APPENDIX H6

Diffuser design investigation

A part of BMT in Energy and Environment

Diffuser Design Investigation Final Report

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October 2010

Diffuser Design Investigation

Final Report

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BMT WBM

CONTENTS

1 INTRODUCTION

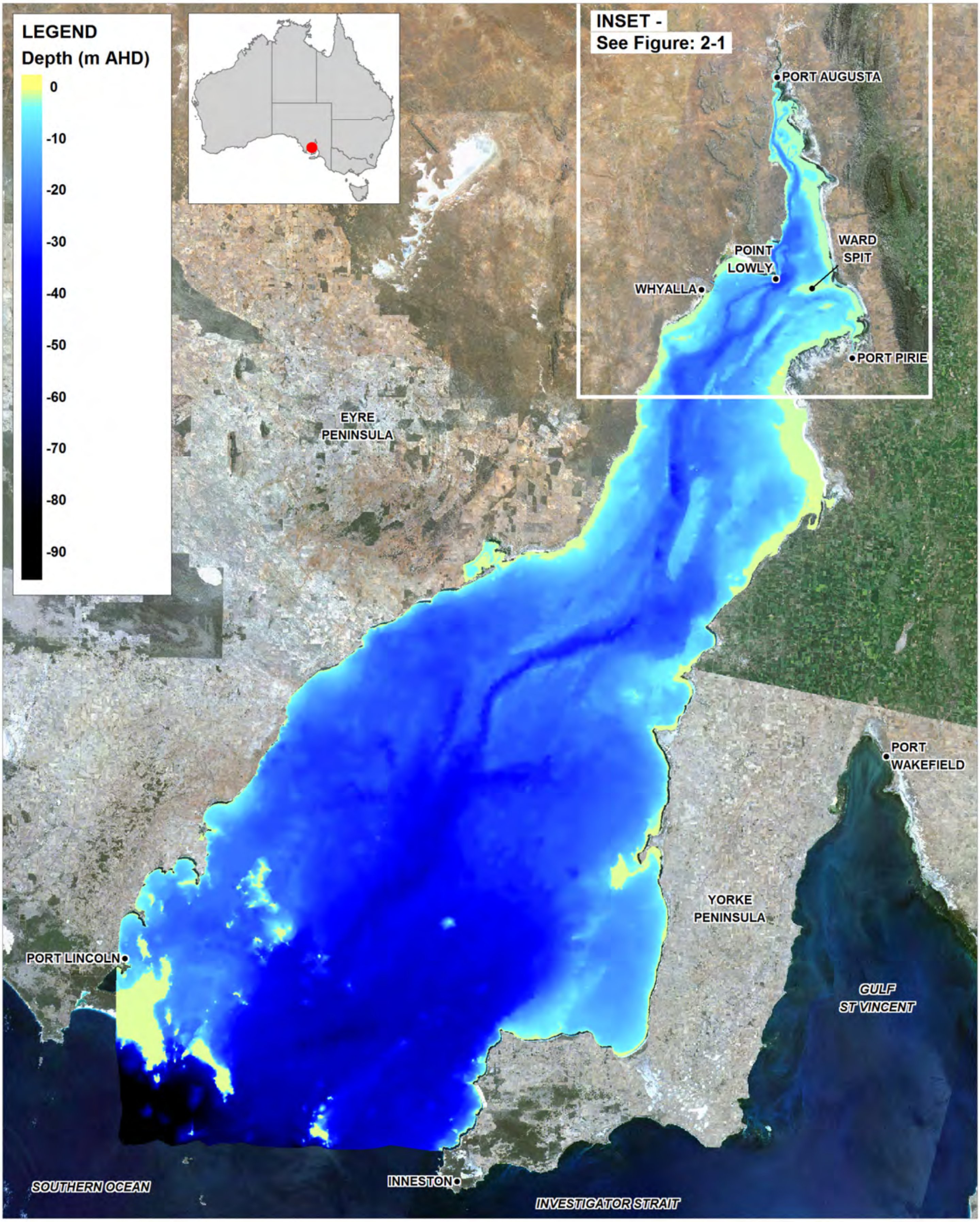
BHP Billiton is proposing to expand its mining operations at Olympic Dam, South Australia. Part of this proposal includes construction and operation of a desalination plant at Point Lowly on the coastline of Upper Spencer Gulf (Figure 1-1). This plant would provide water to the proposed mine if it is approved.

BHP Billiton released a Draft Environmental Impact Statement (DEIS) with respect to the proposed expansion and desalination plant in May 2009. Part of this DEIS described numerical modelling undertaken to better understand any potential impacts that brine discharged from the proposed desalination plant may have on receiving waters and biota. BMT WBM and The Centre for Water Research (CWR) undertook this numerical modelling on behalf of BHP Billiton, and details have been provided in a series of peer reviewed reports appended to the DEIS (BMT WBM 2008a, BMT WBM 2008b).

This DEIS modelling work deployed a three-tiered framework to assist with impact assessment. These models captured different spatial and temporal scales and were referred to as ‘near field’, ‘mid field’ and ‘far field’ models. The near field model was used to predict the brine plume behaviour at short spatial and time scales (i.e. orders of hours and up to a few hundred meters), whereas the far-field model was used to provide information for long-term assessments (i.e. seasonal and inter-annual) at the Spencer Gulf scale. The mid-field model was used to predict the plume behaviour on intermediate time scales (i.e. over a few days to a couple of months) and over the Northern Spencer Gulf.

The current report presents additional works within the ‘near field’ modelling tool that review and investigate further alternatives for the diffuser design reported in the DEIS. Using the ambient tidal conditions measured locally (refer to the DEIS Appendices documents), the assessments described in this report include:

- A review of the initial diffuser configuration and results provided in the DEIS;
- A review of the modelling tools used in this study;
- A screening analysis of the key parameters influencing dilution in the immediate vicinity of the diffuser;
- Simulation of a range of diffuser designs using this screening analysis and numerical tools; and
- Reporting of model predictions.



Title:

Spencer Gulf
Location and Bathymetry

Figure: 1-1

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2 REVIEW OF INITIAL DIFFUSER CONFIGURATION

2.1 DEIS Diffuser Configuration

The diffuser configuration initially proposed in the DEIS (BHP Billiton, 2009) was as follows:

- Total diffuser length: 200m
- Pipe diameter: 2.1m
- Number of ports: 50
- Port diameter: 175mm
- Port spacing: 4m
- Port configuration: 60^{o} angle to the horizontal (alternating directions)
- Riser Height: 0.6m
- Average depth of water: 20m
- Diffuser pipeline located on the seafloor
- Diffuser aligned generally perpendicular to ambient current

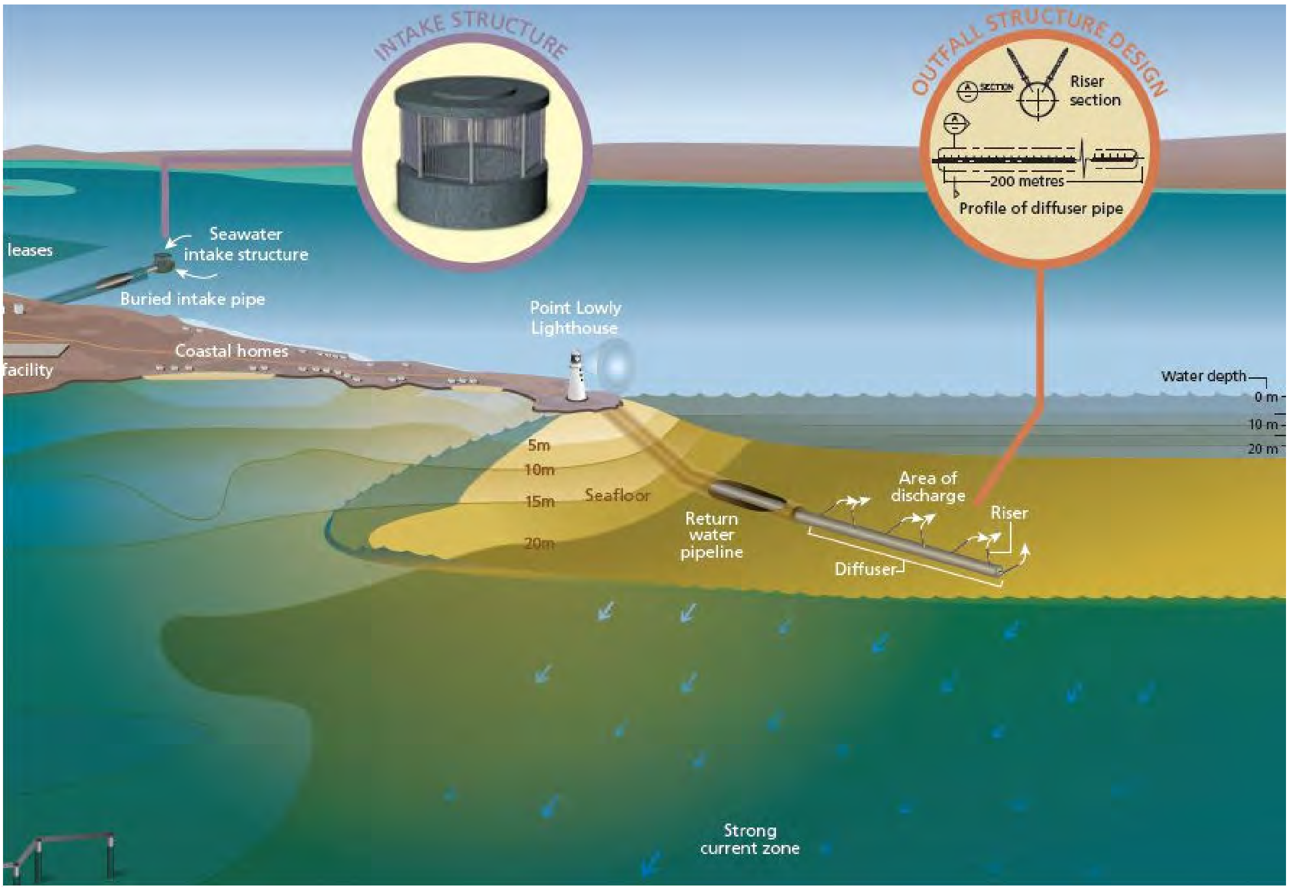

Figure 2-1 Draft EIS Diffuser Design

2.2 Previously Predicted Near Field Dilutions

Previous studies (BMT WBM, 2008a) have examined near field dilutions for the above configuration only. Predicted plume dilutions in relatively low ambient current conditions were (BMT WBM 2008a):

- 18.2:1 at the location of bottom contact; and
- 20.2:1 at a location 100m downstream of the diffuser.

For the greater ambient current velocities that characterise the proposed outfall location, dilutions of up to 62:1 and 97:1 were predicted at bottom contact and 100m downstream of the diffuser, respectively.

3 MODELLING FRAMEWORK

Two modelling approaches were used in this study. These are described below.

3.1 Roberts *et al.* (1997)

Roberts *et al*. (1997) performed a series of laboratory experiments on turbulent dense jets inclined upwards at an angle of 60 degrees to the horizontal into stationary (i.e. still) receiving environments. One of the outcomes of these experiments was a means to predict species (brine) dilution at the jet impact point on the seabed. These predictions were based on the jet densimetric Froude number:

$$F = \frac{u}{\sqrt{gd\,\frac{Rd - Rs}{Rs}}}$$

Where:

- u is the discharge velocity
- Rd is the discharge density
- Rs is the background density
- d is the port diameter
- g is acceleration due to gravity

Figure 3-1 presents a sketch of an inclined dense jet (60 degrees angle) as per these experiments, with the following variables:

- y_t is the height to top of jet
- y_L is the plume thickness beyond the initial (Near Field) zone
- x_i is the distance to the point of contact
- x_m is the distance to the end of the initial mixing zone (end of Near Field)
- S_i is the dilution at the point of contact
- S_m is the dilution at the end of the initial mixing zone (end of Near Field)

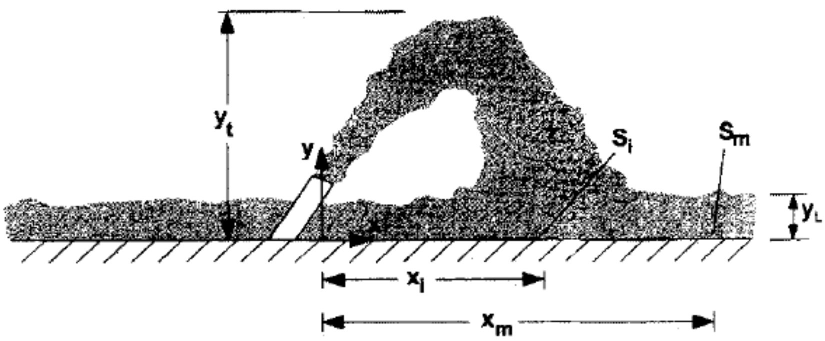

Figure 3-1 Inclined Dense Jet Sketch (reproduced from Roberts *et al.*, 1997)

The Roberts *et al.* (1997) equations for predicting the dilutions at the locations shown in Figure 3-1 (and as applied in this study) for zero ambient current conditions are as follows:

- S_i = 1.6 x F
- S_m = 2.6 x F

3.2 CORMIX Modelling Package

The CORMIX modelling package (http://www.cormix.info/) was used to describe the near field plume dynamics over a greater range of ambient current velocities than was possible using Roberts *et al*. (1997). It is a one dimensional model that uses flow regime parameters and outfall design characteristics to predict the steady state evolution of effluent plume dynamics. CORMIX can simulate a variety of diffuser configurations, including single and multiport arrangements. However for investigation of complex hydrodynamic cases, the user manual recommends the use of single port modelling in order to capture details of the effluent flow behaviour in the vicinity of the diffuser (Figure 3-2).

3.2.1 CORMIX Hydrodynamic Simulation Models

CORMIX1 predicts the geometry and dilution characteristics of effluent flow resulting from a **single port diffuser discharge** of arbitrary density (positively, neutrally, or negatively buoyant), location, and geometry into an ambient receiving water body that may be stagnant or flowing and have ambient density stratification of different types. An example of a single port (above surface) discharge appears in Figure 3.2a.

CORMIX2 applies to three commonly used types of **multiport diffuser discharges** under the same general effluent and ambient conditions as CORMIX1. An example of a multiport diffuser structure appears in Figure 3.2b. CORMIX2 analyzes unidirectional, staged, and alternating designs of multiport diffusers and allows for arbitrary alignment of the diffuser structure within the ambient water body and for arbitrary arrangement and orientation of the individual ports. For complex hydrodynamic cases, CORMIX2 uses the "equivalent slot diffuser" concept and thus neglects the details of the individual jets issuing from each diffuser port and their merging process, but rather assumes that the flow arises from a long slot discharge with equivalent dynamic characteristics (27). Hence, if details of the effluent flow behavior in the immediate diffuser vicinity are needed, an additional CORMIX1 simulation for an equivalent partial effluent flow may be recommended.

Figure 3-2 Extract of CORMIX User Manual (Section 3.2.1, page 24)

The model has the ability to capture the following key phases of plume evolution:

- Near field: the region where plume dynamics are dominated by the momentum of the discharge.
- Buoyant spreading: the region where the buoyancy of the effluent stream is dynamically important. Depending on ambient flow conditions, this regime may lead to either restratification or full vertical mixing.

- Ambient spreading: the region where full vertical mixing has occurred and the effluent stream is largely controlled by the ambient flow regime.

The locations and characteristics of these phases determine the efficacy of the selected diffuser arrangement in dispersing and diluting the effluent stream.

Across a range of studies, we have found CORMIX to be best suited for predicting plume behaviour in the near field zone under relatively high ambient velocity conditions (i.e. greater than approximately 0.2m/s to 0.3m/s). For ambient velocities less than this indicative threshold, we have found CORMIX provides global 'bulk dilutions' averaged across an initial mixing zone, rather than the spatial gradient of dilutions required for this study. An example of a CORMIX output showing this initial bulk dilution feature is provided in Figure 3-3.

```
--------------------------------------------------------------------------
BEGIN MOD234: UNSTABLE RECIRCULATION REGION OVER LAYER DEPTH

 INITIAL LOCAL VERTICAL INSTABILITY REGION:
   Bulk dilution (S = 185.82) occurs in a limited region (horizontal extent
   =   26.43 m) surrounding the discharge location.

  Control volume inflow:
       X         Y        Z         S        C         BV       BH        TT
      0.00      0.00     3.00      1.0 0.100E+03    0.00   112.50   .00000E+00

  Control volume outflow:
       X         Y        Z         S        C         BV       BH        TT
     26.43      0.00    10.00    185.8 0.538E+00   20.00   162.50   .00000E+00
```

Figure 3-3 Example of CORMIX Output with Bulk Dilution Message

As such, we have recommended (elsewhere) that detailed investigation of the likely near field plume dynamics under low ambient velocity conditions be undertaken using a fully three dimensional computational fluid dynamics (CFD) modelling tool. This CFD tool will also be used to provide a more rigorous assessment of plume behaviour and dilution, both in terms of spatial and temporal variability and the potential influence of different ambient and discharge densities on dilution characteristics. This scope or outcomes of this additional modelling study are not described further here.

It is also noted that the CORMIX manual states an accuracy of the model predictions of within ±50% or less (see Figure 3-4 and Figure 3-5). This should be taken into account when considering the dilution results of the various modelling undertaken with this software.

> user not to proceed with the analysis. Whenever the model is applicable, extensive comparison with available field and laboratory data has shown that CORMIX predictions on dilutions and concentrations, with associated plume geometries, are generally accurate to within ± 50% (standard deviation) or less.

Figure 3-4 Extract of CORMIX User Manual (Section 3.1, page 23)

```
******************** FINAL DESIGN ADVICE AND COMMENTS *********************
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
  the design configuration as highly complex and uncertain for prediction.
```

Figure 3-5 Extract of CORMIX Simulation Report Session

In this study, CORMIX was used to predict downstream dilutions for various diffuser arrangements using the single port option (i.e. CORMIX1), as advised by the CORMIX User Manual (2007, Section 3.2.1 page 24). Although the final design will comprise a multiport diffuser, the CORMIX manual states that (within the CORMIX model schematisation) use of the single port analysis tool is the most appropriate investigative tool to use when considering the response of mixing regimes to alterations in diffuser arrangements.

In addition to downstream dilutions, indicative (back-calculated) diffuser lengths and port spacing are also provided (see Section 4.3.2) based on the assumption that individual plumes do not interact at the end of the Near Field zone. This assumption provides an upper bound on this back-calculated total diffuser length, and relaxing it to allow some plume overlap at sufficient downstream distances will result in shorter overall diffuser lengths. Again, use of CFD modelling tools will allow more detailed representation and assessment of plume interaction, and associated impacts on dilution.

4 DIFFUSER DESIGN INVESTIGATION

The diffuser design investigation was undertaken in three phases. The first was a small screening study to provide direction on the likely key (sensitive) parameters to vary within subsequent simulations. This phase used the original DEIS configuration as a reference point. The second phase was execution and interrogation of the Roberts *et al.* (1997) and CORMIX simulations, using the parameters and ranges identified in phase 1. The results from these phases are described below, following a description of parameters that were common (and unchanged) to both Roberts *et al.* (1997) and CORMIX simulations.

In the first two phases, no consideration of the operation pressure was made, i.e. assessments were based solely on the ports exit velocity. Hence, a third phase was undertaken, considering the diffuser operating pressure to define the range of possible design configurations. Results from this third phase are reported at the end of this Section.

4.1 Unchanging Input Parameters

The following sections describe the (unchanging) input data that were applied to both models in both study phases.

4.1.1 Return Water Flow Rate

The following indicative seasonal discharge rates (based on predicted plant processing needs) were provided by BHP Billiton for consideration in this study:

Table 4-1 Indicative Seasonal Discharge Rates

Season	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Average Volume per Season (ML/d)	265	200	190	225
Annual Average Volume (ML/d)	220			

A total discharge flow rate of 265 ML/day (i.e. approximately 3.1 m^3/s) was selected, as agreed with BHP Billiton.

4.1.2 Return Water and Ambient Salinities

Ambient and return water salinities of 40g/L and 78 g/L were selected for this analysis, as agreed with BHP Billiton.

4.1.3 Ambient Current Speed

4.1.3.1 Roberts et al. (1997)

The Roberts *et al.* (1997) method assumes zero ambient current speed, and that value was adopted in this study.

4.1.3.2 CORMIX

In order to derive a current speed for CORMIX simulations, measured ambient tidal conditions at the proposed outfall location were interrogated (BMT WBM, 2009). They are presented in Figure 4-1 from the ADCP deployed at the proposed diffuser location (known as 'The Rip'). Refer to Figure 4-2 for the location.

In order to provide a conservative estimate of plume dilution (i.e. lower bound), we have adopted an ambient tidal velocity of 0.2 m/s, which corresponds to the 20th percentile above for use in the CORMIX simulations. This velocity value was chosen as the lowest velocity for which we felt comfortable applying CORMIX.

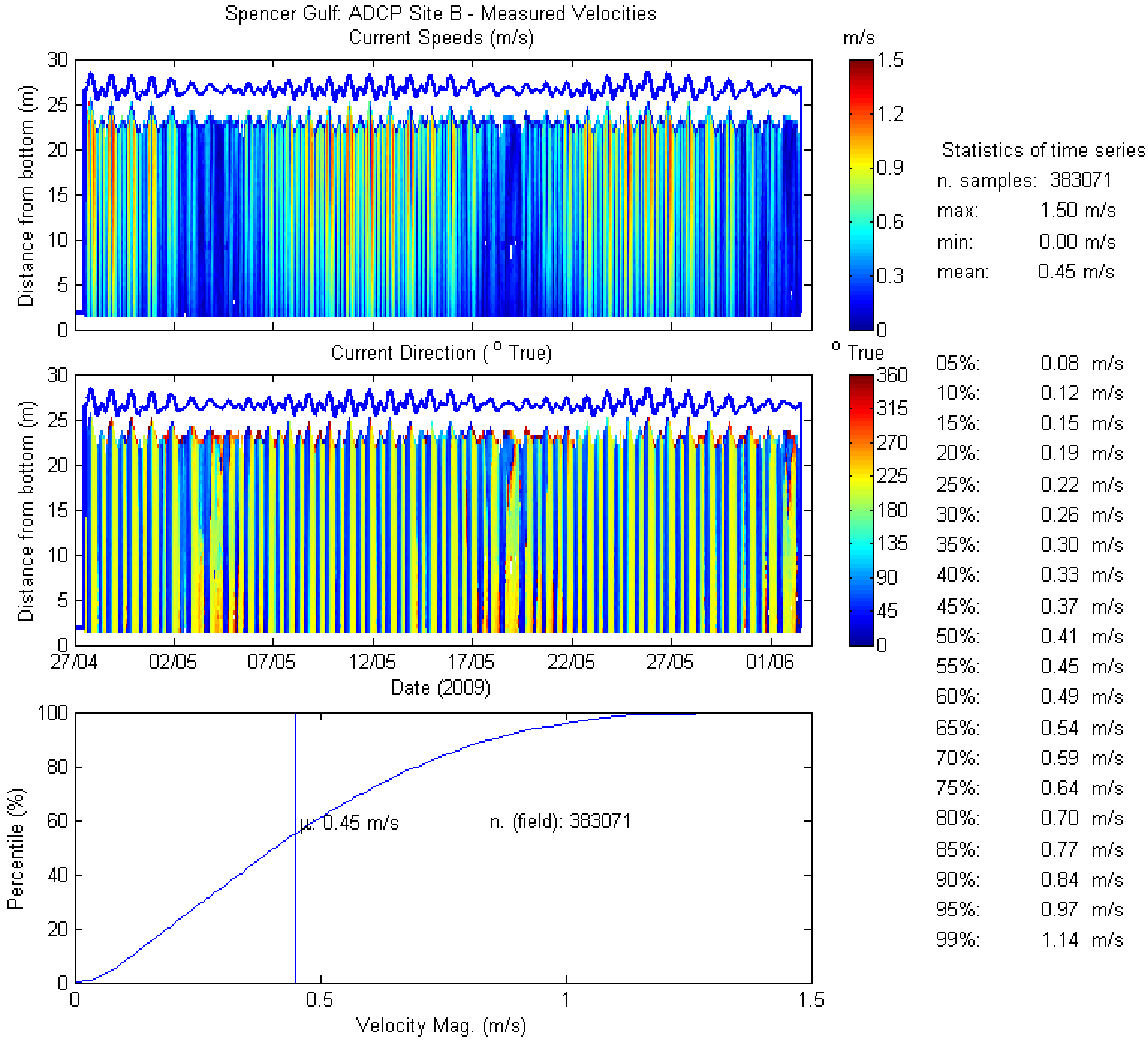

Figure 4-1 Spencer Gulf ADCP Site B (The Rip) – Measured Velocities

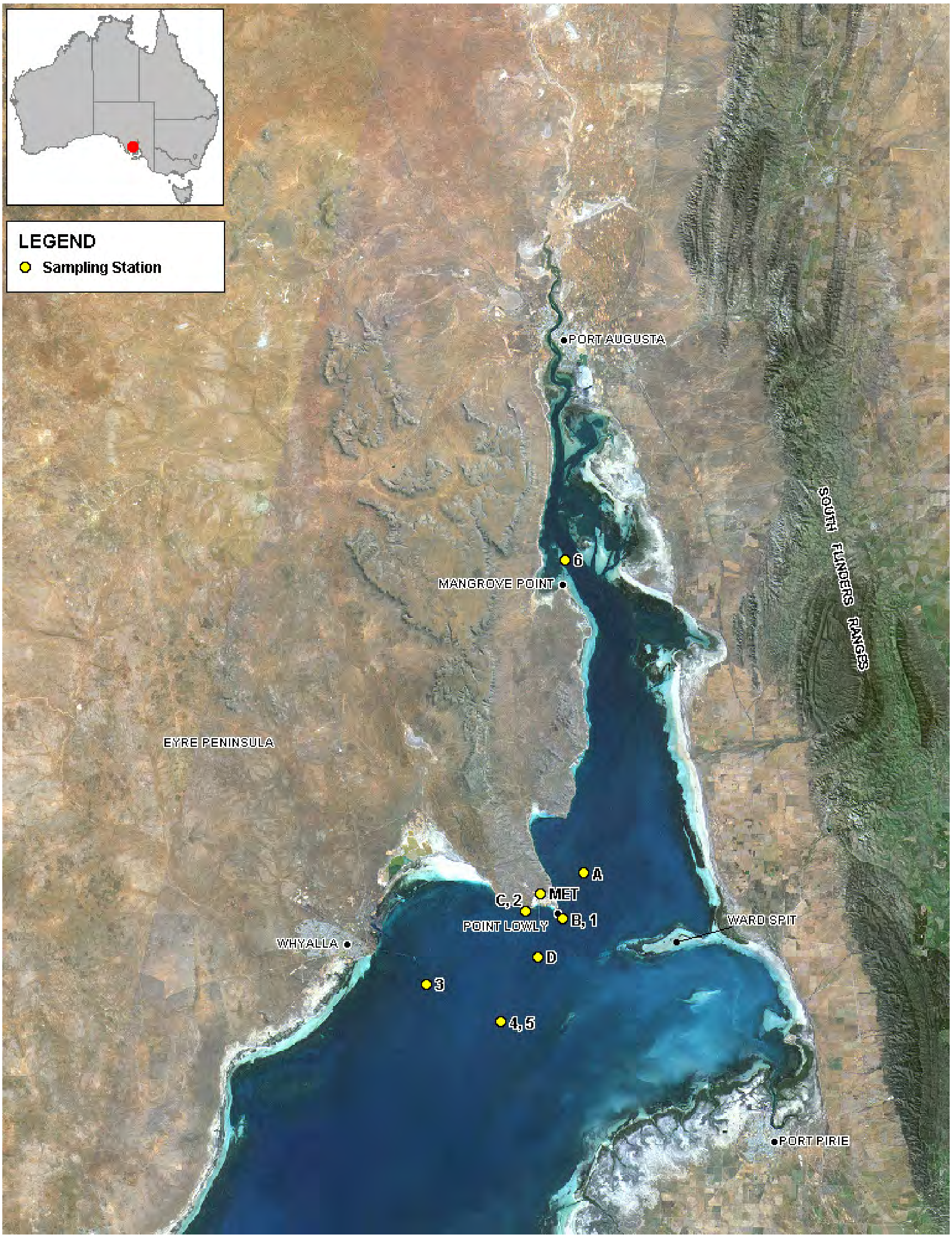

Figure 4-2 Spencer Gulf ADCP Site B (The Rip) Location

4.2 Phase 1: Screening Study

4.2.1 Parameters

In addition to the above, a number of configurational parameters play a role in plume hydrodynamics and subsequent dilution, and can be varied within an outfall diffuser design. These include:

- Port diameter;
- Number of ports;
- Port height above the seabed (within the water column);
- Port angle with respect to the current alignment (subsequently called SIGMA – see Figure 4-3b); and
- Port angle with respect to the horizontal plane (subsequently called THETA – see Figure 4-3c).

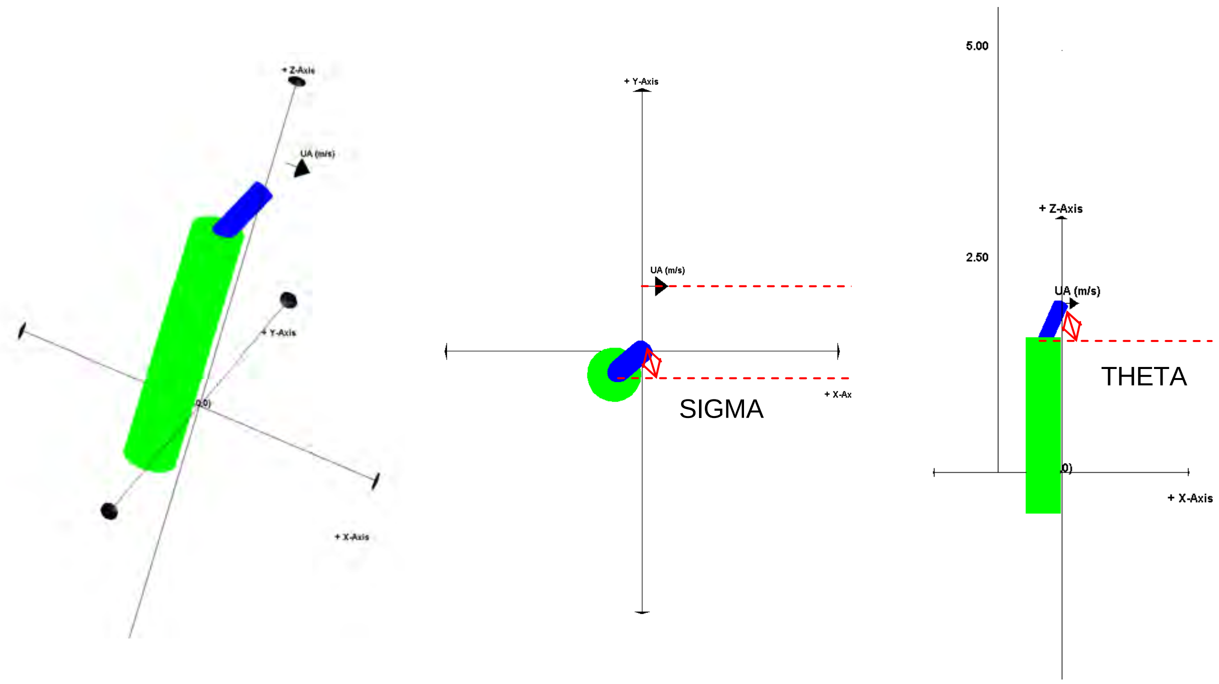

Figure 4-3 Example of Port Design (a. 3D View b. Plan View c. Vertical Section)

A number of initial screening analyses were thus performed to understand the broad impacts of varying these parameters on the predicted plume dilutions, particularly with regards to the sensitivity of results to changes in these parameters. These analyses were undertaken by varying a single parameter at a time. The results are described in the following sections via presentation of a series of response curves.

4.2.2 Response Curves

Figure 4-4 to Figure 4-8 present the impacts of various parameters on the predicted dilutions at plume bottom contact (dark blue line) and at 100m downstream of the diffuser (light blue line). These figures correspond to the following configurations (unless parameters were varied, and if so this variation is reflected by the abscissa of each figure):

- Port diameter: 0.175m
- Number of ports: 50
- Port height: 2m above seabed
- Angle to ambient current: 0 degrees
- Angle to horizontal plane: 60 degrees

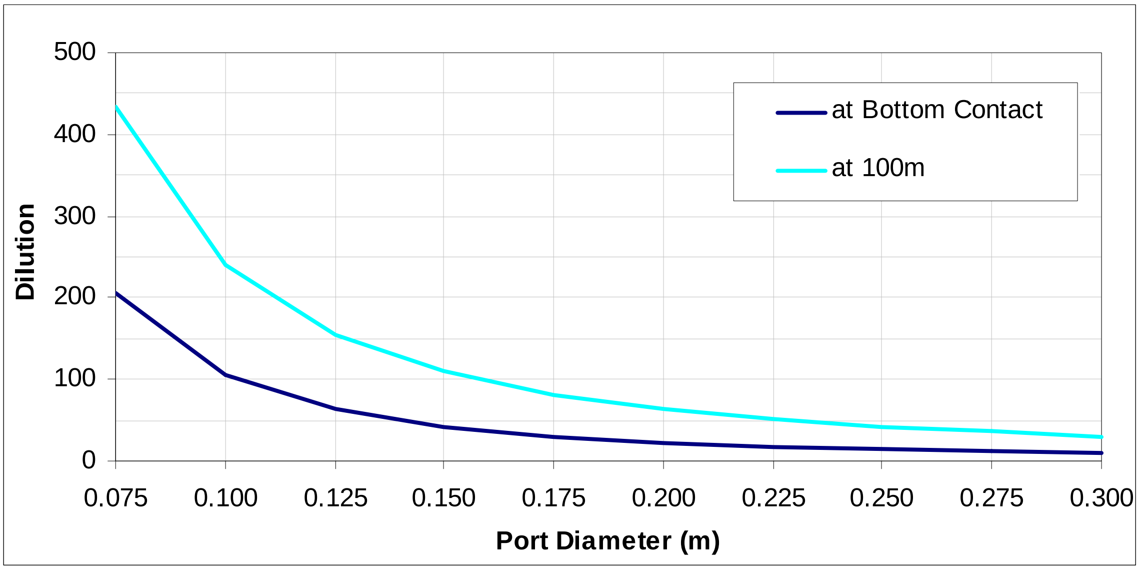

Figure 4-4 Dilution vs. Port Diameter

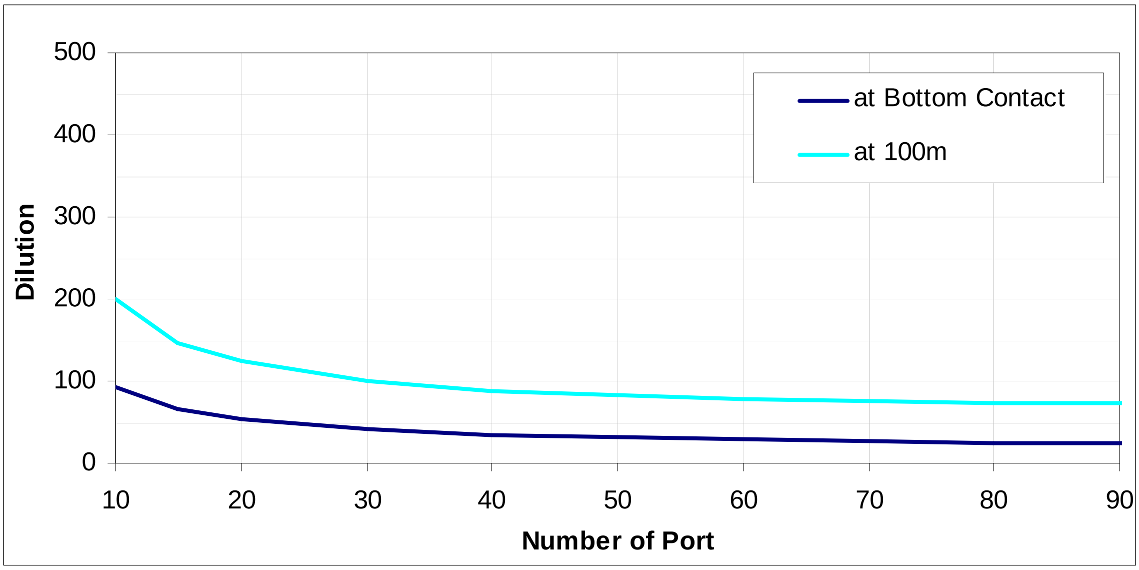

Figure 4-5 Dilution vs. Number of Ports

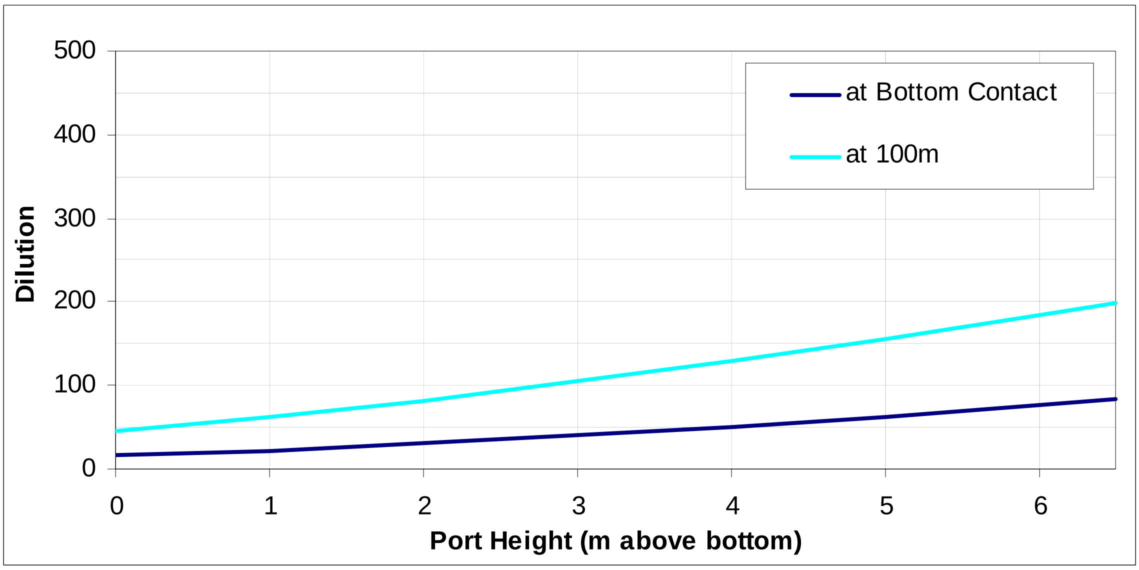

Figure 4-6 Dilution vs. Port Height above Seabed

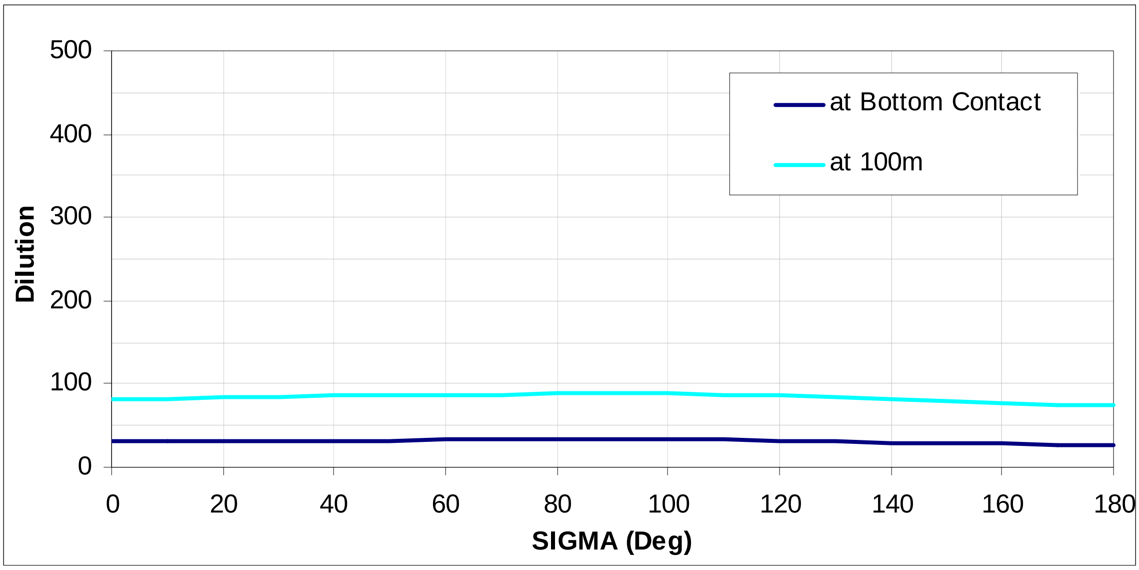

Figure 4-7 Dilution vs. Angle to Ambient Current

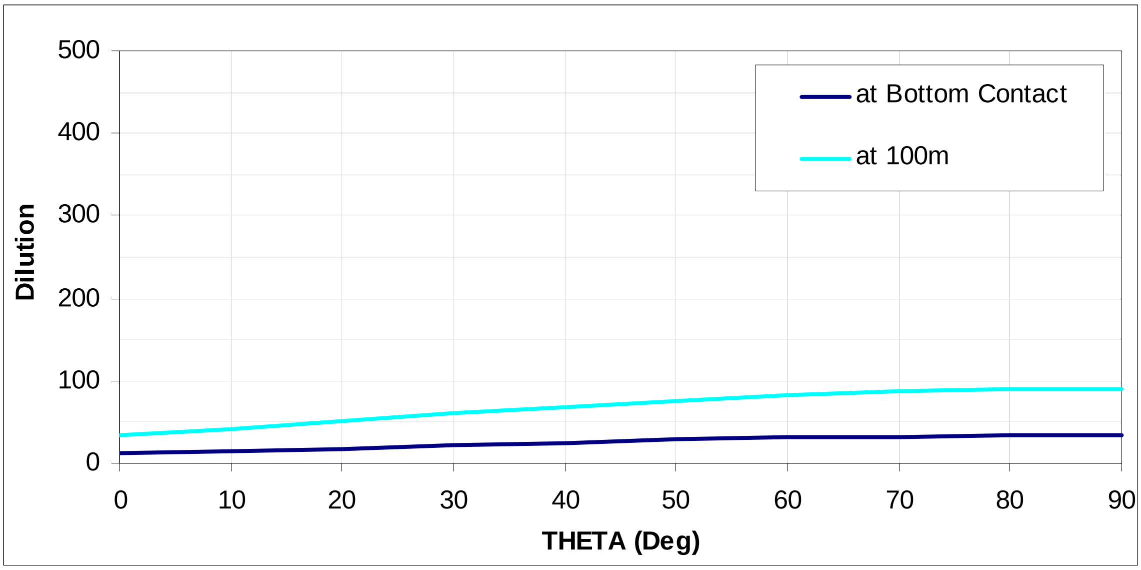

Figure 4-8 Dilution vs. Angle to Horizontal Plane

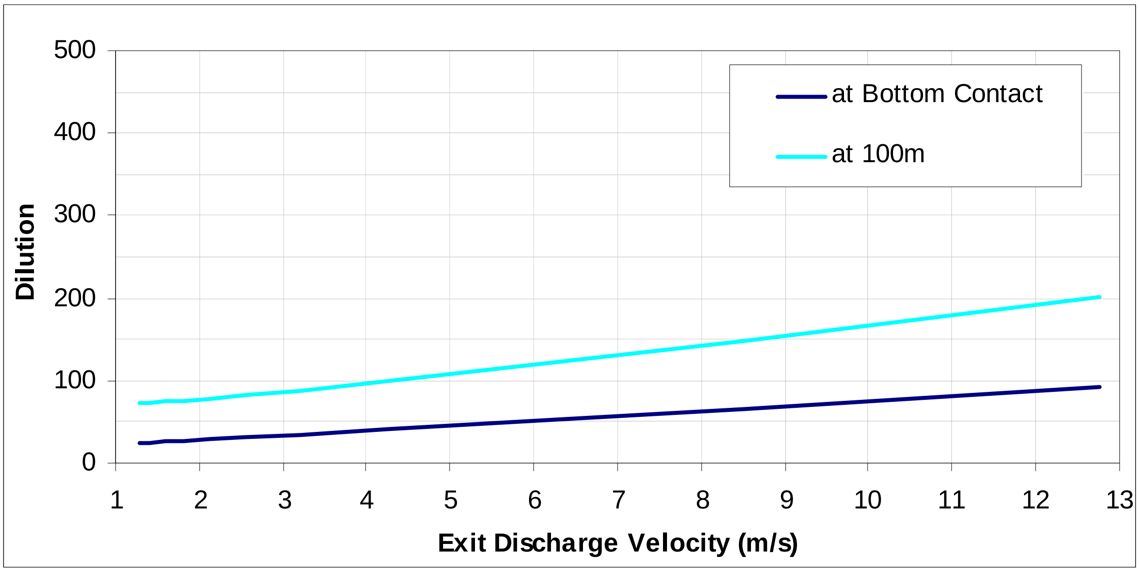

Figure 4-9 Dilution vs. Port Exit Discharge Velocity

The figures highlight the following key features:

- Predicted dilutions are very sensitive to the port diameter, especially over the lower ranges. Notwithstanding this, slope of the curves flatten considerably above diameters of approximately 0.25 m. It is noted that common practice usually recommends use of diameter greater than 0.1m (Cardno Lawson Treloar, 2008).
- Figure 4-5 shows that dilution increases for a smaller number of ports, with the rate of change of dilution increasing with decreasing number of ports. This reflects the fact that for a given flow rate, the port exit discharge velocity per port will increase with decreasing numbers of ports.
- Figure 4-6 shows that port height above the seabed also plays a significant role in the downstream dilution of discharged plumes. This is because the higher the port, the longer the trajectory of the plume through the water column, and the greater potential for mixing to occur prior to the plume interacting with the seabed. It is noted that design for both the Adelaide and the Perth Desalination Plants have previously adopted buried pipelines with 1m high tee risers resulting in discharge port heights above the seabed of 1m (Cardno Lawson and Treloar, 2008).
- Plume dilutions are not sensitive to the angle SIGMA (i.e the angle between the port and the ambient current).
- Plume dilutions are not very sensitive to the angle THETA (i.e. the angle between the port and the horizontal plane). Notwithstanding this, dilution values seem to reach a peak (for the configuration considered) for an angle of 60 to 70 degrees. Roberts and Toms (1987) previously demonstrated that the highest plume trajectory and dilution arise at a discharge orientation of 60 degrees from the horizontal, consistent with our results.
- Additional information is presented in Figure 4-9 which shows the predicted dilution against the port exit discharge velocity. This figure clearly shows that the dilution increases with discharge velocity, with an almost-linear relationship. It is worth noting that there is a limit to this relationship in that it is truncated when plumes interact with the free surface (which is not desirable). This is further discussed in Section 4.3.2.

4.2.3 Summary

Based on the above it was elected to vary the following parameters:

- Port diameter: 0.1 to 0.2m
- Exit Velocity: 1 to 10 m/s
- Port Height: 0 to 6m above seabed

The following were kept constant in all simulations:

- Return water salinity: 78g/L (i.e. 1058 kg/m^3 density)
- Ambient salinity: 40g/L (i.e. 1030 kg/m^3 density)
- Flow rate: 265 ML/d
- Theta: 60°
- Sigma: 0°
- Ambient current velocity: 0m/s for Roberts *et. al* assessments and 0.2m/s for CORMIX assessments

4.3 Phase 2: Assessments

Results from both the Roberts *et al.* (1997) and CORMIX modelling studies are reported and described below.

4.3.1 Roberts *et al.* (1997)

The Roberts *et al.* (1997) method was applied to compute dilution at bottom contact for the range of varying exit discharge velocities and port diameters specified above. It is again noted that this method assumes a still receiving environment (i.e. zero current velocity) and a port located at the seabed level (i.e. zero port height). Results are presented in Table 4-2, as well as graphically in Figure 4-10 and Figure 4-11, respectively against the port exit discharge velocity and the port diameter.

Table 4-2 Roberts Method Dilution at Bottom Contact

Port Diameter (m)		0.1	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.2
Port Exit Discharge Velocity (m/s)	1	9.8	9.3	8.9	8.6	8.3	8.0	7.7	7.5	7.3	7.1	6.9
	2	19.6	18.7	17.9	17.2	16.6	16.0	15.5	15.0	14.6	14.2	13.9
	3	29.4	28.0	26.8	25.8	24.8	24.0	23.2	22.5	21.9	21.3	20.8
	4	39.2	37.4	35.8	34.4	33.1	32.0	31.0	30.1	29.2	28.4	27.7
	5	49.0	46.7	44.7	43.0	41.4	40.0	38.7	37.6	36.5	35.5	34.6
	6	58.8	56.1	53.7	51.6	49.7	48.0	46.5	45.1	43.8	42.6	41.6
	7	68.6	65.4	62.6	60.2	58.0	56.0	54.2	52.6	51.1	49.8	48.5
	8	78.4	74.7	71.6	68.7	66.2	64.0	62.0	60.1	58.4	56.9	55.4
	9	88.2	84.1	80.5	77.3	74.5	72.0	69.7	67.6	65.7	64.0	62.4
	10	98.0	93.4	89.4	85.9	82.8	80.0	77.5	75.1	73.0	71.1	69.3

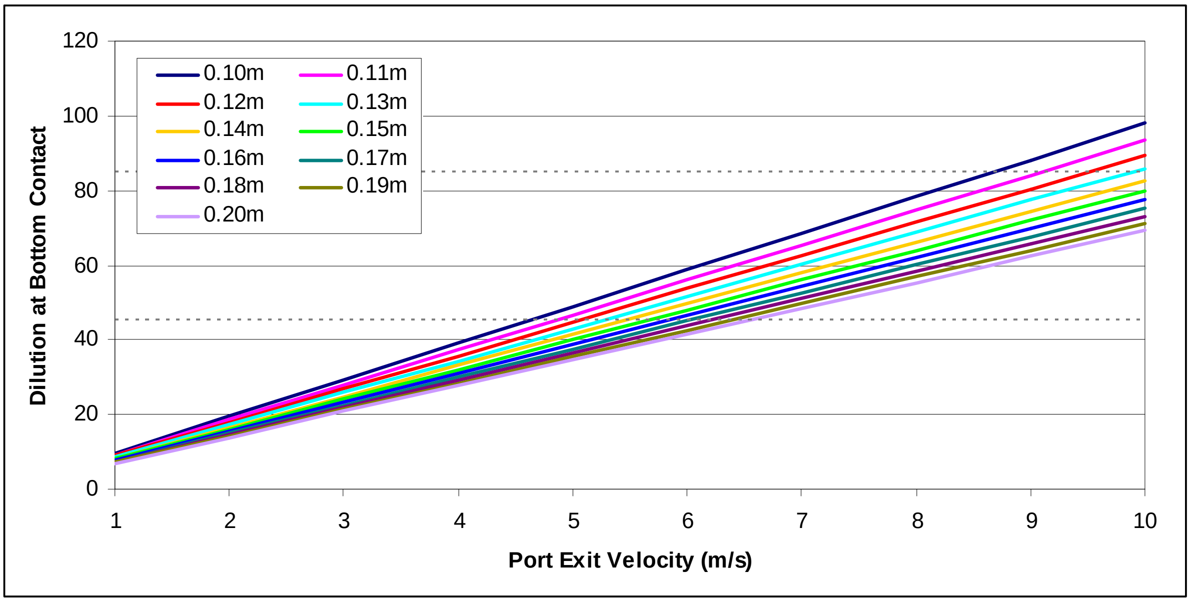

Figure 4-10 Dilution vs. Port Exit Discharge Velocity for a range of Port Diameters

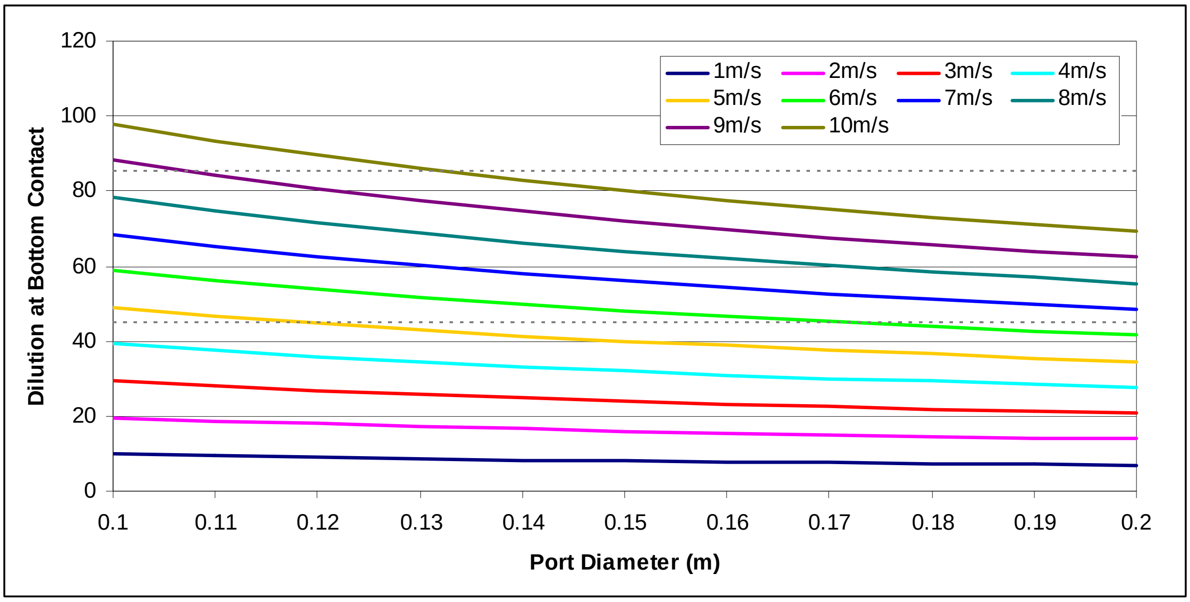

Figure 4-11 Dilution vs. Port Diameter for a range of Port Exit Discharge Velocities

Contours were created in the same manner as for the CORMIX assessments results (see Section 4.3.2) for both the dilution at bottom contact and the number of ports. They are shown in two separate figures, as follows:

- Figure 4-12: The colour contours specify the predicted dilution at the plume contact with the seabed at every 10 units, based on the colour scale shown at the top of the figure. The white dashed line indicates the 45:1 dilution contour, and the red dashed line indicates the 85:1 dilution contour; and
- Figure 4-13: The colour contours specify the number of ports required to meet the total flow rate of 265 ML/d for each diameter/discharge velocity configuration, based on the colour scale shown at the top of the figure, at every 10 units. The black dashed line indicates the 50 ports contour.

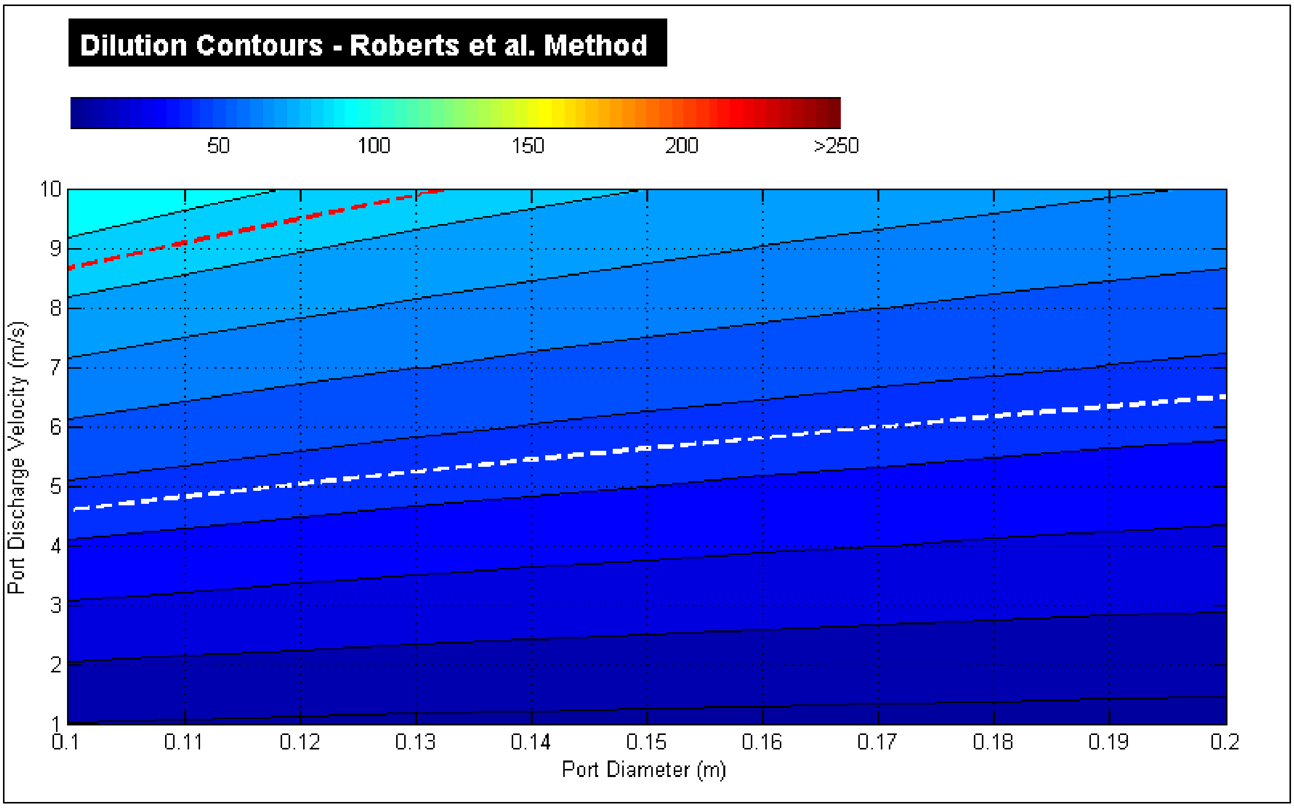

Figure 4-12 Dilution Contours – Roberts *et al.* Method

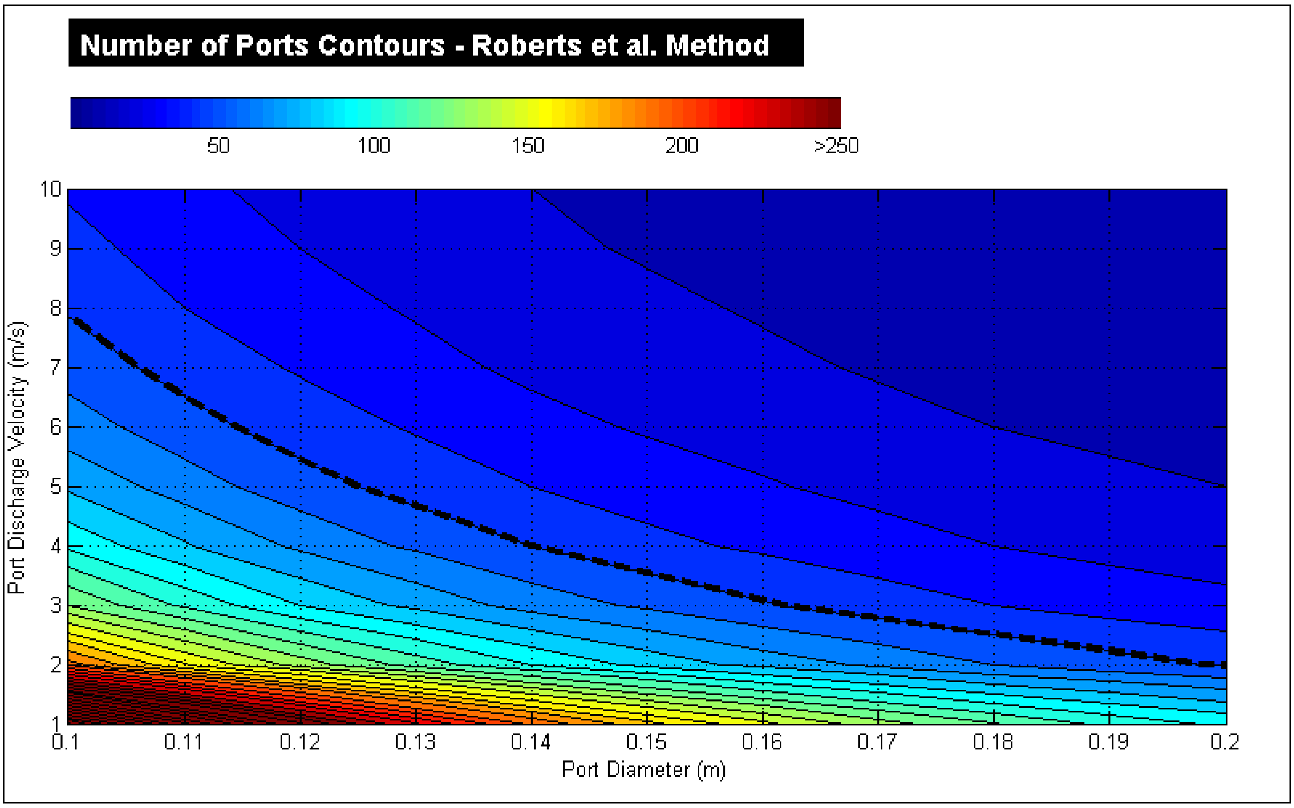

Figure 4-13 Number of Ports Contours – Roberts *et al.* Method

4.3.2 CORMIX

Based on the findings of phase 1 (Section 4.2.3), three parameters were varied:

- port height above the seabed;
- port discharge velocity; and
- port diameter.

To demonstrate the influence of these parameters on downstream dilution, contour plots of dilution (both at the plume contact with the seabed and at a distance 100m downstream of the diffuser) were generated for these parameters across their ranges. The following contours are presented at the end of this section:

- Figure 4-15: Dilution contours for a set port diameter of 0.2m (maximum considered) and varying port height (from 0 – i.e. at the seabed – to 6 m) and port discharge velocity (from 1 to 10 m/s);
- Figure 4-16: Dilution contours for a set port diameter of 0.1m (minimum considered) and varying port height (from 0 – i.e. at the seabed – to 6 m) and port discharge velocity (from 1 to 10 m/s);
- Figure 4-17: Dilution contours for a set port discharge velocity of 3 m/s and varying port height (from 0 – i.e. at the seabed – to 6 m) and port diameter (from 0.1 to 0.2m); and
- Figure 4-18: Dilution contours for a set port discharge velocity of 6 m/s and varying port height (from 0 – i.e. at the seabed – to 6 m) and port diameter (from 0.1 to 0.2m).

The colour contours specify the predicted dilution at every 10 units, based on the colour scale shown at the top of each figure. For each figure, the top panel presents the dilution at the plume contact with the seabed, and the bottom panel presents the dilution at a distance 100m downstream of the diffuser. Additional information is provided on these diagrams as follows:

- The white dashed line indicates the 45:1 dilution contour;
- The red dashed line indicates the 85:1 dilution contour;
- The black box indicates a zone where the proposed design showed potential interaction of the plume with the surface of the water, i.e. the total plume height was predicted to reach a total height within 5m of the surface of the water column (or above in some instances); and
- The corresponding number of ports required to meet the total flow rate of 265 ML/d is provided on an axis to match the port discharge velocity and/or diameter.

In addition, the total length of the diffuser necessary to meet each tested design, assuming no interaction of the plume at the end of the Near Field zone was also computed. The following colour contours are reported at the end of this section:

- Figure 4-19: Diffuser length contours for a set port diameter of 0.2m (maximum considered) and varying port height (from 0 – i.e. at the seabed – to 6 m) and port discharge velocity (from 1 to 10 m/s);
- Figure 4-20: Diffuser length contours for a set port diameter of 0.1m (minimum considered) and varying port height (from 0 – i.e. at the seabed – to 6 m) and port discharge velocity (from 1 to 10 m/s);

- Figure 4-21: Diffuser length contours for a set port discharge velocity of 3 m/s and varying port height (from 0 – i.e. at the seabed – to 6 m) and port diameter (from 0.1 to 0.2m); and
- Figure 4-22: Diffuser length contours for a set port discharge velocity of 6 m/s and varying port height (from 0 – i.e. at the seabed – to 6 m) and port diameter (from 0.1 to 0.2m).

The colour contours specify the predicted diffuser length every 20m, based on the colour scale shown at the top of each diagram. The thick dashed black line indicates the 600m contour.

Table 4-3 presents examples of three design features and associated dilutions determined using these diagrams. The port spacing and associated total diffuser length are provided here for information, based on the assumption that the plume from each individual port do not overlap at the end of the near field zone. This is a conservative assumption in terms of diffuser length (i.e. it will lead to back-calculation of an upper limit on diffuser length), and the port spacing could potentially be reduced (as discussed previously). For instance, assuming that plumes can overlap once a dilution of 85:1 is reached, the port spacing would be reduced to only 4m in example 1 and 5m in example 2, with resulting diffuser lengths of only 260m and 225m respectively. Further gains are possible in this regard if 1:45 dilution is used.

Table 4-3 Examples of Design

Design Feature 1	Value
Port Diameter	0.1 m
Port Discharge Velocity	6 m/s
Port Height above seabed	2 m
Dilution at Bottom Contact	88:1
Dilution at 100m	212:1
Number of Ports Required[1]	65
Port Spacing[2]	10m
Total Diffuser Length[2]	645m

Design Feature 2	Value
Port Diameter	0.12 m
Port Discharge Velocity	6 m/s
Port Height above seabed	3 m
Dilution at Bottom Contact	88:1
Dilution at 100m	205:1
Number of Ports Required[1]	45
Port Spacing[2]	12m
Total Diffuser Length[2]	550m

The full range of existing current velocities at Point Lowly were subsequently modelled for example 2 as described above, in order to provide an understanding of the potential increase in dilution for larger ambient velocities (i.e. >0.2m/s). Results are reported in Figure 4-14. The Roberts *et al.* (1997) predicted dilution for a still environment has also been reported on this figure for completeness (the intersection of the dashed line with the ordinate). However, it is noted that this dilution applies to a port height of zero (i.e. at the seabed) rather than at 2m as per example 2.

[1] For total flowrate of 265 ML/day.
[2] Based on the assumption that individual plumes don't overlap at the end of the Near Field zone.

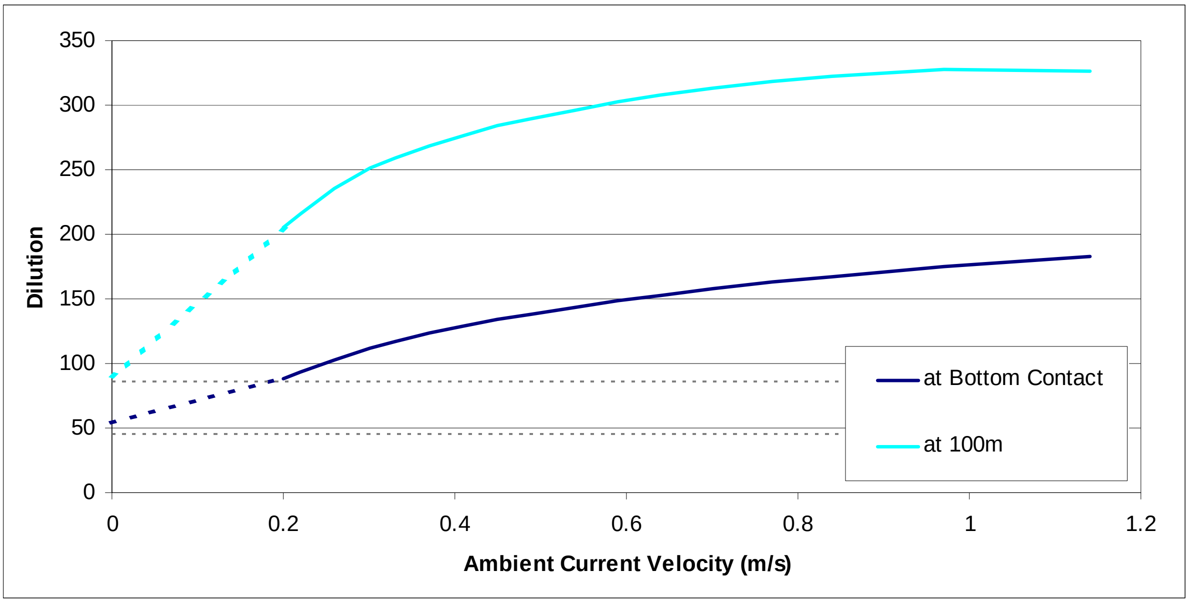

Figure 4-14 Dilution vs. Ambient Current Velocity for Example 2 Design

It is noted that the current CORMIX assessments are intended to provide some bounds of possible design and associated predicted dilutions, rather than full details of every design. Once a design is selected, further assessments can be carried out at a later stage using CFD modelling tools.

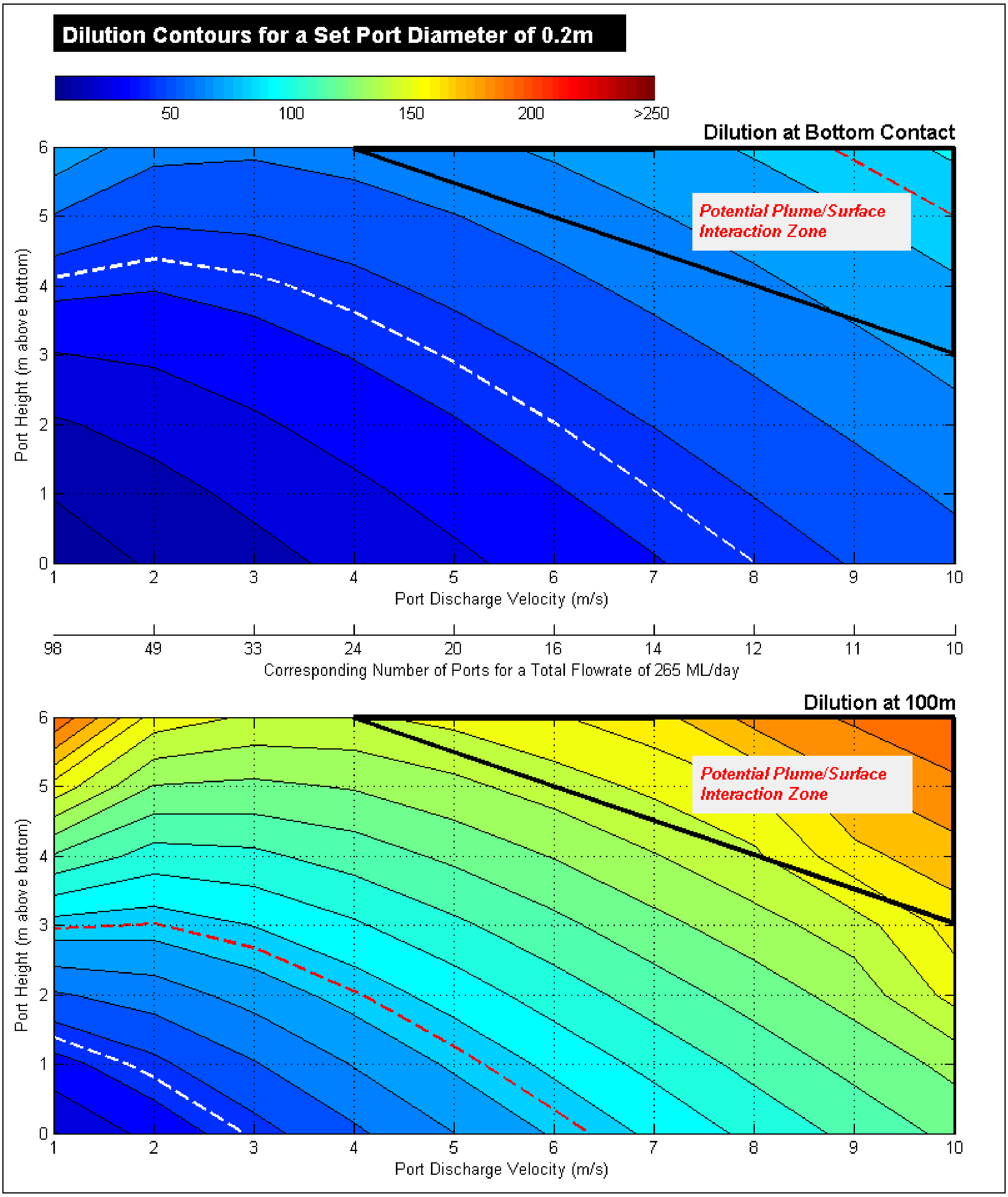

Figure 4-15 Dilution Contours – Port Diameter 0.2m

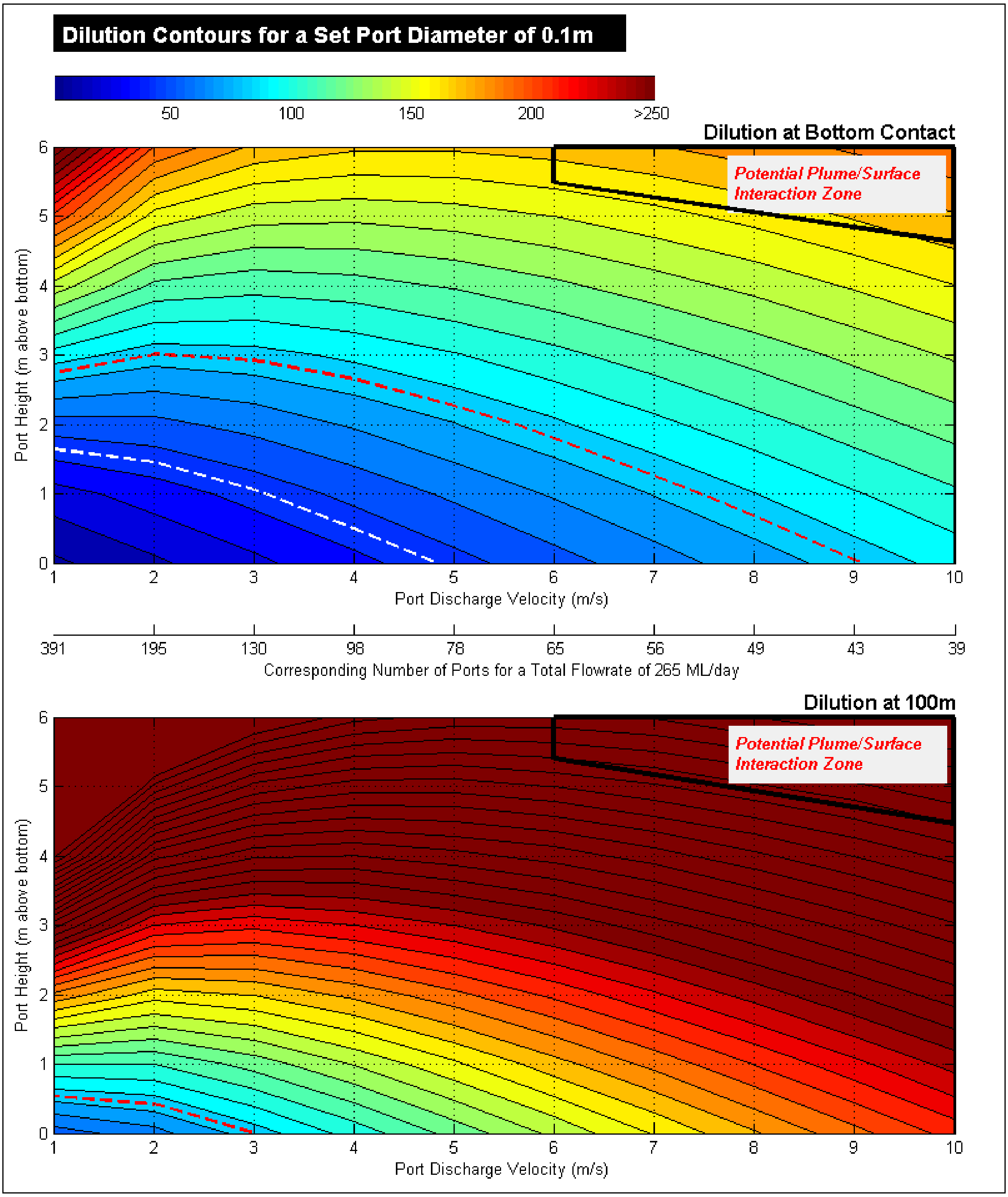

Figure 4-16 Dilution Contours – Port Diameter 0.1m

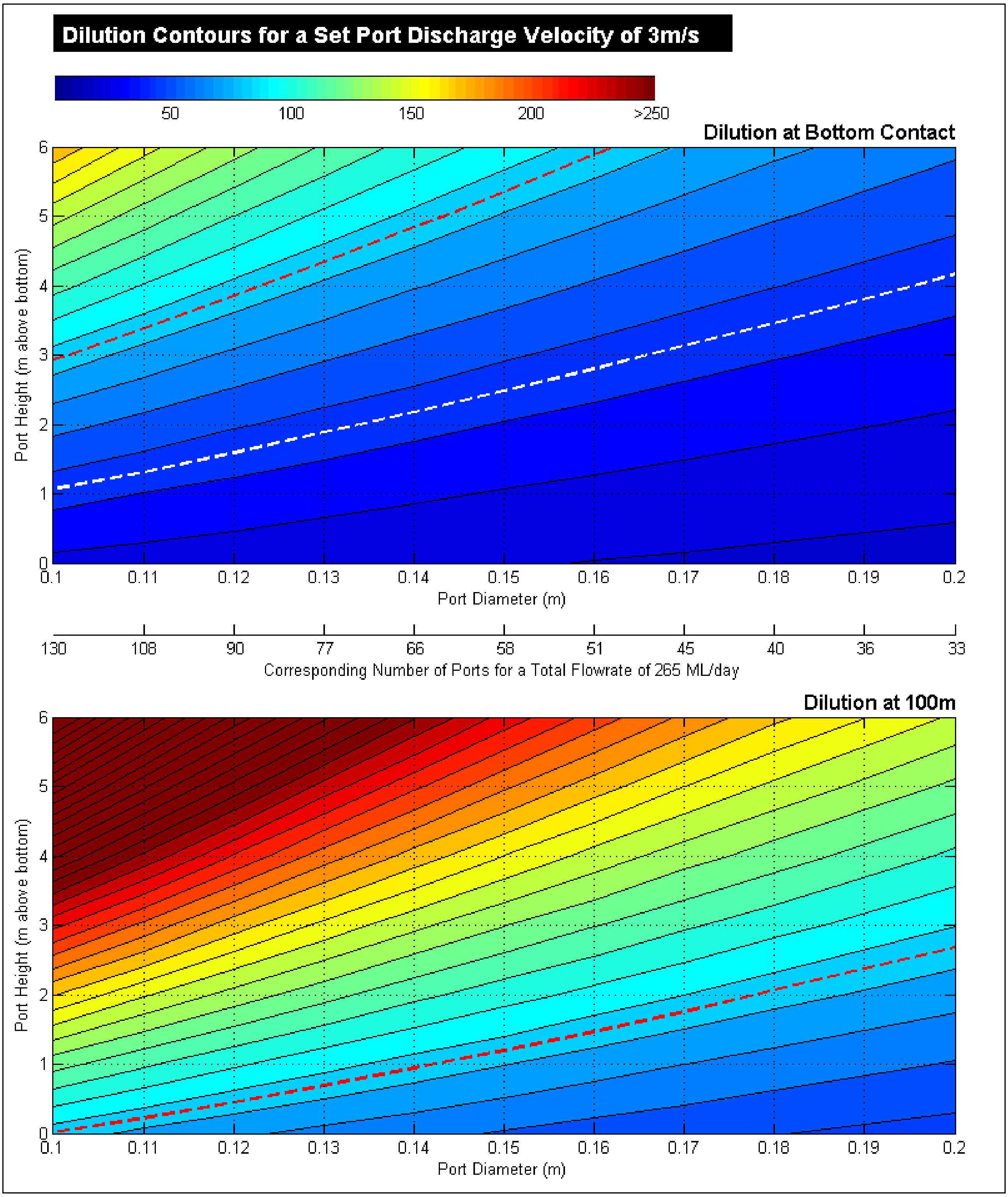

Figure 4-17 Dilution Contours – Port Discharge Velocity 3 m/s

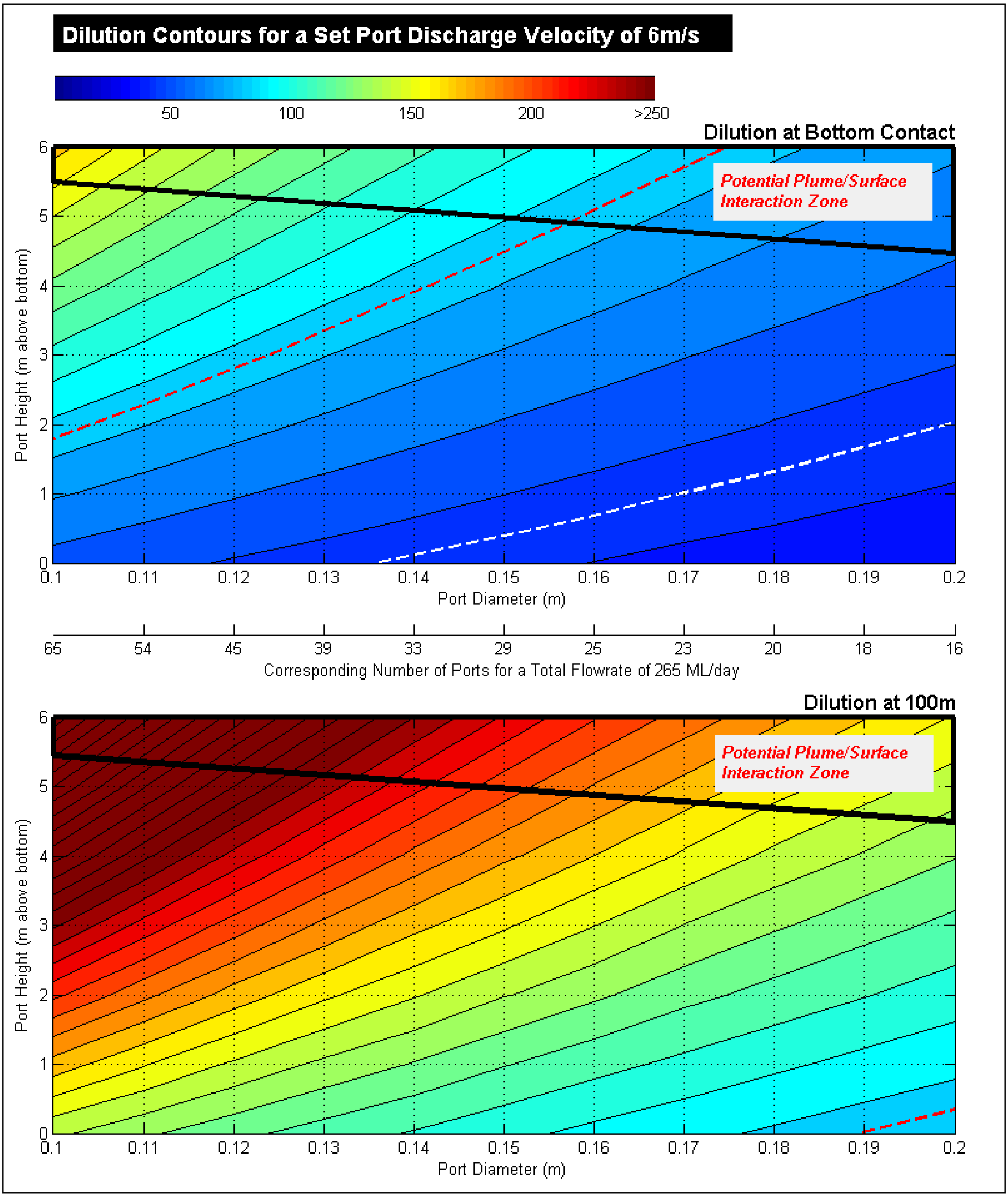

Figure 4-18 Dilution Contours – Port Discharge Velocity 6 m/s

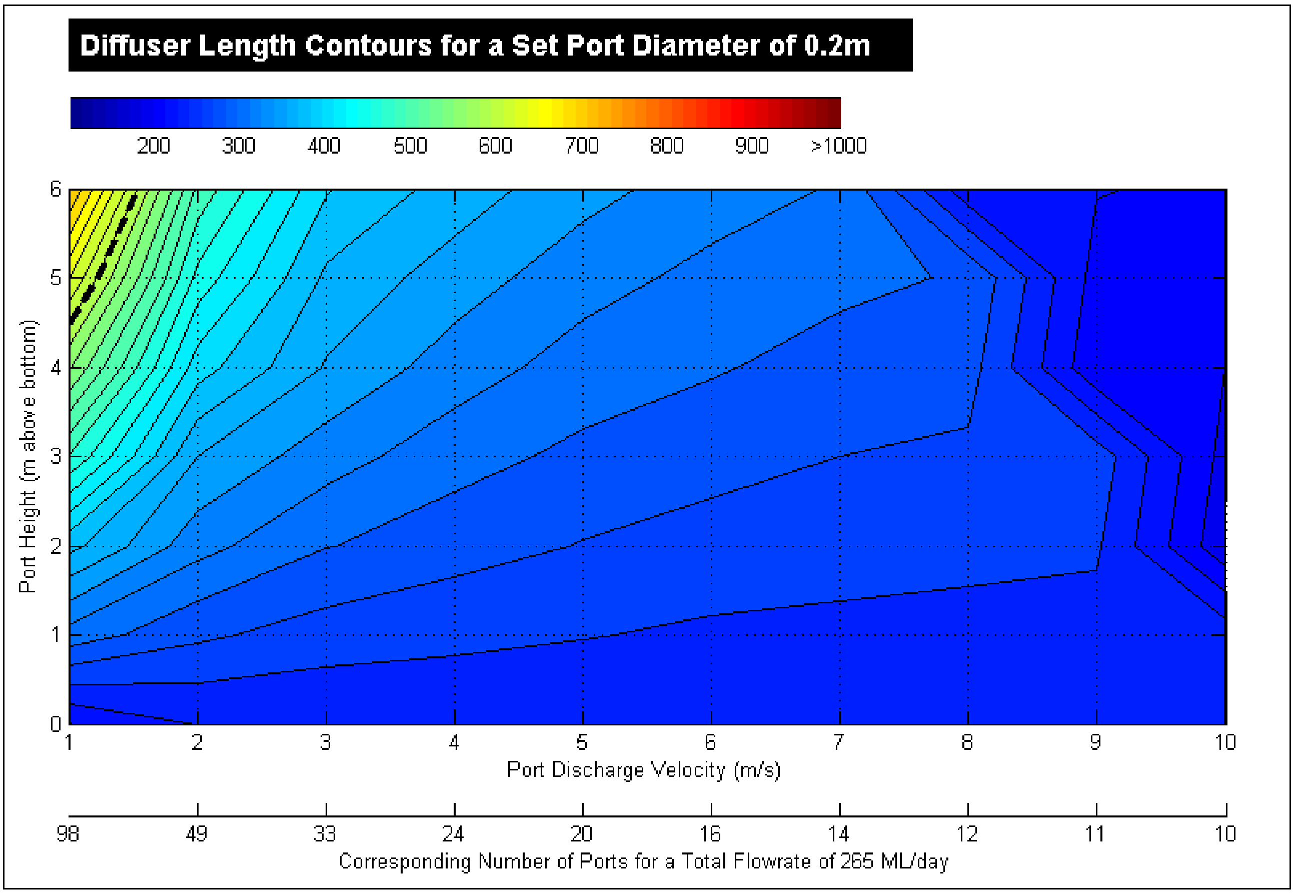

Figure 4-19 Diffuser Length Contours – Port Diameter 0.2m

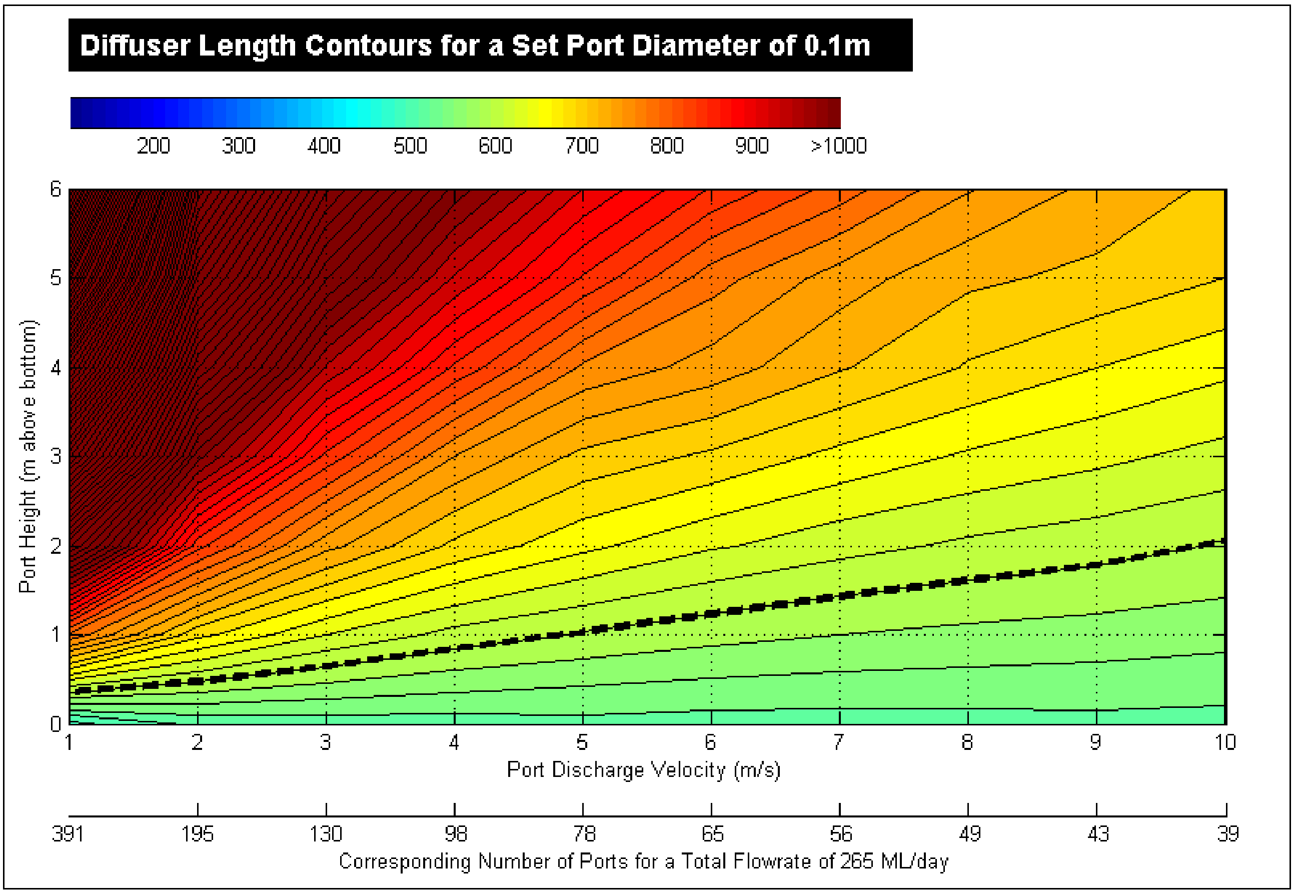

Figure 4-20 Diffuser Length Contours – Port Diameter 0.1m

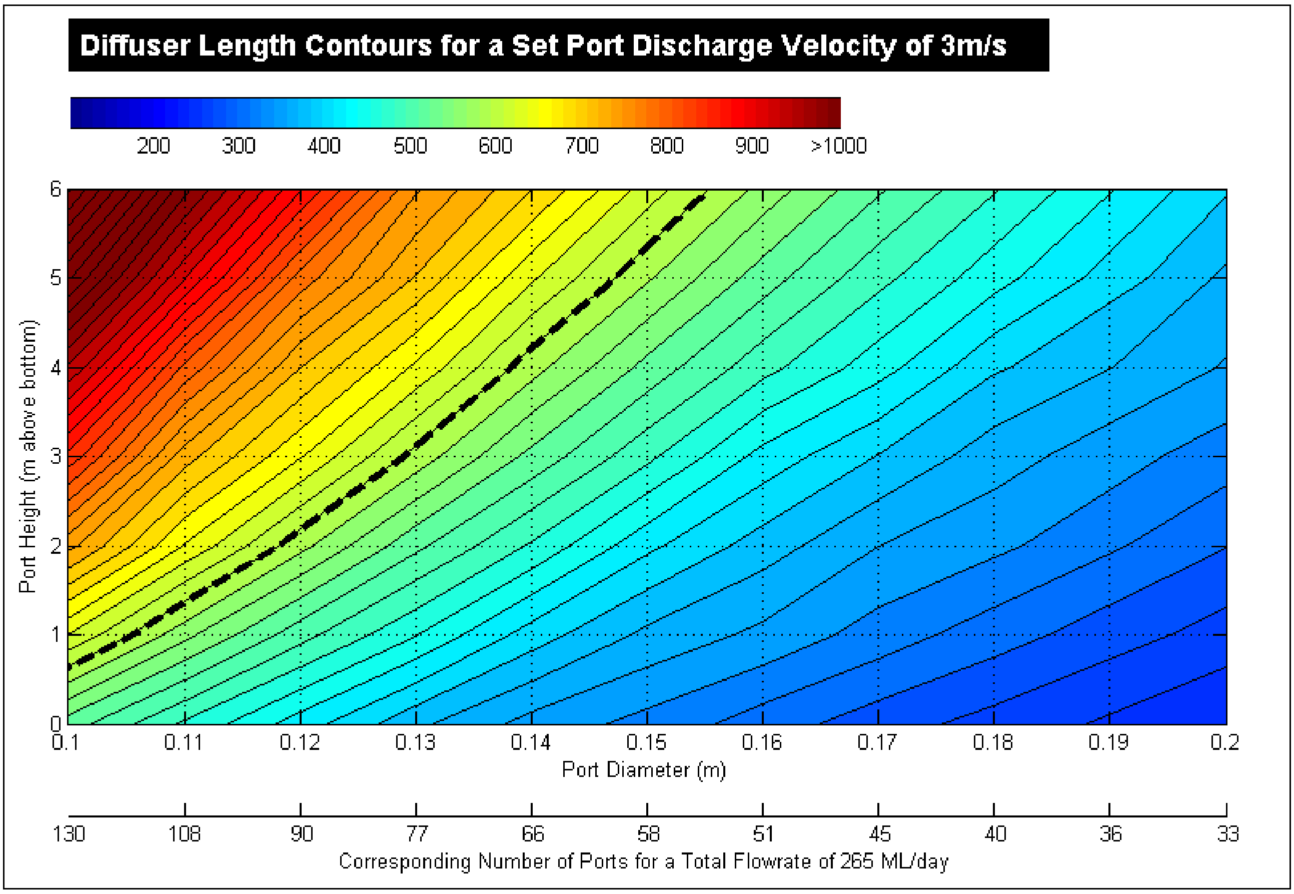

Figure 4-21 Diffuser Length Contours – Port Discharge Velocity 3 m/s

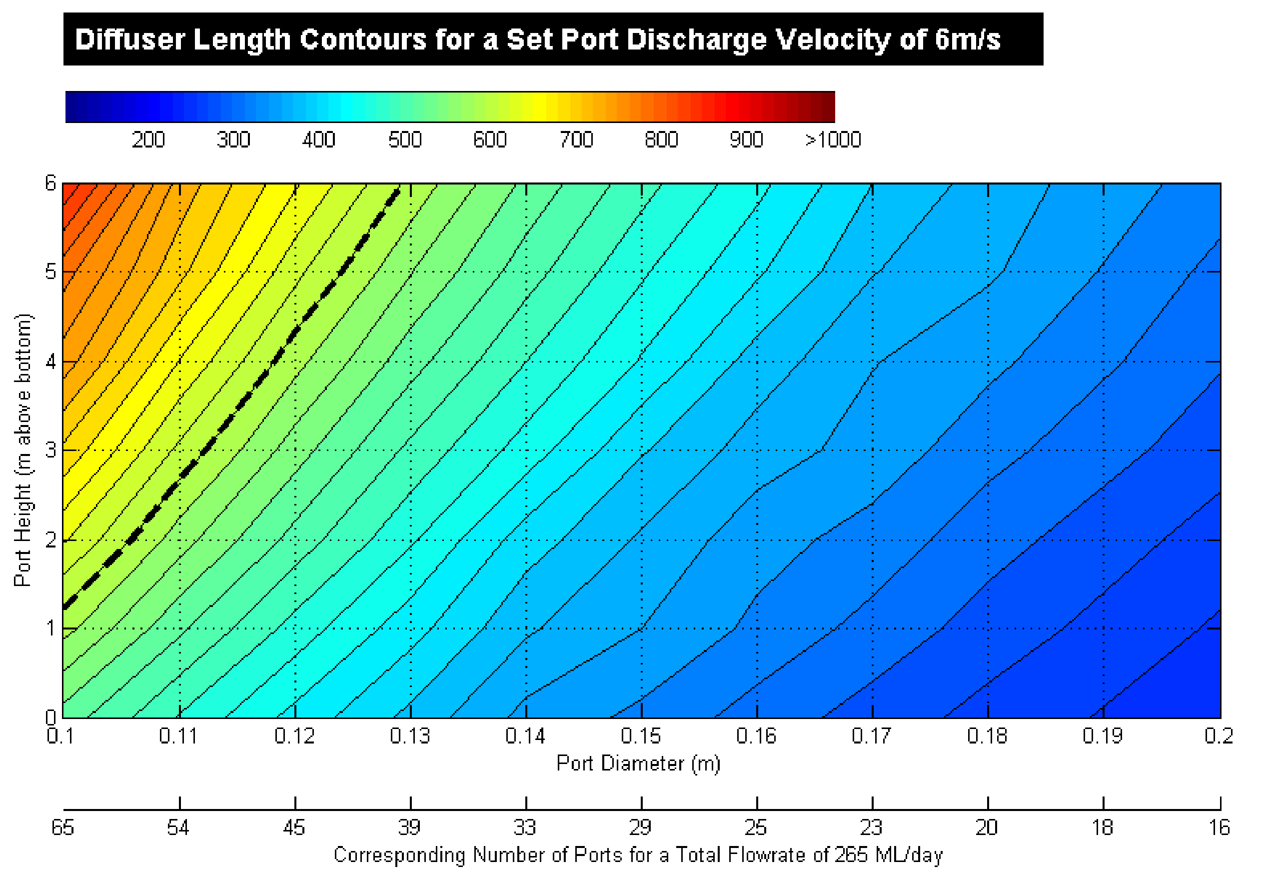

Figure 4-22 Diffuser Length Contours – Port Discharge Velocity 6 m/s

4.4 Phase 3: Diffuser Operating Pressure

As discussed previously, the assessments presented above do not specifically take into account the gravity pressure available from the plant to the diffuser, but rather are focused on a hypothetical range of port exit velocities.

In this section, predictions from an in-house Excel spreadsheet are presented to narrow the range of possible combinations presented above and to provide some real world context for the CORMIX predictions. Predicted dilutions are computed using the Roberts *et al.* method.

4.4.1 Model Parameters

The following parameters were considered in the spreadsheet:

- Main pipe pressure loss (including entry losses and friction losses through the diffuse length);
- Risers entry and exit losses, as well as friction losses;
- Available gravity head above water; and
- Additional head due to water depth above diffuser.

4.4.2 Model Validation

Following construction, the spreadsheet was validated for the Adelaide Desalination Plant configuration (Cardno Lawson Treloar 2008), as follows:

Table 4-4 Adelaide Desalination Plant Configuration

Parameter	Value
Brine Density	1044.6 kg/m^3
Background Density	1025.7 kg/m^3
Volume Flow Rate	5.47 m^3/s
Main Pipe Diameter	1.496 m
Main Pipe Length	1450 m
Diffuser Length	246 m
Main Pipe Entry Loss	0.2
Risers Length	1 m
Risers Entry and Exist Losses	1.2
Friction Factor	0.015[1]
Available Gravity Head above Water	10.7 m
Port Depth below Water	17.5 m
Number of Ports	84

For this configuration, our model predicted a required port diameter of 0.11m for an exit velocity of 6.9m/s. The associated Roberts *et al.* dilution predictions are shown in

Table 4-5. This table shows that our model is consistent with the calculations for the Adelaide Desalination Plant EIS, particularly with regards to dilutions. It is noted that the predictions do not match exactly, but this is most likely due to the inclusion of tee risers is the ADP configuration, and these were not part of the calculations in the BMT WBM spreadsheet.

[1] The friction factor is determined based on a HDPE material and an associated roughness height of 0.5mm for a diffuser diameter of 1.496m as stated in the ADP supplementary report.

Table 4-5 Roberts *et al.* Method – Adelaide Desalination Plant

Parameter	BMT WBM Model Prediction	SA Water (2009)
Port Densimetric Froude Number	48.9	48.6
Dilution at Impact Point	78.4	78
Location of Impact Point (m from port)	12.9	9.2
Dilution at Downstream Layer	127.4	126
Location of Downstream Layer (m from port)	48.3	48.1
Plume Height (m above riser)	11.8	11.8
Downstream Layer Thickness	3.8	3.7

4.4.3 Point Lowly Analysis

4.4.3.1 Initial Configuration

Using the model validated above, the initial configuration was simulated following email advice from BHP Billiton:

Table 4-6 Initial Configuration

Parameter	Value
Brine Density	1058 kg/m^3
Background Density	1030 kg/m^3
Volume Flow Rate	3.07 m^3/s
Main Pipe Diameter	2.1 m
Main Pipe Length (estimated)	500 m
Diffuser Length	200 m
Main Pipe Entry Loss	0.2
Risers Length	1 (2 or 3) m
Risers Entry and Exist Losses	1.2
Friction Factor	0.014[2]
Available Gravity Head above Water	30 m
Port Depth below Water	16.9 m

[2] The friction factor is determined based on a HDPE material and an associated roughness height of 0.5mm for a diffuser diameter of 2.1m, similar to the ADP approach.

It is noted that it is not possible to fix both the number of ports and port diameter within the constraints set by data in the above table and still meet the total discharge requirement (which we understand is critical). As such, two configurations were simulated:

- Configuration 1: 50 ports – In this configuration, a port diameter of 0.062m is required to meet the total discharge requirements; and
- Configuration 2: 0.175m diameter ports – In this configuration, 6 ports are required to meet the total discharge requirements.

These results, together with dilutions, are presented in Table 4-7.

Table 4-7 Roberts *et al.* Method – Configurations 1 and 2

Parameter	Configuration 1	Configuration 2
Exit Velocity (m/s)	20.4	21.5
Port Densimetric Froude Number	158.9	100.0
Dilution at Impact Point	254	160
Location of Impact Point (m from port)	23.6	41.7
Dilution at Downstream Layer	413	260
Location of Downstream Layer (m from port)	88.5	156.5
Plume Height (m above riser)	21.6	38.3
Downstream Layer Thickness	6.9	12.2

The table shows that in both cases, the port exit velocities are greater than 20m/s, which are unreasonably large. The table also shows that the plume heights are very large (notwithstanding that it is possible that these predictions are beyond the range of valid values within the Roberts *et al.* method) and, most importantly, exceed the available water depth. This is due primarily to the combination of utilising the full gravity head available (30m), the relatively low flow rate (ADP was 5.47 m^3/s) and the large main pipe diameter (2.1m, ADP was 1.496 m). These conspire to reduce frictional and pressure losses through the system and deliver very high exit velocities.

To demonstrate this, we re-visited the ADP spreadsheet calculations, and applied the full 20m available head, and our model predicted exit velocities of 13.3 m/s and plume heights of 19.5m in that case. Similarly, if we then also increased the pipe diameter from 1.496m to 2.1m, the exit velocities and plume heights for the ADP system increased further to 16.2 m/s and 22.5m, respectively. To further investigate this with regard to the BHP Billiton diffuser arrangement, we undertook a more detailed sensitivity analysis, and this is described below.

4.4.3.2 Sensitivity Analysis

A sensitivity analysis was undertaken based on the initial BHP Billiton configuration, in order to better understand which (other) parameters are critical to the design and how this design can be varied to reach the desired dilution characteristics. The sensitivity analysis included modification of the following parameters:

- Main pipe diameter, with values of 2.1m (as per initial configuration) and 1m;
- Available gravity head, with values of 30m (maximum available head) and 10m; and
- Port diameter, with values of 0.1m, 0.14m and 0.175m (as advised by BHP Billiton).

Despite the CORMIX results presented in previous sections, it is noted that the riser height does not have a significant effect on the spreadsheet pressure calculations and hence exit velocity predictions. Further, the Roberts *et al.* method (used in our spreadsheet to predict dilutions), assumes that the risers are located at the seabed (i.e. riser height of 0m) so variations in riser height do not materially affect the spreadsheet dilution predictions. As such the results presented do not consider the effect of riser heights.

This sensitivity analysis was also undertaken for three flow rates as follows (as requested by BHP Billiton):

- The maximum proposed flow rate of 265 ML/day (i.e. the proposed summer discharge – see Table 4-1);
- The minimum proposed flow rate of 190 ML/day (i.e. the proposed winter discharge – see Table 4-1); and
- The Draft EIS discharge rate of 370ML/day, which includes a regional Upper Spencer Gulf supply option of 80 ML/day.

For a selected port diameter, the number of ports could be adjusted to go from one discharge requirement to the other (as shown by D1, D10 and D19 below for example).

Results of these sensitivity analyses are reported in Table 4-8, where D refers to a different configuration and the numbering is arbitrary. The following key elements need to be considered when reviewing this table:

- With the maximum available gravity head of 30m, high exit velocities are generally predicted, of up to 21m/s; and
- The plume height values should be compared to total water depth available. In particular, it is recommended that a 5m 'freeboard' be considered in the selected design between the top of the plume and the water surface, in order to avoid plume/surface interactions.

Table 4-8 Sensitivity Analysis

Parameter	Units	D1	D2	D3	D4	D5	D6	D7	D8	D9
Brine Density	kg/m3	1058	1058	1058	1058	1058	1058	1058	1058	1058
Background Density	kg/m3	1030	1030	1030	1030	1030	1030	1030	1030	1030
Flow Rate	ML/day	265	265	265	265	265	265	265	265	265
Flow Rate	m3/s	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
Main Pipe Diameter	m	2.1	2.1	2.1	2.1	2.1	2.1	1	1	1
Main Pipe Length	m	500	500	500	500	500	500	500	500	500
Diffuser Length	m	200	200	200	200	200	200	200	200	200
Main Pipe Entry Loss		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Risers Length	m	1	1	1	1	1	1	1	1	1
Risers Entry/Exit Losses		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Friction Factor		0.014	0.014	0.014	0.014	0.014	0.014	0.0165	0.0165	0.0165
Available Gravity Head above Water	m	30	30	30	10	10	10	10	10	10
Port Depth below Water	m	16.9	16.9	16.9	16.9	16.9	16.9	18	18	18
Port Diameter	m	0.1	0.14	0.175	0.1	0.14	0.175	0.1	0.14	0.175
Port Exit Velocity	m/s	21.1	21.4	21.5	12.3	12.5	12.6	5.6	5.7	5.7
Number of Ports		19	9	6	32	16	10	70	35	22
Port Densimetric Froude Number		128.9	110.6	99.7	75.1	64.5	58.1	34.0	29.3	26.4
Impact Point Dilution		206	177	160	120	103	93	54	47	42
Impact Point Location	m from port	30.9	37.2	41.9	18.0	21.7	24.4	8.2	9.8	11.1
D/s Layer Dilution		335	288	259	195	168	151	88	76	69
D/s Layer Location	m from port	116.0	139.4	157.1	67.6	81.2	91.5	30.6	36.9	41.6
Plume Height	m from riser	28.4	34.1	38.4	16.5	19.9	22.4	7.5	9.0	10.2
D/s Layer Thickness	m	9.0	10.8	12.2	5.3	6.3	7.1	2.4	2.9	3.2

Parameter	Units	D10	D11	D12	D13	D14	D15	D16	D17	D18
Brine Density	kg/m3	1058	1058	1058	1058	1058	1058	1058	1058	1058
Background Density	kg/m3	1030	1030	1030	1030	1030	1030	1030	1030	1030
Flow Rate	ML/day	190	190	190	190	190	190	190	190	190
Flow Rate	m3/s	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Main Pipe Diameter	m	2.1	2.1	2.1	2.1	2.1	2.1	1	1	1
Main Pipe Length	m	500	500	500	500	500	500	500	500	500
Diffuser Length	m	200	200	200	200	200	200	200	200	200
Main Pipe Entry Loss		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Risers Length	m	1	1	1	1	1	1	1	1	1
Risers Entry/Exit Losses		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Friction Factor		0.014	0.014	0.014	0.014	0.014	0.014	0.0165	0.0165	0.0165
Available Gravity Head above Water	m	30	30	30	10	10	10	10	10	10
Port Depth below Water	m	16.9	16.9	16.9	16.9	16.9	16.9	18	18	18
Port Diameter	m	0.1	0.14	0.175	0.1	0.14	0.175	0.1	0.14	0.175
Port Exit Velocity	m/s	21.1	21.4	21.6	12.3	12.5	12.6	9.4	9.6	9.7
Number of Ports		13	7	4	23	11	7	30	15	9
Port Densimetric Froude Number		129.1	110.8	99.9	75.4	64.7	58.3	57.6	49.6	44.8
Impact Point Dilution		207	177	160	121	104	93	92	79	72
Impact Point Location	m from port	31.0	37.2	41.9	18.1	21.7	24.5	13.8	16.7	18.8
D/s Layer Dilution		336	288	260	196	168	152	150	129	116
D/s Layer Location	m from port	116.2	139.6	157.3	67.9	81.5	91.9	51.8	62.5	70.5
Plume Height	m from riser	28.4	34.1	38.4	16.6	19.9	22.5	12.7	15.3	17.2
D/s Layer Thickness	m	9.0	10.9	12.2	5.3	6.3	7.1	4.0	4.9	5.5

Parameter	Units	D19	D20	D21	D22	D23	D24	D25	D26	D27
Brine Density	kg/m3	1058	1058	1058	1058	1058	1058	1058	1058	1058
Background Density	kg/m3	1030	1030	1030	1030	1030	1030	1030	1030	1030
Flow Rate	ML/day	370	370	370	370	370	370	370	370	370
Flow Rate	m3/s	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Main Pipe Diameter	m	2.1	2.1	2.1	2.1	2.1	2.1	1	1	1
Main Pipe Length	m	500	500	500	500	500	500	500	500	500
Diffuser Length	m	200	200	200	200	200	200	200	200	200
Main Pipe Entry Loss		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Risers Length	m	1	1	1	1	1	1	1	1	1
Risers Entry/Exit Losses		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Friction Factor		0.014	0.014	0.014	0.014	0.014	0.014	0.0165	0.0165	0.0165
Available Gravity Head above Water	m	30	30	30	10	10	10	10	10	10
Port Depth below Water	m	16.9	16.9	16.9	16.9	16.9	16.9	18	18	18
Port Diameter	m	0.1	0.14	0.175	0.1	0.14	0.175	0.1	0.14	0.175
Port Exit Velocity	m/s	21.0	21.3	21.5	12.2	12.4	12.5			
Number of Ports		26	13	8	45	23	14			
Port Densimetric Froude Number		128.6	110.3	99.5	74.5	64.0	57.7			
Impact Point Dilution		206	177	159	119	102	92			
Impact Point Location	m from port	30.9	37.1	41.8	17.9	21.5	24.2		Pipe pressure losses exceed total available pressure due to gravity head	
D/s Layer Dilution		334	287	259	194	166	150			
D/s Layer Location	m from port	115.7	139.0	156.7	67.1	80.6	90.8			
Plume Height	m from riser	28.3	34.0	38.3	16.4	19.7	22.2			
D/s Layer Thickness	m	9.0	10.8	12.2	5.2	6.3	7.1			

This analysis confirms that the key parameters to be considered in designing a physically reasonable and satisfactorily performing diffuser are:

- Pipe diameter (smaller diameter pipes produce lower exit velocities);
- Available gravity head (lower head induces lower exit velocities); and
- The main pipe and diffuser length (longer pipes induce lower exit velocities). It is noted however that this influence is strongly related to the pipe diameter, and the sensitivity to reducing exit velocities is largely attenuated for pipes of large diameter.

Given this, and the practical (and cost) constraints around increasing the main pipe length at Point Lowly, it is apparent that the two remaining key variables that can be adjusted to deliver a practically feasible and suitably performing diffuser are pipe diameter and available gravity head.

In terms of pipe diameter, clearly smaller diameter pipes are more cost effective, however we are unaware of other potential constraints on this pipe sizing that may be a result of process or other requirements upstream of the diffuser. We can advise, however, that smaller pipe diameters will result in greater frictional losses (per length of pipe) and hence act to reduce exit velocities.

Reducing the gravity head delivered to the diffuser will do the same, and there are various mechanical engineering means to do so, including installation of variable valve or orifice plate arrangements. The details of these are beyond our expertise, however, BMT WBM mechanical engineering staff will be able to assist further in this regard if required. Importantly, if such arrangements were to be implemented within the Point Lowly diffuser system, it would mean that BHP Billiton would have some gravitational head in 'reserve', and control over the flow rate delivered to the system at any time. For example,, if it was found that over time some fouling of the inside of the diffuser occurred (this increasing frictional losses, reducing volume flow rate and hence port exit velocities and achieved dilutions) some 'reserve' gravitational head could be utilised to maintain operation at the nominal flow rate. It is noted however, that deviating from the target flow rates specified will result in alterations to the diffuser performance, particularly in regard to plume height and achieved dilutions.

Another potential advantage of having access to this reserve gravitational head is that it allows for the brine discharge rate profile to be matched to tidal current (i.e. ambient mixing) conditions. For example, an automated system could be set in place that increases discharge over the daily average rate (via fuller opening of a valve system) prior to the onset of a known 'dodge tide' period so that additional brine is released during favorable mixing conditions. To compensate for this additional brine release, discharge could be halted over the expected low current condition period, if it lasted for a few hours, so that the overall daily average met the desired discharge target. Alternatively, brine could be discharged intermittently (again, at a higher flow rates than the daily average) and only during periods temporally distant from tide turns. Clearly there are process engineering implications for such a system, and these have not been considered here.

In order to provide BHP Billiton with some specifics in this regard as related to the Point Lowly system, Table 4-9 below shows results from several example configurations for a 265ML/d flow rate, based on the following set parameters:

- Main pipe diameter: 2.1m / 1.8m / 1.6m / 1.4m / 1.2m and 1m;

- Gravity Head: 30m / 20m / 15m / 10m and 8m; and
- Port diameter: 0.100m / 0.140m and 0.175m as requested by BHP Billiton.

These configurations have been chosen as illustrative examples only and are not necessarily feasible or practicable. For each configuration, this table highlights key elements, including:

- Number of ports required;
- Individual port exit velocity;
- Predicted dilution at the point of contact with the seabed (calculated using the Roberts *et al.* Method). These results are color coded as follows: orange for dilutions below the 45:1 threshold, yellow for dilutions between 45:1 and 85:1, and green for dilutions greater than 85:1; and
- Predicted plume height. These results have been hatched when values are exceeding the available water depth of 20m. It is however again emphasized that a 'freeboard' of at least 5m between the top of the jets and the water surface is recommended for the selected design in order to avoid potential plume/surface interactions.

Table 4-9 Example Configurations – 265 ML/day

#	*Set Parameters*			*Computed using Spreadsheet Model*		*Computed using Roberts et al. Method*				
	Main Pipe Diameter	**Available Gravity Head**	**Port Diameter**	**Number of Ports**	**Port Exit Velocity**	**Plume Height**	**Impact Point Dilution**	**Location of Impact Point**	**D/s Layer Dilution**	**D/s Layer Location**
	m	m	m		m/s	m		m from port		m from port
1	2.1	30	0.100	19	21.1	28.4	206	30.9	335	116.0
2	2.1	30	0.140	9	21.4	34.1	177	37.2	288	139.4
3	2.1	30	0.175	6	21.5	38.4	160	41.9	259	157.1
4	2.1	20	0.100	23	17.2	23.2	169	25.3	274	95.0
5	2.1	20	0.140	11	17.5	27.9	145	30.4	235	114.1
6	2.1	20	0.175	7	17.6	31.4	131	34.3	212	128.5
7	2.1	15	0.100	26	15.0	20.2	147	22.0	238	82.4
8	2.1	15	0.140	13	15.2	24.2	126	26.4	204	99.0
9	2.1	15	0.175	8	15.3	27.3	113	29.8	184	111.6
10	2.1	10	0.100	32	12.3	16.5	120	18.0	195	67.6
11	2.1	10	0.140	16	12.5	19.9	103	21.7	168	81.2
12	2.1	10	0.175	10	12.6	22.4	93	24.4	151	91.5
13	2.1	8	0.100	35	11.0	14.8	108	16.2	175	60.7
14	2.1	8	0.140	18	11.2	17.8	93	19.4	150	72.9
15	2.1	8	0.175	11	11.3	20.1	83	21.9	136	82.1
16	1.8	30	0.100	19	21.0	28.3	206	30.8	334	115.7
17	1.8	30	0.140	9	21.3	34.0	176	37.1	287	138.9
18	1.8	30	0.175	6	21.5	38.3	159	41.7	258	156.6
19	1.8	20	0.100	23	17.1	23.1	168	25.2	273	94.5
20	1.8	20	0.140	11	17.4	27.8	144	30.3	234	113.5
21	1.8	20	0.175	7	17.5	31.3	130	34.1	211	127.9
22	1.8	15	0.100	26	14.9	20.0	146	21.8	237	81.9
23	1.8	15	0.140	13	15.1	24.0	125	26.2	203	98.4
24	1.8	15	0.175	8	15.2	27.1	113	29.6	183	110.9
25	1.8	10	0.100	32	12.2	16.4	119	17.9	193	67.0
26	1.8	10	0.140	16	12.3	19.7	102	21.5	166	80.4
27	1.8	10	0.175	10	12.4	22.2	92	24.2	150	90.6
28	1.8	8	0.100	36	10.9	14.7	107	16.0	173	60.0
29	1.8	8	0.140	18	11.0	17.6	91	19.2	149	72.0
30	1.8	8	0.175	11	11.1	19.8	82	21.6	134	81.1
31	1.6	30	0.100	19	20.9	28.1	205	30.7	332	115.1
32	1.6	30	0.140	9	21.2	33.8	176	36.9	285	138.2
33	1.6	30	0.175	6	21.4	38.1	158	41.5	257	155.8
34	1.6	20	0.100	23	17.0	22.9	167	25.0	271	93.8
35	1.6	20	0.140	12	17.3	27.5	143	30.0	232	112.7
36	1.6	20	0.175	7	17.4	31.0	129	33.9	210	126.9
37	1.6	15	0.100	27	14.7	19.8	144	21.6	234	81.1
38	1.6	15	0.140	13	14.9	23.8	124	26.0	201	97.4
39	1.6	15	0.175	8	15.1	26.8	111	29.3	181	109.7
40	1.6	10	0.100	33	12.0	16.1	117	17.6	191	65.9
41	1.6	10	0.140	16	12.1	19.4	101	21.1	163	79.2
42	1.6	10	0.175	10	12.2	21.8	91	23.8	147	89.3
43	1.6	8	0.100	37	10.7	14.4	105	15.7	170	58.8
44	1.6	8	0.140	18	10.8	17.3	90	18.8	146	70.7
45	1.6	8	0.175	12	10.9	19.5	81	21.2	131	79.6
46	1.4	30	0.100	19	20.7	27.8	202	30.3	329	113.8
47	1.4	30	0.140	10	21.0	33.4	174	36.5	282	136.7
48	1.4	30	0.175	6	21.1	37.7	156	41.1	254	154.0
49	1.4	20	0.100	23	16.7	22.5	164	24.6	266	92.2
50	1.4	20	0.140	12	17.0	27.1	141	29.5	229	110.8
51	1.4	20	0.175	7	17.1	30.5	127	33.3	206	124.8
52	1.4	15	0.100	27	14.4	19.4	141	21.1	229	79.3
53	1.4	15	0.140	14	14.6	23.3	121	25.4	196	95.2
54	1.4	15	0.175	9	14.7	26.2	109	28.6	177	107.3
55	1.4	10	0.100	34	11.6	15.6	113	17.0	184	63.7

Table 4-9 Continued…

#	Set Parameters			Computed using Spreadsheet Model		Computed using Roberts et al. Method				
	Main Pipe Diameter	Available Gravity Head	Port Diameter	Number of Ports	Port Exit Velocity	Plume Height	Impact Point Dilution	Location of Impact Point	D/s Layer Dilution	D/s Layer Location
	m	m	m		m/s	m		m from port		m from port
56	1.4	10	0.140	17	11.7	18.7	97	20.4	158	76.5
57	1.4	10	0.175	11	11.8	21.1	88	23.0	142	86.2
58	1.4	8	0.100	38	10.2	13.8	100	15.0	163	56.3
59	1.4	8	0.140	19	10.4	16.5	86	18.0	140	67.6
60	1.4	8	0.175	12	10.5	18.6	77	20.3	126	76.2
61	1.2	30	0.100	20	20.0	27.0	196	29.4	319	110.3
62	1.2	30	0.140	10	20.3	32.4	168	35.3	273	132.5
63	1.2	30	0.175	6	20.5	36.5	152	39.8	246	149.3
64	1.2	20	0.100	24	15.9	21.5	156	23.4	254	87.9
65	1.2	20	0.140	12	16.2	25.8	134	28.1	218	105.6
66	1.2	20	0.175	8	16.3	29.1	121	31.7	196	118.9
67	1.2	15	0.100	29	13.5	18.1	132	19.8	214	74.1
68	1.2	15	0.140	15	13.7	21.8	113	23.8	184	89.1
69	1.2	15	0.175	9	13.8	24.5	102	26.8	166	100.3
70	1.2	10	0.100	38	10.4	14.0	102	15.3	165	57.2
71	1.2	10	0.140	19	10.5	16.8	87	18.3	142	68.7
72	1.2	10	0.175	12	10.6	18.9	79	20.6	128	77.4
73	1.2	8	0.100	44	8.9	11.9	87	13.0	141	48.8
74	1.2	8	0.140	22	9.0	14.3	74	15.6	121	58.6
75	1.2	8	0.175	14	9.1	16.2	67	17.6	109	66.1
76	1.0	30	0.100	22	18.0	24.3	176	26.5	287	99.3
77	1.0	30	0.140	11	18.3	29.2	151	31.8	246	119.3
78	1.0	30	0.175	7	18.4	32.8	136	35.8	222	134.4
79	1.0	20	0.100	29	13.3	18.0	131	19.6	212	73.5
80	1.0	20	0.140	15	13.5	21.6	112	23.6	182	88.3
81	1.0	20	0.175	9	13.7	24.3	101	26.5	164	99.5
82	1.0	15	0.100	38	10.2	13.8	100	15.0	163	56.4
83	1.0	15	0.140	19	10.4	16.6	86	18.1	140	67.8
84	1.0	15	0.175	12	10.5	18.7	78	20.4	126	76.4
85	1.0	10	0.100	69	5.6	7.6	55	8.3	90	31.0
86	1.0	10	0.140	35	5.7	9.1	47	9.9	77	37.2
87	1.0	10	0.175	22	5.8	10.3	43	11.2	69	41.9
88	1.0	8	0.100	256	1.5	2.1	15	2.2	24	8.4
89	1.0	8	0.140	128	1.6	2.5	13	2.7	21	10.1
90	1.0	8	0.175	82	1.6	2.8	12	3.0	19	11.4

In order to provide a more succinct summary of the above results, we have extracted example configurations that have:

- Plume height less than 15m;
- Exit velocity less than 12 m/s; and
- Impact dilutions greater than 45:1.

This is a very preliminary representation of the data in Table 4-9, and is not intended to reflect any preferences or recommendations for design, but rather is intended to assist BHP Billiton by showing an example subset of results in a concise manner. Results for the same configurations are also provided for the two other considered flow rates of 190 ML/day and 370 ML/day in Table 4-11 and Table 4-12 respectively.

These summary tables also present indicative diffuser lengths. These lengths have been estimated using CORMIX with a single port simulation at the proposed diameter and port exit velocity for each configuration. Three lengths have been estimated, depending on the following assumptions:

- Length 1: Plumes can interact when the centreline dilution reaches 1:45;
- Length 2: Plumes can interact when the centreline dilution reaches 1:85; and
- Length 3: No interaction of the plumes along the diffuser line until the plumes reach the seabed.

These diffuser lengths should be considered as indicative only, as the CORMIX calculations are not directly related to the Roberts calculations presented in the tables (due to a number of varying parameters, including the ambient current velocity). In interpreting these lengths, there are competing assumptions at play, in terms of the conservativeness of the predictions. On one hand, the length predictions (from CORMIX) are based on higher dilutions at a given point downstream of the diffuser than Roberts (due to the presence of background currents in CORMIX and the additional mixing these provide) with the result that diffuser lengths may be underestimated. On the other hand, the results have some degree of conservatism in that they use centreline dilutions to dictate allowable interactions at the plume edges. In reality, it is expected that these edge dilutions will be considerably higher than centreline values, hence applying this criterion results in longer diffuser length estimates as plume edge dilutions will reach 1:45 or 1:85 at shorter distances downstream from the diffuser line than in the plume centreline. CFD modelling will allow for further assessment of these matters and refinement of the plume characteristics.

4.4.3.3 CORMIX Assessment

As a final check on the results presented above, example configuration 82 with a 265 ML/day flow rate was set up and executed in CORMIX using single plume mode (with 0.2m/s ambient current velocity). The predicted dilutions at impact and at the end of the near field were 128 and 215, respectively, which are not inconsistent with those predicted by the Roberts method.

Table 4-10 Summary of Example Configurations – 265 ML/day (maximum seasonal discharge)

#	*Set Parameters*			*Computed using Spreadsheet Model*		*Computed using Roberts et al. Method*					*Estimated using CORMIX (0.2m/s ambient current)*		
	Main Pipe Diameter	Available Gravity Head	Port Diameter	Number of Ports	Port Exit Velocity	Plume Height	Impact Point Dilution	Location of Impact Point	D/s Layer Dilution	D/s Layer Location	Indicative Length 1	Indicative Length 2	Indicative Length 3
	m	m	m		m/s	m		m from port		m from port	m	m	m
13	2.1	8	0.100	35	11.0	14.8	108	16.2	175	60.7	120	180	630
28	1.8	8	0.100	36	10.9	14.7	107	16.0	173	60.0	120	180	630
43	1.6	8	0.100	37	10.7	14.4	105	15.7	170	58.8	130	180	630
58	1.4	8	0.100	38	10.2	13.8	100	15.0	163	56.3	130	190	630
70	1.2	10	0.100	38	10.4	14.0	102	15.3	165	57.2	130	190	630
73	1.2	8	0.100	44	8.9	11.9	87	13.0	141	48.8	140	200	650
74	1.2	8	0.140	22	9.0	14.3	74	15.6	121	58.6	n/a	140	410
82	1.0	15	0.100	38	10.2	13.8	100	15.0	163	56.4	130	190	630
85	1.0	10	0.100	69	5.6	7.6	55	8.3	90	31.0	n/a	260	710
86	1.0	10	0.140	35	5.7	9.1	47	9.9	77	37.2	n/a	n/a	460

Table 4-11 Summary of Example Configurations – 190 ML/day (minimum seasonal discharge)

#	*Set Parameters*			*Computed using Spreadsheet Model*		*Computed using Roberts et al. Method*					*Estimated using CORMIX (0.2m/s ambient current)*		
	Main Pipe Diameter	Available Gravity Head	Port Diameter	Number of Ports	Port Exit Velocity	Plume Height	Impact Point Dilution	Location of Impact Point	D/s Layer Dilution	D/s Layer Location	Indicative Length 1	Indicative Length 2	Indicative Length 3
	m	m	m		m/s	m		m from port		m from port	m	m	m
13	2.1	8	0.100	25	11.1	14.9	108	16.3	176	61.0	90	130	450
28	1.8	8	0.100	25	11.0	14.8	108	16.2	175	60.6	90	130	450
43	1.6	8	0.100	26	10.9	14.7	107	16.0	173	60.1	90	130	450
58	1.4	8	0.100	26	10.7	14.4	105	15.7	170	58.8	90	130	450
70	1.2	10	0.100	25	11.4	15.4	112	16.8	181	62.8	90	130	450
73	1.2	8	0.100	28	10.0	13.5	98	14.7	160	55.3	100	140	460
74	1.2	8	0.140	14	10.2	16.2	84	17.7	137	66.4	n/a	100	290
82	1.0	15	0.100	22	12.8	17.3	125	18.8	204	70.6	80	120	440
85	1.0	10	0.100	29	9.5	12.8	93	14.0	152	52.5	100	140	460
86	1.0	10	0.140	15	9.7	15.4	80	16.8	130	63.1	n/a	100	300

Table 4-12 Summary of Example Configurations – 370 ML/day (DEIS discharge)

#	*Set Parameters*			*Computed using Spreadsheet Model*		*Computed using Roberts et al. Method*					*Estimated using CORMIX (0.2m/s ambient current)*		
	Main Pipe Diameter	**Available Gravity Head**	**Port Diameter**	**Number of Ports**	**Port Exit Velocity**	**Plume Height**	**Impact Point Dilution**	**Location of Impact Point**	**D/s Layer Dilution**	**D/s Layer Location**	**Indicative Length 1**	**Indicative Length 2**	**Indicative Length 3**
	m	m	m		m/s	m		m from port		m from port	m	m	m
13	2.1	8	0.100	50	10.9	14.7	107	16.0	174	60.1	180	250	880
28	1.8	8	0.100	51	10.6	14.3	104	15.6	169	58.6	170	250	880
43	1.6	8	0.100	53	10.2	13.8	100	15.0	163	56.3	180	260	890
58	1.4	8	0.100	59	9.3	12.5	91	13.6	147	51.0	190	280	900
70	1.2	10	0.100	68	8.0	10.8	79	11.8	128	44.3	n/a	300	920
73	1.2	8	0.100	92	5.9	8.0	58	8.7	94	32.7	n/a	350	980
74	1.2	8	0.140	46	6.0	9.6	50	10.5	81	39.3	n/a	400	630
82	1.1	15	0.100	61	8.9	12.0	87	13.1	141	48.9	200	280	1140
85	1.1	10	0.100	229	2.4	3.2	23	3.5	38	13.1	n/a	n/a	1330
86	1.1	10	0.140	115	2.4	3.9	20	4.2	33	15.8	n/a	n/a	810

5 LIMITATIONS

Some limitations of the results presented above include:

- No specific investigation of the potential for local recirculation within each port has been undertaken as part of this study. This has subsequently been considered through computational fluid modelling (CFD) analyses reported elsewhere.
- The near field modelling is essentially a steady state analysis that cannot take into account the influence of the dynamic ambient tidal conditions on plume evolution. Again, the dynamic evolution of the near field plume has been further investigated with CFD analysis and reported elsewhere.
- It is noted that the predicted dilutions are generally higher for greater ambient current velocities. This relationship can be further investigated for a narrow range of desired configurations.
- The CORMIX software provides dilution results within a ±50% accuracy.
- The BMT WBM spreadsheet model developed to compute head losses is based on the following assumptions:
    - the pipes material will be HDPE, with an associated roughness height of 0.5mm, consistent with the ADP design approach.
    - The head loss in the main feed pipe is calculated using the length to the centre of the diffuser, as an alternative to the more detailed calculation using the reductions in flow rate and pressure along the diffuser.
    - Main and riser pipe entry losses are 0.2 dynamic pressures, and the port exit loss is exactly one dynamic pressure.
- There is likely to be some disconnections between the CORMIX and Roberts *et al.* dilution results (and associated plume characteristics), principally due to the difference in the ambient current velocity considered (CORMIX: 0.2m/s, and Roberts *et al.*: 0.0m/s).

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