# APPENDIX G
# NORTH WEST SHELF PROJECT EXTENSION KARRATHA GAS PLANT WASTEWATER DISCHARGE MODELLING

Revision 1

Woodside

## Appendix G

# Karratha Gas Plant Wastewater Discharge Modelling

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# Contents

## ABBREVIATIONS

| | |
|---|---|
| ADCIRC | Advanced Circulation Model |
| $C_0$ | Initial Discharge Concentration |
| FE | Finite Element |
| HEPA | High Ecological Protection Area |
| KGP | Karratha Gas Plant |
| MEPA | Medium Ecological Protection Area |
| MSL | Mean Sea Level |
| m/s | Metres per secod |
| PSU | Practical Salinity Unit |
| PW | Produced Water |
| Woodside | Woodside Energy Ltd. |
| WW | Wastewater |
| $^{o}C$ | Degree Celsius |

## EXECUTIVE SUMMARY

Woodside Energy commissioned Jacobs to develop a dilution model to review mixing zones & discharge concentrations around the Karratha Gas Plant jetty outfall and Admin Drain. For the jetty outfall, stochastic analysis of 150 deterministic model runs was undertaken and the minimum dilution levels for 95% and 99% of tide, wind and phase-of-discharge conditions predicted. Minimum dilutions for 95% of conditions at 100, 250 and 500 m were 1:150, 1:260 and 1:400 respectively. These values decreased to 1:75, 1:100 and 1:200 at the 99% level.

Simulation of the Admin Drain discharge was more experimental and was undertaken to determine whether the current model setup could be applied and what the limitations might be. Results for a single deterministic simulation are presented. The results should be treated with caution as the hydrodynamic model has not been validated in this nearshore area and does not properly resolve the inner creek nor the drainage channel (evident on the satellite image). Further work would be required to simulate the Admin Drain discharge more accurately and may require coupling a one-dimensional model.

# 1 INTRODUCTION

## 1.1 Background

Woodside Energy has commissioned Jacobs to develop a dilution model to review mixing zones & discharge concentrations around the Karratha Gas Plant jetty outfall and Admin Drain.

## 1.2 Objective

The objective of this study is to simulate dispersion of wastewater (WW) discharged from the KGP jetty outfall and Admin Drain (Figure 2-1). For the jetty outfall, stochastic analysis was undertaken to present minimum dilution levels for 95% and 99% of tide, wind and phase-of-discharge conditions.

## 1.3 Scope of Work

The scope of work is as follows:

**Jetty outfall**

1) Review previous dilution modelling reports provided by Woodside.
2) Collate and assimilate data, including:
    - discharge parameters (location, flow, diffuser dimensions);
    - tidal current and elevations from hydrodynamic model;
    - measured wind data from Woodside;
    - toxicity data for jetty outfall whole effluent.
3) Near field modelling of the jetty outfall to define the mixing zone under a series of steady state current/wind conditions.
4) Far field modelling to demonstrate fate of discharged plume for various tidal and seasonal wind conditions.
5) Stochastic analysis to present minimum dilutions under 95% and 99% of tide, wind and discharge conditions.

**Admin Drain**

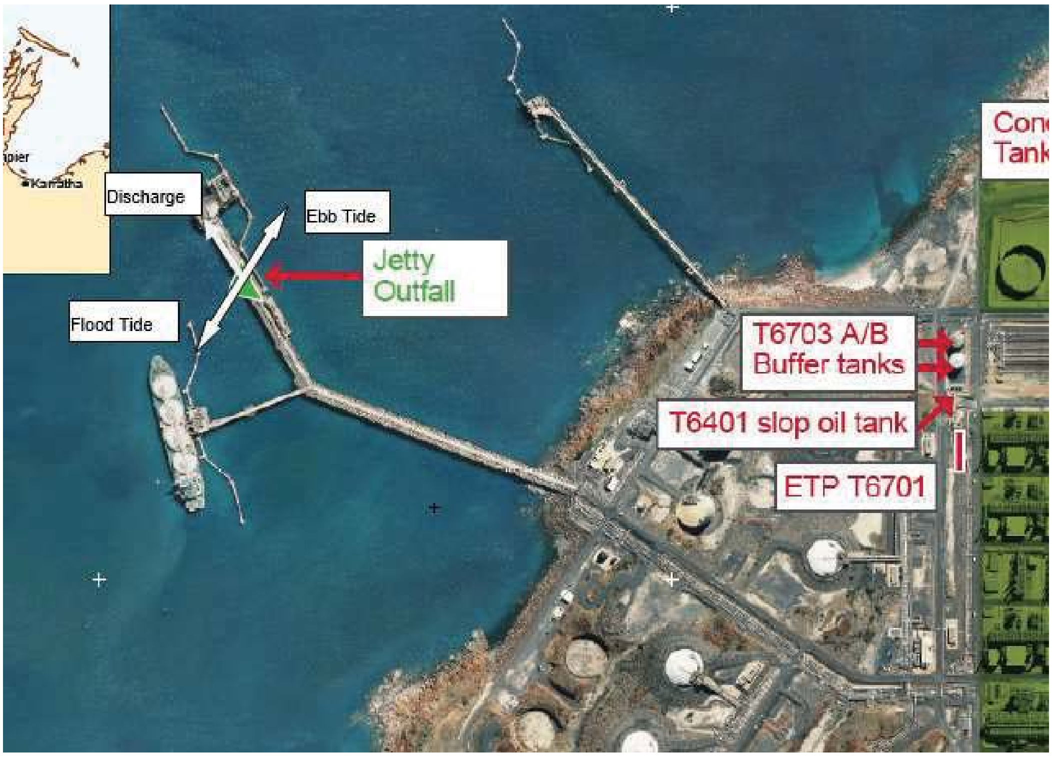
1) Collate and assimilate data, including:
    - discharge parameters (location, flow, hydraulics);
    - tidal current and elevations from hydrodynamic model;
    - measured wind data from Woodside;
2) Far field modelling to demonstrate fate of discharged plume for single tide and wind scenario.

# 2 KARRATHA GAS PLANT WASTEWATER DISCHARGE

The Jetty Outfall receives wastewater from facility process water, primary and secondary containments, and site run-off. Cause–effect pathways for potential impacts on marine environmental quality are associated with emissions from the production of gas and fluids by KGP processes. Maximum discharge size is limited by the size of the final effluent holding basin, which has a maximum volume of 350m$^3$. Frequency of discharges varies, but discharges do not typically occur more than twice per week.

The Administration Drain receives wastewater from the STP, reverse osmosis facility, and site stormwater run-off. Cause–effect pathways for potential impacts on marine environmental quality are associated with emissions from the production of gas and fluids by KGP processes, nutrients/organic matter in discharge from the STP, and concentration of contaminants by the reverse osmosis process. Discharges occur in batches, with total daily discharge volumes over the last 10 years of approximately 72m$^3$/day.

**Figure 2-1 Karratha Gas Plant discharge locations**



# 3 MERMAID SOUND RECEIVING WATERS

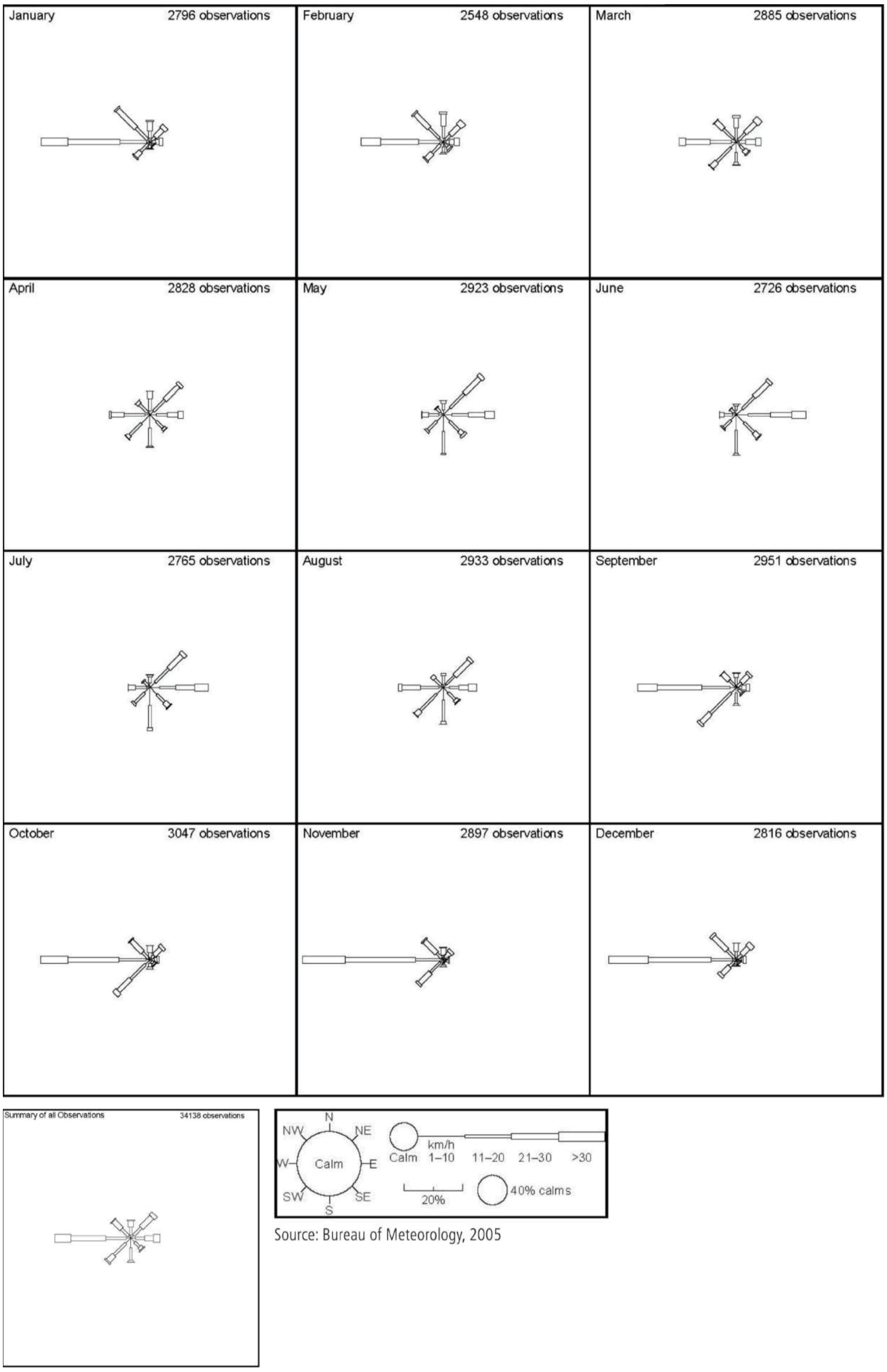
Tides in Mermaid Sound are semi-diurnal giving rise to four current reversals per day. There is a well-defined spring-neap lunar cycle resulting in considerable variation in the speed of the tidal currents over a 14-day period. Tidal currents flood through Mermaid Sound and also from the west (Figure 4-3 (a)). Currents are usually 90° out of phase with tide heights, with maximum speeds occurring at mid-tide and slack water coinciding with high and low waters. The exception to this is where the tidal currents meet adjacent to the intercourse islands where maximum current coincides with high and low water. Ebb currents flow to the northwest out of the sound (Figure 4-3(b)). At the discharge location, peak current speeds range from 0.18 m/s on spring tides to 0.05 m/s on neap tides (Figure 4-4). Wind, wave and density induced currents add a seasonal component to the ambient tidal flows. Net surface drift is dominated by seasonal winds.

Figure 3-1 shows monthly wind roses generated from measured data at Karratha Airport. In summer, (September to March) winds generally blow from the northwest through to the southwest. There is a pattern of daytime sea-breezes and night-time land-breezes. Wind speeds are typically less than 10m/s. In contrast, during winter (May to July), winds blow from the east to southeast. The offshore winds are enhanced by late night to early morning south-easterly land breezes as the land cools and are moderated by afternoon north-westerly sea breezes as the land heats. Winds reach speeds of 10 to 15 m/s inshore and can occasionally peak at over 20 m/s further offshore.

During the transition between the two seasons (April and August) winds tend to be lighter and can blow from either season direction. The typical "rule of thumb" for surface wind driven current flow is 2% to 4% of the wind speed. Surface currents are expected to reflect seasonal wind regimes. Local wind-driven surface currents may attain maximum speeds of 0.7 m/s during extreme wind surges. More typically speeds would be in the range of 0.2 to 0.4 m/s.

Sea surface temperature ranges from 24 – 32°C and salinity is approximately 34 psu. The water column in the Archipelago is essentially well mixed (Mills, 1985).

**Figure 3-1 Monthly wind rose for Karratha Airport (from Bureau of Meteorology)**




Source: Bureau of Meteorology, 2005

# 4 MODELLING METHODS

## 4.1 Overview

The modelling system used in this study is comprised of two components:

- a dispersion module that simulates the near and far field behaviour of the treated waste water; and
- a hydrodynamic module that provides the necessary velocity fields to drive the dispersion models.

## 4.2 Hydrodynamic Model

**Overview**

The hydrodynamics applied in the present study were computed using the ADvanced CIRCulation model (ADCIRC). This model is a system of computer programs for solving time dependent, free surface circulation and transport problems in two and three dimensions (Westerink *et al*., 1994). The algorithms that comprise ADCIRC utilise the finite element (FE) method in space and the model can be applied to computational domains encompassing the Deep Ocean, continental shelves, coastal seas and small-scale estuarine systems.

**Model Details**

Figure 4-1 shows the grid for the Dampier Archipelago. Using the significant flexibility provided by the FE method, grid resolution was increased considerably towards the Mermaid Sound. Node resolution varies from approximately 50km offshore to 40m inshore. The fine nearshore grid spacing was necessary to resolve the complex coastline geometry whilst coarse offshore resolution aids in computational efficiency.

Model bathymetry is shown in Figure 4-2. This was interpolated from the Australian Geological Survey Office database and Admiralty Chart No. AUS58. The model was forced from the open boundary by tidal elevations calculated from the M2, S2, N2, O1 and K1 tidal constituents. Amplitudes and phases for these were taken from the FES-95.2 global ocean model (Le Provost *et al*., 1998).

The model has undergone extensive validation and found to compare favourably against measured currents and tidal elevations in the Dampier Archipelago (Phillips and Luettich 2001).

**Figure 4-1: Dampier Archipelago Finite Element Model Grid**

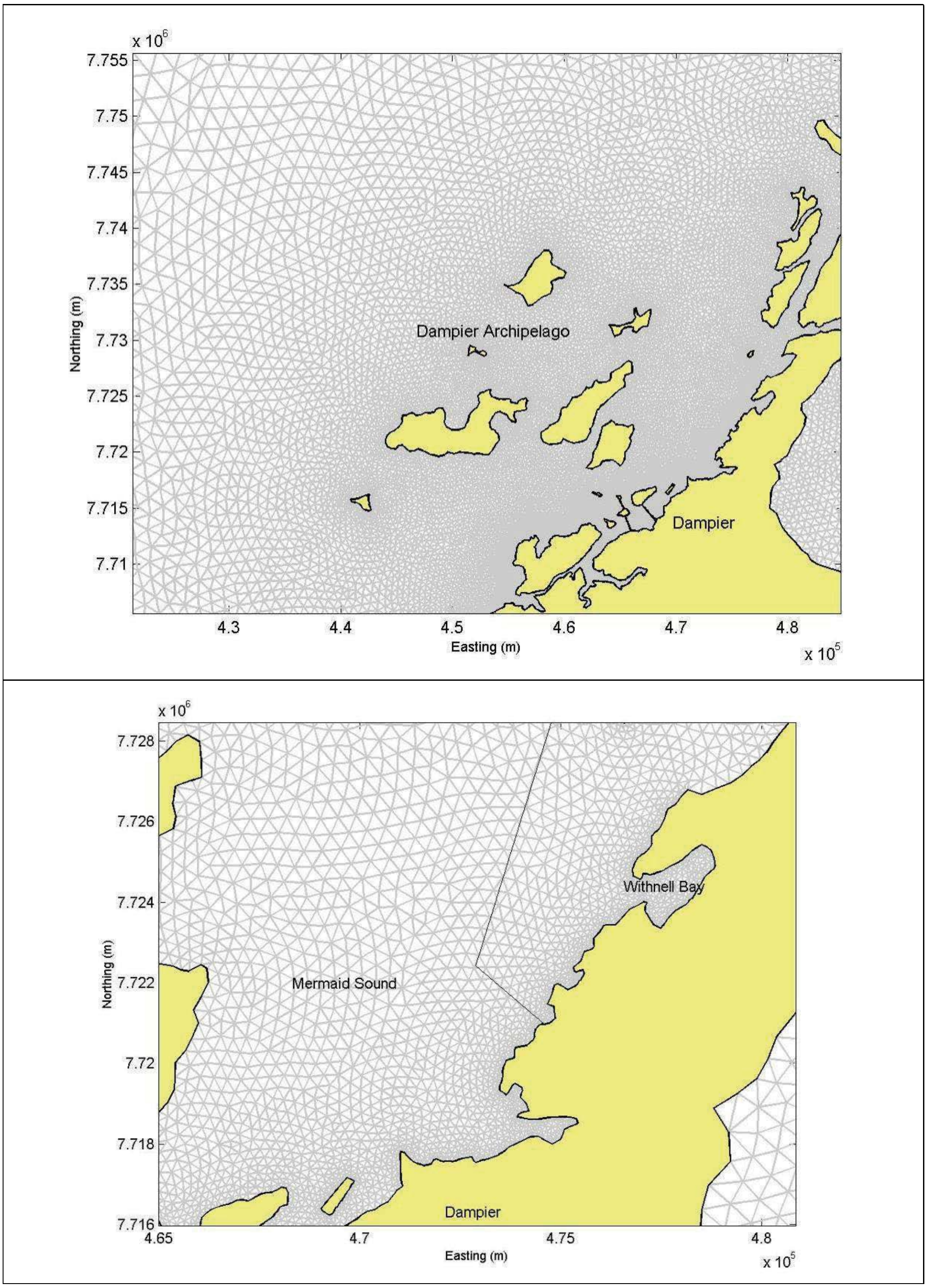


**Figure 4-2: Dampier Archipelago Model Bathymetry (m)**

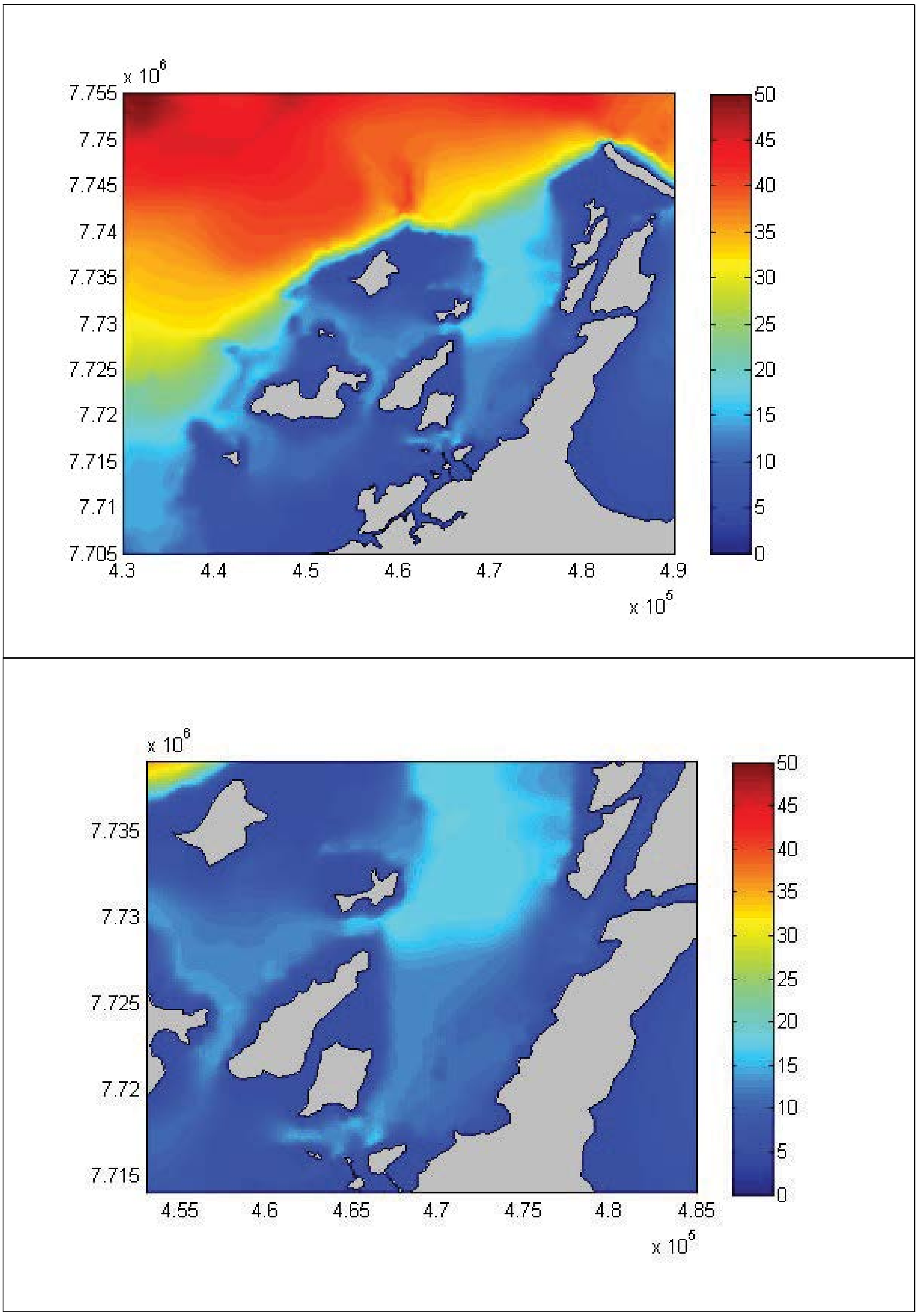
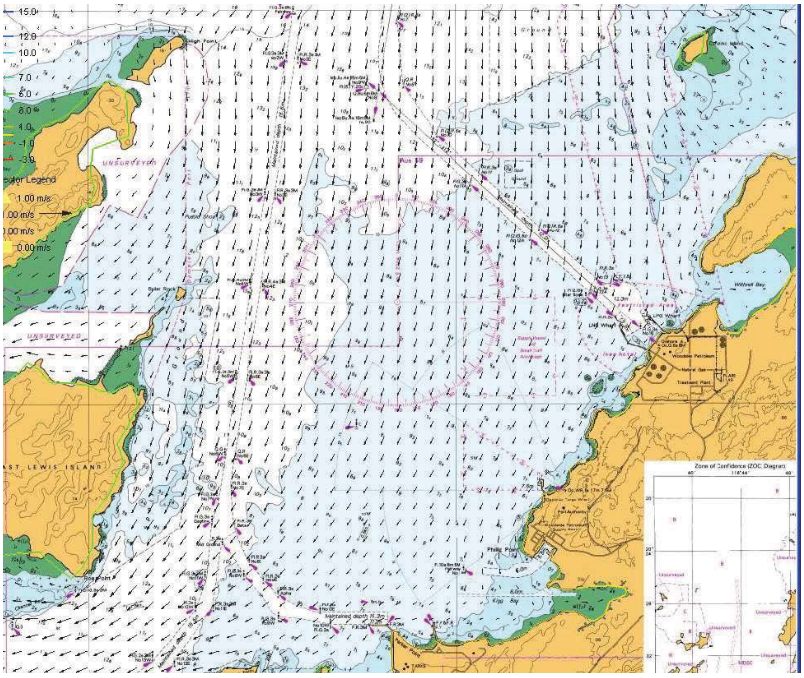


**Figure 4-3: Computed currents in the Mermaid Sound**

(a) Flood tide




(b) Ebb tide

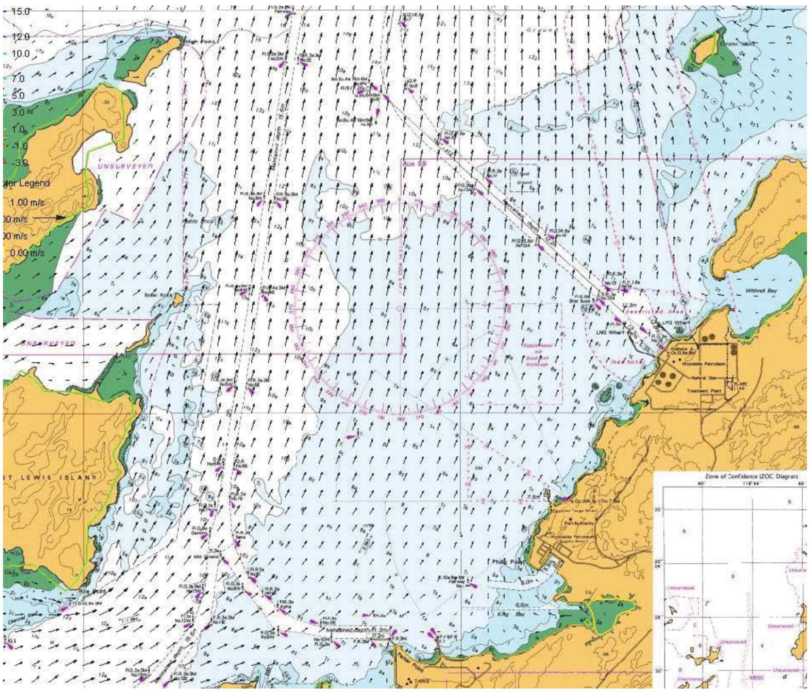
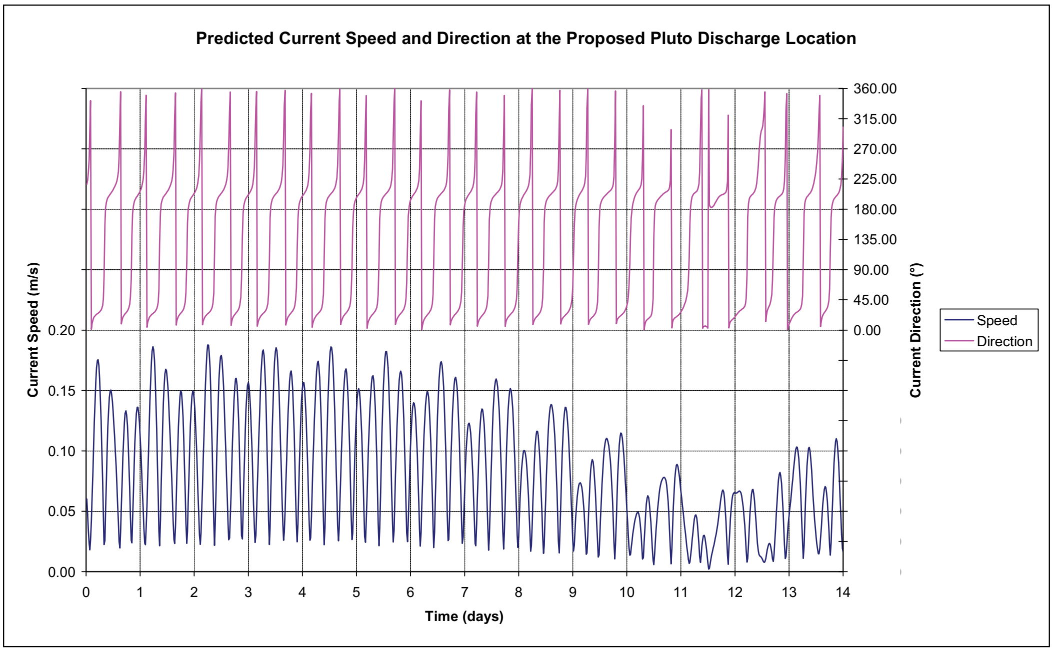


**Figure 4-4: Predicted current speeds and directions at the proposed Pluto discharge location**




## 4.3 Dispersion Module

### 4.3.1 Near field Dispersion

Mixing of a point source discharge is divided into two distinct regions: the near and far fields. The near field is defined as the zone between discharge orifice and impingement on a boundary, either the water surface or a density interface. In the near field, forces are dominated by the momentum and buoyancy of the discharge. Dilution is normally enhanced in this region and is termed ‘initial dilution’.

UM3 was applied to simulate near field mixing. This model is part of the Visual Plumes suite of models maintained by the United States Environmental Protection Agency (Frick, et al. 2003). It has been extensively tested (Roberts and Tian, 2004) and found to provide accurate results for various discharges.

UM3 is a Lagrangian model and solves the three-dimensional hydrodynamic equations governing the conservation of mass and momentum along the curved trajectory of a buoyant jet. To determine the growth of each element, it uses the shear (or Taylor) entrainment hypothesis and projected-area-entrainment hypothesis. The flows begin as round buoyant jets from one side of the diffuser and can merge to a plane buoyant jet (Carvalho et al., 2002). The solution yields values of the trajectory position and of centreline concentrations of pollutant mass, density deficit, temperature and salinity. Dilution is reported as the “effective dilution”, which is the ratio of the initial concentration to the concentration of the plume at a given point (Baumgartner et al., 1994).

### 4.3.2 Far Field Dispersion Modelling

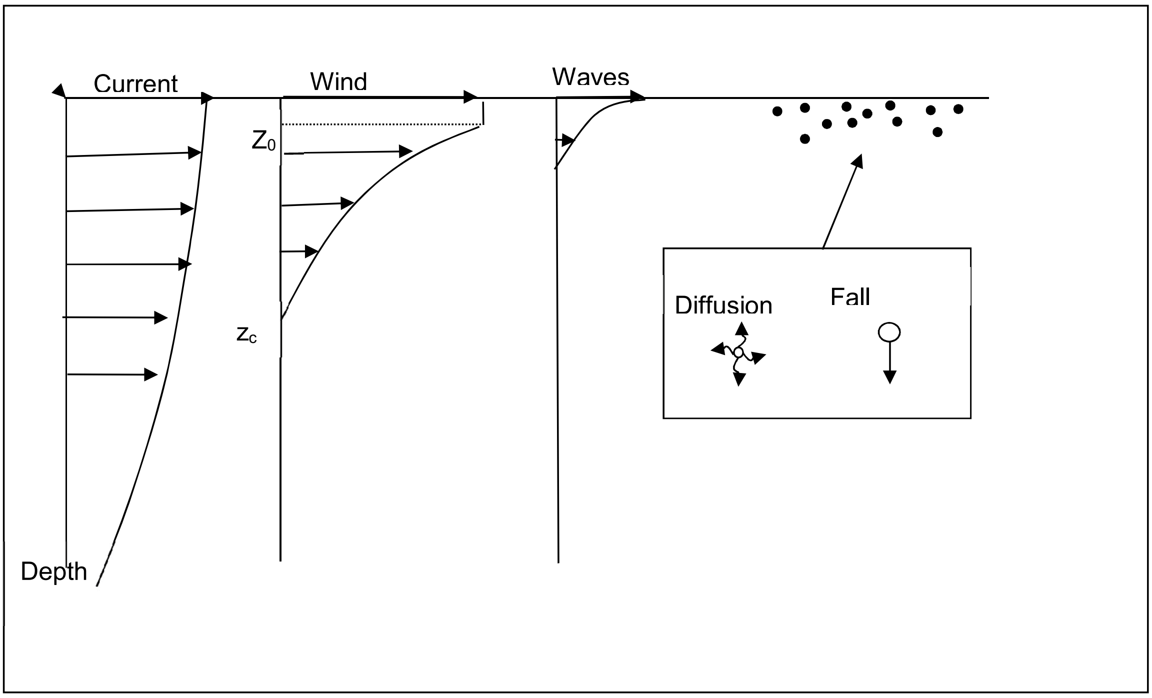
**Model Overview**

The PW dispersion module is based on the classic random walk particle tracking method (Elliot, 1992) and assumes that the mass of the discharge can be idealised as a large number of particles that move independently under the action of prevailing currents.

Physical mechanisms included in the model are illustrated in Figure 4-5 and include:

- advection by ambient currents (tide, residual, wind and wave); and
- dispersion due to turbulence.

**Figure 4-5: Mechanisms included in the three-dimensional model.**




Advection is calculated by stepping through the variations in the current field in time. The effects of wind induced surface shear are modelled by the inclusion of a logarithmic velocity profile. It is assumed that the surface layer, of thickness $z_0$, moves at a velocity $U_s$ (typically 3% of the wind speed) and that the wind induced velocity decays with depth according to:

$$U_z = U_s\left(1 - \frac{\log(z/z_0)}{\log(z_c/z_0)}\right)$$

Where $z_c$ is the depth at which the velocity is zero. It is assumed that $z_c$ scales on the wavelength (L) of the surface waves, $z_c = \mu L$. μ is a free parameter in the model and has been set to 4. $z_0$ is also a free parameter in the model and has been set to 1 cm.

Waves are accounted for by including the Stokes drift to linear waves:

$$U_z = \frac{\omega k a^2 \cosh(2k(H-z))}{2\sinh^2(kH)}$$

Where a is the wave amplitude, H is the water depth, $\omega = 2\pi/T$ and $k = 2\pi/L$ for waves of period T and wavelength L. Wave height and period are calculated from equations provided in the U.S. Army Corps of Engineers Shore Protection Manual (1984). Local depth and fetch are determined in the model from the grid data. At an open grid boundary, a fetch of 100 km (i.e. virtually non-limiting) is assumed.

Dispersion is included by subjecting each particle to a random displacement at each time step. The dispersive displacement (random step) of each particle at each time step (dt) is scaled by the square root of the increment in the variance of the effluent plume which is given by the product:

(increment in variance) = 2Kdt

where K is the horizontal (Kxy) or vertical (Kz) diffusion coefficient. The actual step length taken by each particle is also determined by a random number selected from a normal distribution with zero mean and unit variance which is scaled by the product (2Kdt). Steps in the x, y and z co-ordinate directions are made independently.

The vertical turbulent diffusion coefficient in the mixed surface layer above the pycnocline is related to the wave conditions following Ichiye (1967):

$$K_z = 0.028\frac{H^2}{T}\exp(-2kz)$$

Below the pycnocline depth, Kz is assumed to be a constant equal to $10^{-4}$ $m^2/s$ (Kullenberg, 1982).

The model was verified against a dye dispersion study undertaken at the North Rankin facility on 17 May 2006 (Oceanographic Field Services, 2006).

# 5 JETTY OUTFALL

## 5.1 Discharge Parameterisation

The existing KGP outfall consists of a 450mm diameter pipe routed along the jetty. Directly above the point of discharge, a 90° elbow directs the pipe vertically downwards to a depth of approximately 7m below MSL. Effluent is discharged through a five port diffuser system. Ports are 150mm diameter, positioned 1m apart and orientated downwards at 45° to the horizontal. The salinity of the effluent is around <2 psu and the discharge rate is given as 180 $m^3$/hr (0.05 $m^3$/s) over 116 mins. These and other discharge parameters are summarised in Table 5-1.

**Table 5-1: Summary of KGP discharge parameters**

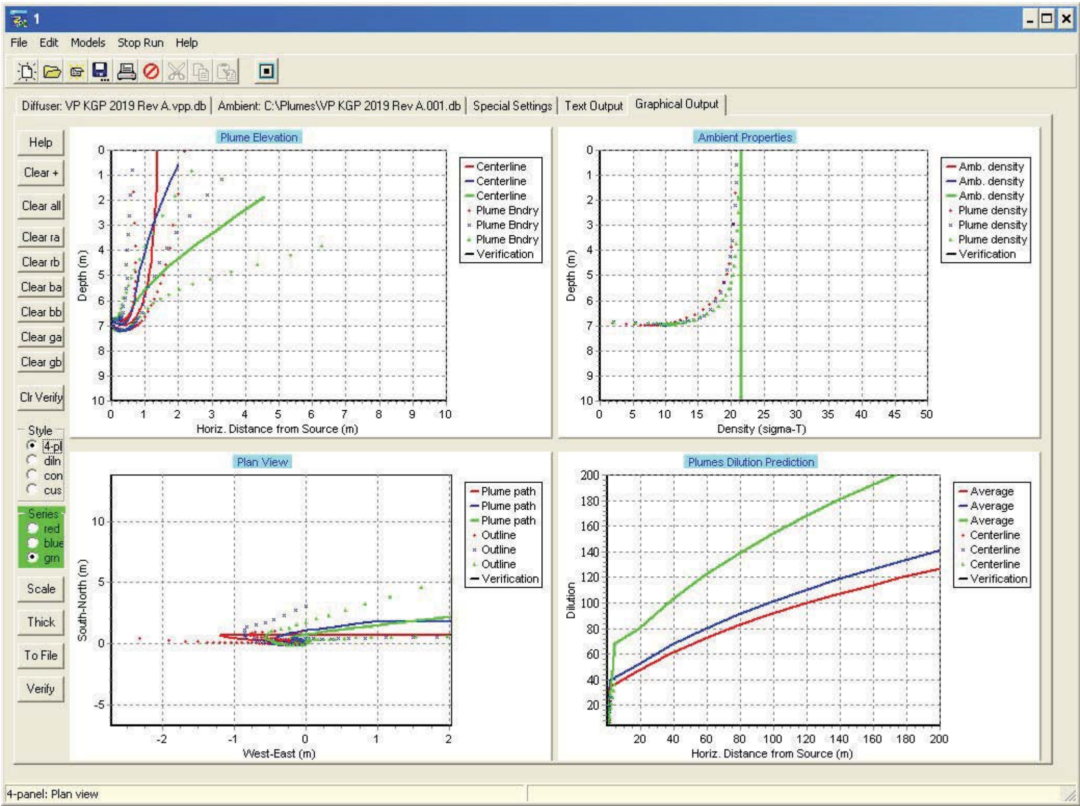
| Parameter | Description |
|---|---|
| Water Depth | 7.78m (relative to MSL) |
| No of Ports | 5 |
| Internal Diameter of Ports | 150mm |
| Discharge orientation | 45° below the horizontal |
| Port Spacing | 1m |
| Depth | 6.78m rel MSL |
| Discharge | 350$m^3$ batch discharged over 116 minutes twice a week |
| Maximum effluent discharges | 0.05 $m^3$/s |
| Salinity | 1psu |
| Initial Discharge Concentration ($C_0$) | 100% wastewater |

## 5.2 Initial Dilution

Figure 5-1 presents the predicted initial dilution trajectory and dilution for spring tide at low water slack, mid tide (maximum currents) and high tide slacks. The effluent exits the five ports, initially directed downwards at 45° to the horizontal before rising under their own buoyancy. The plumes merge before they reach the surface, bending towards the north on the ebb tide and south on the flood tide. At the surface the plume spreads laterally forming a lens of less dense water. Ambient currents advect the plume away from the source, whilst turbulent diffusion entrains seawater, eroding the density difference and reducing plume concentration.

On the spring tide, dilutions at the end of the near field range from 1:34 at low water slack tide to 1:68 at mid tide (Figure 5-1). On the neap tide, dilutions range from 1:34 at low water slack tide to 1:39 at mid tide.

**Figure 5-1: Predicted initial dilutions for Spring tide at low water slack (red), mid tide (green) and high tide slacks (blue)**




## 5.3 Stochastic analysis

### 5.3.1 Method

For the stochastic analysis, 150 deterministic scenarios were undertaken with wind, tide and phase-of-discharge relative to tide selected randomly for each simulation. Measured winds over a two year period between 2016 and 2017 were applied.

The model was run for 24 hours and predicted concentrations stored every hour over the whole grid. Concentrations were converted to dilutions and the durations that they exceeded 10 levels of dilution (50, 100, 200, 300, 400, 560, 600, 700, 800, 900) calculated for each grid cell.

For the 150 scenarios, probability of dilutions exceeding the 10 dilution levels for one hour or more were calculated. The 5 and 1% probability levels were plotted to provide the minimum dilutions achieved for 95 and 99% of model scenarios (i.e. 5% and 1% of worst-case scenarios were excluded from the plots).

### 5.3.2 Results

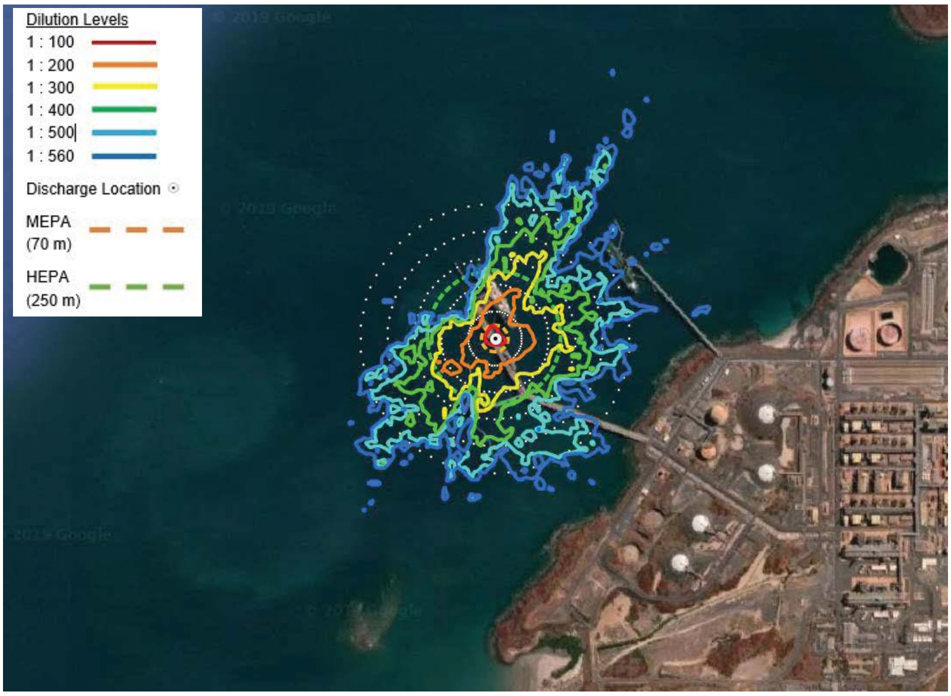
Figure 5-2 shows the minimum dilutions predicted for (a) 95% and (b) 99% of model scenarios. At 100, 250 and 500 m, minimum dilutions at the 95% probability level are 1:150, 1:260 and 1:400 respectively (Table 5-2:). These values decrease to 1:75, 1:100 and 1:200 at the 99% level.

**Table 5-2: Minimum dilutions for 95% and 99% of model scenarios.**

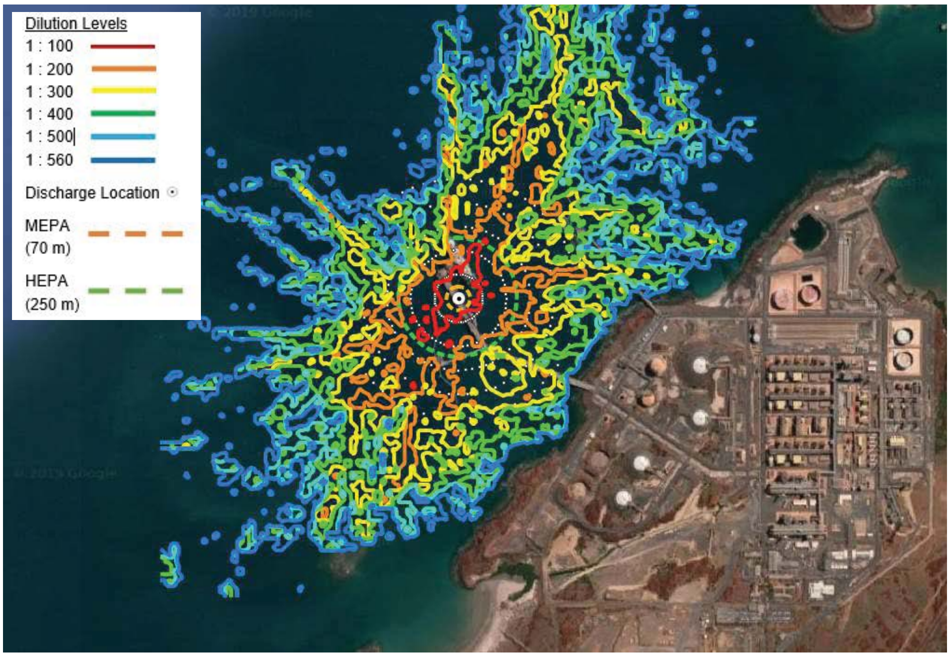
| Distance from discharge (m) | Minimum Dilution (95% probability) | Minimum Dilution (99% probability) |
|---|---|---|
| 100 | 1:150 | 1:75 |
| 250 | 1:260 | 1:100 |
| 500 | 1:400 | 1:200 |

**Figure 5-2: Karratha Gas Plant jetty discharge: minimum dilutions for (a) 95 and (b) 99% of model scenarios.**

(a) 95% probability of occurrence




(b) 99% probability of occurrence




Notes: Flow = 350m$^3$/116mins , $C_0$ = 100%ww, Discharge depth = -6.78m (MSL), PC99(50) = 0.36% (1:280). Range rings (white dots) are drawn at 100m intervals; MEPA (orange dashed ring around the discharge) is the Medium Ecological Protection Area located 70 m from the discharge; HEPA (green dashed ring around the discharge) is Woodside's currently targeted High Ecological Protection Area located 250 m from the discharge.

# 6 ADMIN DRAIN DISCHARGE

## 6.1 Discharge parameterisation

Figure 6-1 shows an aerial image of the Admin Drain discharge. The drain discharges into an inner creek and then into No Name Bay. For the purpose of the discharge modelling, it was assumed (Table 6-1):

- A discharge rate (Q1) of 3 $m^3$/hr (the average discharge rate is 72 $m^3$/day).
- The creek may be represented by a channel of length 150 m, width 3 m and depth 1m to give a volume of 450 $m^3$.
- This channel fills on the flood tide into which the Admin Drain effluent mixes and then discharges on the ebb tide.
- On discharge, the inner channel mixes into 'No Name Bay' over a volume of 50m x 50m x 2m depth.
- The discharge profile is distributed over the simple tidal prism shown in Table 6-1.

The mixing volume in No Name Bay was placed on the model boundary and the model ran for 48 hours. Concentrations were calculated over a 25 m regular grid with cell depth of 1 m.

**Figure 6-1: Schematic of Admin Drain discharge.**

**Table 6-1: Discharge load calculations.**

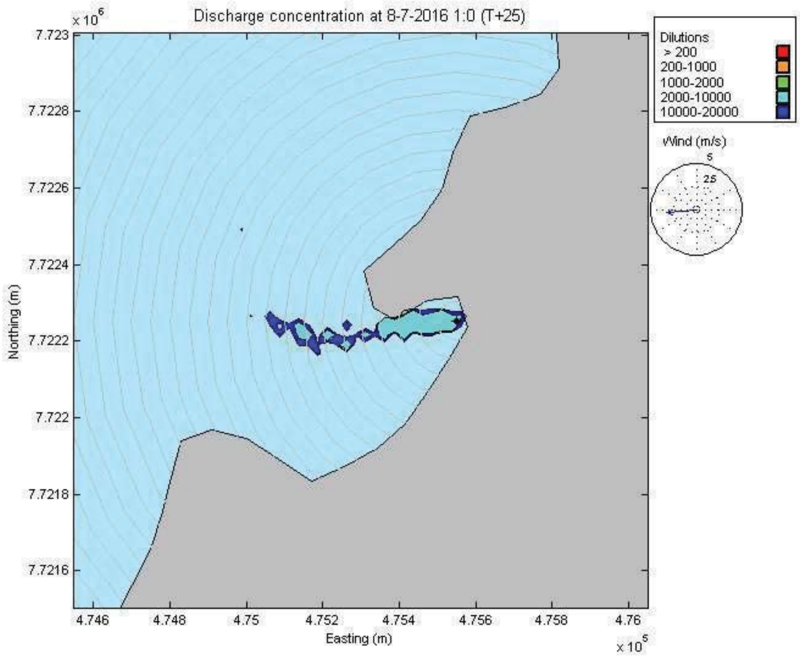
| Parameter | Value | Unit |
|---|---|---|
| Discharge rate from Drain (maximum discharge scenario) | 3 | $m^3/hr$ |
| Volume discharged into Inner Channel over 12 hours | 36 | $m^3$ |
| Inner Channel Volume | 450 | $m^3$ |
| | | |
| Dilution in Inner Channel | 1 : 12.5 | |
| | | |
| Distribution of flow from the inner channel into No Name Bay over the ebb tide | Tidal Prism (%) | $m^3/hr$ |
| HW+1 | 10 | 30 |
| HW+2 | 30 | 90 |
| HW+3 | 60 | 180 |
| HW+4 | 30 | 90 |
| HW+5 | 10 | 30 |
| HW+6 | 10 | 30 |
| Total Volume ($m^3$) | | 450 |

## 6.2 Results

Figure 6-2 shows the predictions of the drain discharging into No Name Bay during a single ebb tide. The discharge receives approximately 150 to 830 dilutions (including the 12.5 dilutions received in the Inner Channel) when it first enters the Bay (depending on the tidal discharge rate). Thereafter, it is dispersed by tide and wind towards the west. At 70m from the discharge location (in the model) concentrations range from 0% (dilution not applicable) on the flood tide to around 0.08% (1:1,200 dilutions) on the ebb tide (Figure 6-3).

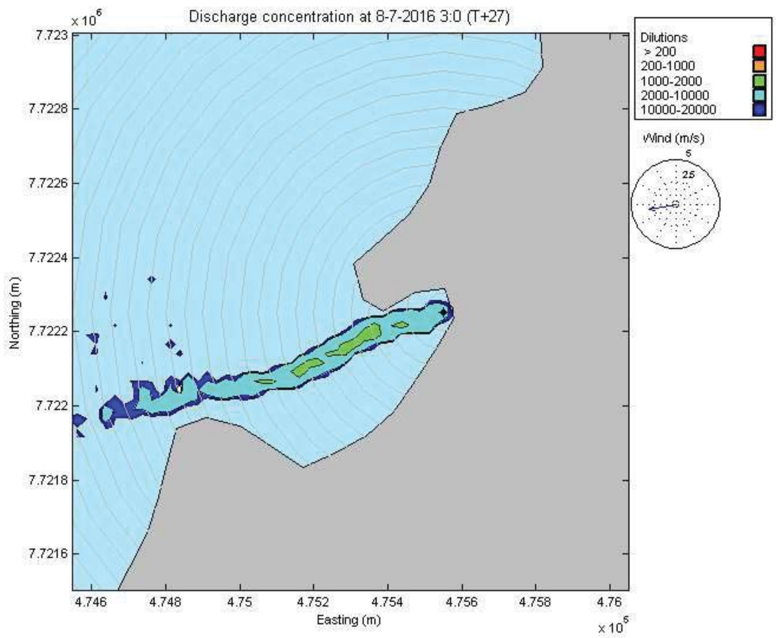
These results should be treated with caution due to the assumptions listed above for the discharge. Also, clearly the model does not properly resolve the inner creek nor the drainage channel, which can be seen on the satellite image. Hence, the discharge location in the model is further into the bay than the actual discharge location shown in Figure 2-1. Further work would be required to simulate the Admin Drain discharge more accurately and may require coupling a one-dimensional model.

**Figure 6-2: Predicted dilutions and concentrations for the discharge from the Admin Drain into No Name Bay**



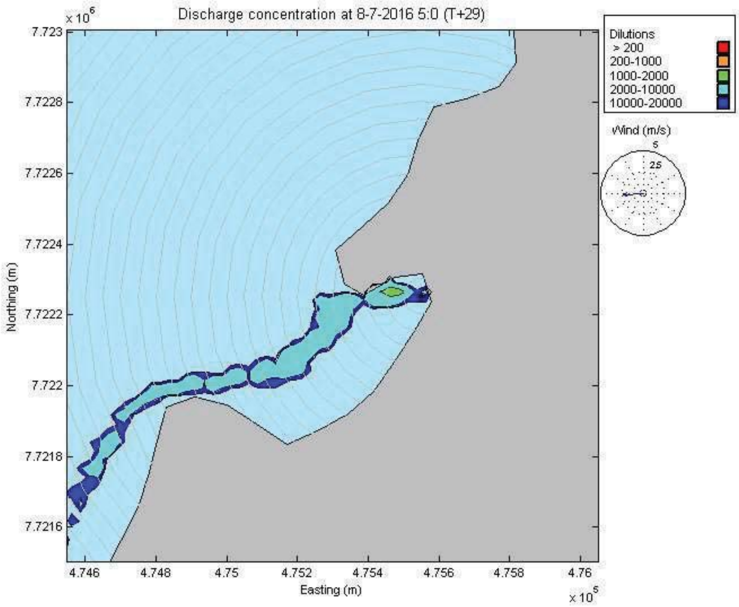

(a) HW+2 hrs

Notes: Flow = 6m$^3$/hr, Range rings are drawn at 50m intervals;



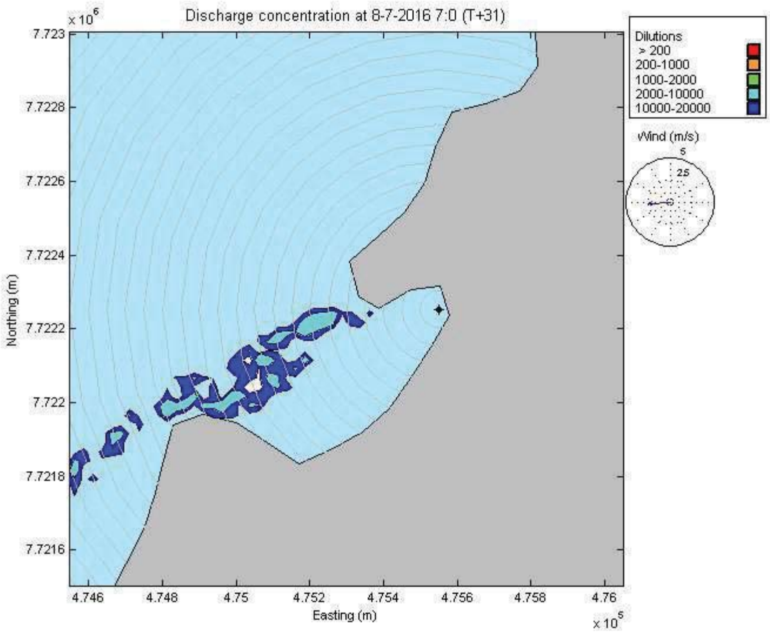

(b) HW +4 hrs

Notes: Range rings are drawn at 50m intervals.




(c) HW +6 hrs

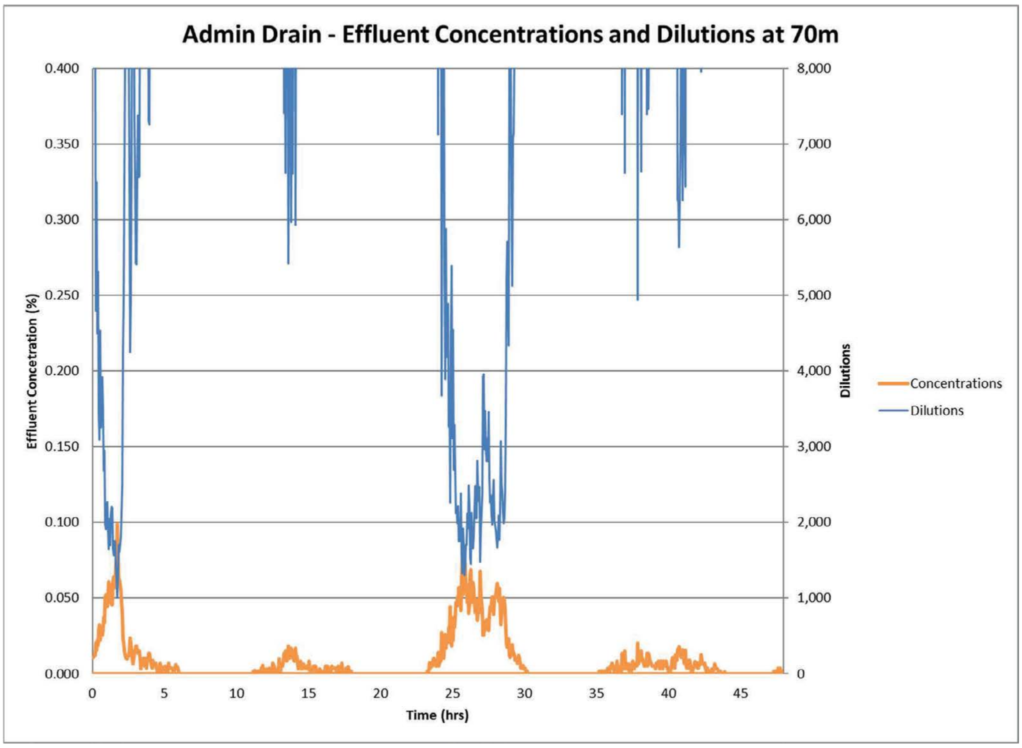
Notes: Range rings are drawn at 50m intervals.




(d) HW +8 hrs

Notes: Range rings are drawn at 50m intervals.

**Figure 6-3: Times series of predicted concentrations and dilutions at 70 m from the Admin Drain Discharge.**




Notes: These are the predicted concentrations at 70 m from the model discharge location not the actual discharge location at the culverts shown in Figure 2-1 and is a limitation of the model.

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