9.0 COASTAL PROCESSES

This Chapter of the EIS will describe the existing coastal processes in the area and assess the impact of the proposed gas storage facility on these processes. It is essential that the discharge of brine during the leaching phase of the construction period does not cause any significant impact to the marine ecology offshore of Islandmagee.

Islandmagee Storage Limited proposes to create seven caverns for gas storage within a rock salt interval underneath Larne Lough, in order to assist meeting the growing demand for gas in Northern Ireland. The proposed cavern construction will be undertaken by solution mining of the salt deposits with the disposal of the saturated brine solution via an outfall located on the eastern side of Islandmagee, near Castle Robin Bay, north west of Muck Island.

The cavern designers anticipate that cavern construction (leaching) will follow a phased approach with up to four caverns being leached in parallel. The maximum leaching rate per cavern is designed to be 300m^3/h, and it not anticipated that more than three caverns will be leached at this rate at the same time. Thus the maximum anticipated brine production rate is 1,000m^3/h (3 @ 300m^3/h, main leaching phase, plus 1 @ 100m^3/h initial sump leaching phase).

A brine dispersion study, involving the development and calibration of a tidal model of the waters along the eastern shore of Islandmagee has been undertaken. This report provides details of the model development, calibration with observed tidal elevations and currents and presents the results of the brine dispersion modelling.

9.1 STUDY METHODOLOGY

RPS used their suite of coastal process models to simulate the tidal flow regime around Islandmagee to provide the base data for the computational modelling of the initial dilution and dispersion of the brine. The tidal flow regime at Islandmagee was simulated for both spring and neap tides. In the absence of specific data relating to brine dispersion around Islandmagee, standard model coefficients derived from other similar studies have been employed in this study. The hydrodynamic models were verified against surface elevation and current meter field survey measurements, prior to running the brine dispersion simulations which are detailed in this report.

The RPS study included a field survey to collect detailed bathymetric and hydrodynamic information for use in the development and verification of the models. The bathymetric data was used to refine the nearshore resolution of an existing hydrodynamic model of the Irish Sea while the current monitoring data collected during the survey was used to verify the predictions of the revised model. An overview of the development and verification of the hydrodynamic model is presented later in this document, as is an overview of the methodology employed for the brine dispersion modelling.

9.2 MODELLING SYSTEM

9.2.1 Irish Sea Model

In order to efficiently model the tidal flow around Islandmagee and Castle Robin, a detailed flexible mesh model was created, which utilised boundary conditions from the more extensive, coarser resolution RPS Irish Sea model. The Irish Sea model stretches from the North-western end of France including the English Channel as far as Dover out into the Atlantic to 16° west, including the Porcupine Bank and Rockall. In the other direction it stretches from the Northern part of the Bay of Biscay to just south of the Faeroes Bank. Overall the model covers the Northern Atlantic Ocean and UK continental shelf up to a distance of 600km from the Irish Coast as illustrated in Figure 9.1.

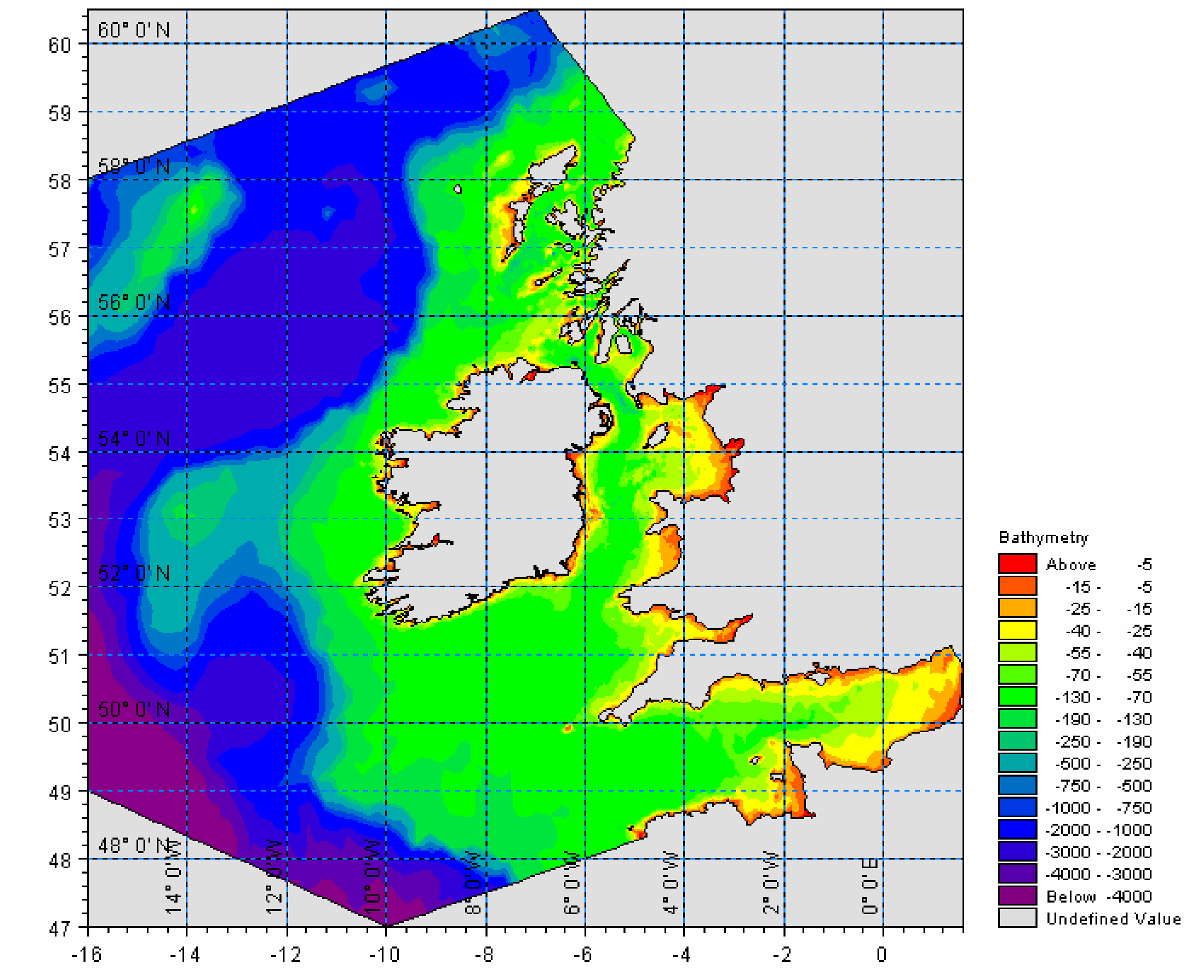

Figure 9.1: Extent of Irish Sea Tidal Surge Model

This model was constructed using flexible mesh technology allowing the size of the computational cells to vary depending on user requirements. Along the Atlantic boundary the model features a mesh size of approximately 24km. The Irish Atlantic coast has been described using cells of on average 3km size while in the Irish Sea, the area of greatest interest to this study, the maximum cell size is limited to 3.5 km decreasing to 200m along the Irish coastline.

The bathymetry was generated from a number of different sources. Large parts of the bathymetric information were obtained from chart data supplied digitally by C-MAP of Norway. Recent surveys of several banks and coastal areas have also been included covering in part or all of

- Wexford and approaches
- Blackwater bank
- Arklow bank
- Codling bank
- Carlingford Lough
- Dublin Bay
- Malahide Estuary
- Rogerstown Estuary
- Greystones

Both the survey data commissioned by RPS and the digitised charts were quality checked by RPS engineers and compared with Admiralty data and known benchmarks. Recent surveys carried out by Geological Survey Ireland (GSI) as part of the Irish National Seabed Survey (INSS) were also incorporated into the model. The datum of the various bathymetry sources was adjusted to mean sea level using over 350 reference levels to obtain a consistent dataset. A custom made routine was used to interpolate the mean sea level corrections for the relevant survey area and adjust the bathymetry values accordingly before incorporation into the overall model.

The simulation of the astronomic tides in the model area is mainly driven by the oscillation of water levels along the open boundaries. The Irish Sea tidal surge model has six open boundaries, five in the Atlantic and one in the English Channel. The time series of tidal elevations along these boundaries were generated using a global tidal model designed by a team at the Danish National Survey and Cadastre Department (KMS). The KMS global tidal model is based on the prediction of tidal elevations using 8 semidiurnal and diurnal tidal constants (as opposed to the United Kingdom Hydrographic Office approach which uses 4-6 constants). These constants were derived through the simulation of the effect of astronomic forces due to the sun and moon on the water surfaces. The model output was further refined with the use of satellite derived altimetry data.

9.2.2 Islandmagee Model

It was necessary to model both a spring tide and a neap tide cycle to simulate the full range of dispersion characteristics therefore a month of tides was generated using the larger RPS Irish Sea Model, which was used to extract boundary conditions for the smaller, more detailed Islandmagee model. The extent of the detailed model for the Islandmagee study includes the North Channel and Larne Lough, as illustrated in Figure 9.2. The northern boundary makes contact with the land just south of Glenarm, with the southern boundary meeting the land north of Whitehead. There are four boundaries in total with the north eastern and south eastern boundaries positioned as far out from the land as necessary to facilitate the generation of the correct tidal flow, and also to encompass any offshore banks/rocks which may affect the tidal currents.

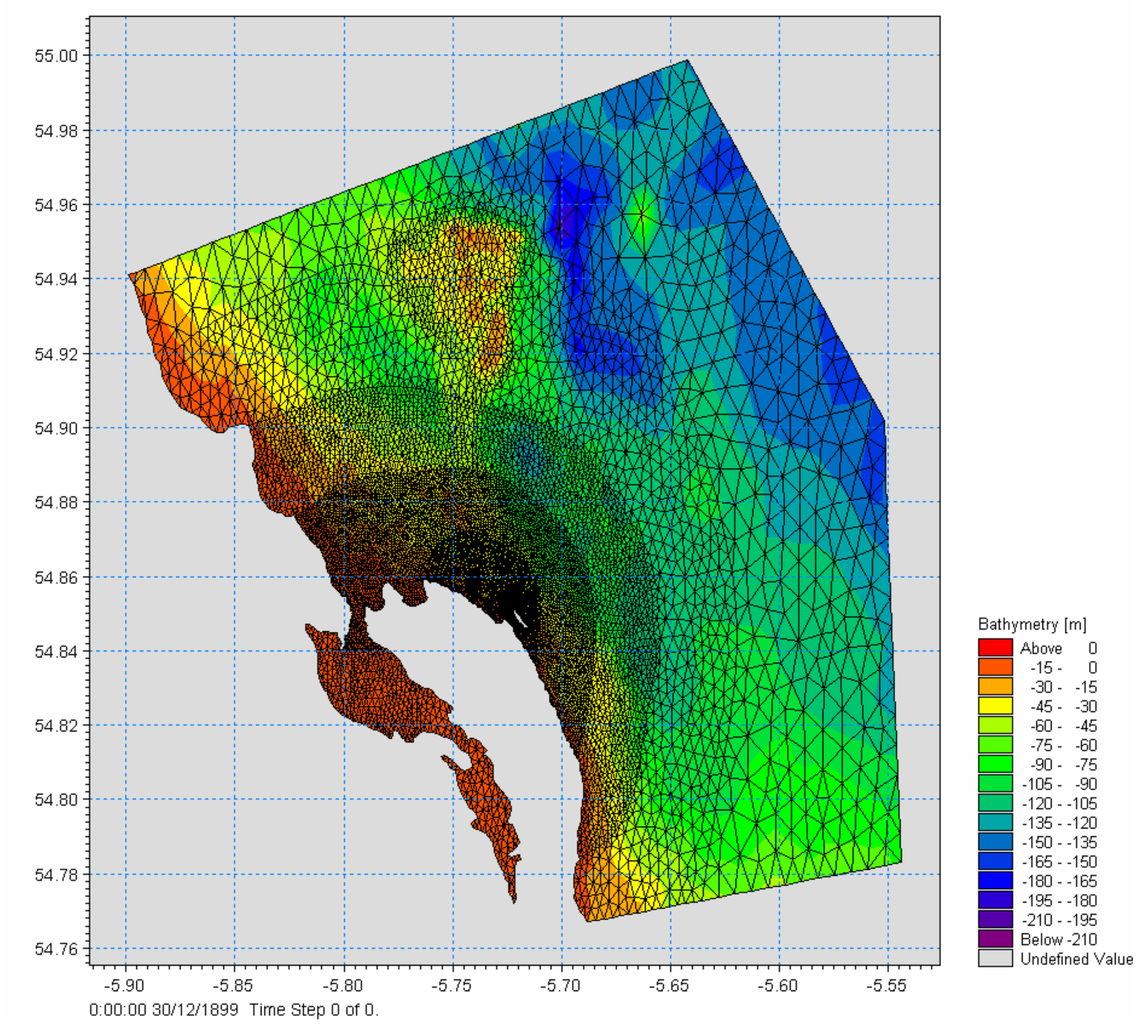

Figure 9.2: Extent of the detailed Islandmagee Tidal Model

The detailed Islandmagee model was also constructed using flexible mesh technology allowing the size of the computational cells to vary depending on user requirements. Along the boundaries, the model features a mesh size of circa 900 metres, decreasing to around 50 metres at the coastline. In order to capture the detail around the proposed outfall, more refined meshing was introduced in this vicinity, with the use of a smaller cell size of only 20 to 30 metres. This can be seen in Figure 9.3.

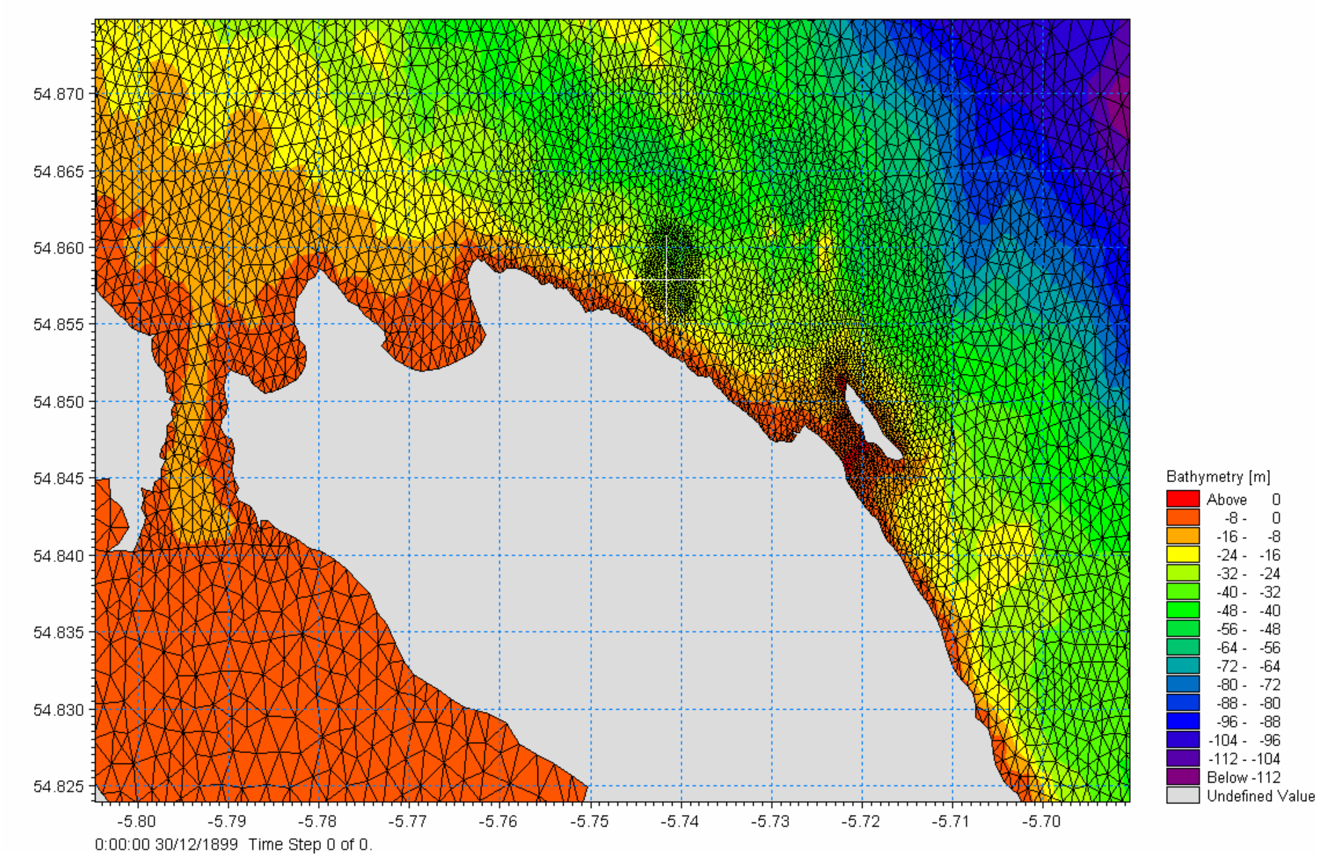

Figure 9.3: Mesh and Bathymetry in the Castle Robin Area

The bathymetry for this model was taken from the same sources as the Irish Sea surge model, as detailed in Section 9.2.1, which was supplemented with the results of a local high resolution multibeam bathymetric survey carried out by between Port Muck and Ferris Bay as part of this study. Figure 9.4 shows the extent of this survey. Bathymetry in the model is given relative to mean sea level which varies with chart datum depending on the location; at Larne mean sea level is 1.75m above chart datum.

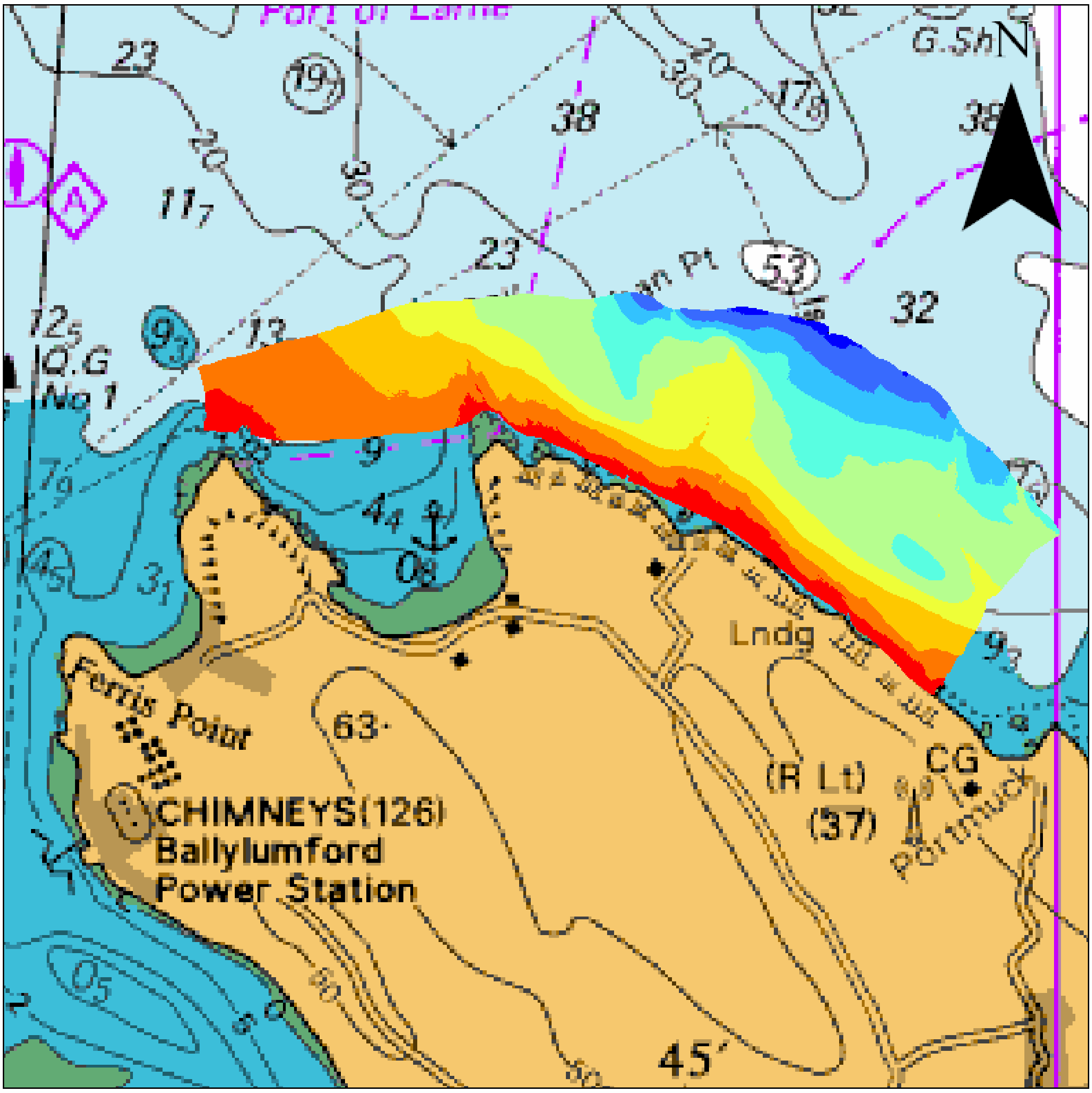

Figure 9.4: Bathymetric Survey Extent

Unlike the Irish Sea Model, the Islandmagee model is 3 dimensional, and was implemented using MIKE 3; a comprehensive modelling system for 3D surface flows. MIKE 3 is applicable to the simulation of hydraulic and related phenomena in lakes, estuaries, bays, coastal areas and seas where stratification or vertical circulation is important. The proposed brine discharge is negatively buoyant therefore 3D modelling is required to evaluate the dispersion of brine at various levels throughout the water column. For this study, brine dispersion was evaluated at sub-surface, mid-depth and near the seabed; as detailed in Section 9.3.

9.2.3 Model Verification

9.2.3.1 Model Verification Data

The hydrodynamic model was verified using field data collected specifically for this study during October 2009. The model simulations were carried out over the same calendar period which included both spring and neap tides i.e. the full extent of the normal astronomic tidal range was covered, thus the full scope of the tidal dispersion characteristics are simulated. The spring tide conditions gives the greatest plume extent but lower concentrations, while the neap tide conditions result in the greatest brine concentrations within the plume but a lesser plume extent.

The model calibration process focused on ensuring that the observed tidal elevations and current meter data at the site were adequately simulated within the model. Figure 9.5 shows the location of the principal current monitoring sites, for which data is presented in this report. These 4 sites, M1, M2, M3 and M4 are shown relative to the location of the proposed outfall.

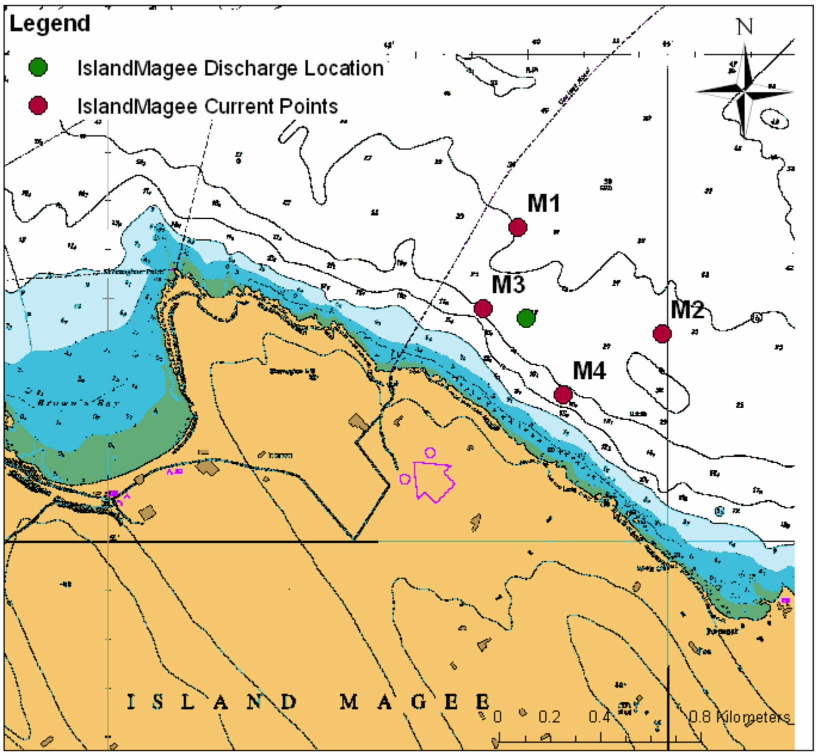

Figure 9.5: Location of Current Meter Points and Outfall Location at Islandmagee

Current data from the four locations were recorded by means of Acoustic Doppler Current Profilers (ADCP), bottom mounted and looking upwards at each location. The profilers at locations M3 and M4 were set up to record in 1 metre bins, with M1 and M2 set up to record at 2m bins, as they were placed further offshore in deeper water. Current velocities at various depths, corresponding to a bottom current, a mid depth current and a sub surface current, were extracted from the ADCP data for comparison against the model predictions at equivalent depths. The actual distances from the bed at each of the four current meter points corresponding to the sub-surface, mid depth and bottom measurements are shown in

Table 9.1.

Table 9.1: Distance from Bed in metres at M1 – M4 for Sub Surface, Mid Depth and Bottom Measurements

	M1	M2	M3	M4
Sub Surface	30.5	26.5	24.0	19.0
Mid Depth	16.5	14.5	13.0	10.0
Bottom	2.5	2.5	2.0	2.0

9.2.4 Model verification results

A comparison was made between the simulated tidal elevations and the measured total water levels in close vicinity to the proposed outfall location. Figure 9.6 and Figure 9.7 show this comparison during typical neap and spring tides respectively. It should be noted that the model simulated only tidal elevations. Other climatic effects were not included, whereas the gauged information includes both normal astronomic tides and surge; i.e. total water level. Exact agreement is therefore only expected in the absence of any tidal surge, however, the comparison provides an indication of the model's tidal elevation accuracy, particularly when the measured wind data available near the location is taken into account, as shown in Figure 9.8.

This is particularly relevant in the validation of the neap tides recorded for this study, since a significant surge event occurred on 24th – 25th October, as can be seen from the wind data in Figure 9.8. This accounts for the apparently large discrepancy of up to 0.3m between the measured total water levels and the simulated tidal elevations during the neap cycle shown in Figure 9.6. A much closer fit is observed towards the end of this neap period, on the 26th October, and again during the spring tidal cycle as shown in Figure 9.7 when there were no significant surge events.

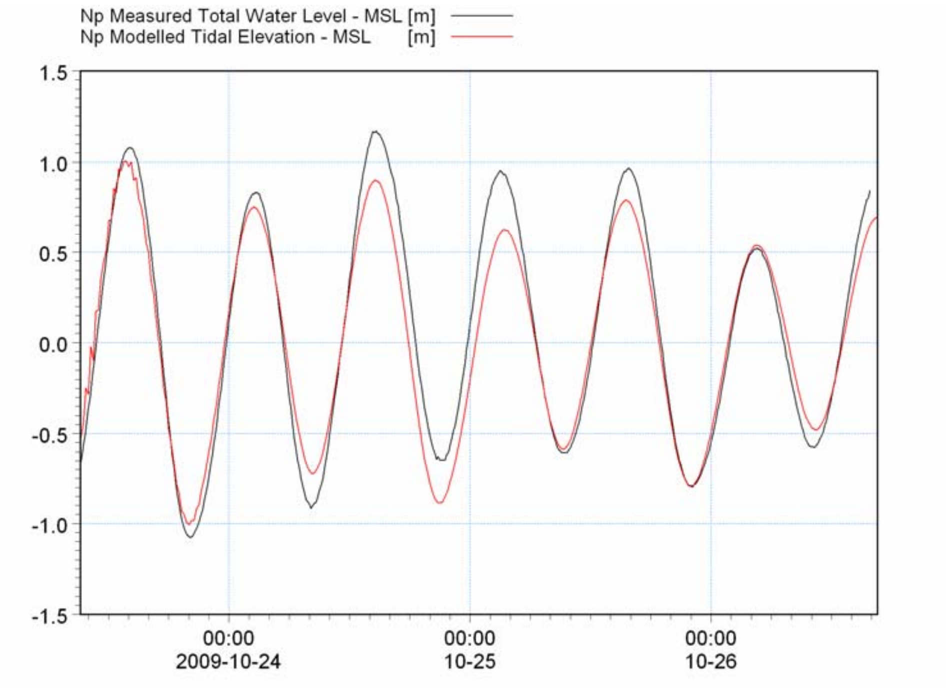

Figure 9.6: Measured Total Water Level compared with Modelled Tidal elevations during a Neap Tidal Cycle

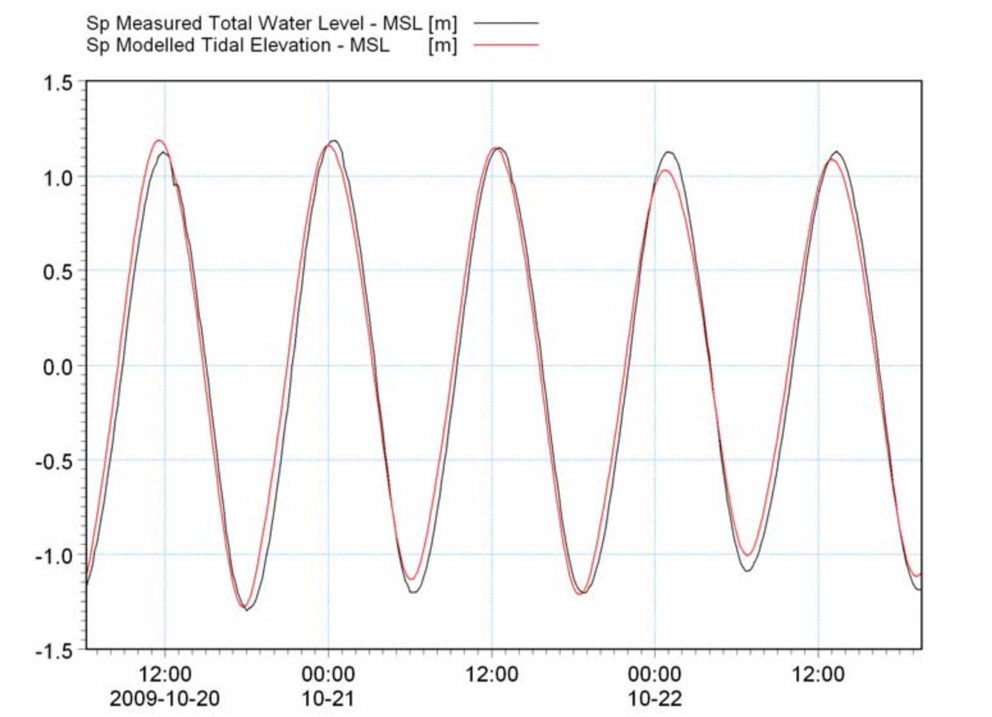

Figure 9.7: Measured Total Water Level compared with Modelled Tidal elevations during a Spring Tidal Cycle

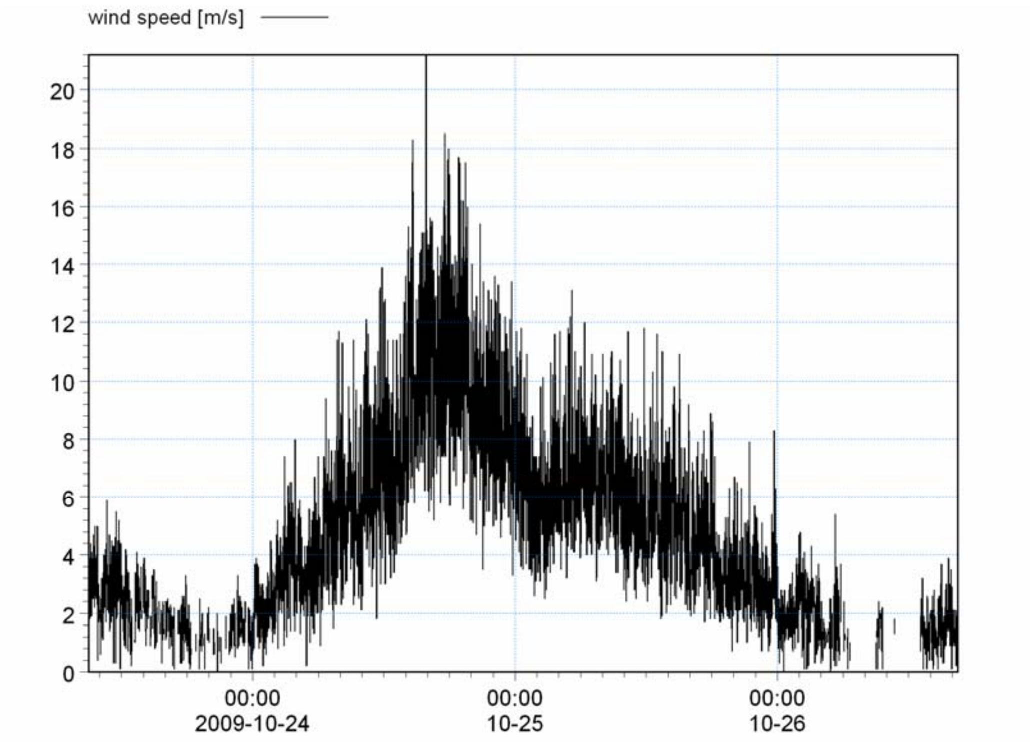

Figure 9.8: Variation of Wind Speed during the Neap Tidal Cycle

The validation of the tidal elevations in the model is only one aspect of the model calibration process, it is also necessary to ensure the model predictions correlate with measured current speeds and directions. As discussed in Section 9.2.3.1, the gauge data provides current speeds and directions at multiple depths throughout the water column. The corresponding data were extracted from the model results and compared, in order to determine the model accuracy. During the model calibration process, various refinements were made to the model mesh and boundary conditions until RPS were satisfied that the model predictions were representative of the observed tidal currents.

Figure 9.9 to Figure 9.15 show the comparison between the measured data and the modelled data at each of the monitoring locations shown in Figure 9.5 for both spring and neap tides. Due to the absence of gauge data, there is no comparison for current metering point M3 for the neap tidal cycle.

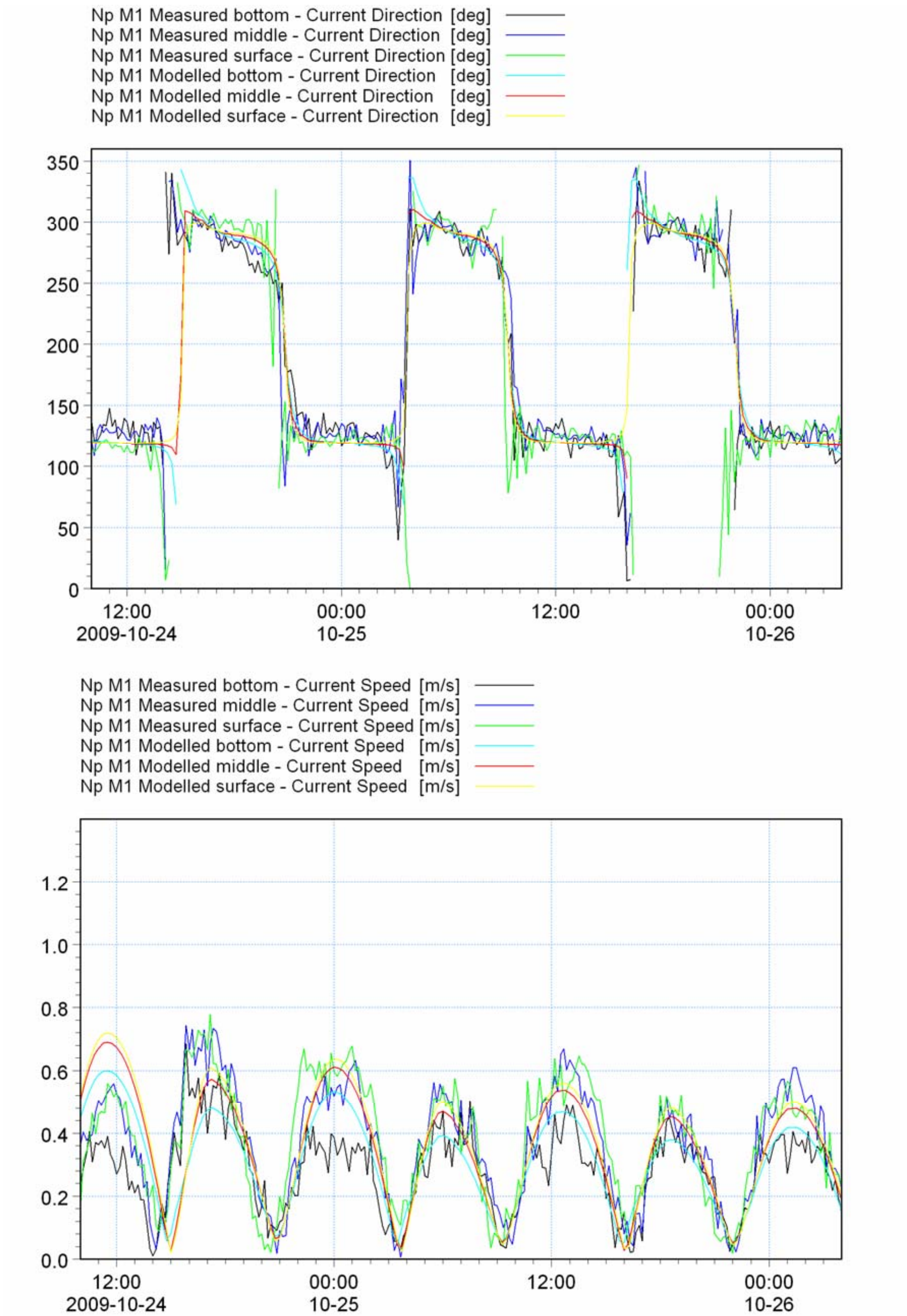

Figure 9.9: Comparison of Modelled and Observed Neap Current Direction (above) and Speed (below) at M1

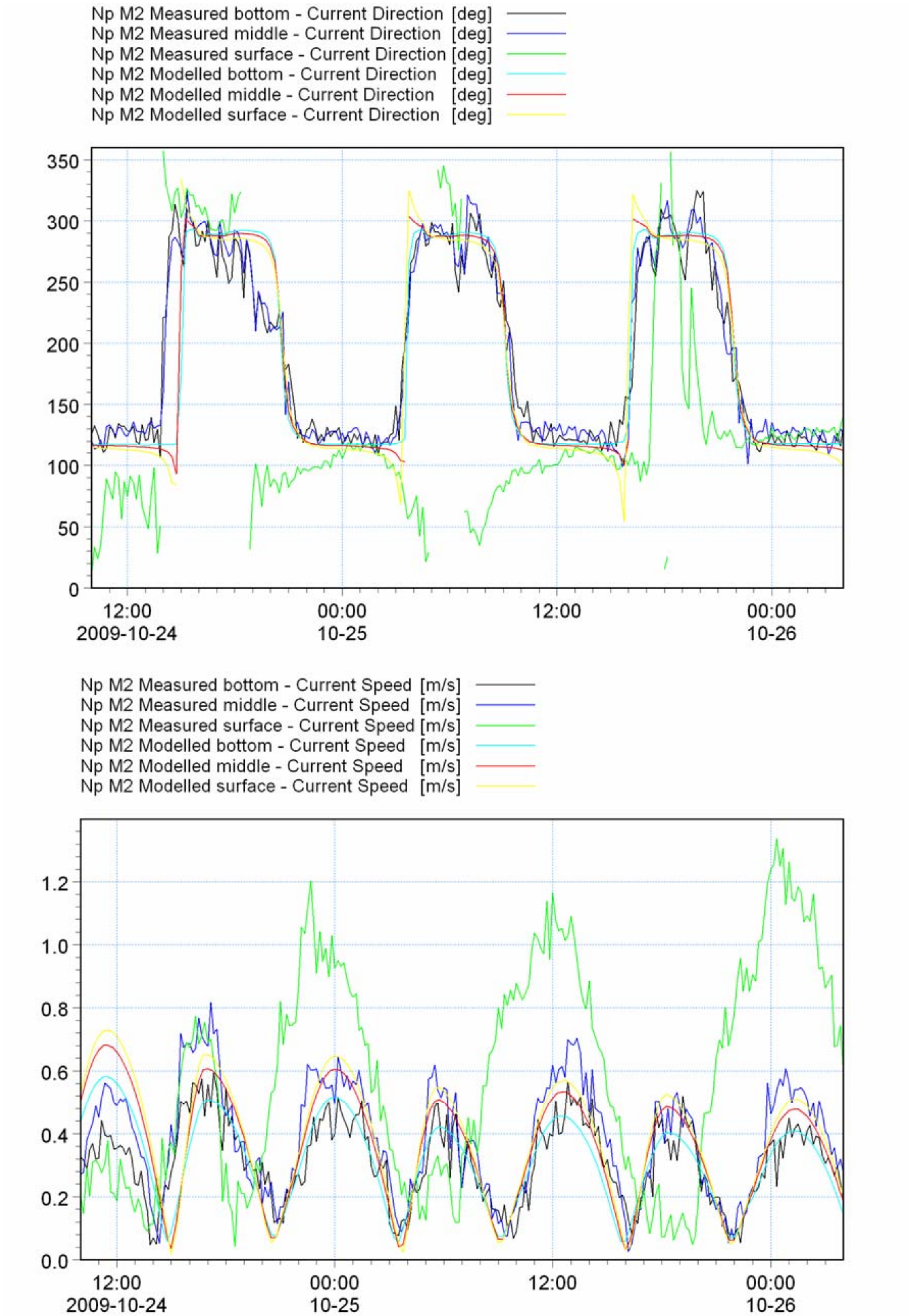

Figure 9.10: Comparison of Modelled and Observed Neap Current Direction (above) and Speed (below) at M2

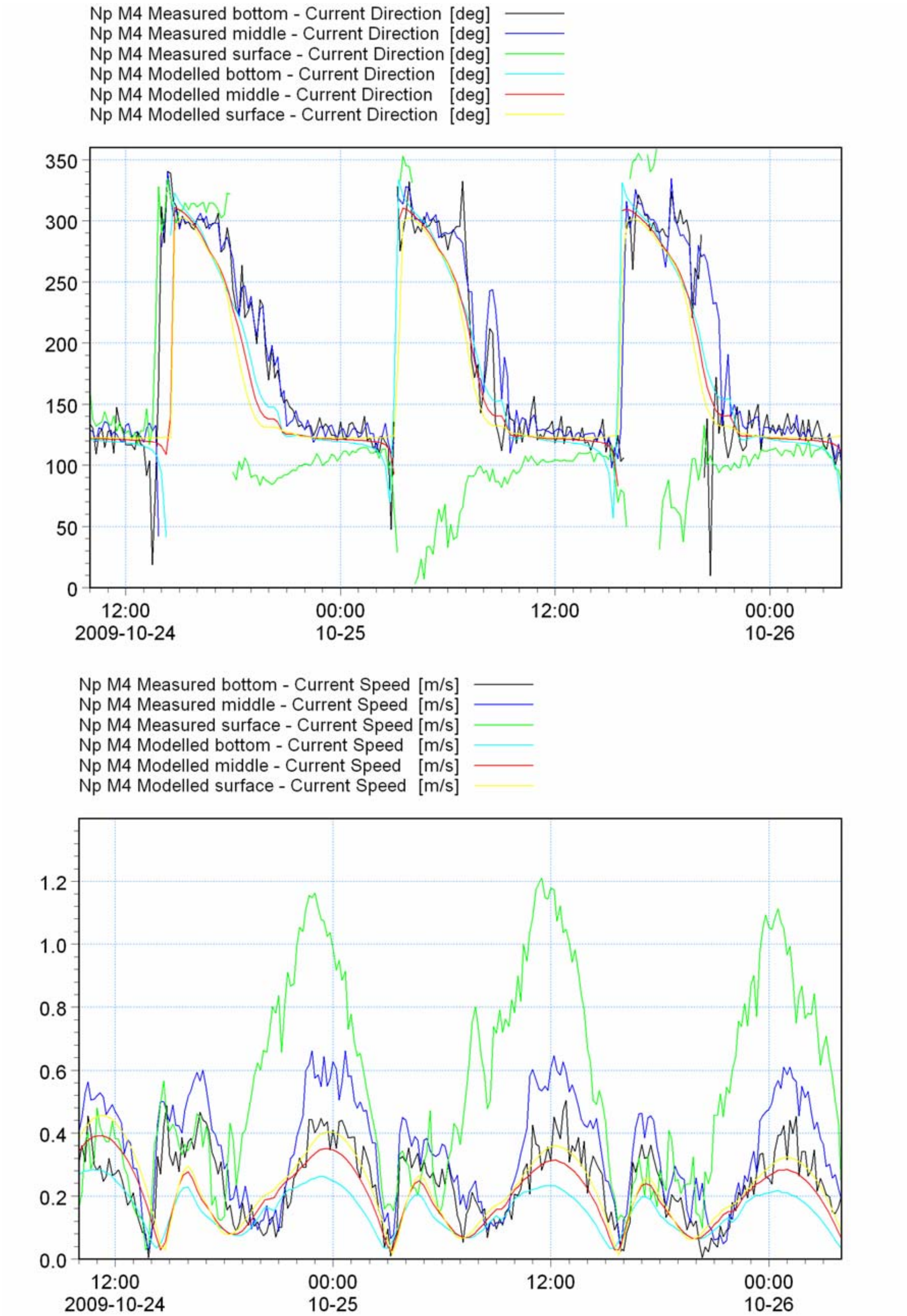

Figure 9.11: Comparison of Modelled and Observed Neap Current Direction (above) and Speed (below) at M4

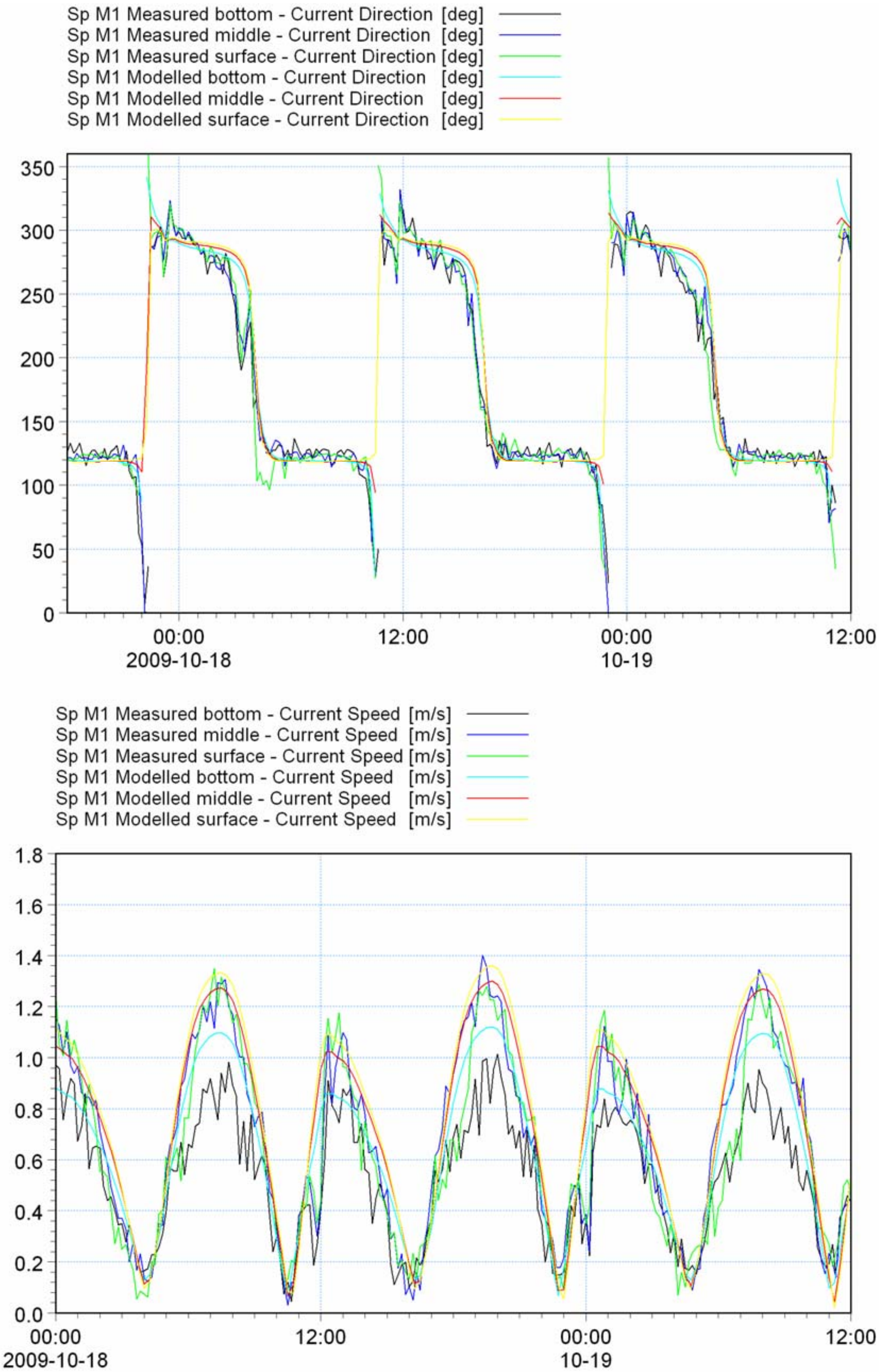

Figure 9.12: Comparison of Modelled and Observed Spring Current Direction (above) and Speed (below) at M1

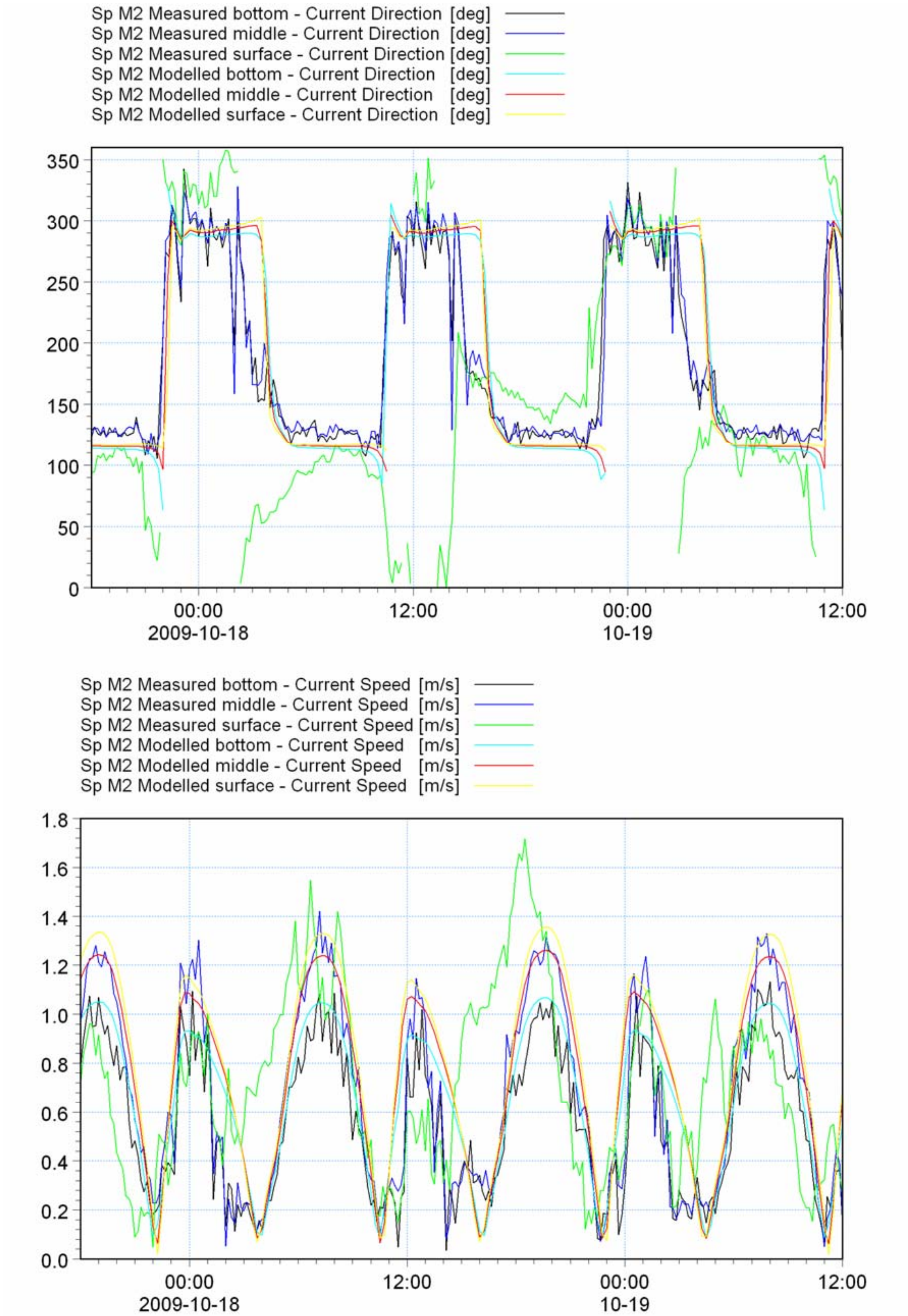

Figure 9.13: Comparison of Modelled and Observed Current Direction (above) and Speed (below) at M2

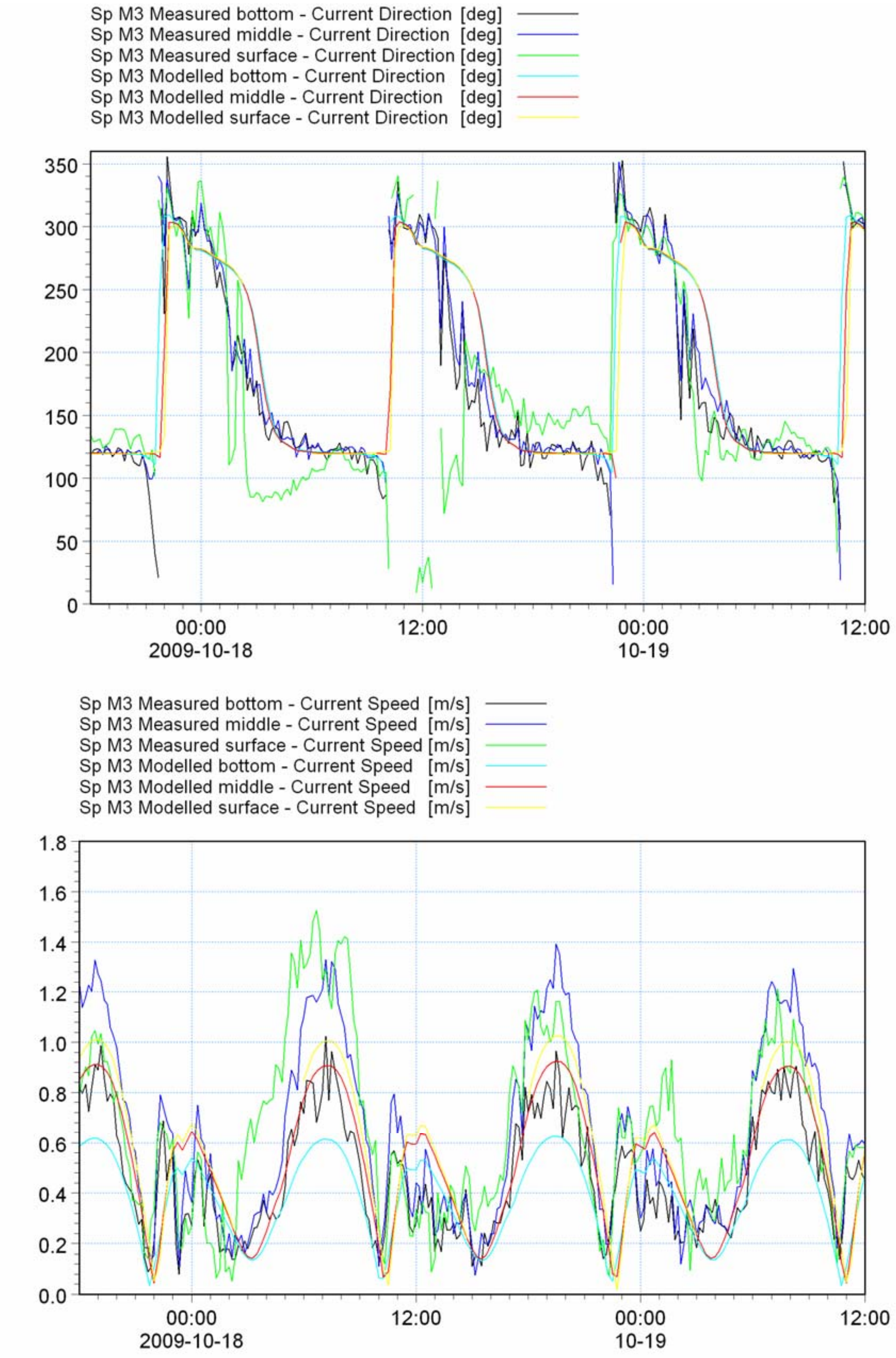

Figure 9.14: Comparison of Modelled and Observed Current Direction (above) and Speed (below) at M3

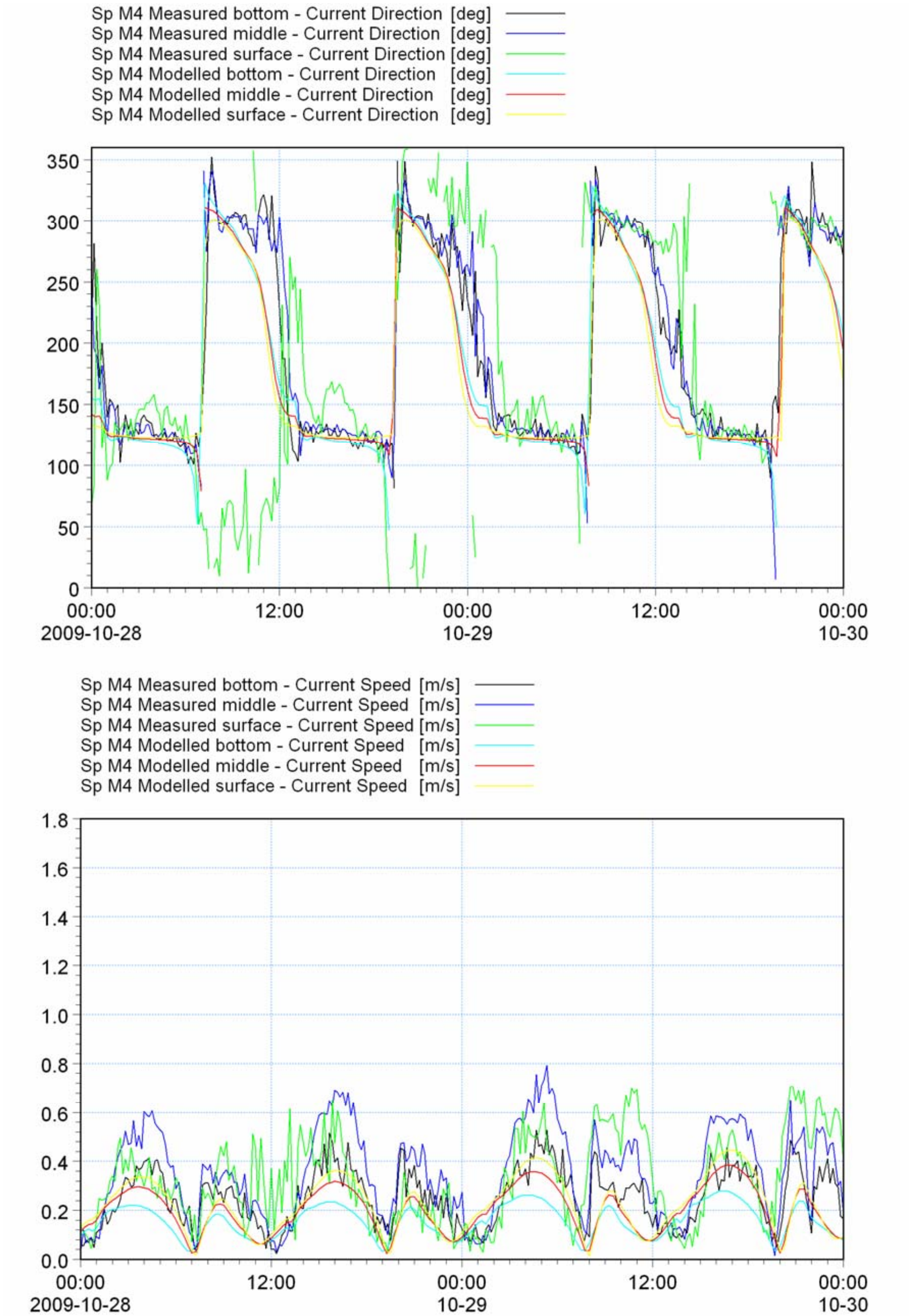

Figure 9.15: Comparison of Modelled and Observed Spring Current Direction (above) and Speed (below) at M4

Examination of the preceding figures shows similar flow patterns at M1 and M2 for both spring and neap tides, likewise, M3 and M4 also show similar flow patterns to each other, but different from M1 and M2. At points M1 and M2 the north and south-going tides are of relatively equal duration whereas at points M3 and M4 the south-going tide is of greater duration. The observed data and model predictions also show higher current velocities during the south-going tide than on the north-going tide which is indicative of localised flow circulation or eddying.

Typical flood and ebb tidal flow patterns for the area are shown in Figure 9.16 and Figure 9.17 respectively and these clearly show the formation of an eddy in the lee of Muck Island on the north-going (ebb) tide. This is caused by the shallower water and rocky outcrops extending north of Muck Island and affects the tidal flows at sites M3 and M4. Sites M1 and M2 lie outside the influence of the tidal eddy and are therefore unaffected. Examination of Figure 9.14 and Figure 9.15 show how the tidal flow runs in a south easterly direction for more than half the tidal cycle at sites M3 and M4 due to the eddy. The correlation between the modelled and observed data shown in these Figures indicates that this tidal asymmetry is well represented within the model.

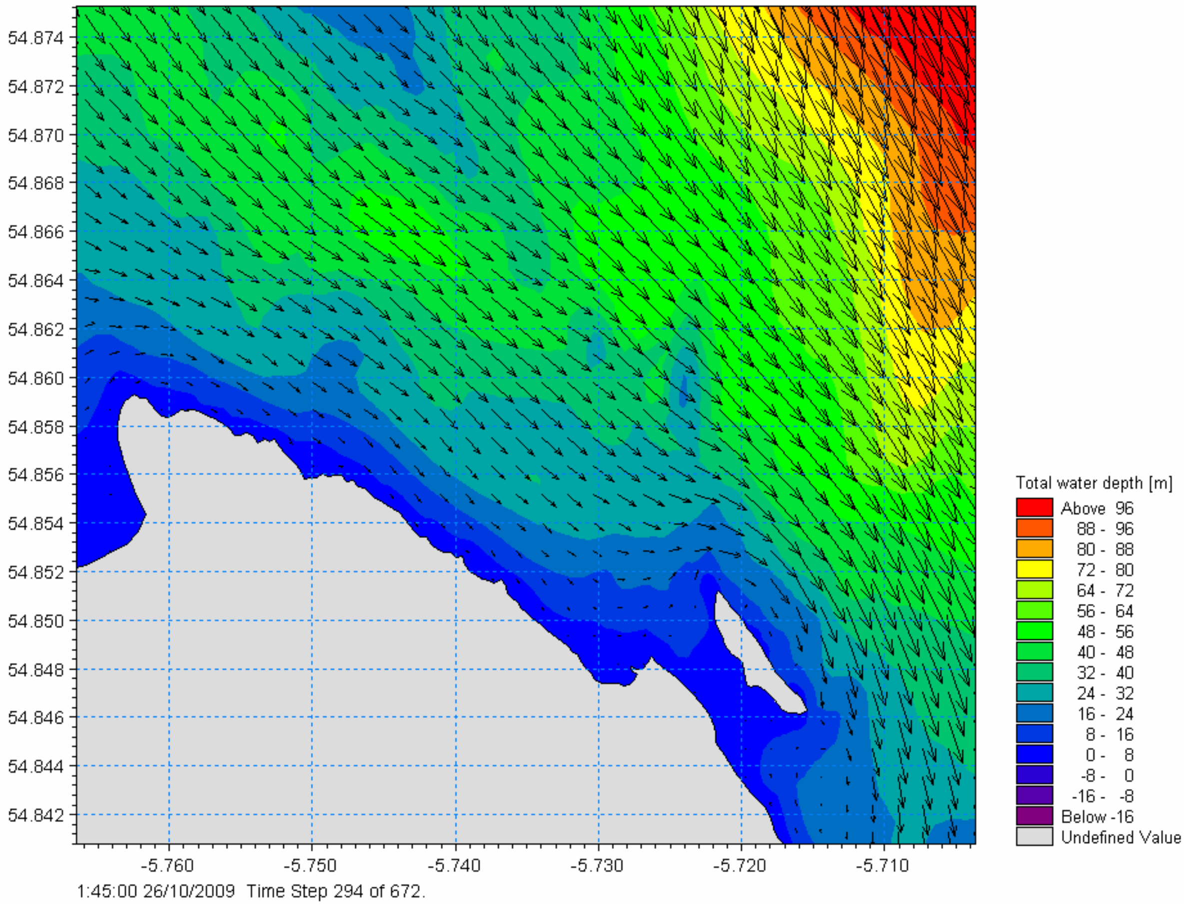

Figure 9.16: Mid Flood tidal patterns during a Neap Tidal Cycle

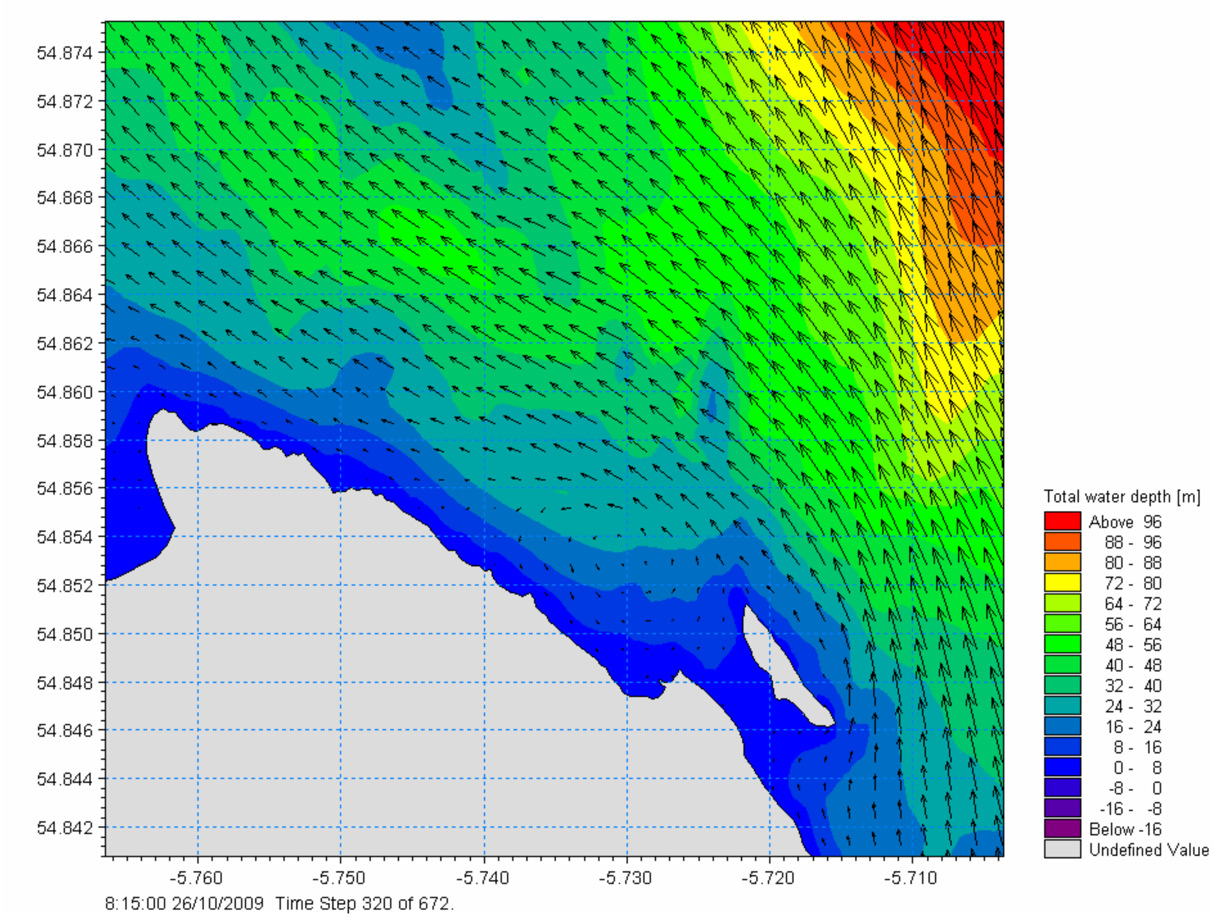

Figure 9.17: Mid Ebb tidal patterns during a Neap Tidal Cycle

The two offshore points, M1 and M2 consistently show a good correlation with gauge data for both current speed and current direction during spring tides. During the neap period, a significant increase in surface current speed is depicted by the measured data at M2. Examination of the recorded wind data indicates that relatively strong winds were experienced during the neap tides and as wind effects were not included in the hydrodynamic model simulations, any effect on the current field is not reflected in the model output. However the observed impact on current speed and direction at the surface is commensurate with the magnitude and direction of the recorded winds and therefore we believe accounts for the differences between the predicted and observed current speeds shown in Figure 9.10. The same effect is mirrored by the results for point M4, as shown in Figure 9.11.

Overall, the model verification results indicate that the spatial distribution of the tidal flow is generally well represented in the model simulations. The nearshore flow is complex with some level of circulation, however for the model extent over which the brine dispersion will take place the verification is considered adequate to give a good prediction of brine concentrations and dispersion. As noted above the apparent discrepancies between the simulated and observed tidal currents, can be explained by the fact that the simulated tidal conditions do not include any climatic effects and storm events were recorded during the field measurement period.

9.3 BRINE DISPERSION MODEL

The calibrated tidal model of the Islandmagee area described in Section 9.2 provided the base data for the initial dilution models and the medium and far field dispersion analysis for the brine discharge.

9.3.1 Computational Models

The modelling of brine dispersion was undertaken with a two stage process

- Initial dilution simulations
- Medium and far field dispersion simulations

The initial dilution studies examine the dispersion of the outfall outlet jets in the immediate area of the outfall diffuser. These simulations have principally been undertaken using the US EPA Visual Plumes programme which examines the flow of the outlet jets under the influence of density, temperature and velocity. The programme ignores the eddy mixing within the water column and is therefore conservative. For comparative purposes some additional analysis was undertaken using the CORMIX-GI model developed by MixZon Inc.

The outfall was assumed to have 3 ports of 0.2m diameter at 20m centres and designed to jet the brine up into the water column. The brine, even at 10°C above ambient, will be more dense than the surrounding seawater, thus there will be a tendency for the brine plume to initially sink. However the eddying in the water column will mix the brine and seawater as the tidal currents flow across the outfall area. This process will be further enhanced by the turbulence generated by the flow around the diffuser protection structures.

The second stage in the dispersion modelling was to examine the dispersion in the medium and far field following initial dilution. This was carried out using the MIKE 3 Flexible Mesh Flow Model. Both modelling approaches are described in more detail in the following sections.

<u>9.3.1.1 Initial Dilution Model</u>

The initial dilution of the brine at the proposed outfall was modelled using the US EPA "Plumes" software. The UM3 routine in the software was used for this study.

UM3 is an acronym for the three-dimensional Updated Merge (UM) model. UM3 simulates single and multi-port submerged discharges. UM3 is a Lagrangian model that assumes that the plume is in steady state. However, ambient and discharge conditions can change as long as they do so over time scales which are long compared to the time in which a discharged element reaches the end of the initial dilution phase.

To make UM three-dimensional, the model includes an entrainment term corresponding to the third-dimension: a cross-current term. As a result, single-port plumes are simulated as truly three-dimensional entities. Merged plumes are simulated by distributing the cross-current entrainment over all plumes. Dilution from diffusers oriented parallel to the current is estimated by limiting the effective spacing to correspond to a cross-diffuser flow angle of 20 degrees.

9.3.1.2 Medium and Far Dispersion Model

The MIKE 3 Flow Model FM was used to simulate the medium and far field dispersion of the brine discharge. This model uses advection dispersion to simulate the transport and fate of solutes or suspended matter, with the hydrodynamics being integral to the dispersion.

The system is based on the numerical solution of the three-dimensional incompressible Reynolds averaged Navier-Stokes equations invoking the assumptions of Boussinesq and of hydrostatic pressure. Thus, the model consists of continuity, momentum, temperature, salinity and density equations and is closed by a turbulent closure scheme.

Spatial discretisation of the equations is performed using a cell-centered finite volume method, where each cell carries one value. The spatial domain is divided into a series of mesh cells; in the horizontal plane, these cells are unstructured and triangular or rectangular in shape, whilst they are structured in the vertical plane, giving rise to prisms or blocks on a 3D scale.

9.3.2 Data for the Brine Dispersion Study

9.3.2.1 Outfall Location

The location of the proposed outfall was determined by the tidal flow and other geographical constraints. The feasible distance for using Horizontal Directional Drilling (H.D.D.) as a construction technique was also a factor in determining the most appropriate outfall distance from the shore. The use of H.D.D. to construct the outfall greatly reduces the environmental impact when compared with traditional trenched construction techniques. With H.D.D., the sea bed is only disturbed at the break out point, causing an extremely limited footprint of seabed disturbance and a very short term increase in turbidity as the mud used to lubricate the drill head exits the drilled hole. The use of conventional trenching and burial construction techniques to construct the outfall at Islandmagee would generate turbidity throughout a much longer period, would likely require the use of explosives and the rubble mound covering the outfall would likely pose a permanent obstruction to fishing vessels such as scallop dredgers. The position of the outfall will be demonstrated to be far enough offshore (approximately 450m) to provide effective dispersion and avoid the plume attaching to the shoreline whilst also providing minimum environmental impact during construction. The discharge point is located at 27 metres water depth (Chart datum) as shown in Figure 9.18.

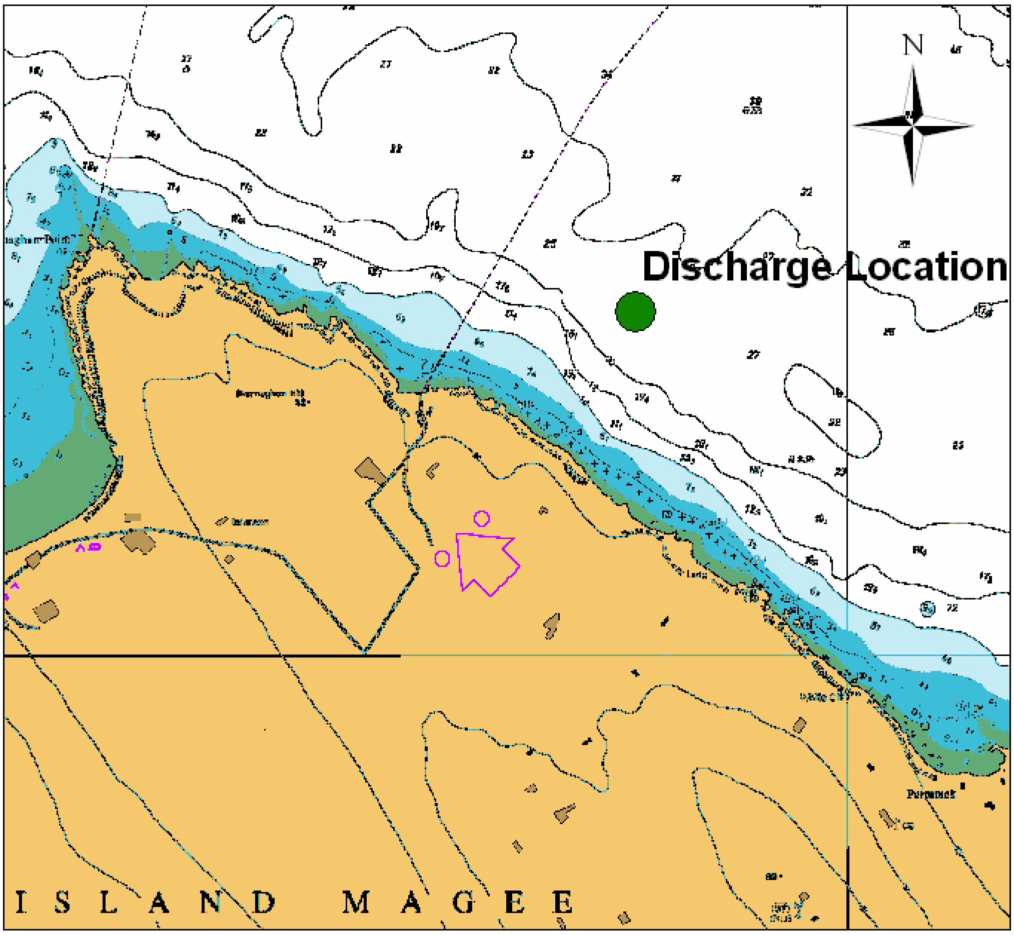

Figure 9.18: Location of the Proposed Outfall

9.3.2.2 Brine Discharge Conditions

The rate of brine discharge will increase as the number of caverns under construction increases with time. The maximum discharge will occur when three caverns are discharging 300m^3/h simultaneously, with a fourth at an early stage of leaching. The following characteristics were assumed for the worst case brine discharge:

- Outfall discharge rate – 1,000 m^3/hour
- Discharge Salinity – 260 PSU
- Discharge Temperature – 21.33°C

Monthly time series data on background salinities and temperatures were acquired from three locations close to the outfall site, one at the entrance to Larne Lough from May 2005 – June 2006, one just west of Skernaghan Point spanning February – November 2009 and one north east of the discharge point at the 60m contour, also 2009. The measurements were taken by AFBI and NIEA as part of their marine water quality monitoring programme. It was found that there was a good degree of correlation of the seasonal variation in salinity and temperature between the sites and years, and that the water column is well mixed with virtually no difference in temperature or salinity observed between measurements taken at the surface and at the bed.

Baseline salinity within the datasets has been observed to fluctuate from 30.5psu[1] to 34.8psu. Calculation of 1 standard deviation across the dataset shows a typical salinity range between 33.9 and 34.5psu and temperature between 8.4 and 12.9°C.

For the purposes of the dispersion model, the following background criteria were therefore used:

- Background Salinity – 34.2 PSU
- Background Temperature – 11.3°C

9.3.3 Brine Dispersion Model Results

9.3.3.1 Initial Dilution

The initial dilution modelling has been undertaken using a diffuser with 3 ports of 0.2m diameter and the flow characteristics given in Section 9.3.2.2. The diffuser ports were at 20m centres with the port exits discharging vertically. The UM3 model was run for a variety of spring and neap flow conditions to simulate the initial dilution at various stages of the tidal cycle.

The brine will initially sink down to the seabed due to the density of the brine solution. The initial trajectory will depend on the tidal velocity. The resulting trajectories for three tidal velocities are presented in Figure 9.19. The plume in red relates to low tidal velocity of <0.1m/s which would be experienced during the turning tide, the plume in blue relates to tidal velocity of 0.3 m/s which would represent peak velocities during neap tide. The plume in green relates to a typical spring tidal velocity of 0.6 m/s.

[1] An anomalous measurement during August/September 2009 which has been attributed to exceptional rainfall events in NI, western Scotland and Cumbria which appear to have influenced the measurements through unusually high levels of surface water discharge

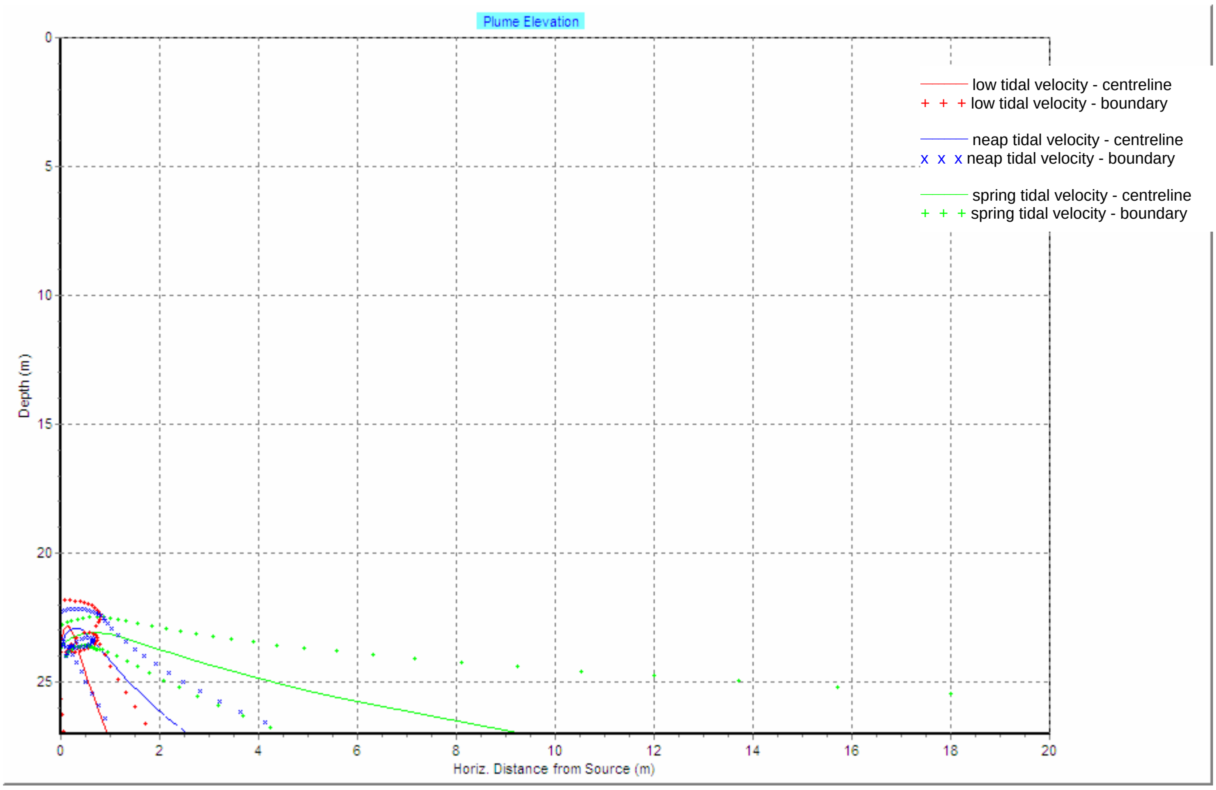

Figure 9.19: Brine plume trajectory, single outlet

The brine will be diluted as the outlet jets spread out with distance from the outfall. Figure 9.20 shows the corresponding initial dilution for the three tidal velocities outlined previously. At 0.1 m/s tidal velocity the initial dilution will be x18 at about 0.9m from the outfall which corresponds to a salinity of 49.4 psu at the point where the plume reaches the seabed. At 0.3 m/s tidal velocity the initial dilution will be x30 at about 2.3m from the outfall with a salinity of 43.5 psu. And finally at 0.6 m/s tidal velocity the salinity is predicted to be 38.5 psu with an initial dilution of x66 when the plume reaches the seabed at a distance of 5.3m from the outfall.

Beyond the point where the brine first contacts the seabed the Plumes model predicts dilution to continue to increase rapidly such that a dilution of >200:1 (36.6psu) is achieved at between 5m and 10m from the point of discharge.

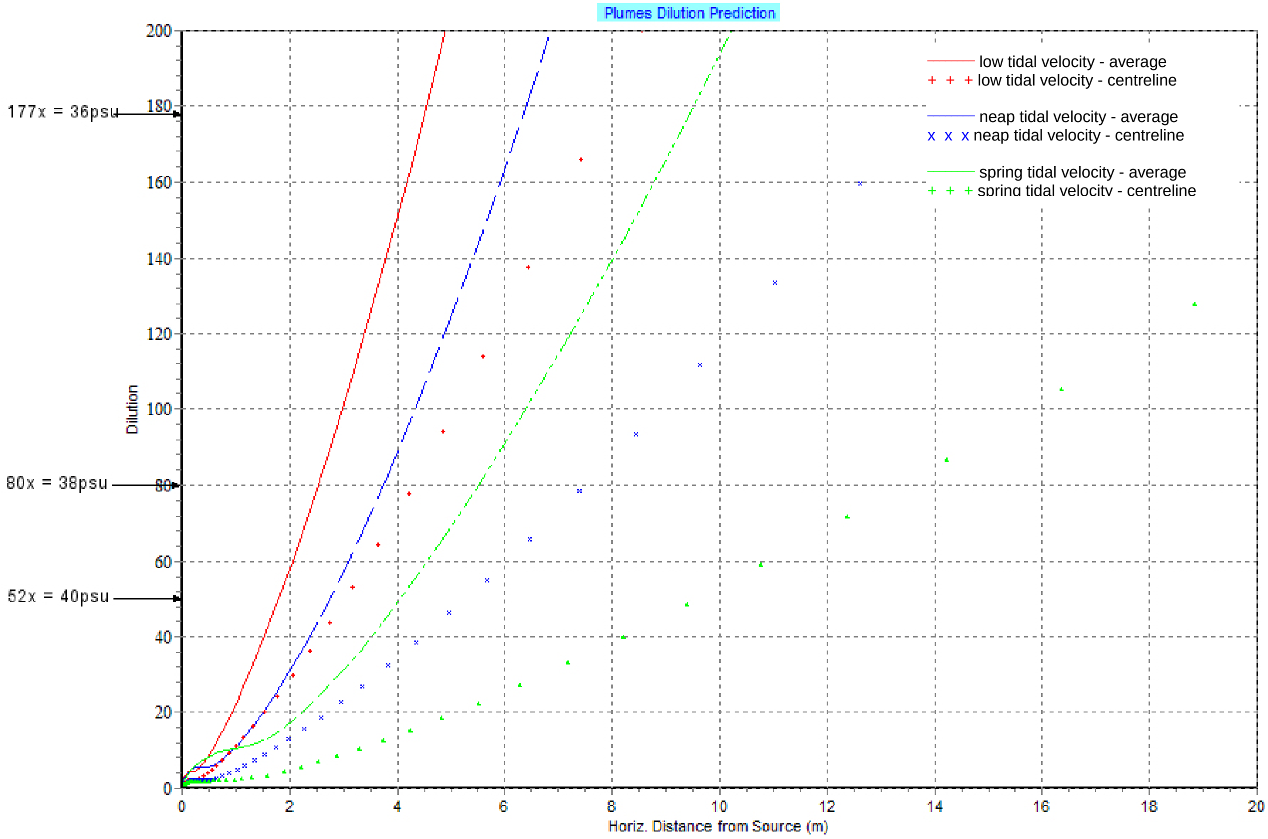

Figure 9.20: Initial dilution prediction

9.3.4 Medium and Far Field Brine Dispersion

The continuing dispersion of the brine in the medium to far field was simulated to show the influence of the brine beyond the initial mixing zone, away from the immediate area of the outfall.

The results of the simulations are shown in terms of overall maximum concentration envelopes, depicting the maximum salinity level recorded in every model cell at any stage during the model simulation period as well as snapshots of salinity concentrations at particular times during the tidal cycle. Since the concentration envelope depicts the maximum salinity at each point even though it may only occur for a very short time during the tidal cycle under consideration it should be viewed in conjunction with the plots that show salinity levels at particular times through the tidal cycle to obtain a measure of the significance of the peak value at any particular location in the model.

The medium and far field simulations demonstrate the way in which the brine is dispersed through the water column as the discharge is advected by tidal currents. As the brine will initially be discharged in the lower part of the water column and is negatively buoyant, the simulations have been undertaken by placing the sources at 1.5m above the bed and tracking the concentrations across four zones within the water column. The actual dimensions of the four zones varied with water depth, but were defined by proportioning the water column, as shown in

Table 9.2 and Figure 9.18. Since the brine discharge is negatively buoyant, it was important to have thinner layers at the bottom of the water column to establish the maximum concentrations being dispersed from the outfall close to the bed. Further up the water column, the brine is more dispersed, and thicker layers could be used.

Table 9.2: Table showing Water Column division into Layers within the Model

Layer	Percentage Depth
Surface Layer 4	35%
Middle Layer 3	35%
Middle Layer 2	15%
Bottom Layer 1	15%

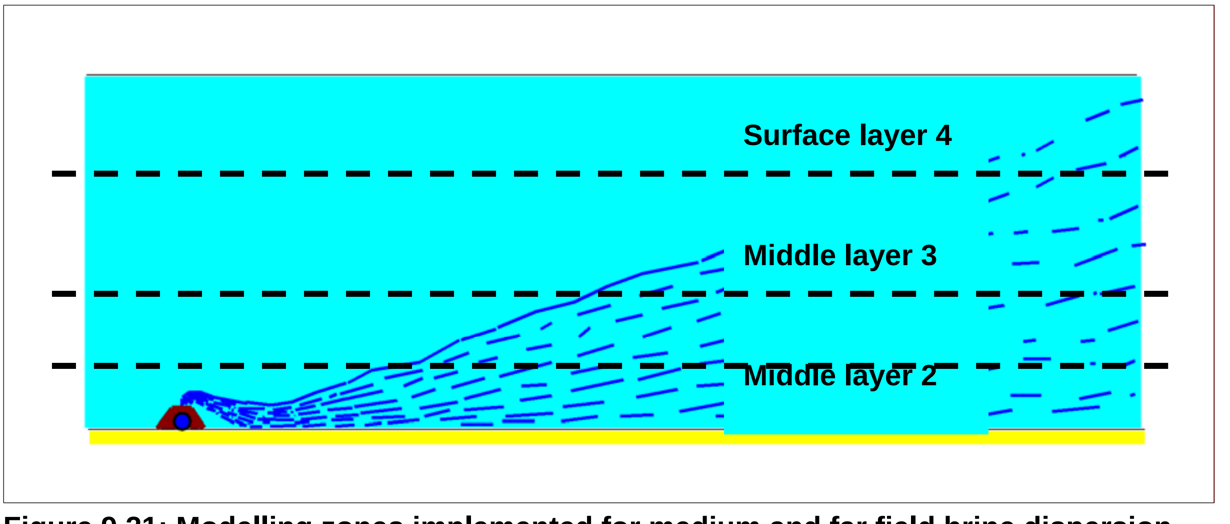

Figure 9.21: Modelling zones implemented for medium and far field brine dispersion

9.3.4.1 Brine dispersion during neap tides

Figure 9.22 shows the maximum salinity envelope for the brine solution during the neap tidal cycle for the bottom layer in which concentrations are greatest. The corresponding salinity distributions at high tide, low tide, mid ebb and mid flood are shown in Figure 9.23, Figure 9.24, Figure 9.25 and Figure 9.26 respectively. Examination of these Figures illustrates that the larger increases in salinity only occur for a short period during the tidal cycle. The maximum salinity for the middle layers (2 and 3) and surface layer (4) are shown in Figure 9.27, Figure 9.28 and Figure 9.29 respectively to illustrate the significant decrease in salinity with distance up through the water column, with very little impact evident at the surface layer. This can also be seen in Figure 9.30, Figure 9.31 and Figure 9.32 which shows a vertical slice through the water column around the outfall at low tide, mid flood and mid ebb respectively.

It should be noted that the salinity increases predicted are relatively small; the contour intervals plotted representing increases of 0.25-0.50PSU. A maximum increase in salinity of less than 4PSU was recorded throughout the simulations. The baseline salinity data obtained from AFBI and NIEA indicate that background salinities in this part of the North Channel off Islandmagee can range between circa 30.5PSU and 34.8 PSU. Any salinity increase in excess of the range normally experienced in seasonal variations is expected to be restricted to the initial mixing zone, which is an area less than 100 metres from the outfall.

With regard to temperature, changes were also very small compared to background, with a noticeable increase only occurring for a short period of time within the tidal cycle, i.e. at slack water when the dispersion was at the lowest levels. Figure 9.33 shows the maximum temperature envelope for the brine solution during the neap tidal cycle for the bottom layer in which the temperature effects are greatest. A vertical slice through the water column is also shown in Figure 9.34 and this illustrates how the temperature decreases towards the water surface. The location of this vertical slice is shown in Figure 9.35.

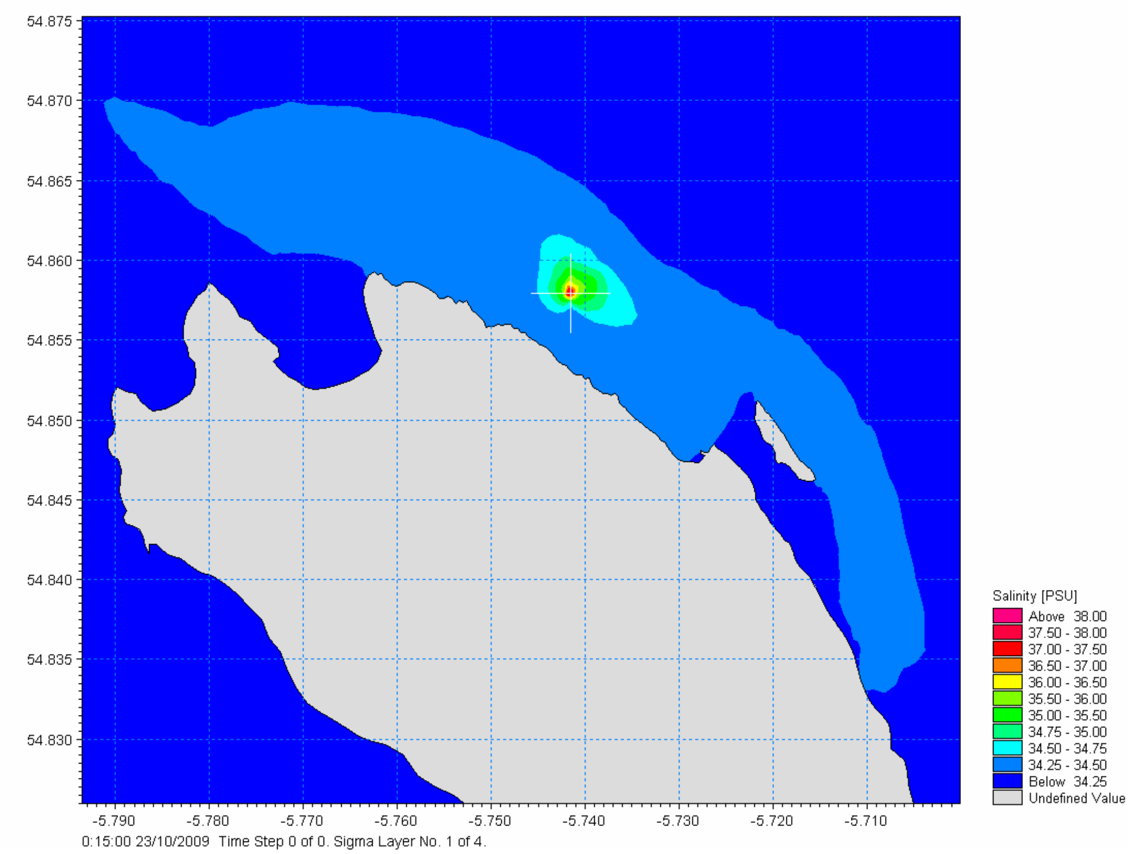

Figure 9.22: Maximum Salinity during a Neap Tide Cycle – Bottom Layer 1

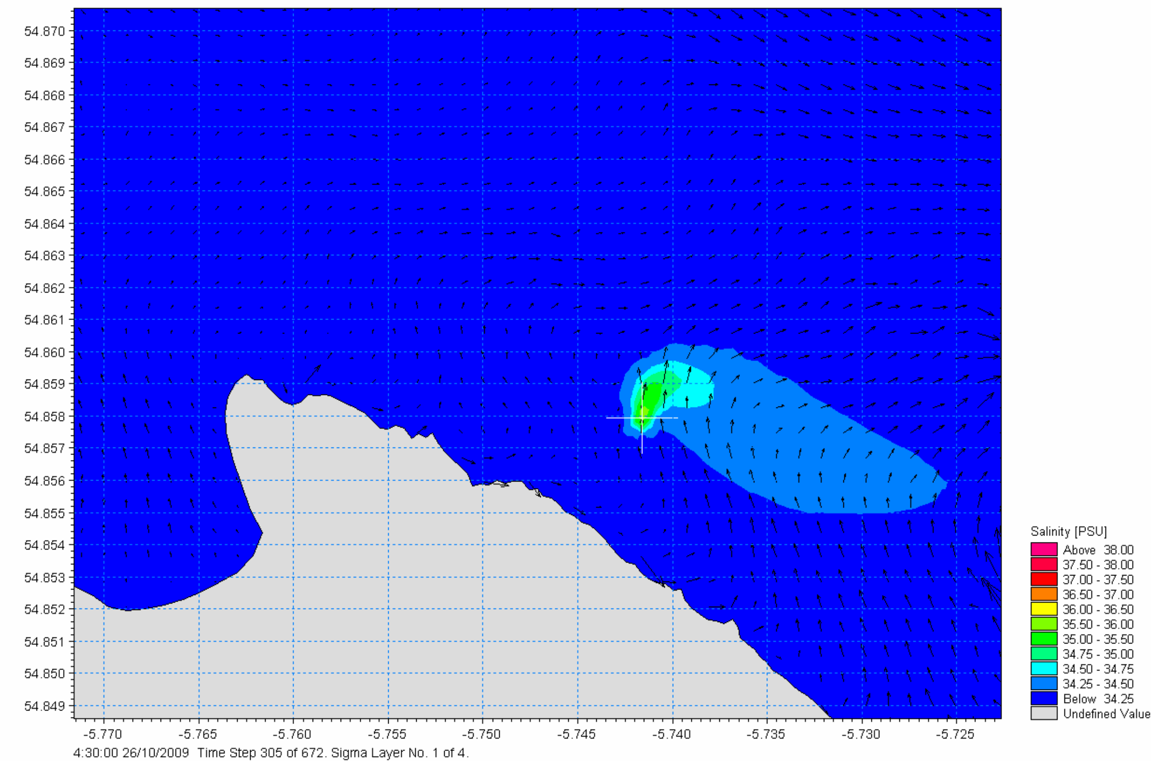

Figure 9.23: Salinity and Current Vectors at High Neap Tide – Bottom Layer 1

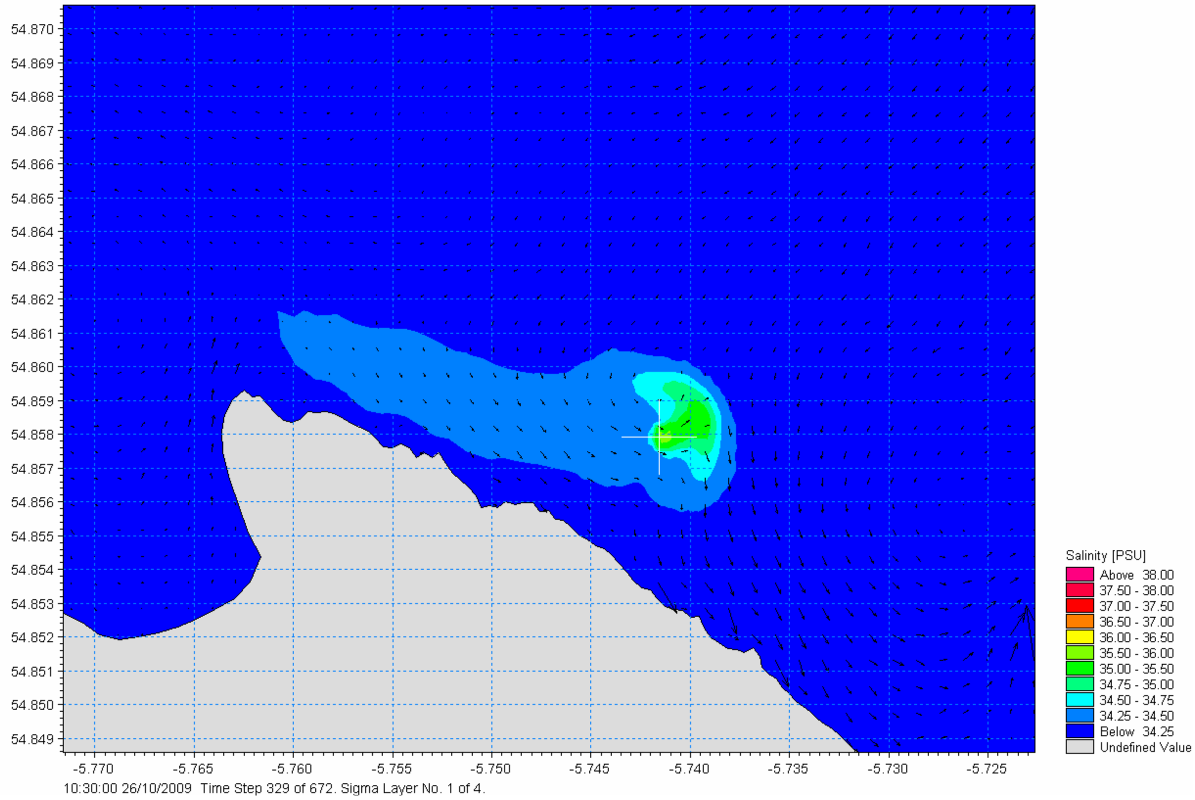

Figure 9.24: Salinity and Current Vectors at Low Neap Tide – Bottom Layer 1

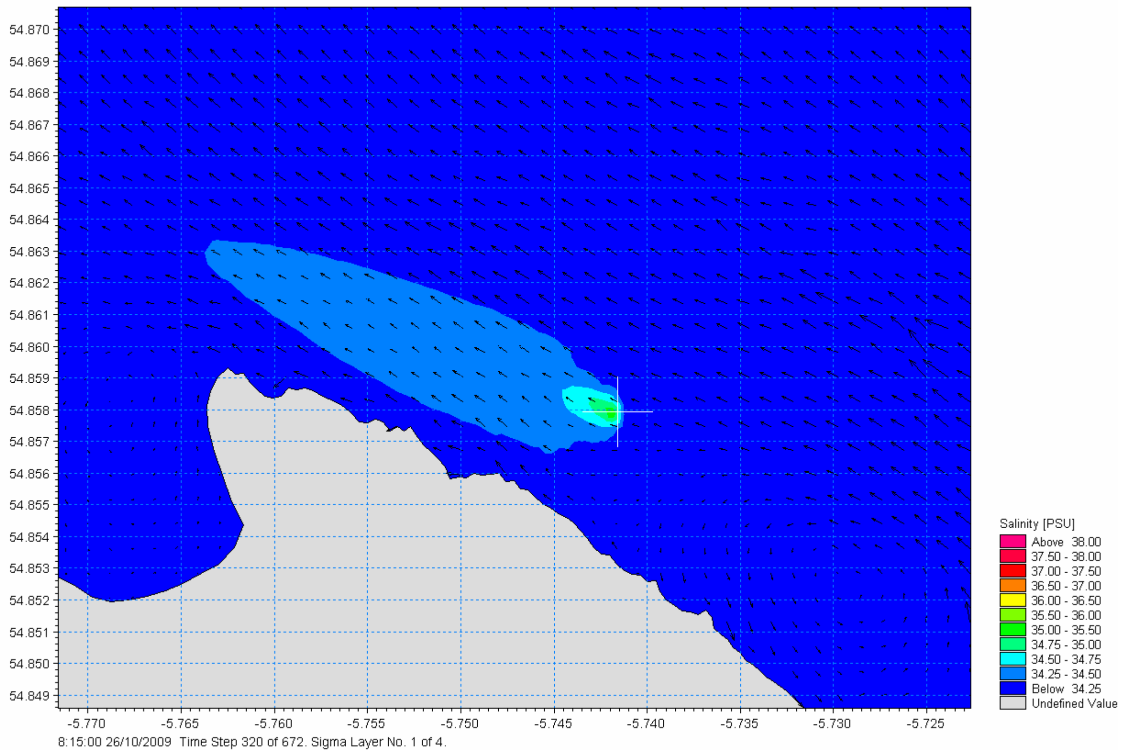

Figure 9.25: Salinity and Current Vectors at Mid Ebb Neap Tide – Bottom Layer 1

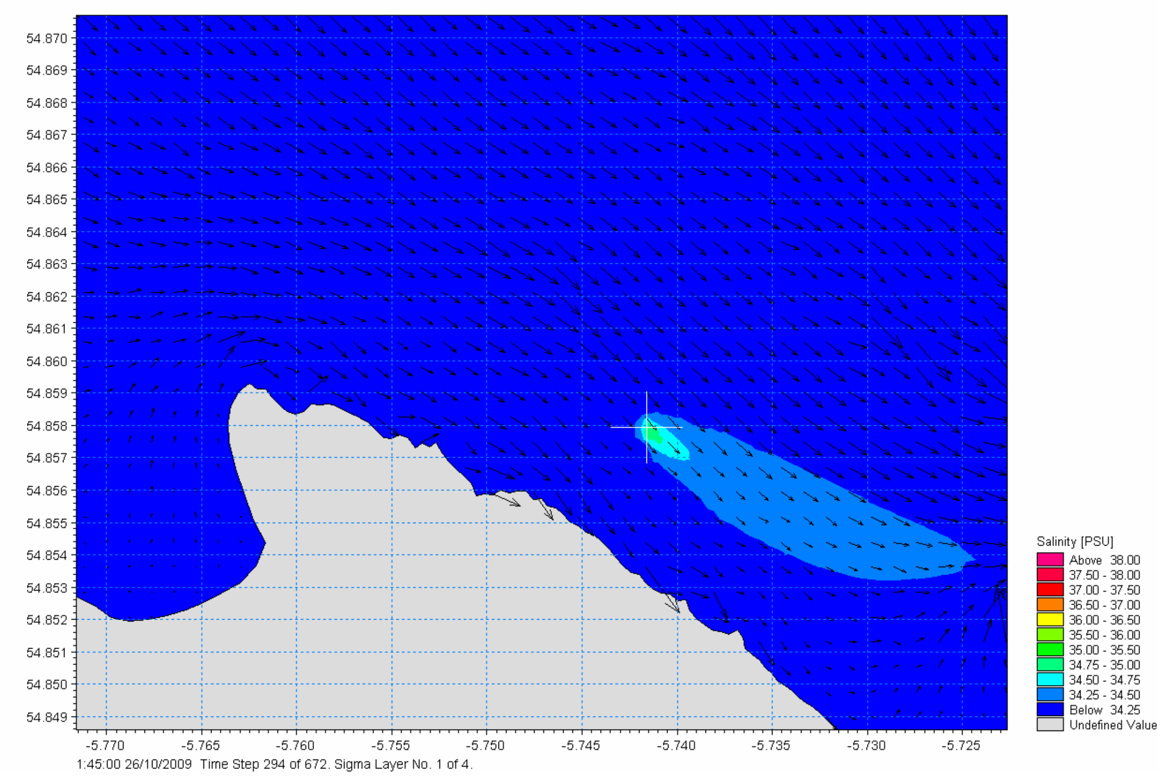

Figure 9.26: Salinity and Current Vectors at Mid Flood Neap Tide – Bottom Layer 1

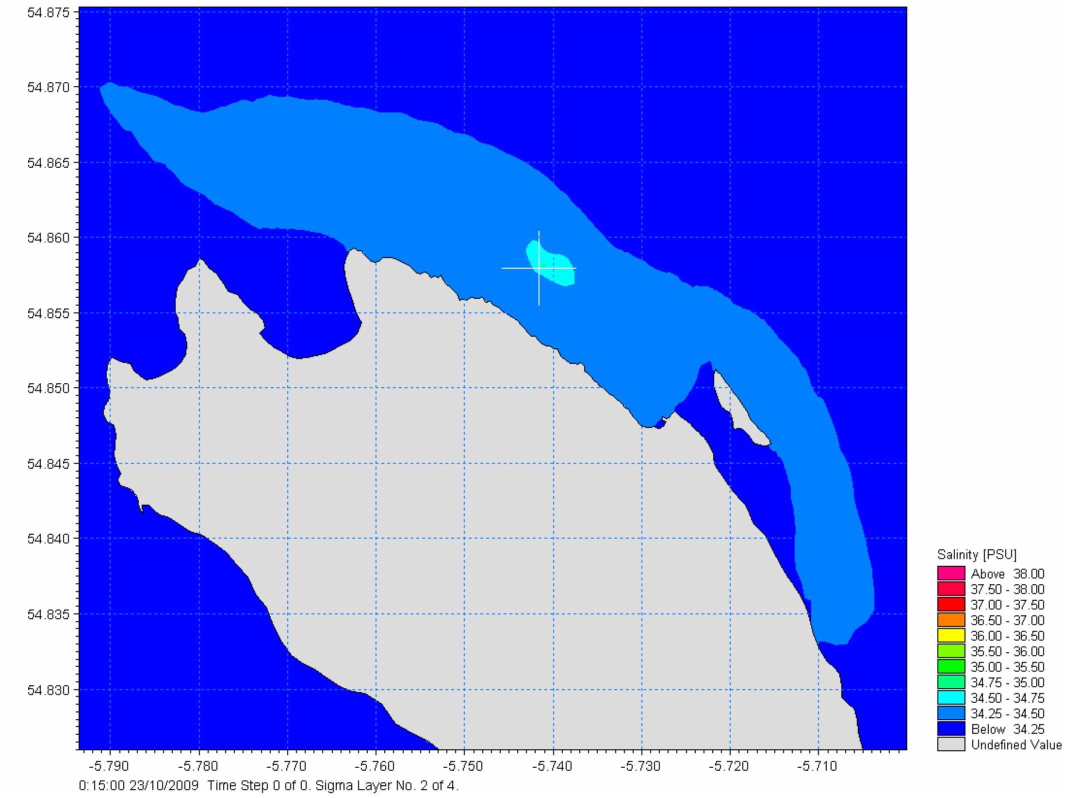

Figure 9.27: Maximum Salinity during a Neap Tide Cycle – Middle Layer 2

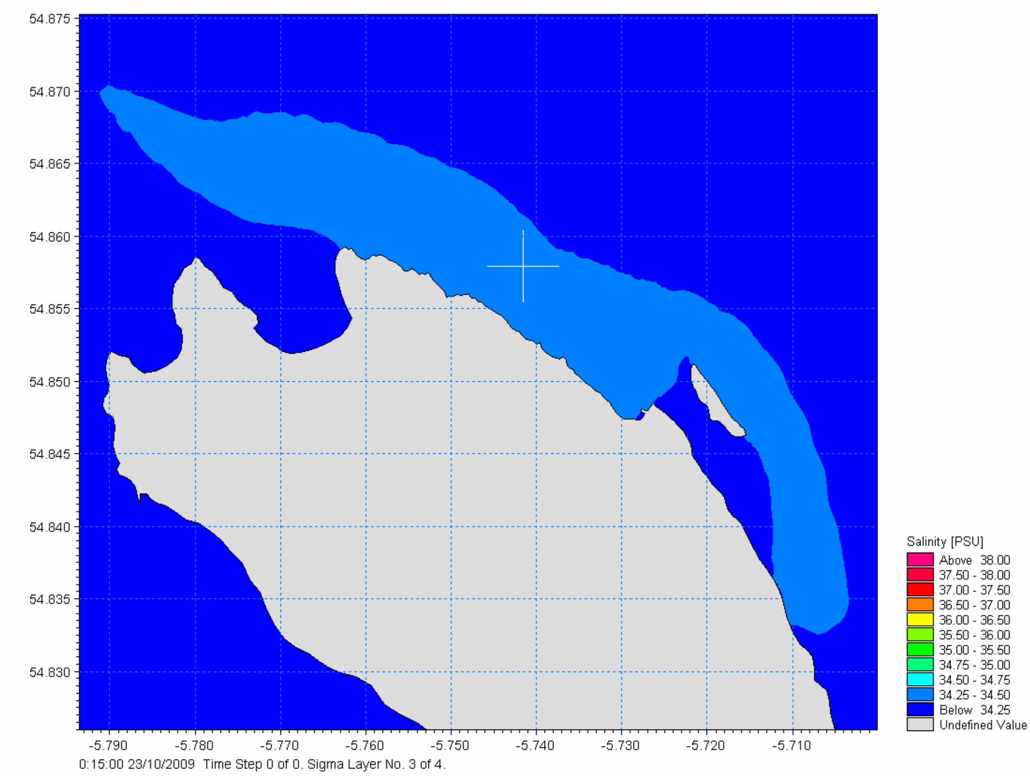

Figure 9.28: Maximum Salinity during a Neap Tide Cycle – Middle Layer 3

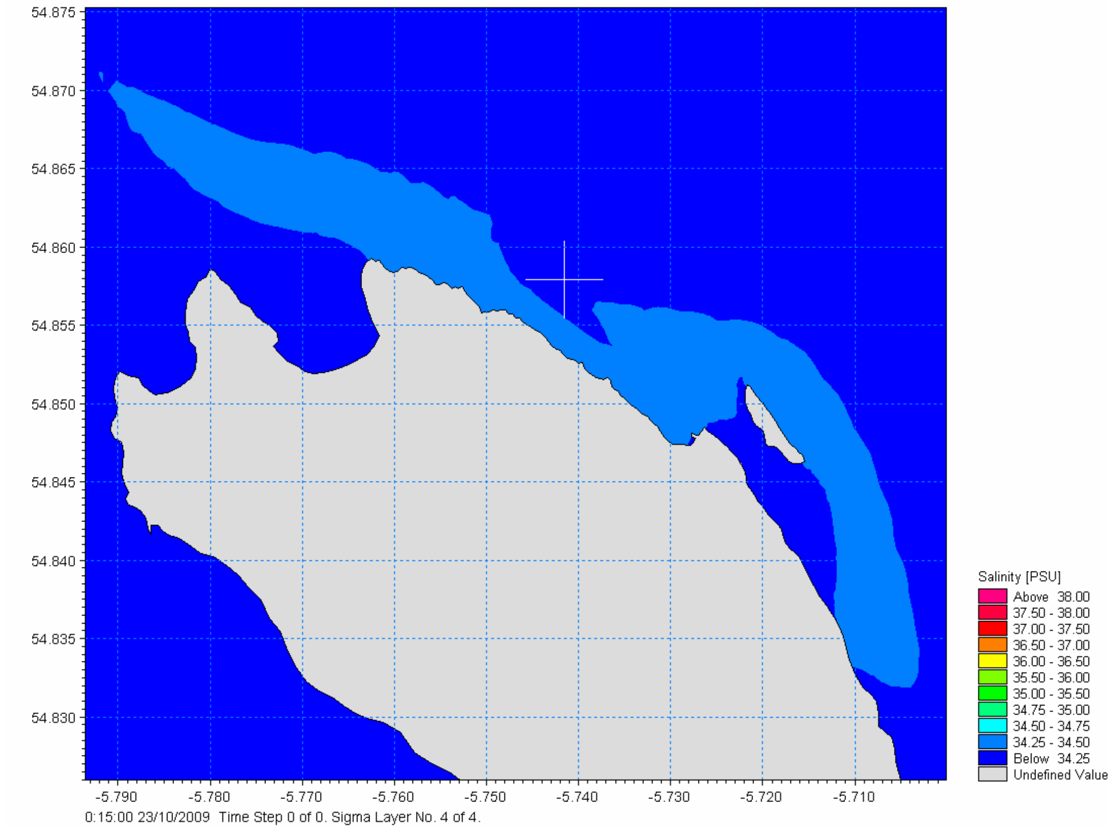

Figure 9.29: Maximum Salinity during a Neap Tide Cycle – Surface Layer 4

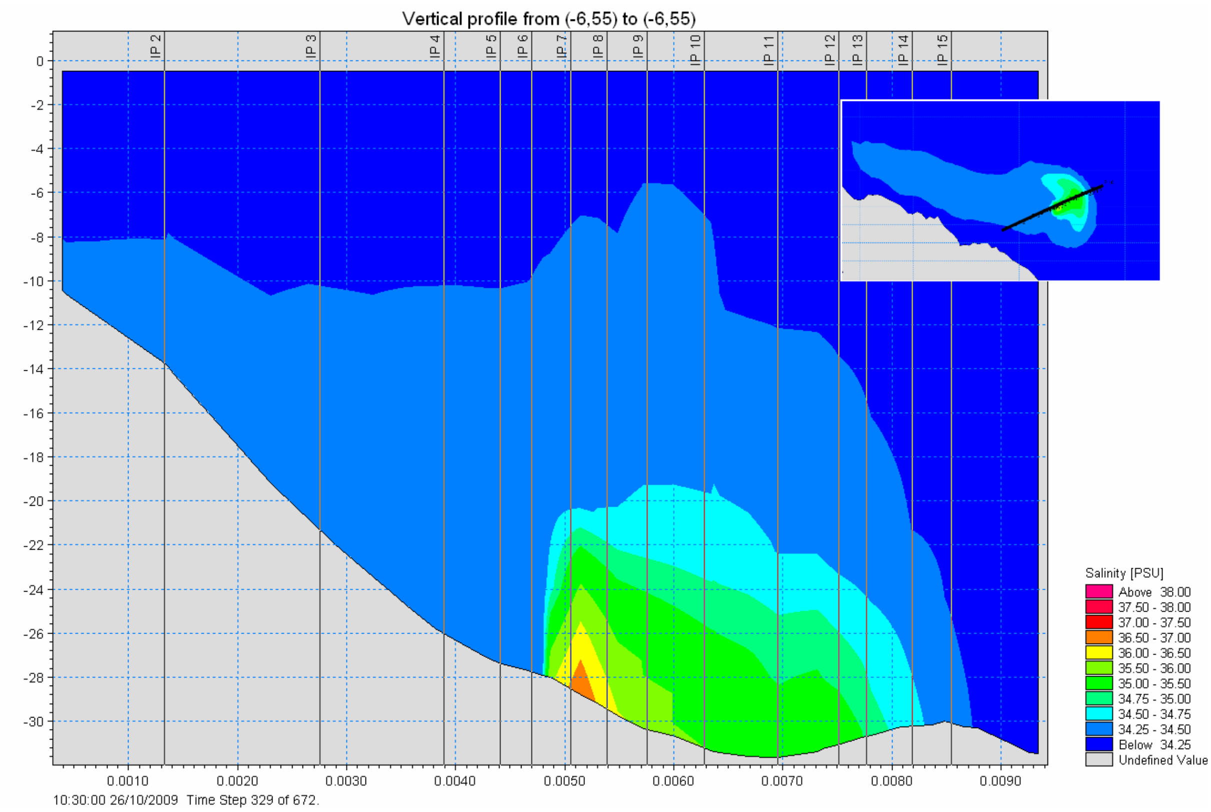

Figure 9.30: Vertical Profile of the Salinity distribution at low tide during a Neap Tide Cycle

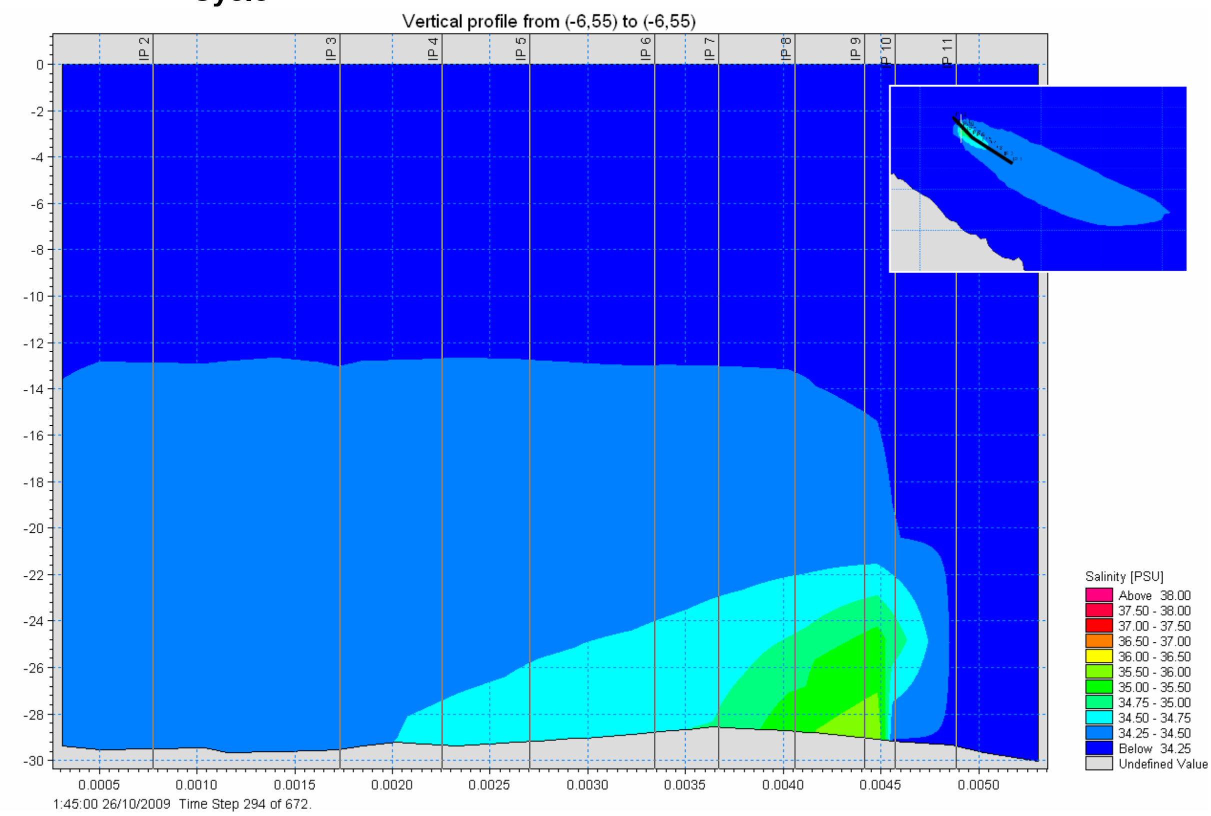

Figure 9.31: Vertical Profile of the Salinity distribution at mid flood during a Neap Tide Cycle

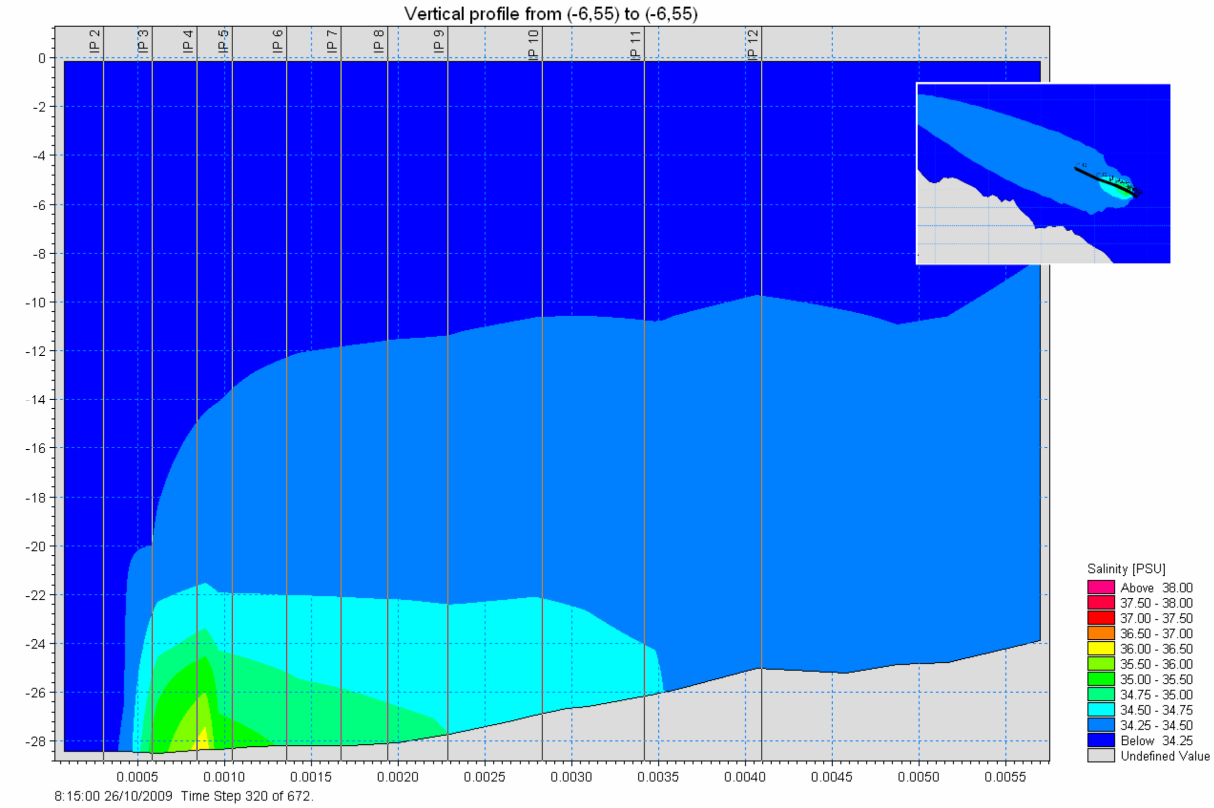

Figure 9.32: Vertical Profile of the Salinity distribution at mid ebb during a Neap Tide Cycle

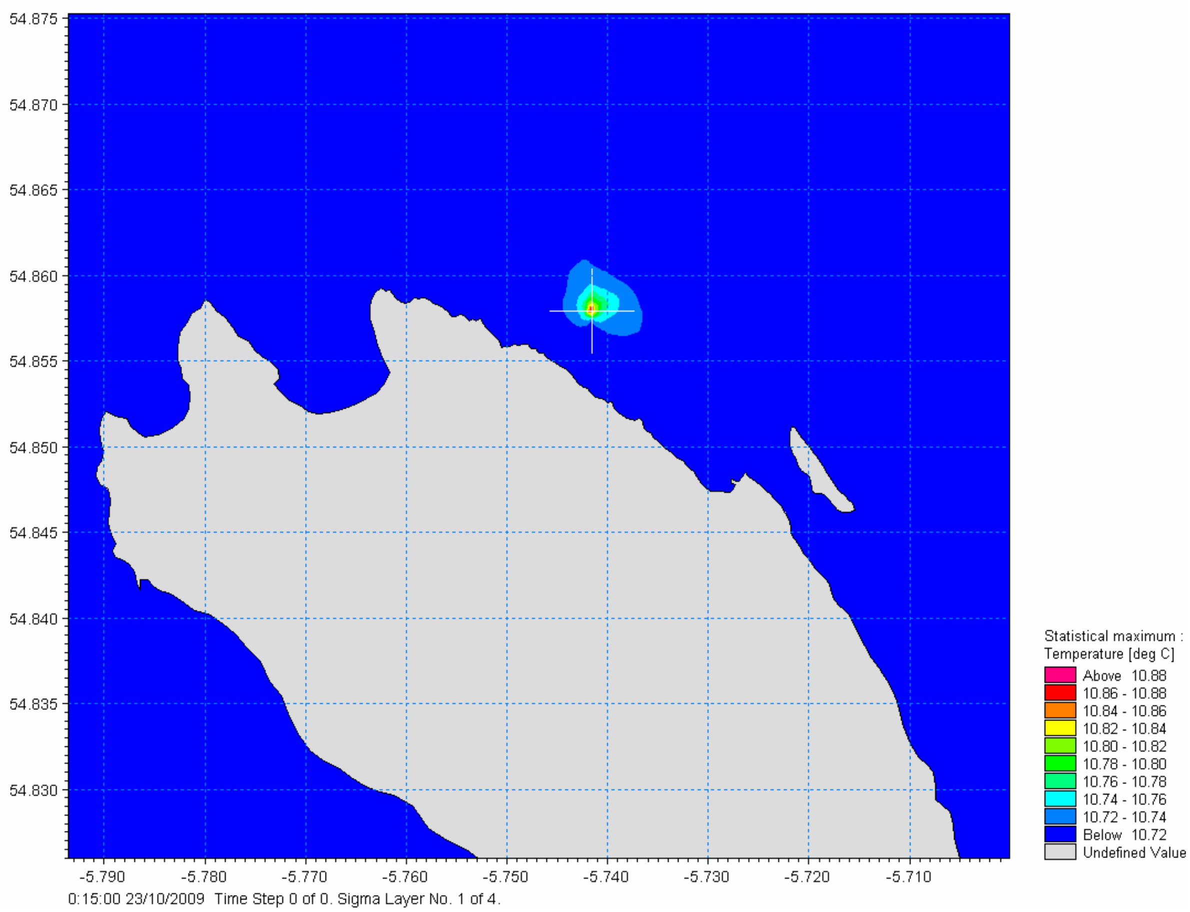

Figure 9.33: Maximum Temperature during a Neap Tide Cycle – Bottom Layer 1

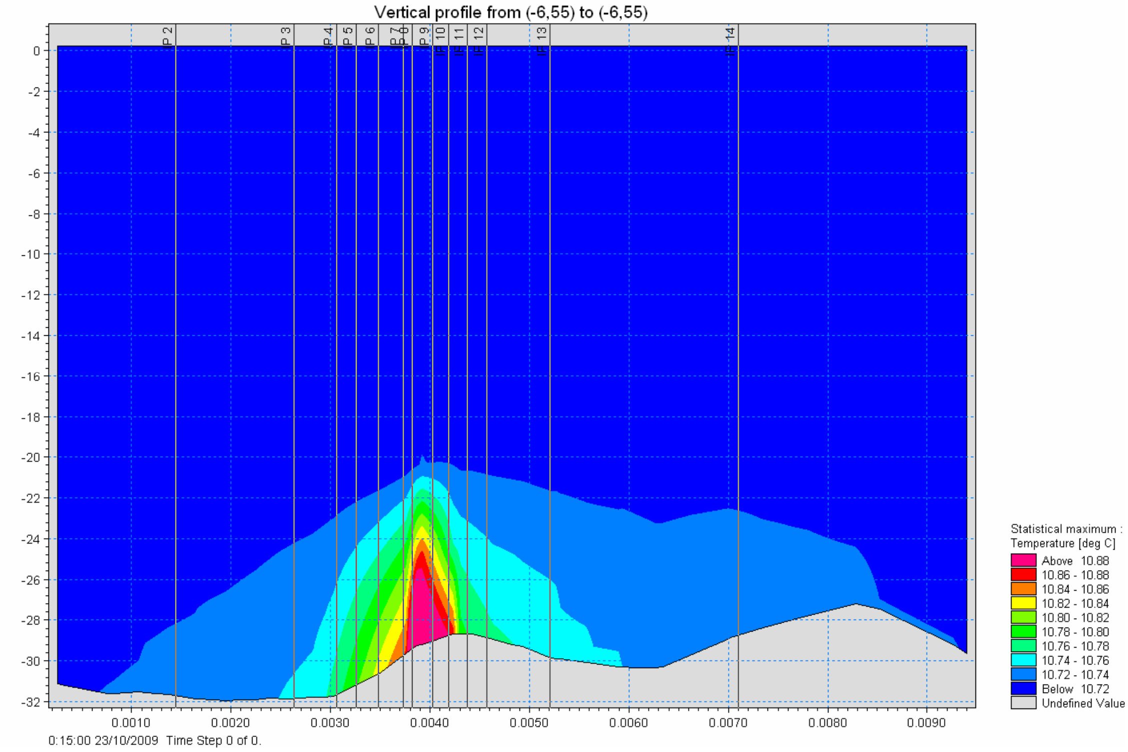

Figure 9.34: Vertical Profile of Maximum Temperature distribution during a Neap Tide Cycle

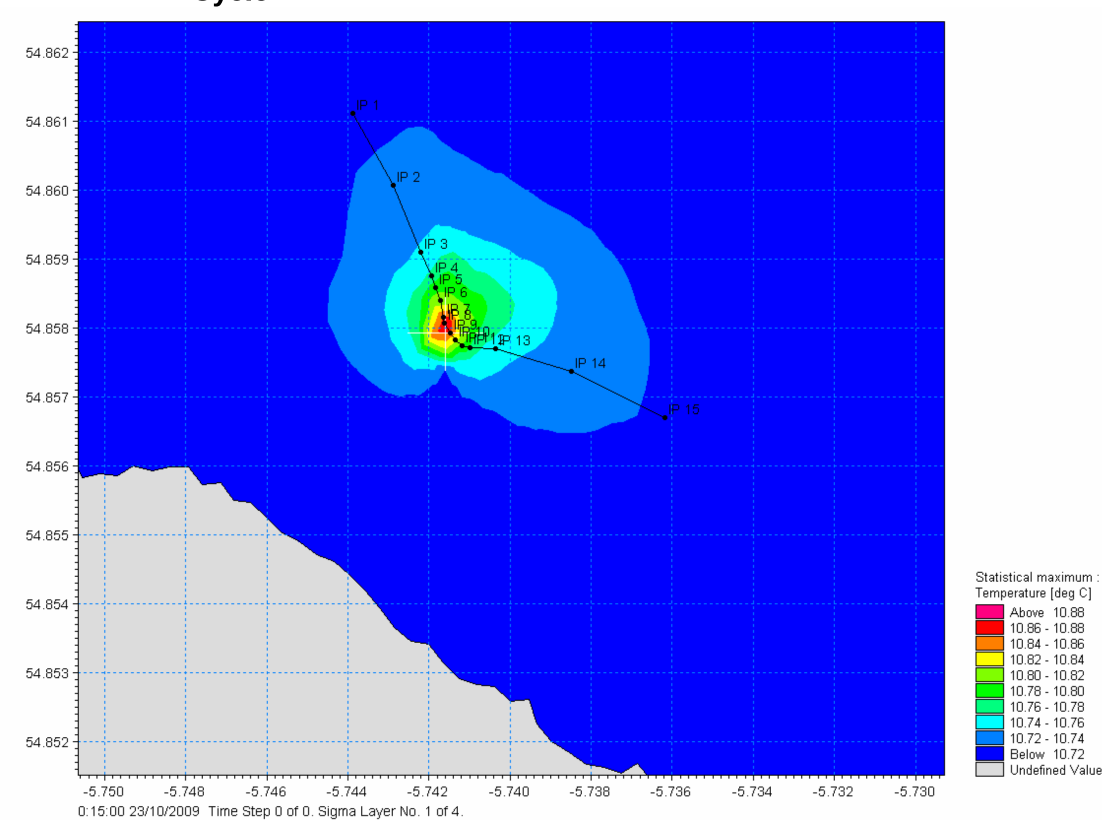

Figure 9.35: Location of Vertical Profile Shown in Figure 4.17

9.3.4.2 Brine dispersion during spring tides

The rate of brine dispersion is directly related to the magnitude of the tidal velocities. The previous section illustrated that during neap tides the impact on ambient salinity concentrations is minimal, therefore during spring tides, where peak tidal velocities are typically double those of the neaps, the impact is expected to be further reduced.

For completeness the maximum concentration envelope for the bottom layer during spring tides is presented in Figure 9.36. Figure 9.37, Figure 9.38, Figure 9.39 and Figure 9.40 show the corresponding salinity concentrations at high tide, low tide, mid ebb and mid flood. As before, these show that the higher salinity levels only occur for short periods beyond the immediate vicinity of the discharge location.

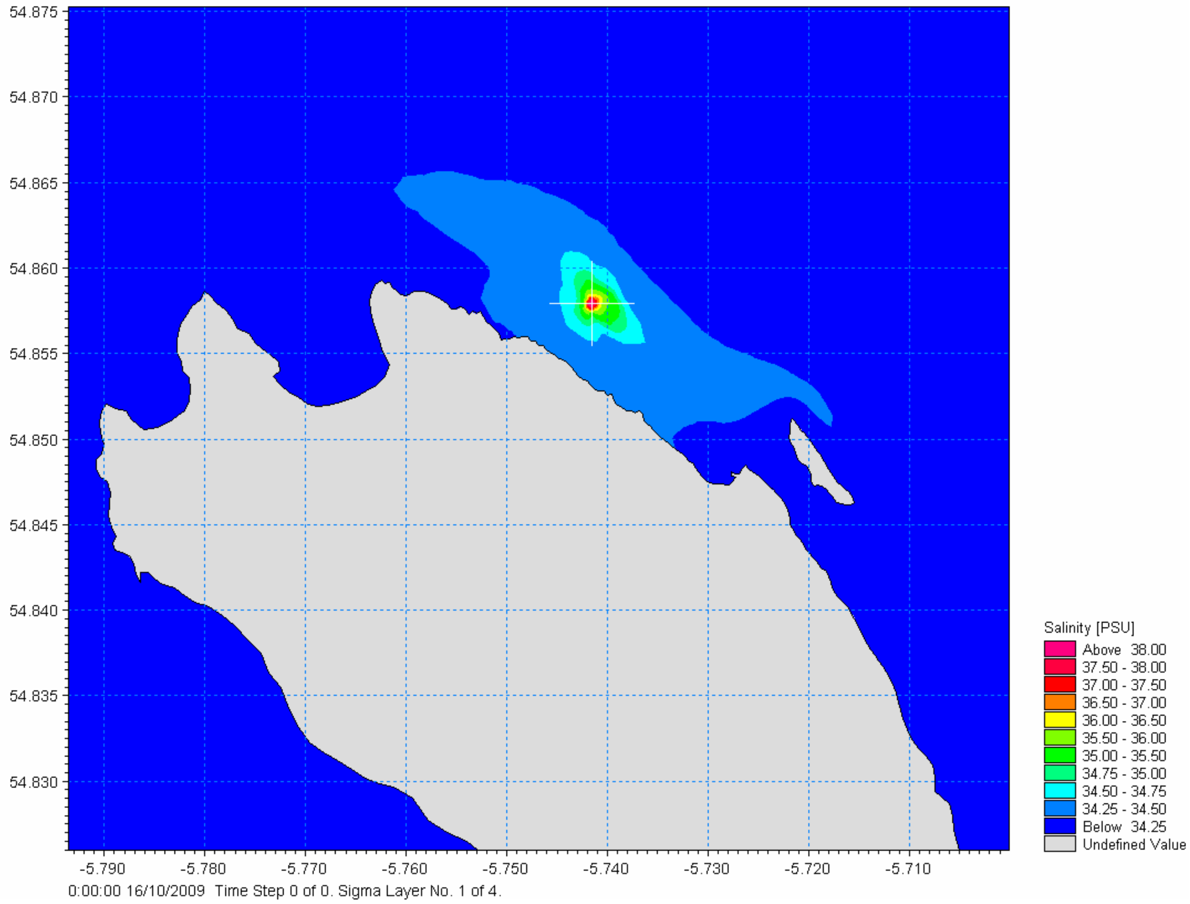

Figure 9.36: Maximum Salinity during a Spring Tide Cycle - Bottom Layer 1

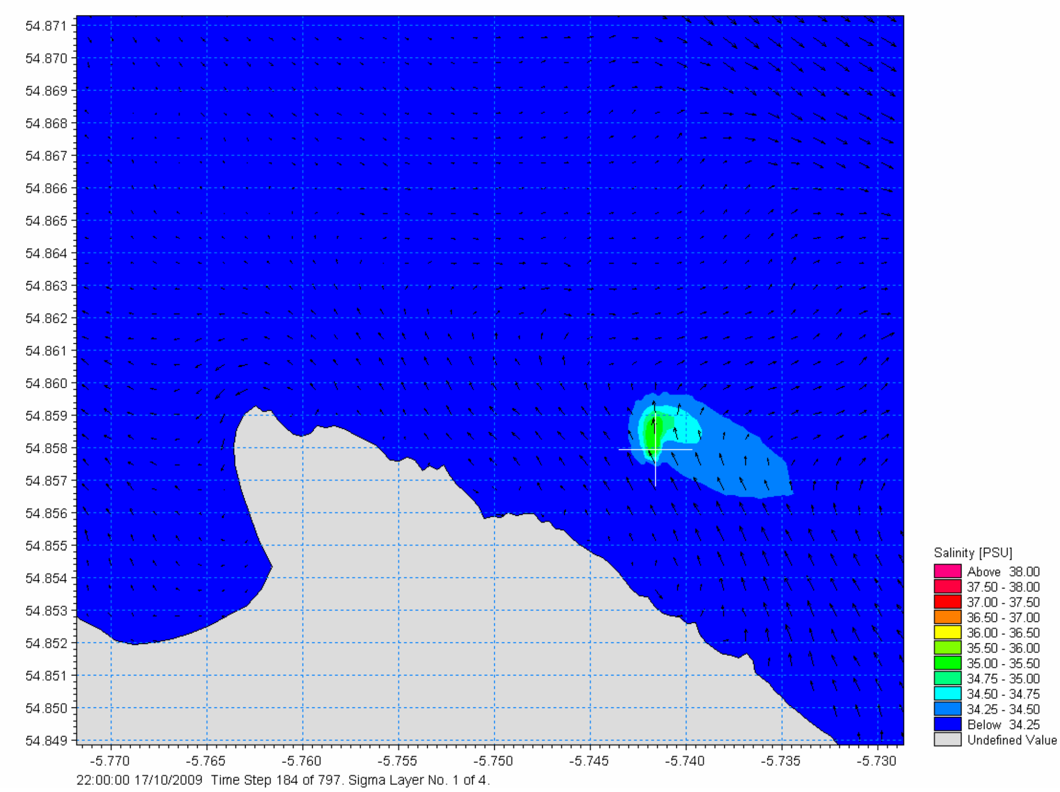

Figure 9.37: Salinity and Current Vectors at High Spring Tide – Bottom Layer 1

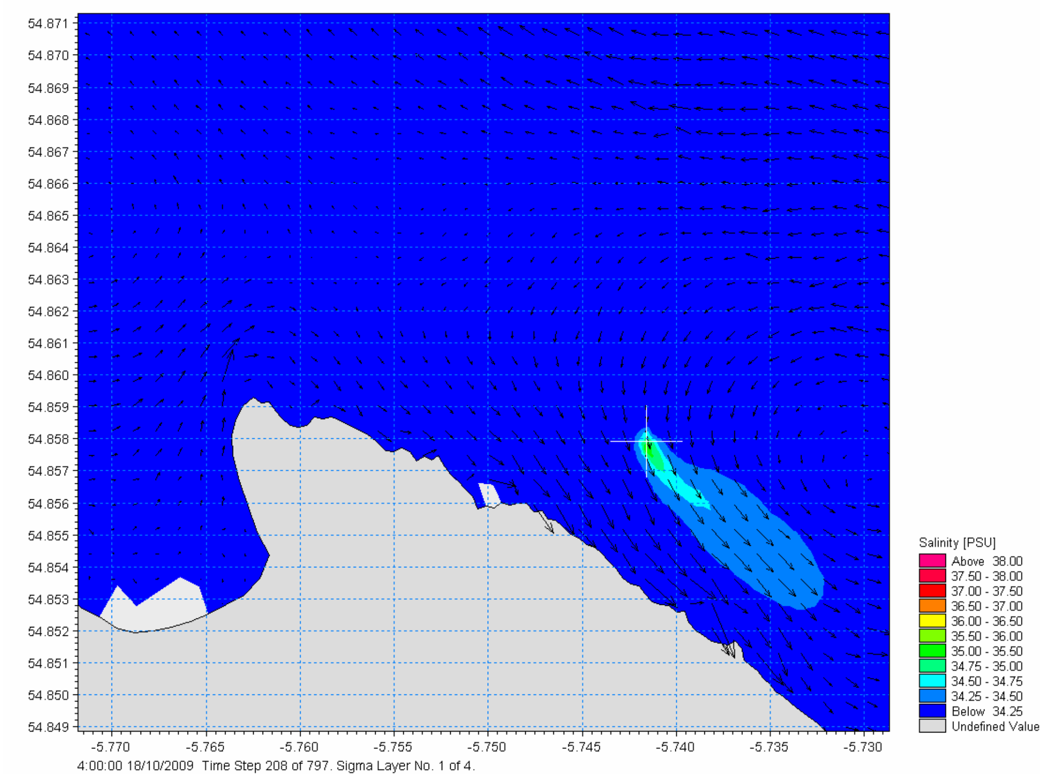

Figure 9.38: Salinity and Current Vectors at Low Spring Tide – Bottom Layer 1

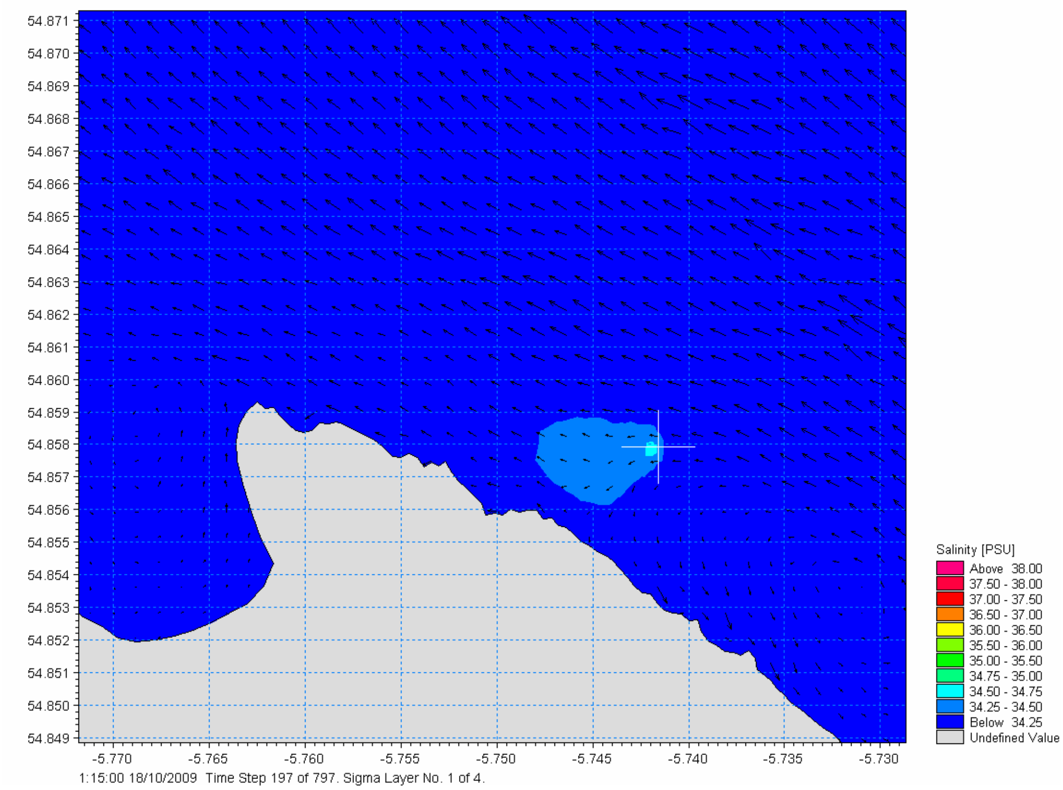

Figure 9.39: Salinity and Current Vectors at Mid Ebb Spring Tide – Bottom Layer 1

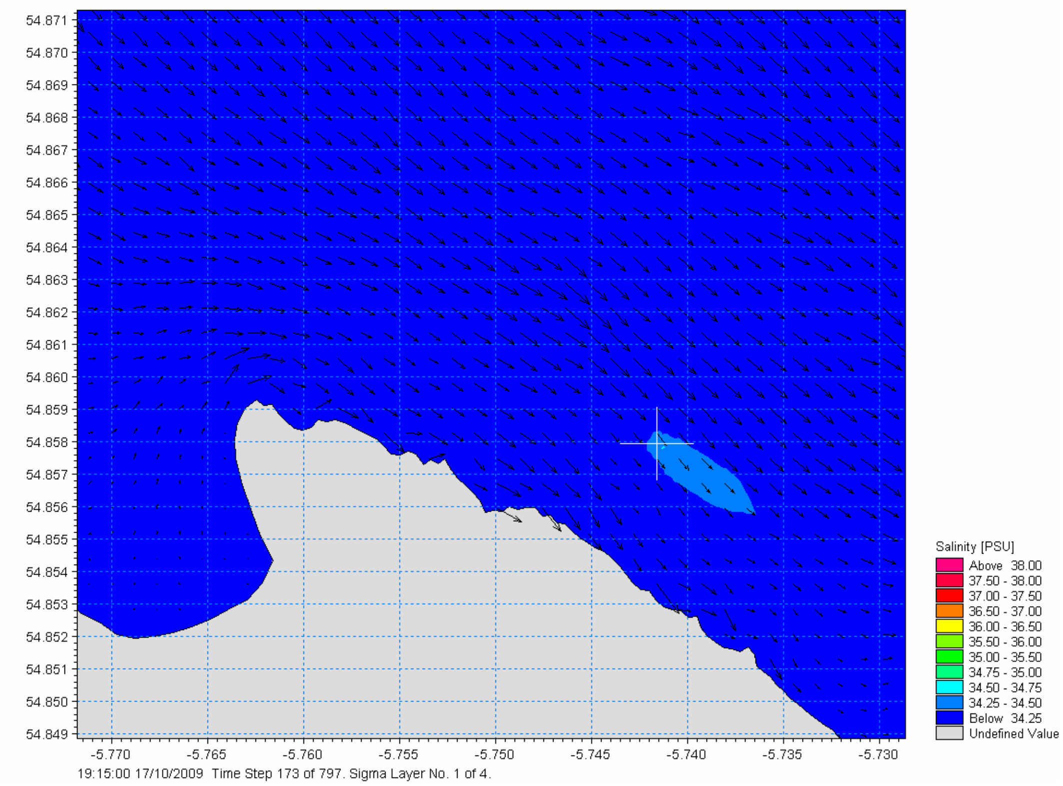

Figure 9.40: Salinity and Current Vectors at Mid Flood Spring Tide – Bottom Layer 1

9.4 Potential for Increased Suspended Sediments to Arise from Leaching Activities

9.4.1 Suspension of Insolubles within the leached salt

At present, the outline leaching model discussed in section 4.6.2 of Chapter 4 *"Project Description"* is based primarily on information obtained from logging of the Larne-2 borehole, and from DEEP Underground Engineering Gmbh (the leaching design engineers)', extensive experience in solution mining of salt caverns.

From the available information, DEEP have estimated the insoluble content within the Permian salt at Larne Lough to be approximately 5%. This will be confirmed upon the recovery of salt cores from the first borehole at the proposed site, but the data acquired during the seismic survey is of sufficient quality to suggest that the actual insolubles content will not vary significantly from this estimate.

The storage volume is created by circulating seawater through the leaching strings during the cavern leaching phase. Two different 'leaching modes' are applied:

- 'direct mode' or 'bottom injection' (injection of sea water through the inner leaching string), and
- 'reverse mode' or 'top injection' (injection of sea water through the annulus or void between the inner and outer leaching strings).

By switching between these leaching modes, the cavern is shaped within the boundaries of the salt layer. A non-leachable "blanket" is used to protect the roof of the cavern, thus maintaining an appropriate thickness of intact, impermeable salt between the cavern roof and the permeable strata above it. For this project, the intention is to use Nitrogen as the blanket medium. Further activities such as changing the depth of the leaching strings as well as moving the blanket level will permit fine tuning of the cavern's shape and size.

The velocities of the circulating water within the caverns as they are being leached will be relatively low. This allows not only the larger insoluble inclusions within the salt to fall to the sump created at the base of the cavern, but also the finer particles will also settle out of suspension where they too will accumulate within the sump. The sump's contents will remain inside the cavern for its lifetime.

In order to further mitigate against elevated levels of suspended sediments being discharged by the outfall, two holding tanks are located on the surface at the brine leaching facilities. These tanks allow further settlement and removal of fine particles which may have made it to the surface. The tanks also allow the temperature and content of the brine to be monitored continuously as it is being discharged.

Monitoring of a currently operational brine outfall from the leaching of salt caverns for the Scottish and Southern Energy gas storage facility at Aldbrough in North East England (Jacobs Engineering, 2009) has shown that the level of suspended sediments within the discharged brine has actually been found to be significantly lower than the natural levels of suspended sediment within the sea water being drawn in through the intake. It is therefore considered that it is unlikely that the proposed brine outfall offshore from Islandmagee will have any significant impact on turbidity.

9.4.2 Potential for discharge of foam

Through the consultations held for this project, Islandmagee Storage have been made aware that local residents are unhappy about a foam which is occasionally discharged from an outfall belonging to Ballylumford Power Station. The foam is created mainly from proteins within algae and other organic matter which are drawn in through the power station's intake. This organic matter becomes vigorously mixed with water and air during the processes within the power station and subsequently a foam is created. The same process occurs in nature, where breaking waves may create sufficient agitation of organic matter to cause foam to be washed up on to beaches.

Although the sea water intakes will be screened to prevent larger organisms from being aspirated into the sea water and brine pumping system for the Islandmagee Storage Project, the screening will not be able to prevent all organic matter from being aspirated and circulated within the caverns. Consequently, there is a small risk that foam may also be generated. However, as outlined above, the dwell time of the leaching water within the caverns and the low velocities will permit the great majority of aspirated organic matter to settle into the sump of the cavern. Sprinkler mechanisms are also employed within the surface tanks to "damp down" and remove the air from any foam which might remain present prior to discharge.

With these mitigation measures in place, it is considered that it is unlikely that the proposed brine outfall offshore from Islandmagee will create a significant amount of foam.

9.5 H.D.D. Breakout Discharge Conditions

The route for the offshore portion of the outfall is proposed to be constructed using the Horizontal Directional Drilling (H.D.D.) construction method (refer to Section 4.2.5 on page 4-29 of Chapter 4, *"Project Description"* for full explanation of the H.D.D. methodology). During H.D.D. the majority of operations occur at the H.D.D. entry point which is located above the cliffs, approximately 150m inland.

The H.D.D. performs as a blind hole with cuttings and drilling mud being retrieved and recycled at the inshore end until the drill breaks through the seabed at, or close to, the discharge point. The drilling mud routinely used for HDD is bentonite, a fine, natural clay which is non-toxic and non-polluting. It is pumped from tanks to the head of the drilling bit through the centre of the drill pipe. The lubricant mixes with the drillings, which are forced back along the hole under pressure, and into a recycling plant to recover much of the bentonite. Waste material (mostly cuttings) is then transported away from site by a licensed waste contractor to a suitably licensed disposal site in accordance with the requirements of the NIEA.

A small discharge of cuttings and drilling mud will occur when the drill finally breaks through the seabed. The assumed quantity of drilling mud and the make up of this material would be as follows:

Volume of mud spilled	116 cubic metres
Duration of spill	3 hours
Percentage of bentonite	6%
Percentage of cuttings	12%

Representative particle sizes for the bentonite and the cuttings were estimated from available published data as follows:

Bentonite	100% clay
Cuttings*	33% Clay at 0.001mm
	39% silt at 0.01mm
	28% fine sand at 0.1mm

*These values will be confirmed during detailed design phase, following ground investigation studies.

The discharge is largely made up of fresh water, with approximately 10 l/s being discharged for the three hour period and with a suspended solids concentration of 325gl. The release would take place into an average water depth of 27m (CD) with an average tidal current speed of 0.22m/s, as illustrated in Figure 9.41. Therefore the magnitude of the discharge constitutes less than 0.3% of the flow passing over the opening alone.

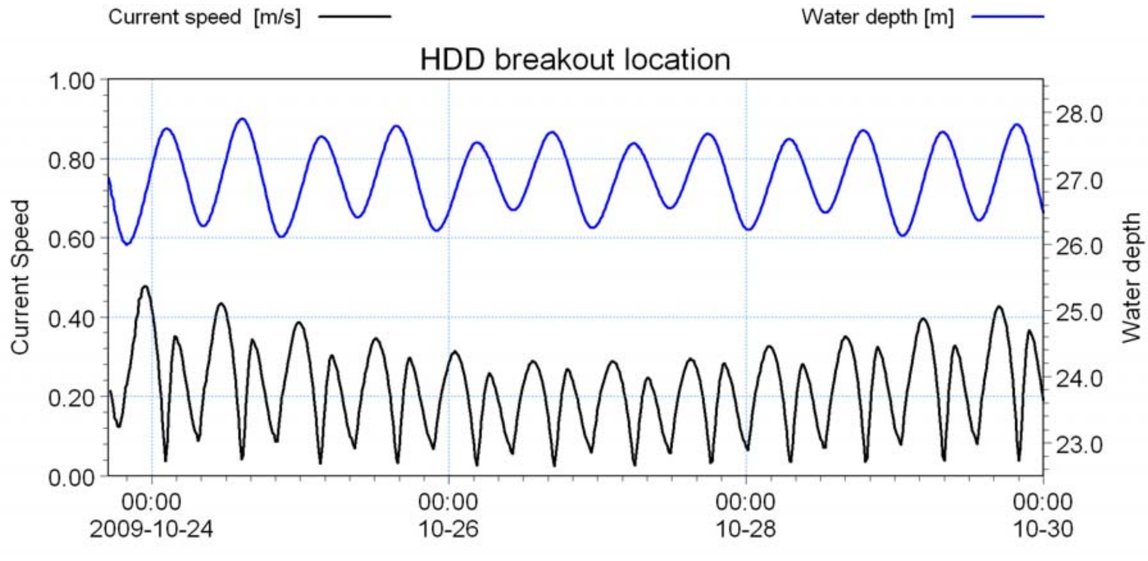

Figure 9.41 Tidal Conditions at Breakout Location

By definition the slurry is a well mixed fluid which carries fine particles which would be readily held in suspension until the current speed reduces significantly. It would therefore be well dispersed following the discharge and the particles are likely to remain in the water column over the full tidal excursion of some 5km.

The fate of the discharged material may be examined by looking at the characteristics of the slurry and utilising results of the brine modelling. The density of the proposed discharge is approximately 1,150kg/m³; with 325g/l of suspended solids in freshwater. This is akin to the brine discharge modelled; with a density of approximately 1,220kg/m3. Therefore, given the fine nature of the suspended material, the dispersion characteristics are likely to be similar with a comparable plume envelope. The bentonite will be dispersed to imperceptible levels within an extremely short distance from the outfall.

However, unlike the brine, the suspended material will eventually settle out of the water column. If it is assumed that this occurs over a similar area to the dispersion of the brine, the excursion along the coast would be 5km with a plume width of (conservatively) 100m, the resulting depth of deposited material would be less than 0.05mm. In total only 21m³ of solid material will be released into the water column during HDD breakout and this will have minimal impact on the area.

9.6 Summary and Conclusions

9.6.1 Initial Dilution

An assessment of initial dilution has been undertaken using accepted methods and modelling techniques to determine the likely salinity concentrations within the mixing zone around the proposed outfall.

This analysis indicates that a diffuser consisting of 3 nominally 200mm diameter ports at 20m centres is sufficient to reduce salinity concentrations from 260psu in the brine to circa 40psu within a few metres of the outfall.

9.6.2 Hydrodynamic Modelling

A detailed hydrodynamic model was constructed to simulate the tidal currents in the North Channel around Islandmagee, incorporating bathymetric data collected specifically for this study. The model simulations were calibrated and verified using field data collected as part of the study

The model was run for spring and neap tidal cycles. The model was found to give a good representation of tidal flow patterns over the proposed outfall area; with particularly good agreement between measured and simulated tidal current directions. Tidal current speeds were also satisfactorily represented for both spring and neap tides with localised circulations observed during the field survey being adequately represented within the model.

Overall the hydrodynamic model verification is therefore considered adequate for use in dispersion modelling of brine discharges from the proposed outfall.

9.6.3 Dispersion Modelling

The Islandmagee tidal model formed the basis of the initial dilution and dispersion assessments for the proposed brine outfall. Initial dilution modelling was implemented using a combination of the Visual Plumes and Cormix software packages. A series of medium and far field brine dispersion simulations were carried out under both spring and neap tidal conditions using the MIKE3 Flow Model FM software.

The brine dispersion study has indicated that a discharge of 1,000 m^3/h of fully saturated brine will have no noticeable effect on the salinity of the sea water outside the immediate vicinity of the outfall. There will also be no noticeable thermal impact on the seawater with the increase in temperatures reduced to less than 0.5°C within circa 15 metres of the outfall.

9.6.4 H.D.D. Breakout

The fate of the material put in to suspension as the H.D.D. breaks through the seabed at the discharge point during the construction of the outfall was also considered. The total amount of solids expected to be discharged is 21m^3. The fine material put in to suspension is anticipated to behave in a similar manner to the brine plume and will be rapidly dispersed.

Unlike the brine, the suspended sediment will eventually settle out of suspension but the predicted depth of settlement, 0.05mm is considered to be insignificant. The mud will appear as a discolouration within the bottom half of the water column for a very short period (3 hours) before it is dispersed to imperceptible levels, similar to the brine.