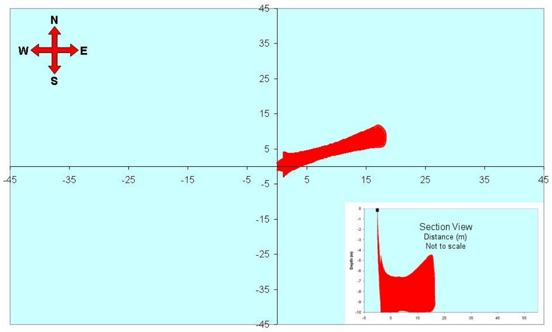

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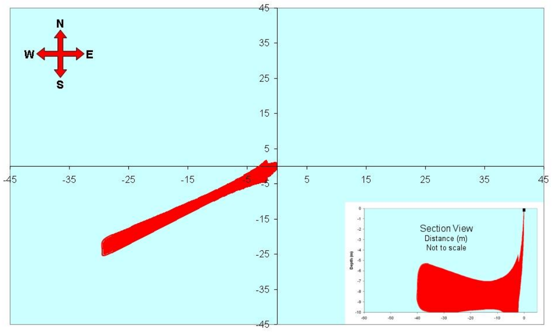

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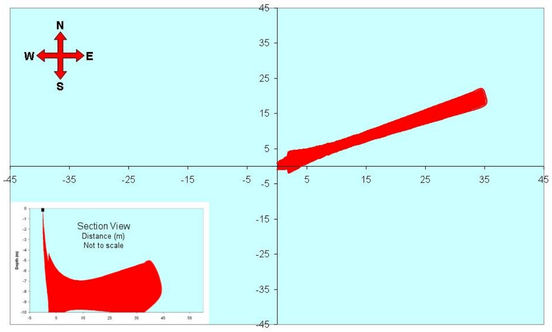

Figure 9: Sample 6-hour time series animation of the predicted brine plume discharged below the water surface.

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