Adelaide Desalination Project (ADP) – DBOM

Outfall Dilution Modelling Assessment

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Adelaide Desalination Project

Outfall Dilution Modelling Assessment

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EXECUTIVE SUMMARY

Water Technology was commissioned by Hatch SMEC JV on behalf of Adelaide Aqua to develop and validate the final design of the outfall diffuser of the Adelaide Desalination Project. This report presents the modelling undertaken to demonstrate that the diffuser design achieves the mixing and dispersion standards set for the project during the project development and EIS phases.

The primary objectives of the analysis and modelling as presented in this report is to demonstrate:

- Initial dilution of the saline concentrate discharge equivalent to 50:1
- Rapid dispersion of the saline concentrate into the surrounding sea water

The assessment of the environmental impact of the excess salinity generated in the environment surrounding the diffuser is not within the scope of this report.

The Outfall Diffuser Concept

The underlying design philosophy of the outfall diffuser design is to achieve the required initial dilution criteria and achieve rapid dilution of the saline concentrate in the vicinity of the diffuser over the full range of outfall discharges and ambient environmental conditions. The diffuser design has also been developed to fulfill the Project goals of safety, timeliness and reliability of delivery and economy. The diffuser is 140 m long and consists of 4 ports on each of 6 equidistant risers. The discharge ports are to be fitted with 250 mm duckbill valves to enhance their dilution characteristics over the full range of operating conditions required.

Initial Dilution

The reverse osmosis process employed by Adelaide Aqua achieves a higher freshwater production efficiency than that used in the EIS. As such, the initial dilution requirement is increased to 1:58, to achieve the same effective dilution as the 1:50 used in the EIS.

Near-field modelling predicts that an initial dilution of 1:81 is achieved when the plant is operating at 100% of its full production capacity. At lower freshwater production capacities the initial impact dilution decreases, as discharge velocity decreases. For flows corresponding to less than about 40% of full production augmentation of the outfall flows by seawater bypassing will be implemented to achieve the minimum required initial dilution of 1:58.

Terminal Rise Height: Near-field modelling has shown that for all operating conditions, the plume centrelines will be well below the sea surface. It has also show that for all normal operating conditions, the top of the plumes will be well below the sea surface. Some disturbance of the sea surface is only likely to occur if the discharge rate increases to 120% of the normal production rate during a lower than average spring tide low water and low current conditions.

Diffuser Plume Footprints: The riser spacing and orientation of the individual diffuser ports has been optimised to avoid of overlap of the individual plume footprints at the highest production capacity outfall flow rate. Due to the orientation of the individual diffuser ports the 140m long diffuser has an effective overall length of approximately 170m at the 100% production capacity outfall flow rate.

Two-Dimensional Gulf Model

A detailed two-dimensional hydrodynamic model of Gulf St Vincent has been developed for the primary purpose of providing accurate boundary conditions for the more detailed three-dimensional mid-field model of the coastal waters in the main area of interest around Port Stanvac.

The calibration of the two-dimensional model has paid particular attention to ensuring that the combination of astronomical tides, low frequency shelf waves and local wind shear forcing processes are accurately resolved. This has been undertaken to ensure these features of the hydrodynamics in Gulf St Vincent are accurately translated into the three-dimensional mid-field model that has been used for the detailed analysis of the saline concentrate dilution.

Three-Dimensional Mid-Field Model

Full three-dimensional mid-field modelling has been undertaken to simulate the performance of the outfall diffuser. The model domain covers an area of 20 km by 11.5 km, and was selected to ensure that it encompassed the area covered by the movement of the saline concentrate plume over the short to medium-term (from days to weeks). The model uses a flexible-mesh system that allows for significantly increased resolution in the vicinity of the diffuser. The mid-field model mesh uses triangular elements with length scales of around 1000 m in outer areas, reducing down to 50 m and 20 m in the vicinity of the diffuser. In the immediate vicinity of the diffuser a much finer 8 m quadrilateral mesh is used.

The model uses “sigma” coordinates with 17 equal thickness layers in the vertical and includes eddy viscosity formulations to take into account the effects that sub-grid scale turbulence has on mixing. For horizontal mixing, a “Smagorinsky”-type formulation is used to calculate time and space varying eddy viscosity coefficients as a function of the local flow conditions. For vertical mixing, a more sophisticated *“k-є”* formulation is used to include the effects that density stratification can have on reducing the effects of vertical mixing. The horizontal and vertical dispersion coefficients used in the saline concentrate dispersion computations are directly linked to the corresponding eddy viscosity coefficients.

The mid-field model boundaries are derived directly from the results of the two-dimensional Gulf model. As such, they include the multiple tidal and meteorological forcing processes that influence the hydrodynamics of the Port Stanvac region.

The model has been calibrated against observed water levels and current data from Port Stanvac. Overall, it is considered that the mid-field model is capable of providing a realistic description of the water level variations and currents in the vicinity of the outfall diffuser.

Representation of Near-Field Processes

The results of physical model tests have been used to represent the main physical characteristics of the discharge plumes at the point of terminal rise. At this point the dimensions of the plumes are of the same order of magnitude as the 8 m model horizontal mesh size.

The saline concentrate discharges representing the diffuser plumes at the terminal height of rise were introduced as source points at the appropriate horizontal location in the model mesh. For each individual diffuser port plume, the saline concentrate was introduced as 4 separate source points in the vertical. These were located at alternate vertical elements and covered the approximate location and depth of the plume as determined in the physical model tests. The outfall diffuser, comprising 24 ports, was therefore represented by a total of 96 separate saline concentrate source points in the three-dimensional model.

To allow for the increased turbulent mixing within the area directly around the diffuser, the horizontal eddy viscosity was increased in this area.

Validation of the Representation of Near-Field Processes

The hydrodynamic model was run for the 100% production capacity discharge case, and impact dilutions and plume footprints were compared to those derived empirically. It was found that the modelled impact dilutions corresponded well to the empirically derived values, and that the overall impact footprint of the diffuser plumes was in good agreement with the empirically derived footprint.

It was also found that the fine scale of the outfall modelling made it possible to resolve additional density-driven mixing processes that improve the dilution performance of the outfall as a whole and assist in limiting the magnitude of the accumulation of excess salinity around the diffuser during slack water.

Dilution Modelling Assessment

The three-dimensional mid–field model was used to assess the outfall performance for a range of operating conditions and receiving water scenarios. The key receiving water scenarios considered were:

- Ambient Scenario 1 - Six week scenario from 1 May to 15 June 2006. (The case used in the EIS.)
- Ambient Scenario 2 – A worst case dodge tide scenario
- Ambient Scenario 3 – A scenario containing an upwelling (onshore advection) of bottom waters

The results for the scenarios tested as summarised as follows:

Six Week Scenario at 100% Capacity Saline Concentrate Discharge: Comparisons of dilution isopleths from the EIS show that the dilution performance of the diffuser concept is at least equivalent to that of the reference design.

Worst Case Dodge Tide Scenario at 100% Capacity Saline Concentrate Discharge: It was found that the accumulation of salinity above ambient even under worst case conditions is below the ecotoxicity trigger values established by ecotoxicity testing.

Upwelling Scenario at 100% Capacity Saline Concentrate Discharge: It was found that there is little likelihood of significant advection of diluted saline concentrate plumes onshore from the outfall diffuser.

An additional scenario to demonstrate performance of the diffusers under low flow conditions was analysed as follows:

Worst Case Dodge Tide Scenario at 10% Capacity Saline Concentrate Discharge: The results show that even without any bypass flows, the impact of the saline concentrate discharge is significantly less than that for the standard 100% capacity discharge ***scenarios.***

Details of the test scenario results are presented in appendices C, D, E and F.

Sensitivity Tests

Sensitivity tests were carried out to assess the effect of the loss of two duckbill valves on the outfall diffuser ports, assess the likely effects of modifying the outfall source description to include entrainment of water from lower layers and assess the dilution performance of the outfall with a different alignment.

Loss of Two Duckbill Valves: It was found that the loss of two duckbill valves would have only a minor impact on the dilutions achieved by the remaining duckbill valves. The initial dilutions from the two damaged (now circular) ports would, however, become significantly lower (of order 1:40 at 100% production capacity). Additionally, the absolute terminal height of rise of the plumes from the two damaged diffuser ports would be expected to extend to approximately the level of mean high water spring tide.

Entrainment Tests: It was found that including the effects of entrainment of water from the lower layers of the water column had little overall effect on the model results. If anything, the inclusion of the additional entrainment effects appeared to provide a minor improvement to the overall dilution performance of the outfall diffuser.

Diffuser Orientation: It was found that orientating the outfall so that it was aligned approximately parallel with the seabed slope resulted in a lower overall dilution performance than the original outfall alignment. By aligning the outfall less perpendicular to the predominant north-south going tidal currents the volume of water in which the saline concentrate is diluted in over each tidal excursion is significantly reduced compared to the original alignment resulting in a lower dilution performance overall.

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GLOSSARY

ADCP	Acoustic Doppler Current Profiler: an acoustic current meter that is capable of measuring currents throughout the water column.
astronomical tide	Water level variations due to the combined effects of the Earth's rotation, the Moon's orbit around the Earth and the Earth's orbit around the Sun
diffusion	Transfer of salt or momentum from a region of higher concentration to one of lower concentration by turbulent mixing.
dilution	Reduction in salt concentration by mixing with water having a lower salt concentration.
dispersion	Transfer of salt from a computational cell having higher concentration to one of lower concentration by the combination of turbulent diffusion and sub-grid scale mixing processes
diurnal	Occurring once per lunar day (24 hours 50 minutes)
diurnal inequality	The difference in level between two successive high or low waters within one lunar day (24 hours 50 minutes).
dodge tide	A period of one or two days when the gravitational effects of the moon and the sun effectively cancel each other out, and there is little or no tide (approximately once per fortnight).
eddy viscosity	Transfer of momentum from a computational cell having higher momentum to one of lower momentum by the combination of turbulent diffusion and sub-grid scale mixing processes
empirical	Information gained by means of observation, experience, or experiment
Initial dilution	The initial dilution at the sea bed that would occur in the absence of any salt accumulation
isobath	A contour line connecting points of equal depth in a body of water
isopleth	A contour line connecting points where a given variable has equal values (e.g., salt)
LAT	Lowest Astronomical Tide: the lowest water level that can occur due to the effects of the astronomical tide in isolation from meteorological effects.
MHWS	Mean High Water Springs: the average of the levels of two successive high waters occurring during the spring tide peak (approximately once per fortnight).
MLWS	Mean Low Water Springs: the average of the levels of two successive low waters occurring during the spring tide peak (approximately once per fortnight).
MSL	Mean Sea Level: the long-term average level of the sea surface.
percentage exceedance	The percentage of time that a variable (e.g., dilution or salinity) exceeds a given value.
semi-diurnal	Occurring twice per lunar day (24 hours 50 minutes).
spring tides	Tides of increased range, which occur when the gravitational effects of the moon and the sun have the greatest resultant effect (approximately once per fortnight).
tidal constituent	The amplitude and phase of a single cosine wave that can be used to describe the effect of an individual component contributing to the astronomical tide at a given location.
tidal residuals	The remaining (or residual) variations in sea levels when the effects of the astronomical tide have been removed. These are typically associated with meteorological effects.

1. INTRODUCTION

1.1 Scope of works

Water Technology was commissioned by Adelaide Aqua to develop the final design of the outfall diffuser to ensure the diffuser achieves the mixing and dispersion requirements under the full range of operating and ambient environmental conditions.

The hydrodynamic modelling scope for the assessment has been developed considering the issues encountered in the marine modelling component of the EIS and highlighted in the 'DBOM Requirements – Hydrodynamic Modelling Scope of Works' provided by SA Water.

The hydrodynamic assessment of the outfall diffuser has been undertaken at the following three different spatial scales:

1. Two-dimensional, far-field numerical modelling for the hydrodynamics of the whole of Gulf St. Vincent.
2. Three-dimensional, mid-field numerical modelling of the outfall diffuser and coastal waters at Port Stanvac
3. Near-field modelling of the individual saline concentrate diffuser plumes

2. OVERVIEW OF OCEANOGRAPHIC PROCESSES

2.1 Bathymetry

Gulf St Vincent is a large inlet on the southern coast of Australia. It is bordered to the west by the Yorke Peninsula, to the south east by the Fleurieu Peninsula and to the south by Kangaroo Island. The main entrance to the Southern Ocean is via Investigator Strait which is located between the south coast of the Yorke Peninsula and the north coast of Kangaroo Island. There is a secondary entrance via Backstairs Passage, which lies between the Dudley Peninsula at the east end of Kangaroo Island and Cape Jervis on the southwest tip of the Fleurieu Peninsula.

The Gulf St Vincent–Investigator Strait system has a length of just over 200km, and widths typically of between 40 and 60 km. Maximum depths in Investigator Strait and the central part of the Gulf are in the order of 40 m. These reduce to around 20m in the northern part of the Gulf.

2.2 Astronomical Tides

The astronomical tide is caused by the movement of the Moon and Sun, relative to the Earth, and is the main phenomenon forcing the hydrodynamics of Gulf St Vincent. The tide propagates into the Gulf from the Southern Ocean via Investigator Strait, and to a lesser extent through Backstairs Passage. The tide is predominantly semi-diurnal (i.e., there are generally two tides per day), with a significant diurnal inequality (i.e., one tide each day has a significantly greater range than the other).

Throughout the Gulf, the amplitudes of the main solar S2 and lunar M2 semi-diurnal constituents are almost identical. During spring tides, the two constituents combine to increase the tidal range. During neap tides, however, the two constituents cancel each other out and there is virtually no semi-diurnal tide. This feature is called a "dodge tide", and occurs approximately once every 14 to 15 days (i.e., the period of the normal spring-neap tidal cycle).

The length and depth dimensions of the Gulf are such that it takes just over 3 hours for a tidal wave to propagate from the entrance to Investigator Strait to the head of the Gulf. This is close to one quarter of the 12.0 and 12.4 hour periods of the main solar (M2) and lunar (M2) semi-diurnal components of the tide. The resulting resonance causes a significant increase in the amplitudes of the semidiurnal components of the tide with distance towards the head of the Gulf. As a result, spring tide ranges increase from less than 1.0m at the entrance to Investigator Strait to more than 3.0 m at Ardrossan near the head of the Gulf.

2.3 Meteorological Conditions

Meteorological conditions can also have a significant impact on the hydrodynamics of Gulf St Vincent. This includes the effects of variations in atmospheric pressure and the action of wind on the sea surface.

Prevailing wind conditions within the Gulf are strongly influenced by season. In general, winds in the Gulf come predominantly from the south-west quarter during summer and north-west quarter during winter. The action of wind on the sea surface results in a shear stress that forces surface water in the direction of the wind and influences currents within the Gulf.

Low-frequency water level oscillations also occur in the Gulf. These are associated with complex interactions of large low pressure systems in the Southern Ocean and the effects of wind set-up along the continental margin of the Australian land mass.

3. TWO-DIMENSIONAL GULF ST VINCENT MODEL

A detailed two-dimensional hydrodynamic model of Gulf St Vincent has been developed for the primary purpose of providing accurate boundary conditions for the more detailed three-dimensional mid-field model of the coastal waters in the main area of interest around Port Stanvac.

The calibration of the two-dimensional model has paid particular attention to ensuring that the combination of astronomical tides, low frequency shelf waves and local wind shear forcing processes are accurately resolved. This has been undertaken to ensure these features of the hydrodynamics in Gulf St Vincent are accurately translated into the three-dimensional mid-field model that has been used for the detailed analysis of the saline concentrate dilution.

The details of the two-dimensional Gulf St Vincent model setup and calibration are provided in the following sections.

3.1 Model Setup

The hydrodynamic (HD) module of the Danish Hydraulic Institute's MIKE 21 modelling system has been used to develop the Gulf St Vincent model. MIKE 21 is a state of the art modelling system for simulating water level variations and depth averaged flows in response to a variety of forcing functions in rivers, lakes, estuaries and coastal areas. MIKE 21 HD solves the vertically integrated equations for the conservation of continuity and momentum in two horizontal directions.

3.1.1 Domain Schematisation

The extent and bathymetry of the Gulf model is shown in Figure 3-1. The model is aligned north-south, and covers the whole of Gulf St Vincent and the main part of Investigator Strait. The main western boundary of the model extends from Stenhouse Bay on the southern tip of the Yorke Peninsula to Western River on the north coast of Kangaroo Island. There is a second boundary offshore from Backstairs Passage. This extends southwards to just south of Cape Willoughby on Kangaroo Island, and eastwards to Victor Harbour.

The bathymetric data for the model was developed from a combination of the GeoScience Australia bathymetric data set (2005) and the following Royal Australian Navy Hydrographic Survey Charts; AUS 442, AUS 444, AUS 780 and AUS 781.

The model uses a 500 m square grid, and a time step of 60 seconds.

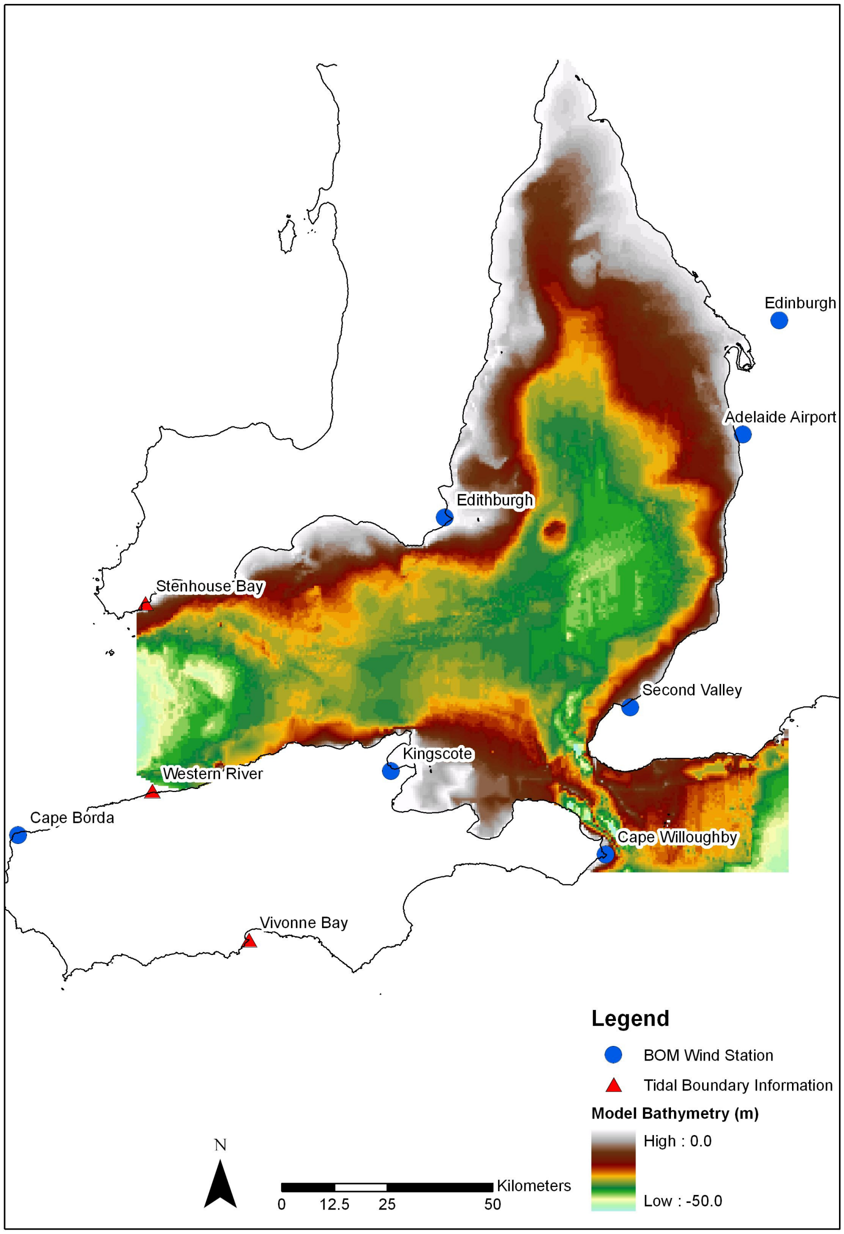


Figure 3-1 The Two-Dimensional Gulf Model Domain and Bathymetry

3.1.2 Boundary Conditions

The open boundaries at the entrance to Investigator Strait and offshore from Backstairs Passage are driven by a combination of astronomical tides and meteorologically derived water level variations.

For the Investigator Strait boundary, the astronomical tides were developed from tidal constituents derived from tidal measurements at Stenhouse Bay and Western River. For the Backstairs Passage boundary, the astronomical tides were developed from a combination of tidal constituents for Victor Harbour and Vivonne Bay. The development of the astronomical tidal component of the model boundary conditions formed part of the model calibration process, and is described in more detail in Section 3.2.

For both boundaries, the meteorologically derived water level variations were developed from a detailed analysis of measured water level variations at Thevenard. As for the astronomical tide, the development of the meteorologically derived component of the model boundary conditions formed part of the model calibration process, and is described in more detail in Section 3.2.

3.1.3 Wind Forcing

Wind shear on the water surface drives secondary circulations within Gulf St Vincent. These were modelled by the development of spatially and temporally varying wind fields for the Gulf. These wind fields were derived from wind measurements from the Bureau of Meteorology (BOM) weather stations, as shown in Figure 3-1 below.

3.2 Model Calibration

Calibration of the two-dimensional hydrodynamic model has been undertaken in two parts. The first part consisted of calibration of the model's capability to reproduce astronomical tides and tidal currents throughout Gulf St Vincent. The second part consisted of calibrating the model's response to observed meteorologically driven water level variations within the Gulf.

The calibration methodology and level of agreement achieved is described in more detail in the following sections.

3.2.1 Calibration of Astronomical Tides and Tidal Currents

The model was calibrated against predicted water levels and tidal currents derived from measurements reported by Bowers and Lennon (1990). The locations of their 10 tidal water level and 12 tidal current observation stations are shown in Figure 3-2

The calibration process consisted of applying predicted tidal elevations at the Investigator Strait and Backstairs Passage boundaries, running the model for several spring-neap tidal cycles, and comparing the model results against predicted tidal water levels and currents derived for the various comparison locations throughout the Gulf.

The first stage of the calibration involved making adjustments to the model bed-friction coefficients to obtain the correct amplification of the tidal range as the tide propagates into the Gulf, and to obtain the correct magnitude of the tidal currents at the various comparison locations throughout the Gulf. Through this process, it was found that best results could be obtained using a Mannings *"n"* bed friction coefficient of *n=0.025* throughout the model domain.

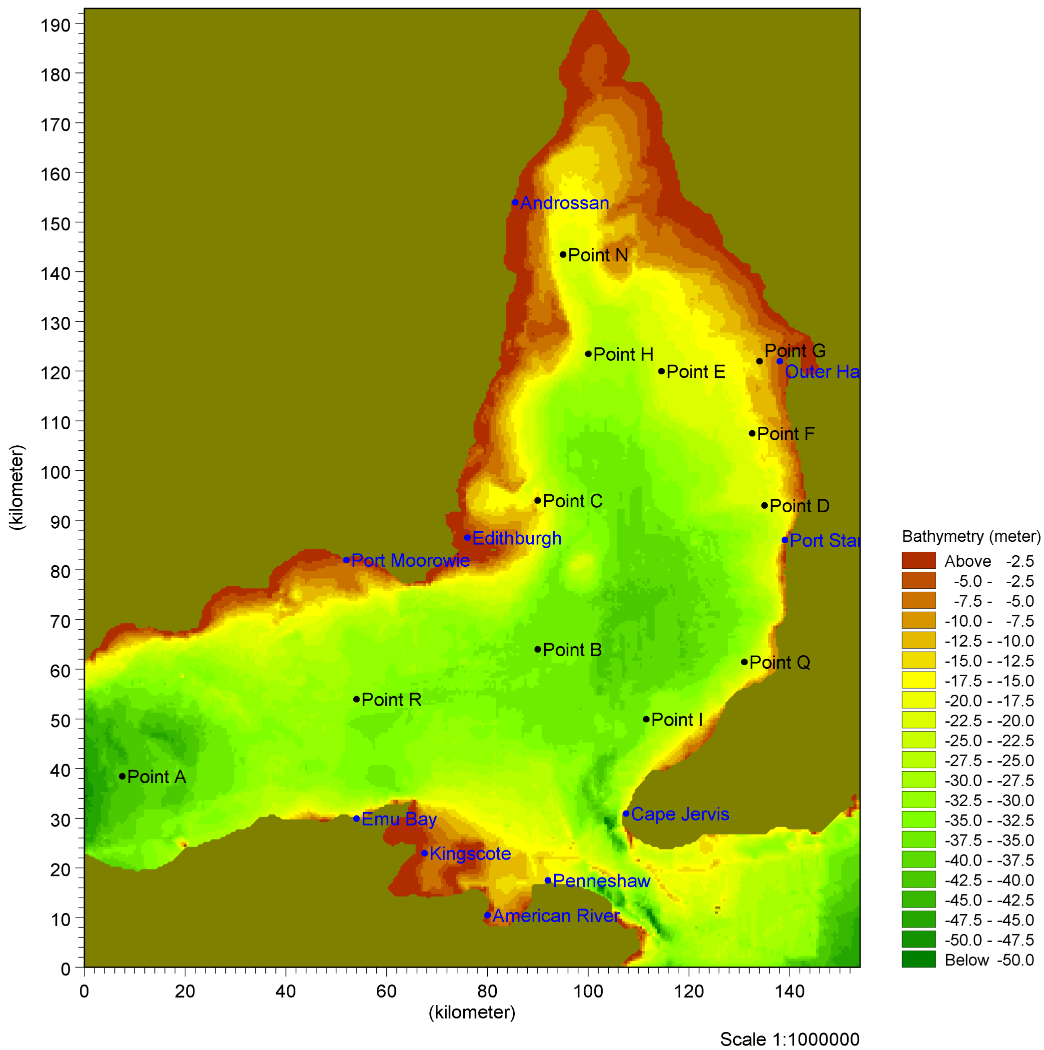


Figure 3-2 Locations of Tidal Water Level and Current Observation Comparisons

The next stage of the calibration consisted of fine tuning the tidal boundary conditions by making relatively minor alterations to the amplitude and/or phase of the tidal constituents used at the model boundaries. Initially, only the four main diurnal and semi-diurnal tidal constituents (O1, K1, M2 and S2) were used as these were available for all the locations being considered. In later work, however, it was found that better results, particularly around the dodge tide, could be obtained when three additional tidal constituents were used (P1, K2 and MU2).

For the Investigator Strait boundary, combinations of the main tidal constituents for Stenhouse Bay and Western River were adjusted to provide the best overall comparisons with predicted tides throughout the Gulf. The final calibrated boundary tidal constituents for the Investigator Strait boundary compared to available tidal information at Stenhouse Bay and Western River are shown in Table 3-1. It is noted that there were no P1, K1 or MU2 constituents available for Western River and the final boundary values were taken directly from those for Western River. The final Investigator Strait tidal boundary conditions are shown for a 25 day comparison period in Figure 3-3. This period covers a full neap-spring-neap tidal cycle. These results show that the spring tidal range at Investigator Strait is typically around 1.0 to 1.2m.

Table 3-1 Comparison of Tidal Constituents for the Investigator Strait Boundary

Location	M2		S2		O1		K1		P1		K2		MU2	
	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)
ANTT														
Stenhouse Bay	0.170	33	0.160	91	0.180	35	0.130	9	-	-	-	-	-	-
Western River	0.114	40.4	0.191	87.1	0.193	40.2	0.138	12.2	0.065	36	0.041	86.2	0.016	154.6
Model Boundary														
Investigator Strait	0.170	15	0.180	73	0.130	6	0.190	34	0.065	36	0.041	86.2	0.016	154.6

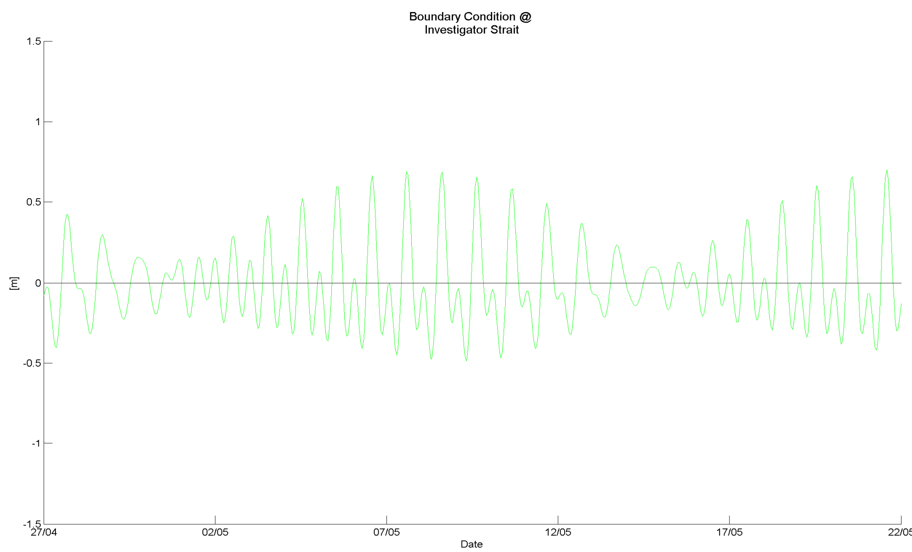


Figure 3-3 Predicted Tidal Elevations at the Investigator Strait Model Boundary

The same approach was used for the Backstairs Passage boundary, where combinations of the main tidal constituents for Victor Harbour and Vivonne Bay were adjusted to provide the best overall comparisons with predicted tides throughout the Gulf. It was found that best results were obtained when the Vivonne Bay constituents were used directly at the model boundary. Table 3-2 shows the final calibrated boundary tidal constituents for the Backstairs Passage boundary compared to the available tidal information at Vivonne Bay and Victor Harbour. The final Backstairs Passage tidal boundary conditions are shown for the 25 day comparison period in Figure 3-4. These results show that the spring tidal range at Backstairs Passage is a little smaller than that at Investigator Strait, and is typically around 1.0m.

Table 3-2 Comparison of Tidal Constituents for the Backstairs Passage Boundary

Location	M2		S2		O1		K1		P1		K2		MU2	
	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)
ANTT														
Vivonne Bay	0.141	337.4	0.155	30.6	0.117	354.7	0.166	18.1	0.054	14.7	0.047	33.3	0.008	83
Victor Harbour	0.131	349.8	0.151	46.8	0.140	2.6	0.201	31.8	-	-	-	-	-	-
Model Boundary														
Backstairs Passage	0.141	337.4	0.155	30.6	0.117	354.7	0.166	18.1	0.054	14.7	0.047	33.3	0.008	83

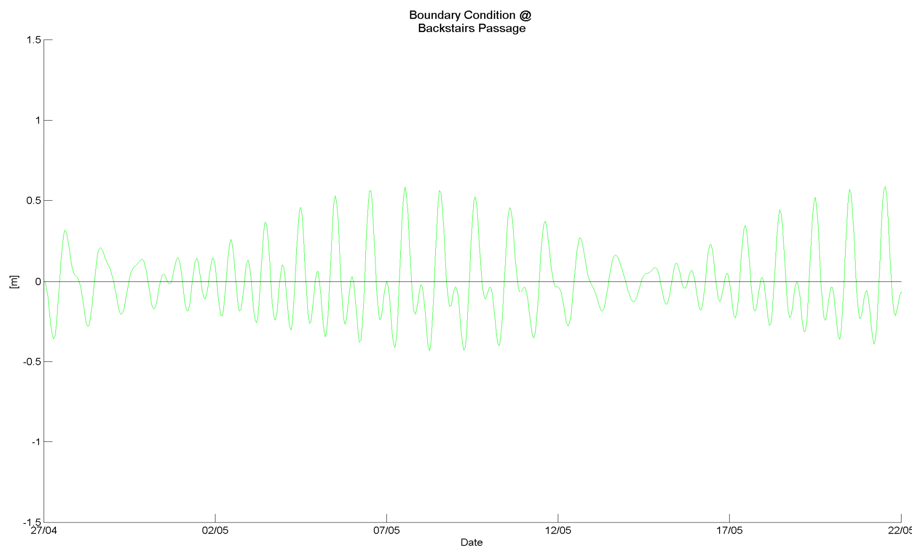


Figure 3-4 Predicted Tidal Elevations at the Backstairs Passage Model Boundary

3.2.2 Tidal Water Level Comparisons

The capability of the calibrated model to reproduce the main characteristics of the astronomical tide and its variation throughout Gulf St Vincent has been demonstrated by:

- Comparisons of time-series of predicted and modelled tides at selected locations.
- Correlations of predicted and modelled tides from the 10 comparison locations around the Gulf.
- Comparisons of tidal constituents derived from the model results with those provided by the Australian National Tide Tables (ANTT, 2004)
- Comparisons of contours of the amplitudes of the main M2 and S2 tidal constituents throughout the Gulf with those presented by Grzechnik (2002)

Time Series Comparisons

Comparisons of predicted and modelled tidal elevations at Port Stanvac, Edithburgh and Ardrossan are presented in Figure 3-5, Figure 3-6 and Figure 3-7. These are given for the same 25 day comparison period used for the model boundary conditions in the previous section. For the present comparisons, the predicted tidal elevations have been derived from constituents obtained from the Australian National Tide Tables (ANTT, 2004).

When compared with the corresponding boundary values given in Figure 3-3 and Figure 3-4, these results show that the model is capable of providing a good reproduction of the main features of the astronomical tide within Gulf St Vincent, including:

- The amplification of the tide from the Investigator Strait and Backstairs Passage model boundaries up to Ardrossan, near the head of the Gulf.
- The predominantly semi-diurnal tidal variation, including the distinct diurnal inequality
- The main characteristics of the dodge tide.

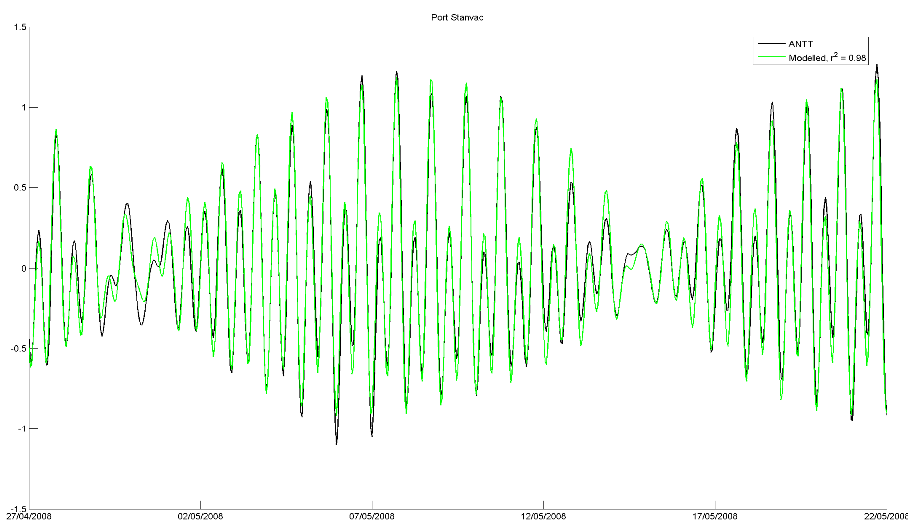


Figure 3-5 Comparison of Modelled and Predicted Astronomical Tides at Port Stanvac

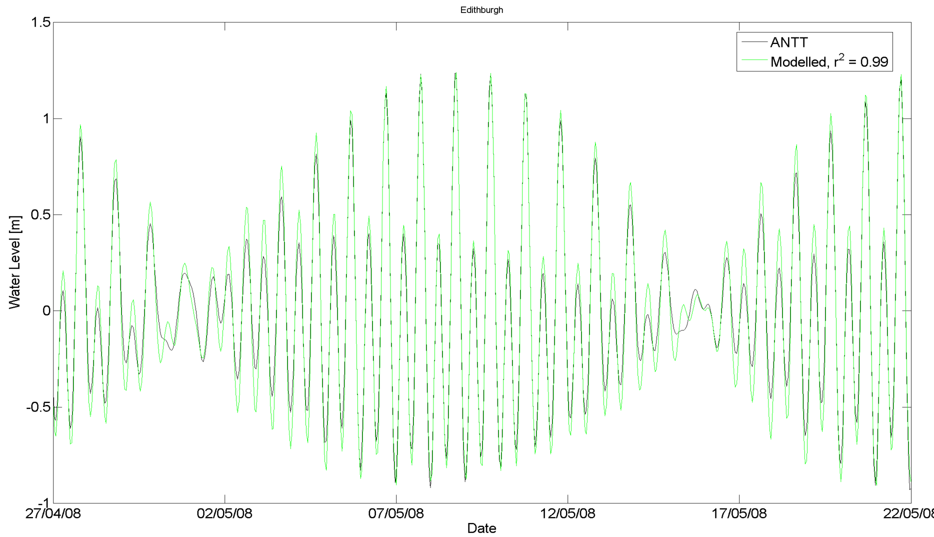


Figure 3-6 Comparison of Modelled and Predicted Astronomical Tides at Edithburgh

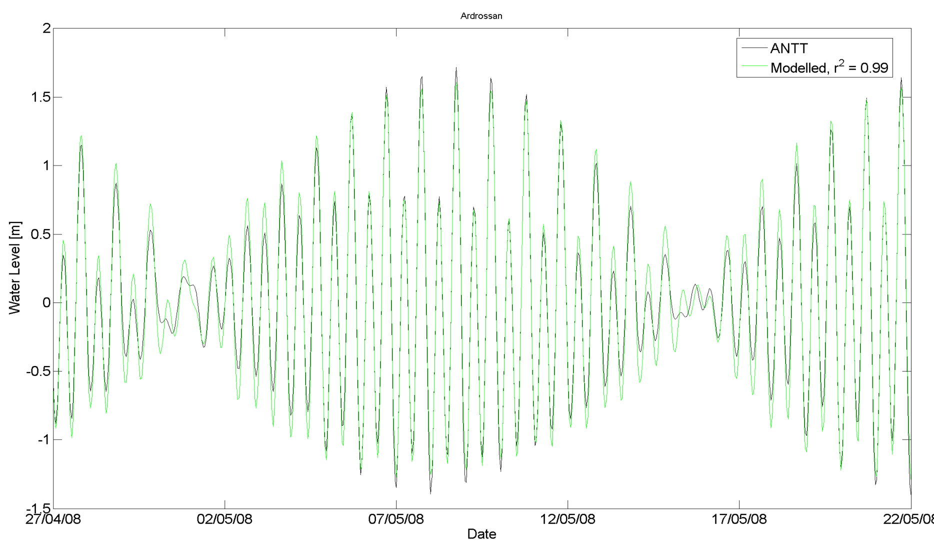


Figure 3-7 Comparison of Modelled and Predicted Astronomical Tides at Ardrossan

Tidal Correlations

Time-series of the predicted and modelled tidal elevations have been compared and correlated for each of the 10 tidal comparison stations. The resulting *"r^2"* correlation coefficients for each of the locations are provided in Table 3-3. With correlation coefficients of *$r^2 \geq 0.98$* for all locations, these results show excellent agreement between the predicted and modelled tidal elevations throughout the Gulf.

Table 3-3 Tidal Calibration – Time-series Correlation

Location	Latitude	Longitude	Correlation Coefficient (r^2)
American River	-35.8	137.8	0.98
Ardrossan	-34.4	137.9	0.99
Cape Jervis	-35.6	138.1	0.98
Edithburgh	-35.1	137.8	0.99
Emu Bay	-35.6	137.5	0.99
Kingscote	-35.6	137.6	0.99
Outer Harbour	-34.8	138.5	0.99
Penneshaw	-35.8	138.0	0.99
Port Moorowie	-35.2	137.5	0.99
Port Stanvac	-35.1	138.5	0.98

Tidal Constituents

Tidal constituents have been derived from the model results for each of the 10 tidal comparison locations. These have been compared with the corresponding values from the ANTT (2004). The results of the comparison for Port Stanvac are presented in Table 3-4. These have been given for the 7 main tidal constituents used to derive the model boundary conditions. The results show only minor differences between the predicted and modelled amplitudes and phases of the main tidal constituents at Port Stanvac.

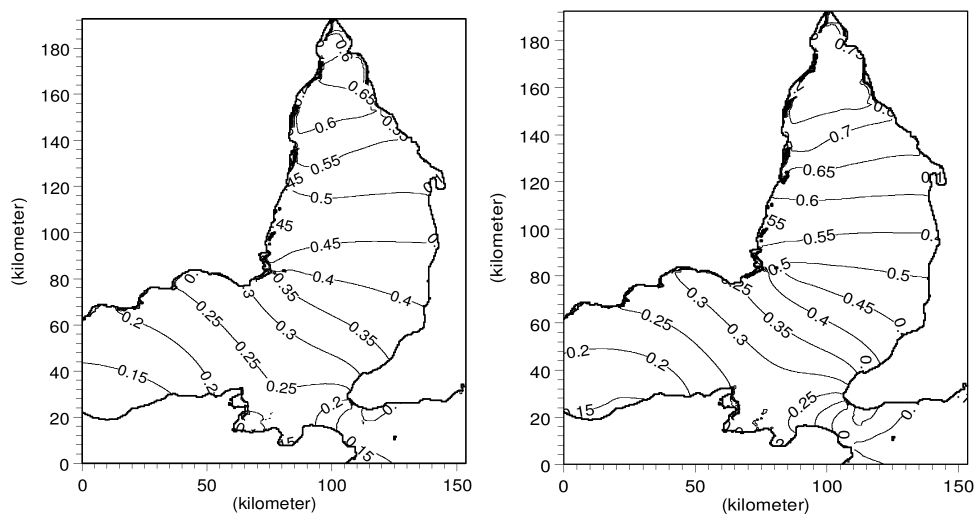
Table 3-4 Comparison of Modelled and Predicted Tidal Constituents at Port Stanvac

Location	M2		S2		O1		K1		P1		K2		MU2	
	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)
Predicted	0.435	103.8	0.425	172.2	0.167	19.8	0.248	48.1	0.068	41.4	0.124	172.1	0.075	211.8
Modelled	0.430	101.6	0.417	170.1	0.160	18.6	0.239	47.0	0.076	50.3	0.097	174.5	0.065	215.5
Difference	-0.005	-2.2	-0.008	-2.1	-0.007	-1.2	-0.009	-1.1	0.008	8.9	-0.03	2.4	-0.01	3.7

The results of the comparisons for the other tidal comparison locations are presented graphically in Appendix A. These have been given in terms of the amplitudes and phases of the 4 main diurnal and semi-diurnal (M2, S2, O1 and K1) tidal constituents. As for Port Stanvac, these results show only minor differences between the predicted and modelled amplitudes and phases of the main tidal constituents at the other locations around the Gulf.

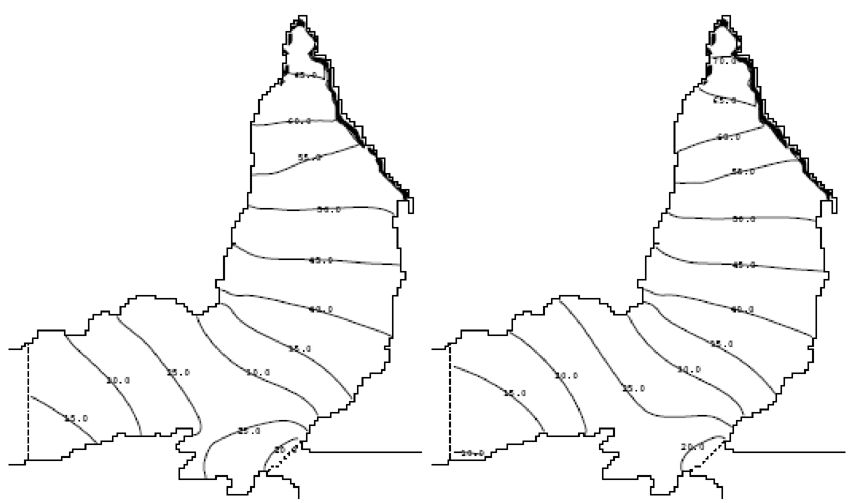
Spatial Comparisons

The amplitudes of the main modelled semi-diurnal lunar and solar tidal constituents (M_2 and S_2) have been analysed spatially over the model domain and compared to those presented by Grzechnik (2002). The results are presented in Figure 3-8 and Figure 3-9. Comparison of the results of the two different models shows they are in relatively good agreement.



(a) M_2 amplitude (b) S_2 amplitude

Figure 3-8 Spatial Variation of Modelled M_2 and S_2 Amplitudes



(a) M_2 amplitude (b) S_2 amplitude

Figure 3-9 Predicted Spatial Variation of M_2 and S_2 (Grzechnik, 2002)

Overall, it is considered that the two-dimensional Gulf St Vincent model is capable of providing a good reproduction of the main features of the astronomical tide within Gulf St Vincent.

3.2.3 Tidal Current Comparisons

The capability of the calibrated model to reproduce the main characteristics of tidal currents and their variation throughout Gulf St Vincent has been demonstrated by:

- Comparisons of time-series of predicted and modelled tides at selected locations.
- Comparisons of the main tidal current constituents derived from the model results with those provided by Bowers and Lennon (1990).

Time Series Comparisons

Comparisons of predicted and modelled tidal currents are presented in Figure 3-10, Figure 3-11 and Figure 3-12. The predicted tides presented in these figures have been derived from tidal current constituents provided by Bowers and Lennon (1990). The results are given in terms of u (north-south) and v (east-west) velocity components for current comparison locations D, C and N, given in Figure 3-2. These locations correspond to the closest current measurement stations to Port Stanvac, Edithburgh and Ardrossan, respectively.

The results show that the model is capable of providing a good reproduction of the main features of the tidal currents within Gulf St Vincent. This includes the main features of the reduced currents during dodge tides. One point of interest is that the signal of the diurnal inequality is less distinctive in both the modelled and predicted currents, relative to that in the water levels.

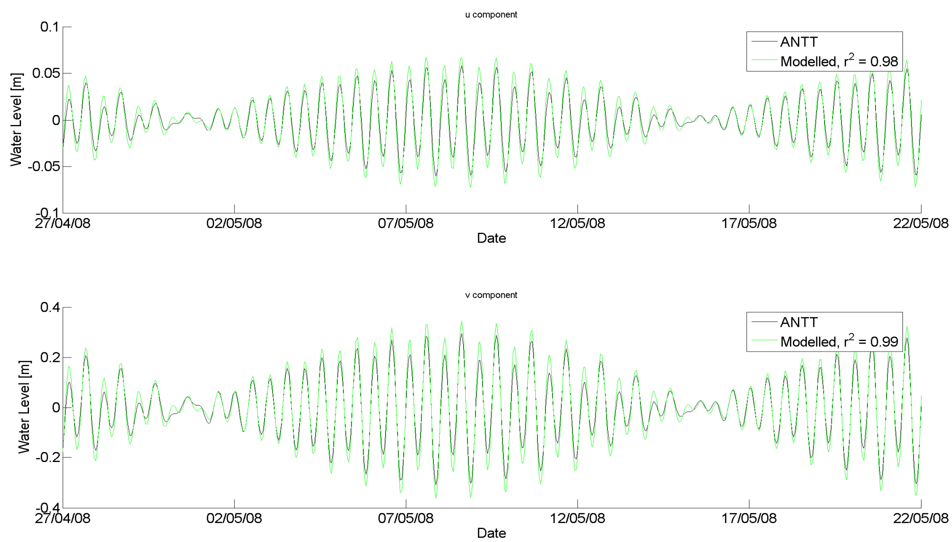


Figure 3-10 Comparison of Modelled and Observed Astronomical Tidal Currents at Point D

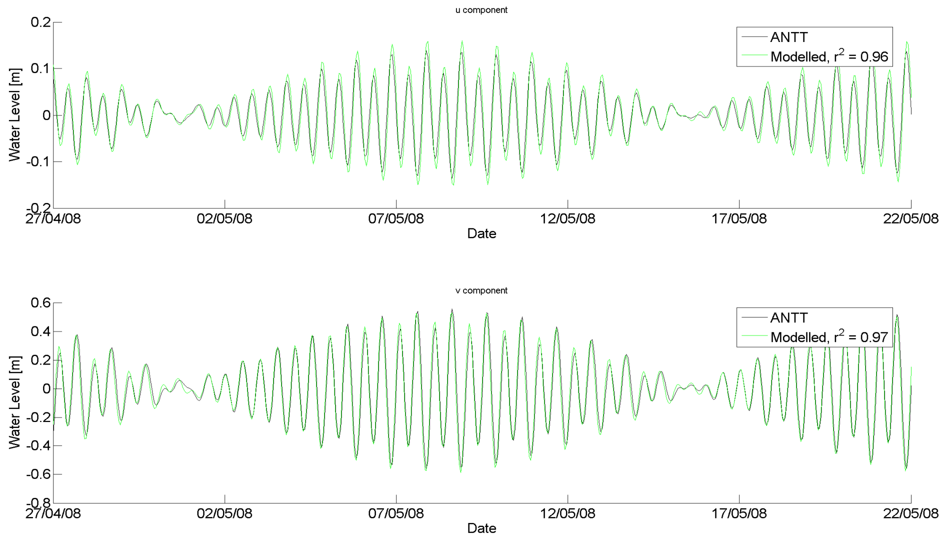


Figure 3-11 Comparison of Modelled and Observed Astronomical Tidal Currents at Point C

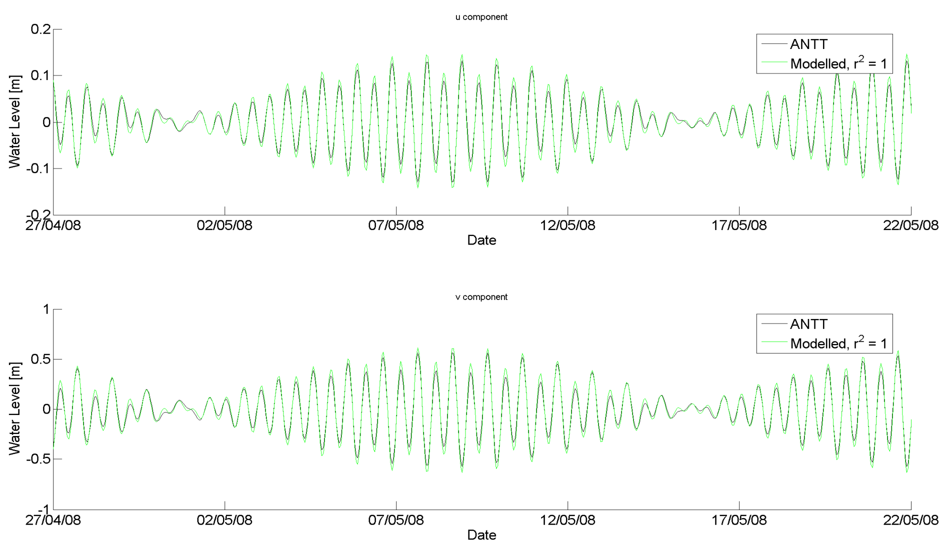


Figure 3-12 Comparison of Modelled and Observed Astronomical Tidal Currents at Point N

Tidal Constituent Comparisons

Tidal current constituents have been derived from the model results for each of the tidal current comparison locations. These have been compared with the corresponding values from Bowers and Lennon (1990). The results of the comparisons are presented graphically in Appendix B. These have been given in terms of the amplitudes and phases of the 4 main diurnal and semi-diurnal (M2, S2, O1 and K1) tidal current constituents. As for the water levels, these results show only minor differences between the predicted and modelled amplitudes and phases of the main tidal current constituents throughout the Gulf.

Overall, it is considered that the two-dimensional Gulf St Vincent model is capable of providing a good reproduction of the main features of the tidal currents within Gulf St Vincent.

3.2.4 Calibration of Meteorologically Derived Water Level Variations

Water level variations within Gulf St Vincent can also be caused by low-frequency shelf waves propagating into the Gulf, and local wind forcing within the Gulf.

To validate the models ability to represent these hydrodynamic features of the Gulf St Vincent, the model has been compared to a specific period of observed water level data at Port Stanvac, commencing the 1st June 2008.

An estimate of the non-tidal sea level variations due to shelf waves on the model boundaries was provided by filtering the tidal signal from the observed water level data for the tide gauge at Thevenard. Although Thevenard is approximately 400 km from Investigator Strait, it was found that the non-tidal water level variations (tidal residuals) at this location were reasonably representative of the tidal residuals along much of the coast in the general area. This can be seen in the comparison of the tidal residuals at Thevenard and Port Stanvac presented in Figure 3-13.

From, Figure 3-13 it can be seen that, with the exception of a small phase shift, the two records are highly correlated. This indicates that a significant proportion of the overall variation in non-tidal water levels at Port Stanvac is associated with broad, low-frequency shelf waves propagating into Gulf St Vincent. In this respect, it is noted that some of the variations between the two sets of residuals will be due to local wind set-up within the Gulf.

It was therefore concluded that, when allowance was made for the phase shift, the tidal residuals at Thevenard could be used to represent the non-tidal signal in the water levels at the model boundaries.

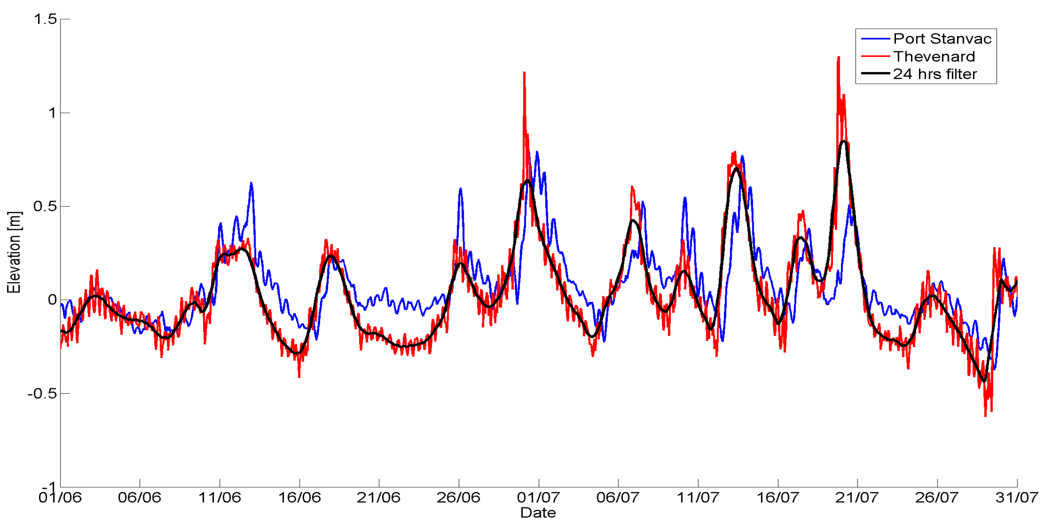


Figure 3-13 Comparison of Tidal Residual at Thevenard and Port Stanvac

The wind boundary file was generated from wind measurements obtained from the Bureau of Meteorology wind stations shown in Figure 3-1. The observations were interpolated to form a spatially varying wind field over the Gulf, and applied for the model calibration simulations.

The model was simulated over the 2 month period from the 1 June 2008 to 31 July 2008 and the results compared to the observed water level record at Port Stanvac for the same period. Minor adjustments to the wind friction coefficients and fine tuning the phase shift of the Thevenard tidal residual record at the model boundaries was undertaken as part of the calibration.

For the wind forcing, it was found that best results were obtained with a wind friction factor increasing linearly with wind speed from $f = 0.0016$ for no wind, to $f = 0.0026$ for a wind speed of 24 m/s, and remaining constant at $f = 0.0026$ for higher wind speeds.

For the meteorologically derived water level variations, it was found that the best results were obtained when the model boundary residuals lagged those measured at Thevenard by 9.5 hours. The final calibrated boundary conditions for the Investigator Strait boundary are presented in Figure 3-14 . This shows that, at this location, the astronomical tide has a maximum range of around 1.0 m during spring tides, and that the meteorologically derived water level variations have much longer periods and can have magnitudes similar to those of the astronomical tide. The boundary conditions for Backstairs Passage show similar characteristics; but with the amplitude of the astronomical tide being slightly smaller than that for Investigator Strait, as noted in Section 3.1.2.

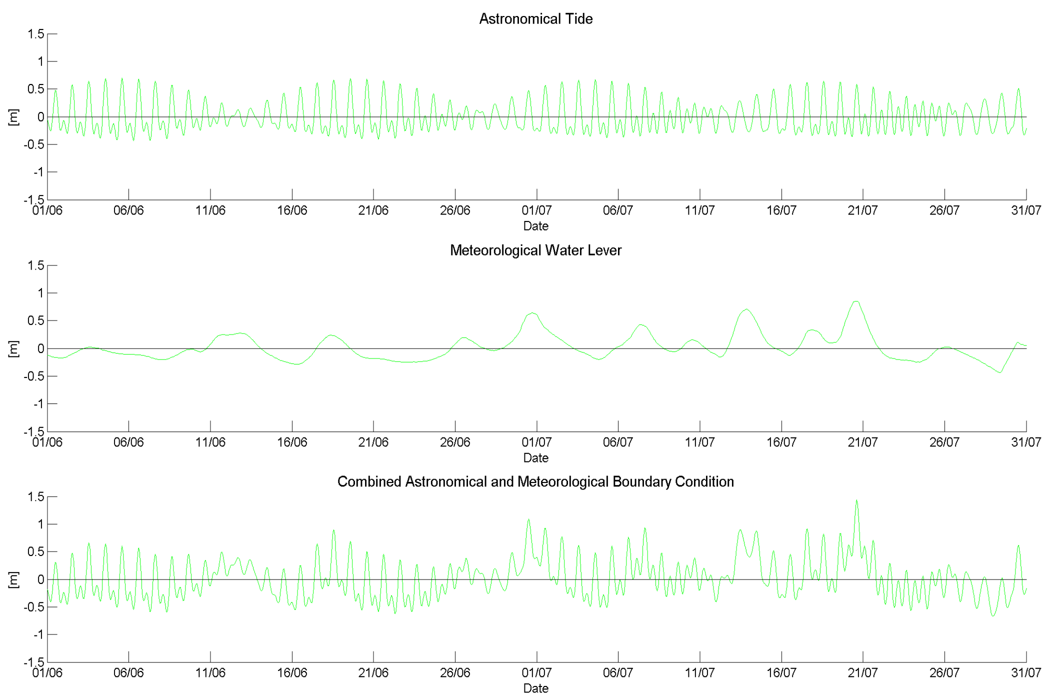


Figure 3-14 The Make-up of the Investigator Strait boundary conditions from the combination of the Astronomical Tide and the Meteorologically derived water level variations

The results of the final calibration simulation are presented in Figure 3-15 and Figure 3-16. Figure 3-15 is considered to show that the model is capable of providing a good description of the overall water level variations at Port Stanvac for the 2 month calibration period.

Figure 3-16 shows that the model is capable of providing an accurate description of the tidal residuals (i.e., the non-tidal water level variations) at Port Stanvac. The correlation coefficients of $r^2 = 0.98$ for the water level comparisons, and of $r^2 = 0.91$ for the non-tidal residual comparisons are considered to be excellent.

Overall, it is concluded that the calibrated Gulf St Vincent model is capable of providing a good representation of both the tidal and non-tidal water level variations at Port Stanvac.

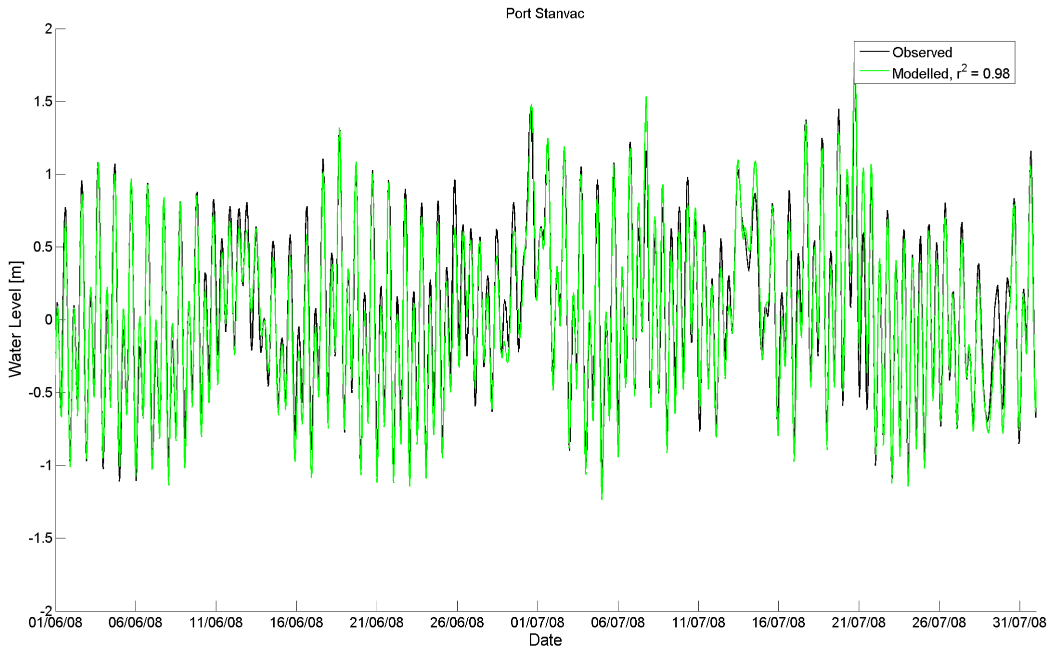


Figure 3-15 Comparison of Modelled and Observed Water Level Variations at Port Stanvac

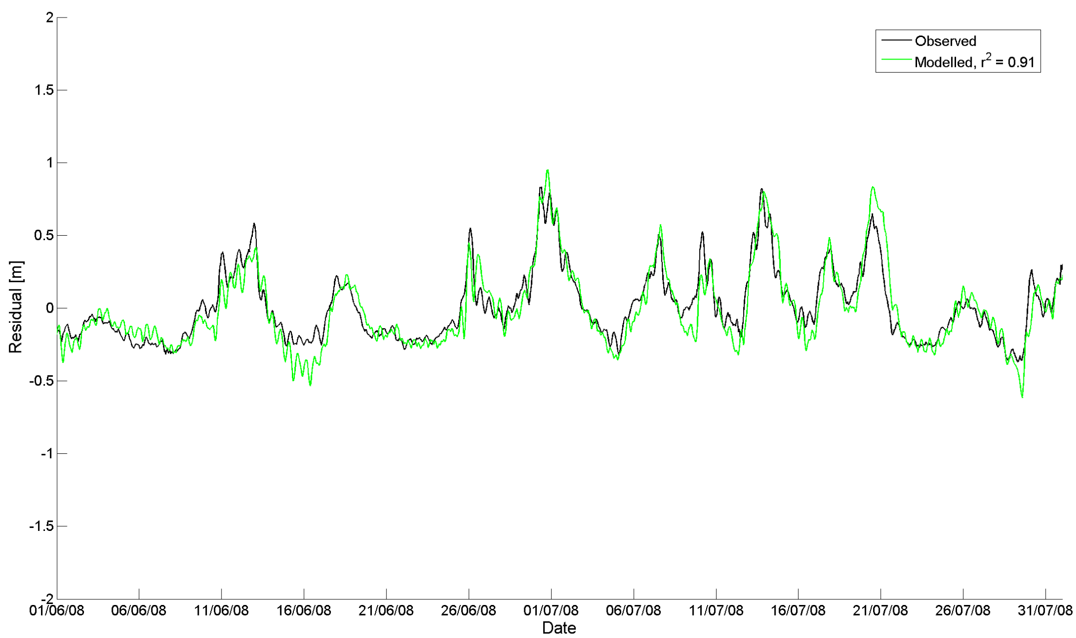


Figure 3-16 Comparison of Modelled and Observed Tidal Residuals at Port Stanvac

4. THREE-DIMENSIONAL MID-FIELD MODEL

Detailed mid-field numerical modelling of the hydrodynamics in the coastal waters in the vicinity of Port Stanvac has been undertaken to model the dilution performance of the Adelaide desalination plant outfall. The following sections describe the model establishment and calibration.

4.1 Model Setup

The Danish Hydraulic Institute's (DHI), MIKE 3 modelling system has been used to develop a three-dimensional model of Gulf St Vincent. MIKE 3 is a state-of-the-art modelling system for free surface flows in response to a variety of forcing functions in rivers, lakes, estuaries and coastal areas. The modelling has been carried out using the Flexible Mesh (FM) version of MIKE 3. This uses finite volume techniques to solve the variable density Reynolds-averaged Navier-Stokes equations for the conservation of mass and momentum. The model domain can be described as a combination of triangular and quadrilateral elements of varying size.

MIKE 3 has the capability to model the effects that both salinity and temperature have on the density of water and includes eddy viscosity formulations to take into account the effects that sub-grid scale turbulence has on mixing. For horizontal mixing, a "Smagorinsky"-type formulation is used to calculate time and space varying eddy viscosity coefficients as a function of the local flow conditions. For vertical mixing, a more sophisticated *"k-ϵ"* formulation is used to include the effects that density stratification can have on reducing the effects of vertical mixing.

4.1.1 Domain Schematisation

The domain of the mid-field model was selected to ensure that it encompassed the area covered by the movement of the saline concentrate plume over the short to medium-term (i.e., on a time scale of days to weeks). The model domain covers an area 20 km by 11.5 km and approximates that of the three-dimensional model employed in the modelling investigations for the EIS (Pattiaratchi, 2008). The coordinates of the extents of the model domain are provided below. These are given in terms of the Geocentric Datum of Australia (GDA94) Zone 54 in metres.

	Northern 6122500	
Eastern 262000		Western 273500
	Southern 6102500	

The domain of the three-dimensional mid-field model is shown relative to that of the two-dimensional Gulf model in Figure 4-1.

The flexible mesh modelling system has enabled the horizontal resolution of the model to be significantly increased in the vicinity of the outfall diffuser and intake riser where the density gradients are greatest. The significant increase in the resolution of the domain schematisation in the vicinity of the outfall is considered critical to enable the density driven gradients and plume behaviour to be resolved accurately.

Additionally, the significantly reduced element sizes at the location of the diffuser enables significantly greater control over the volume in which the saline concentrate concentrate is instantaneously distributed in the domain and greatly assists in limiting the potential for overestimation of the dilutions in the near field for the scenario modelling discussed in Section 7.2.

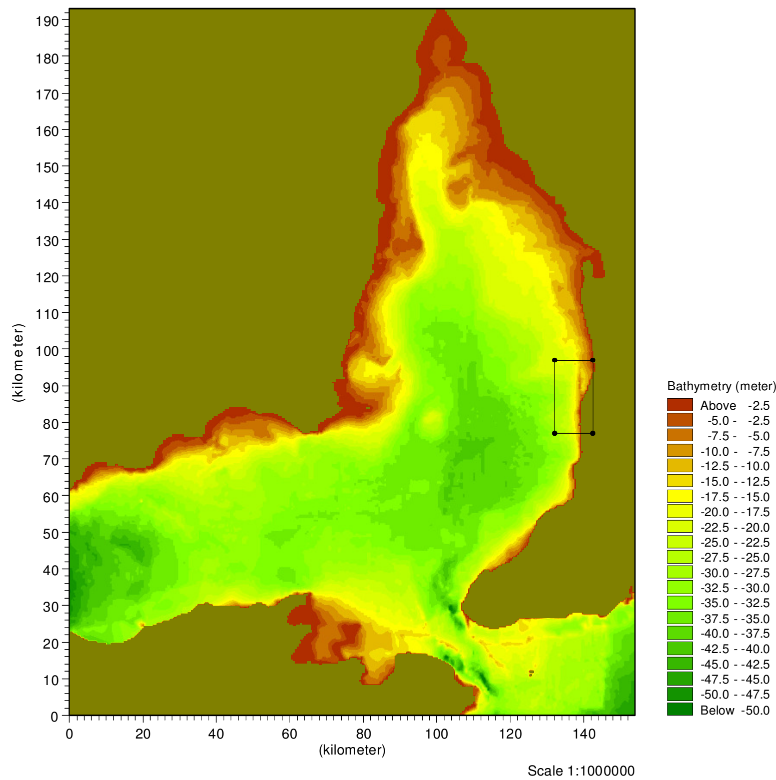


Figure 4-1 Mid-Field Three-Dimensional Model Extent Compared to Gulf St Vincent Model

Vertical layering within the model is represented by 17 layers of equidistant thickness (sigma coordinates). At the location of the outfall diffuser in approximately 17 m depth, the vertical resolution is therefore equal to approximately 1 m.

The mid-field model mesh has been developed as a composite of triangular and quadrilateral elements of varying sizes. In the outer areas, the model uses a triangular horizontal mesh with a side length scale in the order of 1000 m. This reduces successively down to 50 m then 20 m in the vicinity of the diffuser. In the immediate vicinity of the diffuser a much finer quadrilateral mesh with a side length of 8 m is used. This grid size was selected as it was of the same order of magnitude as the dimensions of the diffuser plumes at their maximum height of rise, and was the smallest that could be used and allow for model simulations to be completed in a reasonable time.

The overall mid-field model domain and mesh schematization is presented in Figure 4-2. More details of the model schematization in the vicinity of the diffuser are shown in Figure 4-3. A close-up of the model schematisation in the immediate vicinity of the outfall diffuser is shown in Figure 4-4.

MIKE 3 FM uses an explicit finite volume solution procedure. As a result of the numerical stability constraints of this method, the maximum time step that can be used is limited to just over 0.5 seconds. The model simulations run at approximately one-third of real time, using parallel processing on a four-core computer. The 6-week EIS simulations take approximately 2 weeks to complete, while the shorter 2-week dodge tide simulations take 4 to 5 days.

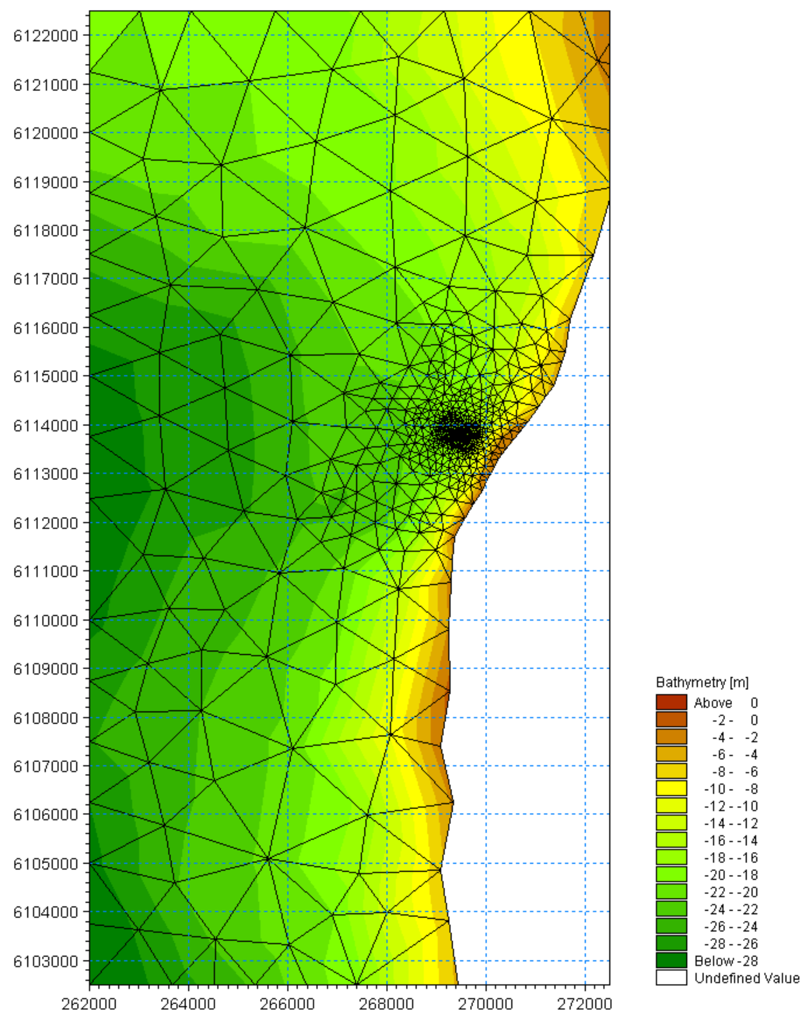


Figure 4-2 Mid Field Model Domain and Schematisation

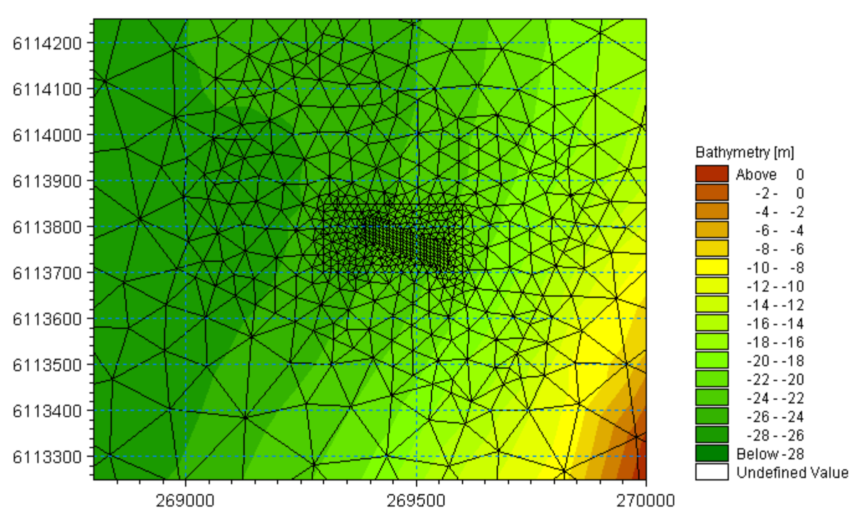


Figure 4-3 More Detail of the Model Schematisation in the Vicinity of the Outfall Diffuser

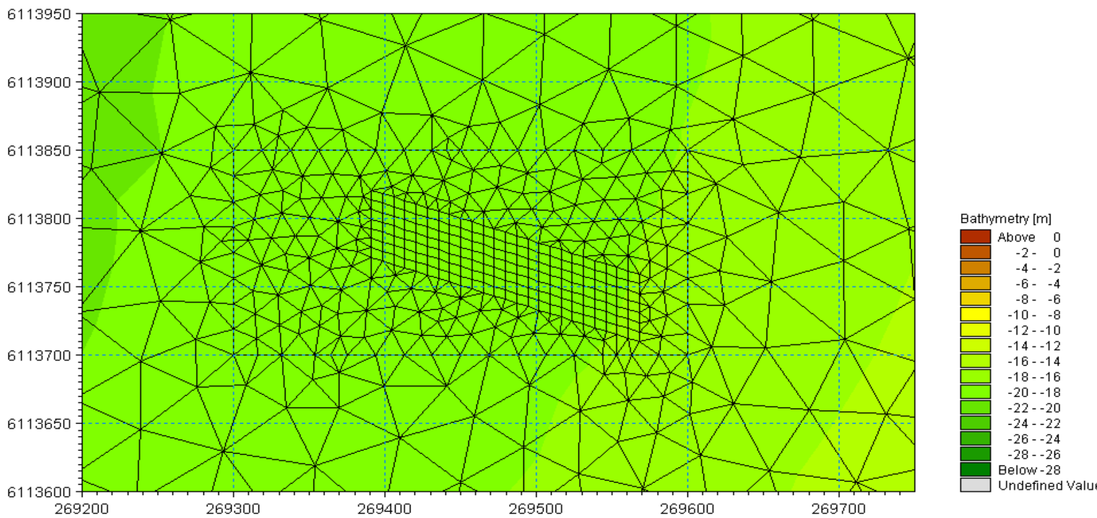


Figure 4-4 A Close-up of the Model Schematisation in the Vicinity of the Outfall Diffuser

4.1.2 Boundary Conditions

The mid-field model boundaries were derived directly from the results of the Gulf St Vincent model. The northern boundary was specified in terms of time and space-varying water level elevations along the boundary. The west and southern boundaries were specified in terms of time and space-varying discharges along the boundaries. These discharges were given in terms of the depth-averaged velocity times the depth. Directional information was provided by specifying the discharges in terms of north and east-going vector components at each point along the boundaries.

The mid-field model was effectively nested within, but decoupled from the Gulf St Vincent model. The mid-field model boundaries were therefore fully specified, in a two-dimensional sense, to the multiple forcing processes that influence the hydrodynamics at Port Stanvac.

4.1.3 Wind Conditions

The shear stresses at the sea surface due to wind action are an important mechanism for developing vertical mixing in the coastal waters at Port Stanvac. The wind observations over the calibration period at Port Stanvac were applied over the entire mid-field model domain. Calibration of the friction factor was an important component of the calibration process and was undertaken through close comparison of the Acoustic Doppler Current Profiler (ADCP) current measurements and the modelled currents. Ultimately, the best results were obtained using the same wind friction factors as used in the Gulf St Vincent model. That is, a wind friction factor increasing linearly with wind speed from $f = 0.0016$ for no wind, to $f = 0.0026$ for a wind speed of 24 m/s, and remaining constant at $f = 0.0026$ for higher wind speeds.

4.1.4 Ambient Temperature and Salinity

Seasonal variations in ambient salinity and water temperature are observed at Port Stanvac. The influence of these variations is, however, not considered particularly significant in the assessment of the dilution performance of the outfall. For the calibration and dilution modelling assessment, an ambient water temperature of 16°C and salinity of 37 ppt has been adopted.

4.1.5 Eddy Viscosity and Dispersion

The transfer of momentum through sub-grid scale turbulence is modelled through the inclusion of eddy viscosity in both the horizontal and vertical.

The horizontal eddy viscosity is given by a "Smagorinsky-type" formulation. This expresses the effects of sub-grid scale turbulence by an effective eddy viscosity related to a characteristic length scale and the local spatial current variations.

The vertical eddy viscosity is modelled using a standard k-ε formulation, as described for example by Rodi (1980). The turbulence model solves two additional transport equations for the turbulent kinetic energy (k), and the dissipation (ε) of turbulent kinetic energy. The damping effect of stratification on vertical mixing is included through a Richardson number dependent damping coefficient.

The horizontal and vertical dispersion coefficients used in the saline concentrate dispersion computations are directly linked to the eddy viscosity through a scaling factor such that the amount of dispersion is governed by the turbulence in the flow.

The vertical eddy viscosity formulation employed in the model has not included the impact of wave orbital motions which enhance vertical mixing and therefore the vertical eddy viscosity (although this capability can be incorporated in the model). The wave climate at Port Stanvac is considered relatively subdued and therefore the impact on the vertical eddy viscosity is expected to be relatively minor over the long term. By excluding this feature of the hydrodynamics at Port Stanvac the modeling results are considered slightly conservative in that the amount of vertical mixing is slightly underestimated.

4.2 Model Calibration

Calibration of the three dimensional hydrodynamic model has been undertaken by comparison with observed water levels and ADCP current data at Port Stanvac.

A two week period of observed water levels and current information commencing the 8th June 2008 has been used to calibrate the model and display the models ability to reproduce the observed three -dimensional hydrodynamic current features at Port Stanvac.

Figure 4-5 displays the observed wind conditions and modelled and observed water level variations at Port Stanvac over the two week calibration period. The two week calibration period is considered to provide a good representation of the range of hydrodynamic features of interest for the modelling including:

- A strong spring-neap tide cycle, including a period of minimal tidal water level variations (dodge tide).
- A low-frequency shelf wave surge of approximately 0.5m over 48 hours.
- A relatively strong wind event from the south-south west with average wind speeds approaching 12 m/s (24 knots).

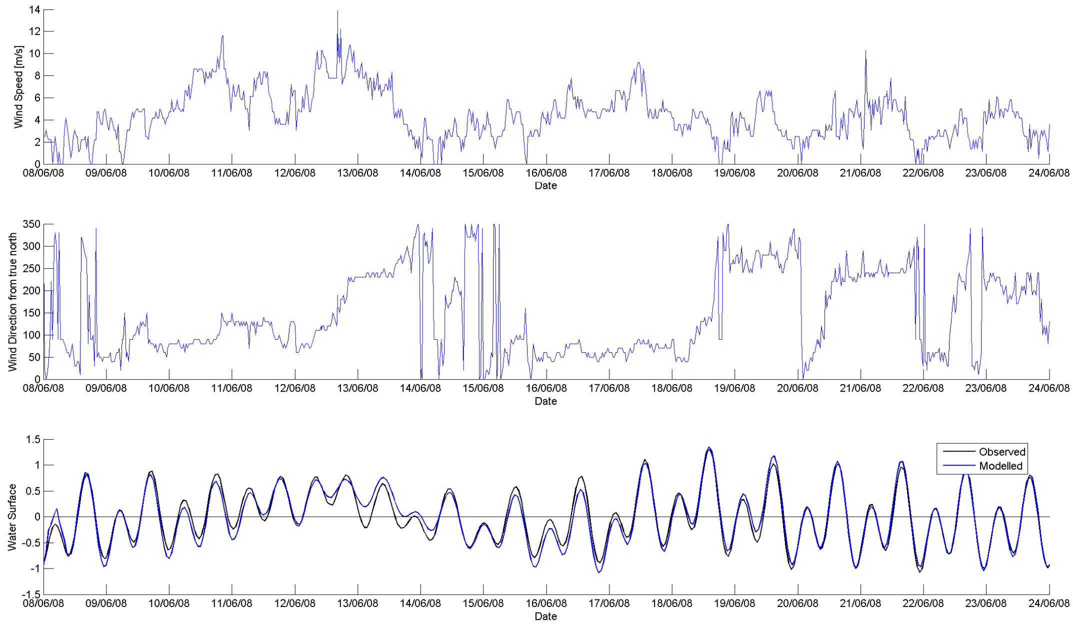


Figure 4-5 Calibration Period Water Level and Wind Conditions at Port Stanvac

The ADCP data has been processed at the 15 m (bottom), 10 m (middle) and 5 m (surface) isobaths over the calibration period and summarised into the following components:

- Cross shore (v) velocity vector component.
- Longshore (u) velocity vector component.
- Total current speed as the vector sum of the u and v velocity components.
- Current direction.

The distribution of near surface current speeds and directions has been compared by way of rose plots over the calibration period in Figure 4-6. This shows that the model is capable of providing a good representation of the distribution of near surface current speeds and directions.

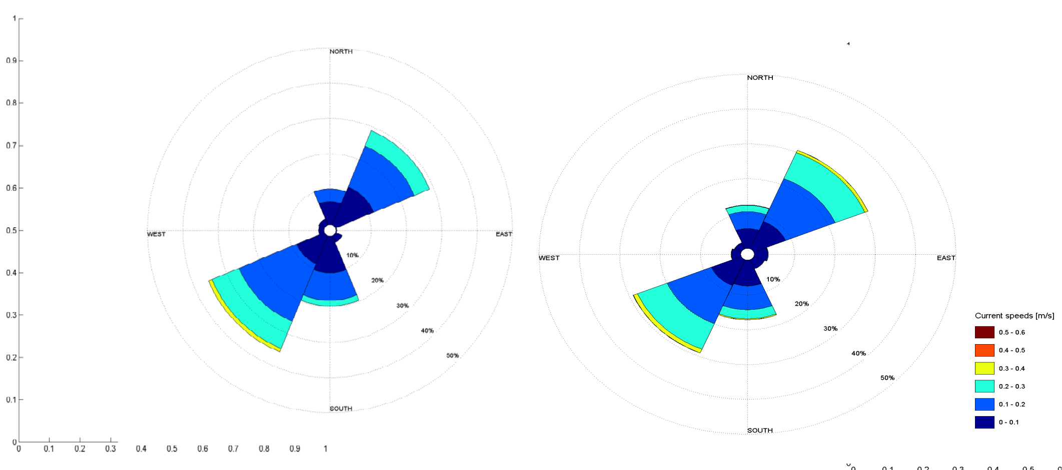


Figure 4-6 Comparison of Modelled (left) and Observed (right) Near Surface Current Speed and Direction Distributions over the Calibration Period

The current components derived from the ADCP data have been compared directly to the modelled current results in Figure 4-7, Figure 4-9, and Figure 4-10 for the 15m (bottom), 10m (middle) and 5m (top) isobaths respectively. It is considered that these figures show a high level of agreement between the modelled and measured velocity components, total current speed and direction over the entire depth. There are some increasing higher order fluctuations in the measured surface layer currents associated with wave action and interaction of the ADCP acoustics with the sea surface.

Overall, it is considered that the mid-field model is capable of providing a realistic description of the currents in the vicinity of the outfall diffuser, and their variation with depth.

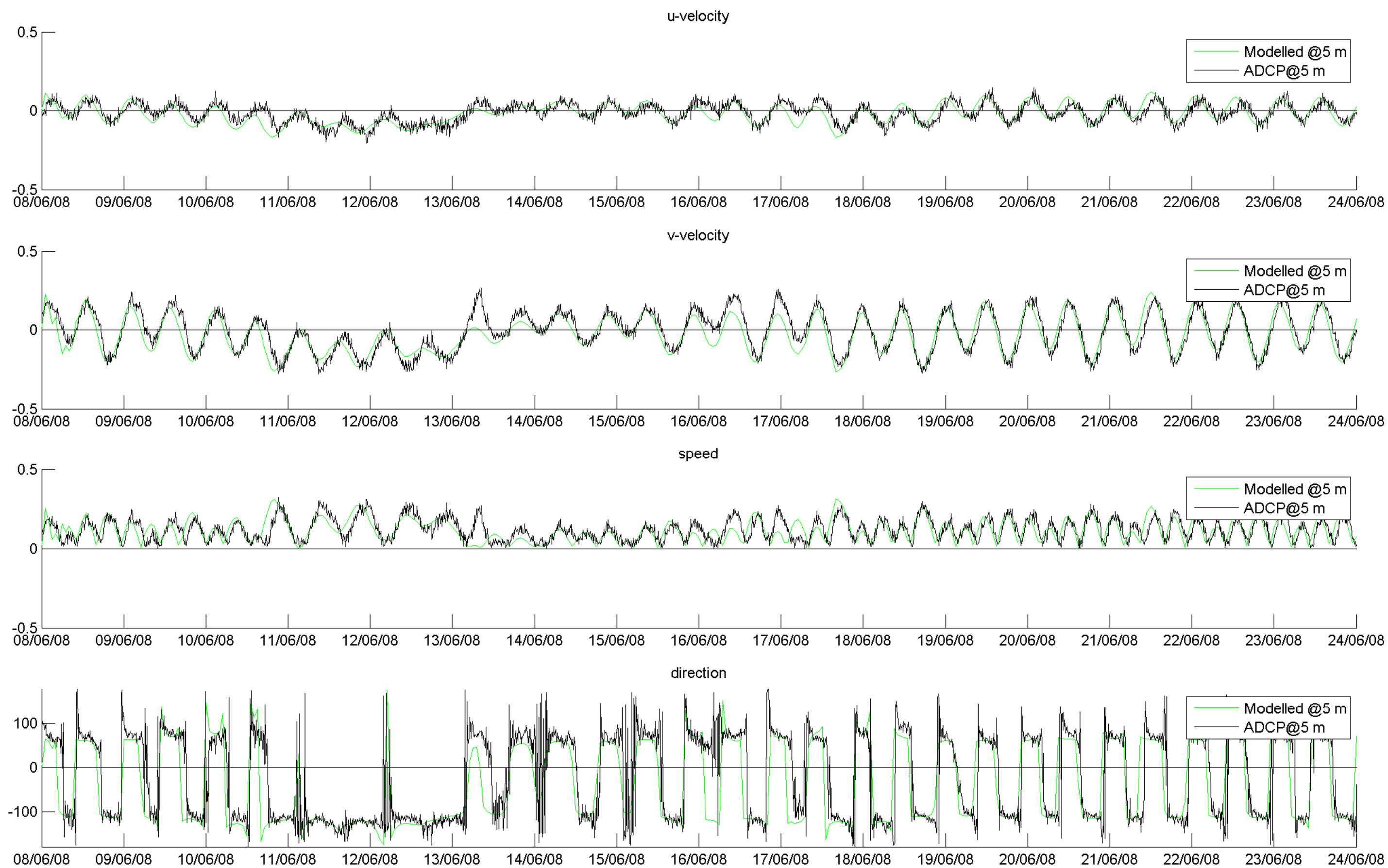


Figure 4-7 Comparison of velocity components, speed and direction between 3D model and the measured ADCP data at z = 5 m above bed.

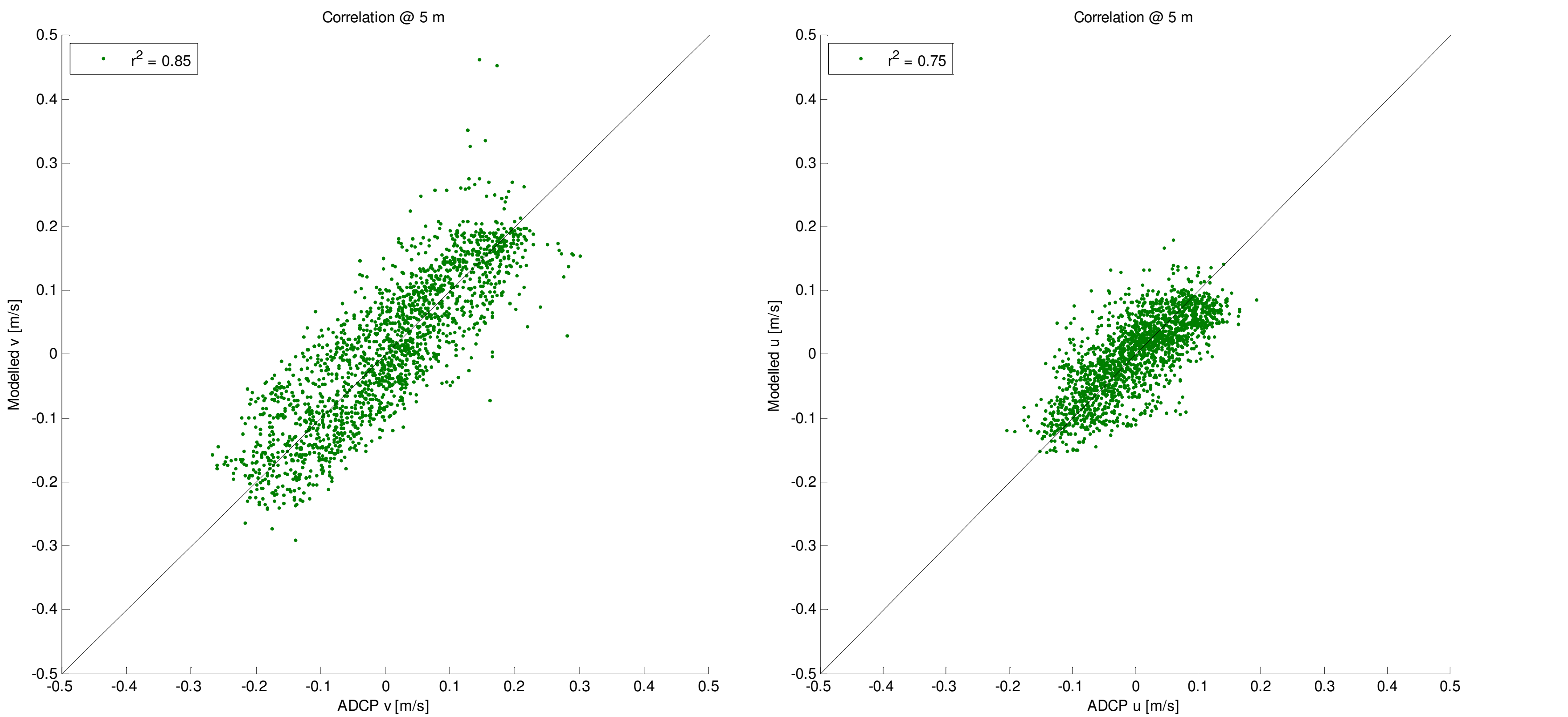


Figure 4-8 Correlation of longshore (v) and cross shore (u) velocity components at z = 5 m above bed

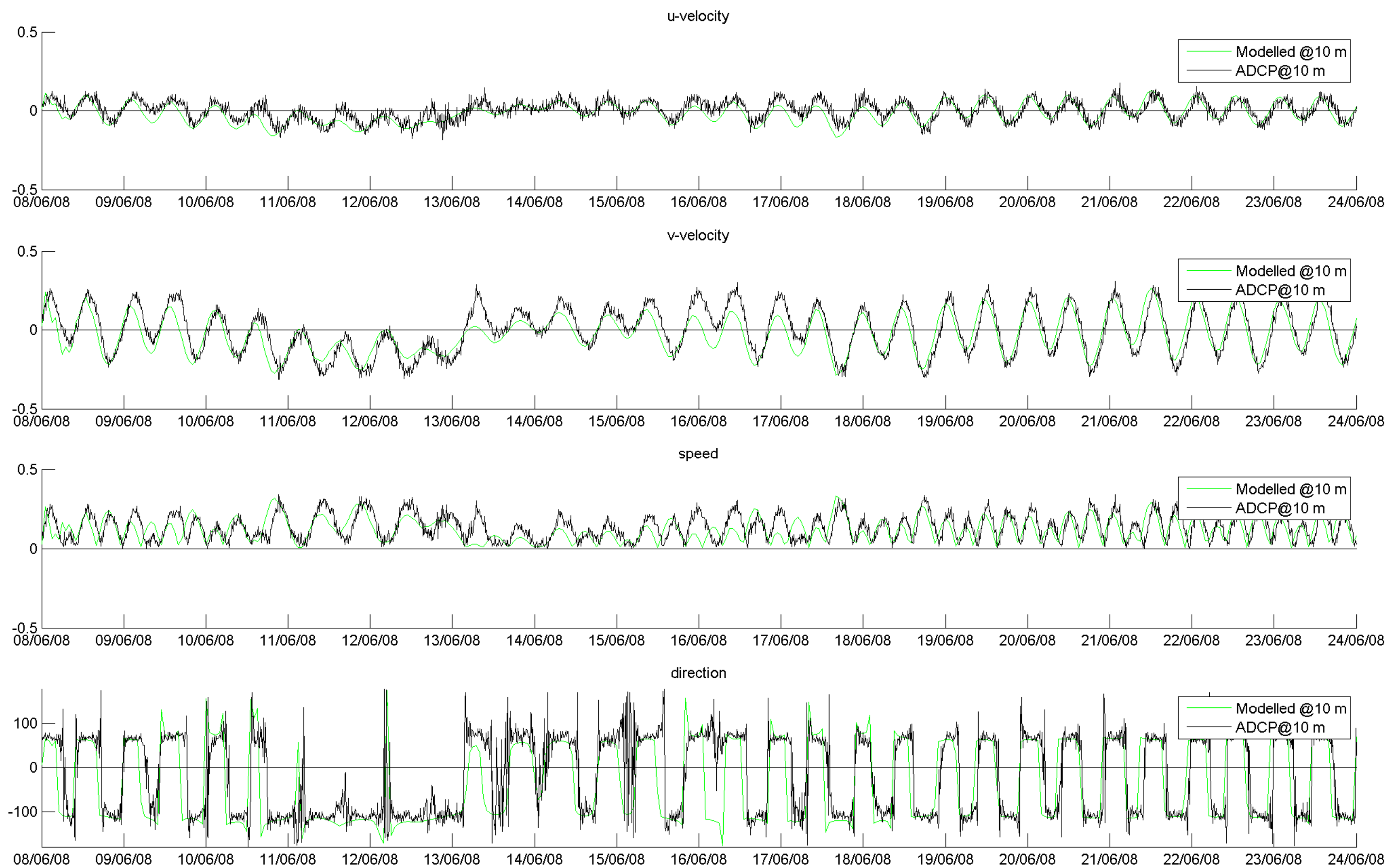


Figure 4-9 **Comparison of velocity components, speed and direction between 3D model and the measured ADCP data at z = 10 m above bed.**

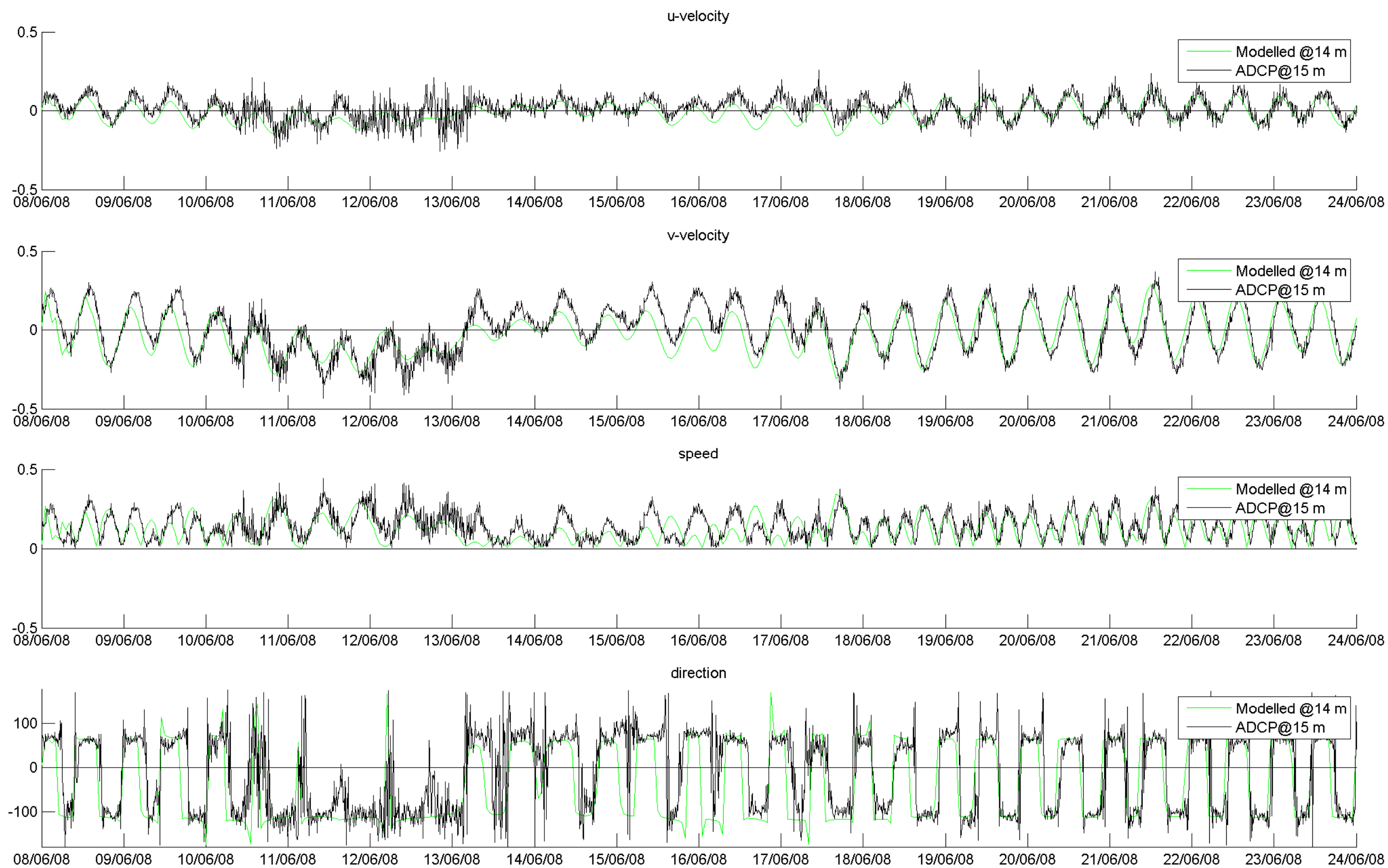


Figure 4-10 Comparison of velocity components, speed and direction between 3D model and the measured ADCP data at z = 15 m above bed.

5. OUTFALL DIFFUSER DESIGN

The underlying design philosophy of the outfall diffuser design is to achieve the required initial dilution criteria and achieve rapid dilution of the saline concentrate in the vicinity of the diffuser over the full range of outfall discharges and ambient environmental conditions. The diffuser design has also been developed to fulfill the Project goals of safety, timeliness and reliability of delivery and economy.

The tender design outfall diffuser concept was developed incorporating 6 risers from an underground tunnel rather than a sea bed pipeline to reduce project risk (exposure to the marine environment during construction) and to reduce the environmental impact during construction by minimizing the construction footprint and volume of dredging and materials on the sea bed. The tender outfall diffuser comprised 36 circular (200mm) fixed diameter ports on six risers spaced over a total length of 115 metres. The outfall tunnel was split on to two conduits (pipe within a pipe) with each conduit servicing three risers. This design was demonstrated to be superior in dilution performance to the reference design (SA Water design used for the EIS and tendering basis) during the tender design stage.

The detailed design development of the outfall included omission of the pipe within pipe concept and the inclusion of duckbill valves for superior safety and maintainability of the outfall system. In order to improve the dilution performance of the outfall, extensive physical model and prototype testing of duckbill valves was undertaken as part of the detailed design of the outfall diffuser. These investigations were undertaken to evaluate the capability of duckbill valves to develop appropriate hydraulic conditions at the diffuser ports and thereby maintain adequate initial dilutions over the full range of outfall flow rates. More details on the investigations into the application of the duckbill valves on the outfall diffuser are provided by Water Technology (2009).

As a result of the above developments, the outfall diffuser arrangement was adjusted to 24 x 250mm duckbill diffuser ports on six risers with the riser spacing increased so as to provide a total distance from first to last diffuser of 140 m (effective diffuser length in the order of 170 m). This outfall diffuser arrangement alleviated outfall tunnel pressure constraints and improved the dilution performance of the outfall.

The critical dilution, outfall discharge and diffuser plume terminal rise height criterion that have been considered for the diffuser design are discussed in the Sections 5.1.1, 5.12 and 5.1.3 respectively.

It should be noted that the diffuser design has been developed under quiescent conditions. That is, under the assumption that there is zero cross-current. This is effectively an artificial scenario and significantly more conservative in terms of initial dilution than a worst case “dodge tide” ambient conditions scenario that would be experienced during the operation of the outfall diffuser. The reported initial dilutions based on the Roberts equations are therefore provided to indicate the magnitude of the mixing will be achieved by a single diffuser port. The absolute dilution performance of the outfall can only be considered in its entirety and this has been undertaken utilising the three-dimensional mid field model as described in Section 6. Adelaide Aqua is evaluating the environmental effects of the outfall diffuser dilution performance to ensure that the diluted saline concentrates discharges do not adversely affect the marine environment.

5.1 Critical Outfall Diffuser Design Criteria

5.1.1 Dilution Criteria

The EIS criteria for the dilution of the saline concentrate discharge require an initial dilution of 1 part in 50 at the impact point with the seabed (SA Water, 2008). Freshwater production efficiencies of up to 45% were considered in the development of this dilution criteria. The reverse osmosis process employed by Adelaide Aqua achieves a higher freshwater production efficiency of 48.5%. In order to achieve the same effective dilution ratio the equivalent initial dilution for the saline concentrate density of the outfall is therefore equal to 1 part in 57.6 (1:58).

5.1.2 Critical Outfall Discharge Criteria

For an ultimate freshwater production capacity of 300 ML/d, the saline concentrate diffuser must cater for a flow of 3.7 m^3/s. This flow corresponds to the plant operating at 100% of the ultimate design freshwater production. Other key flow rates for consideration include those corresponding to 10% production, where the minimum initial dilution is the main design constraint, and 50% production, which corresponds to the full Stage 1 design flow (150 ML/d freshwater production capacity).

In addition to the above, it is noted that, for operational reasons, the outfall flow may occasionally need to exceed the 100% design flow. The outfall flow during these periods may increase up to 120.5% of the design flow, but with a reduced salinity. Table 5-1 shows the range of outfall saline concentrate discharge rates considered in the conceptual design of the diffuser.

Table 5-1 Critical Outfall Discharge Criteria

Outfall saline concentrate Discharge (m^3/s)	Salinity (ppt))	% of Design Production (300ML/d)
0.37	72	10%
1.85	72	50%
3.7	72	100%
4.46	67*	120.5%

* assumes maximum 45% extraction at this flow rate

5.1.3 Terminal Rise Height Criterion

A significant design criterion for the diffuser concept is to ensure that turbulence associated with the diffuser discharge plumes does not disturb the water surface.

Minimum depths at the inshore edge of the construction zone, where the first riser is to be located are approximately 17.9 m at mean sea level (MSL). Variations about mean sea level are predominately associated with astronomical tides. The critical tidal planes in Table 5-2 have been considered in the diffuser concept designs. These values have been derived from the Australian National Tide Tables, and include Mean High Water Springs (MHWS), the average high spring tide level, Mean Low Water Springs (MLWS), the average low spring tide level, and Lowest Astronomical Tide (LAT), the lowest possible tide excluding meteorological effects.

The critical depth constraint for the rise height of the diffuser plumes would occur for short durations of low currents at low tide, or for longer durations of low currents (typically a day or more) during dodge tides. In this respect, MLWS would be representative of the average low water level during spring tides, while LAT would be representative of the lowest tide possible at the site. MSL would be representative of water level that will occur during dodge tides.

Table 5-2 Key Tidal Planes at Port Stanvac (Australian Tide Tables 2004)

Tidal Plane	Tidal Planes relative to MSL.
MHWS	+0.8m
MSL	0.0m
MLWS	-0.9m
LAT	-1.3m

As shown in Section 3.2.4, meteorologically derived water level variations can result in non-tidal variations in water level ranging from about -0.5m up to about +1.0m. It is noted that the combination of an extreme negative meteorological tide and a lower than normal spring tide low water will at times result in water levels that will be below LAT at the site. These occurrences are likely to be relatively infrequent, and the tidal planes presented in Table 5-2 have been used as the main guide as to the likely impact of the diffuser plumes at the sea surface.

5.2 Key Outfall Diffuser Performance Characteristics

The key variables describing the diffuser plume characteristics are provided in the following sections. These are based on the Roberts equations and the empirical relationships developed as part of the investigations into the application of duckbill valves on the diffusers (Water Technology, 2009).

5.2.1 Initial Impact Dilution

Initial dilutions at the bed under quiescent conditions are provided for the range of production capacity outfall flow rates based on the Roberts equations in Figure 5-1. At the 100% outfall flow rate an initial mean impact dilution of 1:81 is achieved.

At lower freshwater production capacities when the outfall flow rate under quiescent conditions is less than 40% of the full production capacity, the minimum required initial impact dilution of 1:58 can be achieved through the augmentation of the outfall flows by seawater bypassing to maintain appropriate hydraulic conditions at the diffuser ports. This is only likely to be required during low current conditions such as slack water and during dodge tides when there are low residual tidal and/or wind-driven currents. The amount of flow augmentation that may be required under these conditions is presented in Table 5-3.

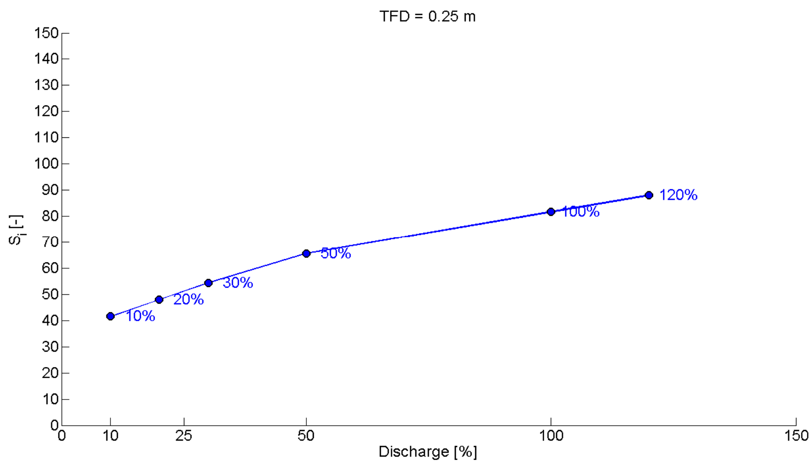


Figure 5-1 Initial Mean Impact Dilution as a Function of Production Capacity Outfall Flow Rate

Table 5-3 The Amount of Flow Augmentation Required to Provide 1:58 Initial Dilution as a Function of % Production Capacity

Production (%)	Flow (m^3/s)				Increase (%)
	Intake	Freshwater	Diffuser	Increase	
10	0.79	0.35	0.45	0.078	11
20	1.51	0.69	0.81	0.076	5
30	2.18	1.04	1.14	0.036	2
50	3.57	1.73	1.84	-	-
100	7.15	3.47	3.68	-	-
120	8.57	4.16	4.42	-	-

5.2.2 Height of Rise

The terminal height of rise of the individual diffuser plumes under quiescent conditions has been determined for the full range of discharge conditions being considered. These have been based on the Roberts equations and the empirical relationships developed as part of the investigations into the application of duckbill valves on the diffusers (Water Technology, 2009). The results are presented in Figure 5-2.

The terminal rise heights are provided in terms of the plume centre lines and the absolute terminal plume rise height; the highest point of the plume. These results correspond to quiescent ambient conditions. They show that in all cases, the plume centrelines will be well below the sea surface. They also show that for all normal operating conditions, the top of the plumes will also be well below the sea surface. It is only when one of the occasional times that the discharge rate may need to increase to 120% of the normal production rate corresponds with a lower than average spring tide low water that there may be some disturbance at the sea surface. Even then the disturbance would only be for a relatively short duration.

Ambient tidal and wind driven currents will reduce the height of rise of the diffuser plumes and the heights displayed under quiescent conditions in Figure 5-2 are therefore considered conservative.

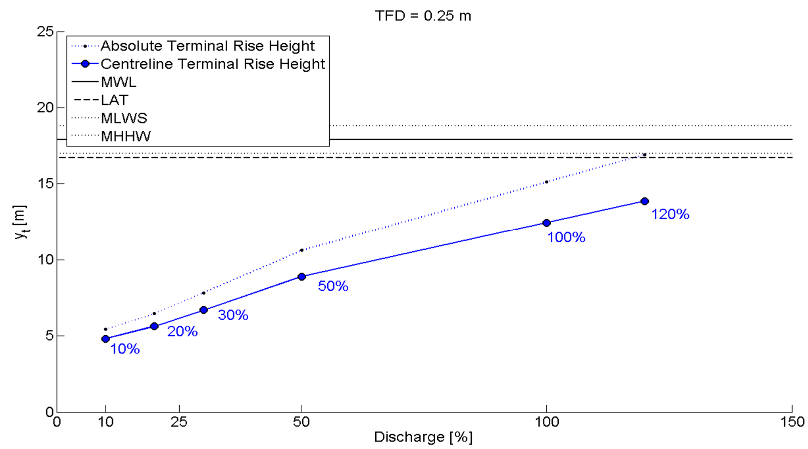


Figure 5-2 Terminal Rise height of Diffuser Plumes as a Function of Production Capacity Outfall Flow Rate

5.2.3 Diffuser Plume Footprints

The footprint of the diffuser plumes at the point where they contact the seabed has been determined from the empirical relationships derived from the experiments undertaken as part of the investigations into the application of duckbill valves on the diffusers (Water Technology, September 2009).

The riser spacing and orientation of the individual diffuser ports has been optimised to avoid an unreasonable degree of overlap of the individual diffuser plume footprints at the highest production capacity outfall flow rates. The final concept design has a riser spacing of 28m providing a total length from the first riser to the last of 140m. Due to the orientation of the individual diffuser ports the outfall will be diffusing over a total length of approximately 170m at the 100% production capacity outfall flow rate. The capability to extend the outfall diffuser has been allowed for in the design as required to suit EPA requirements.

Figure 5-3 displays the estimated diffuser plume footprints at the 10% production capacity outfall flow rate. Figure 5-4 displays the estimated diffuser plume footprints at the 100% production capacity outfall flow rate. The outer speckled areas are the estimated plume widths corresponding to approximately the 95% percentile of saline concentrate concentration at the sea bed. The inner circle represents the estimate of the width corresponding to the mean impact dilution reported by the Roberts equations at the sea bed.

From Figure 5-3 it can be seen from the impact footprints of the individual diffuser plumes that the trajectories of the individual diffuser plumes will not intersect under quiescent conditions. When cross currents occur at the outfall, the trajectories of the individual diffuser plumes will be modified and depending on the strength of the currents, interaction of diffuser plumes with adjacent plumes is possible. However, the existence of cross currents at the outfall will significantly increase the dilutions within the individual diffuser plumes such that the net impact of cross currents at the outfall will be to significantly increase initial dilutions above those which are calculated under quiescent conditions. The potential impact of the accumulation of saline concentrate around the outfall and subsequent entrainment into the diffuser plumes resulting in lower absolute initial dilutions is considered as part of the sensitivity testing in Section 7.3.2 and was found not be significant.

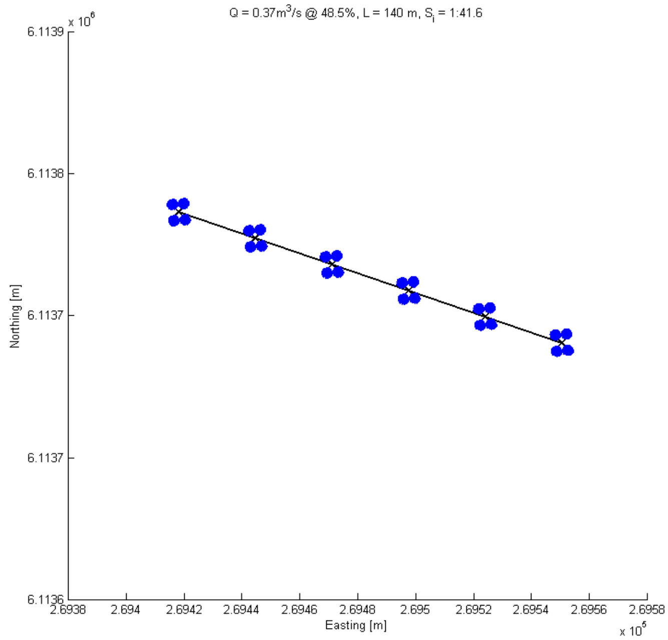


Figure 5-3 **Estimated outfall diffuser plume footprints at the bed at the 10% production capacity outfall flow rate under quiescent conditions**

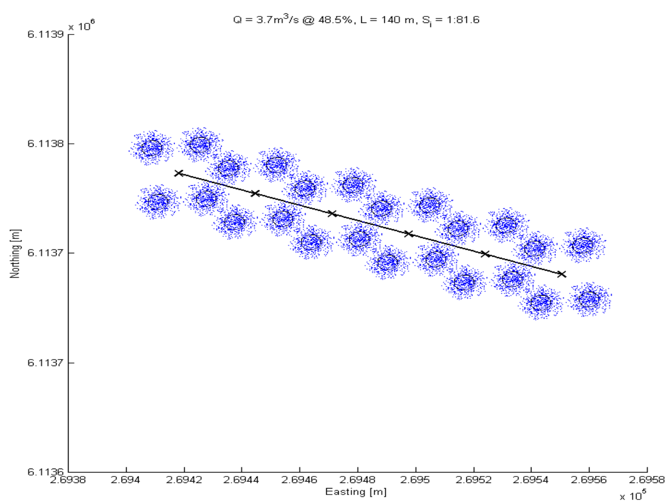


Figure 5-4 **Estimated outfall diffuser plume footprints at the bed at the 100% production capacity outfall flow rate under quiescent conditions**

6. OUTFALL DIFFUSER HYDRODYNAMICS

6.1 Reconciliation of Nearfield and Midfield Initial Dilutions

The investigations relating to the application of duckbill valves on the outfall diffuser (Water Technology, 2009) have provided a significant amount of data characterising the geometry of the saline concentrate plumes and dilutions at both the terminal rise height and at the impact point with the sea bed. This information has been used to validate the density driven plume behaviour in the three-dimensional mid-field model under quiescent conditions. The intent has been to validate the impact dilutions and footprints in the three-dimensional mid-field model to ensure that there are no significant differences between the empirical, nearfield impact dilutions and plume footprints for the individual saline concentrate plumes derived from the Roberts equations. This has been undertaken to ensure that the density driven hydrodynamics of the diluted saline concentrate plumes are appropriately reproduced in the mid-field model.

6.2 Representation of Near-Field Processes

It is not possible to describe in detail the mixing processes in the momentum dominated jet in the immediate vicinity of each diffuser discharge port. Instead, the aim was to use the results of the physical model tests described in Water Technology (2009) to represent the main physical characteristics of the resulting plume at the point of terminal rise. At this point, the jet will have been diluted significantly, and only the horizontal component of the discharge momentum will remain. The focus was on the full 100% freshwater production case, as this was considered to be the most demanding in relation to possible saline concentrate accumulation effects.

As discussed in Section 4, the 8m mesh size used in the immediate vicinity of the diffuser was selected as this was of the same order of magnitude as the dimensions of the diffuser plumes at their terminal height of rise, as determined in the physical model tests. That is, the horizontal dimensions of the model mesh are consistent with the dimensions of the diffuser plumes at this location.

The saline concentrate discharges representing the diffuser plumes at the terminal height of rise were introduced as source points at the appropriate horizontal location in the model mesh. The actual locations in the mesh are shown in Figure 6-1. Here the locations of the diffuser risers are represented as black crosses and the saline concentrate source points as red arrows. The shaded elements are the elements in which the brine sources were applied. The direction of the arrows represents the direction of the remaining horizontal momentum associated with each discharge.

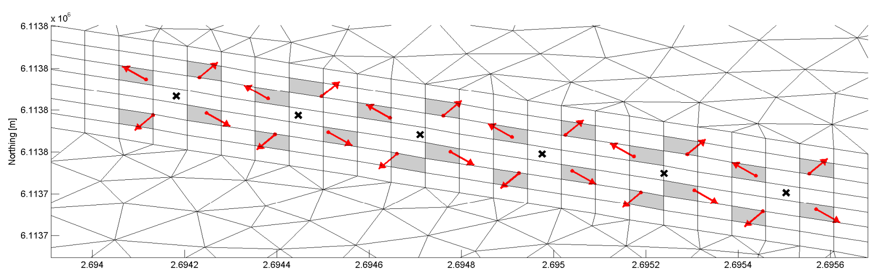


Figure 6-1 Locations of the saline concentrate source points relative to the model mesh

With the horizontal locations of the source points defined, the problem remained as to how to provide a realistic representation of the plumes in the vertical mesh. Here the key variables that were required to be defined in order to reconcile the nearfield, empirical plume behaviour with that of the hydrodynamic model were:

- The number and location of source points required to be introduced into the hydrodynamic model to achieve similar plume geometry and dilutions at the terminal rise height of the individual saline concentrate plumes such that, under quiescent conditions, the gravity driven plume behaviour at the impact point with the bed resulted in plume footprints and impact dilutions that were in close agreement with the empirical estimates.

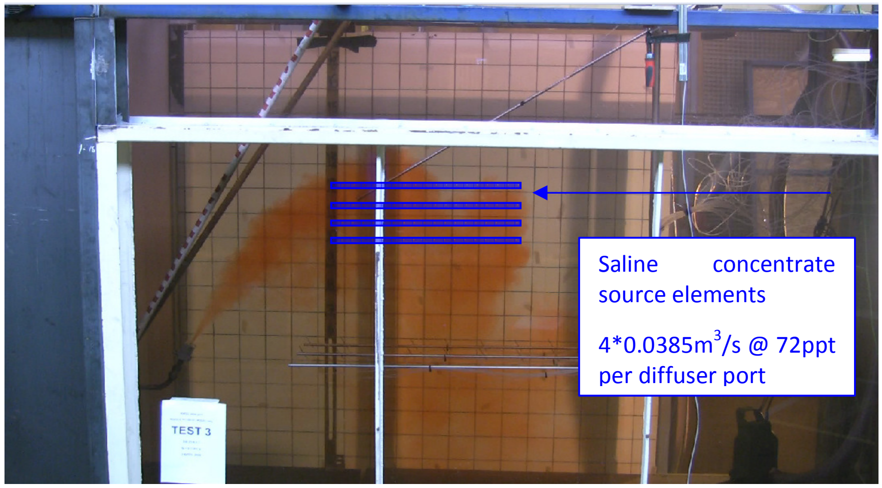
- The parameters describing the vertical and horizontal diffusion when considering a hydrodynamic environment within the vicinity of the outfall diffuser that will be significantly more turbulent than would occur generally in a marine environment.

In order to determine appropriate values to the above variables an iterative approach was adopted. This required trialling a number of different combinations of source points and locations and turbulent diffusion coefficients within the hydrodynamic model (which was simulated under quiescent ambient conditions) and comparing the impact dilutions and plume footprints directly with the equivalent empirically derived dilutions and plume footprints.

This process resulted in a solution that was considered to provide a very good level of agreement between the empirical plume dilutions and impact footprints. The details of the adopted solution are as follows:

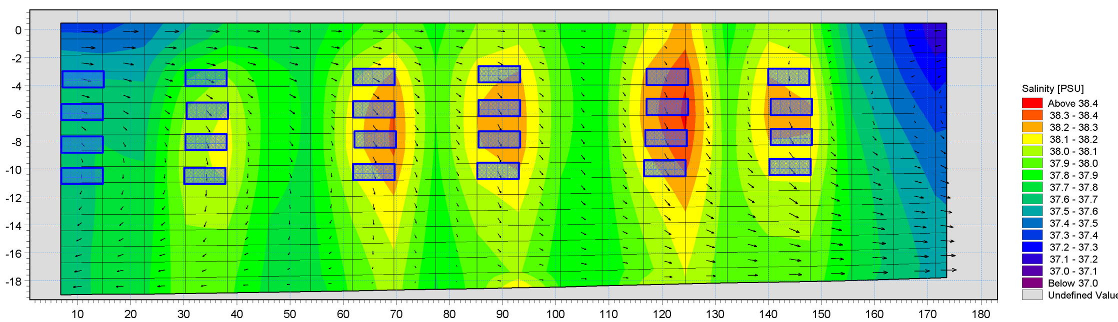
- For each individual diffuser port plume, the saline concentrate was introduced as 4 separate source points in the vertical. These were located at alternate vertical elements and covered the approximate location and depth of the plume as determined in the physical model tests. The outfall diffuser, comprising 24 ports, was therefore represented by a total of 96 separate saline concentrate source points in the model.
- Within the area directly around the diffuser and encompassing the extent of the turbulence associated with the momentum driven sections of the diffuser plumes, the Smagorinsky coefficient controlling the amount of horizontal eddy viscosity was increased to unity.

Figure 6-2 displays how the saline concentrate source elements in the midfield model for an individual diffuser port were located relative to the physical model plume geometry. From Figure 6-2 it can be seen that the saline concentrate is applied to a volume that closely approximates the volume of the individual diffuser plumes at the terminal rise height. Figure 6-3 displays an example cross section through the outfall showing the location of the saline concentrate source points for each individual diffuser port and the resulting **saline concentrate plumes and velocity vectors during slack water.**



Blue boxes indicate the elements in which the saline concentrate source points were applied in the model relative to the empirical plume geometry for each individual diffuser port.

Figure 6-2 Example of the location of the saline concentrate source points relative to the empirical plume geometry



Example cross section of the elements (Blue boxes) in which the saline concentrate source points were applied in the model for the each individual diffuser port and the resulting saline concentrate plumes and velocity vectors during slack water

Figure 6-3 Example cross section through outfall showing saline concentrate source points

6.3 Validation of the Representation of Near-Field Processes

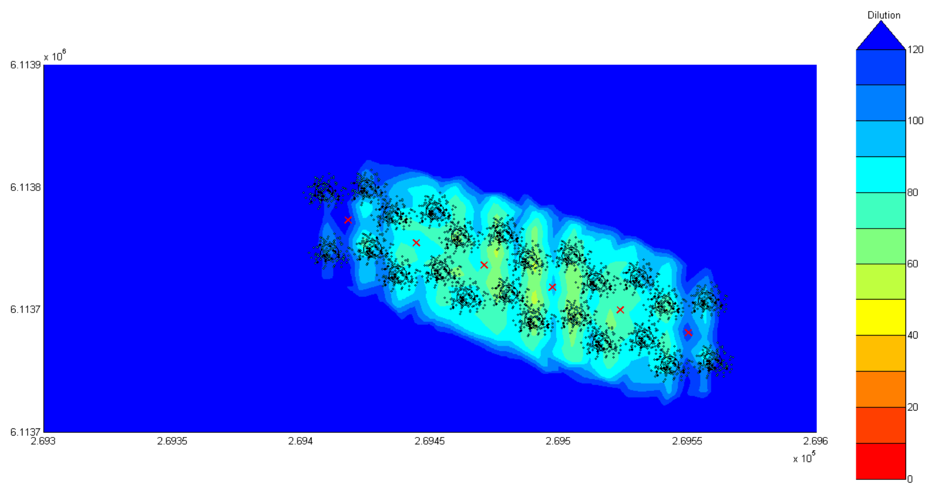
A comparison of the hydrodynamic model impact dilutions and plume foot prints compared to those derived empirically with the adopted solution discussed above is shown in Figure 6-4 (considering the 100% production capacity outfall flow rate (3.7 m^3/s) and 48.5% recovery efficiency).

From the comparison provided in Figure 6-4, the following observations are provided:

- The impact dilutions at the bed in the hydrodynamic model are generally within 80-90:1.This is considered to correspond well with the empirically derived mean impact dilutions of 81:1. This is considered to demonstrate that the density of the saline concentrate plumes at the impact with the bed are in close agreement with the empirically derived estimates and the subsequent density driven behaviour of the plumes in the midfield will not be impacted due to significant under/overestimation of the initial dilutions around the diffuser.
- The total impact footprint of the outfall diffuser is considered to be in very good agreement with the empirically derived footprints in that there is no gross over/under estimation of the footprint extents. This is considered to demonstrate that the volume over which the saline

concentrate is instantaneously diffused in the hydrodynamic model closely approximates the volume predicted from the empirical relationships. There are some differences in the footprints at the ends of the outfall and these are associated with the three-dimensional hydrodynamics of the outfall and interaction of density driven plumes at the margins with adjacent plumes. These three-dimensional processes are considered to be very important in the macro-dilution performance of the outfall diffuser and are discussed in more detail in Section 6.4.

- It is noted that the incorporation of the physical plume geometry to validate the hydrodynamic model impact dilutions has been undertaken for quiescent conditions only. When significant cross currents occur at the outfall the geometry of the saline concentrate plumes will be impacted. However, under these conditions the dilutions will be significantly enhanced above those predicted under quiescent conditions. The methodology employed in this assessment has therefore been developed to provide the most realistic and conservative estimate of the outfall dilution performance during the worst case slack water conditions.



Red crosses indicate the location of the risers. Speckled circular areas are empirical impact footprints from each diffuser. Coloured shading is the impact dilution footprints produced by the hydrodynamic model

Figure 6-4 Comparison of physical model and hydrodynamic model impact dilutions and footprints

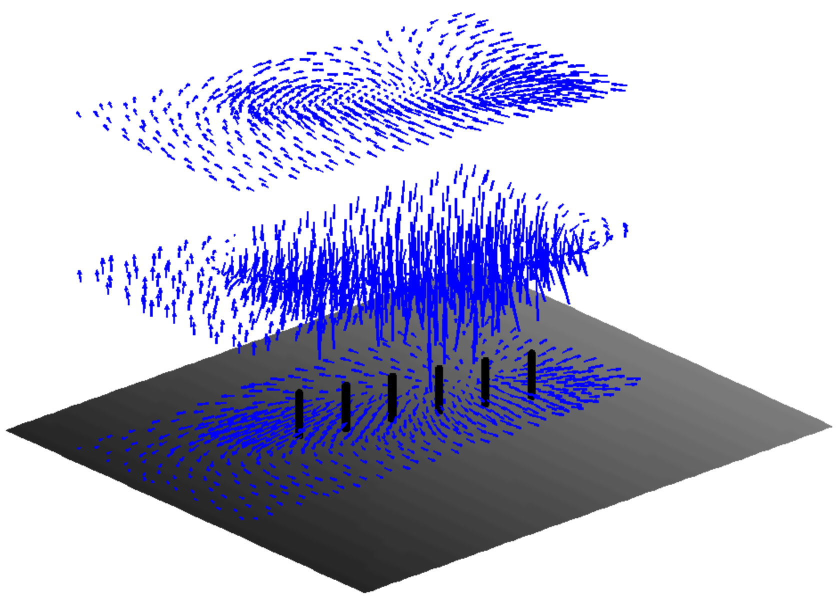
6.4 Outfall Dilution Hydrodynamics

Hydrodynamic modelling at the resolution undertaken for this assessment enables the three dimensional hydrodynamics of the outfall to be resolved in significant detail. Analysis of the hydrodynamics of the outfall in this detail is considered very important as it reveals additional 'macro' scale mixing processes that improve the dilution performance of the outfall as a whole. This broader scale mixing process assists to limit the magnitude of the excess salinity accumulation around the diffuser during slack water. Analysis of the three-dimensional hydrodynamics of the outfall diffuser at the 100% production capacity outfall flow rate has been undertaken. Velocity vectors representative of the surface, middle and bottom layers in relation to the outfall riser during slack water are displayed in Figure 6-5.

The hydrodynamics of the momentum-driven section of the individual saline concentrate plumes is not modelled in this analysis and would result in some local differences in the velocity fields compared to that shown in Figure 6-5. However, the net, 'macro' scale mixing behaviour of the outfall is considered to be resolved with a high degree of detail and is considered to reveal the following important details relating to the hydrodynamics of the outfall:

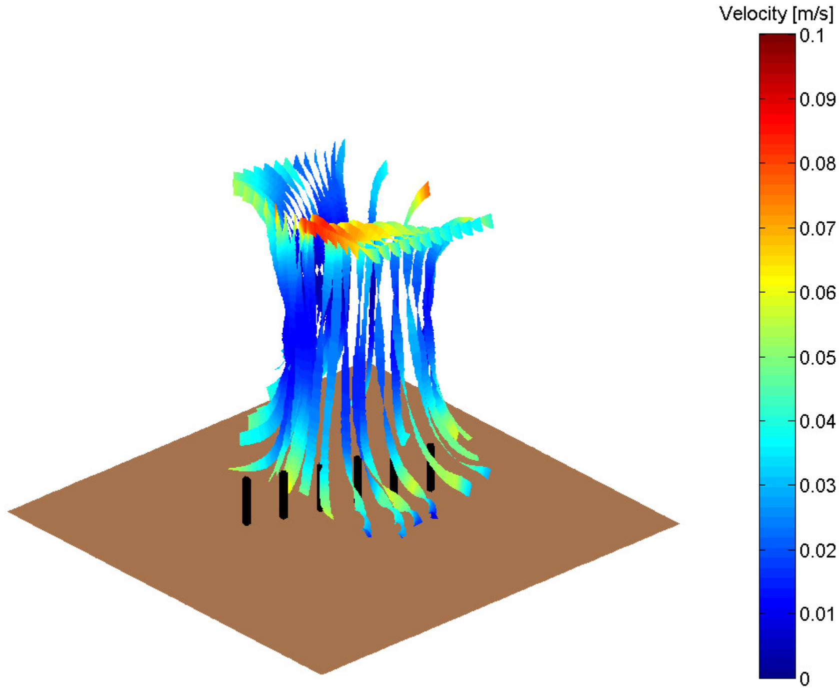
- As the individual saline concentrate plumes reach the terminal height of rise in the upper part of the water column, they begin to fall under gravity, where they continue to entrain surrounding water. This additional water must be replaced and results in a net flow of water from the surface layers towards the outfall which rotates due to the coriolis affect. This net flow of water from the surface layers towards the outfall is significant as this water has background salinities close to ambient and reduces the amount of re-entrainment of water with excess salinities in the mixing processes of the individual diffuser plumes. This process assists to effectively limit the magnitude of the excess salinities that can occur around the diffuser during slack water periods as water with ambient salinities is continually drawn in towards the diffuser from the surface layers even in the absence of significant ambient tidal and wind driven currents.
- At the bed, the saline concentrate plumes hit the bed and travel out laterally, initially this flow is largely driven by the inertia of the sinking saline concentrate plumes but outside the immediate vicinity of the diffuser the lateral flows are driven by gravity down the natural slope of the bed.

Figure 6-6 displays the streamline paths of the surface layers at the same time as was discussed above and is displayed in Figure 6-5. These figures show the net circulation of surface waters towards the outfall where they become entrained as part of the mixing of the saline concentrate plumes and fall towards the bed and then away from the outfall.



Surface, middle and bottom velocity vectors during slack water in the vicinity of the outfall at 100% production capacity outfall flow rate ($3.7m^3/s$) and 48.5% recovery efficiency.

Figure 6-5 Example of Velocity Vectors around the Outfall during Slack Water



Surface layer streamlines during slack water in the vicinity of the outfall at 100% production capacity outfall flow rate (3.7m^3/s) and 48.5% recovery efficiency

Figure 6-6 Example of Surface Streamlines around the Outfall during Slack Water

7. DILUTION MODELLING ASSESSMENT

The three-dimensional hydrodynamic model has been used to simulate a number of ambient environmental scenarios and outfall flow rate scenarios to enable the absolute dilution performance of the outfall diffuser to be quantified.

7.1 Ambient Environmental Scenarios

Three ambient tidal and meteorological scenarios have been assessed and are considered to capture the envelope of conditions that would influence the dilution performance of the outfall diffuser. The following scenarios have been considered:

- Ambient Scenario 1 - Six week scenario from 1 May to 15 June 2006. This is the six week scenario considered in the hydrodynamic modelling component of the EIS.
- Ambient Scenario 2 - Worst case dodge tide scenario determined from analysis of the 12 months of ADCP data collected at Port Stanvac (discussed below).
- Ambient Scenario 3 – A scenario containing an upwelling (onshore advection) of bottom waters determined from the analysis of the 12 months of ADCP data collected at Port Stanvac (discussed below).

7.1.1 Ambient Scenario 1 – Six Week Ambient Scenario

Ambient Scenario 1 is a six week simulation of tides and wind conditions considered as part of the hydrodynamic modelling component of the EIS. The wind speed and direction and water levels at Port Stanvac for the duration of this scenario are displayed in Figure 7-1.

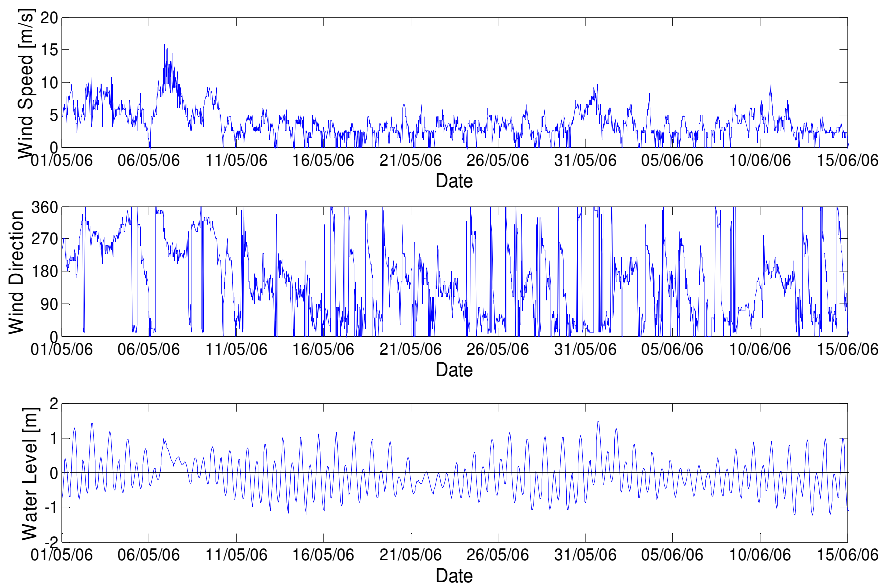


Figure 7-1 Scenario 1 – Six week ambient scenario (1 May – 15 June 2006)

7.1.2 Ambient Scenario 2 – Worst Case 3 Day Dodge Tide

A worst case dodge tide scenario has been selected based on the analysis of approximately 12 months of ADCP data collected offshore of Port Stanvac in approximately 20m depth. The current speed observations from the individual depth "bins" from the ADCP were averaged to provide a mean current speed which was then analysed to determine the 48 hour period with the minimum average current speed over the record. Figure 7-2 displays the depth averaged current speeds from the ADCP over the available record. The 48 hour period from the 19th-20th April 2009 was subsequently identified as the period of lowest average current speeds. Figure 7-3 displays the corresponding wind speeds and directions and water level variations one week either side of this period. From Figure 7-3 it can be seen that the 48 hour period of lowest average current speeds corresponds to a dodge tide and a period of very low wind speeds.

In order to validate the three-dimensional model results over this period of very low current speeds, the model was simulated with the observed wind and water level forcing a week either side of this period. The three-dimensional model results were then compared directly to the ADCP measurements at the 15 m (bottom), 10 m (middle) and 5 m (surface) isobaths as shown in Figure 7-4, Figure 7-5 and Figure 7-6 respectively.

From the level of agreement achieved between the observed and modelled currents in these figures, the model results are considered to be validated and could be considered somewhat conservative (from a dilution perspective) as the model is slightly under predicting the magnitude of the current speeds on average during these periods.

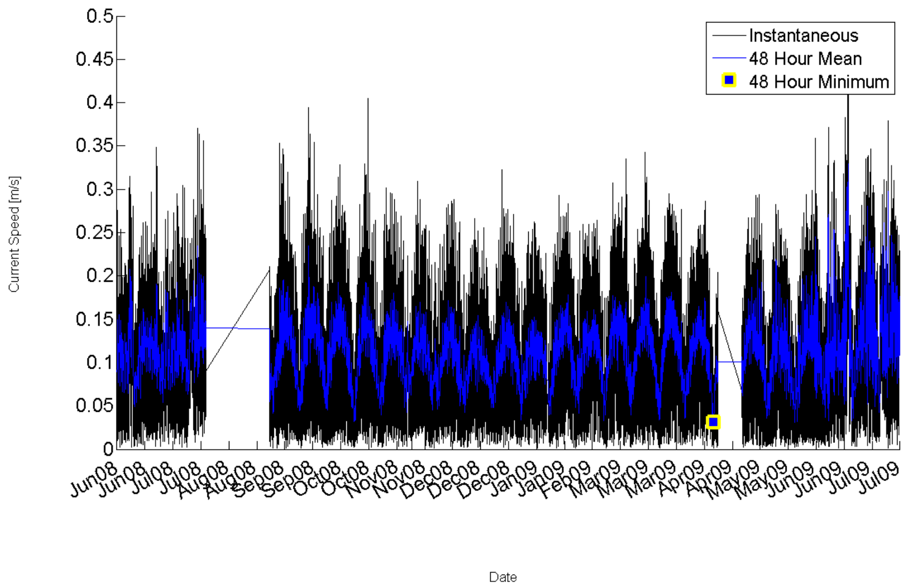


Figure 7-2 Analysis of ADCP Data to Determine Minimum 48 hour Current Period

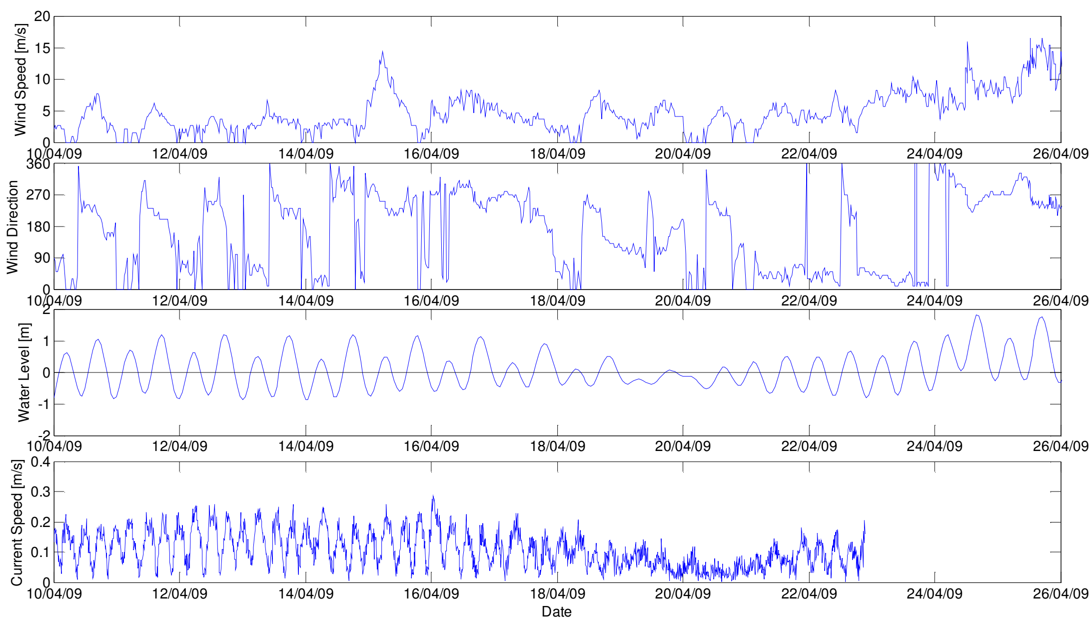


Figure 7-3 Scenario 2 – Worst Case 3 day Dodge Tide Scenario (19 April – 21 April 2009)

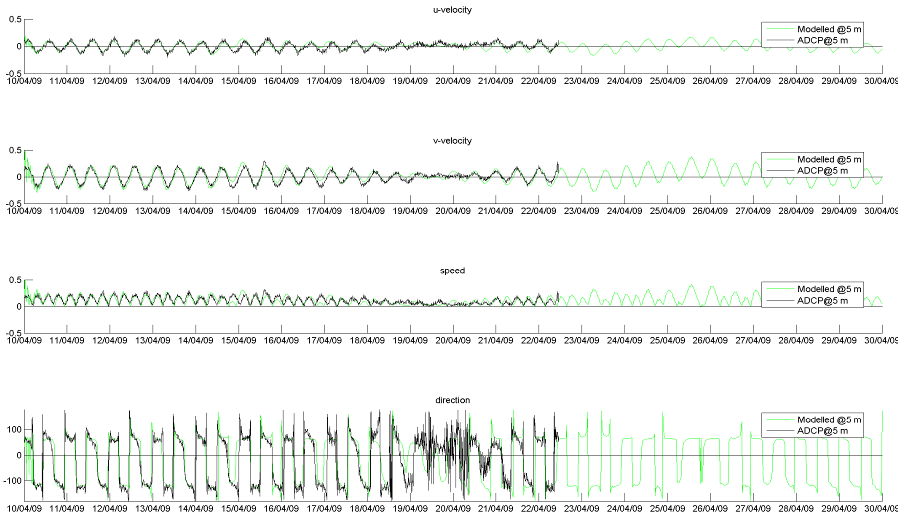


Figure 7-4 **Validation of Velocity Components, Speed and Direction between 3D Model and the Measured ADCP Data at z = 5 m Above Bed.**

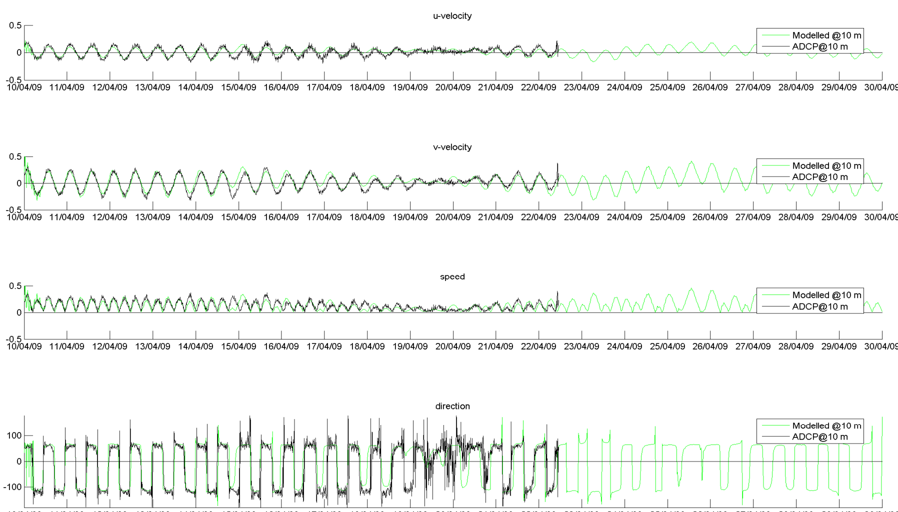


Figure 7-5 **Validation of velocity components, speed and direction between 3D model and the measured ADCP data at z = 10 m above bed.**

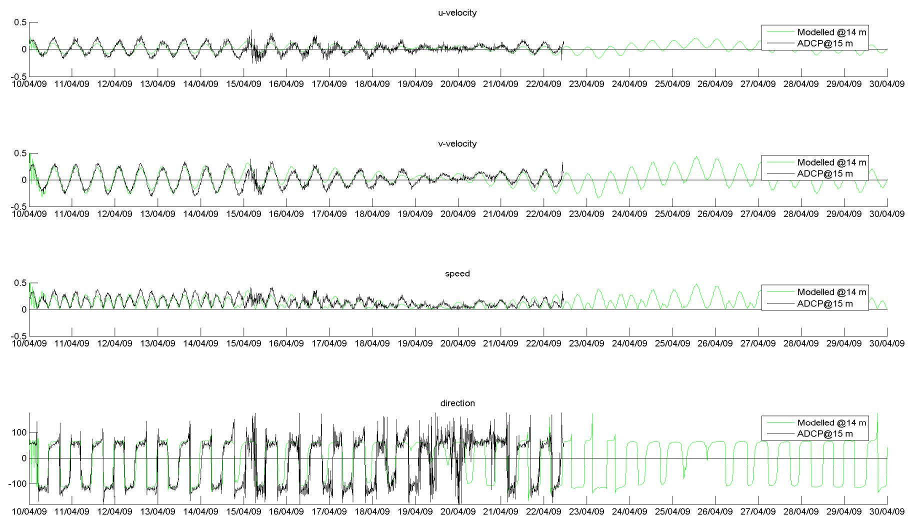


Figure 7-6 Validation of velocity components, speed and direction between 3D model and the measured ADCP data at z = 15 m above bed.

7.1.3 Scenario 3 – Onshore Upwelling

Ambient Scenario 3 includes a period where the currents at the bed are most strongly orientated onshore. Analysis of the approximate 12 months of ADCP data identified a period during a dodge tide and moderate south easterly winds that resulted in period of modest onshore currents at Port Stanvac around the 23rd December 2008 and is displayed in Figure 7-7. The potential for diluted saline concentrate plumes to be advected inshore during this period was assessed in the hydrodynamic model.

Figure 7-7 Scenario 3 –Upwelling Scenario

7.2 Mid-field Dispersion Assessment

7.2.1 Outfall Flow Rate and Recovery Efficiency Scenarios

The following outfall flow rate and recovery efficiency scenarios have been considered in conjunction with the ambient environmental scenarios:

- Outfall Scenario 1 - 100% Production Capacity Outfall Flow Rate ($3.7m^3/s$) @ 48.5% Recovery Efficiency
- Outfall Scenario 2 - 10% Production Capacity Outfall Flow Rate ($0.37m^3/s$ @ 48.5% Recovery Efficiency and no bypass flow augmentation

7.2.2 Presentation of Midfield Dispersion Simulation Results

The results of the midfield dispersion simulations have been processed to statistically summarise the spatial and temporal variability of excess salinity around the outfall. Analysis of the temporal variability of excess salinity around the outfall has been undertaken by averaging the model results across indicative offshore and inshore arcs aligned relative to the longshore tidal currents at distances of 50, 100, 200 and 400 metres around the outfall as displayed in Figure 7-8.

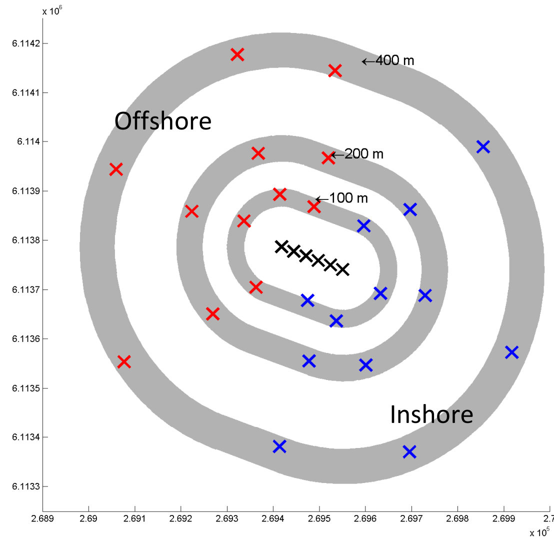


Figure 7-8 Offshore and Inshore Dispersion Performance Arc Locations

The following statistical summaries of the dispersion performance of the outfall have been generated for the offshore and inshore arcs displayed in Figure 7-8:

Salinity Timeseries

1 hour, 6 hour and 24 hour average salinity timeseries have been provided inshore and offshore of the outfall at distances of 100, 200 and 400 metres.

Dilution Histograms

1 hour, 6 hour and 24 hour average percentage occurrence dilution histograms have been summarised inshore and offshore of the outfall at distances of 100, 200 and 400 m.

Magnitude-Frequency-Duration Curves

1 hour average magnitude-frequency-duration curves have been developed inshore and offshore of the outfall at distances of 100, 200 and 400.

Percentage Exceedance Dilution Isopleths

The diffused saline concentrate plumes have been summarised spatially as percentage exceedance dilution isopleths where:

- The percentage exceedance (p^{th} value) is the value at which the p% of the population is equal to or less than this value when ordered from smallest to largest.
- The dilution at any point in space relative to the salinity of the saline concentrate discharge and the ambient background salinity as per Fischer et al., 1979:

  $D = S_{discharge} – S_{background} / S_{measured} - S_{background}$

The percentile exceedance dilution isopleths have been provided for the equivalent 1:50 (1:58) and 1:100 (1:116) dilutions, corresponding to an excess salinity 0.60ppt and 0.30ppt respectively.

Intake Salinity Excess Timeseries

Instantaneous salinity excess timeseries, averaged over the depth of the intake grill, has been provided.

7.2.3 Ambient Scenario 1 (Six Week Ambient Scenario) and Outfall Scenario 1 (100% @ 48.5%)

The results from the simulation have been summarised as discussed in Section 7.2.2 and presented in Appendix C.

The following observations are provided with reference to these figures:

- Over a long period of ambient tide and wind conditions, including dodge tide periods, the percentage of time that the 1:58 (0.60ppt) dilution isopleth is exceeded in the vicinity of the outfall diffuser is likely to be limited to approximately 10% of the time. (i.e., a cumulative period of approximately 4 days over a total period of 42 days in which excess salinity exceeds 0.60ppt due to periodic accumulation during slack water periods and dodge tides).
- The areas where the 1:116 (0.30ppt) dilution isopleth is exceeded are orientated north-south around the diffuser and highlight that the dilution of the saline concentrate is dominated by the tidal currents over the long term.

The dilution isopleth figures presented in Appendix C have been compared against the equivalent figures from the dilution modelling of the reference design for the EIS at similar scales (Pattiaratchi, 2008). The comparison of these figures is considered to show that the dilution performance of the concept design in the mid-field is at least equivalent to that of the reference design diffuser.

7.2.4 Ambient Scenario 2 (Worst Case 3 Day Dodge Tide Scenario) and Outfall Scenario 1 (100% @ 48.5%)

The results from the simulation have been summarised as discussed in Section 7.2.2 and presented in Appendix D.

The percentile exceedance plots for the 1:58 (0.60ppt) and 1:116(0.30ppt) dilution isopleths are presented for the 3 day dodge tide period (19-21 April). The following observations are provided with reference to these figures:

- Even during the worst case 3 day dodge tide, low wind scenario, the percentage of time that the 1:58 (0.60 ppt) dilution isopleth is exceeded in the vicinity of the outfall diffuser is essentially limited to approximately only 25% of the time (i.e., only approximately 18 hours of the total 3 day scenario would excess salinity exceed 0.60 ppt due to accumulation).
- Over the worst case 3 day dodge tide period, the 1:116 (0.30 ppt) dilution isopleth will be exceeded for approximately 50% of the time over a relatively large area around the diffuser. i.e., for approximately 36 hours of the total 3 day scenario, accumulated excess salinity at the bed would exceed 0.3 ppt).
- The significant difference in the spatial and temporal extent of the 1:58 (0.60ppt) and 1:116 (0.30ppt) dilution isopleths around the diffuser is considered in part to be due to the design of the outfall diffuser and subsequent three-dimensional hydrodynamics which continually draw in surface waters at ambient salinity to limit the re-entrainment of water with excess salinity in the dilution of the saline concentrate streams. This results in the outfall effectively diluting the saline concentrate into a larger volume of water (than is provided by the weak ambient tidal and wind driven currents passing the outfall) and limits the absolute

magnitude of the excess salinities that can accumulate around the diffuser during extended periods of low ambient currents.

7.2.5 Ambient Scenario 3 (Upwelling Scenario) and Outfall Scenario 1 (100% @ 48.5%)

The results from the simulation have been summarised as discussed in Section 7.2.2 and presented in Appendix E.

The following observations are provided with reference to these figures:

- The weak onshore currents at the bed associated with the upwelling scenario identified in the ADCP data in this scenario are not predicted to be significant enough to overcome the gravity driven flow of the diluted saline concentrate plumes that are orientated offshore. The likelihood of significant advection of diluted saline concentrate plumes onshore from the outfall diffuser are considered very low based on the results of this scenario.

7.2.6 Ambient Scenario 2 (Worst Case 3 Dodge Tide Scenario) and Outfall Scenario 2 (10% @ 48.5%)

The results from the simulation have been summarised as discussed in Section 7.2.2 and presented in Appendix F.

The following observations are provided with reference to these figures:

- Whilst the initial dilutions at the 10% outfall flow rate without flow augmentation are estimated at 1:41 under quiescent conditions, the ambient currents, even during a worst case dodge tide scenario, are significant enough to enhance mixing such that the 1:58 dilution is achieved more than 90% of the time. Analysis of the dilution results in close detail is considered to show that a current at the bed of 2cm/s or greater is significant enough to prevent the impact dilutions exceeding 1:58. The percentage exceedance of bed currents collected from the ADCP measurements at Port Stanvac indicate that this critical current threshold is exceeded approximately 95% of the time. Therefore it is considered that augmentation of the low production capacity outfall flow rates by seawater bypassing is likely to be only required for relatively short periods during worst case dodge tide and low wind scenarios. Low flow augmentation with seawater may not be required given the duckbill valves still maintain relatively high initial dilutions at the low outfall flow rates and the impact in terms of excess salinity accumulating around the outfall is significantly less than the 100% outfall flow rate.

- The 1:116 (0.30ppt) dilution isopleth is not exceeded for more than 10% of time during the worst case 3 day dodge tide scenario.

7.3 Sensitivity Testing

The following scenarios have been considered in order to provide an indication as to the sensitivity of the mid-field dispersion assessment results to the following:

Sensitivity Scenario 1 – The loss of two duckbill valves on the outfall diffuser ports to the initial dilutions achieved by the outfall.

Sensitivity Scenario 2 – Incorporating a representation of entrainment of diluted saline concentrate into the initial dilution.

Sensitivity Scenario 3 – Changing the orientation of the outfall such that it is approximately parallel with the slope of the seabed

7.3.1 Sensitivity Scenario 1 – Duckbill Valve Damage

The sensitivity of the dilution performance of the outfall due to a scenario in which two duckbill valves on the diffuser ports are damaged such that they operate as fixed port circular diffusers has been assessed by considering the impact on the initial dilutions on both the remaining duckbill valves diffusers and damaged (circular) diffuser ports. The assessment has been undertaken assuming the headloss across the remaining duckbill valve diffusers and the two damaged diffuser ports are equal. The estimated flow spilt between the remaining functioning duckbill valves and the two damaged ports are provided in Table 7-1.

Figure 7-9 displays the predicted impact dilutions based on the Roberts equations as a function of the production capacity outfall flow rates for the remaining 22 operational duckbill valves and the two failed valves (circular ports) in comparison to the 24 operational duckbill diffuser ports. From Figure 7-9 it can be seen that this scenario results in only very minor impact to dilutions from the remaining duckbill diffusers as the reduction in pressure at the diffuser ports results in the duckbill valve contracting and maintaining relatively high port velocities and therefore initial dilutions. The initial dilutions from the two damaged (circular) ports are however significantly lower however initial dilutions of 40:1 are still achieved at the 100% production capacity outfall flow rate. It should be noted that approximately greater than 80% of the outfall flow at the 100% production capacity is still expected to be discharged through the remaining duckbill valve diffusers with the remaining discharging through the two damaged (circular) ports. The impact on the dilution performance of the outfall as a whole is therefore not considered to be significantly impacted from this scenario.

Table 7-1 Estimated Flow Splits between Duckbill Valves and Damaged Ports (*2)

Production % (300ML/d)	Outfall Flow(m^3/s)	Flow per Duckbill (m^3/s)	Flow per Circular (m^3/s)	Duckbill (% of Total Outfall Flow)	Circular (% of Total Outfall Flow)
10	0.37	0.01	0.05	72	28
25	0.92	0.03	0.13	72	28
50	1.84	0.06	0.24	74	26
100	3.68	0.13	0.37	80	20
120	4.46	0.17	0.41	81	19

From Figure 7-10 it can be seen that the absolute terminal height of rise of the two damaged (circular) diffuser port plumes are predicted to extend to approximately the mean high water springs tidal plane in this scenario.

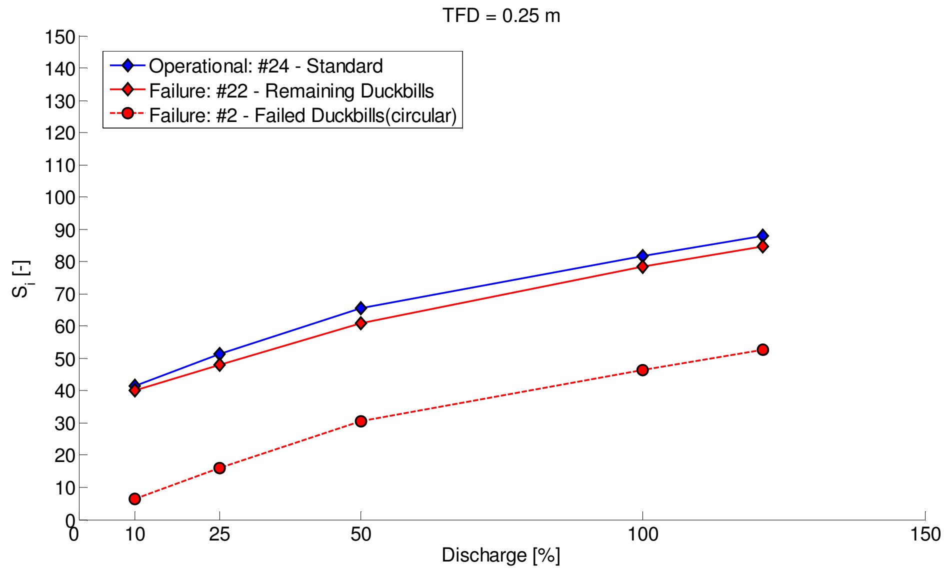


Figure 7-9 Initial Mean Impact Dilutions Due to Failure of Two Duckbill Valve Diffusers

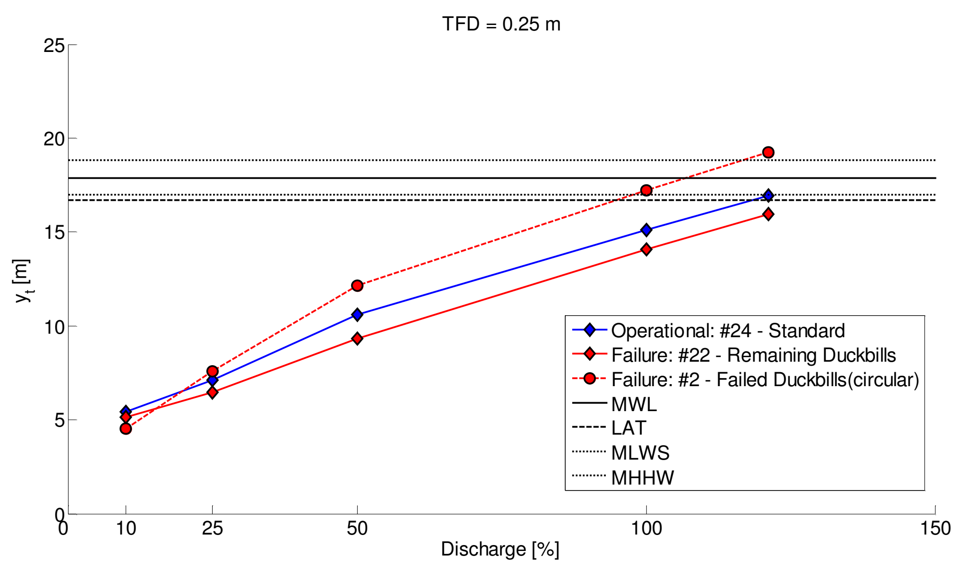


Figure 7-10 Absolute Terminal Height of Rise Due to Failure of Two Duckbill Valve Diffusers

7.3.2 Sensitivity Scenario 2 – Entrainment

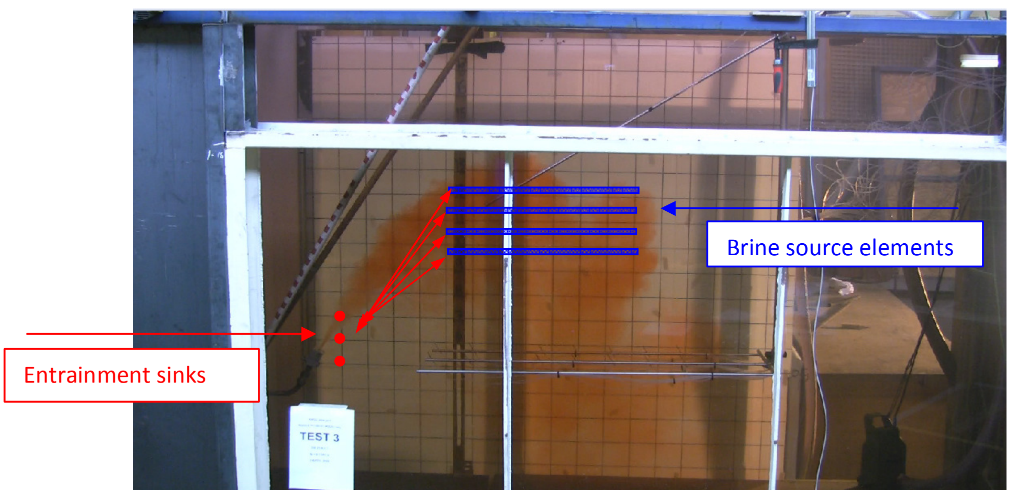
In discussions with the Independent Technical Reference Panel (ITRP), there was some concern as to whether the source representation of the diffuser plumes described in Section 6.2 was providing a realistic description of the initial dilution caused by entrainment of the surrounding water. The concern was that initial dilution in the model would occur at the levels of the source points where there may be little or no effect of saline concentrate accumulation, whereas in reality, some of the early dilution caused by jet entrainment would be in the lower layers which are more likely to be affected by saline concentrate accumulation.

The potential for entrainment of saline concentrate accumulation to impact the dilution performance of the outfall has been assessed by incorporating 3 “sink” points in the bottom layers at the location of each of the diffuser ports. Entrainment of water from these lower levels was then represented by drawing saline water from each of the sink points and distributing it over the four source points used to represent the saline concentrate discharge at the terminal height of rise of the diffuser plumes.

The rate at which the mass and salt is transferred between the source and sink points has been scaled based on the volumetric dilution derived from the empirical plume geometry calculated in some earlier work with the Visjet near-field model. The discharge ports will be located 2.5m above the sea bed. The sink points used to represent entrainment from the lower layers have been located at approximately 3 m, 5 m and 7 m above the sea bed. The relative dilutions and magnitudes of the coupled sink/sources used to represent the entrainment from each of these levels is given in Table 7-2. Figure 7-11 displays how the re-entrainment source-sink points for an individual diffuser port were located relative to the physical model plume geometry.

Table 7-2 Entrainment source-sinks

Elevation (m) (Above Bed)	Plume Dilution	Source-Sink (m^3/s) (Q=Diffuser Port Discharge)
7	1:10	5Q
5	1:5	3Q
3	1:2	1Q

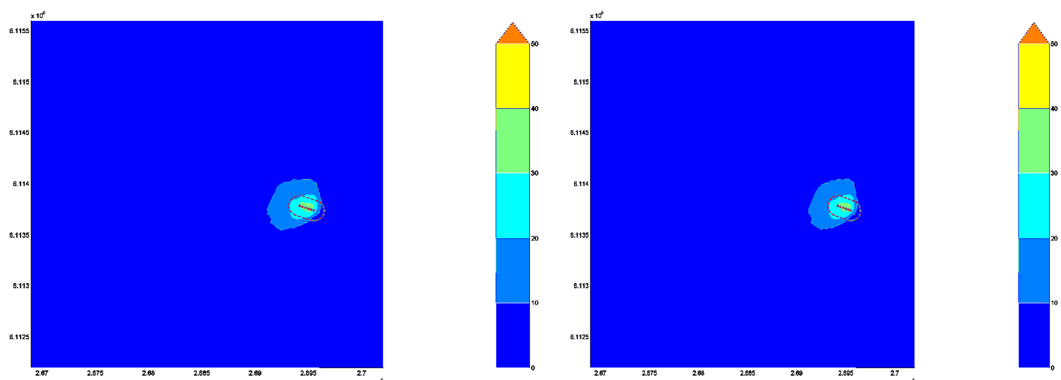


Blue boxes indicate the elements in which the saline concentrate source points were applied in the model relative to the empirical plume geometry for each individual diffuser port. Red dots indicated the sink points applied in the model to approximate the re-entrainment of water from the bottom layers into the diffuser plumes.

Figure 7-11 Example of the location of the entrainment source sink points relative to the empirical plume geometry

The model has been simulated over the Ambient Scenario 2 (Worst Case Dodge Tide Scenario) and Outfall Scenario 1 (100% @ 48.5%) including the re-entrainment source-sinks points and the results have been compared to the results of the same simulation without the re-entrainment. Figure 7-12 displays the comparison of the 0.3ppt salinity exceedance isopleths with and without the recirculation source-sink points. From Figure 7-12 it can be seen that there is not predicted to be any significant difference at this scale in the dilution performance results of the outfall by excluding the re-entrainment.

Comparison of the model results in more detail along the centreline of the outfall diffuser has been undertaken and displayed in Figure 7-13. From Figure 7-13 it can be seen that the incorporation of the re-entrainment source sink points as described above has resulted in a minor improvement in the overall dilution performance of the outfall. These results could be considered somewhat counter intuitive however analysis of the results in close detail is considered to show that the re-entrainment of bottom layers into the diffuser plumes where they are driven into the upper layers of the water column actually enhances the vertical mixing around the diffuser by limiting the accumulation of a stable dense layer around the outfall diffuser and enhancing the rate at which the diluted saline concentrate can be advected away from the diffuser by the slightly stronger ambient currents experienced in the upper layers of the water column. The net effect of the re-entrainment is therefore predicted to result in a minor improvement of the dilution performance of the outfall and the dilution results from the scenario simulations without re-entrainment are therefore considered conservative.



Comparison of 0.30ppt salinity exceedance isopleths between scenario simulations with (Right) and without (Left) the approximation of re-entrainment in the diffuser plumes for the Ambient Scenario 2 (Worst Case Dodge Tide Scenario) and Outfall Scenario 1 (100% @ 48.5%)

Figure 7-12 Comparison of 0.30ppt salinity exceedance isopleth with and without entrainment

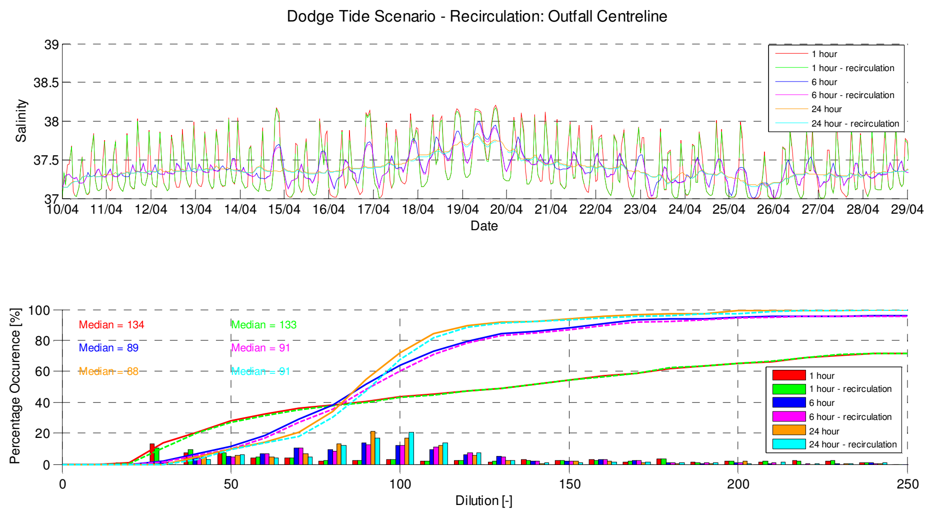


Figure 7-13 **Comparison of the dilution results along the outfall centreline with and without re-entrainment**

7.3.3 Sensitivity Scenario 3 – Outfall Alignment

The sensitivity of the dilution performance of the outfall if it were to be orientated such that is aligned approximately 225^0 from north so that the outfall is approximately parallel with the seabed slope in the vicinity of the outfall (By comparison, the original outfall alignment is approximately 285^0 from north).

As part of the review process it was considered that the alternative orientation of the outfall could potentially assist in improving the dilution performance of the outfall by creating a broader front in which the diluted saline concentrate plume could flow down the seabed slope away from the diffuser and thereby limit the absolute magnitude of the excesses salinity accumulation around the outfall during slack water conditions.

The model has been simulated over the Ambient Scenario 2 (Worst Case Dodge Tide Scenario) and Outfall Scenario 1 (100% @ 48.5%) with the outfall orientated at 225^0 from north and the results have been compared to the results of the same simulation with the original outfall alignment. Comparison of the model results along the centreline of the outfall diffuser has been undertaken and is displayed in Figure 7-14. Figure 7-15 displays the comparable 0.30ppt salinity exceedance isopleths over the duration of this scenario. From these two figures it can be seen that the dilution performance of the alternative diffuser alignment is less than the original alignment. By orientating the outfall at 225^0 from north the outfall is aligned less perpendicular to the predominate north-south going tidal currents effectively reducing the volume of water in which the saline concentrate is diluted in over each tidal excursion resulting in a lower dilution performance overall.

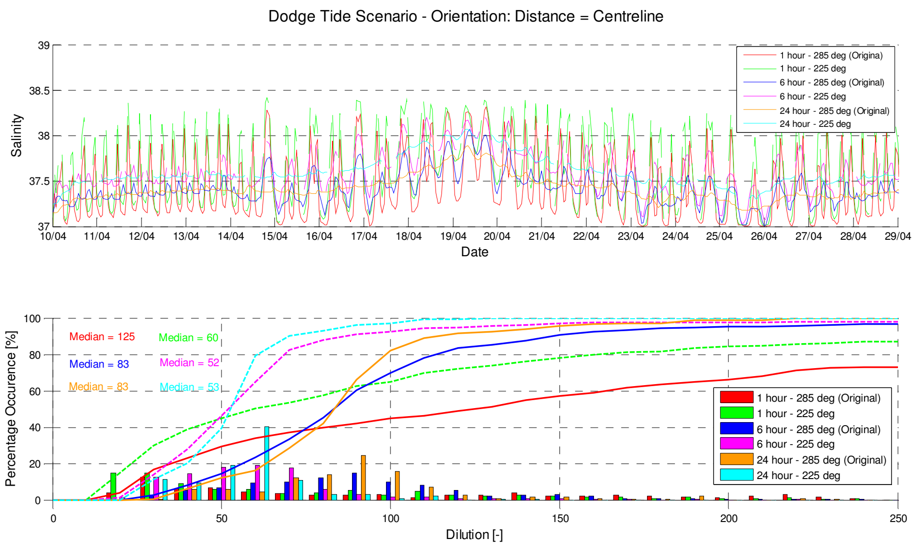
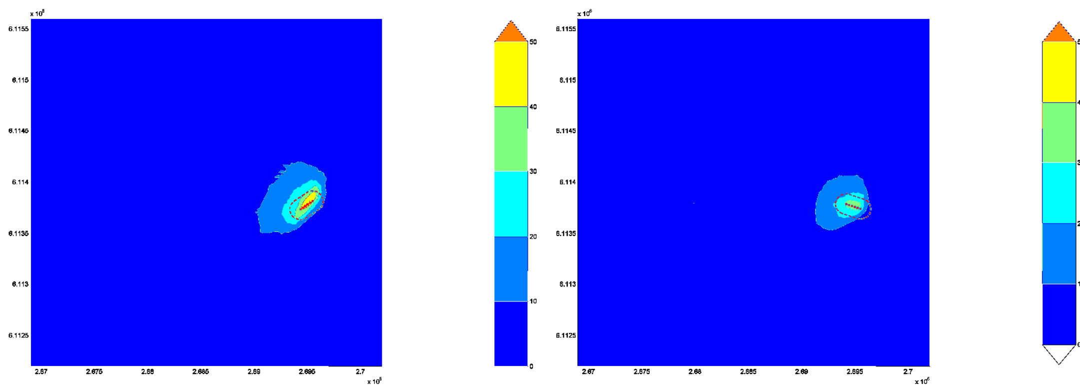


Figure 7-14 Comparison of the dilution results along the outfall centreline with alternative outfall orientation



Comparison of 0.30ppt salinity exceedance isopleths between scenario simulations with the sensitivity (225^0) orientation (Left) and the original (285^0) orientation (Right) for the Ambient Scenario 2 (Worst Case Dodge Tide Scenario) and Outfall Scenario 1 (100% @ 48.5%)

Figure 7-15 Comparison of 0.30ppt salinity exceedance isopleth with alternative outfall orientation

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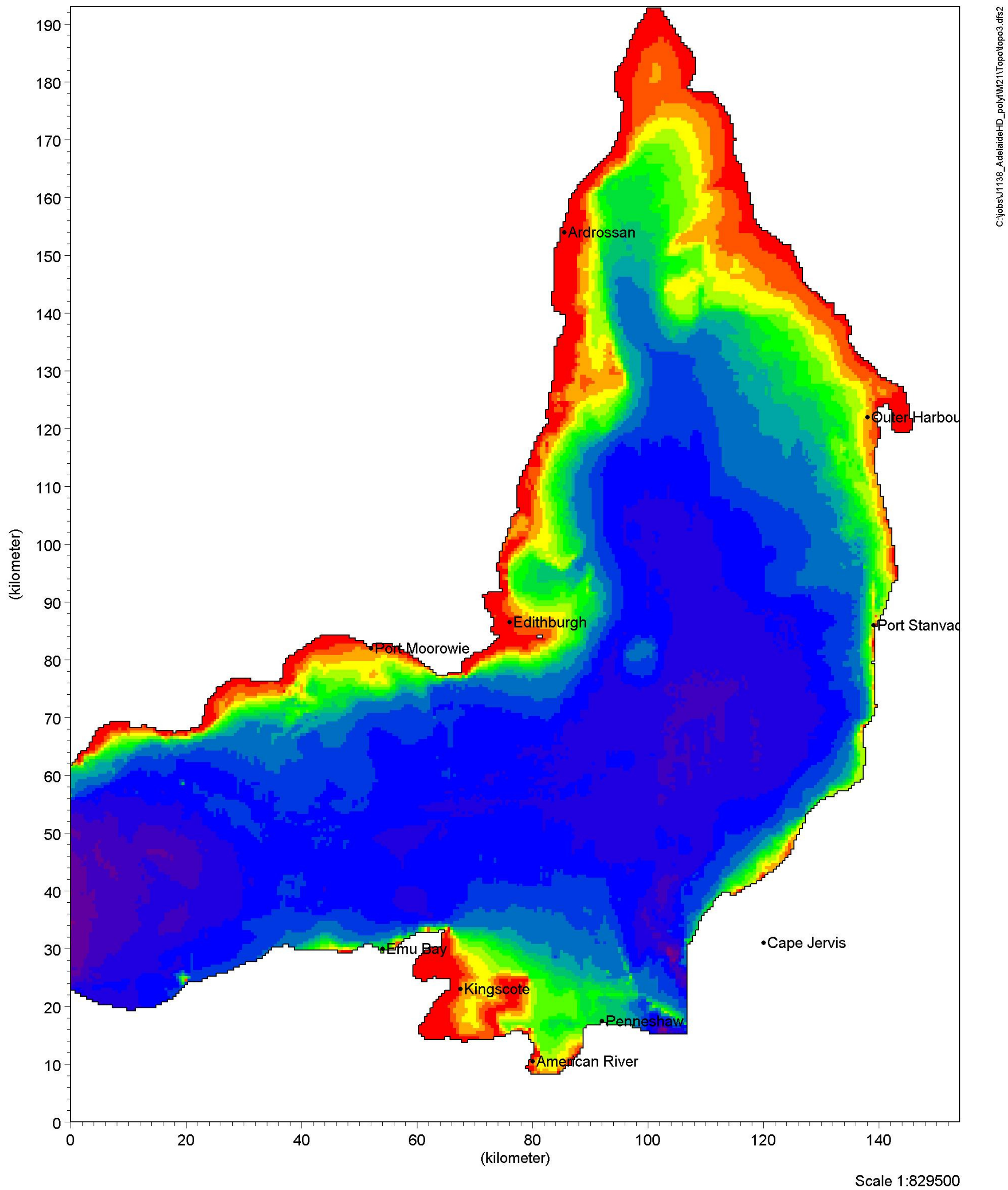
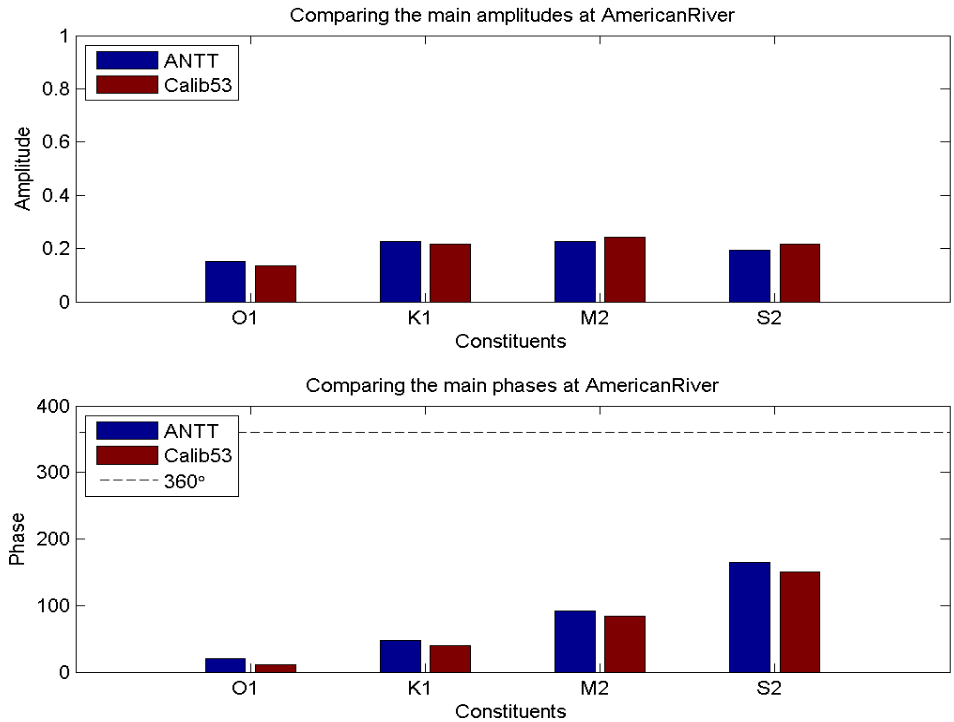
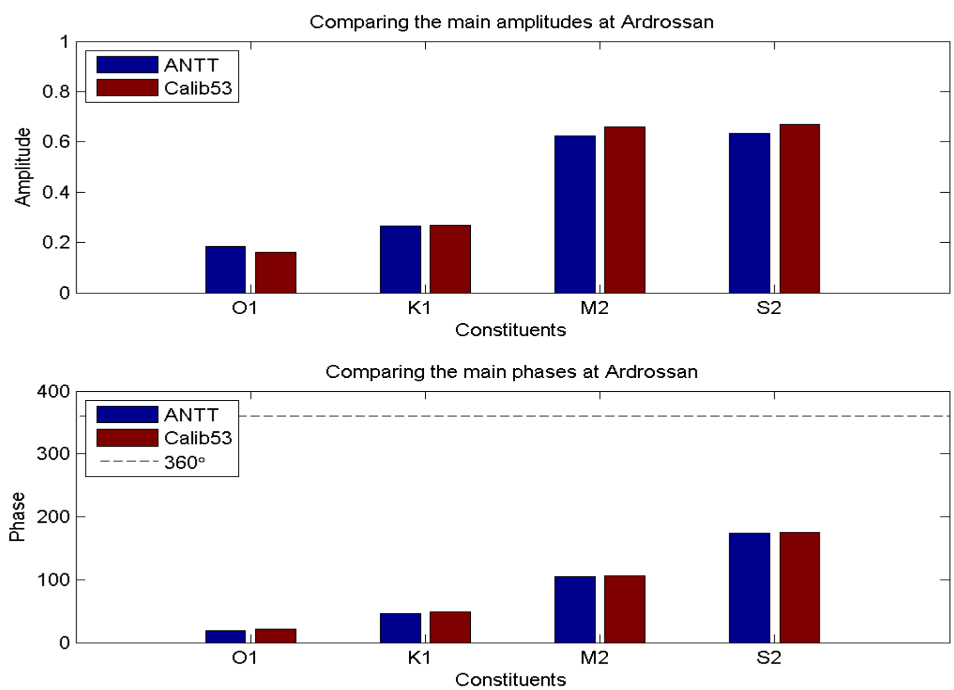
APPENDIX A – GULF ST VINCENT MODEL ANTT CONSTITUENT COMPARISON



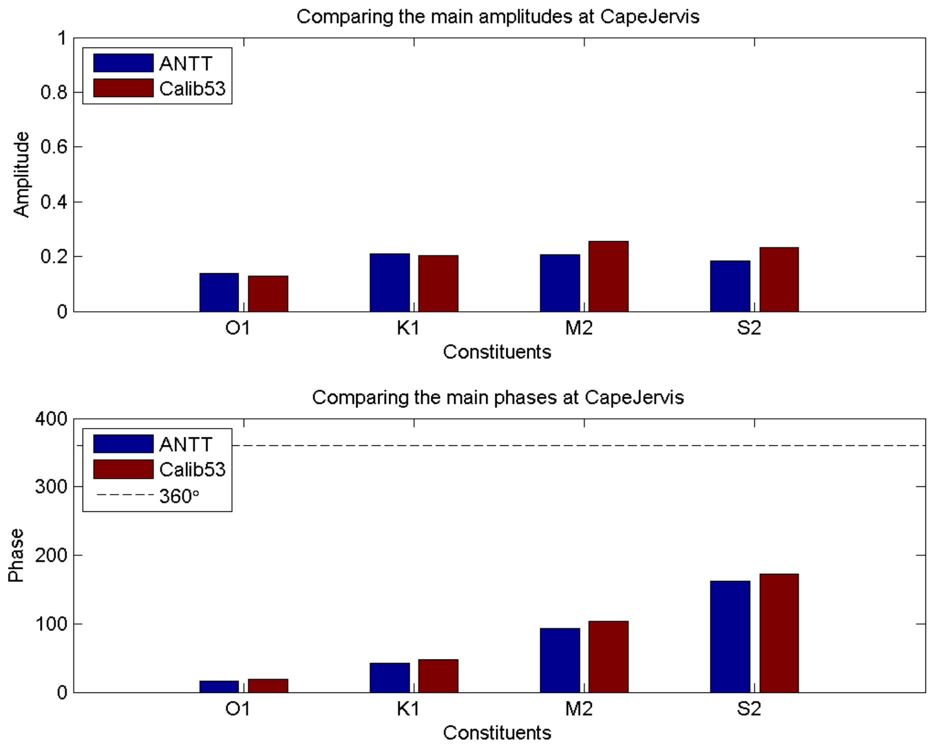
Location of ANTT Tidal Comparison Points



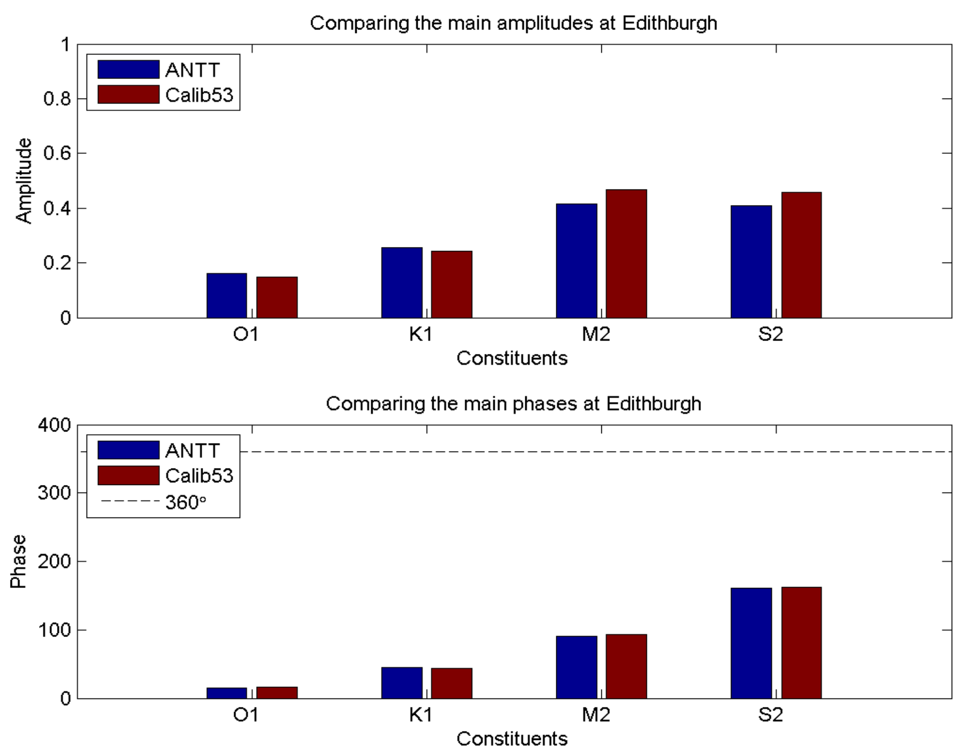
Comparison of tidal constituents at American River



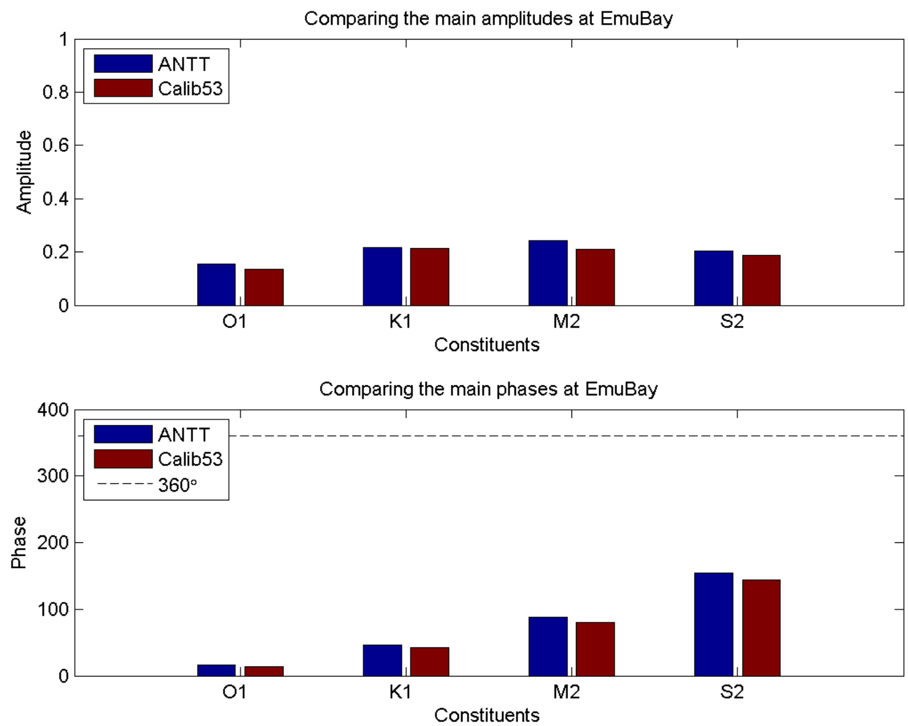
Comparison of tidal constituents at Androssan



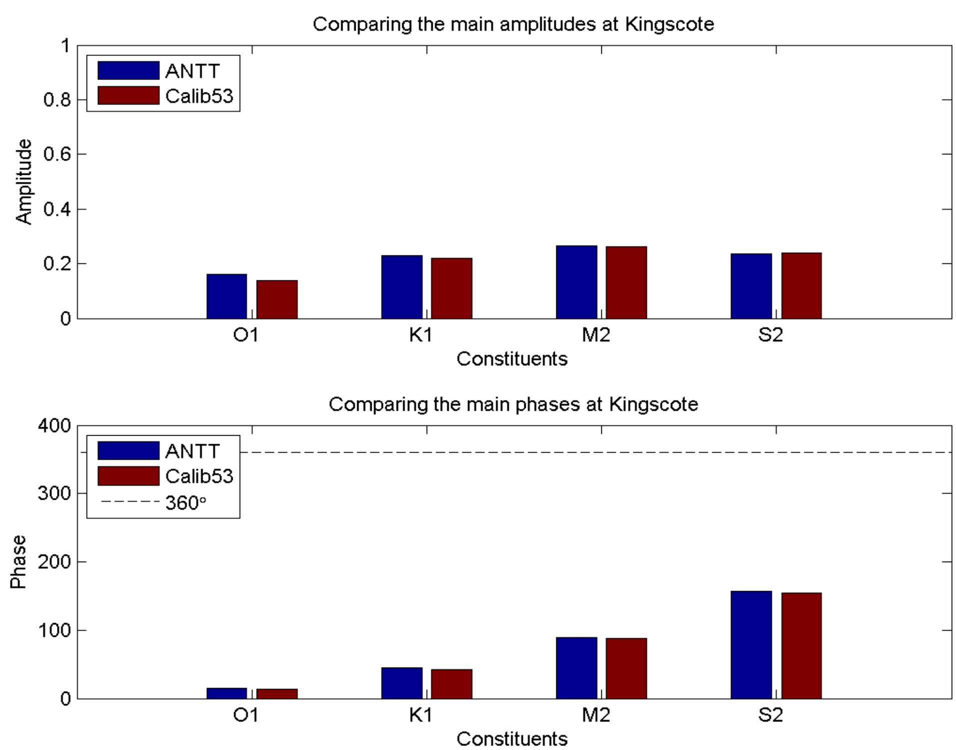
Comparison of tidal constituents at Cape Jervis



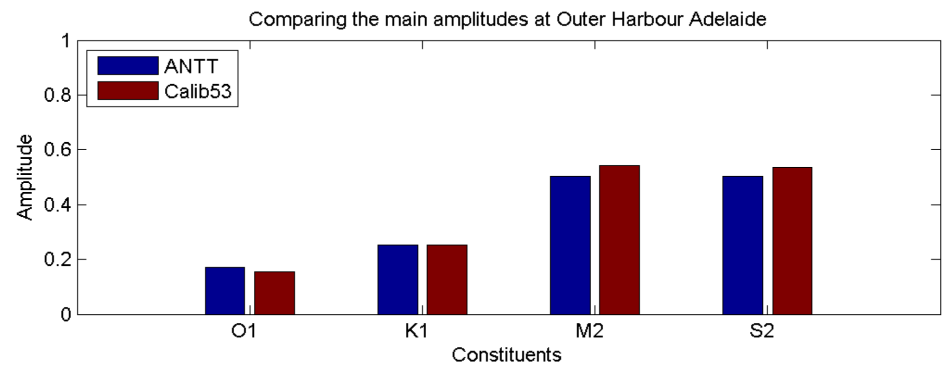
Comparison of tidal constituents at Edithburgh

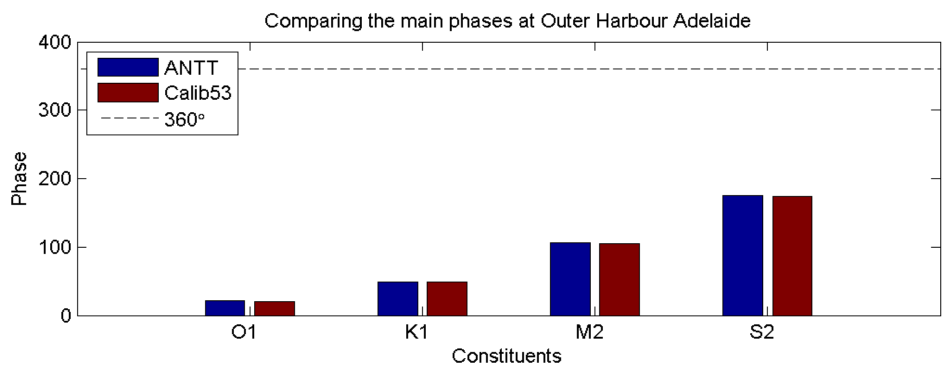


Comparison of tidal constituents at Emu Bay

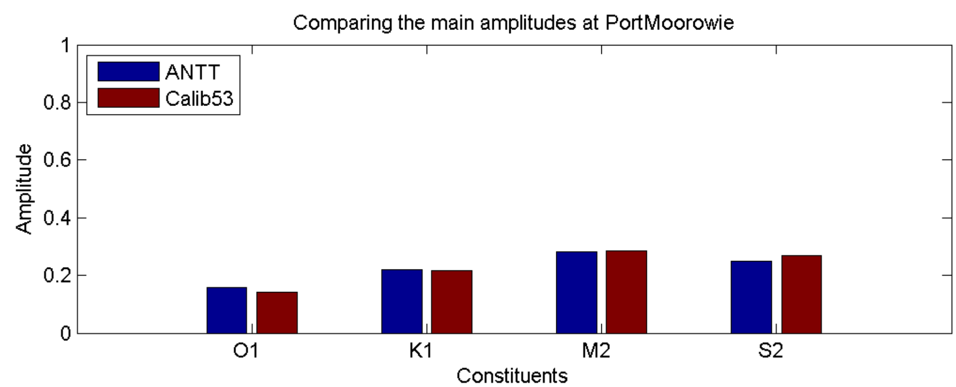


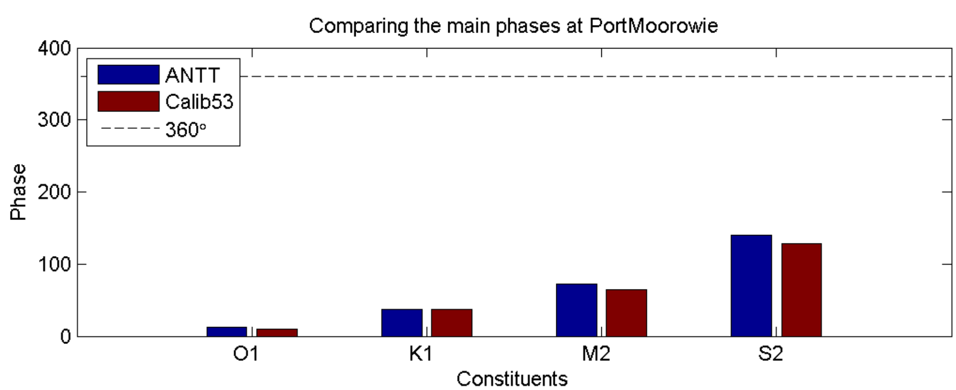
Comparison of tidal constituents at Kingscote





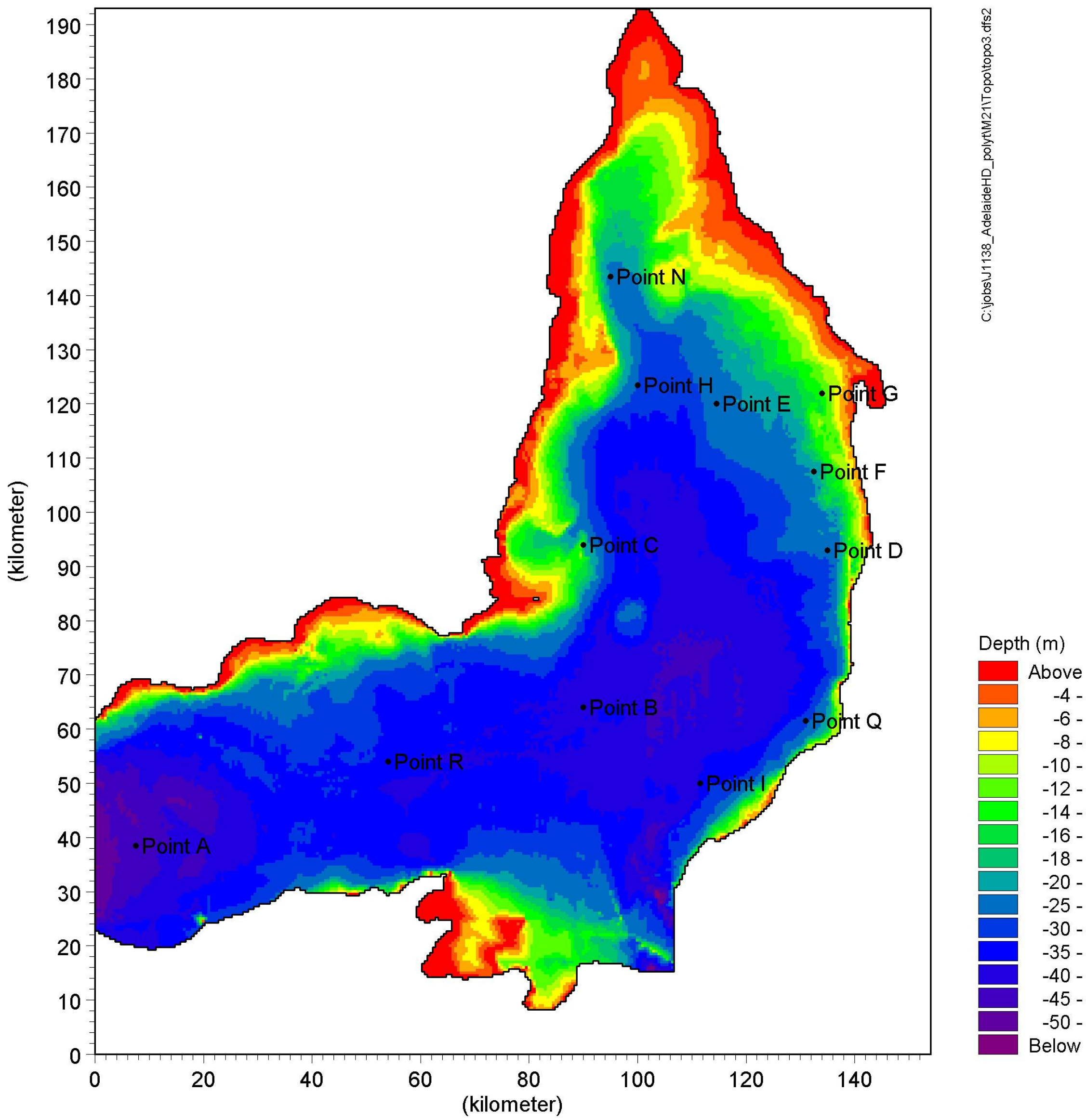
Comparison of tidal constituents at Outer Adelaide Harbour



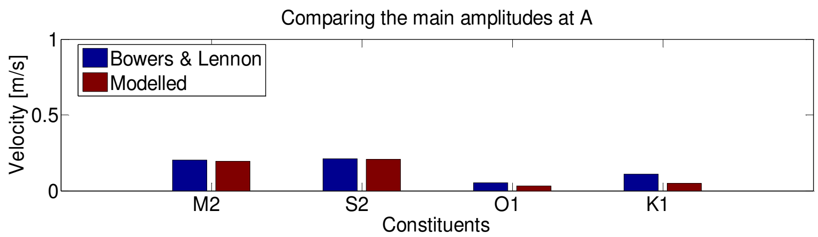


Comparison of tidal constituents at Port Moorowie

APPENDIX B – GULF ST VINCENT MODEL MEASURED CURRENT CONSTITUENT COMPARISON



Location of Measured Current Tidal Constituent Comparison Points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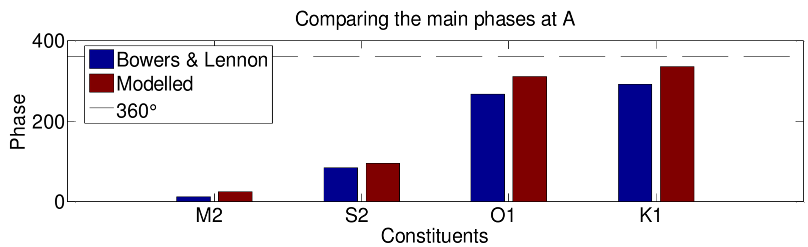
Bowers & Lennon
Modelled
M2
S2
O1
K1
Constituents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M2
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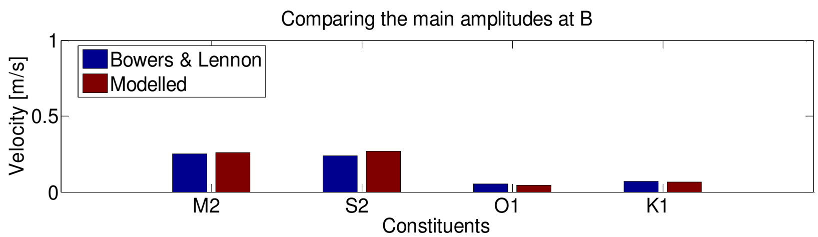
K1
Constituents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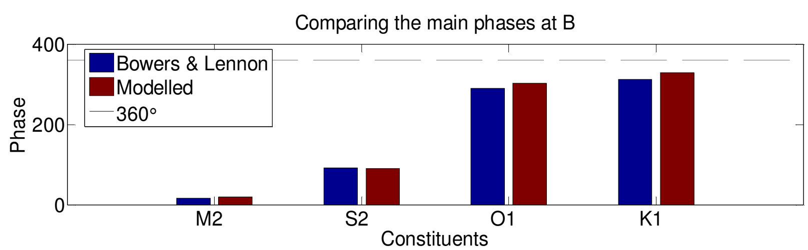
K1
Constituents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Modelled
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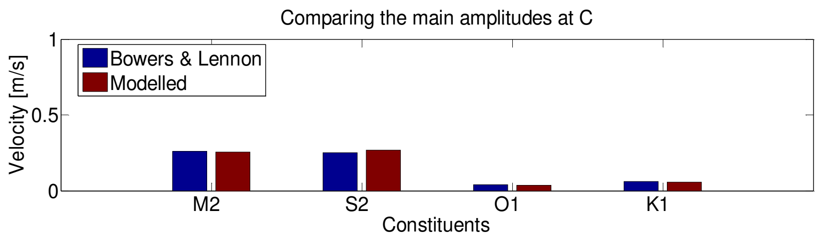
M2
S2
O1
K1
Constituents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Modelled
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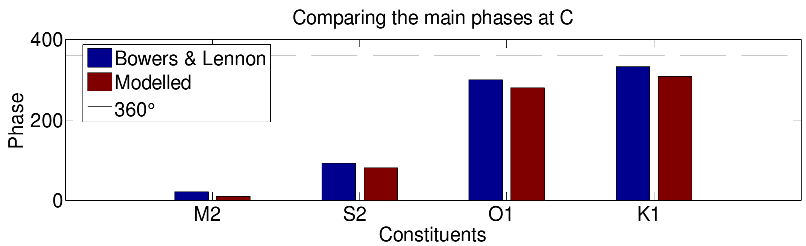
K1
Constituents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Phase
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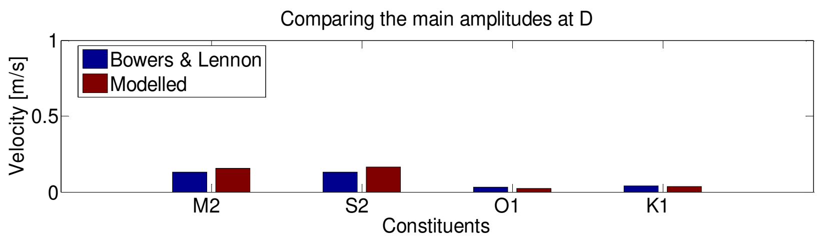
M2
S2
O1
K1
Constituents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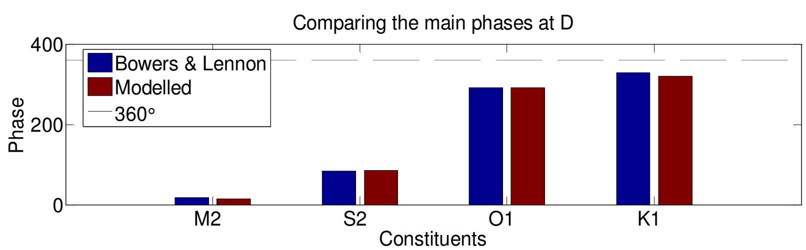
Constituents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O1
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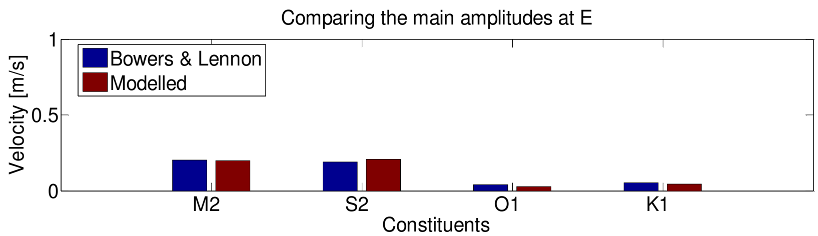
Constituents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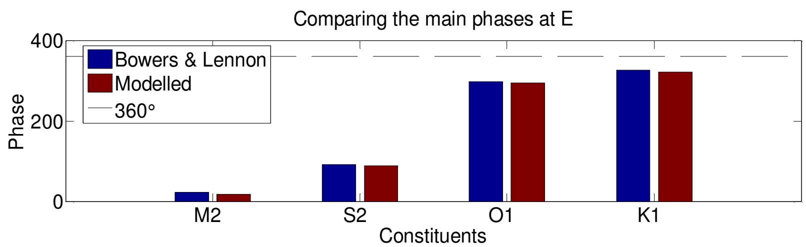
Constituents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Phase
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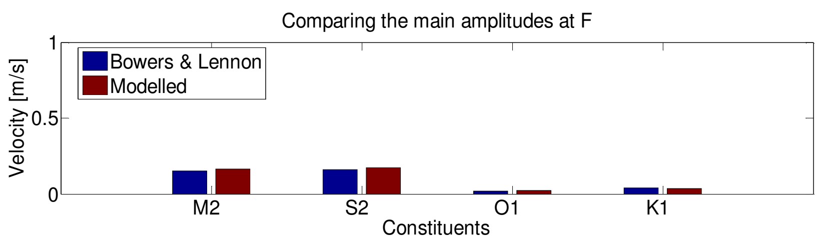
M2
S2
O1
K1
Constituents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Modelled
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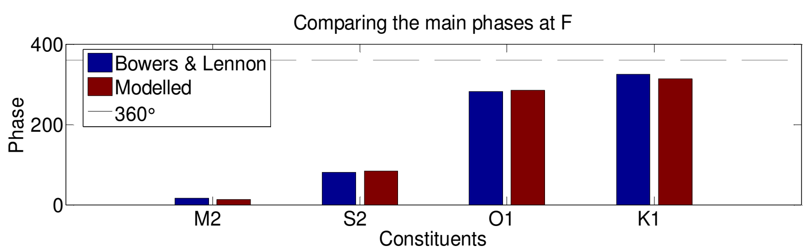
M2
S2
O1
K1
Constituents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Bowers & Lennon
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360°
Phase
400
200
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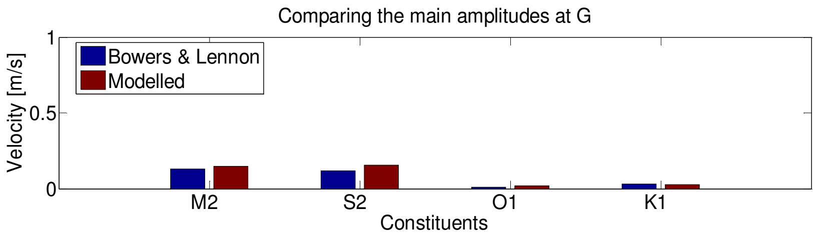
M2
S2
O1
K1
Constituents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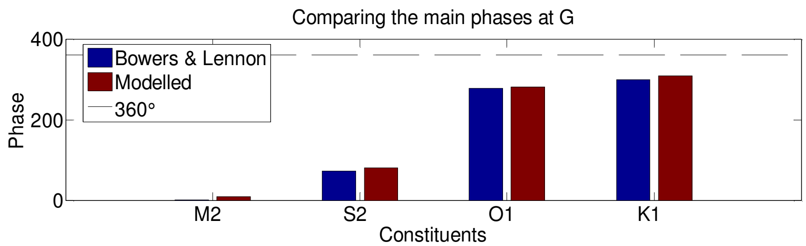
Modelled
M2
S2
O1
K1
Constituents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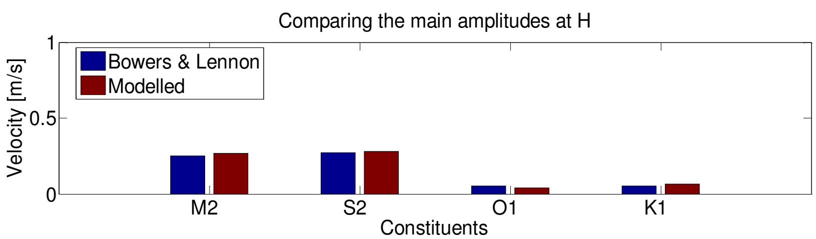
S2
O1
K1
Constituents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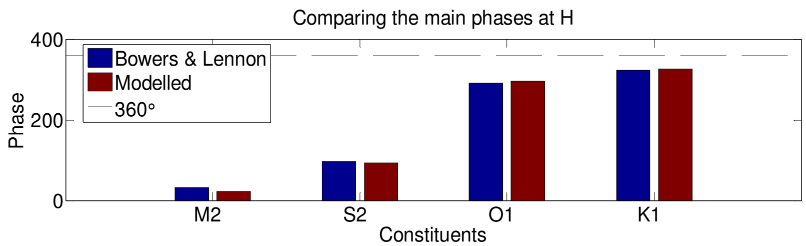
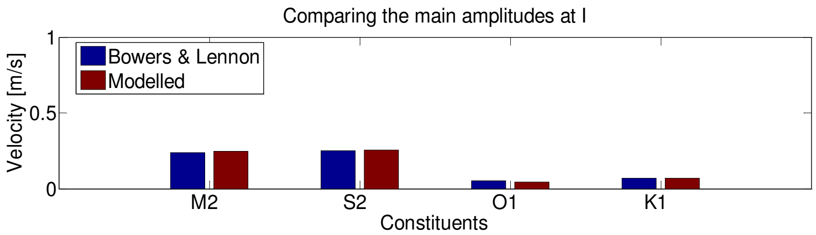
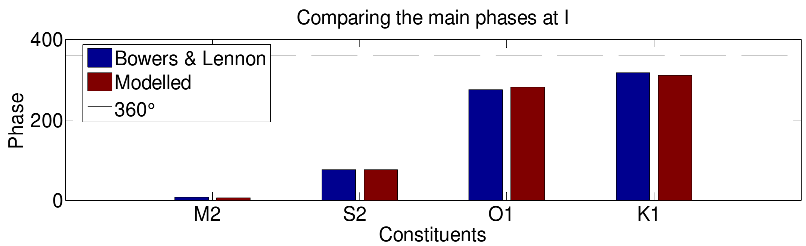
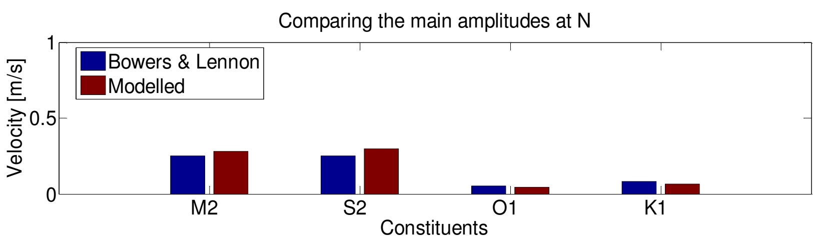
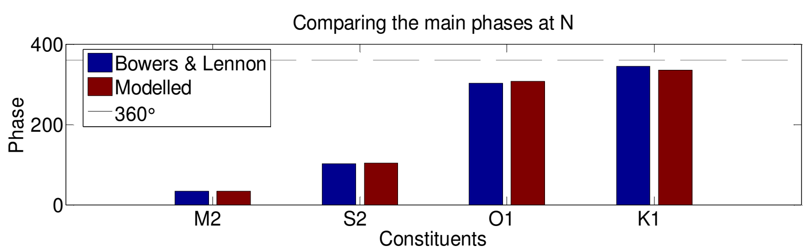
0
Bowers & Lennon
Modelled
M2
S2
O1
K1
Constituents

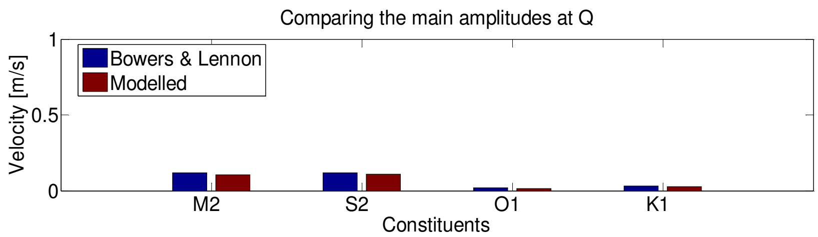

Comparing the main phases at H
Phase
400
200
0
Bowers & Lennon
Modelled
360°
M2
S2
O1
K1
Constituents

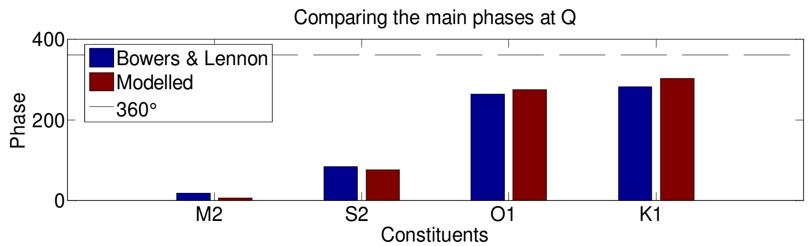

Comparing the main amplitudes at I
Velocity [m/s]
1
0.5
0
Bowers & Lennon
Modelled
M2
S2
O1
K1
Constituents

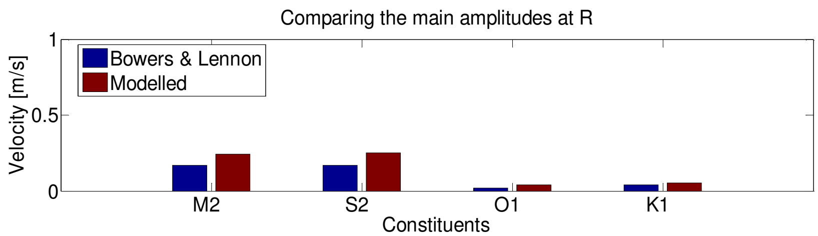

Comparing the main phases at I
Phase
400
200
0
Bowers & Lennon
Modelled
360°
M2
S2
O1
K1
Constituents

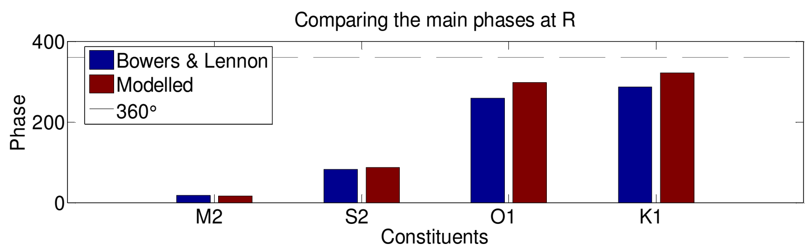

Comparing the main amplitudes at N
Velocity [m/s]
1
0.5
0
Bowers & Lennon
Modelled
M2
S2
O1
K1
Constituents


Comparing the main phases at N
Phase
400
200
0
Bowers & Lennon
Modelled
360°
M2
S2
O1
K1
Constituents

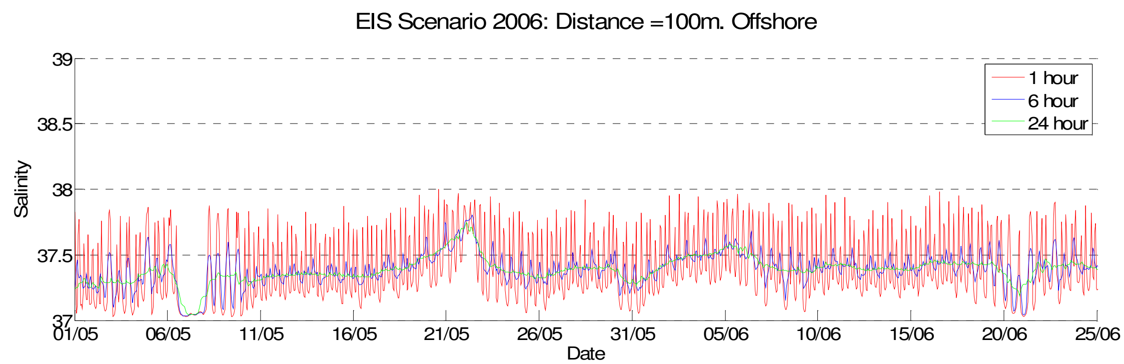

Comparing the main amplitudes at Q
Velocity [m/s]
1
0.5
0
Bowers & Lennon
Modelled
M2
S2
O1
K1
Constituents

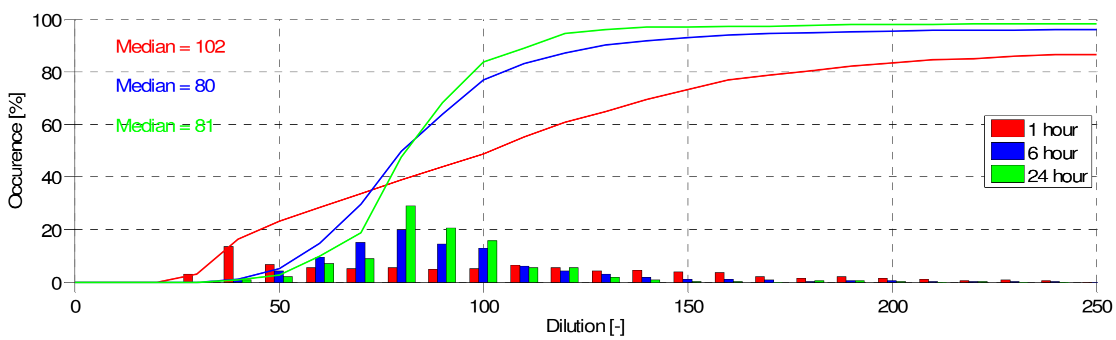

Comparing the main phases at Q
Phase
400
200
0
Bowers & Lennon
Modelled
360°
M2
S2
O1
K1
Constituents

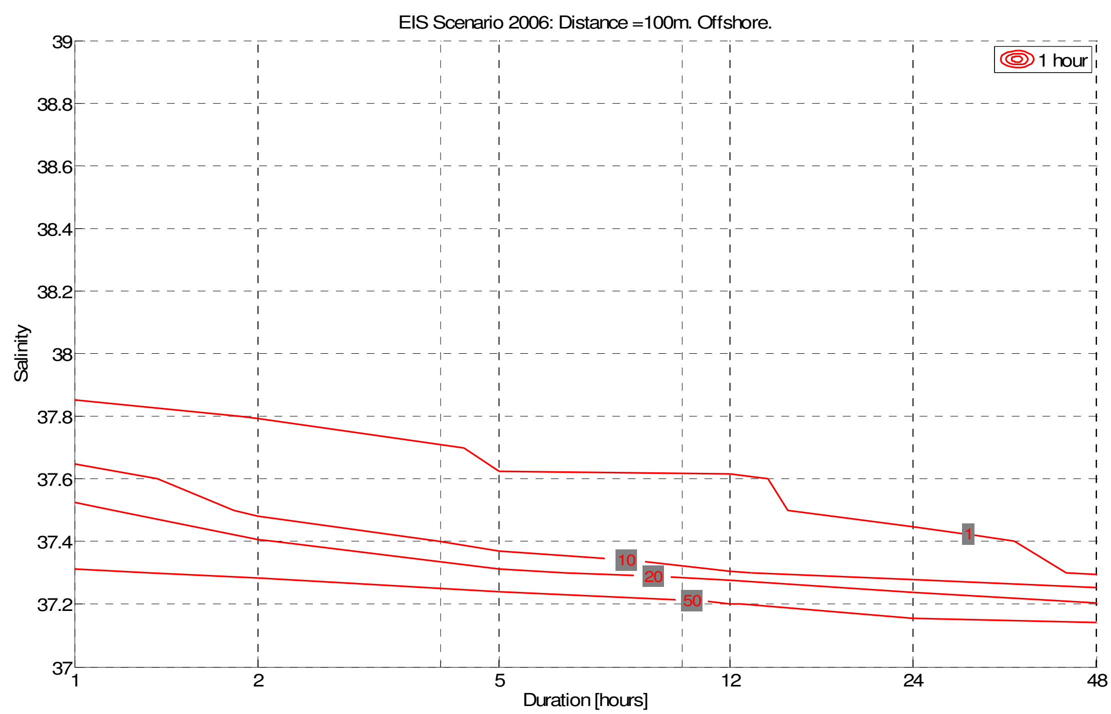

Comparing the main amplitudes at R
Velocity [m/s]
1
0.5
0
Bowers & Lennon
Modelled
M2
S2
O1
K1
Constituents

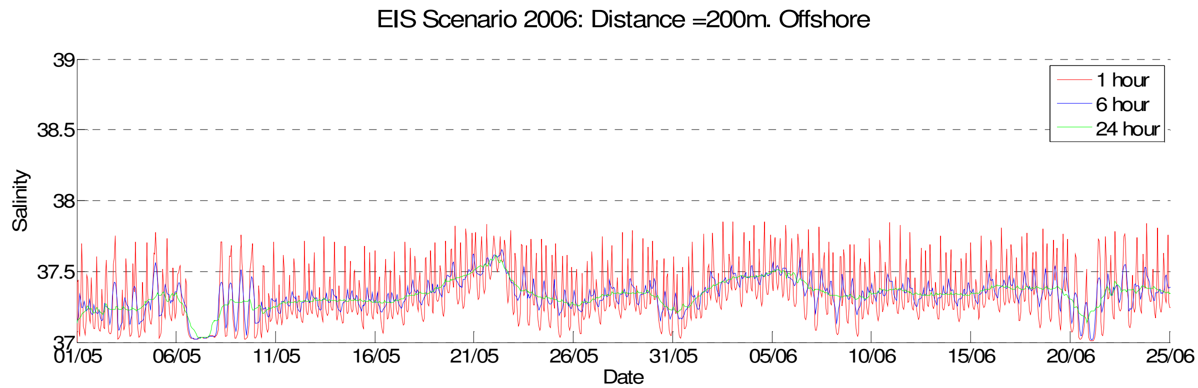

Comparing the main phases at R
Phase
400
200
0
Bowers & Lennon
Modelled
360°
M2
S2
O1
K1
Constituents

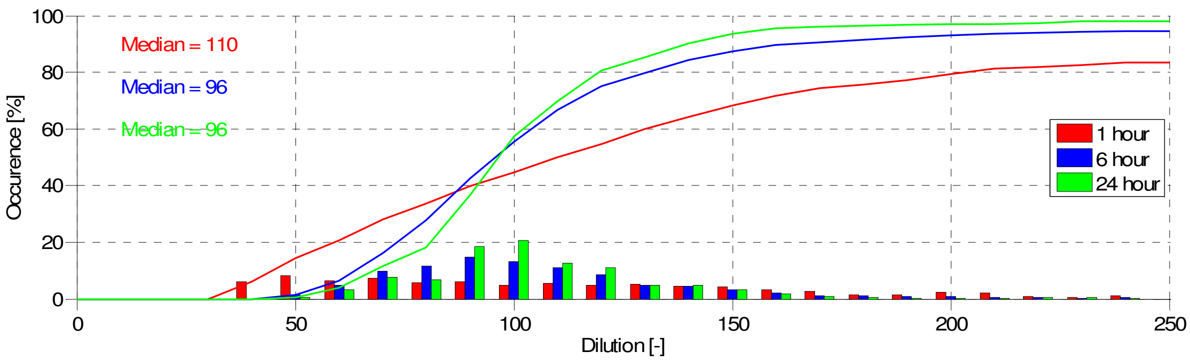
APPENDIX C – AMBIENT SCENARIO 1 (SIX WEEK AMBIENT SCENARIO) AND OUTFALL SCENARIO 1 (100% @ 48.5%)

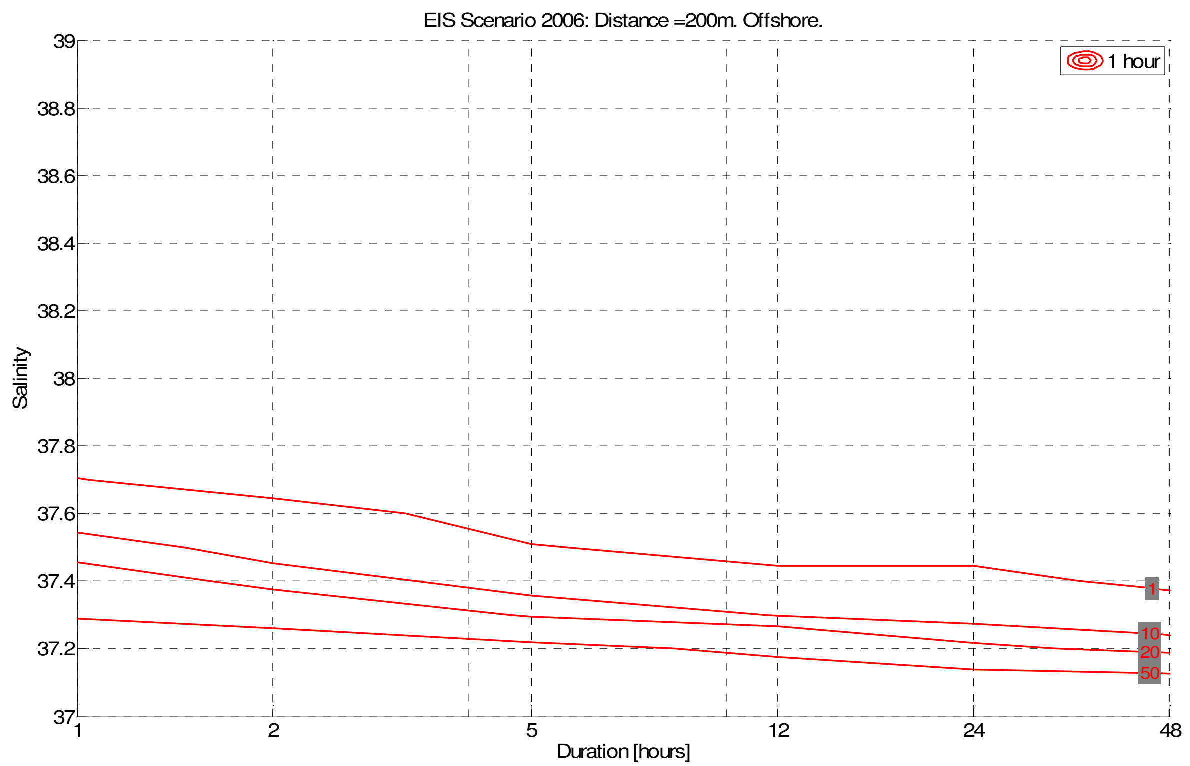


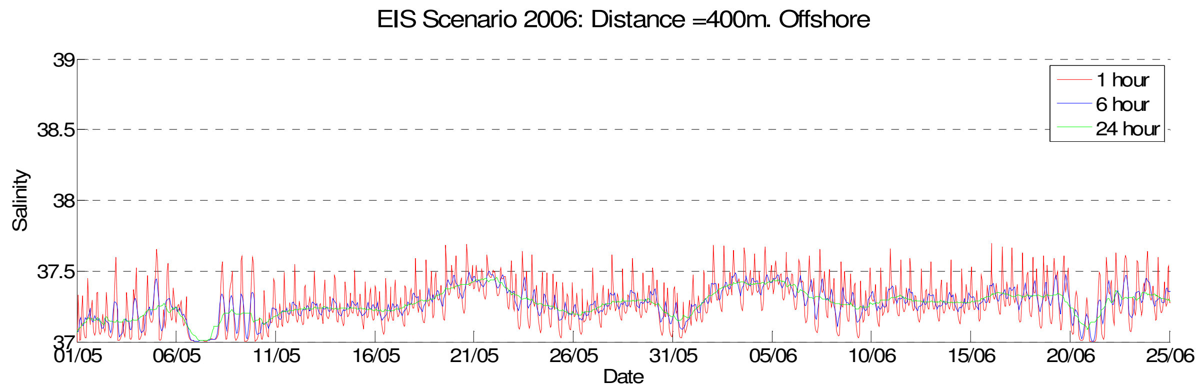


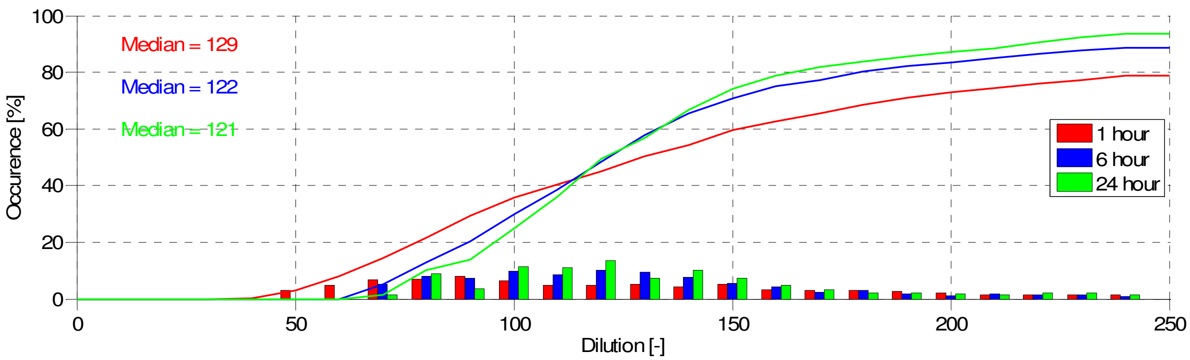


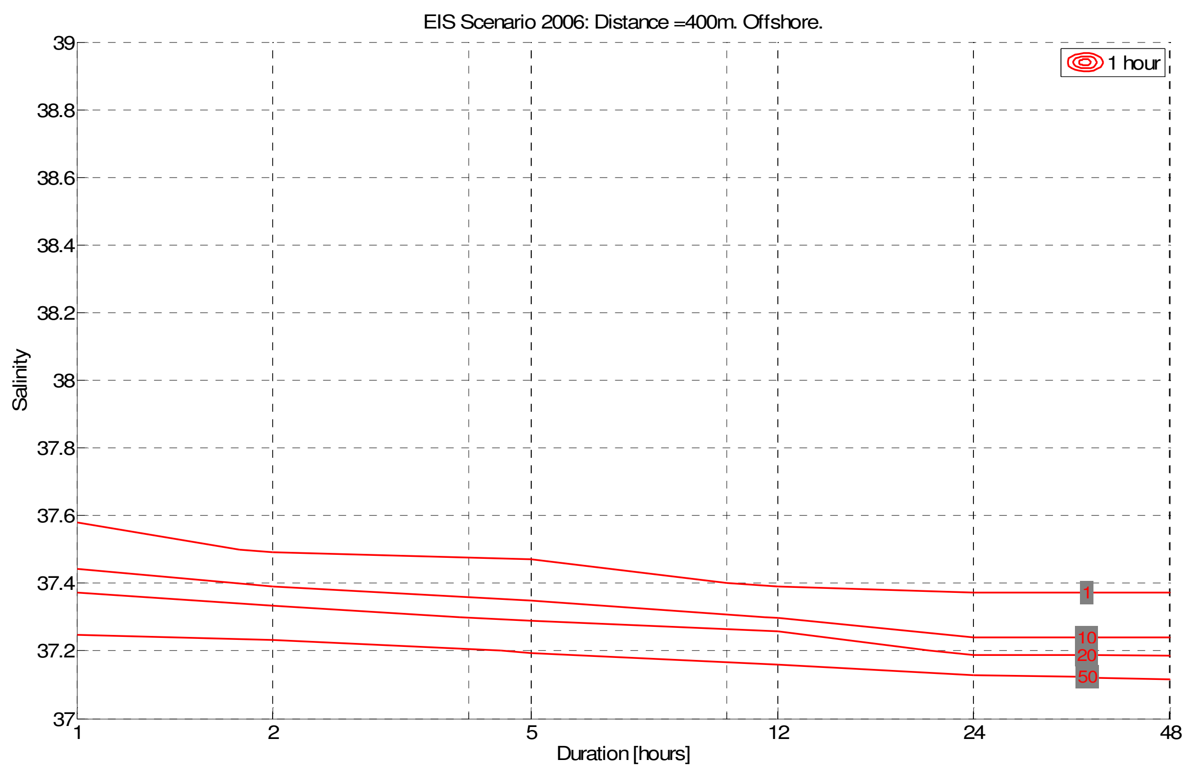

EIS Scenario 2006: Distance =200m. Offshore
Salinity
Date
1 hour
6 hour
24 hour
39
38.5
38
37.5
37
01/05
06/05
11/05
16/05
21/05
26/05
31/05
05/06
10/06
15/06
20/06
25/06

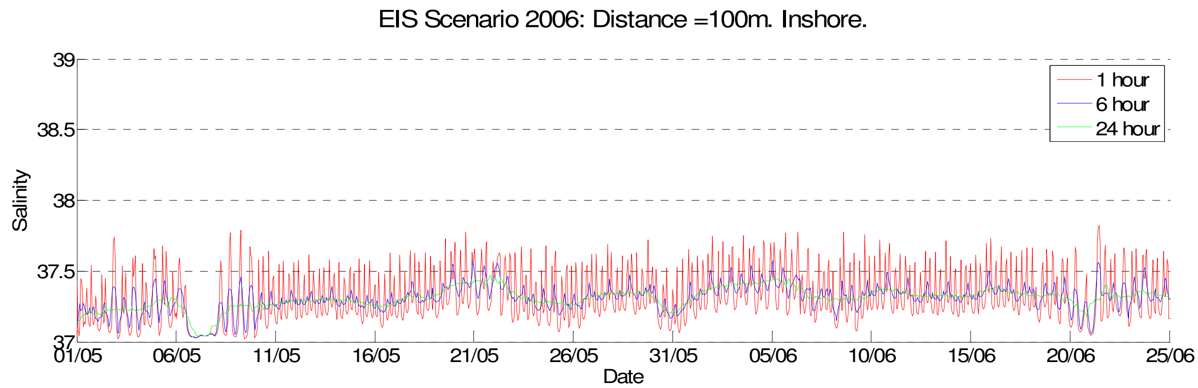

Median = 110
Median = 96
Median = 96
Occurence [%]
Dilution [-]
1 hour
6 hour
24 hour
100
80
60
40
20
0
0
50
100
150
200
250

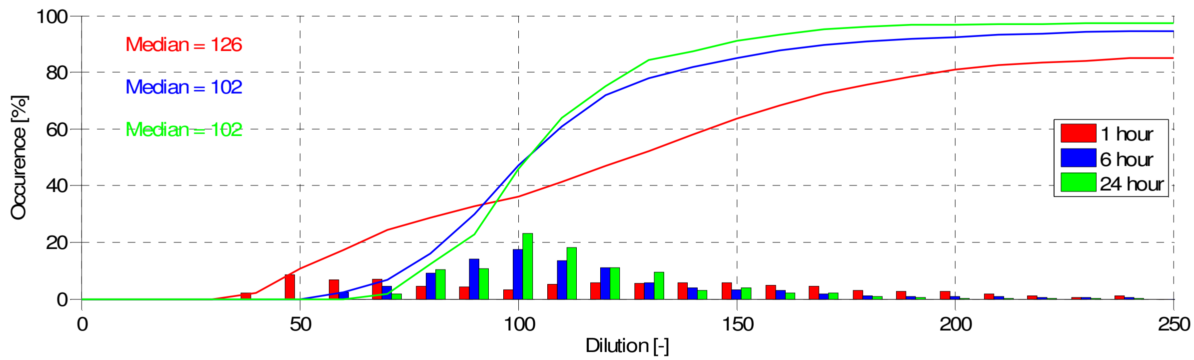

EIS Scenario 2006: Distance =200m. Offshore.
1 hour
Salinity
Duration [hours]
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1
2
5
12
24
48
1
10
20
50

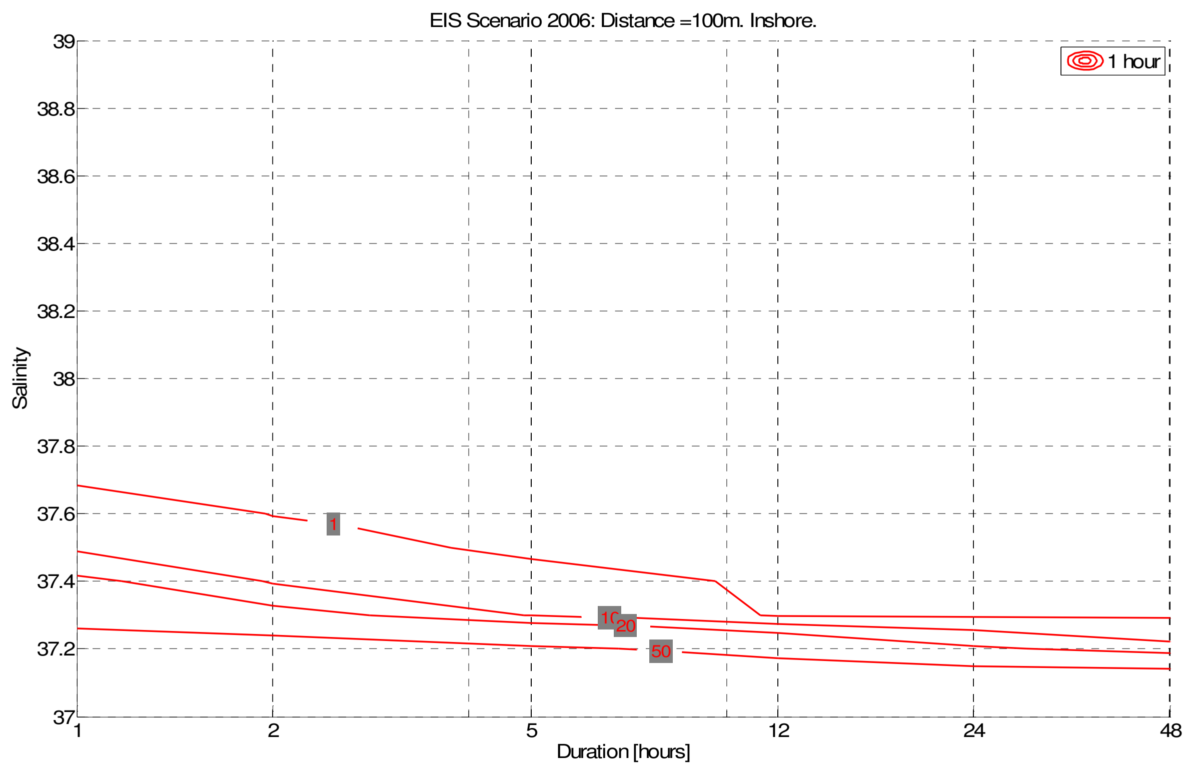

EIS Scenario 2006: Distance =400m. Offshore
Salinity
Date
1 hour
6 hour
24 hour
39
38.5
38
37.5
37
01/05
06/05
11/05
16/05
21/05
26/05
31/05
05/06
10/06
15/06
20/06
25/06

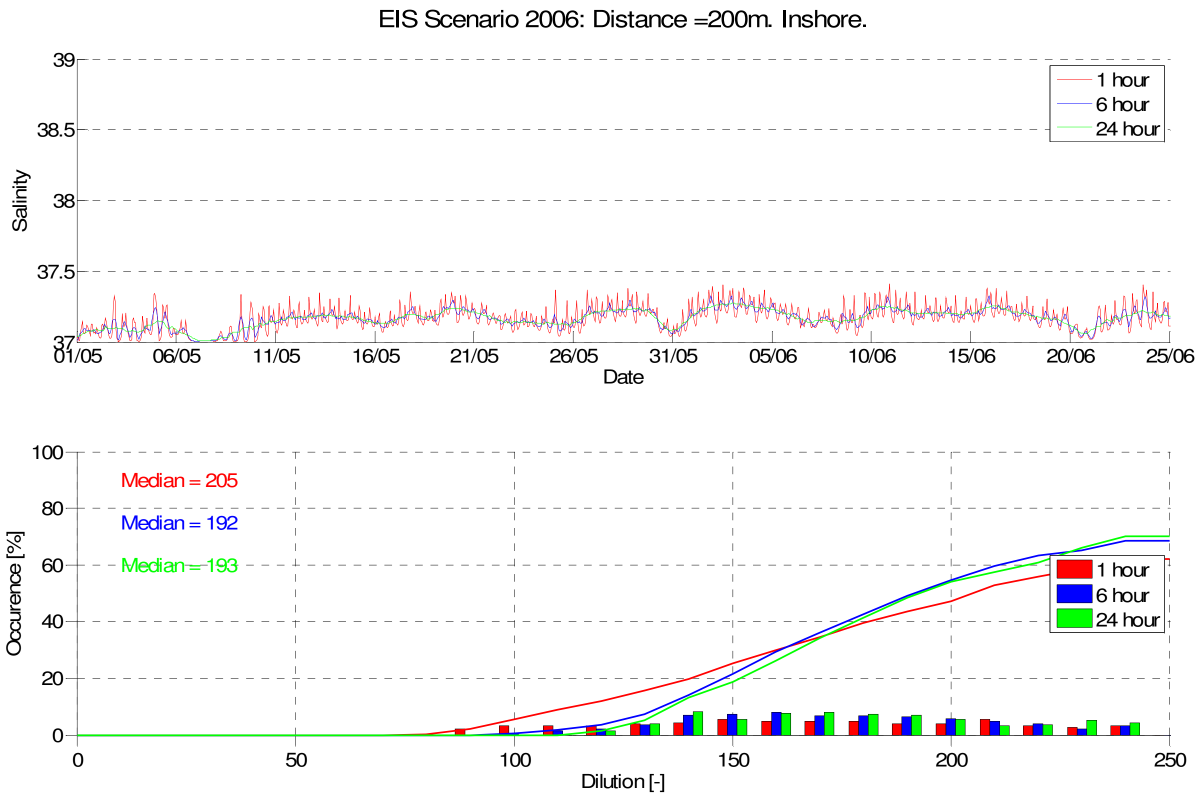

Median = 129
Median = 122
Median = 121
Occurence [%]
Dilution [-]
1 hour
6 hour
24 hour
100
80
60
40
20
0
0
50
100
150
200
250

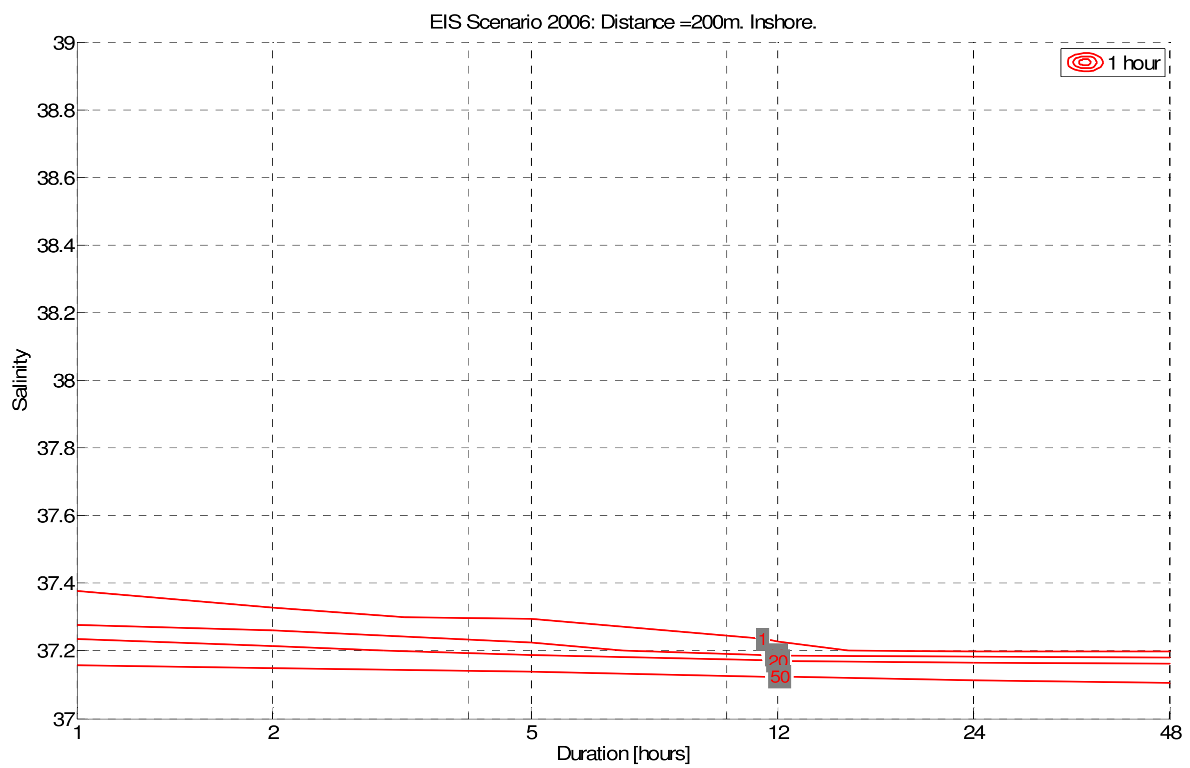

EIS Scenario 2006: Distance =400m. Offshore.
1 hour
Salinity
Duration [hours]
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1
2
5
12
24
48
1
10
20
50

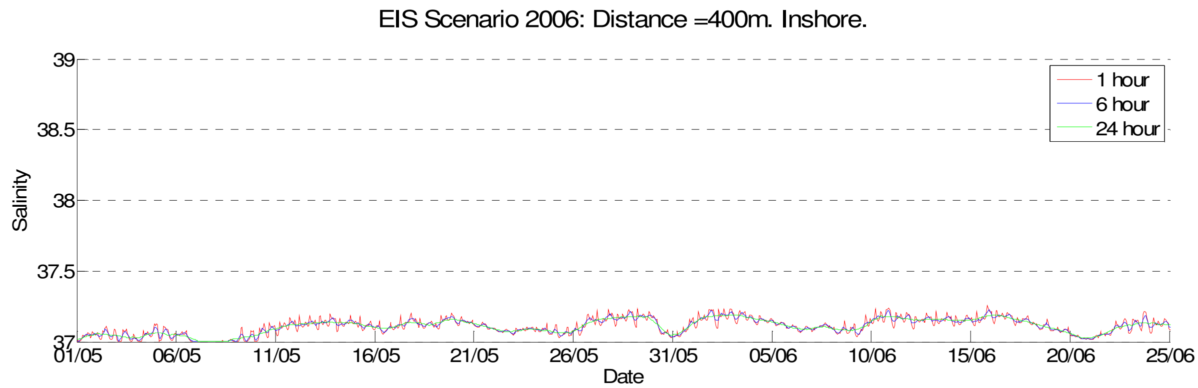

EIS Scenario 2006: Distance =100m. Inshore.
1 hour
6 hour
24 hour
Salinity
39
38.5
38
37.5
37
01/05
06/05
11/05
16/05
21/05
26/05
31/05
05/06
10/06
15/06
20/06
25/06
Date

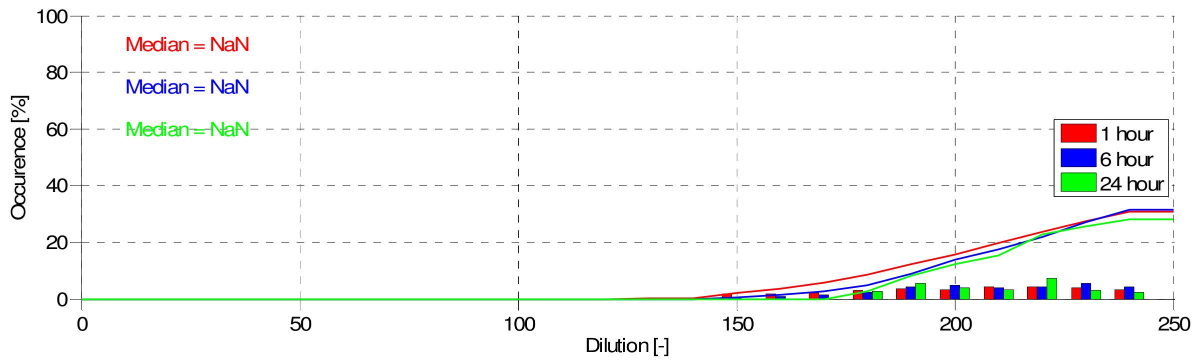

Median = 126
Median = 102
Median = 102
1 hour
6 hour
24 hour
Occurence [%]
100
80
60
40
20
0
0
50
100
150
200
250
Dilution [-]

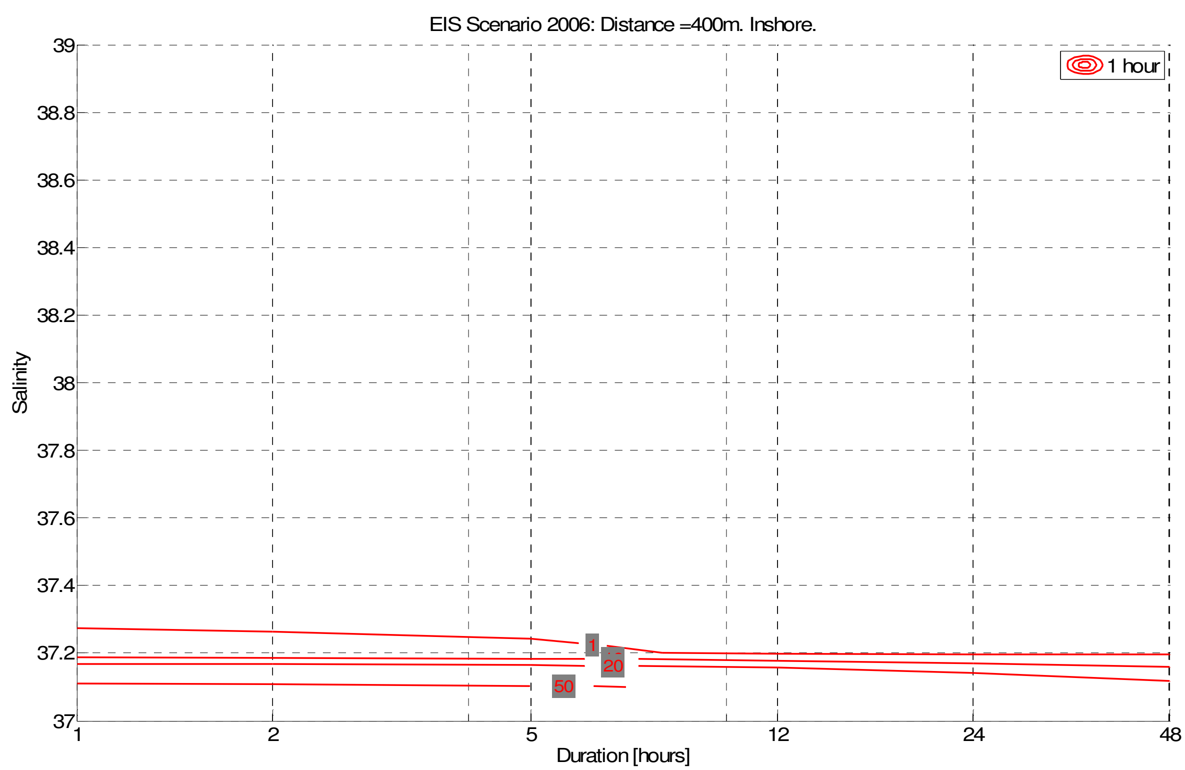

EIS Scenario 2006: Distance =100m. Inshore.
1 hour
Salinity
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1
10
20
50
1
2
5
12
24
48
Duration [hours]

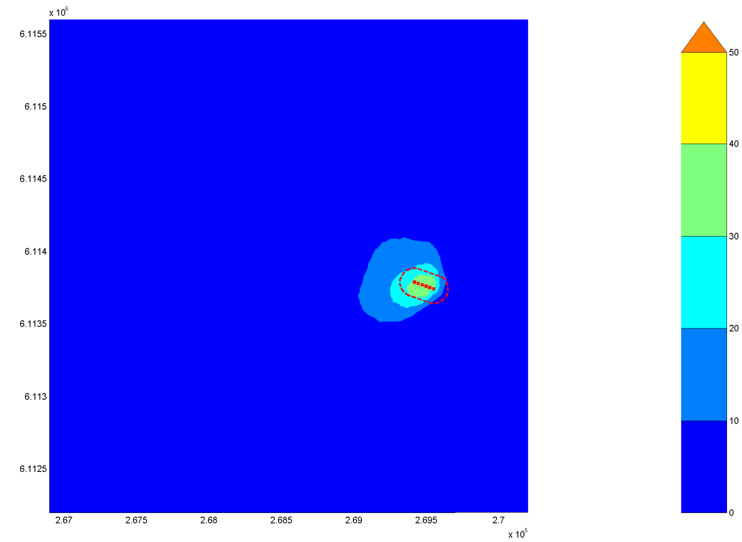

EIS Scenario 2006: Distance =200m. Inshore.
1 hour
6 hour
24 hour
Salinity
Date
01/05
06/05
11/05
16/05
21/05
26/05
31/05
05/06
10/06
15/06
20/06
25/06
Median = 205
Median = 192
Median = 193
Occurence [%]
Dilution [-]


EIS Scenario 2006: Distance =200m. Inshore.
1 hour
Salinity
Duration [hours]
1
20
50

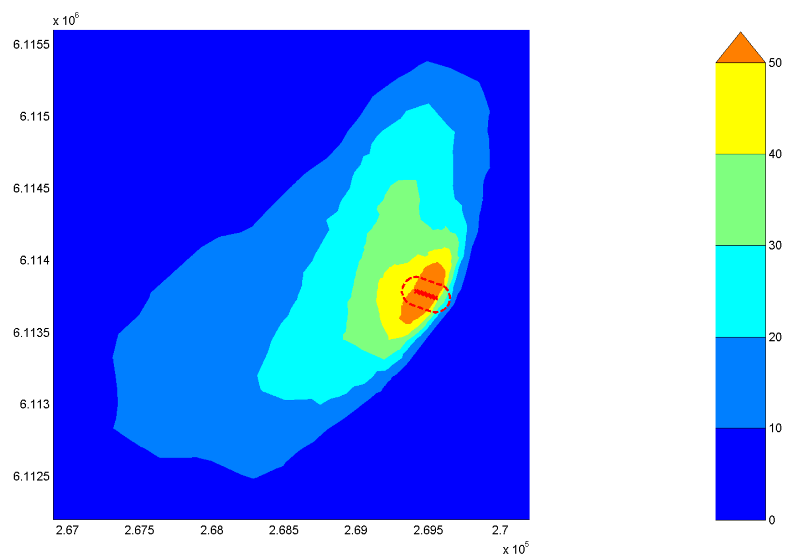

EIS Scenario 2006: Distance =400m. Inshore.
Salinity
39
38.5
38
37.5
37
01/05
06/05
11/05
16/05
21/05
26/05
31/05
05/06
10/06
15/06
20/06
25/06
Date
1 hour
6 hour
24 hour


Occurence [%]
100
80
60
40
20
0
Median = NaN
Median = NaN
Median = NaN
1 hour
6 hour
24 hour
0
50
100
150
200
250
Dilution [-]

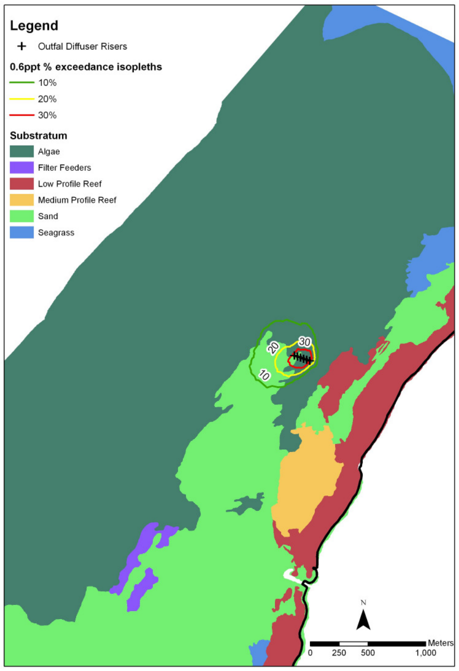

EIS Scenario 2006: Distance =400m. Inshore.
Salinity
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1 hour
1
20
50
1
2
5
12
24
48
Duration [hours]



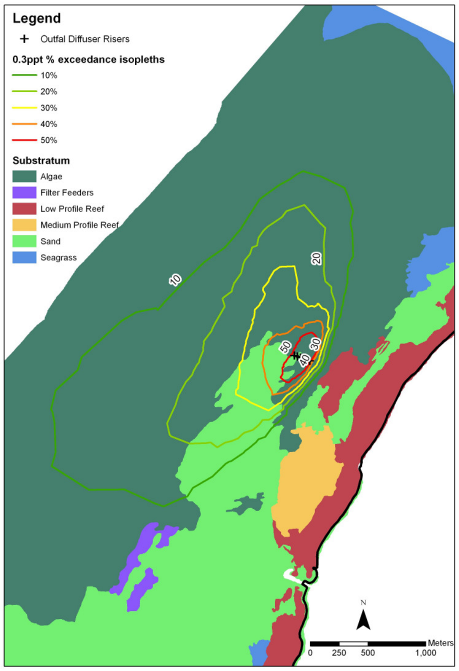
Percentage exceedance of 0.6ppt salinity isopleth at the bed. Dashed red oval is a 100m distance around outfall provided for scale. Contour intervals are reported at the 10, 20, 30, 40 and 50th%



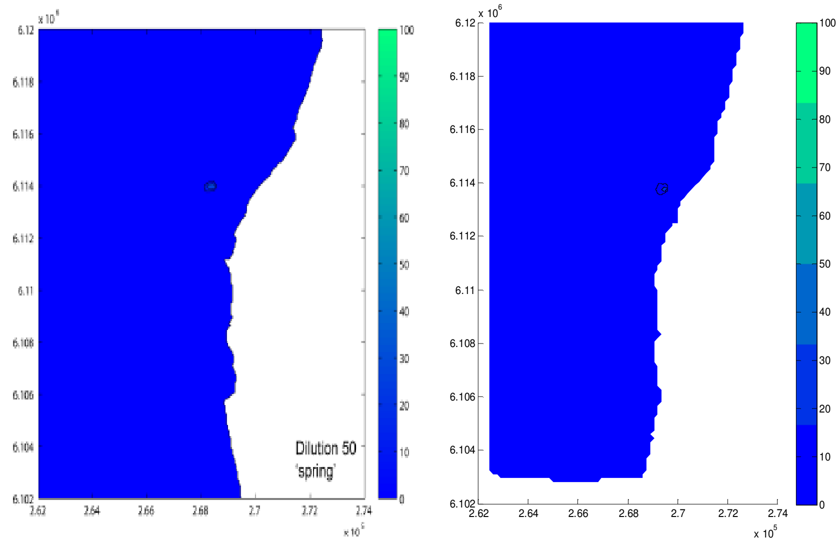
Percentage exceedance of 0.3ppt salinity isopleth at the bed. Dashed red oval is a 100m distance around outfall provided for scale. Contour intervals are reported at the 10, 20, 30, 40 and 50th%



Percentage exceedance of 0.6ppt salinity isopleths at the bed relative to substratum type. Contour intervals are reported at the 10, 20, 30, 40 and 50th%

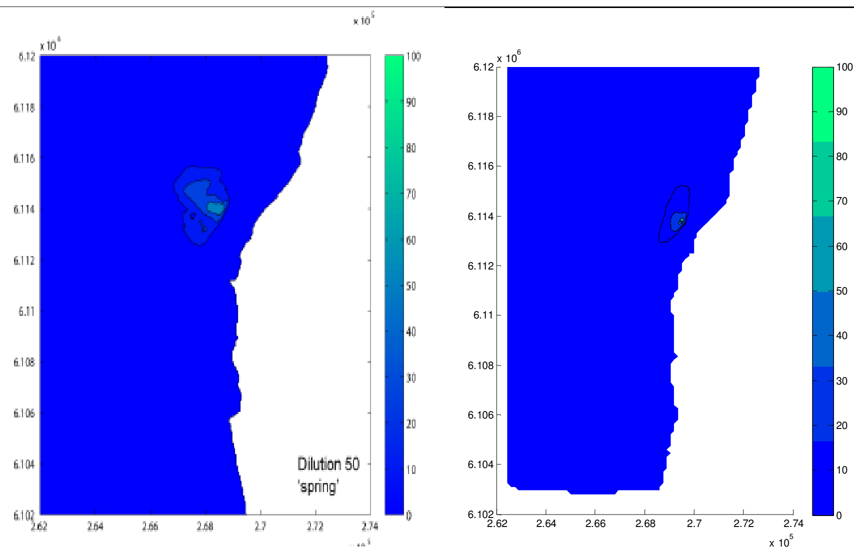


Percentage exceedance of 0.3ppt salinity isopleths at the bed relative to substratum type. Contour intervals are reported at the 10, 20, 30, 40 and 50th%



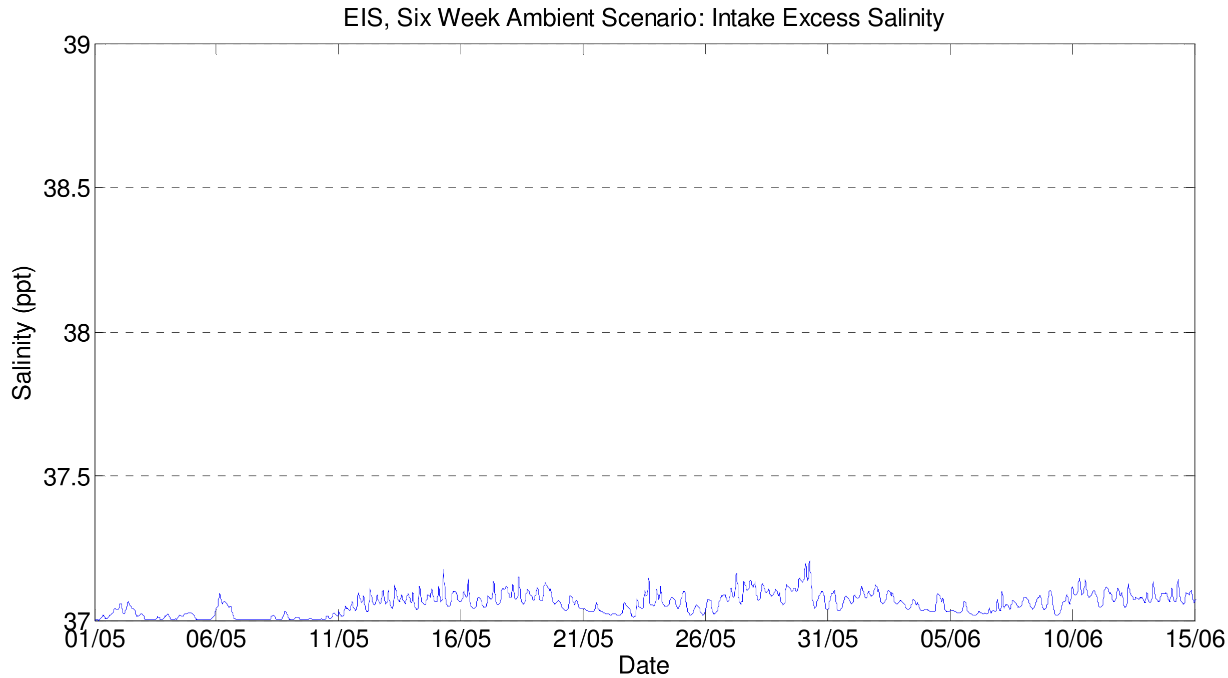
Comparison of 0.60ppt salinity exceedance isopleths between reference design and Adelaide Aqua design

((Left) Figure 45 (Pattiaratchi, 2008) 250m long reference design diffuser, spring tides, (Right) Adelaide Aqua design diffuser, 6 week ambient scenario)

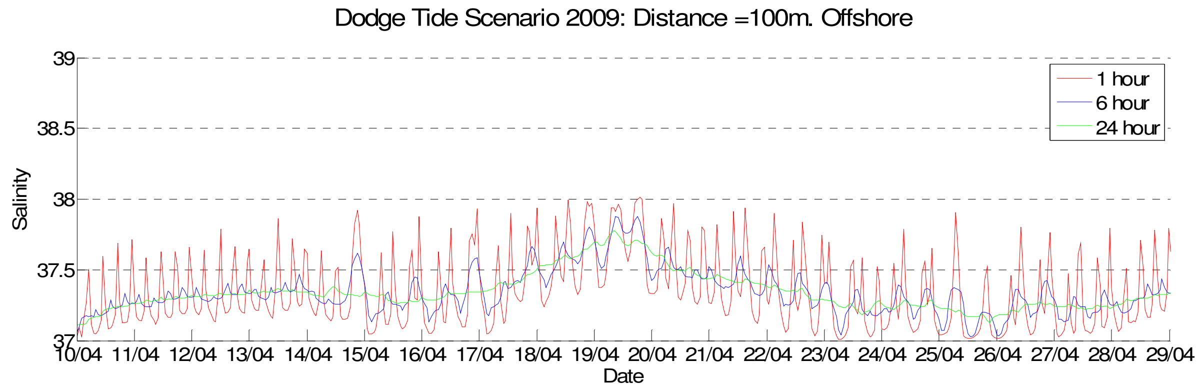


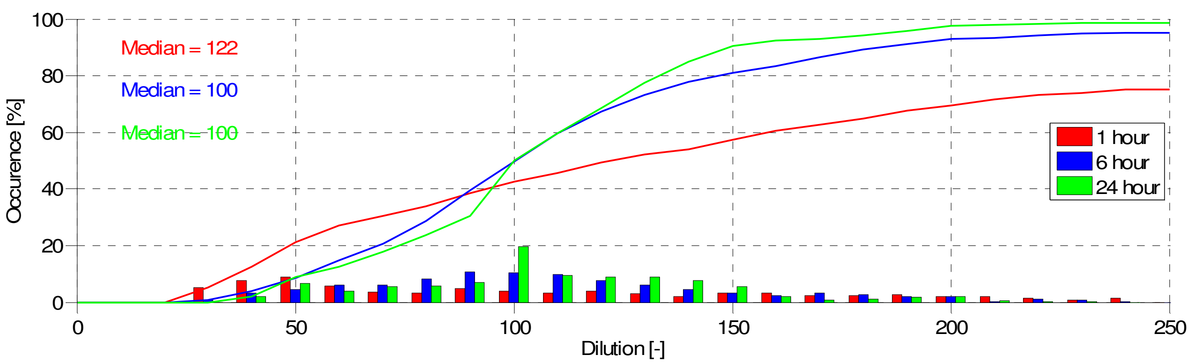
Comparison of 0.30ppt salinity exceedance isopleths between reference design and Adelaide Aqua design

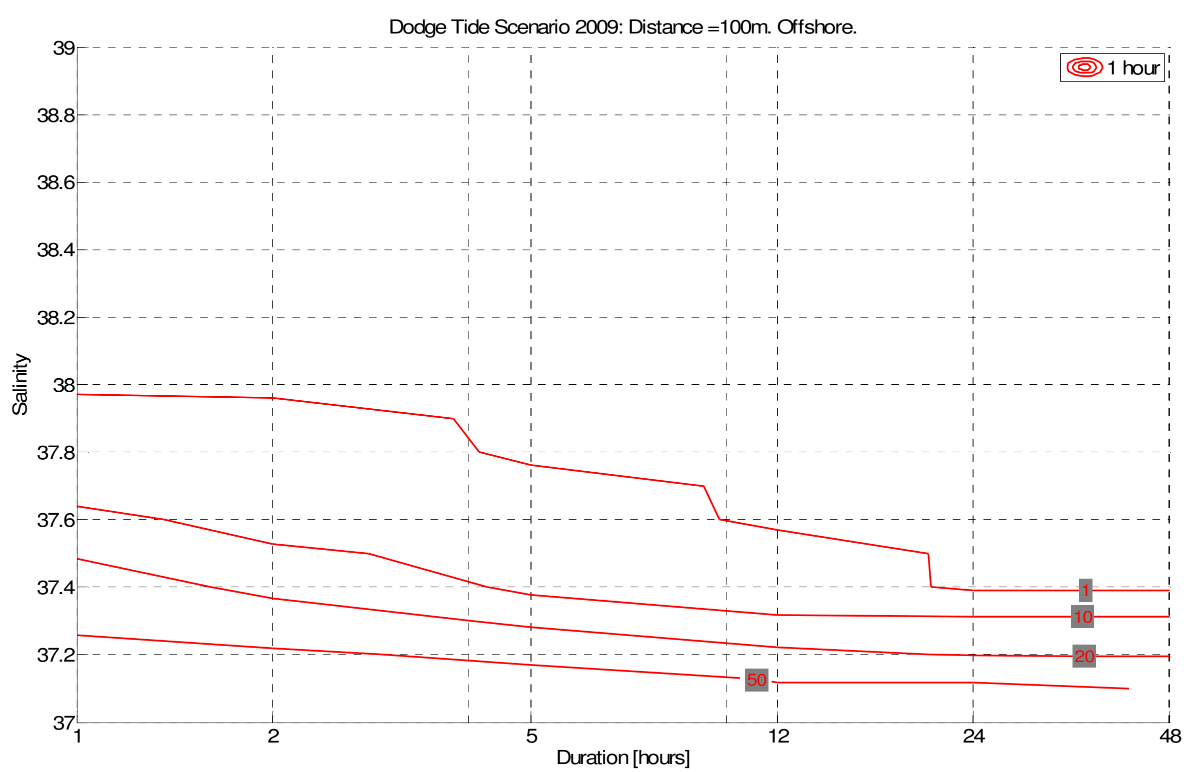
((Left) Figure 45 (Pattiaratchi, 2008) 250m long reference design diffuser, spring tides, (Right) Adelaide Aqua design diffuser, 6 week ambient scenario)

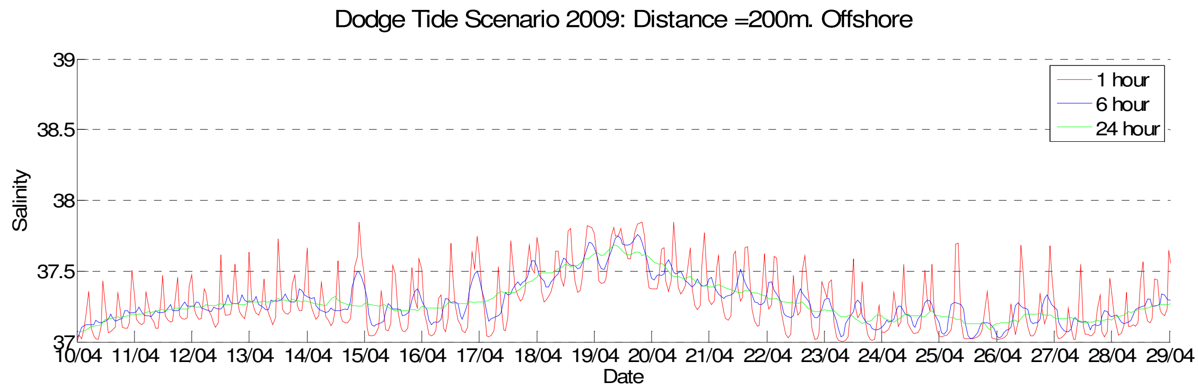

EIS, Six Week Ambient Scenario: Intake Excess Salinity
Salinity (ppt)
39
38.5
38
37.5
37
01/05
06/05
11/05
16/05
21/05
26/05
31/05
05/06
10/06
15/06
Date

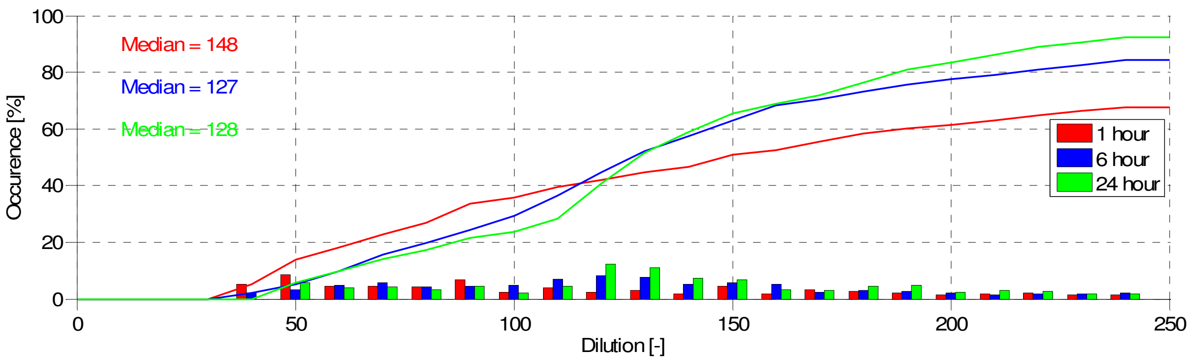
APPENDIX D – AMBIENT SCENARIO 2 (WORST CASE 3 DAY DODGE TIDE SCENARIO) AND OUTFALL SCENARIO 1 (100% @ 48.5%)

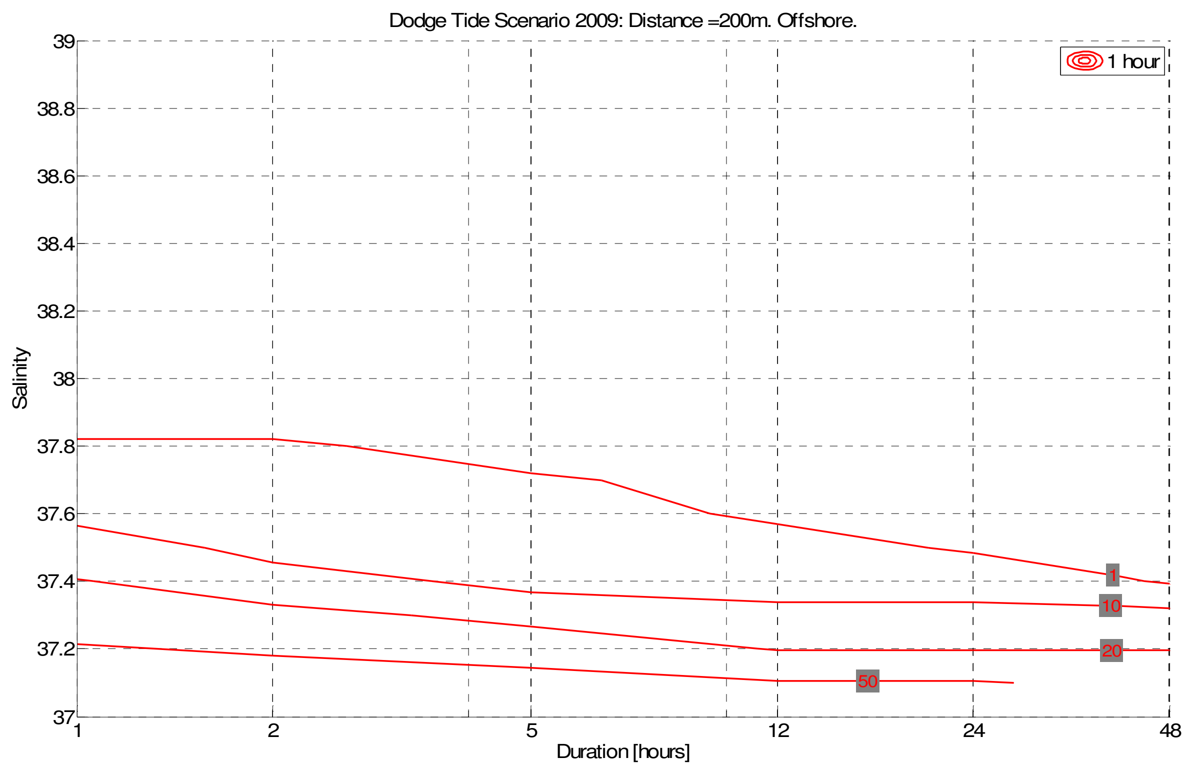


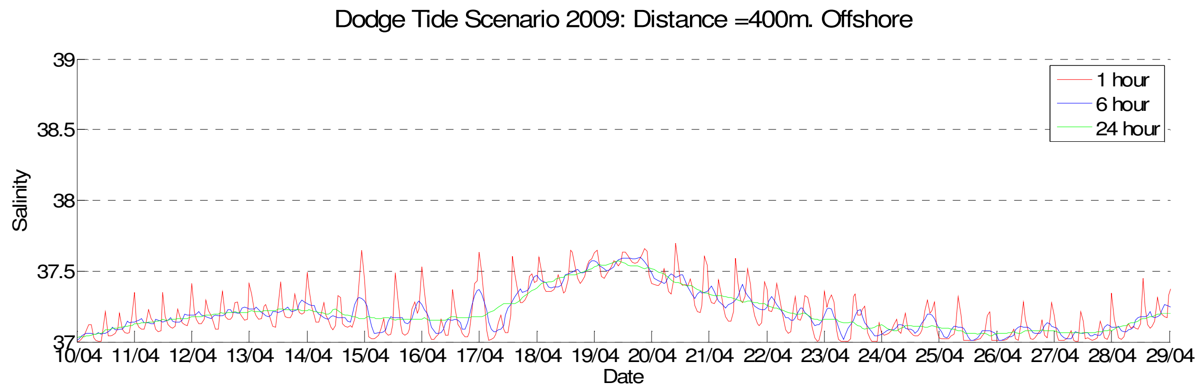


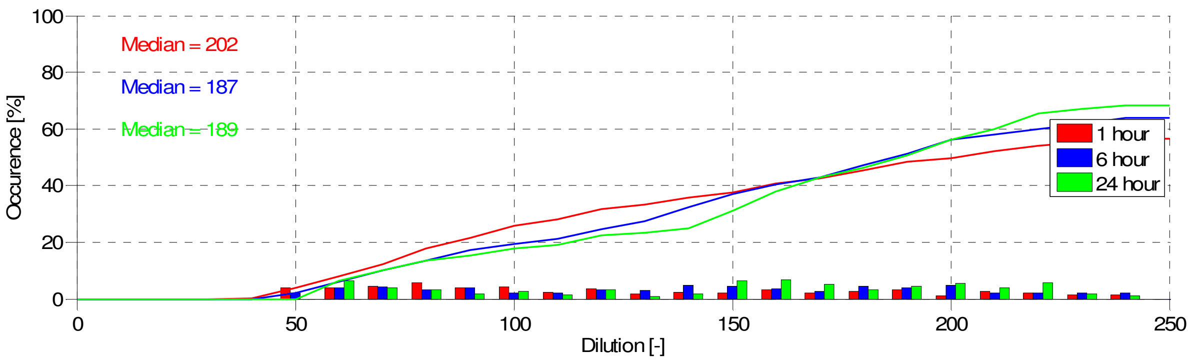


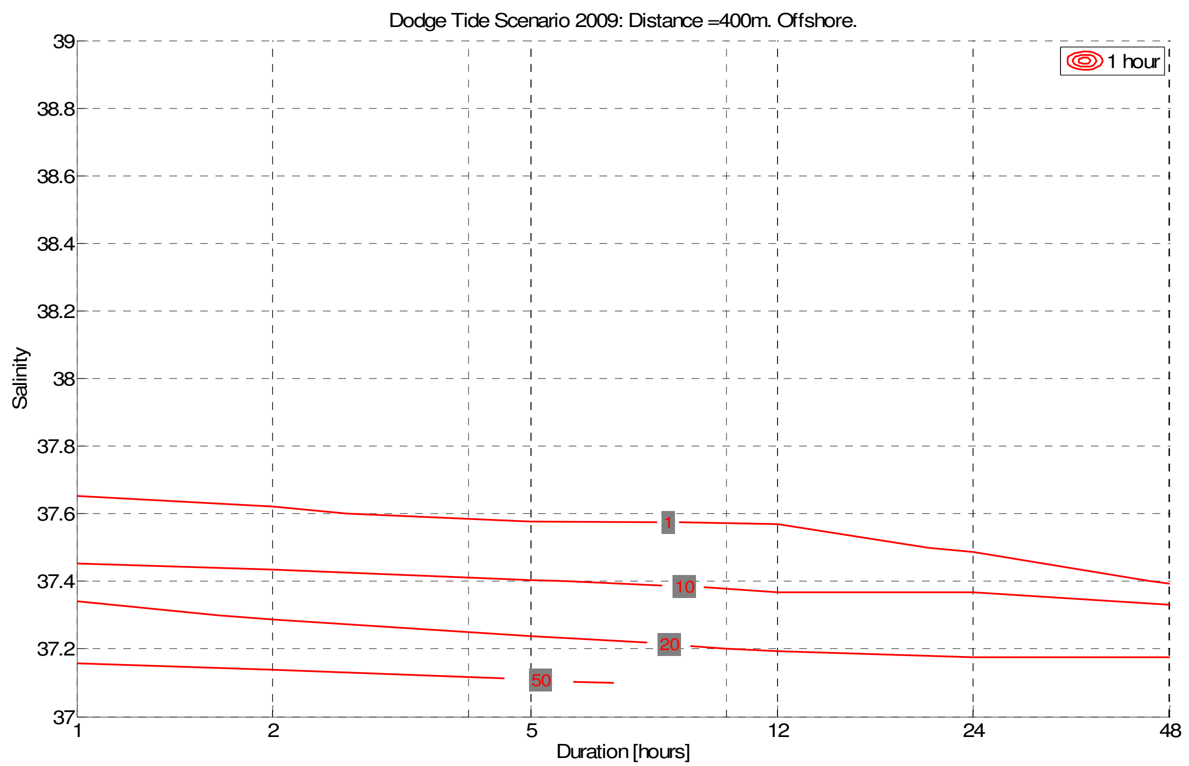

Dodge Tide Scenario 2009: Distance =200m. Offshore
1 hour
6 hour
24 hour
Salinity
Date
10/04 11/04 12/04 13/04 14/04 15/04 16/04 17/04 18/04 19/04 20/04 21/04 22/04 23/04 24/04 25/04 26/04 27/04 28/04 29/04


Median = 148
Median = 127
Median = 128
1 hour
6 hour
24 hour
Occurence [%]
Dilution [-]

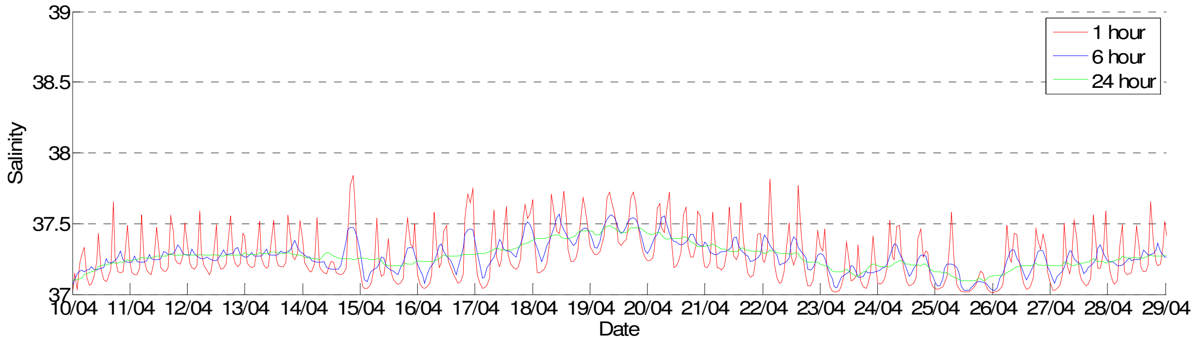

Dodge Tide Scenario 2009: Distance =200m. Offshore.
1 hour
Salinity
Duration [hours]
1
10
20
50

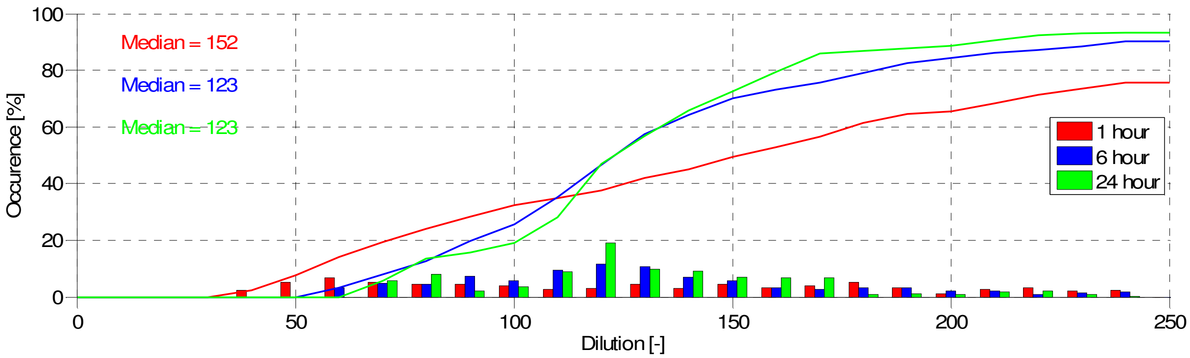

Dodge Tide Scenario 2009: Distance =400m. Offshore
1 hour
6 hour
24 hour
Salinity
39
38.5
38
37.5
37
10/04 11/04 12/04 13/04 14/04 15/04 16/04 17/04 18/04 19/04 20/04 21/04 22/04 23/04 24/04 25/04 26/04 27/04 28/04 29/04
Date


Median = 202
Median = 187
Median = 189
1 hour
6 hour
24 hour
Occurence [%]
100
80
60
40
20
0
0
50
100
150
200
250
Dilution [-]

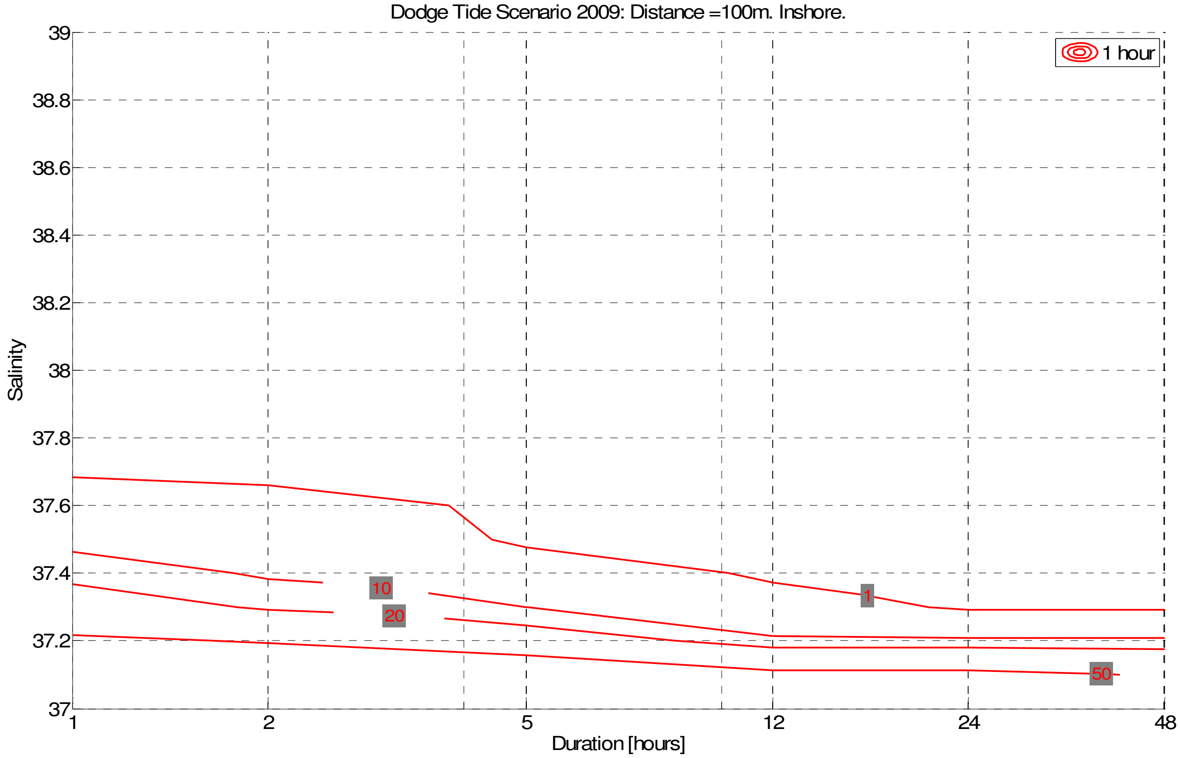

Dodge Tide Scenario 2009: Distance =400m. Offshore.
1 hour
Salinity
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1
10
20
50
1
2
5
12
24
48
Duration [hours]

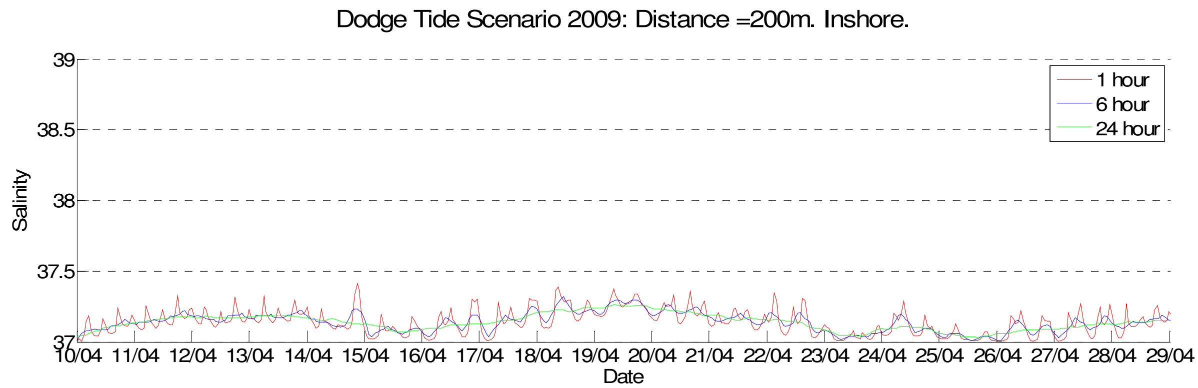
Dodge Tide Scenario 2009: Distance =100m. Inshore.

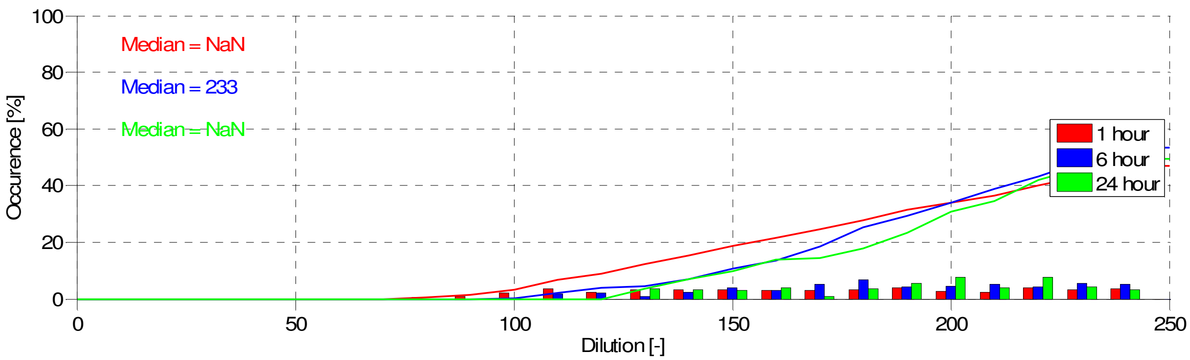


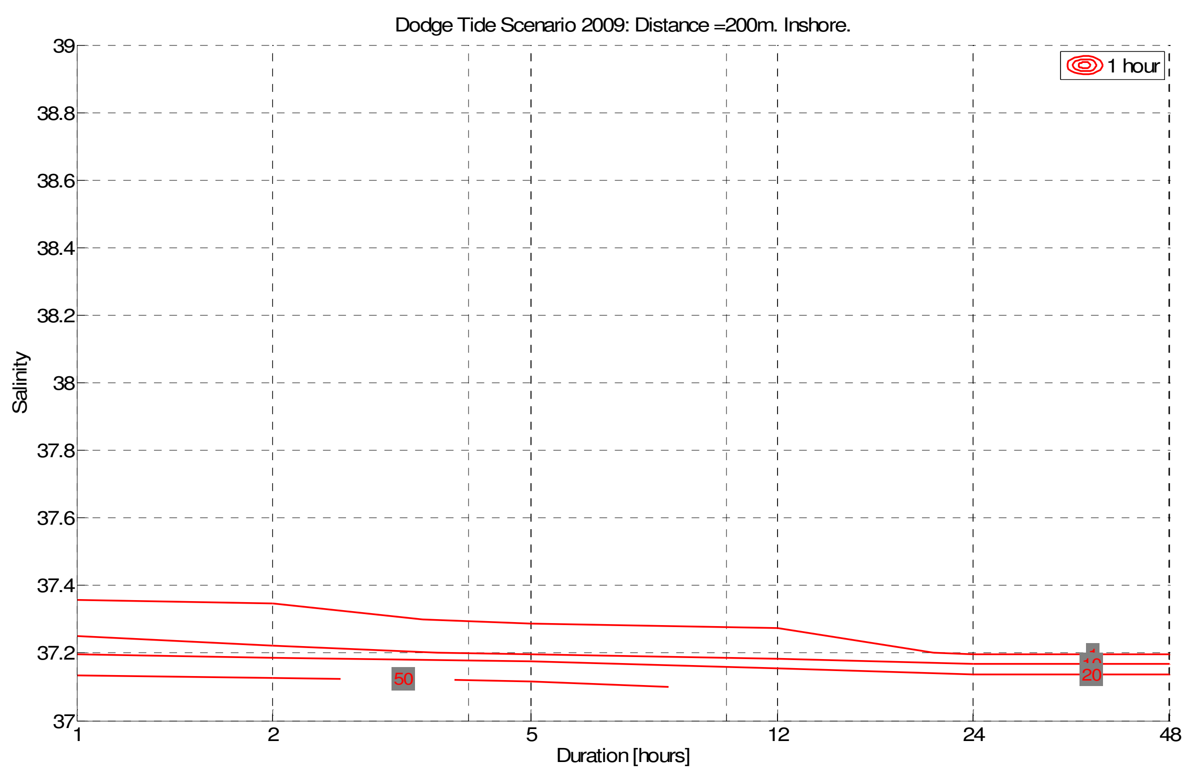


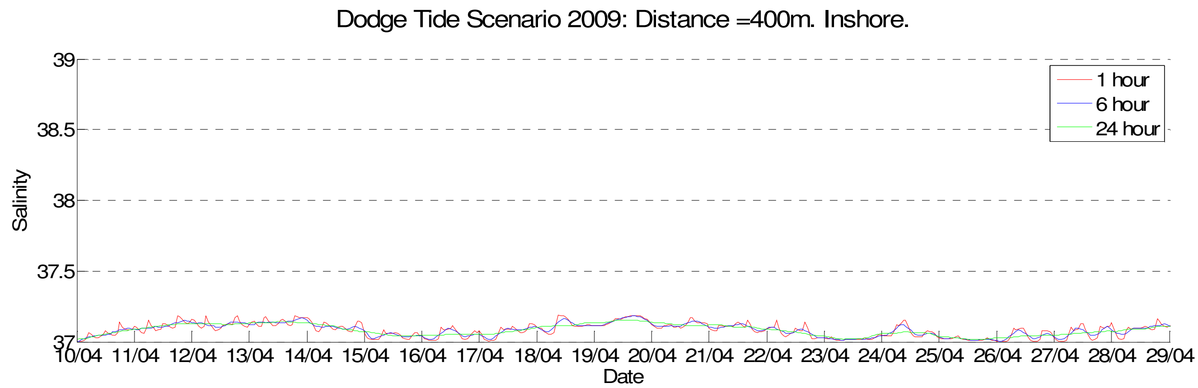
Dodge Tide Scenario 2009: Distance =100m. Inshore.

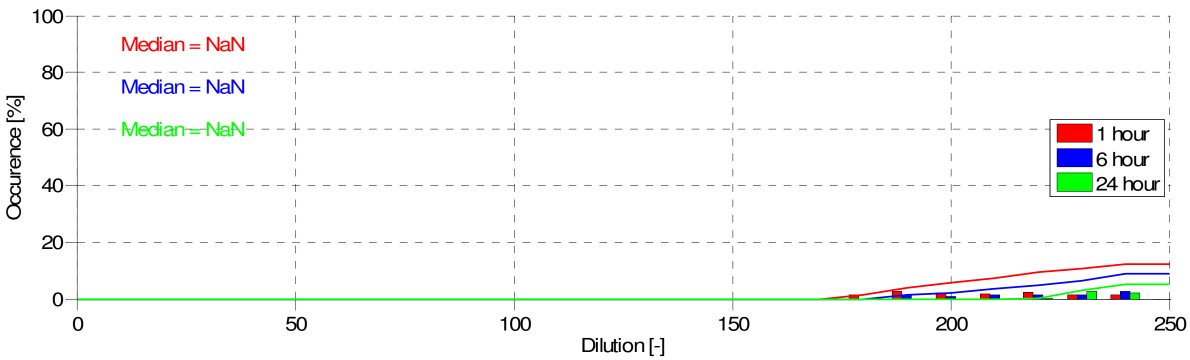


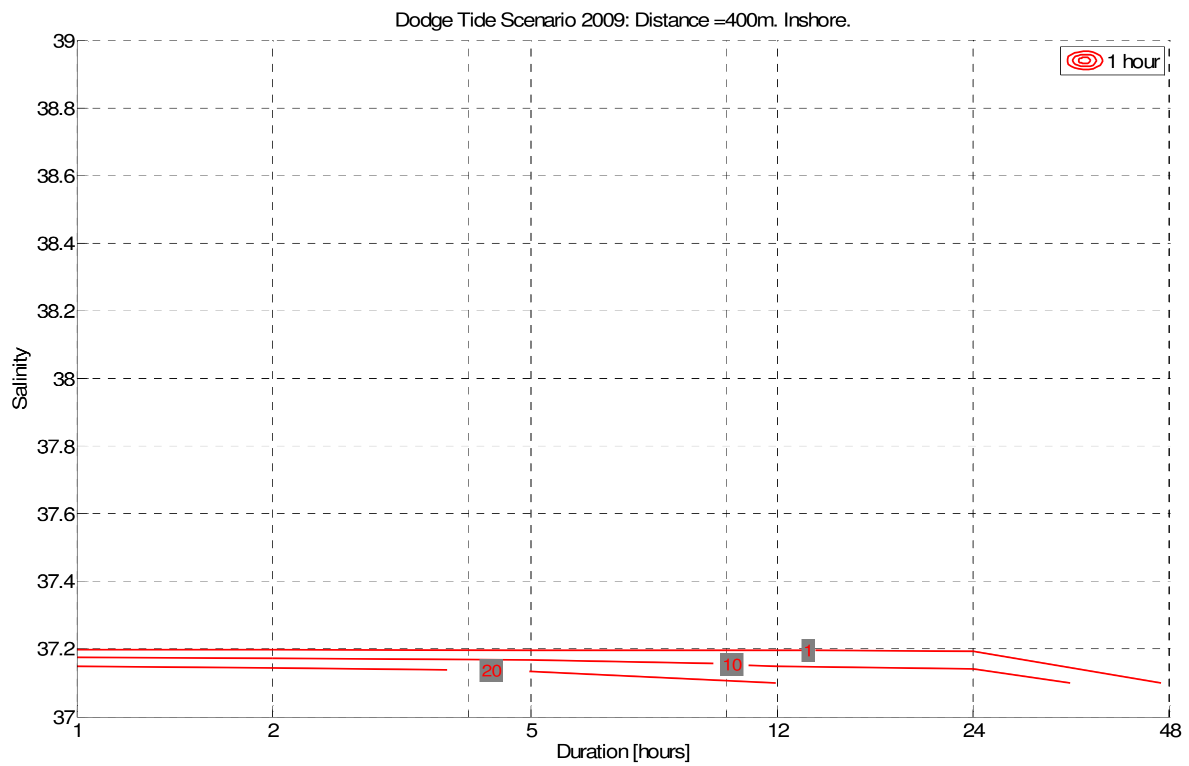

Dodge Tide Scenario 2009: Distance =200m. Inshore.
1 hour
6 hour
24 hour
Salinity
Date
39
38.5
38
37.5
37
10/04 11/04 12/04 13/04 14/04 15/04 16/04 17/04 18/04 19/04 20/04 21/04 22/04 23/04 24/04 25/04 26/04 27/04 28/04 29/04

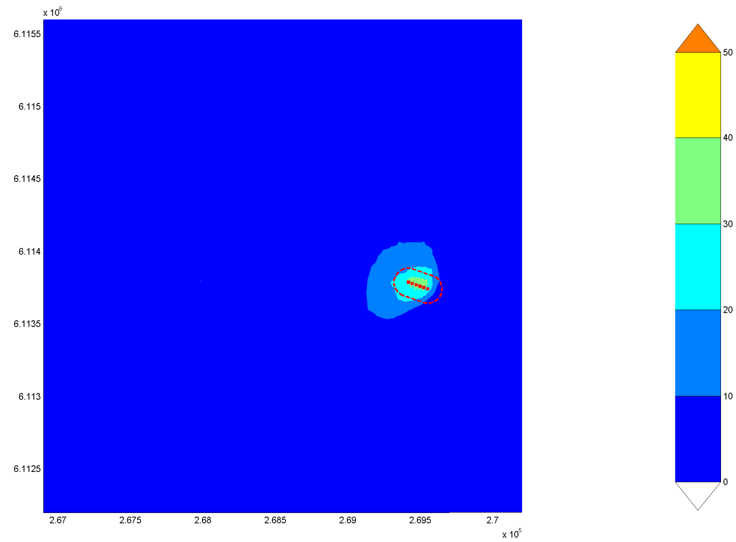

Median = NaN
Median = 233
Median = NaN
1 hour
6 hour
24 hour
Occurence [%]
Dilution [-]
100
80
60
40
20
0
0 50 100 150 200 250


Dodge Tide Scenario 2009: Distance =200m. Inshore.
1 hour
Salinity
Duration [hours]
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1 2 5 12 24 48
50
20

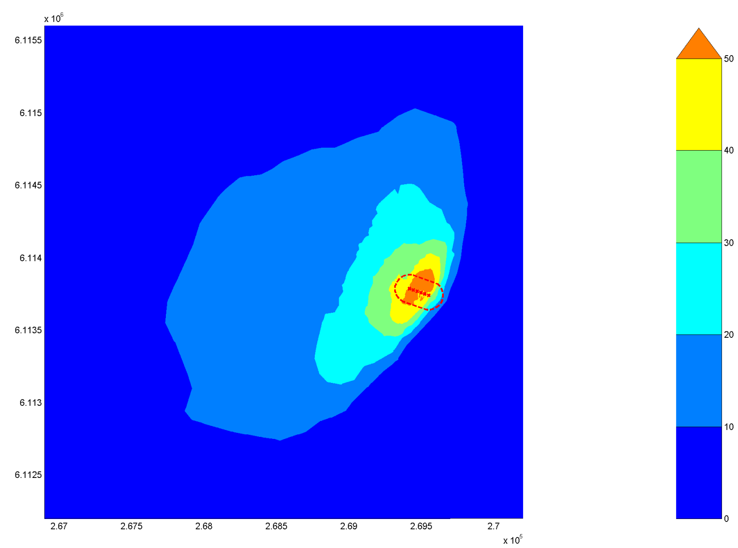

Dodge Tide Scenario 2009: Distance =400m. Inshore.
1 hour
6 hour
24 hour
Salinity
39
38.5
38
37.5
37
10/04 11/04 12/04 13/04 14/04 15/04 16/04 17/04 18/04 19/04 20/04 21/04 22/04 23/04 24/04 25/04 26/04 27/04 28/04 29/04
Date


Median = NaN
Median = NaN
Median = NaN
1 hour
6 hour
24 hour
Occurence [%]
100
80
60
40
20
0
0
50
100
150
200
250
Dilution [-]

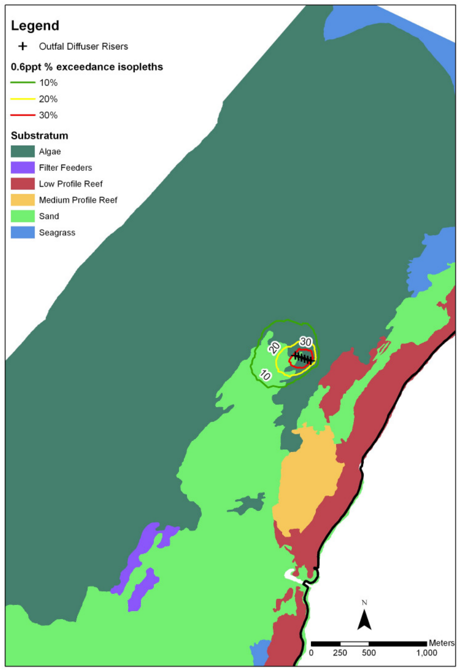

Dodge Tide Scenario 2009: Distance =400m. Inshore.
1 hour
Salinity
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
20
10
1
1
2
5
12
24
48
Duration [hours]



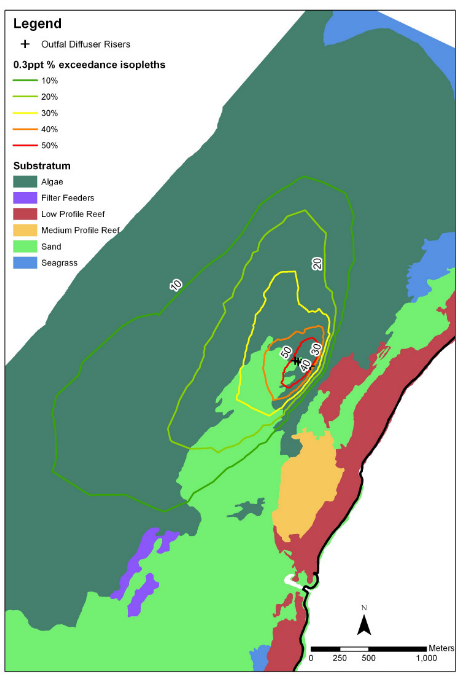
Percentage exceedance of the 0.6ppt salinity isopleth at the bed. Dashed red oval is a 100m distance around outfall provided for scale. Contour intervals are reported at the 10, 20, 30, 40 and 50th%



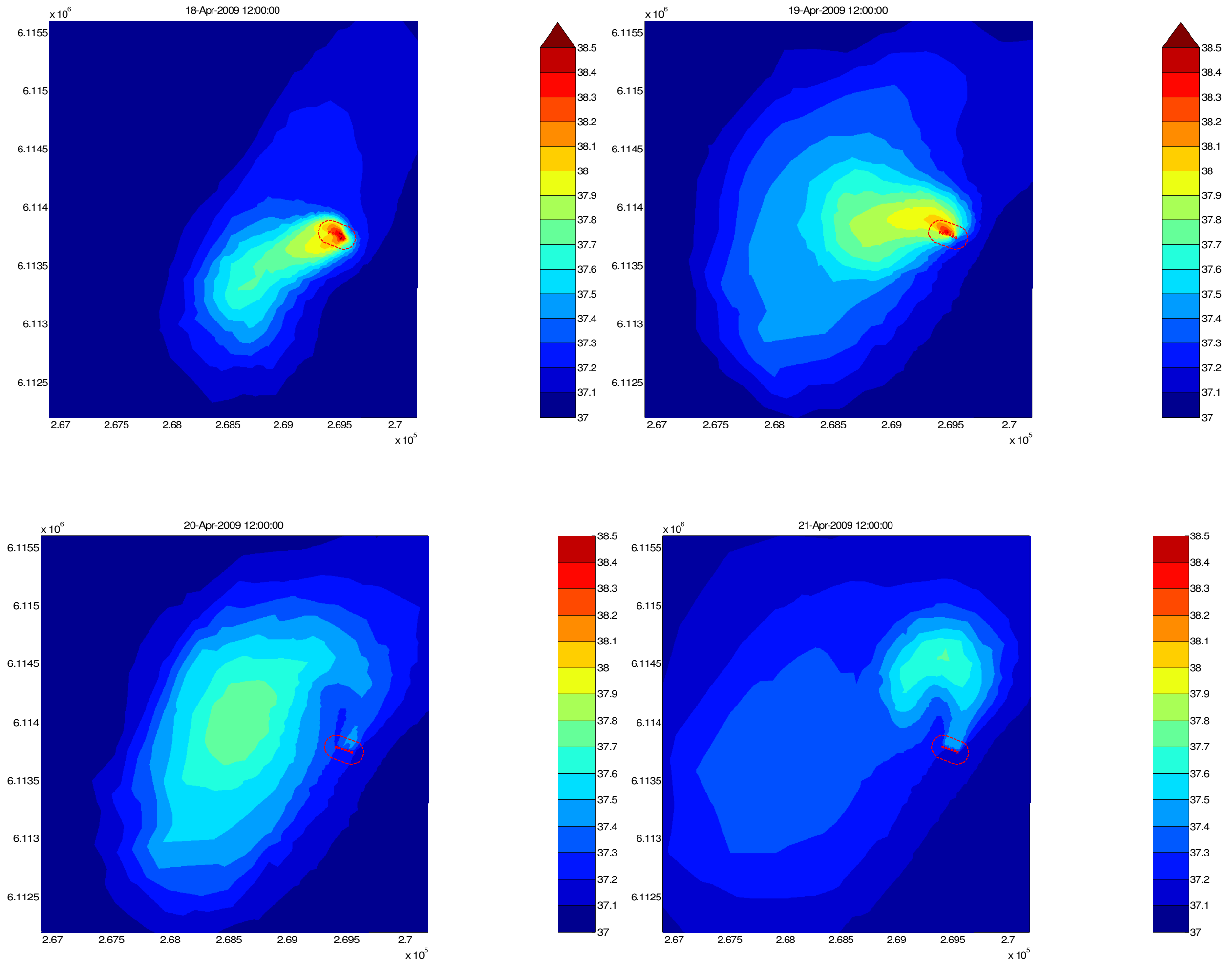
Percentage exceedance of the 0.3ppt salinity isopleth at the bed. Dashed red oval is a 100m distance around outfall provided for scale. Contour intervals are reported at the 10, 20, 30, 40 and 50th%



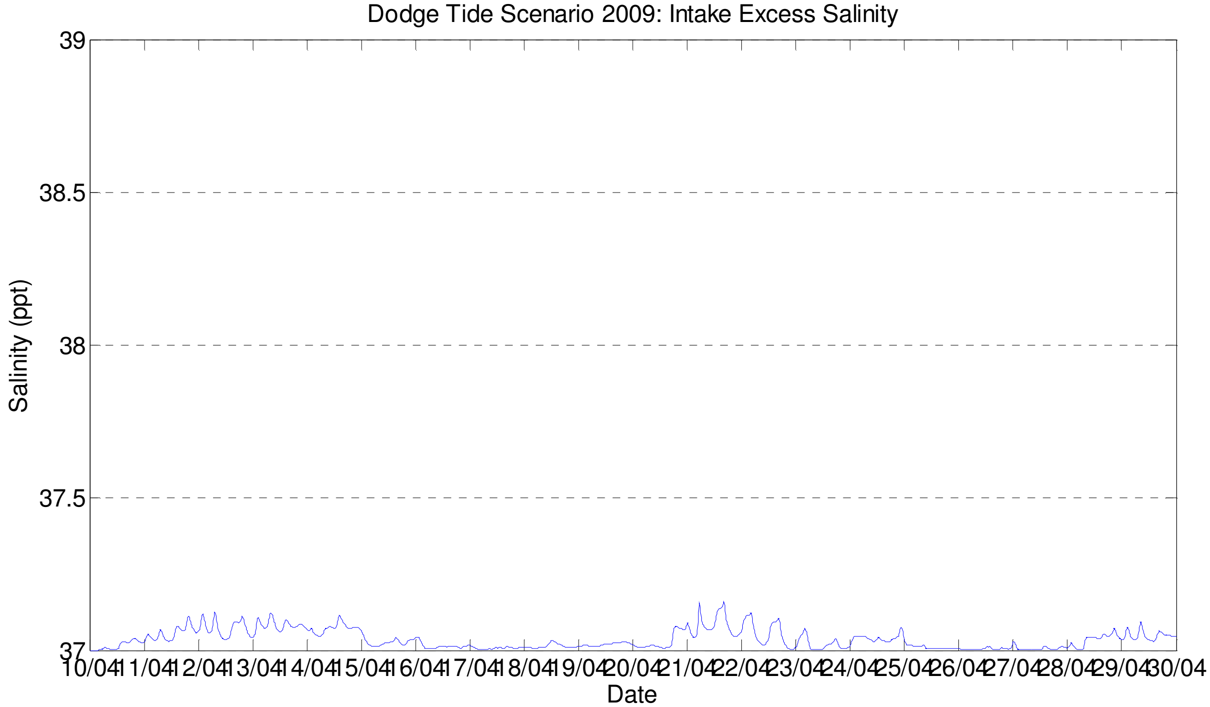
Percentage exceedance of 0.6ppt salinity isopleths at the bed relative to substratum type. Contour intervals are reported at the 10, 20, 30, 40 and 50th%



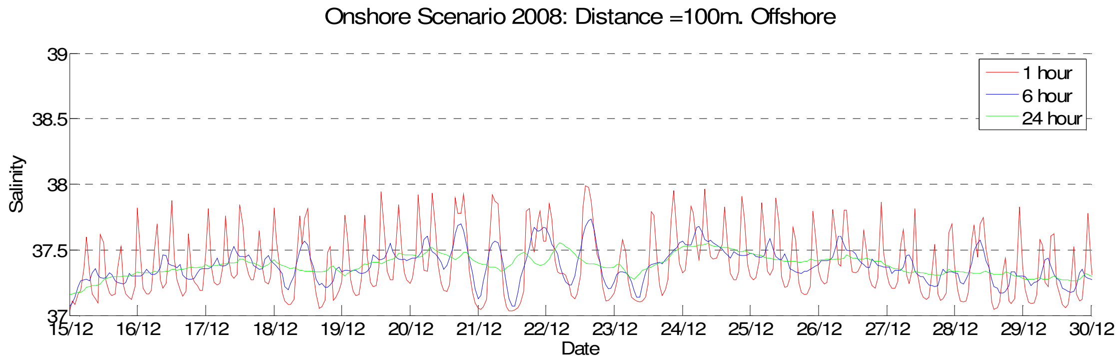
Percentage exceedance of 0.3ppt salinity isopleths at the bed relative to substratum type. Contour intervals are reported at the 10, 20, 30, 40 and 50th%

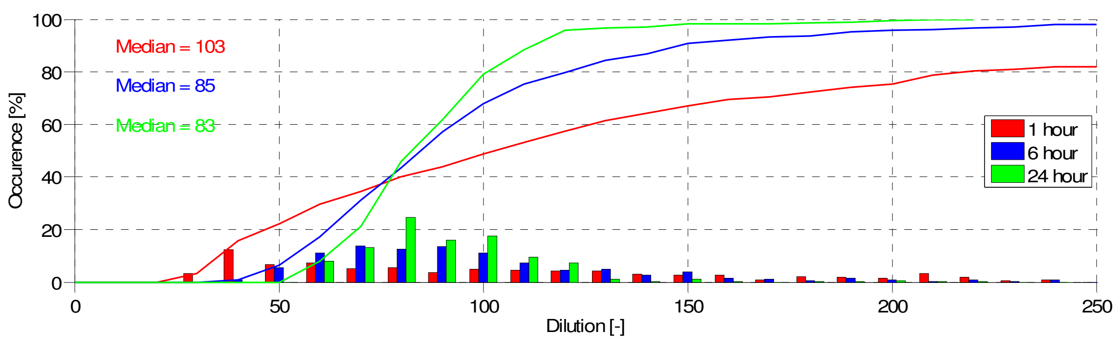


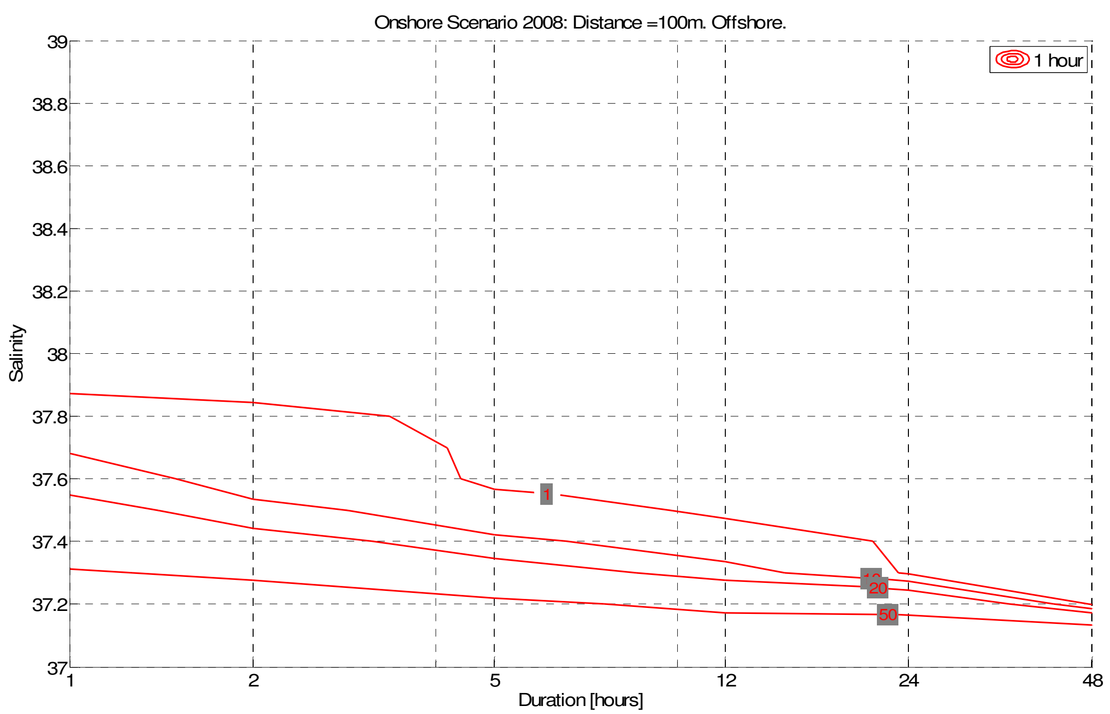
24 hr instantaneous salinity (ppt) isopleths over the worst case dodge tide (18th – 21st April 2009). Dashed red oval is a 100m distance around outfall provided for scale. Contour intervals are reported at 0.1ppt increments

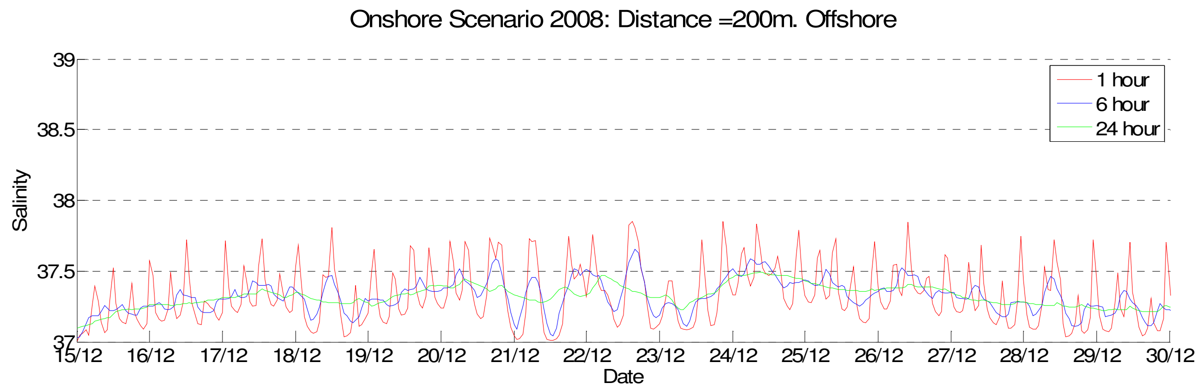

Dodge Tide Scenario 2009: Intake Excess Salinity
39
38.5
38
37.5
37
Salinity (ppt)
10/04
11/04
12/04
13/04
14/04
15/04
16/04
17/04
18/04
19/04
20/04
21/04
22/04
23/04
24/04
25/04
26/04
27/04
28/04
29/04
30/04
Date

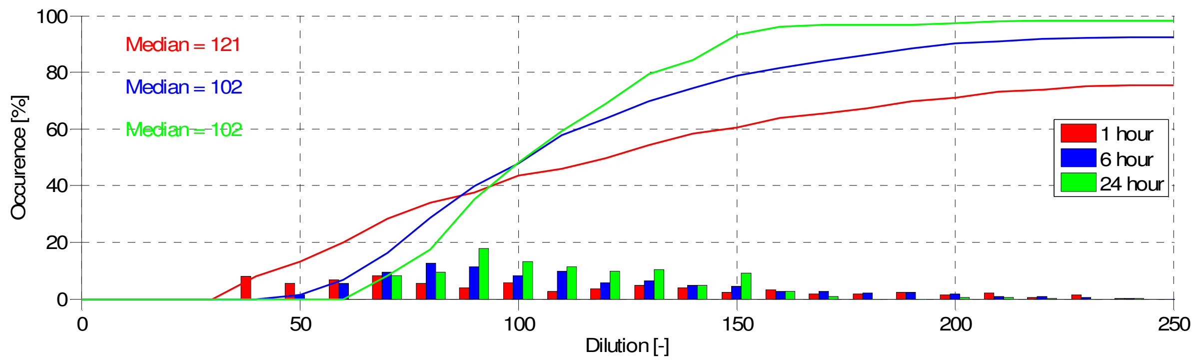
APPENDIX E – AMBIENT SCENARIO 3 (UPWELLING SCENARIO) AND OUTFALL SCENARIO 1 (100% @ 48.5%)

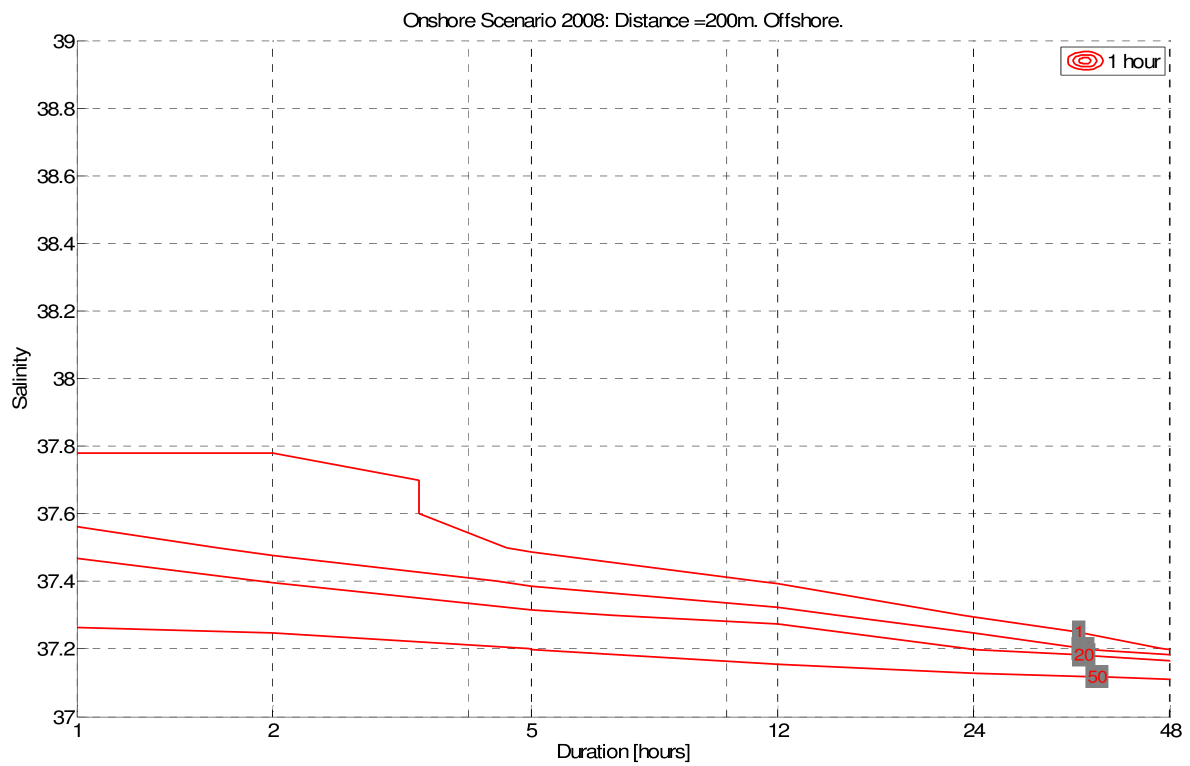


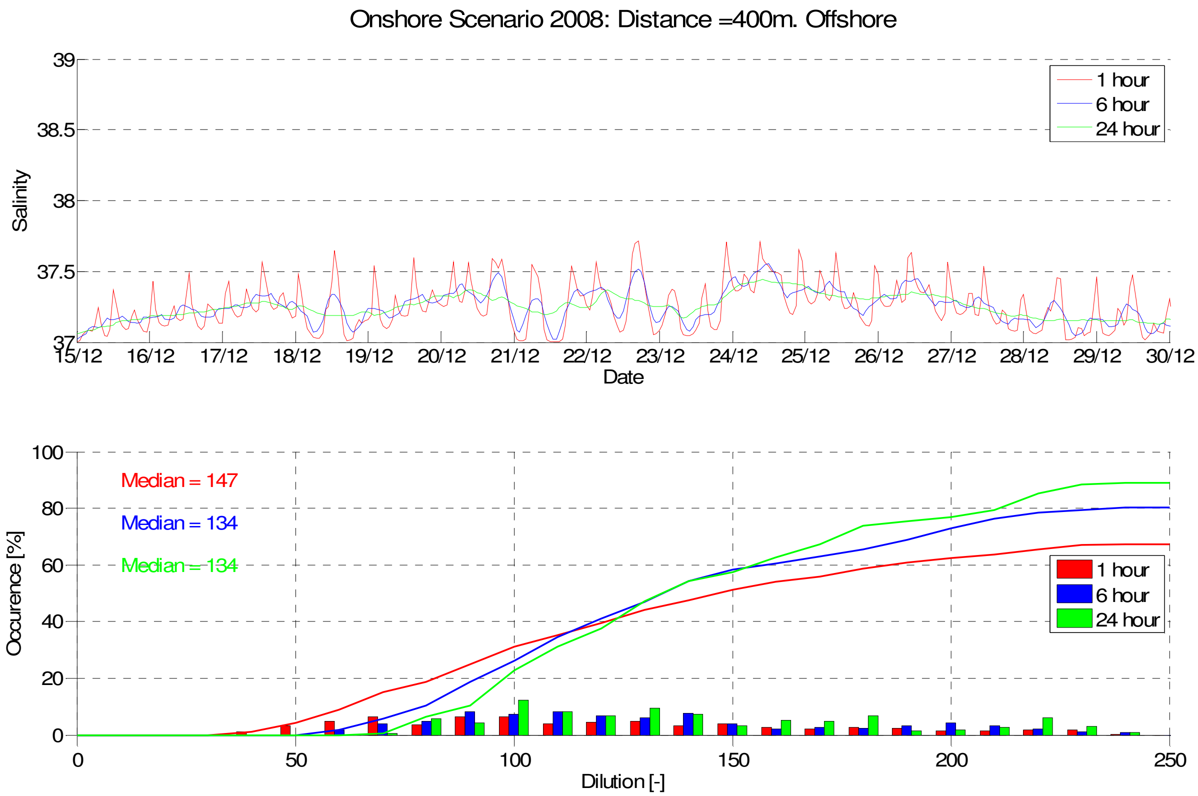


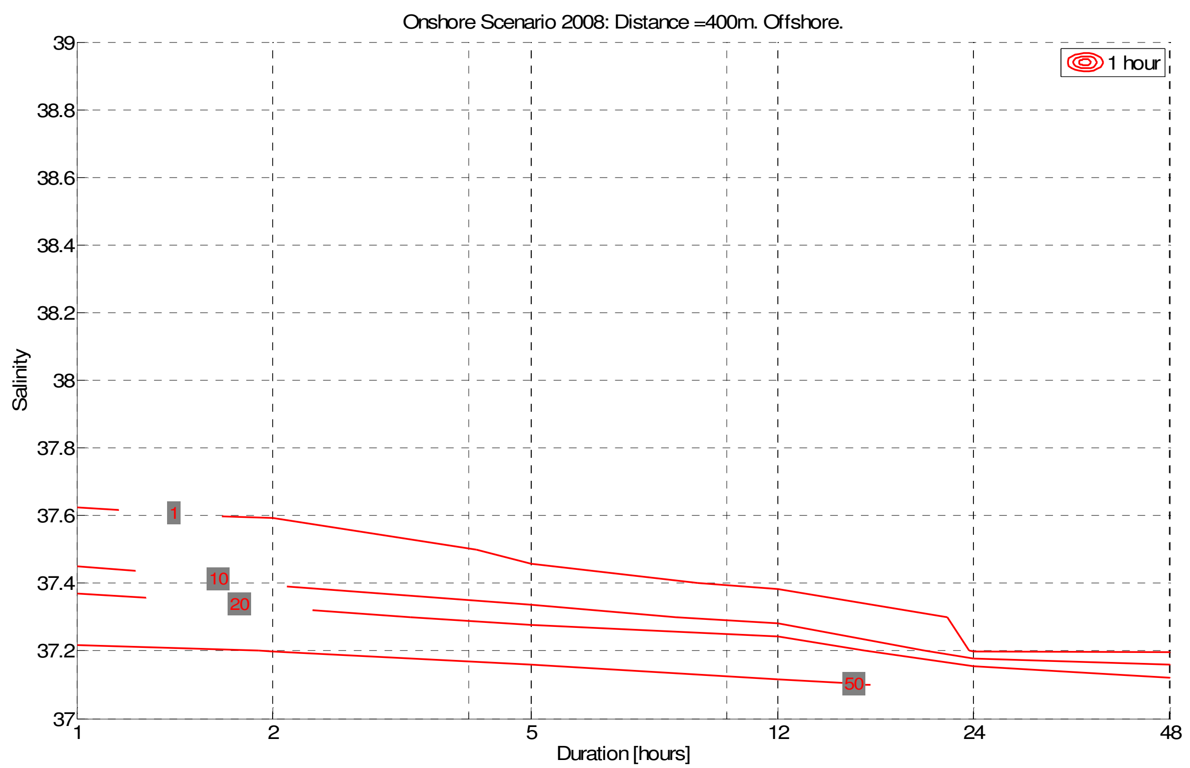


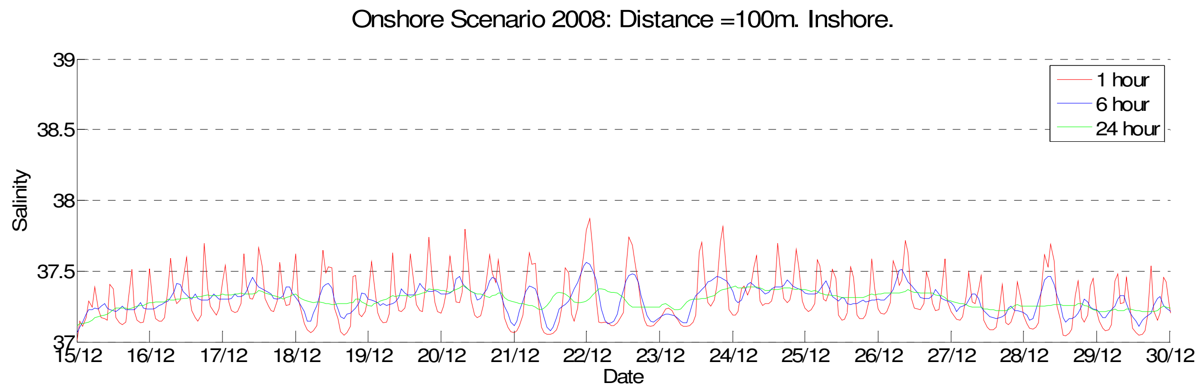

Onshore Scenario 2008: Distance =200m. Offshore
Salinity
Date
1 hour
6 hour
24 hour
39
38.5
38
37.5
37
15/12
16/12
17/12
18/12
19/12
20/12
21/12
22/12
23/12
24/12
25/12
26/12
27/12
28/12
29/12
30/12

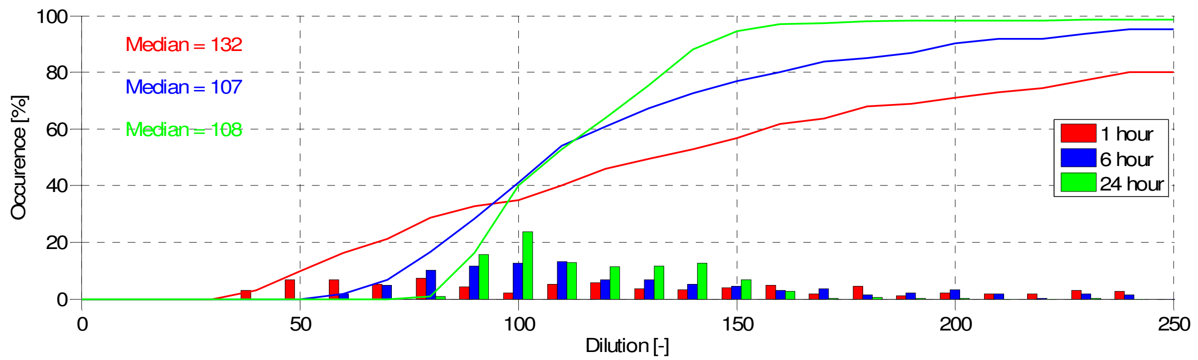

Median = 121
Median = 102
Median = 102
Occurence [%]
Dilution [-]
1 hour
6 hour
24 hour
100
80
60
40
20
0
0
50
100
150
200
250

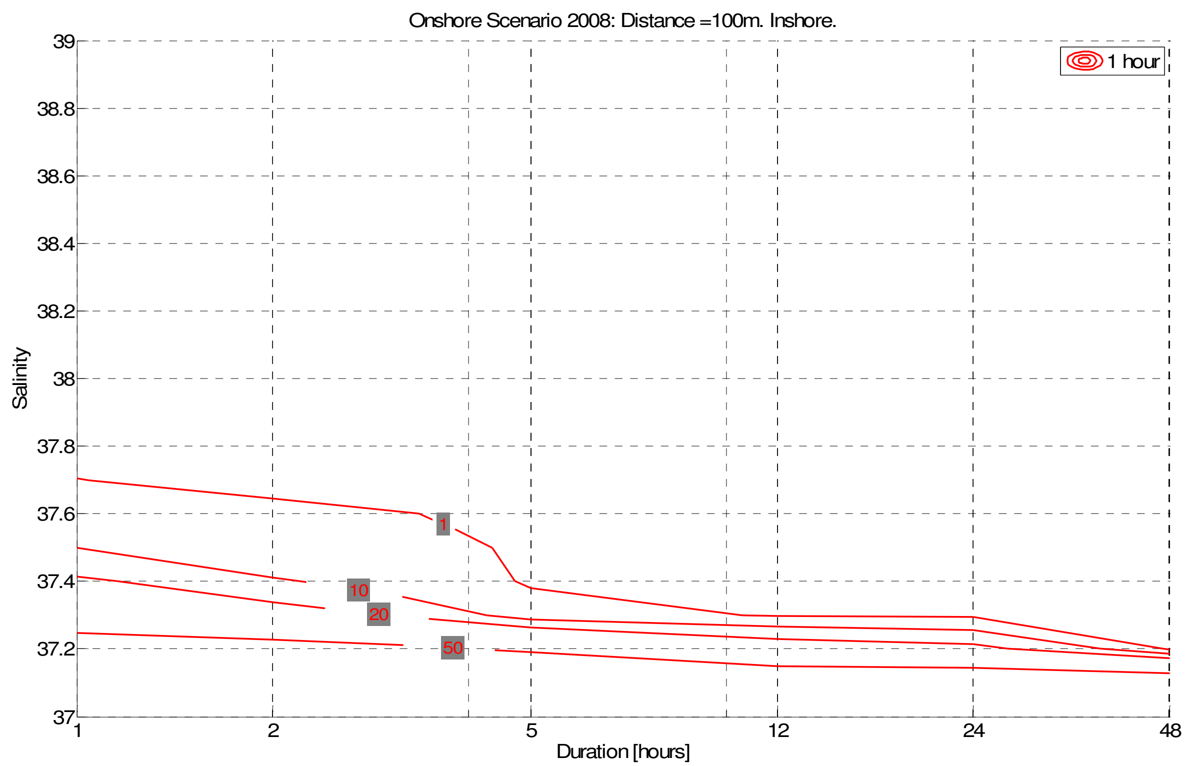

Onshore Scenario 2008: Distance =200m. Offshore.
1 hour
Salinity
Duration [hours]
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1
2
5
12
24
48
1
20
50

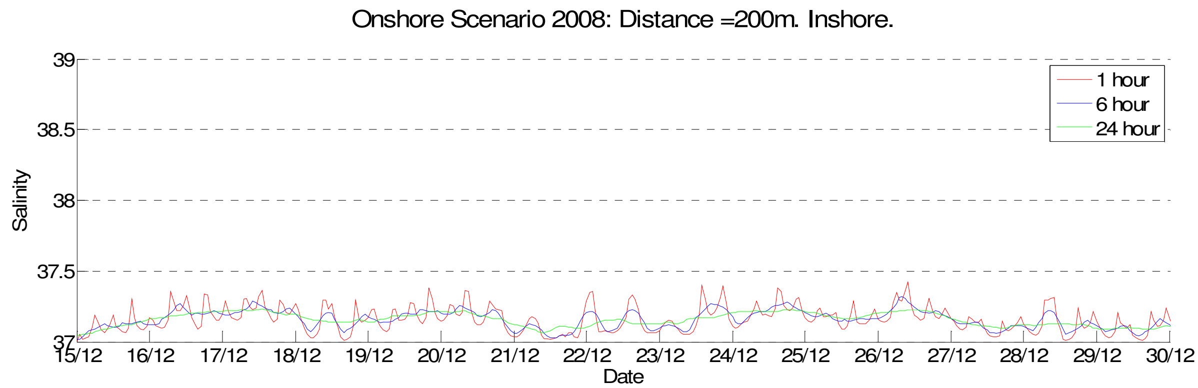

Onshore Scenario 2008: Distance =400m. Offshore
Salinity
Date
1 hour
6 hour
24 hour
15/12
16/12
17/12
18/12
19/12
20/12
21/12
22/12
23/12
24/12
25/12
26/12
27/12
28/12
29/12
30/12
Median = 147
Median = 134
Median = 134
Occurence [%]
Dilution [-]

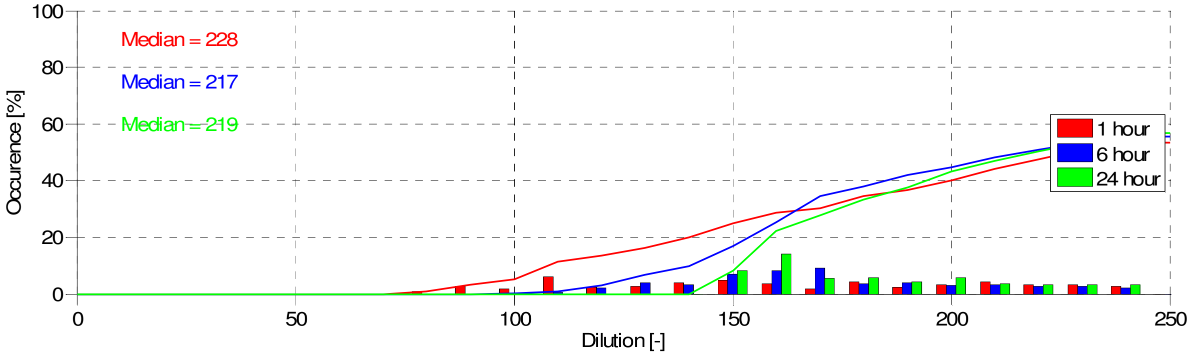

Onshore Scenario 2008: Distance =400m. Offshore.
1 hour
Salinity
Duration [hours]
1
10
20
50

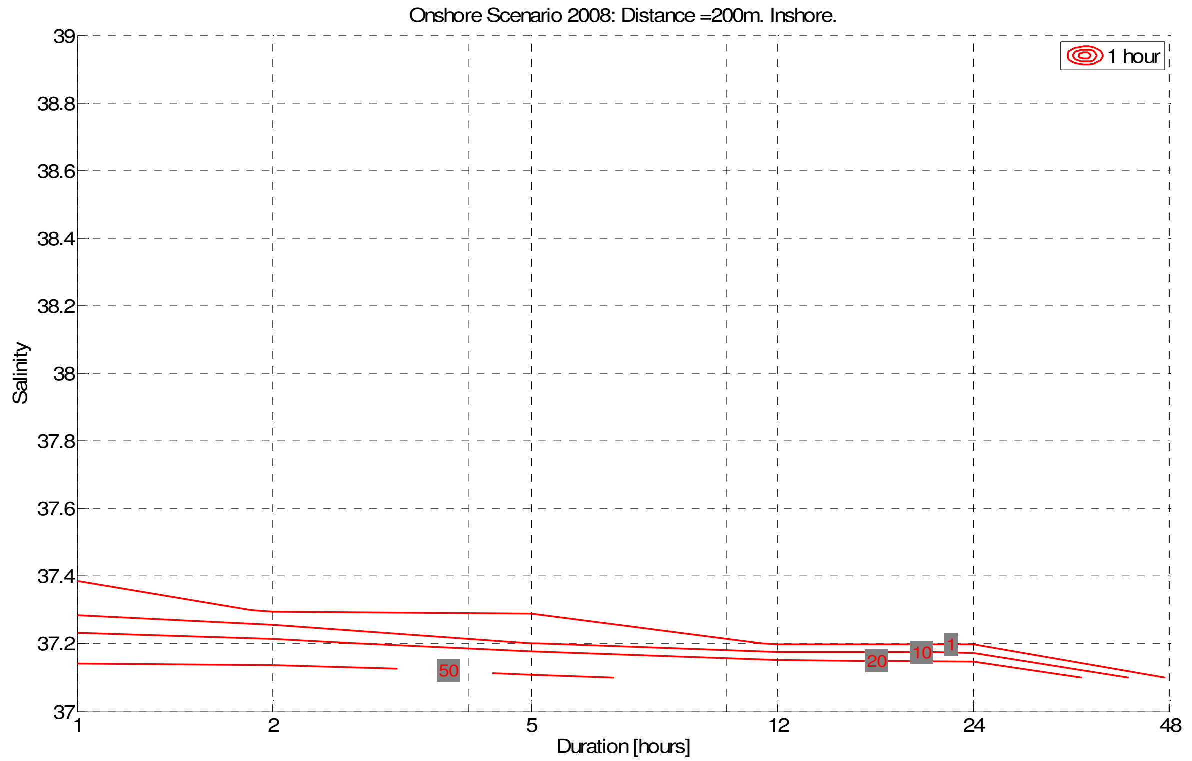

Onshore Scenario 2008: Distance =100m. Inshore.
1 hour
6 hour
24 hour
Salinity
39
38.5
38
37.5
37
15/12
16/12
17/12
18/12
19/12
20/12
21/12
22/12
23/12
24/12
25/12
26/12
27/12
28/12
29/12
30/12
Date

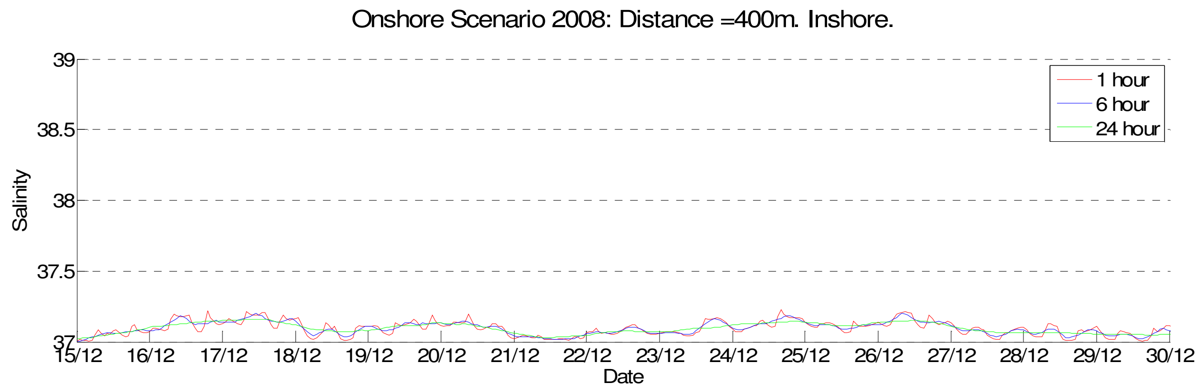

Median = 132
Median = 107
Median = 108
1 hour
6 hour
24 hour
Occurence [%]
100
80
60
40
20
0
50
100
150
200
250
Dilution [-]

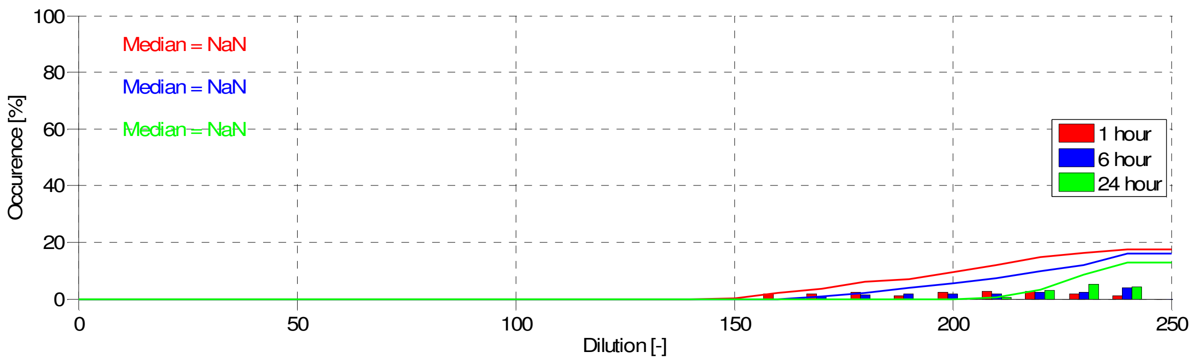

Onshore Scenario 2008: Distance =100m. Inshore.
1 hour
Salinity
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1
10
20
50
1
2
5
12
24
48
Duration [hours]

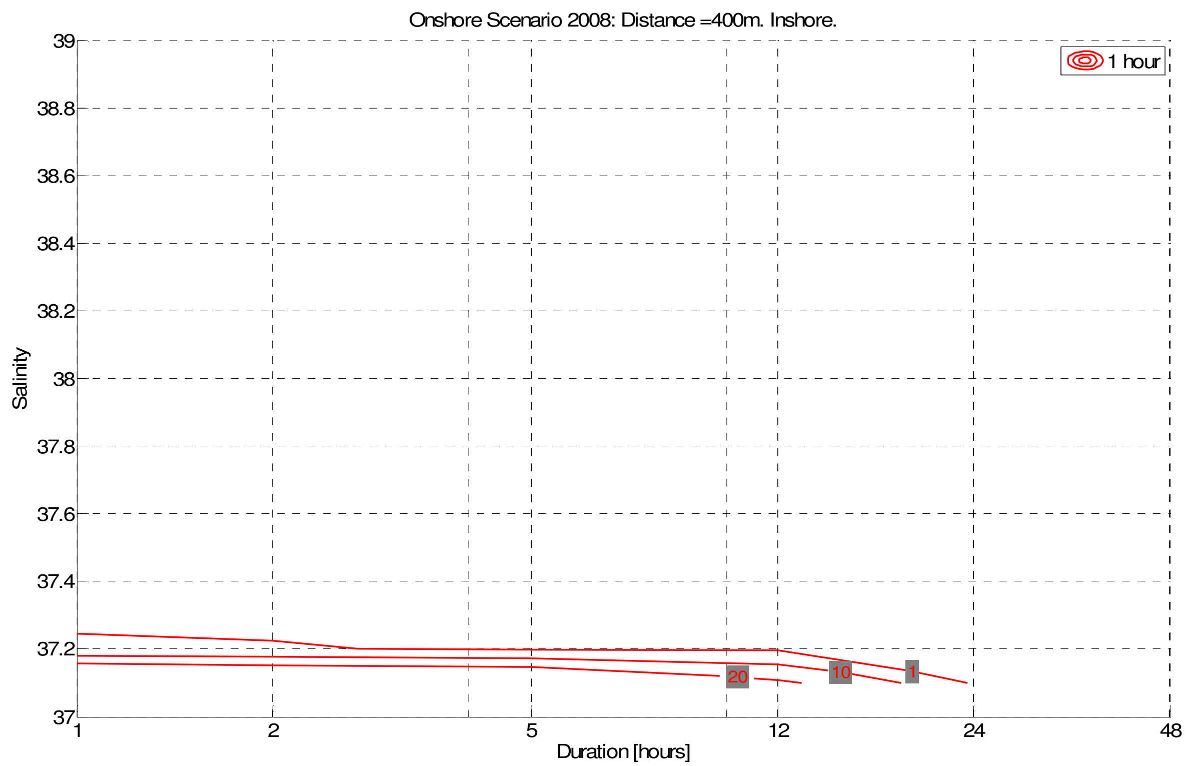

Onshore Scenario 2008: Distance =200m. Inshore.
Salinity
Date
1 hour
6 hour
24 hour
39
38.5
38
37.5
37
15/12
16/12
17/12
18/12
19/12
20/12
21/12
22/12
23/12
24/12
25/12
26/12
27/12
28/12
29/12
30/12

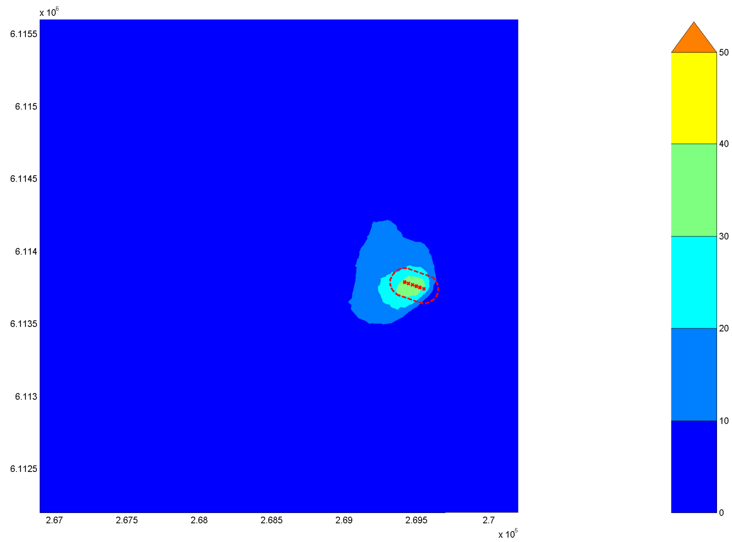

Median = 228
Median = 217
Median = 219
Occurence [%]
Dilution [-]
1 hour
6 hour
24 hour
100
80
60
40
20
0
0
50
100
150
200
250


Onshore Scenario 2008: Distance =200m. Inshore.
Salinity
Duration [hours]
1 hour
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1
2
5
12
24
48
50
20
10
1

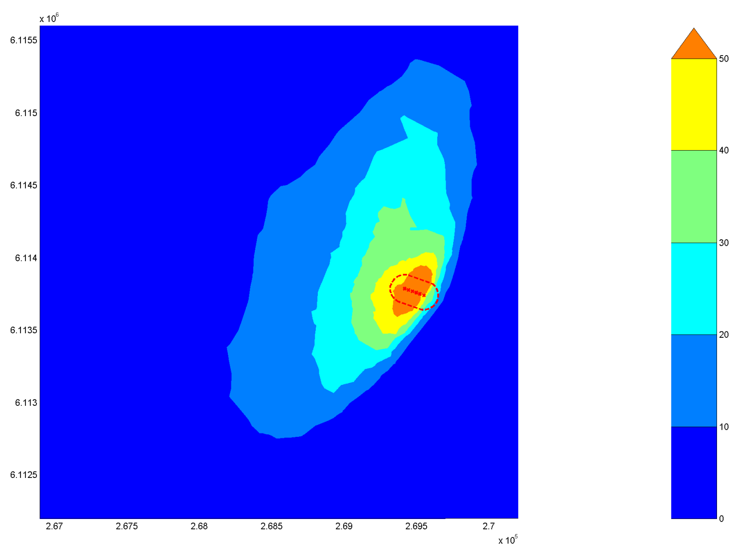

Onshore Scenario 2008: Distance =400m. Inshore.
1 hour
6 hour
24 hour
Salinity
39
38.5
38
37.5
37
15/12 16/12 17/12 18/12 19/12 20/12 21/12 22/12 23/12 24/12 25/12 26/12 27/12 28/12 29/12 30/12
Date


Median = NaN
Median = NaN
Median = NaN
1 hour
6 hour
24 hour
Occurence [%]
100
80
60
40
20
0
0 50 100 150 200 250
Dilution [-]

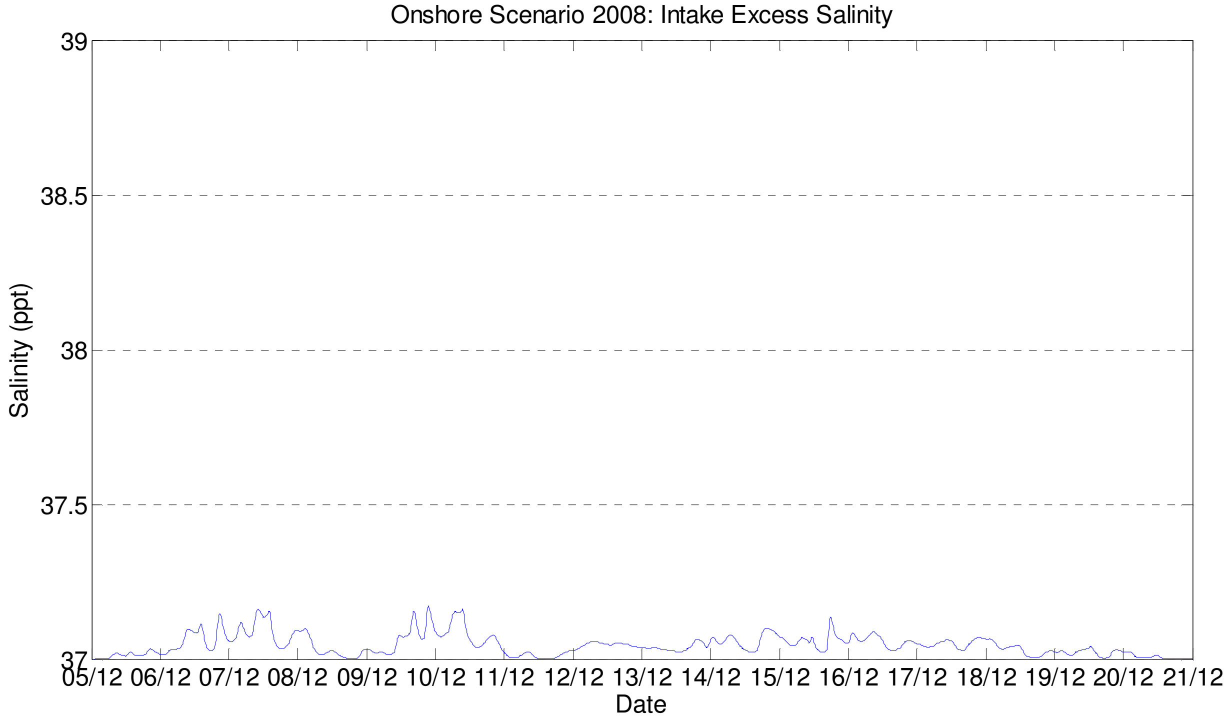

Onshore Scenario 2008: Distance =400m. Inshore.
1 hour
Salinity
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
20
10
1
1 2 5 12 24 48
Duration [hours]



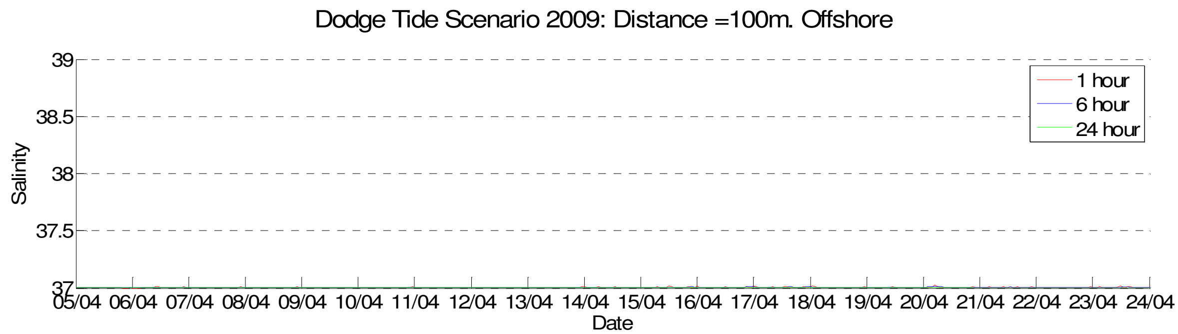
Percentage exceedance of the 0.6ppt salinity isopleth at the bed. Dashed red oval is a 100m distance around outfall provided for scale. Contour intervals are reported at the 10, 20, 30, 40 and 50th%

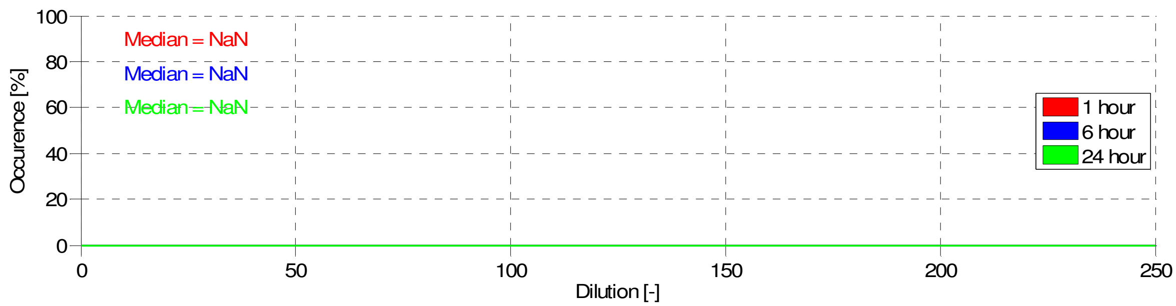


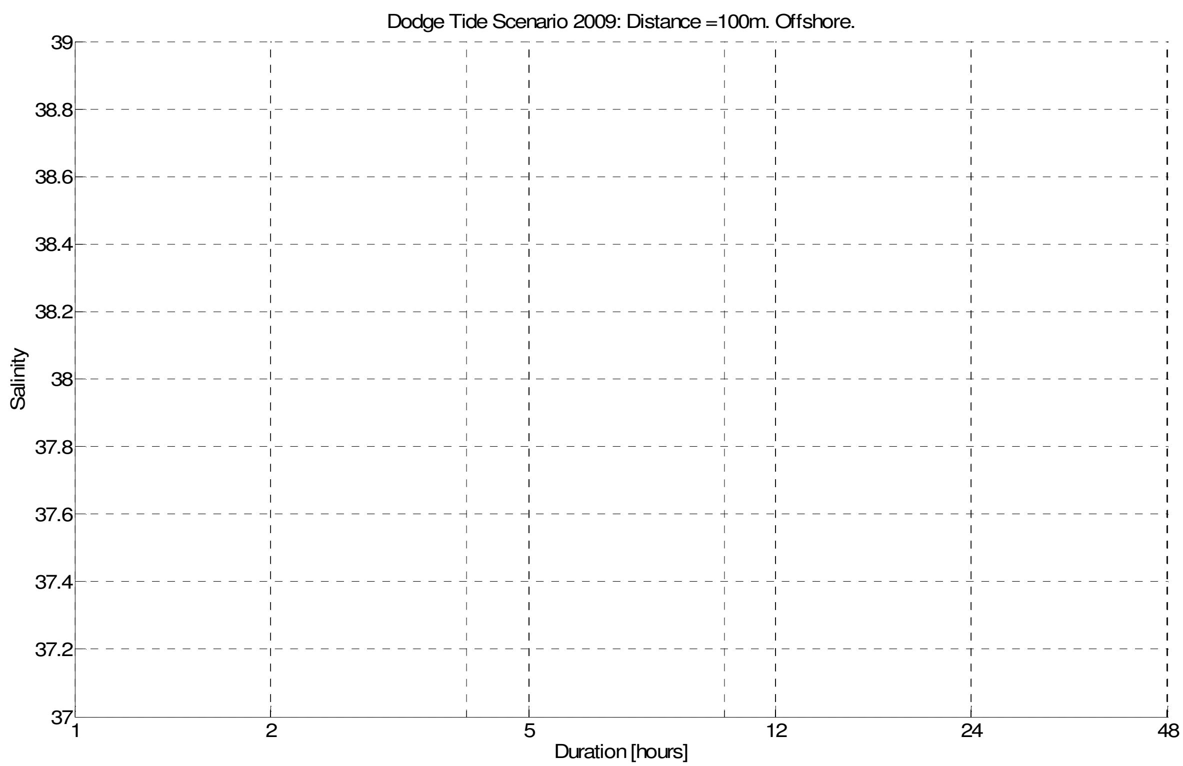
Percentage exceedance of the 0.3ppt salinity isopleth at the bed. Dashed red oval is a 100m distance around outfall provided for scale. Contour intervals are reported at the 10, 20, 30, 40 and 50th%

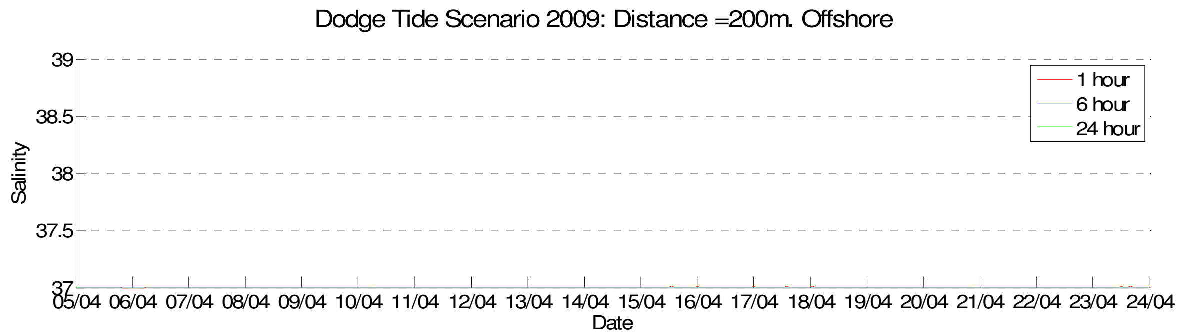

Onshore Scenario 2008: Intake Excess Salinity
39
38.5
38
37.5
37
Salinity (ppt)
05/12 06/12 07/12 08/12 09/12 10/12 11/12 12/12 13/12 14/12 15/12 16/12 17/12 18/12 19/12 20/12 21/12
Date

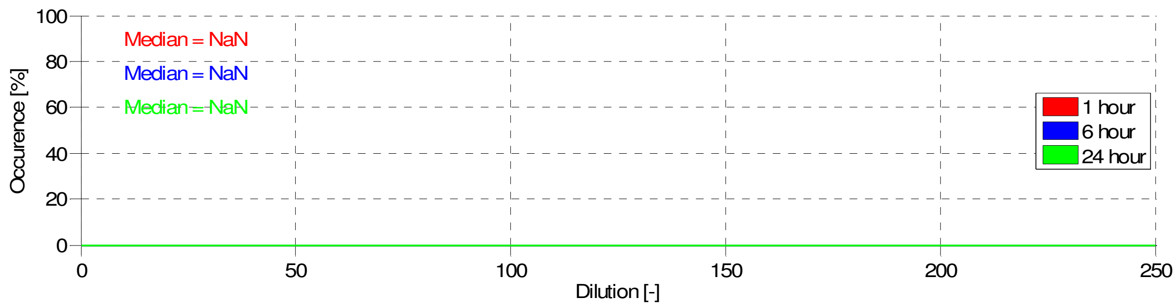
APPENDIX F – AMBIENT SCENARIO 2 (WORST CASE DODGE TIDE) AND OUTFALL SCENARIO 2 (10% @ 48.5%)

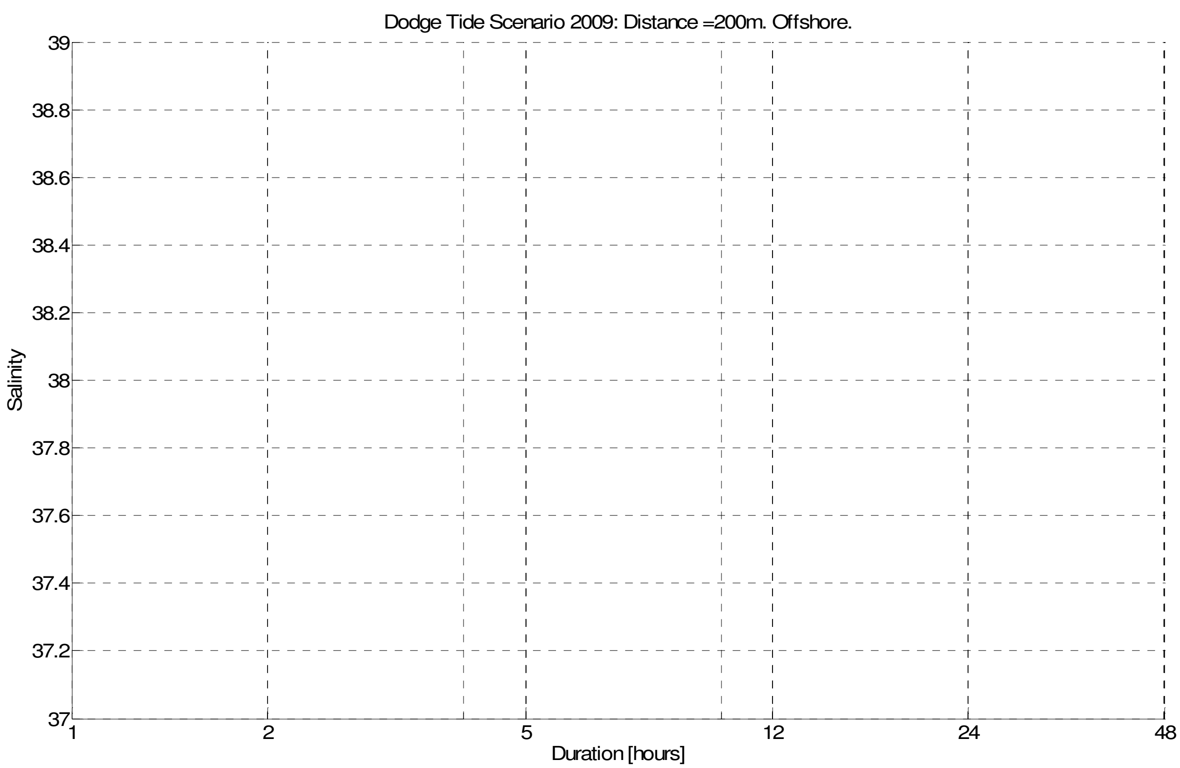


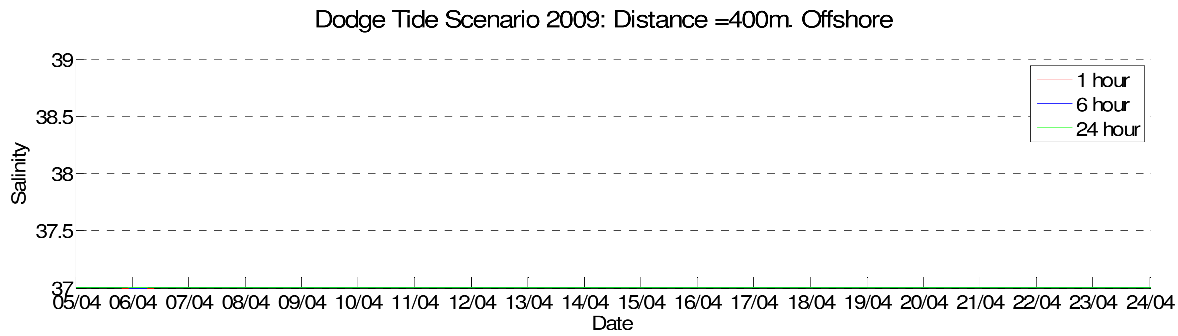


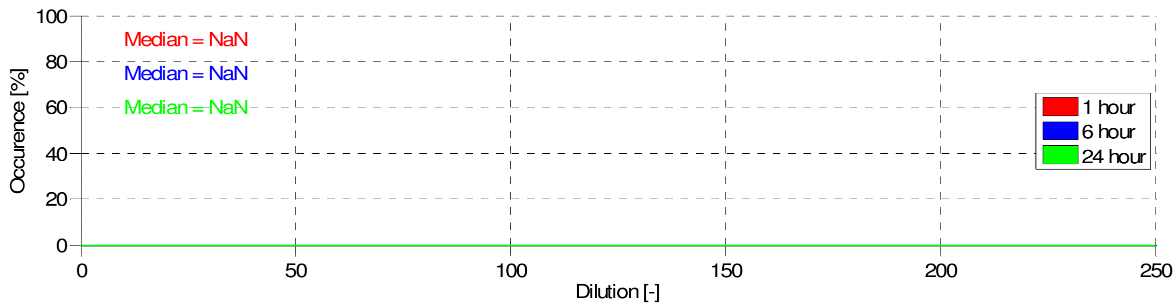


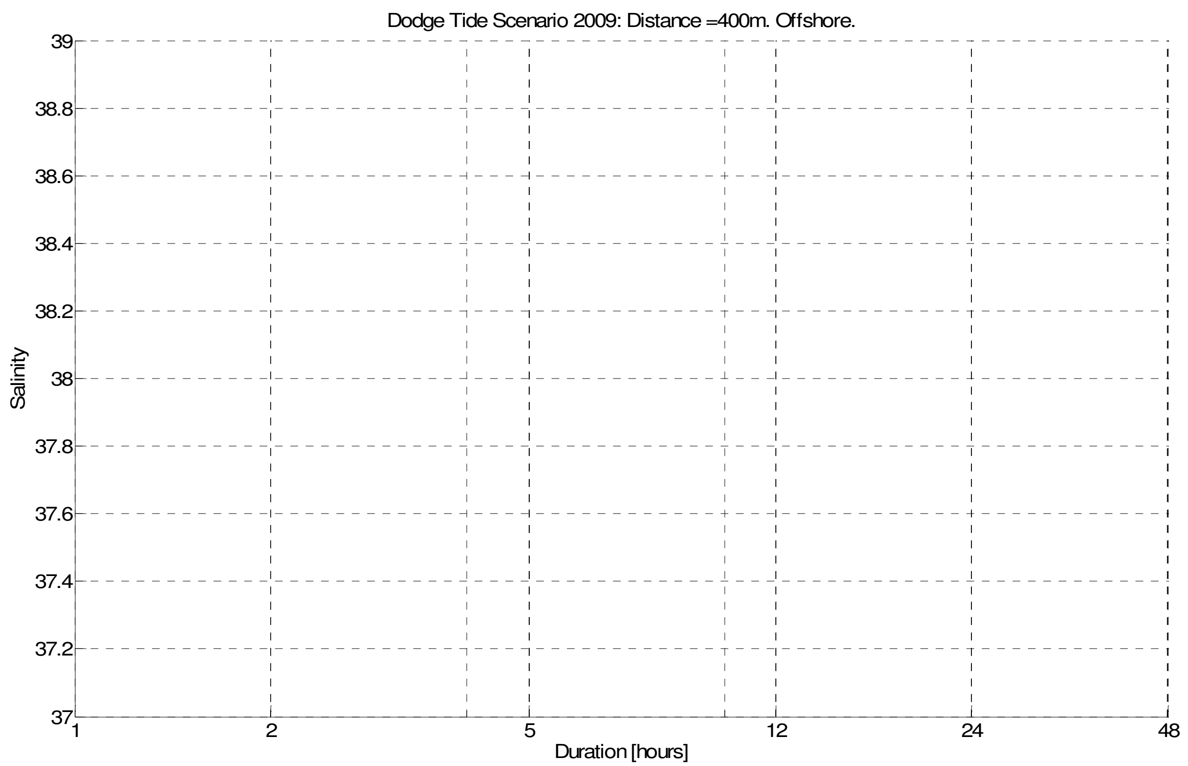

Dodge Tide Scenario 2009: Distance =200m. Offshore
Salinity
39
38.5
38
37.5
37
05/04 06/04 07/04 08/04 09/04 10/04 11/04 12/04 13/04 14/04 15/04 16/04 17/04 18/04 19/04 20/04 21/04 22/04 23/04 24/04
Date
1 hour
6 hour
24 hour

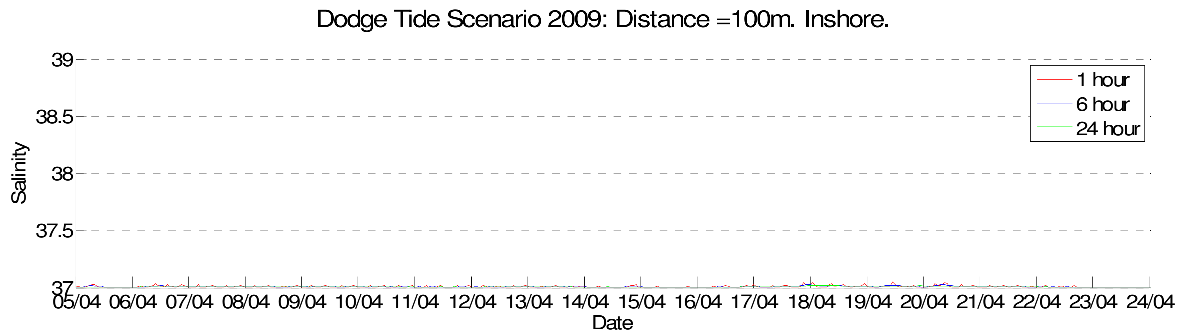

Occurence [%]
100
80
60
40
20
0
Median = NaN
Median = NaN
Median = NaN
1 hour
6 hour
24 hour
0
50
100
150
200
250
Dilution [-]

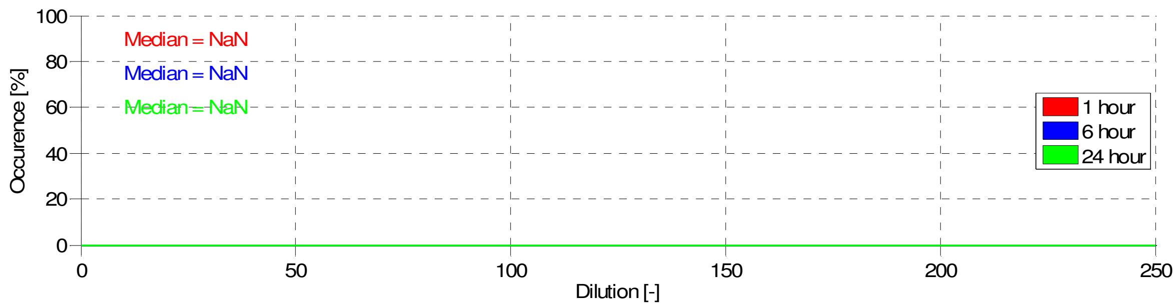

Dodge Tide Scenario 2009: Distance =200m. Offshore.
Salinity
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1
2
5
12
24
48
Duration [hours]

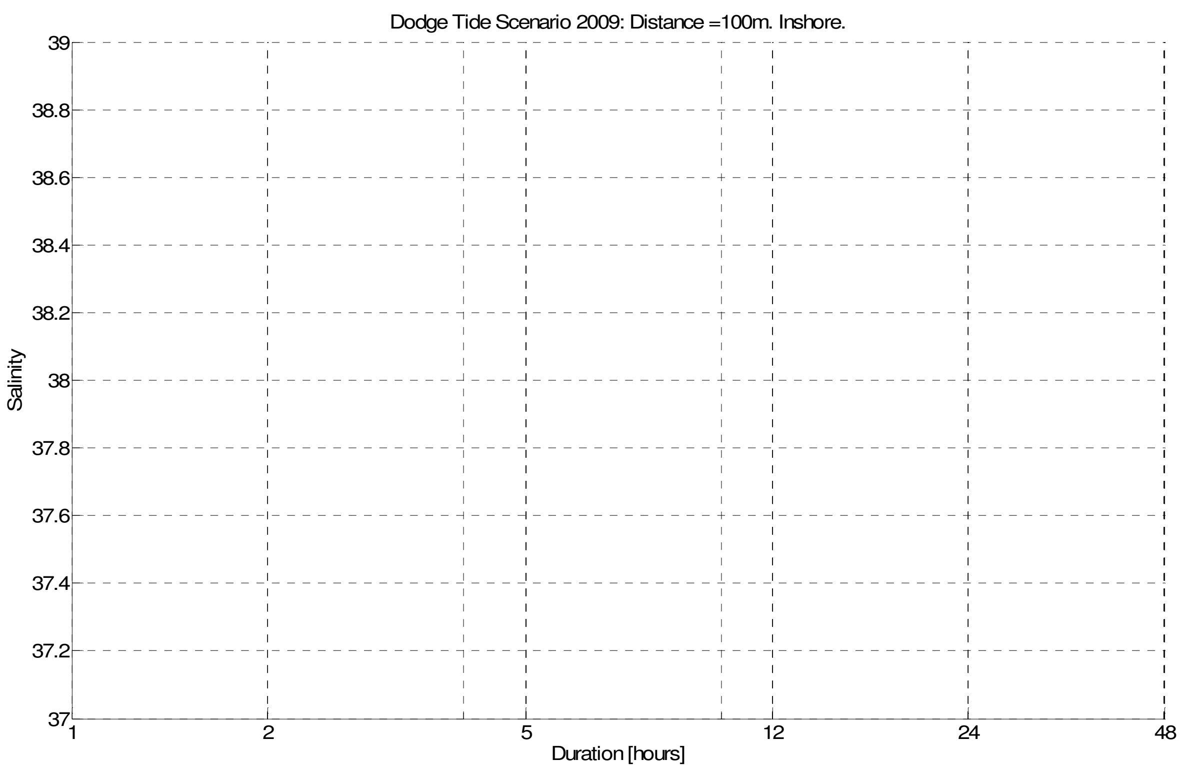

Dodge Tide Scenario 2009: Distance =400m. Offshore
Salinity
39
38.5
38
37.5
37
05/04 06/04 07/04 08/04 09/04 10/04 11/04 12/04 13/04 14/04 15/04 16/04 17/04 18/04 19/04 20/04 21/04 22/04 23/04 24/04
Date
1 hour
6 hour
24 hour

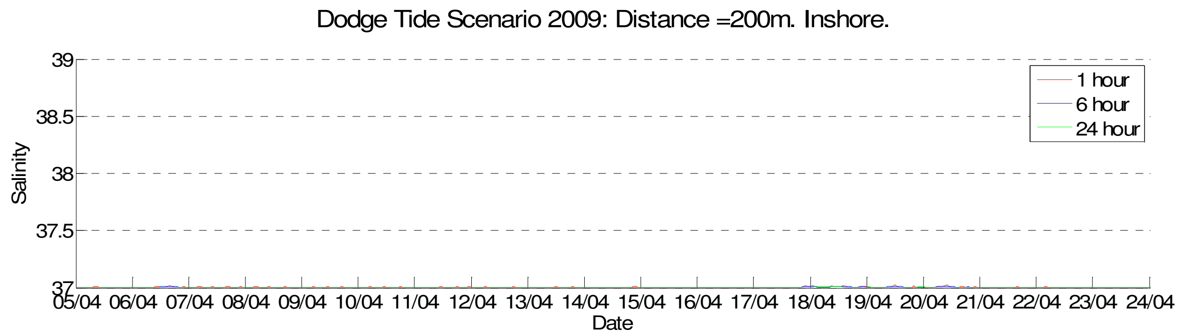

Median = NaN
Median = NaN
Median = NaN
Occurence [%]
100
80
60
40
20
0
0 50 100 150 200 250
Dilution [-]
1 hour
6 hour
24 hour

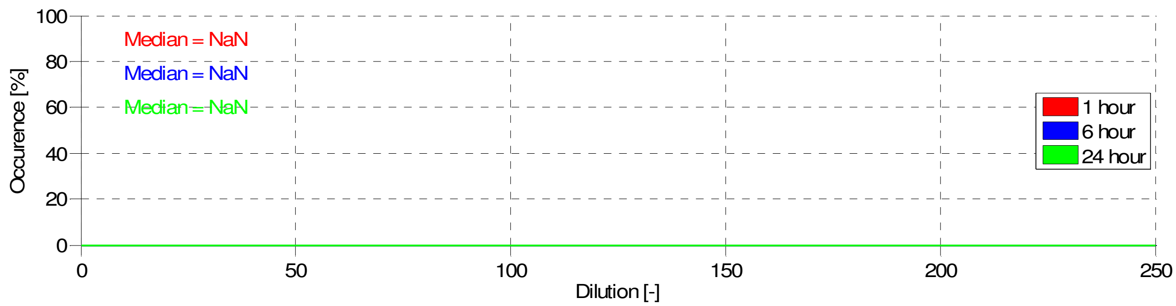

Dodge Tide Scenario 2009: Distance =400m. Offshore.
Salinity
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1 2 5 12 24 48
Duration [hours]

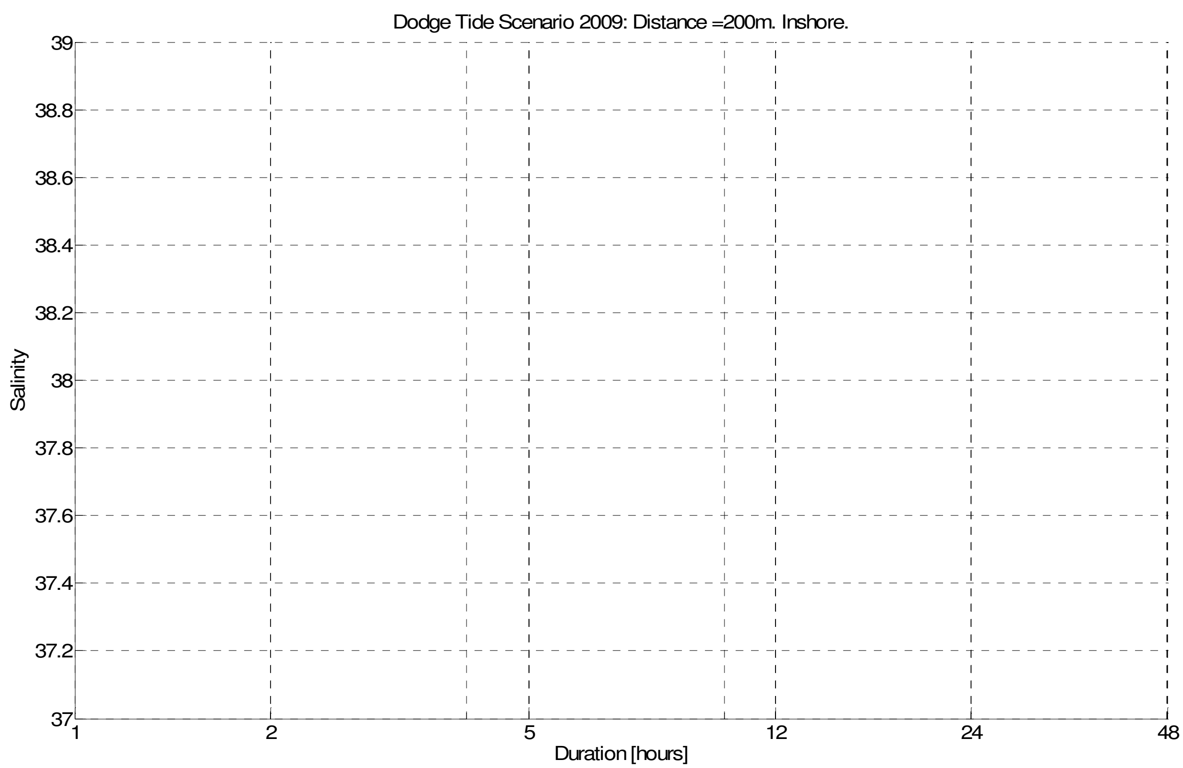

Dodge Tide Scenario 2009: Distance =100m. Inshore.
Salinity
39
38.5
38
37.5
37
05/04 06/04 07/04 08/04 09/04 10/04 11/04 12/04 13/04 14/04 15/04 16/04 17/04 18/04 19/04 20/04 21/04 22/04 23/04 24/04
Date
1 hour
6 hour
24 hour

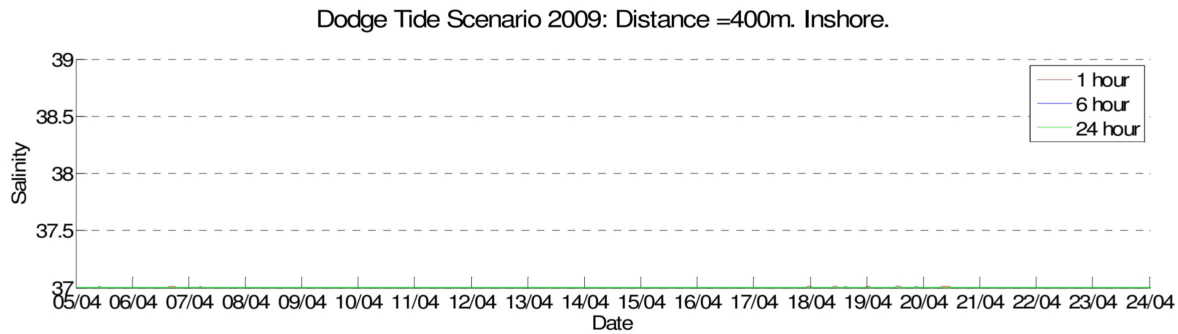

Median = NaN
Median = NaN
Median = NaN
Occurence [%]
100
80
60
40
20
0
0
50
100
150
200
250
Dilution [-]
1 hour
6 hour
24 hour

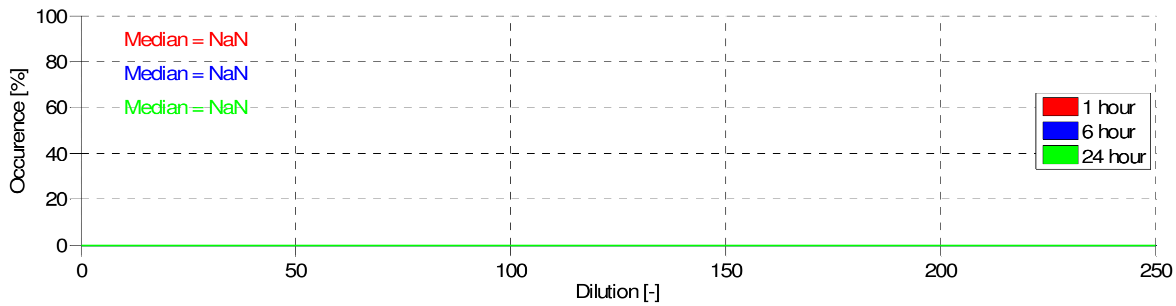

Dodge Tide Scenario 2009: Distance =100m. Inshore.
Salinity
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1
2
5
12
24
48
Duration [hours]

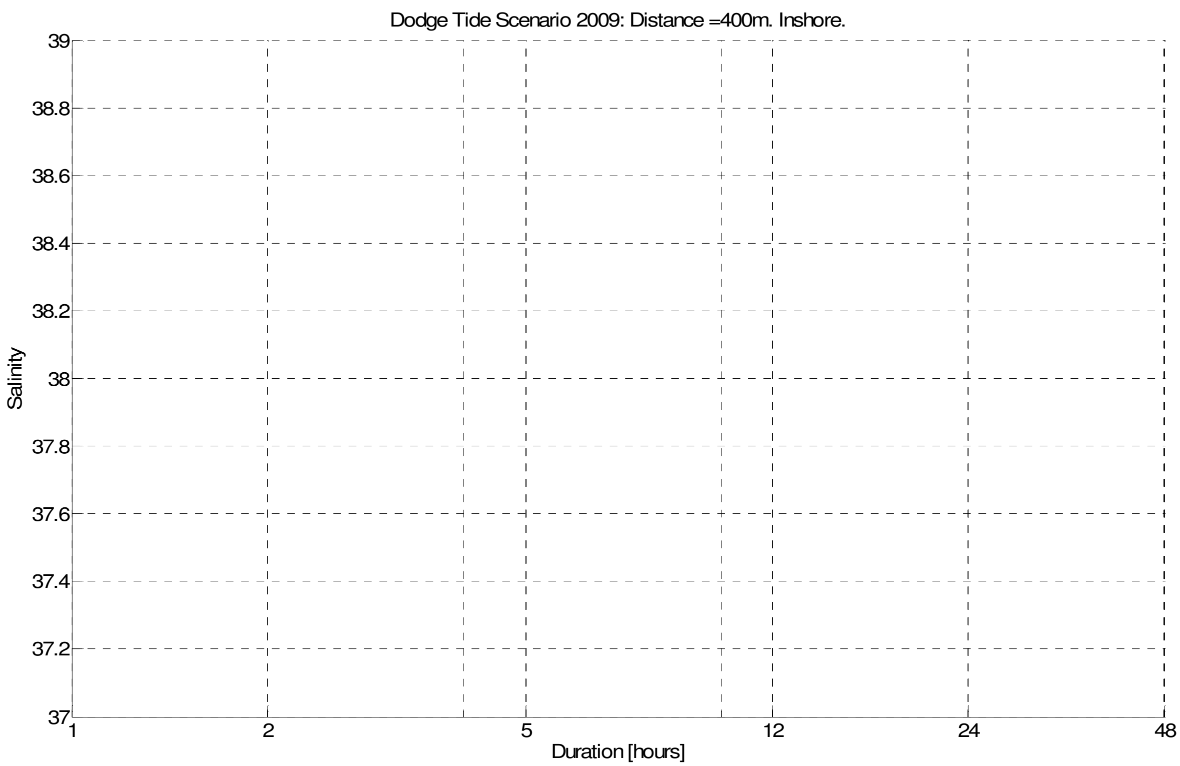

Dodge Tide Scenario 2009: Distance =200m. Inshore.
Salinity
39
38.5
38
37.5
37
05/04 06/04 07/04 08/04 09/04 10/04 11/04 12/04 13/04 14/04 15/04 16/04 17/04 18/04 19/04 20/04 21/04 22/04 23/04 24/04
Date
1 hour
6 hour
24 hour

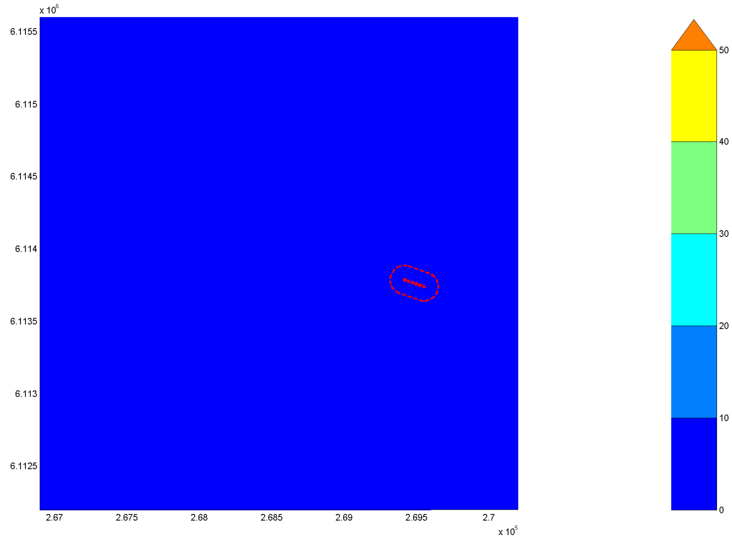

Median = NaN
Median = NaN
Median = NaN
Occurence [%]
100
80
60
40
20
0
0 50 100 150 200 250
Dilution [-]
1 hour
6 hour
24 hour


Dodge Tide Scenario 2009: Distance =200m. Inshore.
Salinity
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1 2 5 12 24 48
Duration [hours]

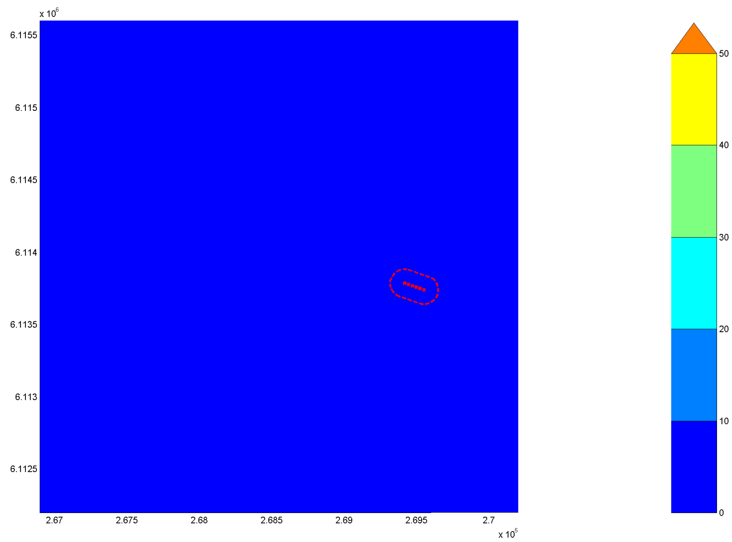

Dodge Tide Scenario 2009: Distance =400m. Inshore.
Salinity
Date
1 hour
6 hour
24 hour
39
38.5
38
37.5
37
05/04 06/04 07/04 08/04 09/04 10/04 11/04 12/04 13/04 14/04 15/04 16/04 17/04 18/04 19/04 20/04 21/04 22/04 23/04 24/04


Median = NaN
Median = NaN
Median = NaN
Occurence [%]
Dilution [-]
1 hour
6 hour
24 hour
100
80
60
40
20
0
0 50 100 150 200 250


Dodge Tide Scenario 2009: Distance =400m. Inshore.
Salinity
Duration [hours]
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
1 2 5 12 24 48



Percentage exceedance of the 0.3ppt salinity isopleth at the bed. Dashed red oval is a 100m distance around outfall provided for scale. Contour intervals are reported at the 10, 20, 30, 40 and 50th%



Percentage exceedance of 0.6ppt salinity isopleth at the bed. Dashed red oval is a 100m distance around outfall provided for scale. Contour intervals are reported at the 10, 20, 30, 40 and 50th%