Appendix B - Brine Dispersion Modelling Report

IGSF BRINE DISPERSION MODELLING

FEED Update

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EXECUTIVE SUMMARY

The initial dilution and far-field dispersion likely to be achieved by the brine discharge from the proposed Islandmagee Gas Storage Facility (IGSF) under a range of flow and tidal conditions has been assessed using accepted computational modelling techniques.

The ambient conditions employed in terms of water depths, tidal flows and salinities are identical to those adopted for the earlier modelling study associated with the terrestrial consenting process for the IGSF.

The recently complete Front End Engineering Design (FEED) stage of the IGSF has confirmed that the salinity of the discharge brine will be a maximum of 260 psu and that the excess temperature of the brine will be around 2°C above the temperature of the intake water.

The initial dilution modelling results show that for the proposed diffuser the salinity of the brine at first contact with the seabed will be between 50.5 psu and 37.6 psu depending on the discharge flow and number of active ports on the diffuser.

The medium to far-field dispersion assessment has confirmed that the discharge of up to 1,000m^3/hour of saturated brine via the proposed IGSF outfall and diffuser will have minimal impact on salinity levels beyond the immediate vicinity of the outfall. Maximum salinity increases of greater than 0.5 psu above background are not anticipated to occur more than a few hundred metres from the diffuser and salinities in excess of 36 psu are not predicted to occur more than 100m from the diffuser. These conclusions apply over the full range of leaching discharges proposed for the Islandmagee Gas Storage Facility, 250m^3/hour to 1,000m^3/hour, provided the diffuser is operated in the way reported; with one port used for discharges of less than 500m^3/hour and two active ports for larger discharges.

Cores from the proposed salt sequence at Islandmagee within which the IGSF caverns will be created, were recovered and dissolved in North Channel seawater to produce a saturated brine representative of the brine that will be produced by the cavern creation process at Islandmagee as part of the FEED process. Comparison of the concentration of non-salt compounds in the Islandmagee brine to levels reported from other similar UK sites (Alborough) and applicable EQS thresholds for marine waters has established that the concentrations in the Islandmagee brine are generally lower than for other similar UK operations and in all cases are lower than the relevant EQS. Thus with the dilution and dispersion that will occur after discharge the non-salt components in the IGSF brine discharge do not pose a threat to marine water quality at Islandmagee.

1 INTRODUCTION

This document has been produced following the completion of the confirmation borehole at Islandmagee and the Front End Engineering Design (FEED) stage for the proposed Islandmagee Gas Storage Facility. It is intended to illustrate the dispersion of brine from the proposed outfall diffuser and comment on any difference from the original concept considered at the planning stage. The brine dispersion study has utilised the same underlying hydrodynamic and dispersion models that informed the preparation of the Environmental Statement which accompanied the original consent applications. Brief details of the descriptions of the model development and calibration are presented below.

1.1 Brine Dispersion Modelling Approach

In line with the original study the modelling of brine dispersion for the revised proposals that have emerged from the FEED stage was undertaken as a two stage process comprising;

- Initial dilution simulation
- Medium and far field dispersion simulation

The initial dilution study examined the dispersion of the outfall outlet jets in the immediate area of the outfall diffuser. These simulations were 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. This programme is primarily a near-field model and consequently a separate mid- and far-field model is required to simulate the plume dispersion over the wider area.

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 utilising the initial dilution algorithms implemented within the latest version of the MIKE3 software which are essentially the same as those utilised in the CORMIX-GI model developed by MixZon Inc.. Due to computational constraints two MIKE 3 FM models were developed for this study, the first was a very high resolution model covering the medium field out to circa 1km from the point of discharge designed to determine the dispersion of the brine in the area beyond the immediate jet flow from the diffuser and out to the boundary of the mixing zone. The second model was identical to that used in the original study and was used to illustrate the dispersion and fate of the discharged brine in the far-field i.e. beyond the mixing zone.

Two variants of the medium field model were developed, one with 9 layers in the vertical plane and the second with 14 layers in order to ensure that the model results were not affected by the specified vertical resolution of the model. The horizontal resolution of the model mesh in both these models ranged from 3m at the diffuser to circa 35m at the outer extent of the model. The horizontal mesh resolution of the medium field model is illustrated in Figure 1-1.

Flather boundary conditions were extracted from the previously calibrated and validated far field model to drive the medium field model thus ensuring compatibility between the hydrodynamic conditions driving both medium and far field models.

The far field model was constructed with 4 layers in the vertical plain as described in Section 5 and had a horizontal resolution ranging from 20m in the vicinity of the outfall to 900m at the offshore boundaries as shown in Figure 1-2 and Figure 1-3.

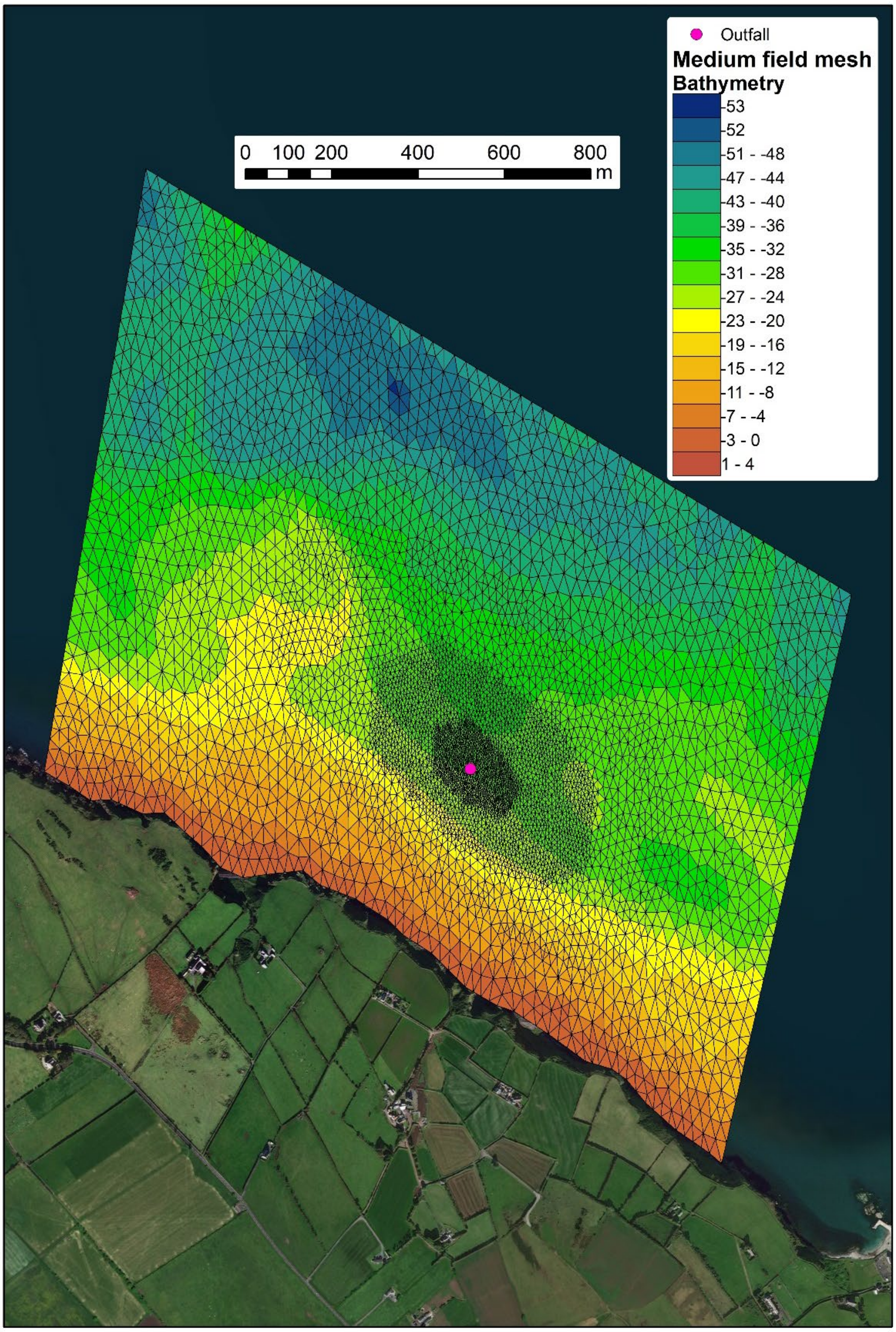

Figure 1-1 – Mesh and Bathymetry of the Islandmagee Medium Field Tidal Model

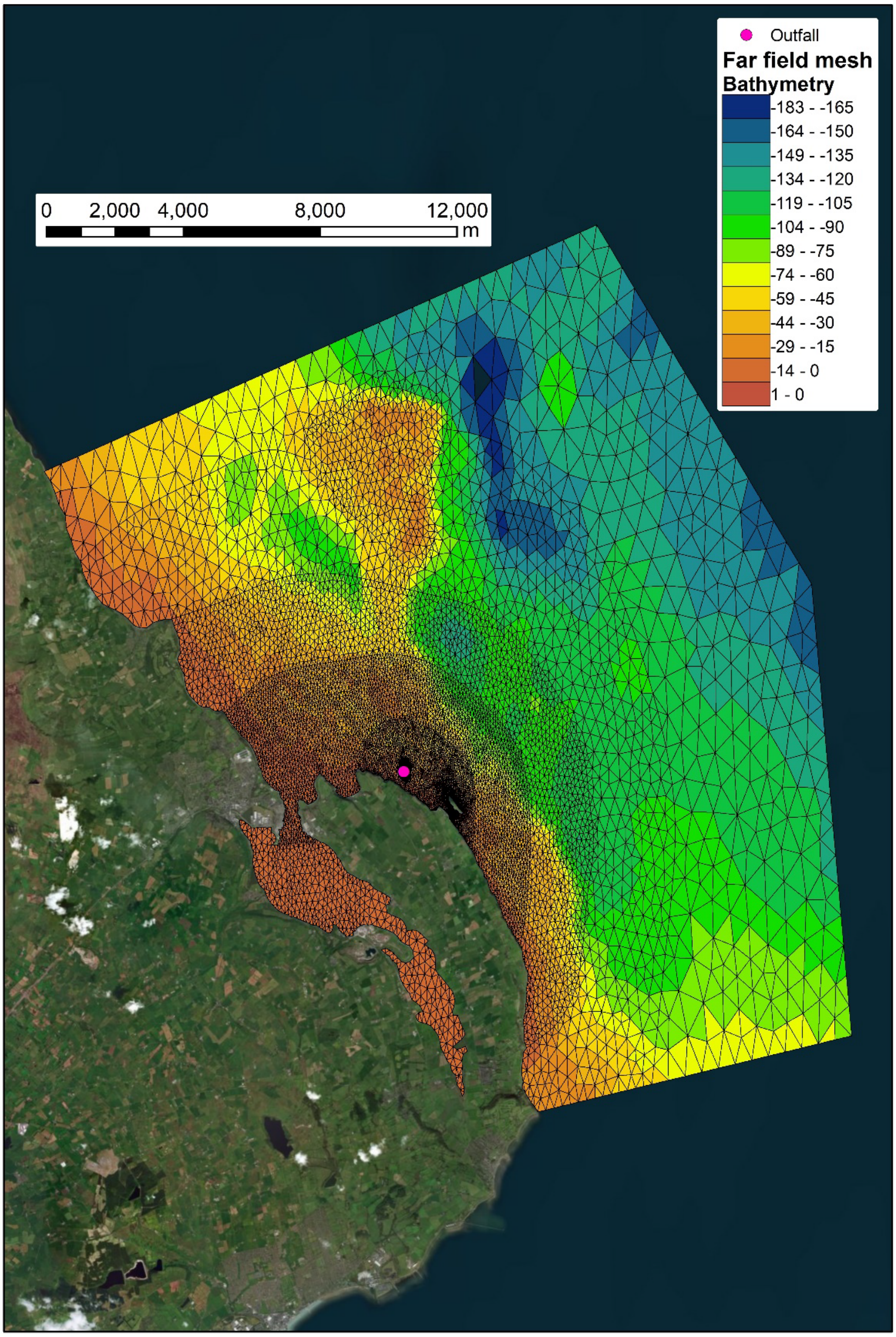

Figure 1-2 – Extent of the Islandmagee Far Field Tidal Model

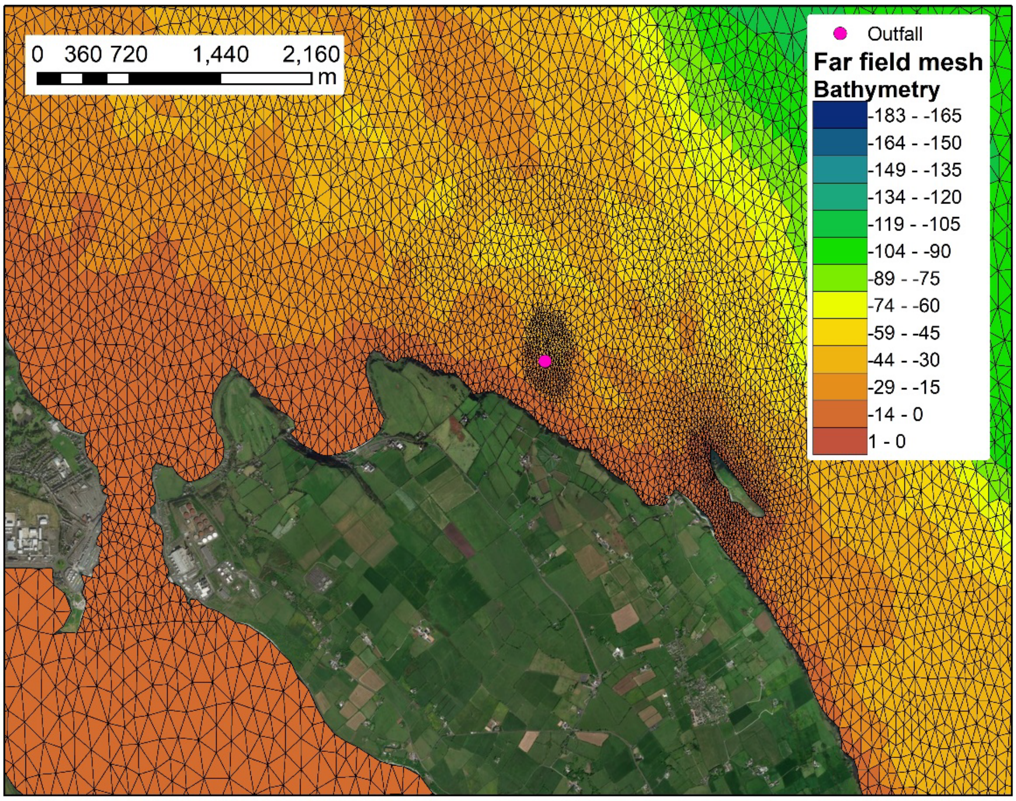

Figure 1-3 – Mesh and Bathymetry in the Castle Robin Area, Field Tidal Model

The hydrodynamic models were generally verified by comparing model predictions to the results of a field survey completed in 2009 as part of the original study that informed the initial planning phase of the Islandmagee Gas Storage Facility project. The locations from which information on tidal currents was available are shown in Figure 1-4. To address a lack of data recovery during the original survey an ADCP device was redeployed at M3 for a period of neap tides as part of this update whilst additional data was also collected at M0.

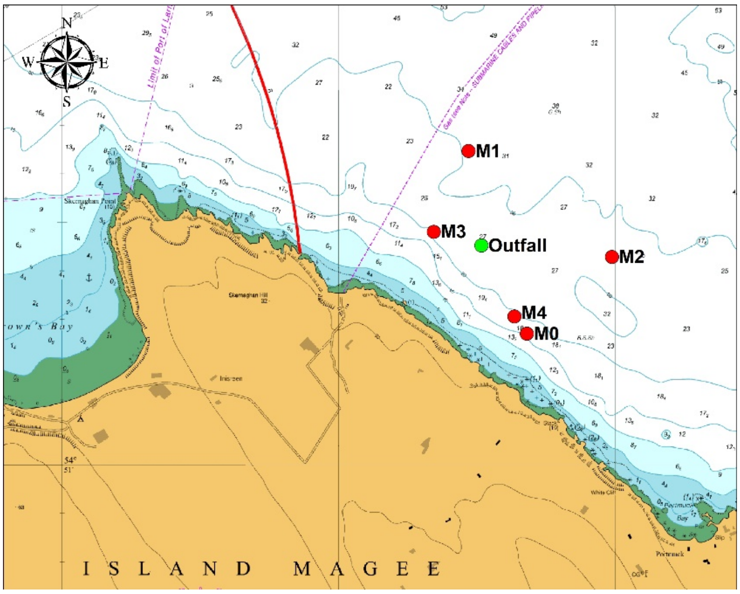

Figure 1-4 – Location of current metering stations relative to outfall at Islandmagee

Current data at the five survey locations were recorded by means of Acoustic Doppler Current Profilers (ADCP), bottom mounted and looking upwards at each location. The profilers at locations M3, M4 and M0 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 near surface current, were extracted from the ADCP data for comparison against the model predictions at equivalent depths.

Figure 1-5 to Figure 1-14 show the comparison between the measured data and the modelled data at each of the monitoring locations shown in Figure 1-4 for both spring and neap tides.

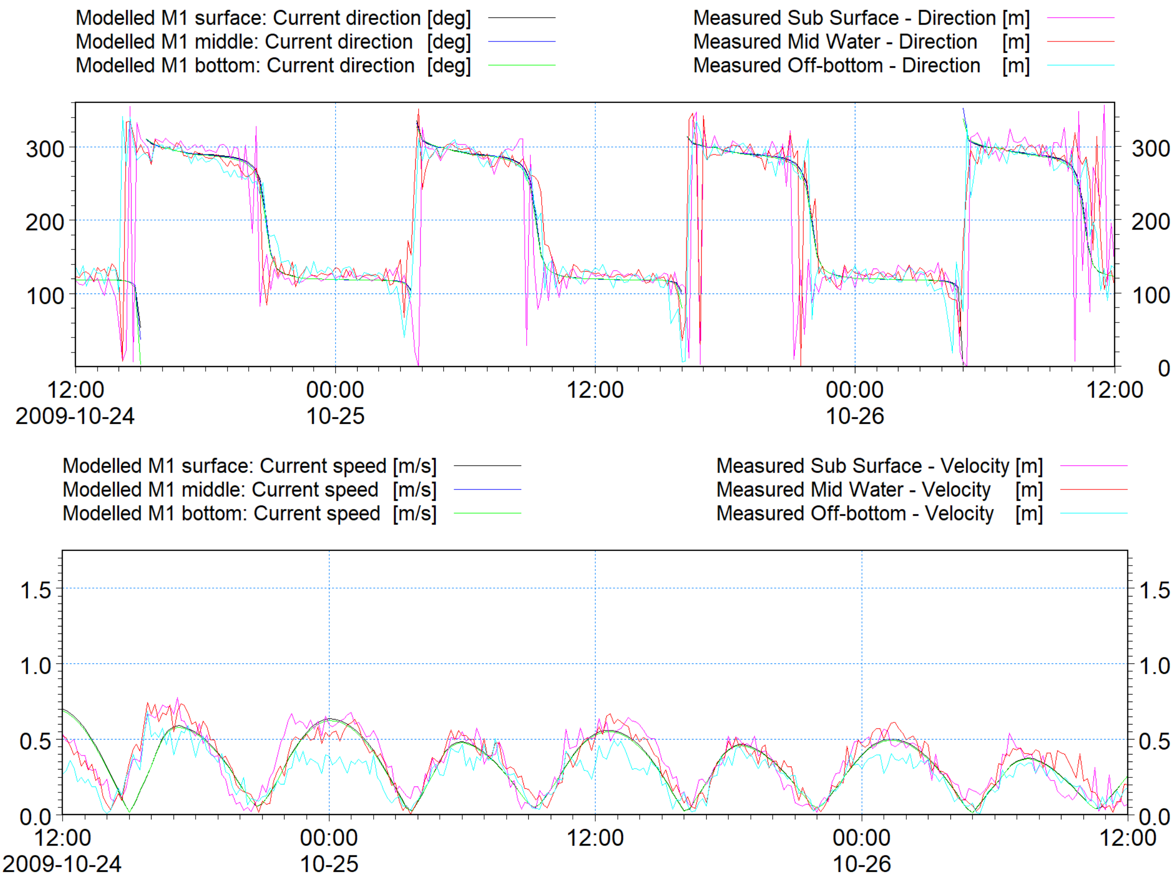

Figure 1-5 – Comparison between modelled and observed Neap current direction and speed at M1

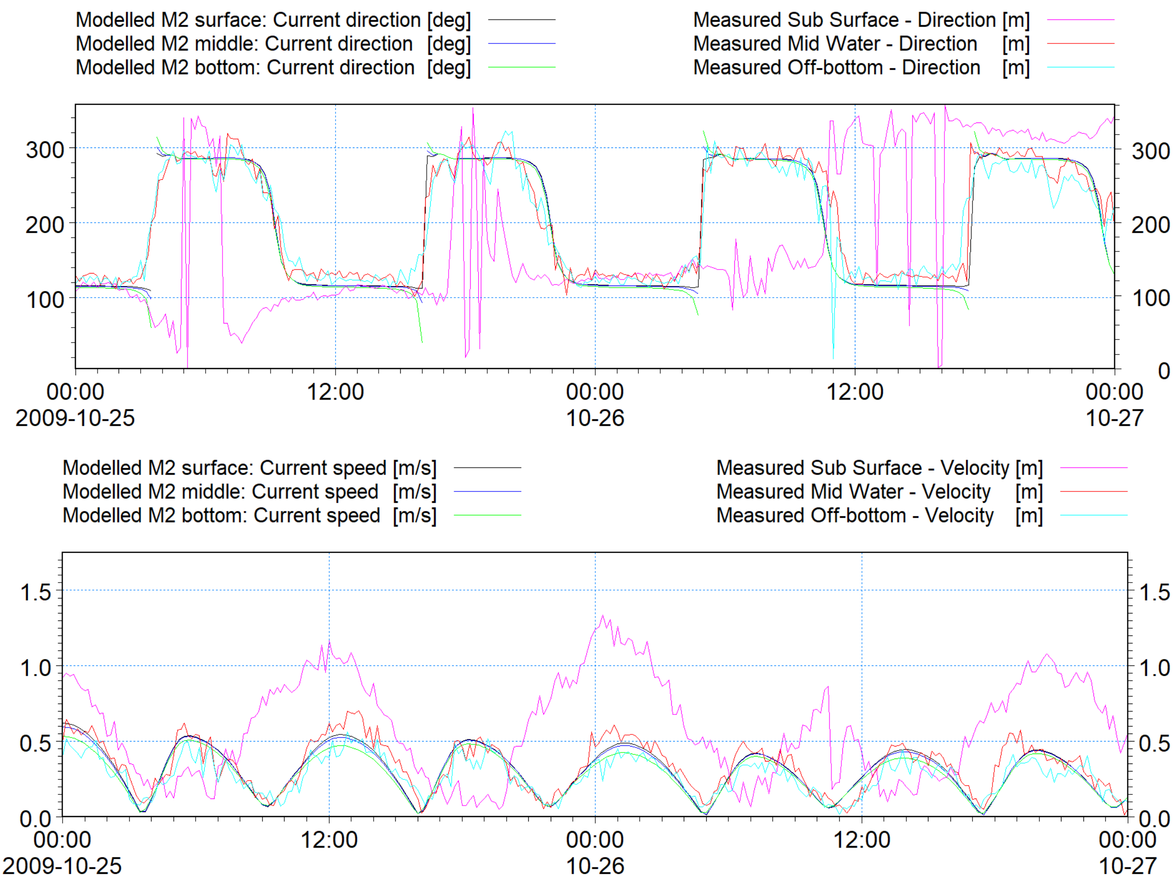

Figure 1-6 – Comparison between modelled and observed Neap current direction and speed at M2

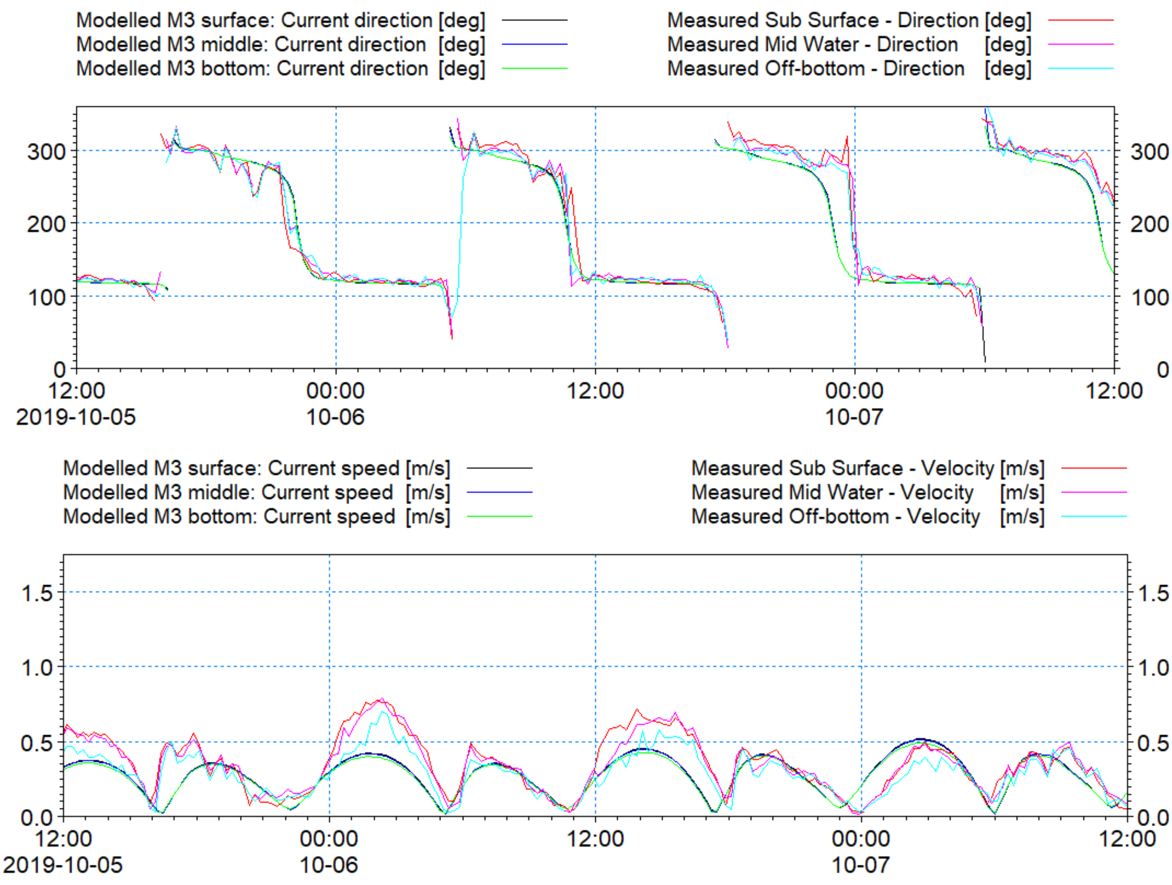

Figure 1-7 – Comparison between modelled and observed Neap current direction and speed at M3

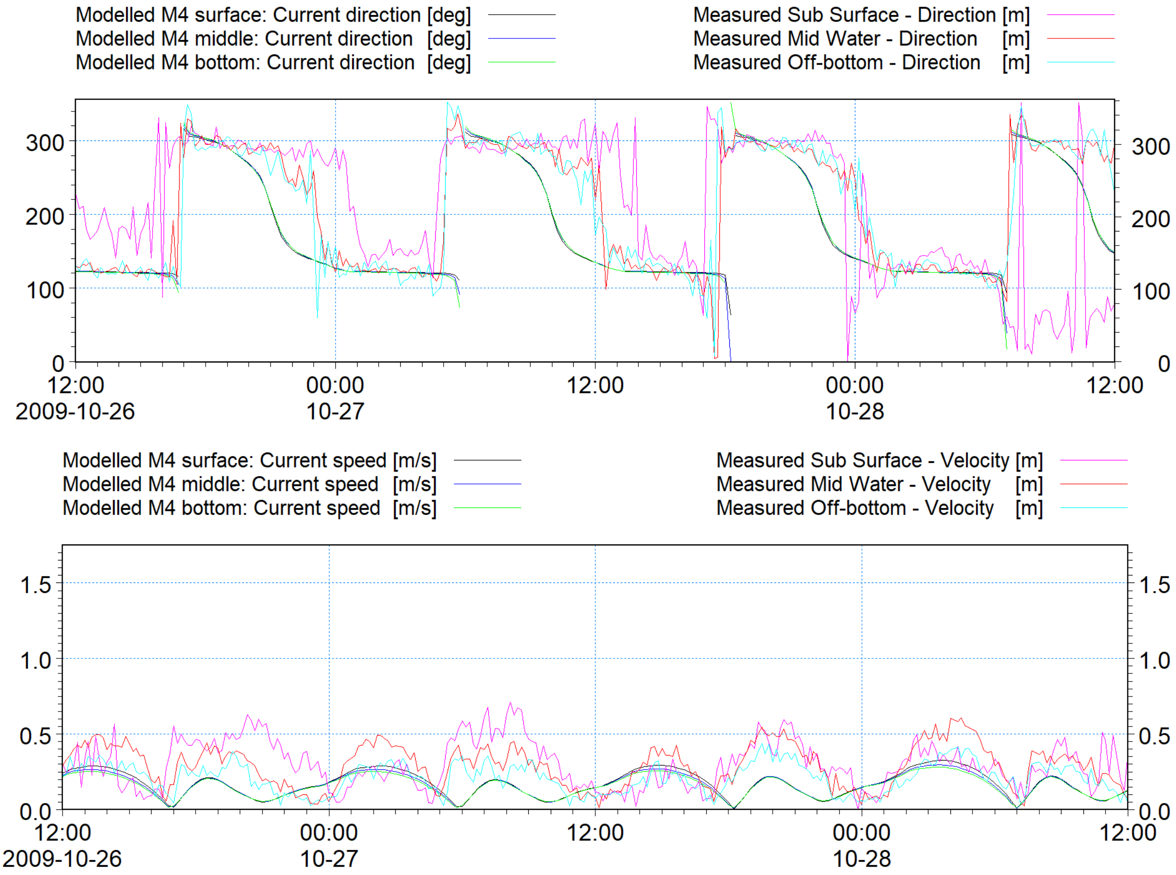

Figure 1-8 – Comparison between modelled and observed Neap current direction and speed at M4

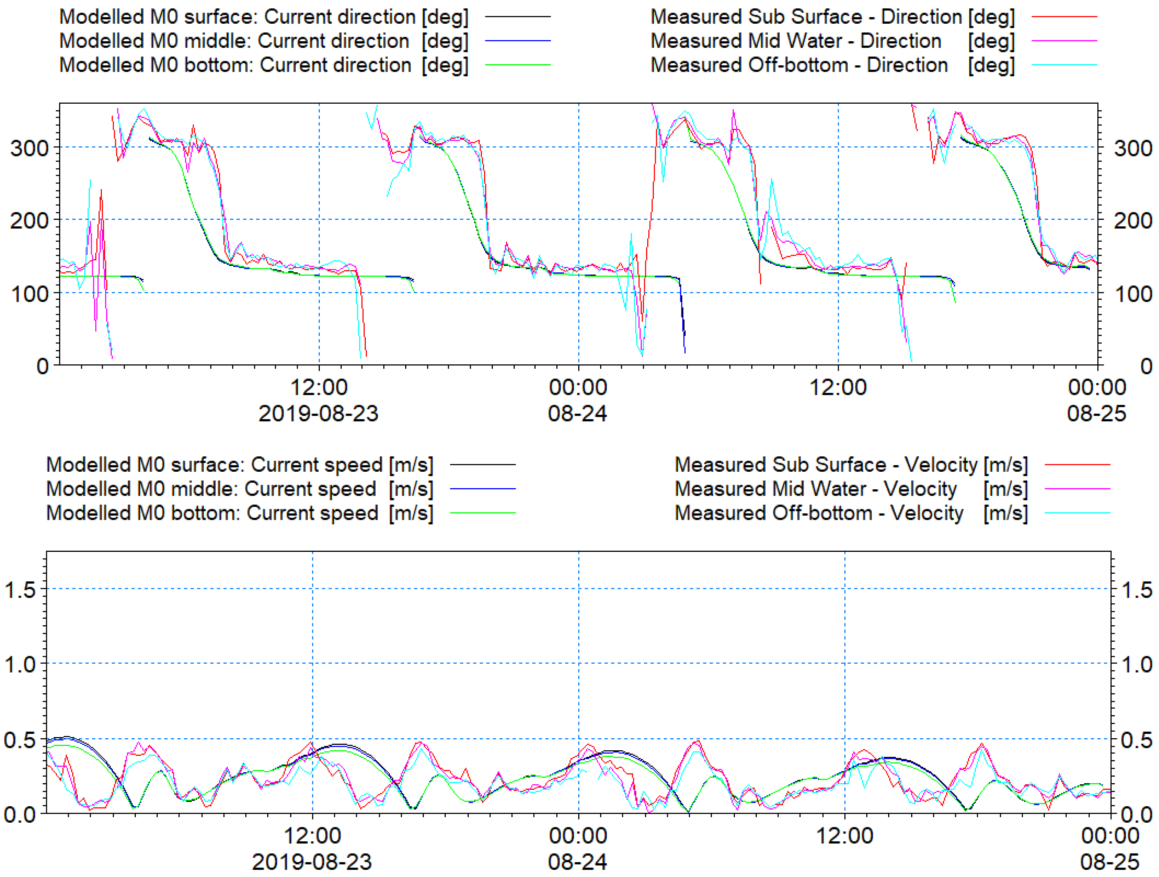

Figure 1-9 – Comparison between modelled and observed Neap current direction and speed at M0

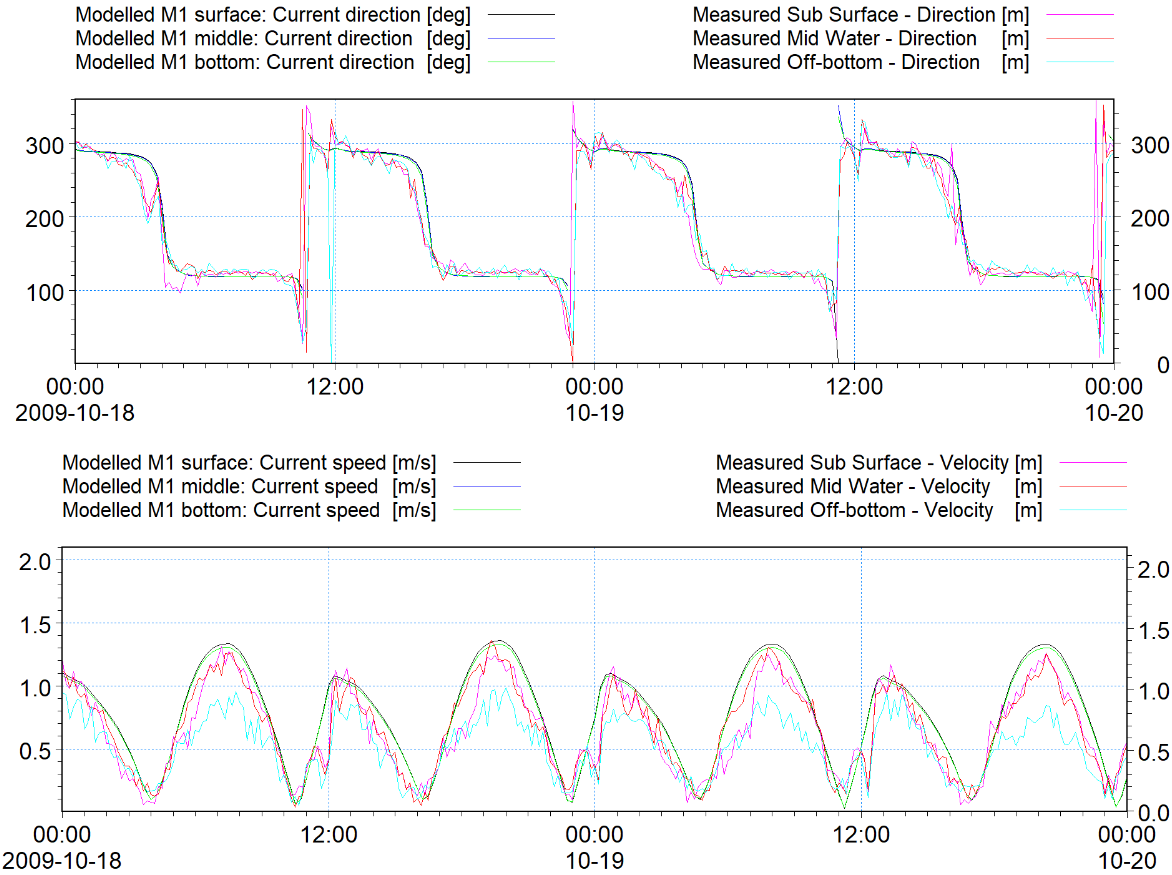

Figure 1-10 – Comparison between modelled & observed Spring current direction and speed at M1

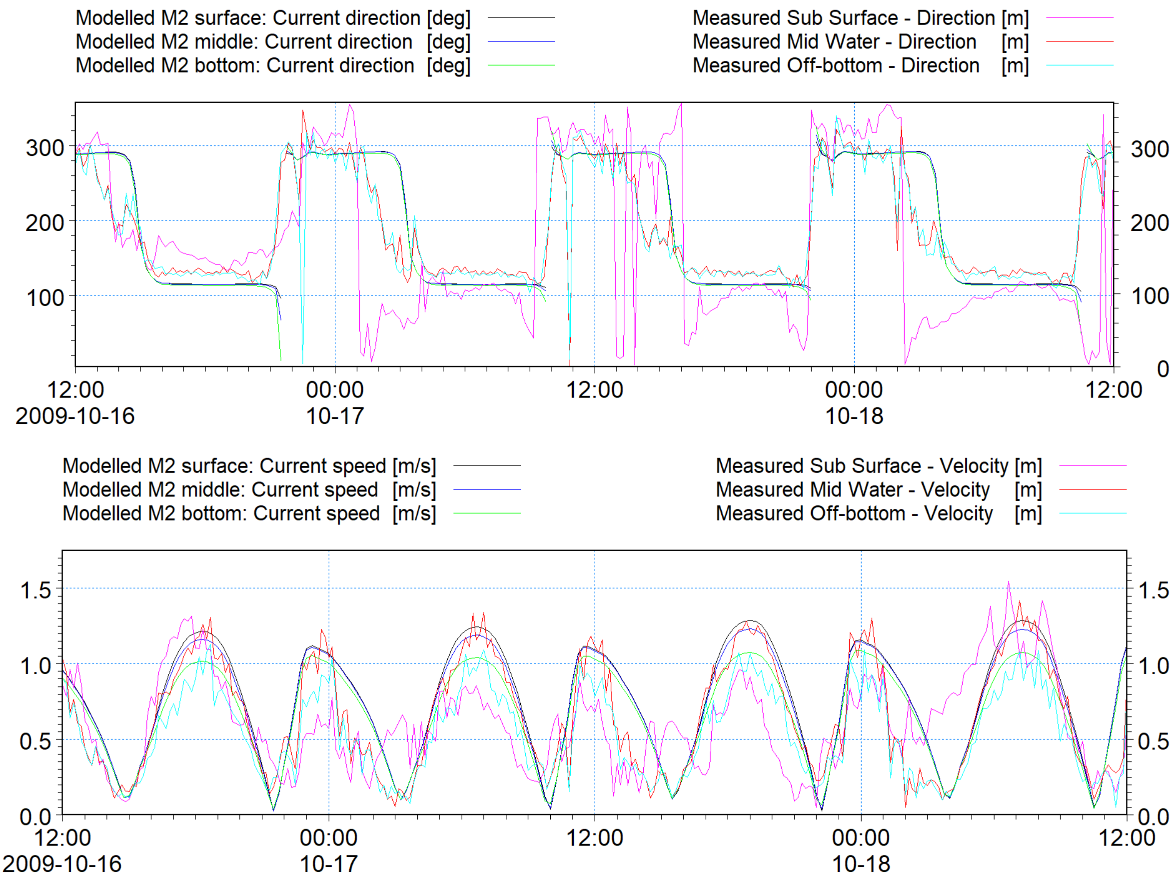

Figure 1-11 – Comparison between modelled & observed Spring current direction and speed at M2

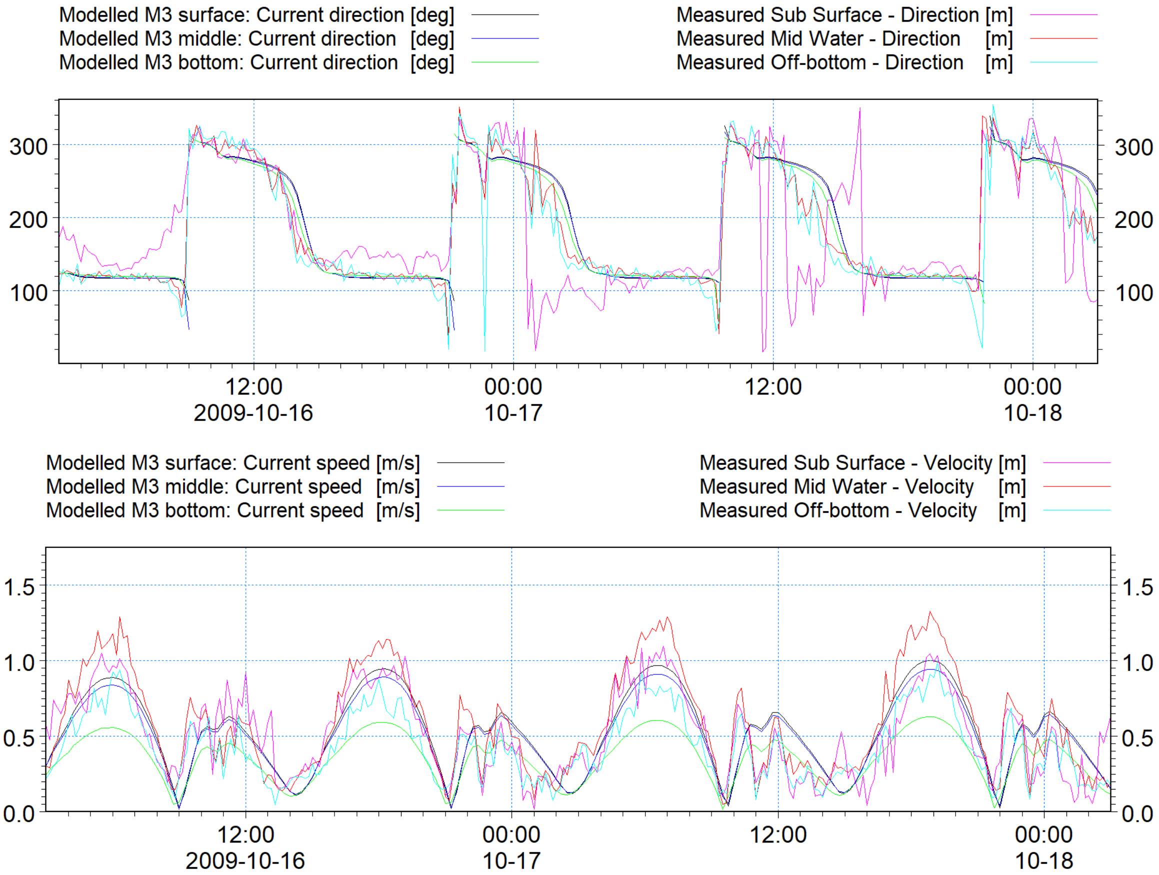

Figure 1-12 – Comparison between modelled & observed Spring current direction and speed at M3

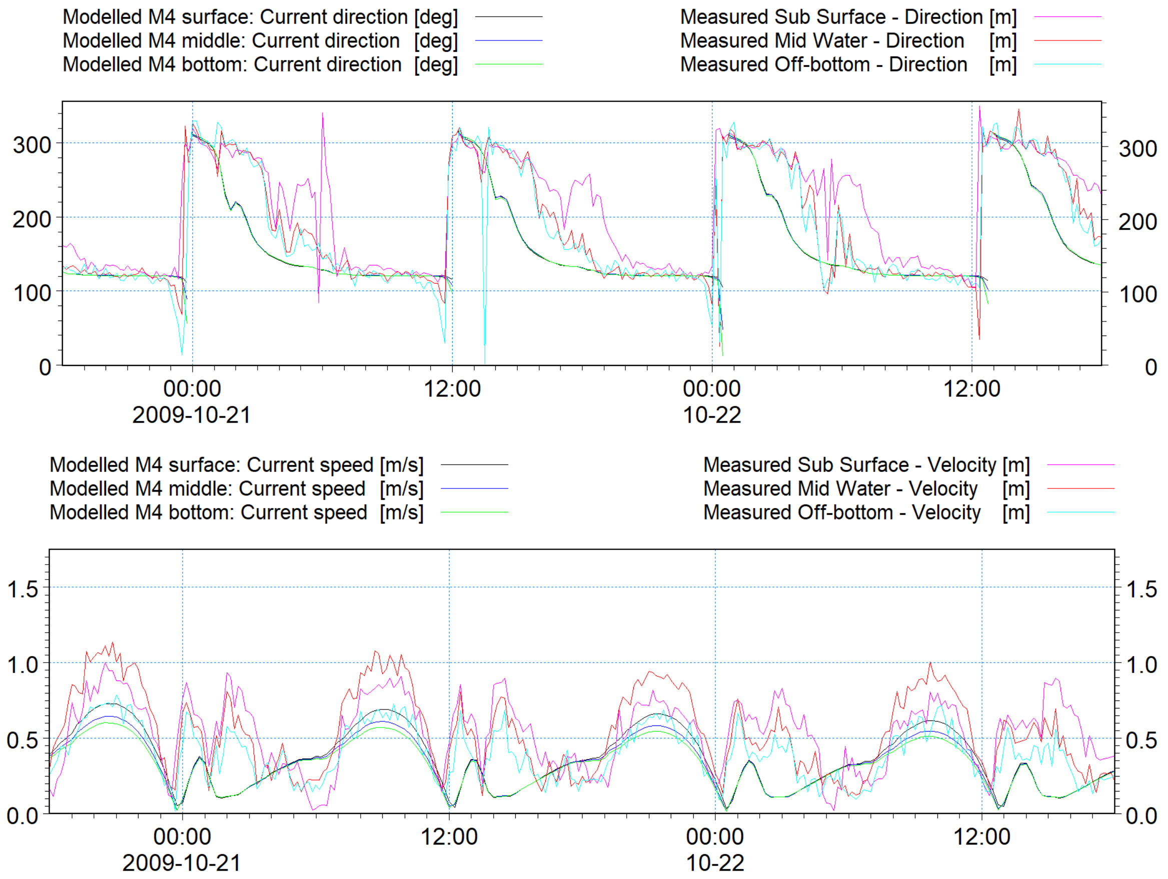

Figure 1-13 – Comparison between modelled & observed Spring current direction and speed at M4

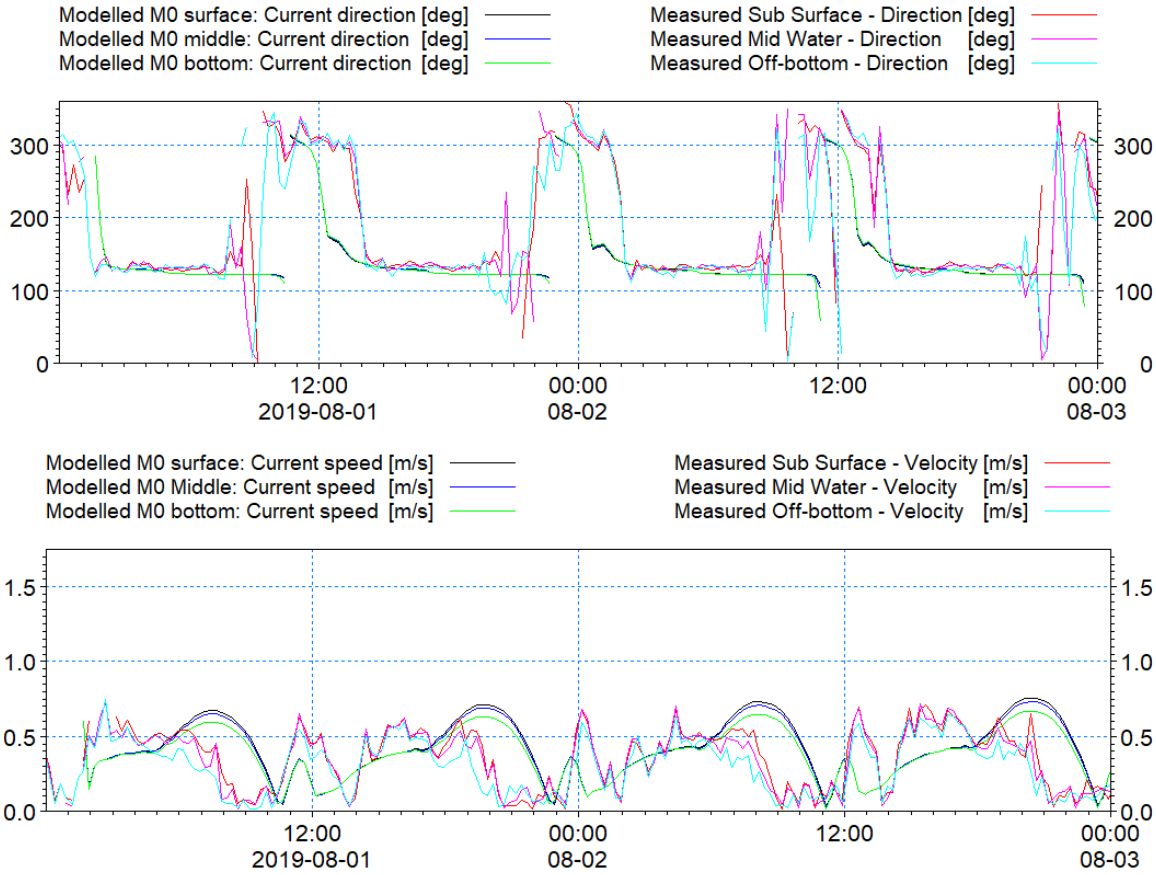

Figure 1-14 – Comparison between modelled & observed Spring current direction and speed at M0

Examination of the preceding figures shows similar flow patterns at M1 and M2 for both spring and neap tides, likewise, M3, M4 and M0 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, M4 and M0 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.

Examination of typical flood and ebb tidal flow patterns for the area generated by the model clearly showed 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, M4 and M0. The model shows the tidal flow runs in a south easterly direction for more than half the tidal cycle at sites M3, M4 and M0 due to the eddy. This correlates well with the observed data and indicates that this tidal asymmetry is well represented within the model. Sites M1 and M2 lie outside the influence of the tidal eddy and therefore show less tidal asymmetry.

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 was 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 at this location. The same effect was mirrored by the results for point M4. However this effect is not seen to the same extent in the results for M0 which is close to the original M4 location but was recorded during a period of lower winds and thus confirms the hypothesis presented above of the original M2 and M4 data being influences by prevailing wind conditions.

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 sufficient to give a good prediction of brine concentrations and dispersion. As noted above the apparent differences 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. Due to the dense nature of the brine discharge the reduced correlation in the near surface levels is not a significant limitation of the model as the near bed current regime is the primary influence on the dispersion. Indeed the fact that some of the field observations coincided with storm conditions and yet the model was still able to satisfactorily replicate the tidal movement at the level of most interest is further proof that the model is fit for purpose.

1.2 Proposed Brine Discharge Arrangements

During of the FEED process the diffuser geometry was refined and is now proposed to consist of up to two ports fitted with 6” Tideflex valves at 20m centres, designed to jet the brine vertically upwards into the water column. Under the current project programme the rate of brine discharge will increase in stages as the number of caverns under construction increases with time and will range from 250m^3/hour at initial start-up, to potentially 1,000m^3/hour at the maximum possible cavern construction rate. The design of the leaching facilities is such that this will be achieved in a stepped process by uprating and commissioning additional pumps, hence there will in effect be three potential discharge scenarios, 250m^3/hour, 500m^3/hour and 1,000m^3/hour.

To accommodate this range of flows it is proposed that initially only one diffuser port will be utilised, the second will be installed when the outfall is constructed but blanked off until such time that the required leaching flow exceeds 500m^3/hour, thereafter the discharge will utilise both diffuser ports.

2 INPUTS TO THE DISPERSION ASSESSMENT

2.1 Outfall Location

The location of the proposed outfall was previously determined by studies that informed the planning application for the proposed project in 2010. As part of this process the position of the outfall (approximately 450m offshore) was demonstrated to be far enough offshore to provide effective dispersion and avoid the plume attaching to the shoreline whilst also minimising environmental impact during construction. The proposed discharge is located at 27 metres water depth (Chart datum) as shown in Figure 2-1.

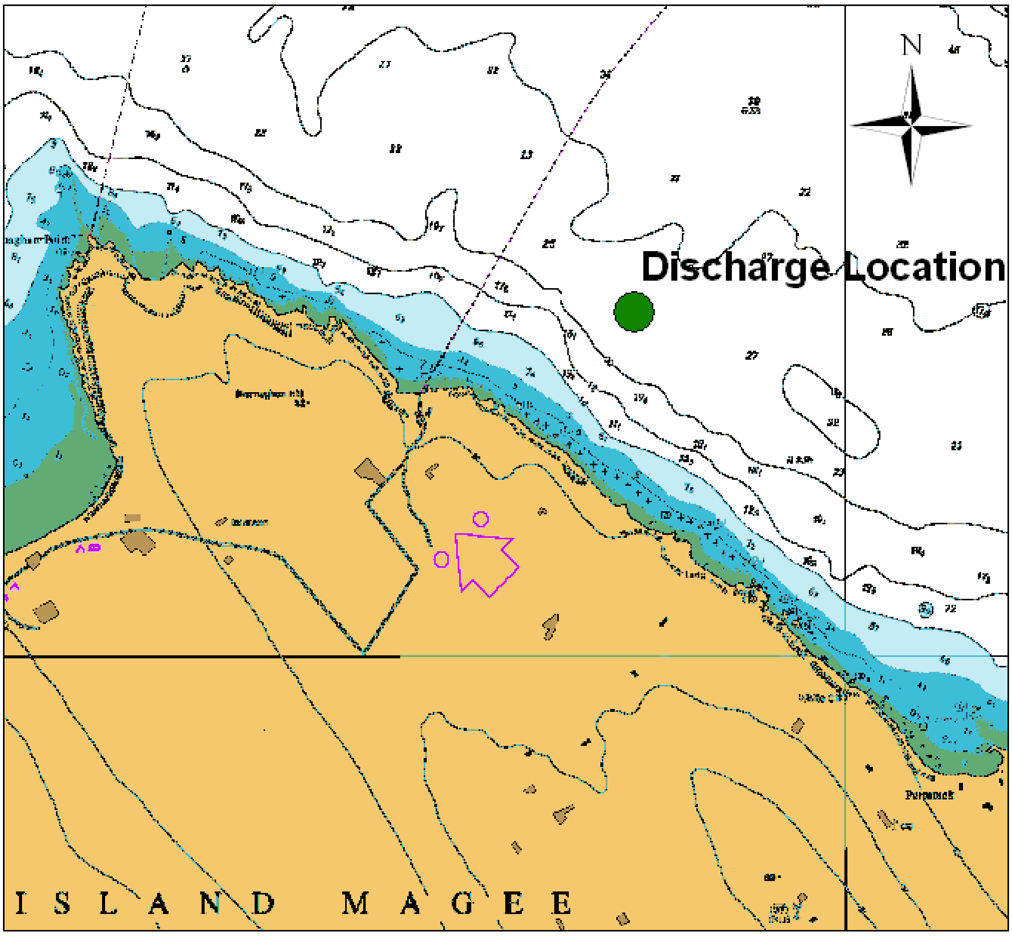

Figure 2-1 – Location of Proposed Outfall

2.2 Brine Discharge

The rate of brine discharge will increase as the number of caverns under construction increases with time and is likely to range from 250m^3/h to 1,000m^3/h. The following characteristics were assumed for the brine discharge in the various scenarios investigated:

- Outfall discharge rate: 250 to 1,000 m^3/hour
- Discharge Salinity: 260 psu
- Discharge Temperature: 2°C above intake

Monthly time series data on background salinities and temperatures were acquired during the preparation of the original Environmental Statement for the IGSF facility. This comprised data 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 from 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 in the seasonal variation of salinity and temperature between the sites and years, and that the water column was 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 was 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: 8.4°C

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[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

3 INITIAL DILUTION MODELLING

The initial dilution study examines the dispersion of the brine discharged from the outfall diffuser jets in the immediate area around the diffuser. For this study the initial dilution achieved by the brine discharge from the proposed outfall was modelled using the US EPA “Plumes” software utilising the UM3 routine. The Visual Plumes programme simulates the flow of the outlet jets under the influence of density, temperature and velocity. The programme is primarily a near-field model and a mid- and far-field model is therefore also required to simulate the plume dispersion over the wider area.

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 a 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 i.e. 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.

3.1 Initial Dilution Model Results

The initial dilution modelling was undertaken using a diffuser with either 1 or 2 ports depending on the flow range as stated in Section 2.2. The diffuser ports were at 20m centres with the port exits discharging vertically upwards at approximately 0.75m above the seabed. Following discharge it is expected that the brine will sink down towards the seabed due to the density of the brine solution, with the initial trajectory depending on the tidal velocity. Consequently the UM3 model was run for a variety of spring and neap flow conditions to simulate the initial dilution achieved at various stages of the tidal cycle.

3.1.1 Scenario 1: 250m^3/hr via a Single Port

This scenario represents the early stages of project development when the leaching of the caverns is just commencing and the full flow of leaching water is not required. For this stage of the process it was assumed that one port on the diffuser would be blanked off and hence the 250m^3/h would be discharged via one diffuser port.

The trajectories for the discharge from a 6” Tideflex port across the range of tidal velocities are presented in Figure 3-1. The trajectory in red relates to low tidal velocity of <0.1m/s which would be experienced during the turning tide, the trajectory in blue relates to tidal velocity of 0.3 m/s which would represent peak velocities during neap tide. The trajectory in green relates to a typical spring tidal velocity of 0.6 m/s.

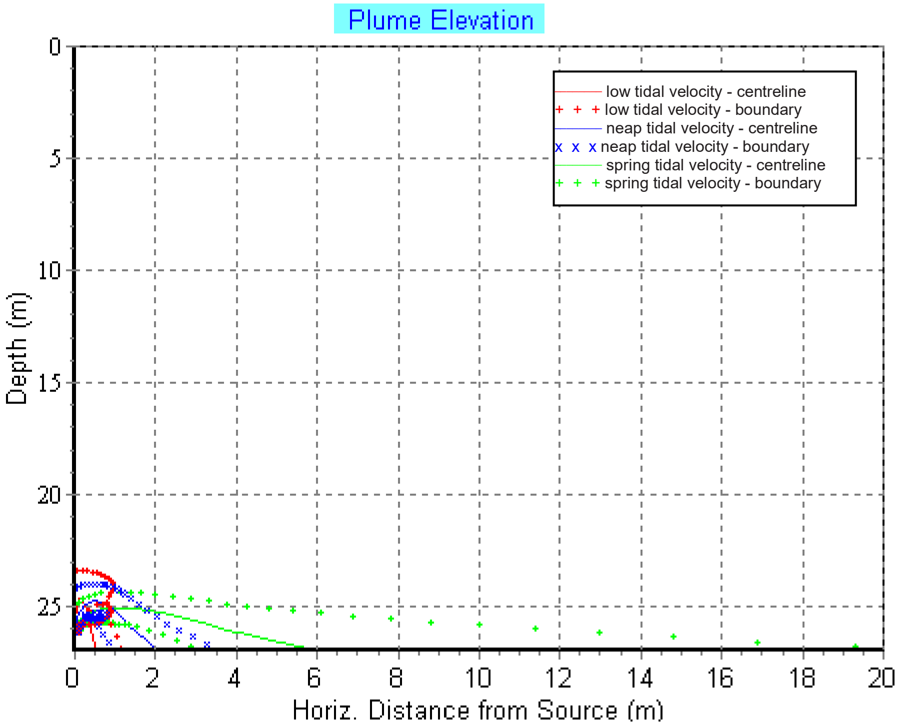

Figure 3-1 – Brine Plume Trajectory, 250m^3/hr, single 6” port

The brine undergoes dilution as the outlet jet spreads out with distance from the outfall. Figure 3-2 shows the initial dilution achieved by the discharge for the three tidal velocities outlined previously. At 0.1 m/s tidal velocity (slack water) the initial dilution achieved before the brine makes contact with the seabed will be approximately x13 which corresponds to a salinity of 50.5 psu. At 0.3 m/s tidal velocity (neap tide) the initial dilution will be approximately x21 with a salinity of 44.3 psu on contact with the seabed and finally at 0.6 m/s tidal velocity (spring Tide) the salinity is predicted to be 40.3 psu when the plume reaches the seabed.

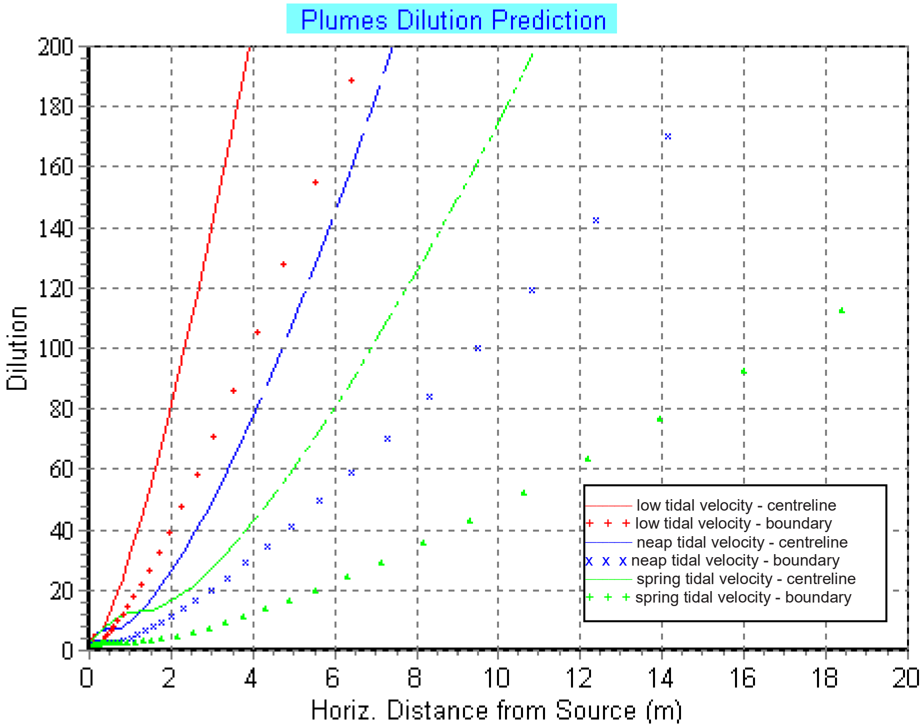

Figure 3-2 – Initial Dilution Predictions, 250m3/hr single 6" port[2]

3.1.2 Scenario 2: 500m^3/hr via a Single Port

This scenario represents the situation where leaching is progressing on a single cavern and the full flow of leaching water has not been implemented. For this stage of the process it was assumed that one port on the diffuser would still be blanked off and hence the 500m^3/h would be discharged via one diffuser port.

The trajectories for the discharge from a 6" Tideflex port across the range of tidal velocities are presented in Figure 3-3. The trajectory in red relates to low tidal velocity of <0.1m/s which would be experienced during the turning tide, the trajectory in blue relates to tidal velocity of 0.3 m/s which would represent peak velocities during neap tide. The trajectory in green relates to a typical spring tidal velocity of 0.6 m/s.

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[2] Note that dilution rates may be over-estimated beyond the point of impact with the seabed

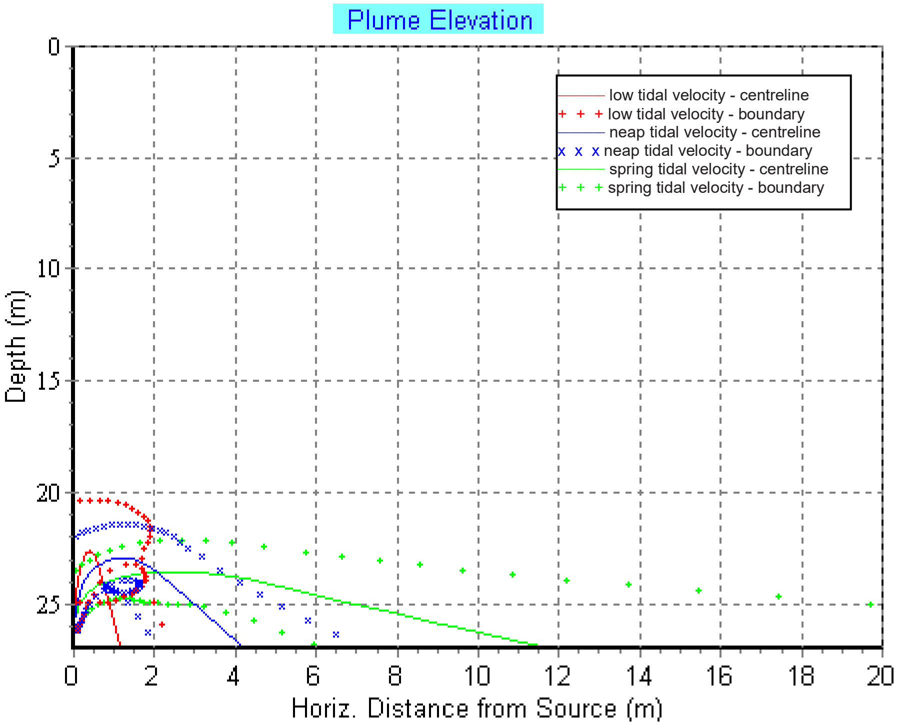

Figure 3-3 - Brine Plume Trajectory, 500m^3/hr, single 6” port

Figure 3-4 shows the initial dilution achieved by the discharge for the three tidal velocities outlined previously. At 0.1 m/s tidal velocity (slack water) the initial dilution achieved before the brine makes contact with the seabed will be approximately x25 which corresponds to a salinity of 43.2 psu. At 0.3 m/s tidal velocity (neap tide) the initial dilution will be approximately x40 with a salinity of 39.7 psu on contact with the seabed and finally at 0.6 m/s tidal velocity (spring Tide) the salinity is predicted to be 37.6 psu when the plume reaches the seabed.

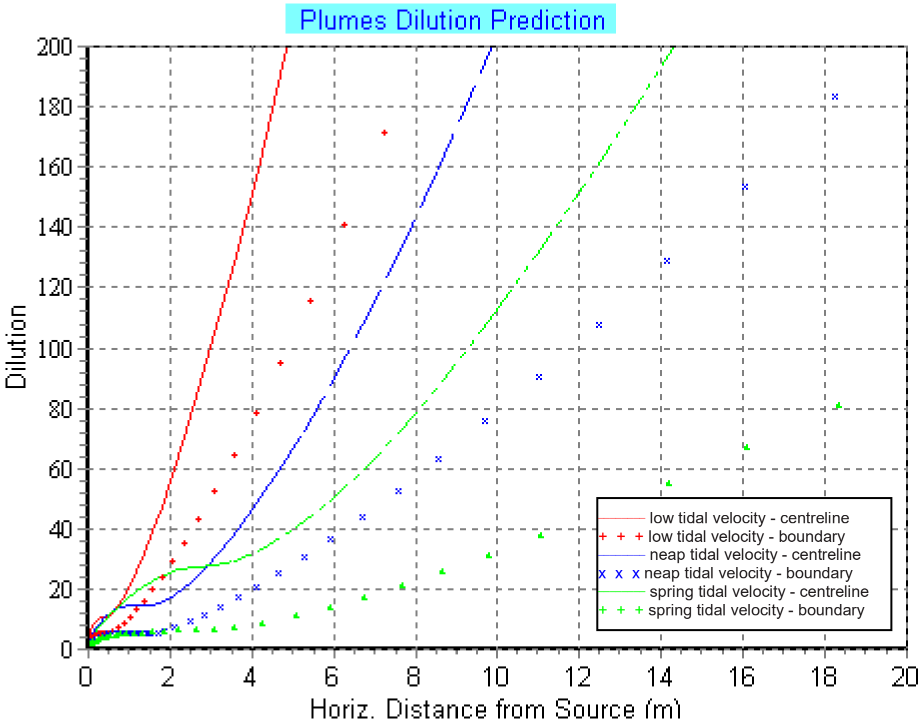

Figure 3-4 - Initial Dilution Predictions, 500m3/hr single 6" port[3]

3.1.3 Scenario3: 1,000m^3/hr via Two Ports

This scenario represents the situation where leaching is progressing on multiple caverns at the maximum leaching flow. By this stage of the process additional pumps would have been commissioned and the second port on the diffuser activated hence 500m^3/h would be discharged via each diffuser port.

The trajectories for the discharge from 6" Tideflex ports across the range of tidal velocities are presented in Figure 3-5. The trajectory in red relates to low tidal velocity of <0.1m/s which would be experienced during the turning tide, the trajectory in blue relates to tidal velocity of 0.3 m/s which would represent peak velocities during neap tide. The trajectory in green relates to a typical spring tidal velocity of 0.6 m/s.

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[3] Note that dilution rates may be over-estimated beyond the point of impact with the seabed

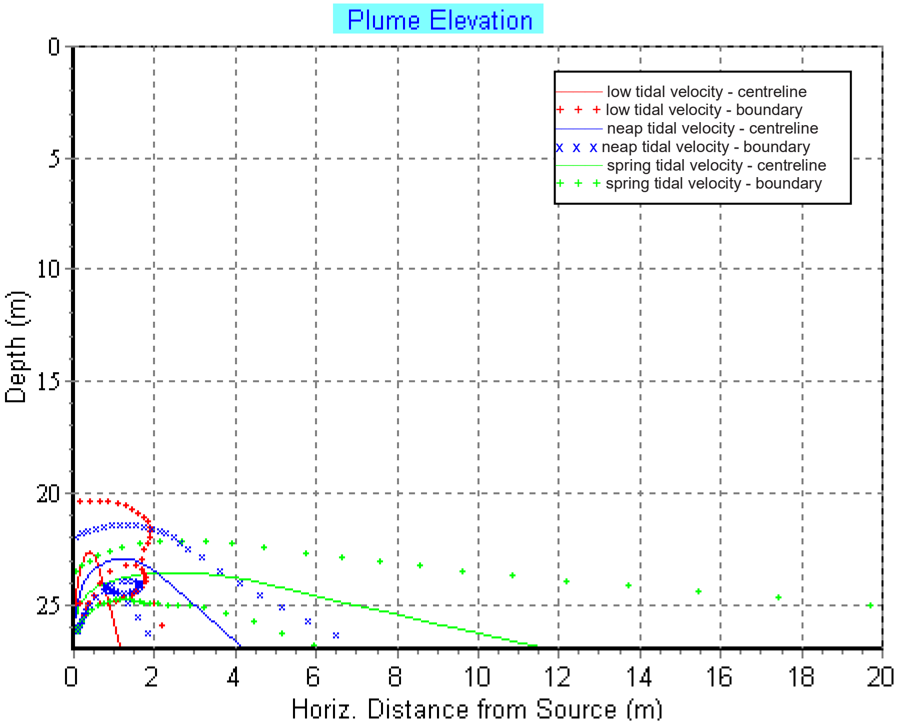

Figure 3-5 - Brine Plume Trajectory, 1,000m^3/hr, two 6” ports

Figure 3-6 shows the initial dilution achieved by the discharge for the three tidal velocities outlined previously. At 0.1 m/s tidal velocity (slack water) the initial dilution achieved before the brine makes contact with the seabed will be approximately x25 which corresponds to a salinity of 43.2 psu. At 0.3 m/s tidal velocity (neap tide) the initial dilution will be approximately x40 with a salinity of 39.7 psu on contact with the seabed and finally at 0.6 m/s tidal velocity (spring Tide) the salinity is predicted to be 37.6 psu when the plume reaches the seabed.

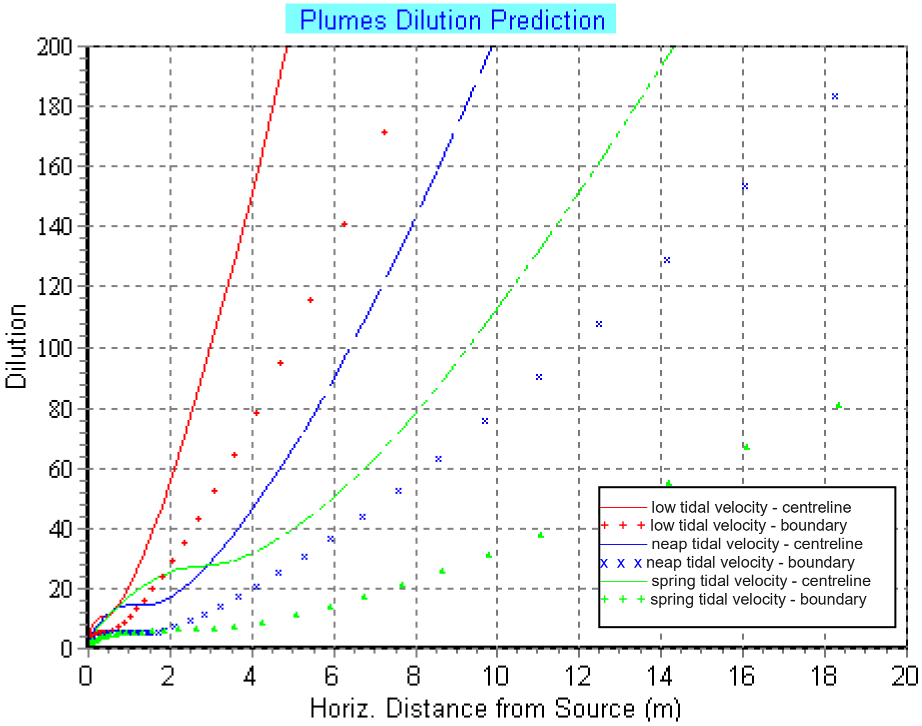

Figure 3-6 - Initial Dilution Predictions, 1,000m3/hr two 6” ports[4]

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[4] Note that dilution rates may be over-estimated beyond the point of impact with the seabed

4 MEDIUM FIELD DISPERSION MODELLING

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-centred 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.

The inbuilt near-field model was implemented within the MIKE simulations where the treatment of a jet is based on dynamic coupling of a near field integral jet model and the far field hydrodynamic model. The jet model determines the steady state solution of the jet by solving conservation equations for flux and momentum, salinity and temperature as well as the equations for the trajectory of the jet and the equation of state for the centreline density. When the jet becomes passive it has reached its final position and becomes part of the ambient flow. The determination of the steady state jet is performed at every hydrodynamic time step using the local flow conditions at the jet location.

4.1 Sensitivity to Vertical Resolution

In order to ensure the model results were not affected by the vertical schematisation of the zones within the water column a sensitivity test was undertaken using 4, 9 and 14 zones to determine the optimal balance between resolution and computational efficiency. The actual dimensions of the zones varied with water depth, but were defined by proportioning the water column, as shown in Table 4-1 and illustrated in Figure 4-1. 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 were used.

Table 4-1: Table showing Water Column division into Layers within the Models in terms of % of overall water depth assigned to each layer.

	14 Layer	9 Layer	4 Layer
Layer 14	40	-	-
Layer 13	20	-	-
Layer 12	11	-	-
Layer 11	8.5	-	-
Layer 10	6.5	-	-
Layer 9	4.5	40	-
Layer 8	3	25	-
Layer 7	2	15	-
Layer 6	1.5	9.3	-
Layer 5	1	4.5	-
Layer 4	0.8	2.5	35
Layer 3	0.6	1.5	35
Layer 2	0.5	1.2	15
Bottom Layer 1	0.1	1	15

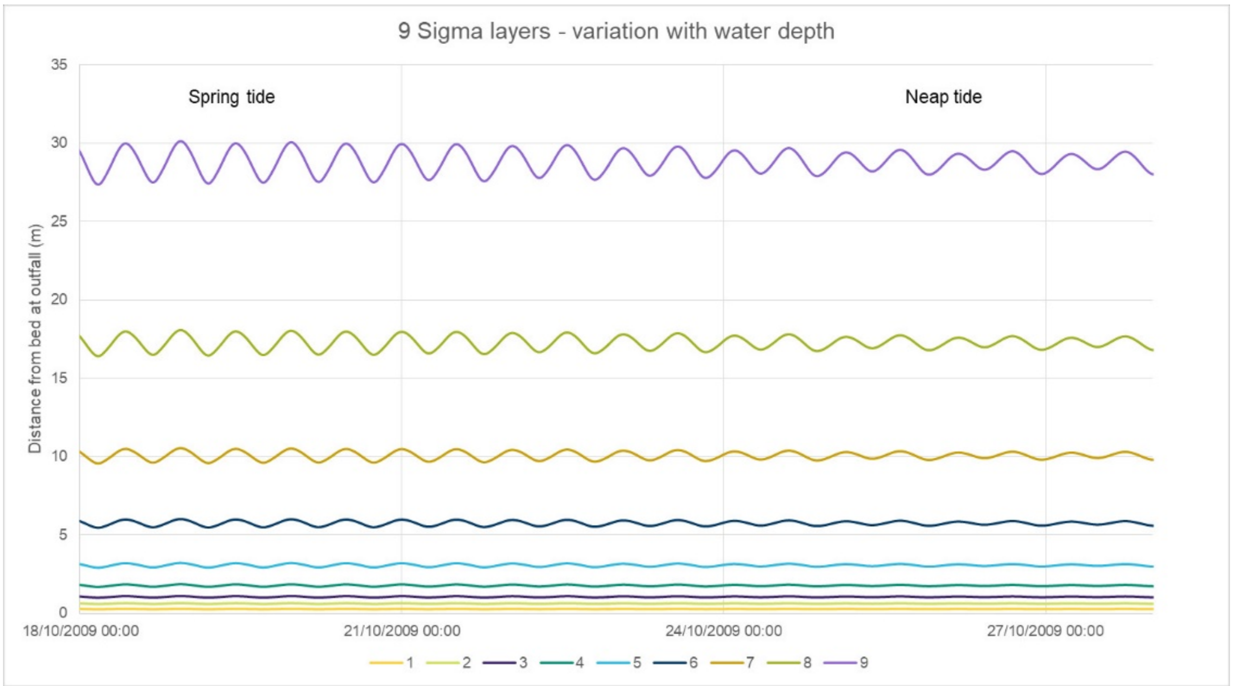


Figure 4-1: Variation of sigma layers with water depth (9 layers)

For the sensitivity testing the 1,000m^3/hr scenario was selected as this represents the maximum input of salt and hence density effects will be more prevalent than with lower salt inputs. The results of the sensitivity testing in terms of maximum seabed salinity levels are presented in Figure 4-2 to Figure 4-4 for the 4 layer, 9 layer and 14 layer models respectively. It should be noted in all figures presented the colour contour bands are not linear with smaller intervals at the lower salinity values in order to fully illustrate the range whilst also defining the plume. The 36 psu threshold is shown where the blue contours change to green and in each figure the white ellipse denotes the 100m mixing zone boundary associated with the two port diffuser.

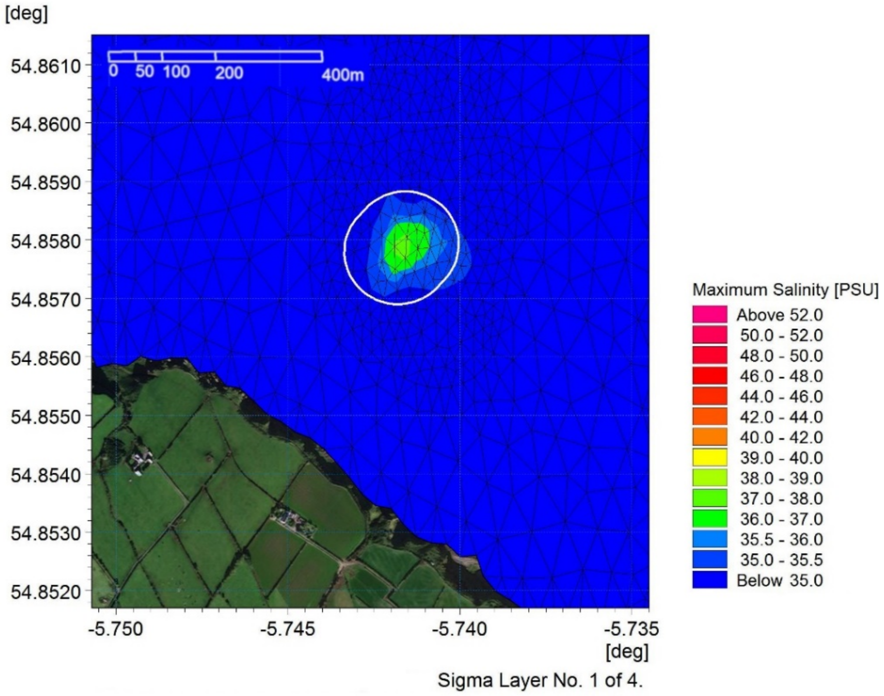


Figure 4-2: Maximum Salinity at Bed – 4 layer model

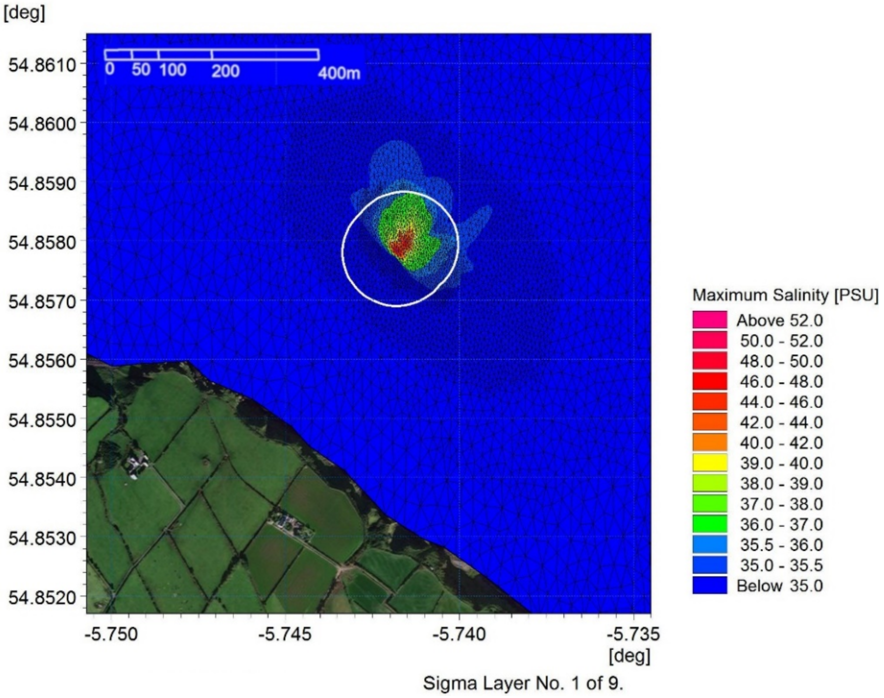


Figure 4-3: Maximum Salinity at Bed – 9 layer model

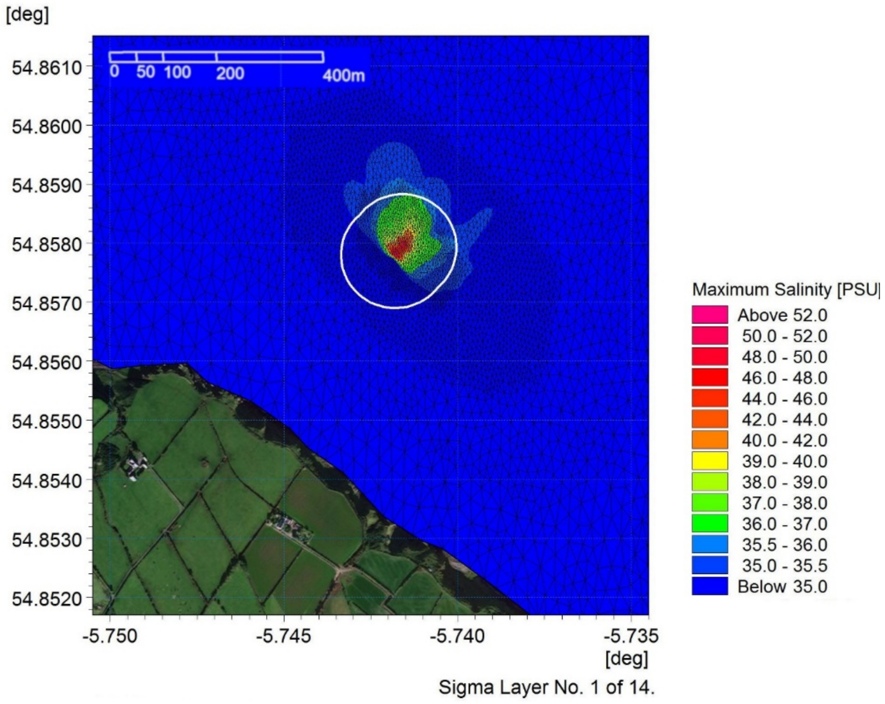
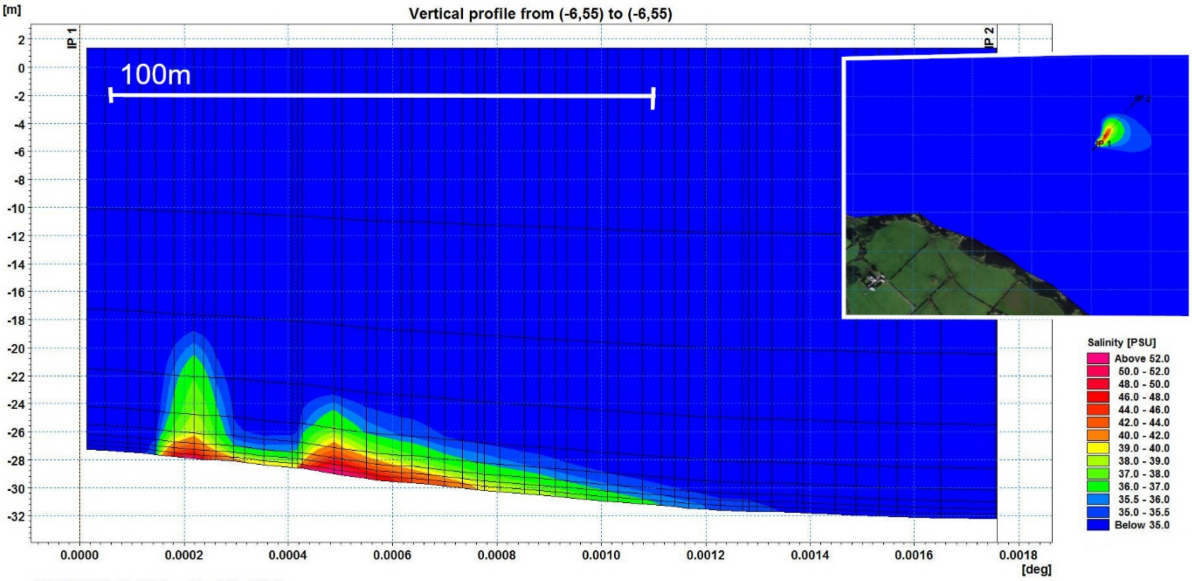


Figure 4-4: Maximum Salinity at Bed – 14 layer model

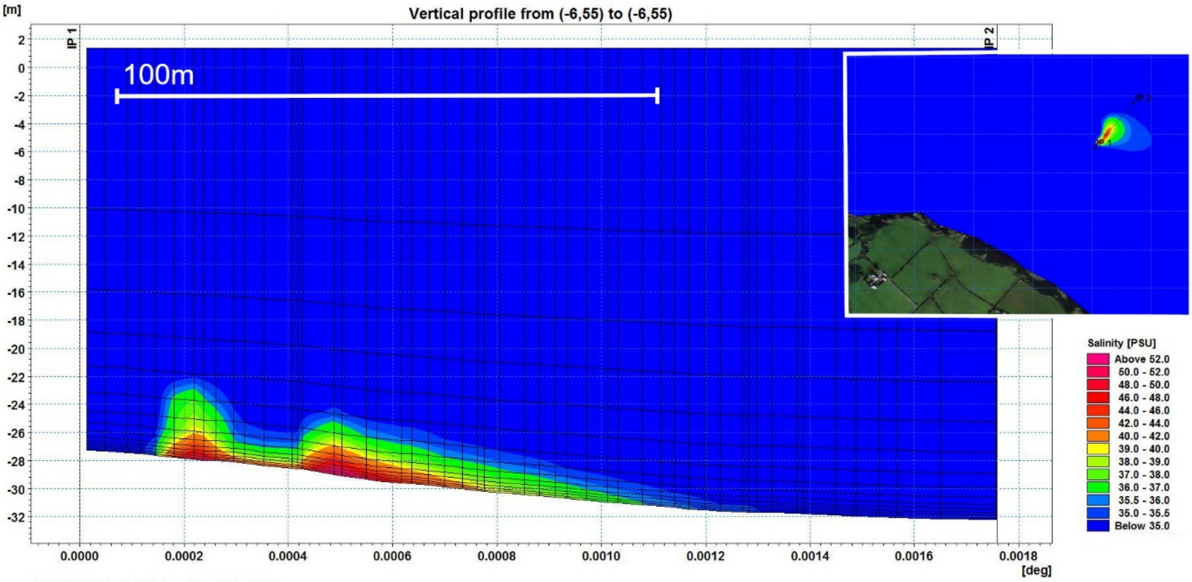
The results presented in the figures above clearly show that the 9 and 14 layer models predict higher salinity levels close to the point of discharge than the 4 layer model, however beyond approximately 100-150m from the discharge location the results for all models are virtually identical. This was not unexpected given the significantly increased horizontal and vertical resolution of the 9 and 14 layer models compared to the 4 layer model. The sensitivity testing results therefore demonstrate that the 4 layer model is suitable for assessment of the far field effects as reported in Section 5.

When the result of the 9 and 14 layer models were examined in detail there was virtually no discernible difference in the predicted salinity concentrations within the 100m mixing zone as indicated in Figure 4-5 and Figure 4-6 which show vertical profiles through the discharge plume at high water spring tides for the 9 and 14 layer models respectively. Consequently the 9 layer model was selected for use in the medium field assessment reported below.



17/10/2009 22:00:00 Time Step 184 of 1344.

Figure 4-5: Vertical profile through discharge – 9 layer model



17/10/2009 22:00:00 Time Step 184 of 245.

Figure 4-6: Vertical profile through discharge – 14 layer model

4.2 Dispersion Modelling Results

The continuing dispersion of the brine in the medium field was simulated using the MIKE 3 FM model to show the influence of the brine beyond the initial boil but within the permitted mixing zone, away from the immediate area of the discharge.

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 selected tidal cycle of the model simulation 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 field simulations demonstrate the way in which the brine is initially dispersed through the water column as the discharge is advected by tidal and density currents. These simulations include the MIKE inbuilt near-field jet modelling function whereby the brine discharge to the lower part of the water column is represented by placing two sources at 0.75m above the bed with an upward trajectory. Salinity concentrations are subsequently calculated across zones within the water column.

Due to the limited spatial extent of elevated salinities the figures presenting the results of the model simulations only show the localised area as indicated by the red square in Figure 4-7. In each figure the 100m mixing zone associated with the two port diffuser is shown by a white ellipse, while the 36psu threshold is indicated by the green contour.

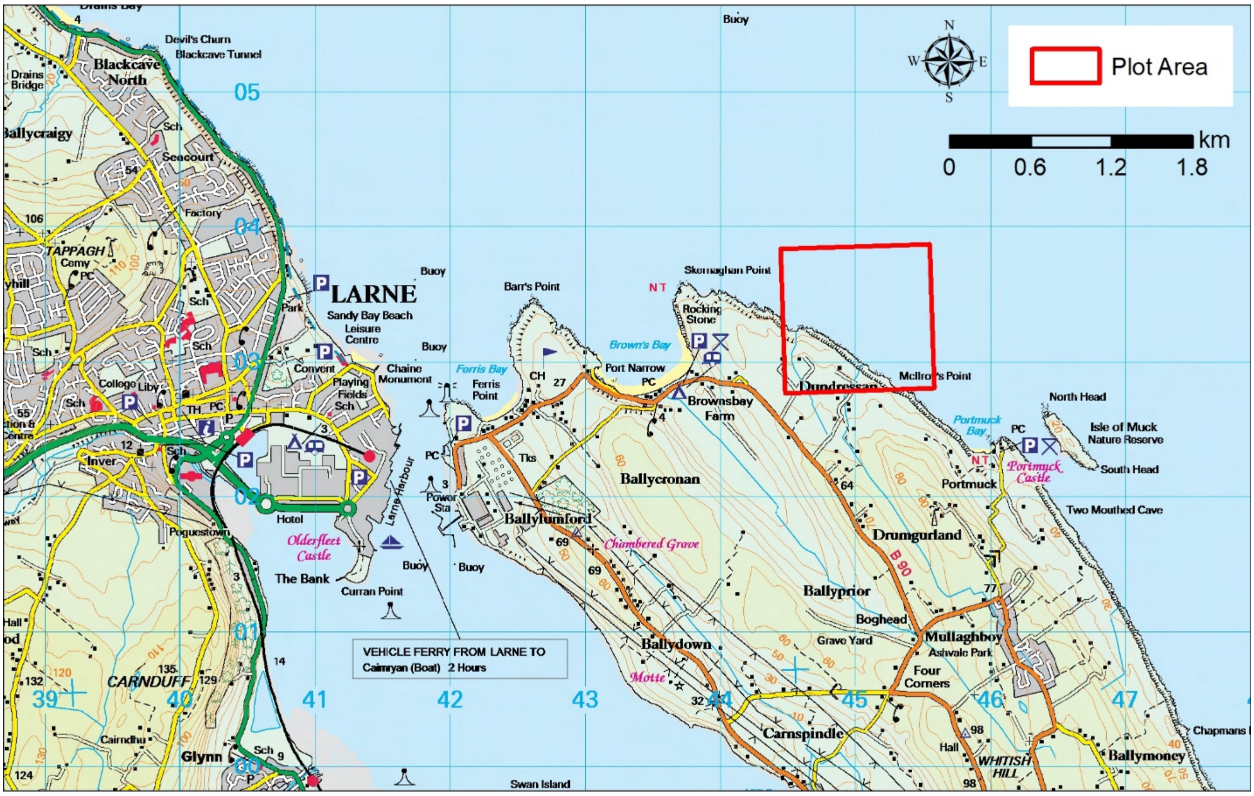


Figure 4-7: Map of Islandmagee area showing extent of model output plots

4.2.1 Neap Tides

Figure 4-8 shows the maximum salinity envelope for the bottom layer in which concentrations are greatest during the neap tidal cycle for the 1,000m^3/hour discharge. Maximum salinity levels at 1m, 3m and 6m above the bed i.e. the region affected by the discharge jet from the diffuser, are shown in Figure 4-9 to Figure 4-11 respectively.

The salinity increases predicted beyond the initial discharge in all cases are relatively small; the contour intervals plotted representing small increases of 0.50 psu. The maximum salinity levels predicted at the seabed are circa 50PSU which is commensurate with the levels predicted by the initial dilution assessment for first contact with the seabed. Salinity levels in excess of 40 psu are only predicted to extend for a for approximately 10-15m from the diffuser with concentrations in excess of 36 psu only occurring just beyond 100m of the diffuser location during the maximum leaching rate with the maximum discharge salinity. This correlates with the predictions of the original assessment undertaken in support of the original planning application for the Islandmagee Gas Storage Facility.

Figure 4-9 to Figure 4-11 clearly show a significant reduction in salinity levels with height above the seabed, such that by 6m above the bed, Figure 4-11, the maximum salinity levels only just exceed 36 psu at the diffuser.

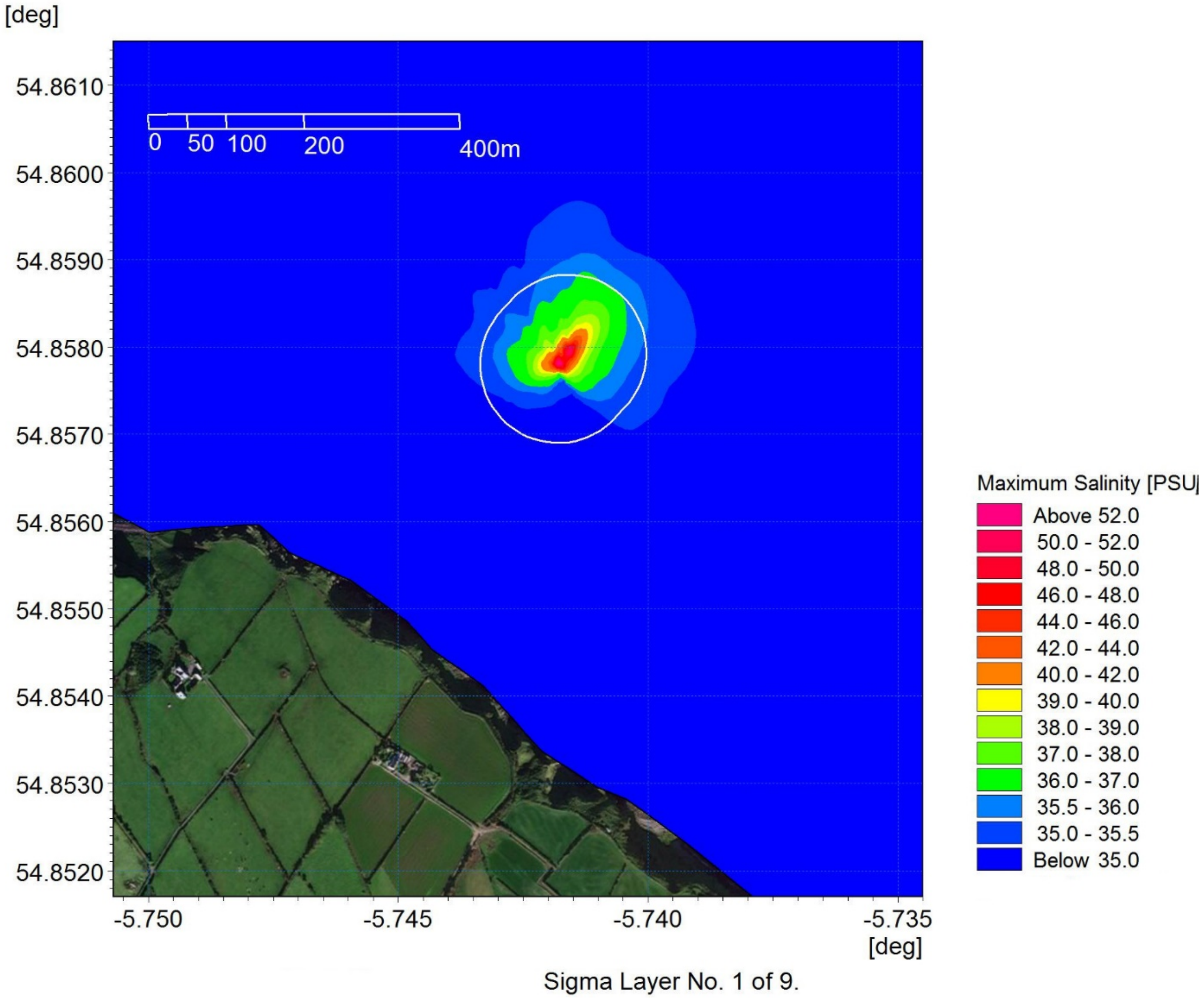


Figure 4-8: Maximum Salinity at Bed – Neap Tide

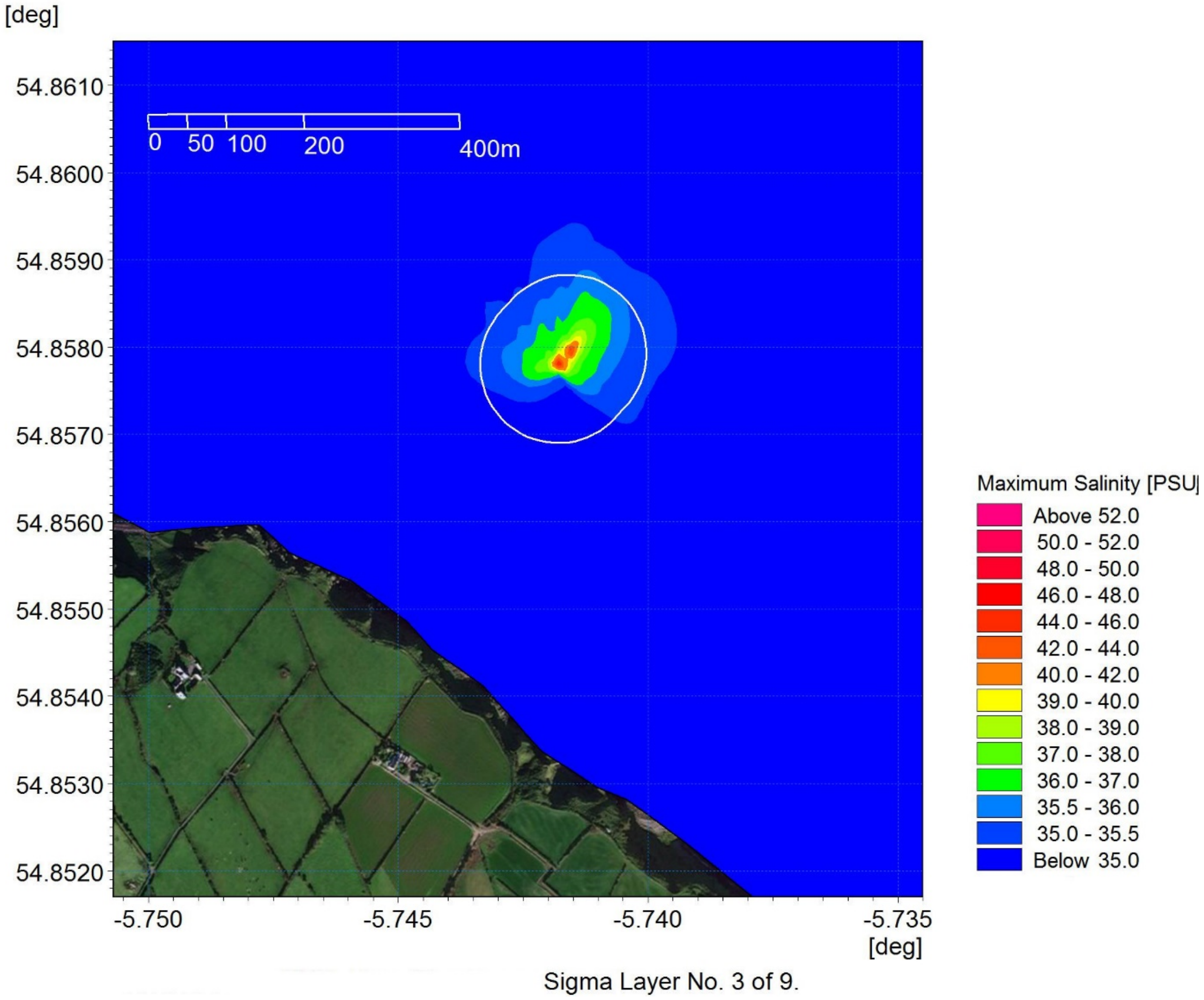


Figure 4-9: Maximum Salinity at 1m above Bed – Neap Tide

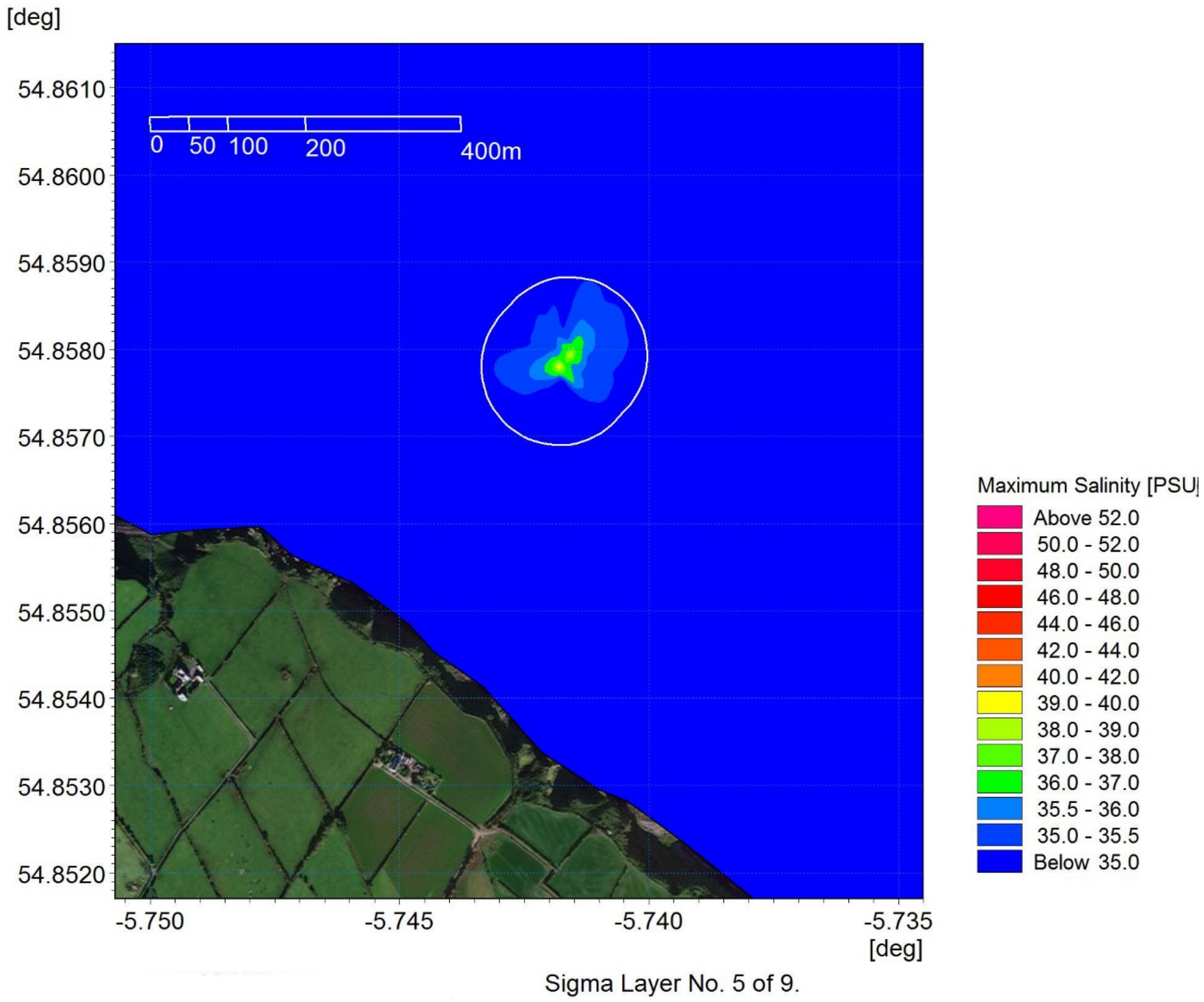


Figure 4-10: Maximum Salinity at 3m above Bed – Neap Tide

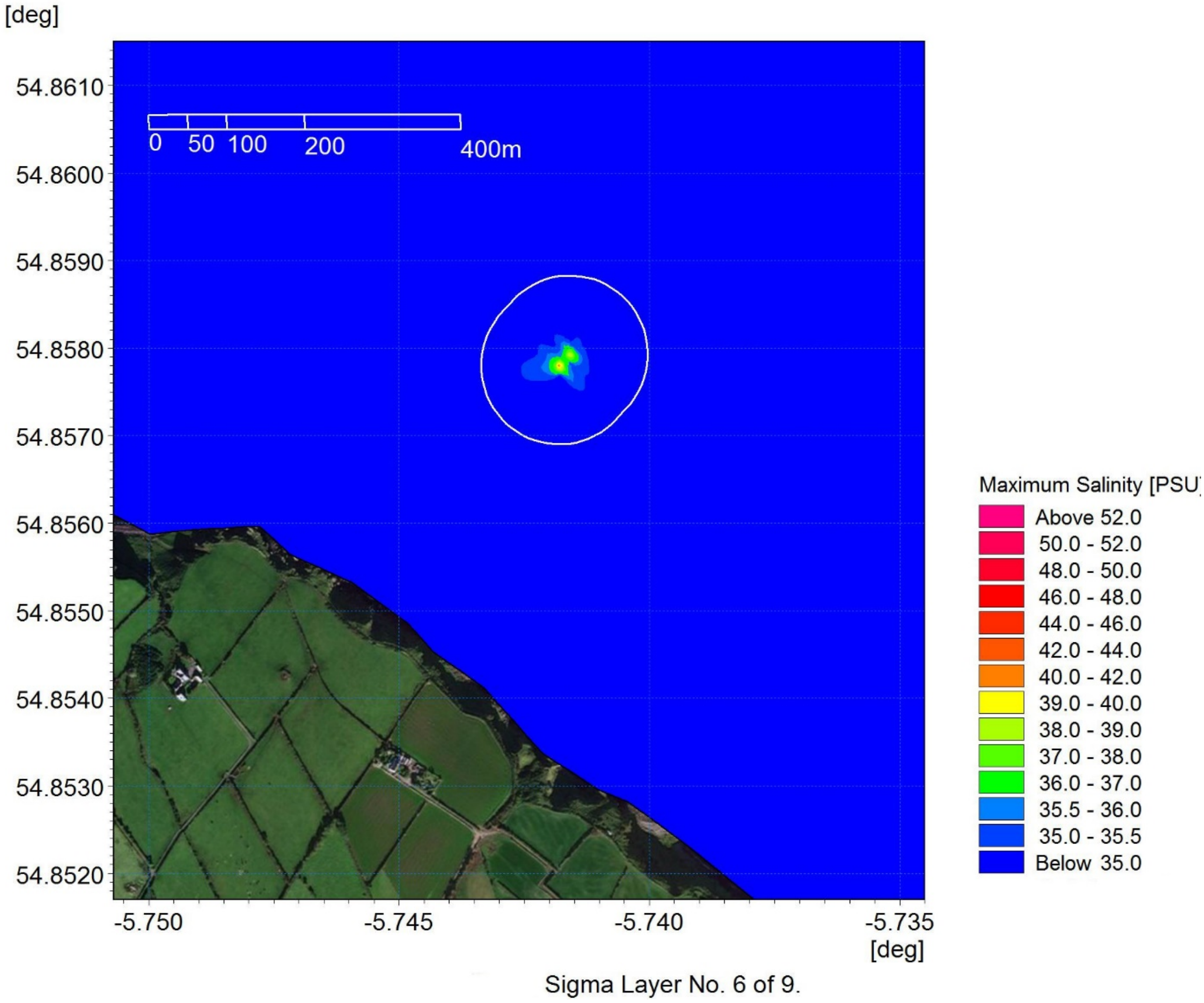


Figure 4-11: Maximum Salinity at 6m above Bed – Neap Tide

Salinity distributions in the lowest most layer of the model i.e. near the seabed, at intervals through the tidal cycle corresponding to high tide, mid-ebb, low tide and mid flood associated with the proposed maximum 1,000m^3/hour discharge are shown in Figure 4-12, Figure 4-13, Figure 4-14 and Figure 4-15 respectively. Examination of these Figures illustrates that the larger increases in salinity only occur for short periods during the tidal cycle close to the times of slack water.

The maximum salinity for the higher layers in the water column, layer 2 and above, reduce quite rapidly with height above the seabed. Figure 4-16 to Figure 4-19 respectively show vertical profiles through the water column at low tide, mid flood, high tide and mid ebb respectively. These figures clearly illustrate the significant decrease in salinity with distance up through the water column, with very little impact evident more than a few metres above the bed.

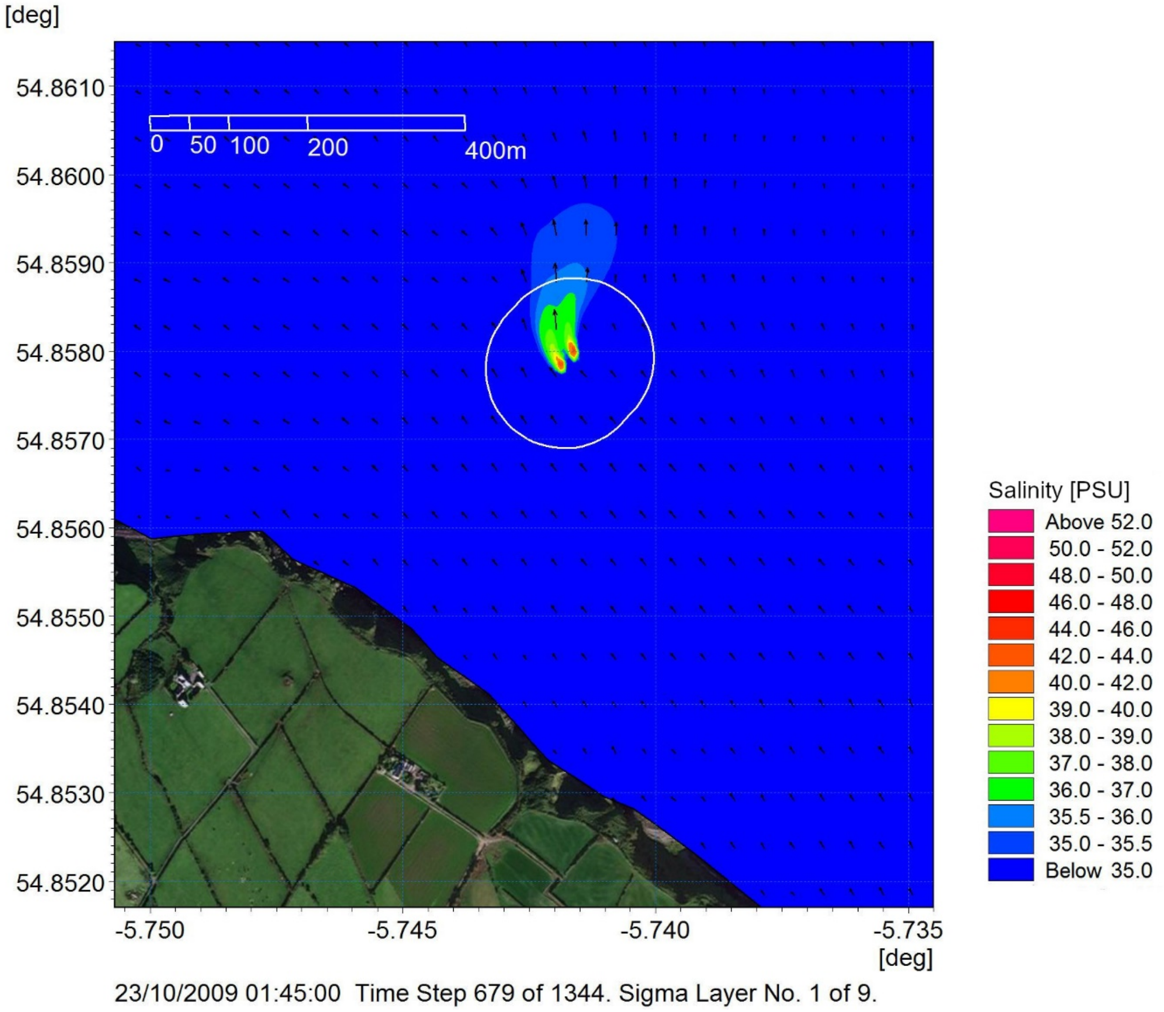


Figure 4-12: Salinity & Current Vectors at High Water Neap – 1,000m^3/hour Discharge

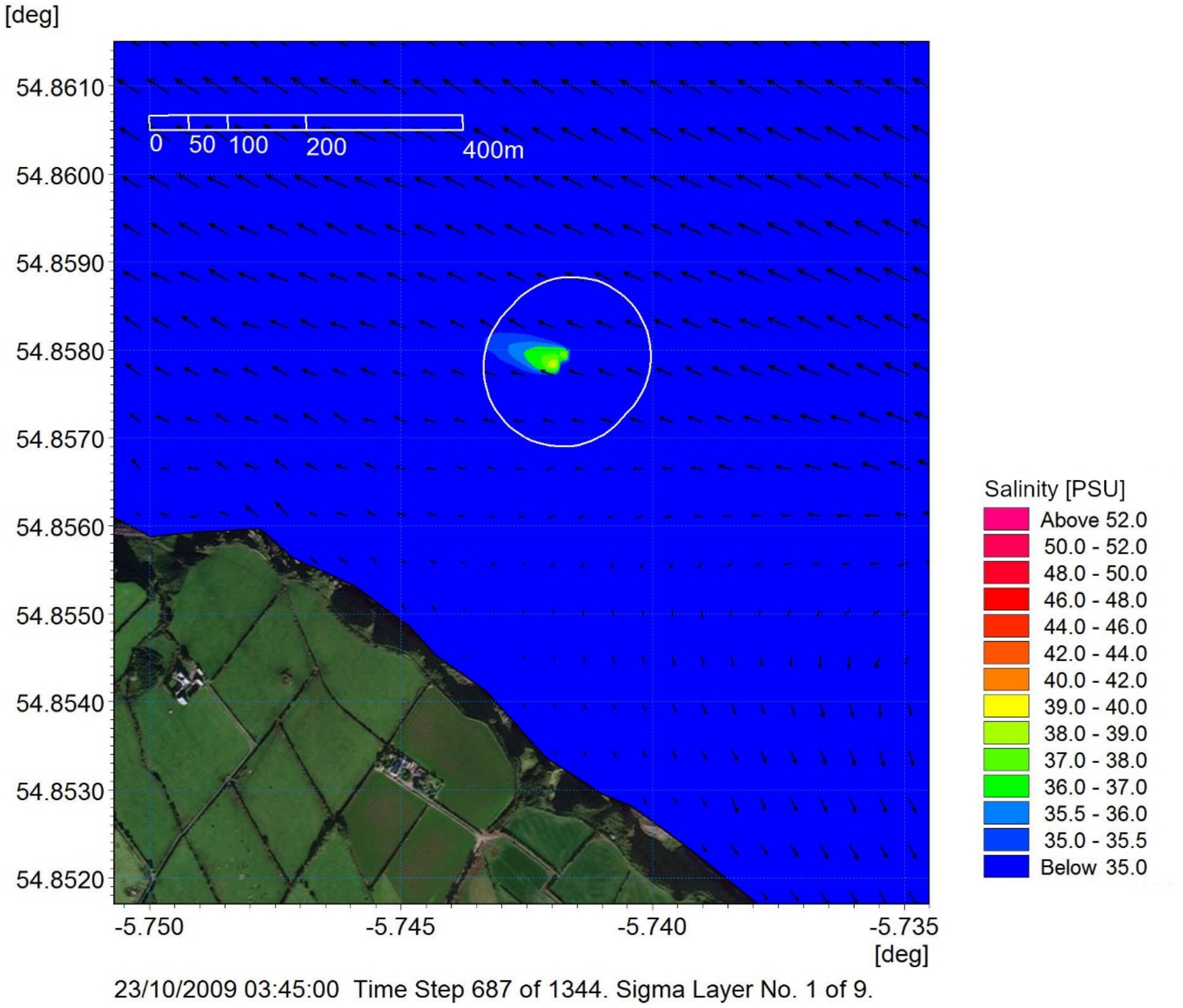


Figure 4-13: Salinity & Current Vectors at Mid-Ebb Neap Tide – 1,000m^3/hour Discharge

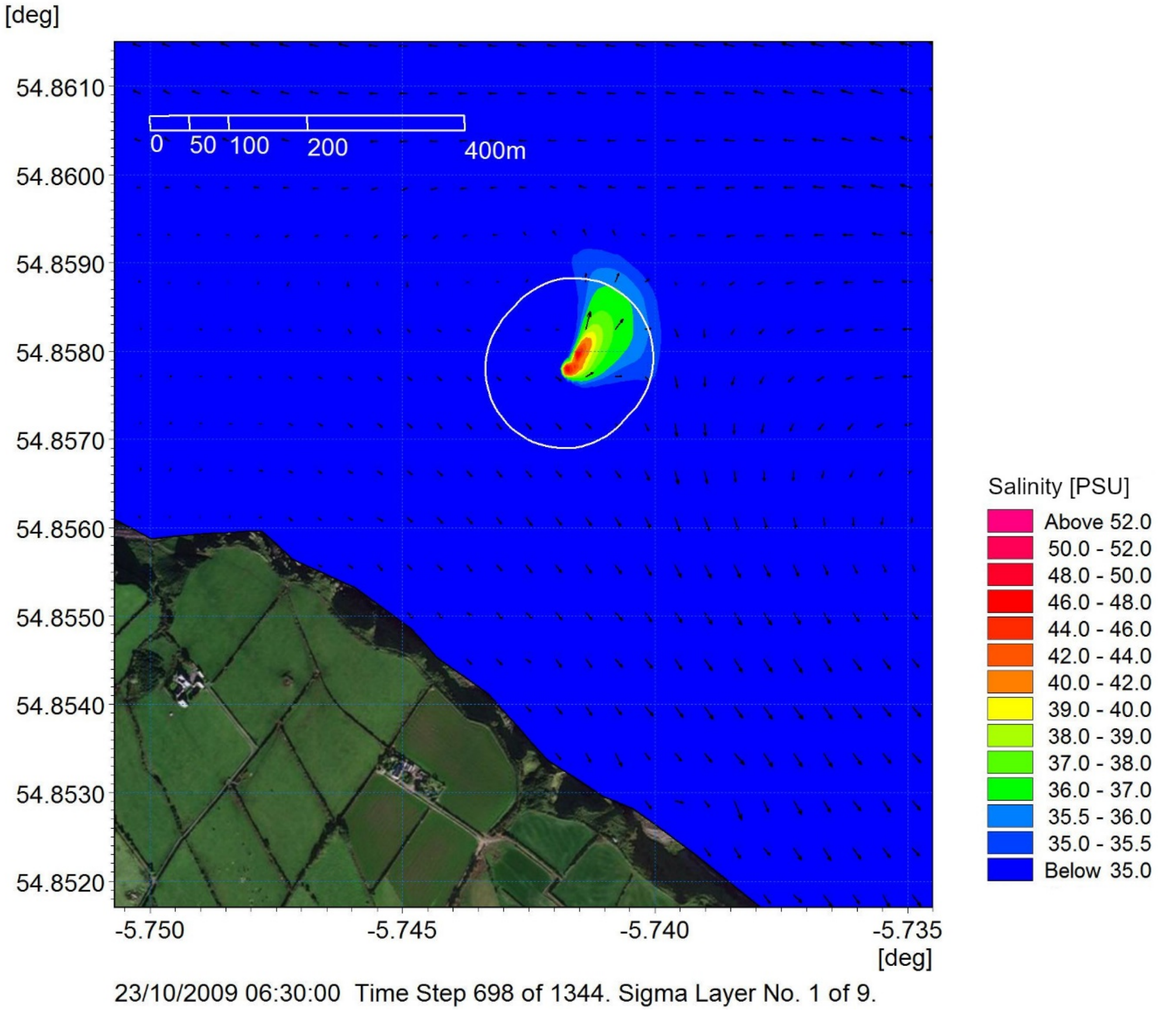


Figure 4-14: Salinity & Current Vectors at Low Water Neap – 1,000m^3/hour Discharge

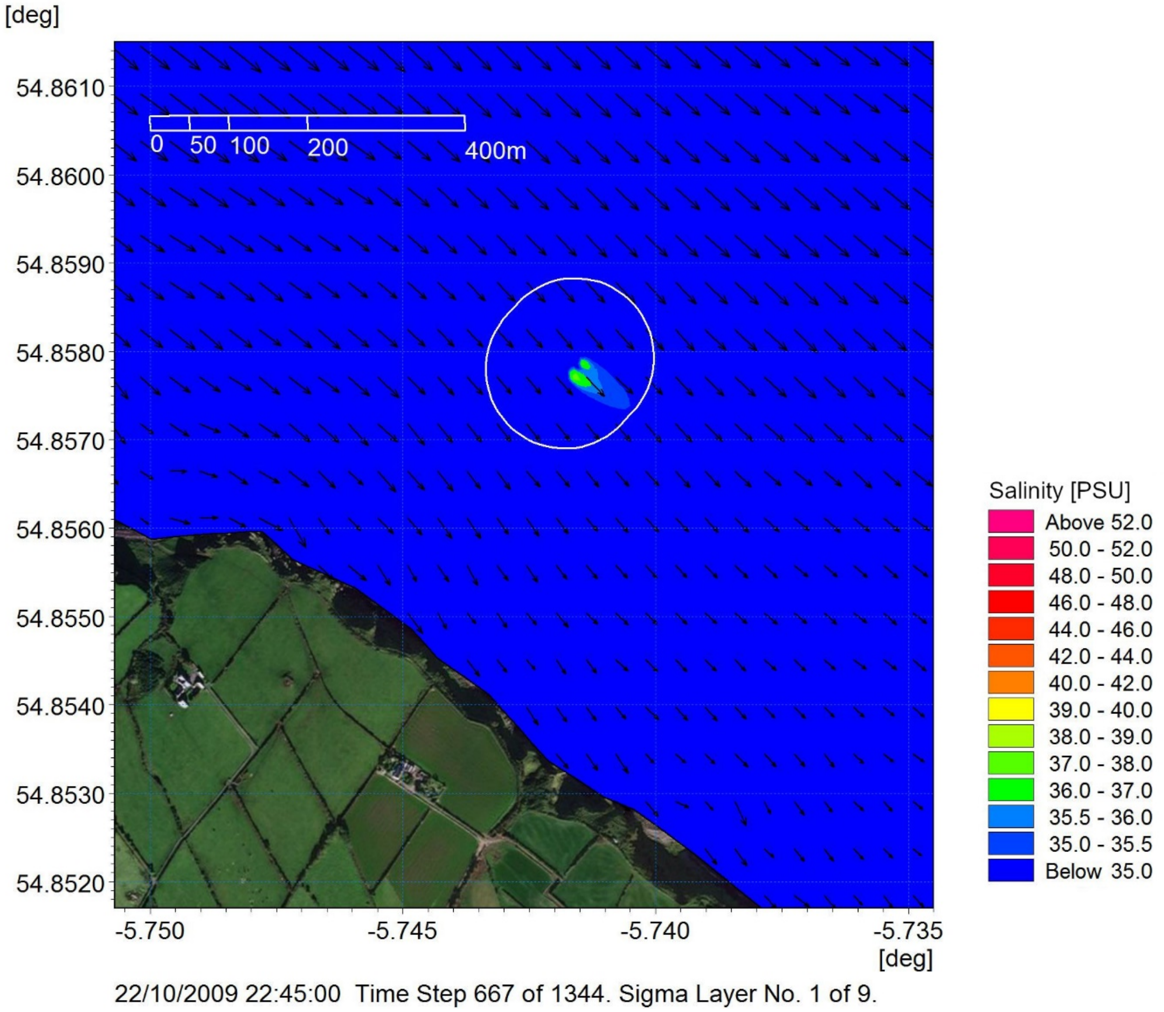


Figure 4-15: Salinity & Current Vectors at Mid-Flood Neap Tide – 1,000m^3/hour Discharge

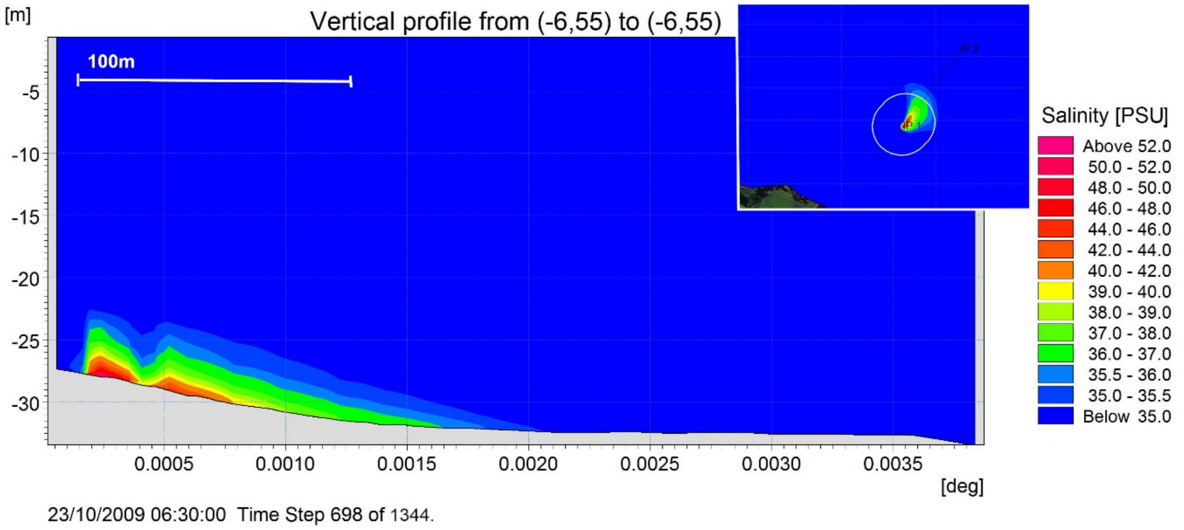


Figure 4-16: Vertical Profile of the Salinity at Low Tide during a Neap Tidal Cycle – 1,000m^3/hour Discharge

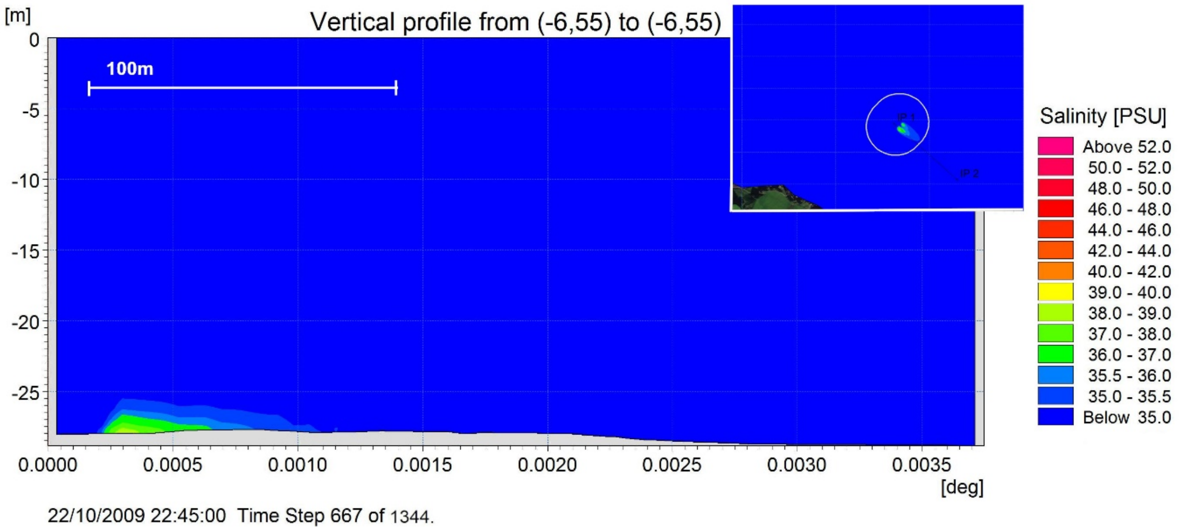


Figure 4-17: Vertical Profile of the Salinity at Mid-Flood during a Neap Tidal Cycle – 1,000m^3/hour Discharge

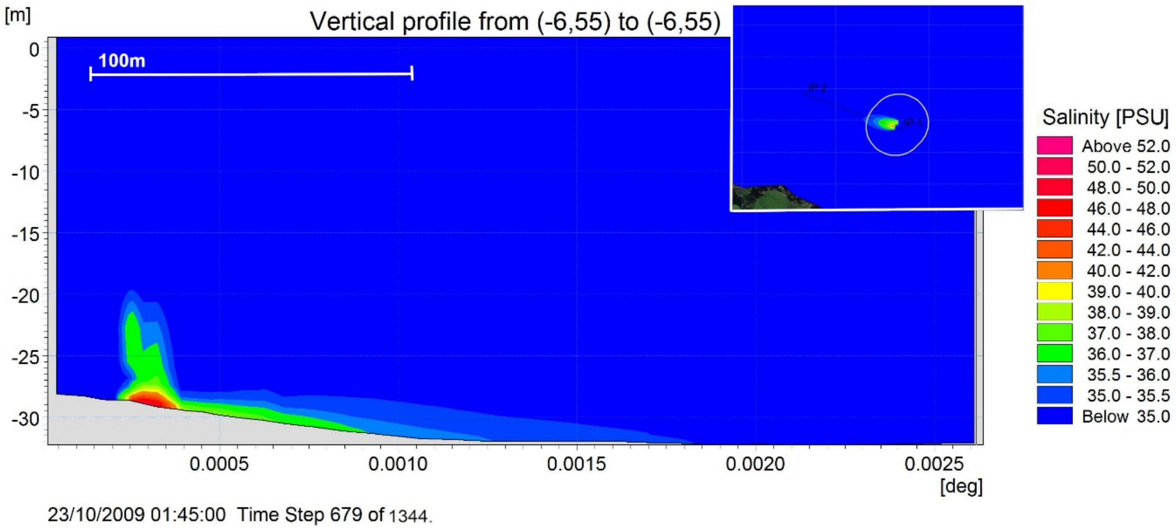


Figure 4-18: Vertical Profile of the Salinity at High Tide during a Neap Tidal Cycle – 1,000m³/hour Discharge

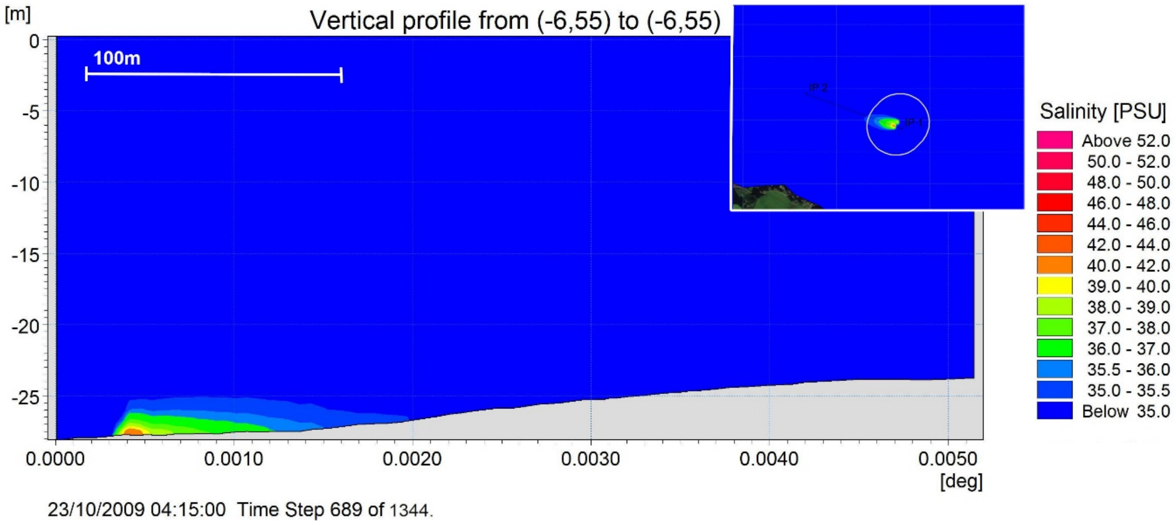


Figure 4-19: Vertical Profile of the Salinity at Mid-Ebb during a Neap Tidal Cycle – 1,000m³/hour Discharge

4.2.2 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 outside of the mixing zone was minimal, therefore during spring tides, where peak tidal velocities are typically double those of the neaps, the impact would be expected to be further reduced.

However for completeness the salinity concentrations for the bottom layer at high water, mid ebb, low water and mid flood during spring tides under the maximum 1,000m^3/hour scenario are presented in Figure 4-20 to Figure 4-23 respectively.

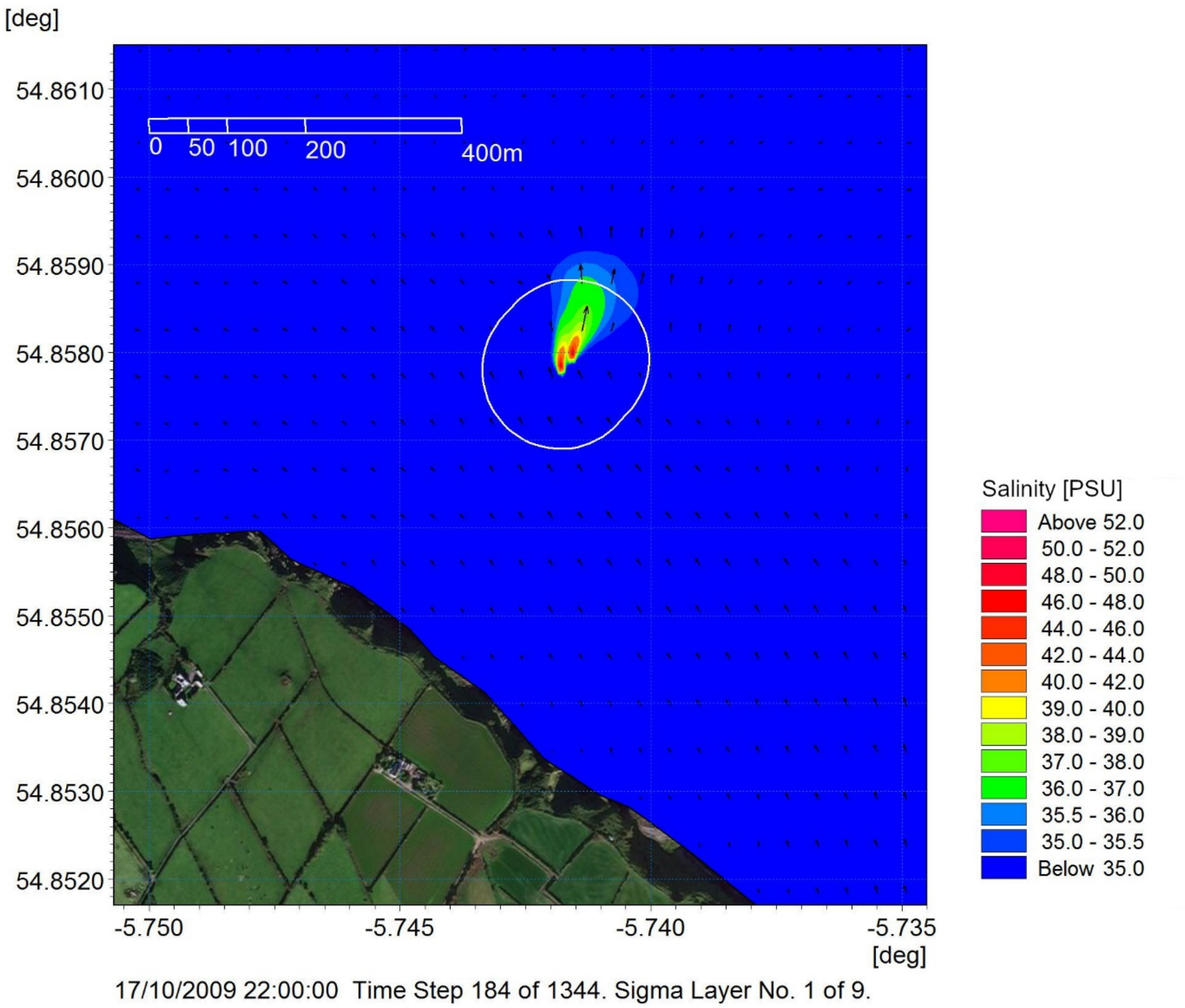


Figure 4-20: Salinity & Current Vectors at High Water Spring – 1,000m^3/hour Discharge

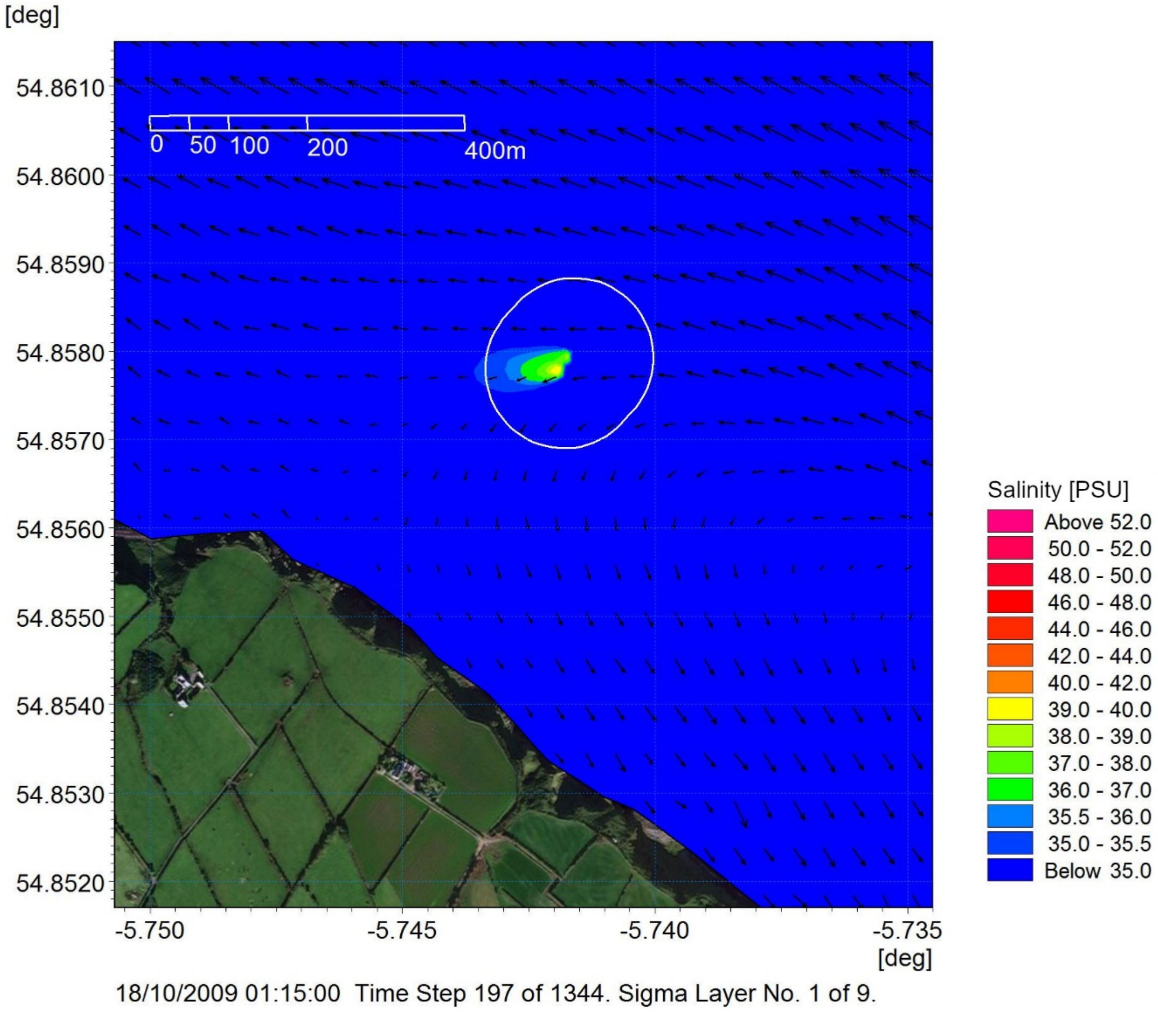


Figure 4-21: Salinity & Current Vectors at Mid-Ebb Spring Tide – 1,000m^3/hour Discharge

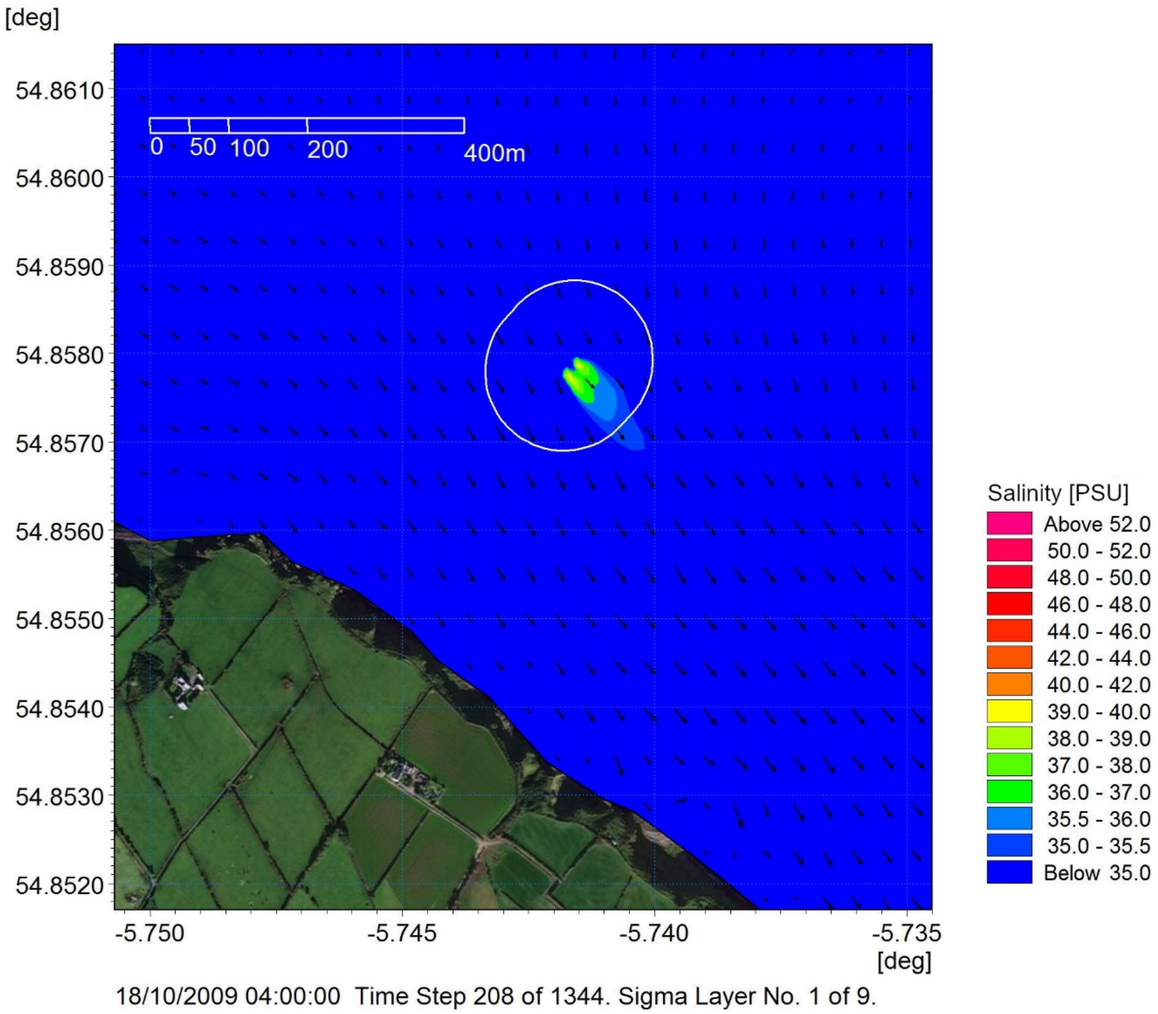


Figure 4-22: Salinity & Current Vectors at Low Water Spring – 1,000m^3/hour Discharge

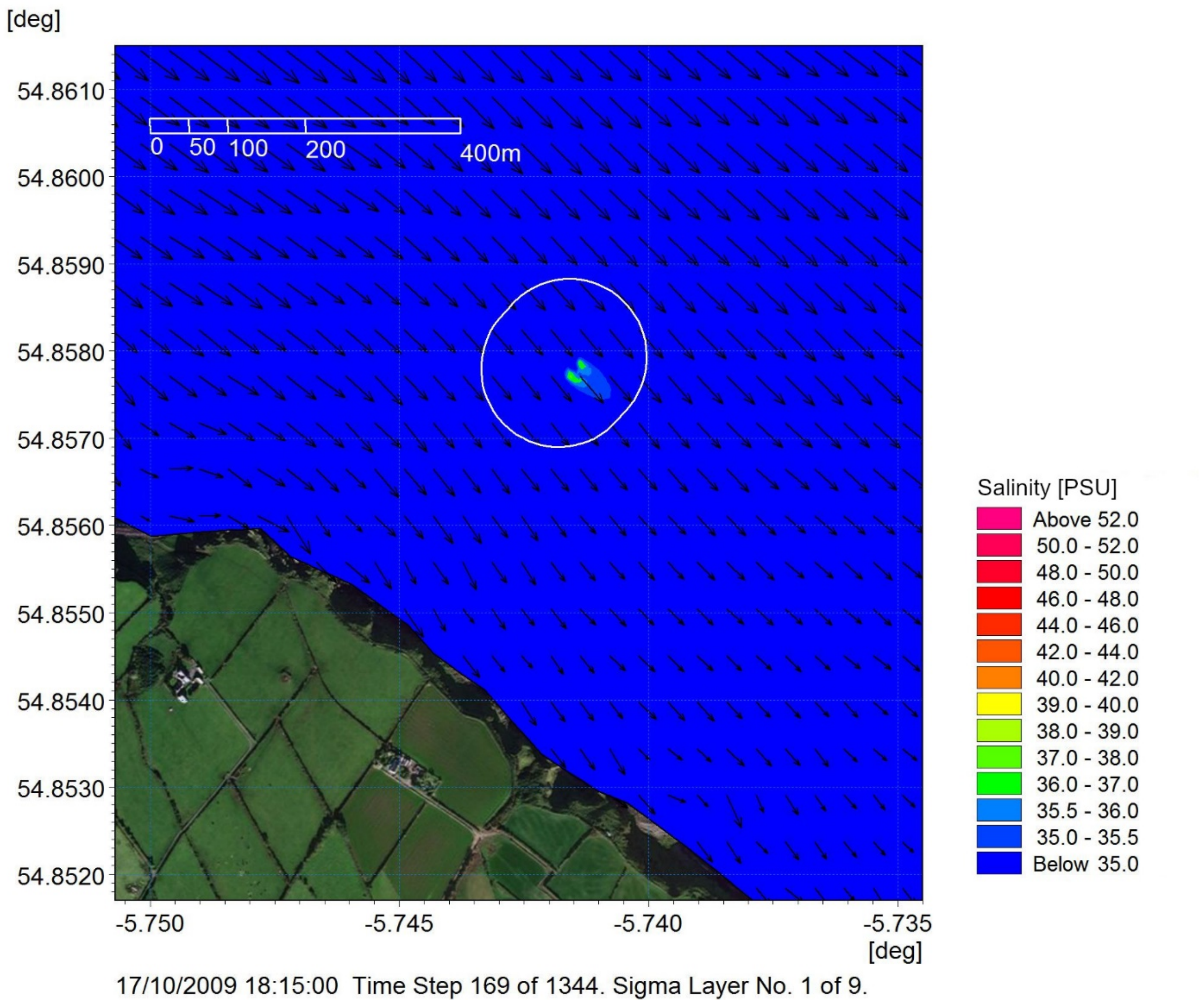


Figure 4-23: Salinity & Current Vectors at Mid-Flood Spring Tide – 1,000m^3/hour Discharge

4.2.3 Maximum Brine Plume Envelope

The results presented previously show the anticipated salinity levels during typical mean spring and neap tidal cycles, however the overall model simulation period selected for this study also included a period of very small neap tides with tidal ranges approaching 1m. When the overall results were examined it was noted that slightly elevated salinity levels, were shown to extend further from the discharge than indicated by the standard neap tide simulations. The maximum extent of influence of these slightly elevated salinities in illustrated in Figure 4-24. While it must be emphasised that this situation would only occur if a period of very small neap tides coincided with the leaching plant operating at maximum capacity, even under these conditions any elevation in salinity levels above 36 psu is still restricted to the immediate vicinity of the discharge and is flushed with the subsequent spring tides.

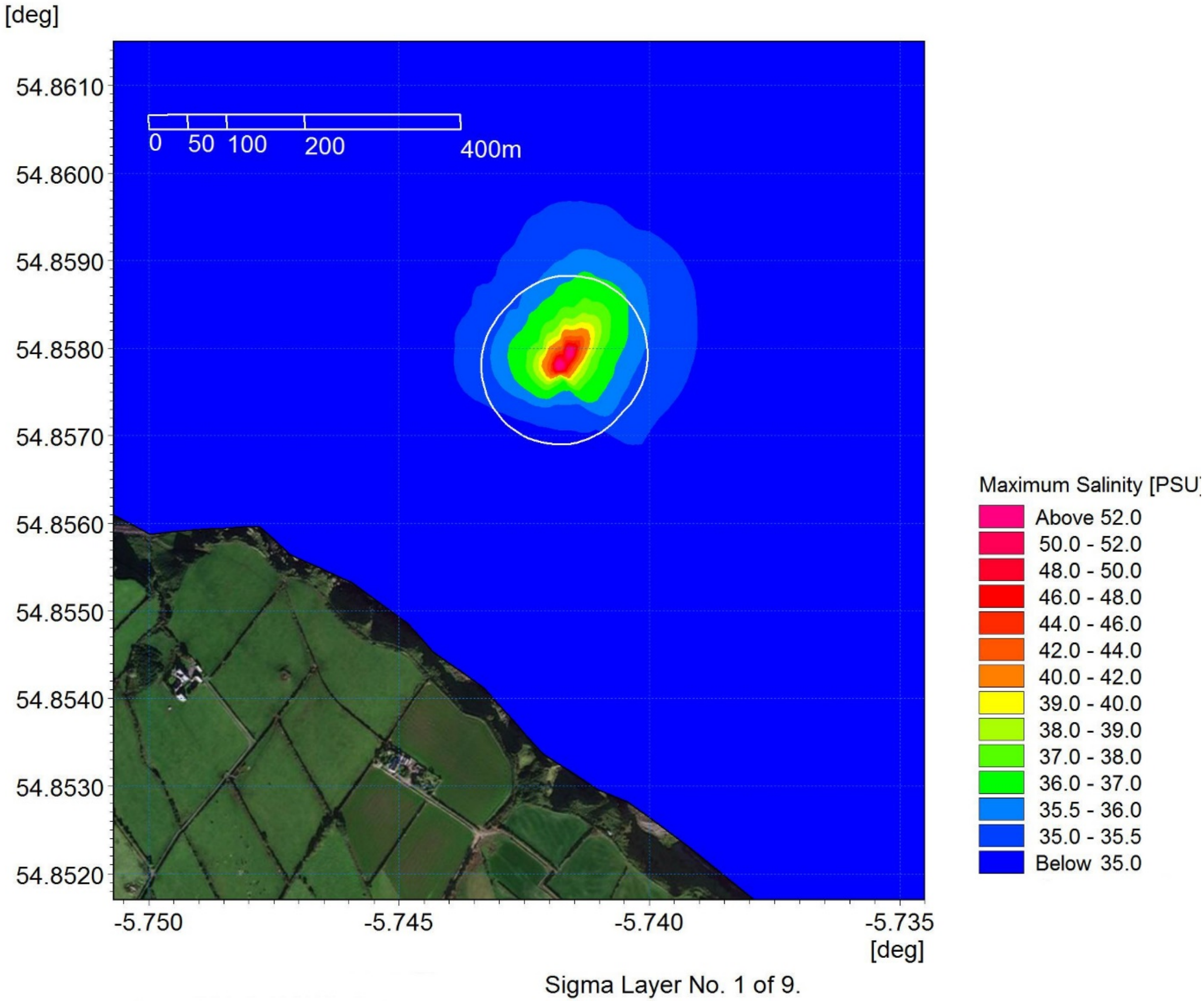


Figure 4-24: Maximum Salinity @ bed during a Spring - Neap Tidal Cycle – 1,000m^3/hour Discharge

5 FAR FIELD DISPERSION MODELLING

The MIKE 3 Flow Model FM was again used to simulate the far field dispersion of the brine discharge in order to show the influence of the brine beyond the initial mixing zone i.e. within the overall water body away from the immediate area of the outfall.

5.1 Dispersion Modelling Results

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 selected tidal cycle of the model simulation. 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 and actual salinity levels will almost always be lower than those shown due to variations in dispersion through the tidal cycle.

The 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 far field simulations have been undertaken by placing the sources at 0.75m above the bed with an upward trajectory 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 Figure 5-1. Whilst the medium field modelling reported in the previous section demonstrates that the brine discharge is relatively well mixed by the edge of the mixing zone, the brine is still negatively buoyant, hence it is 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 thicker layers could be used.

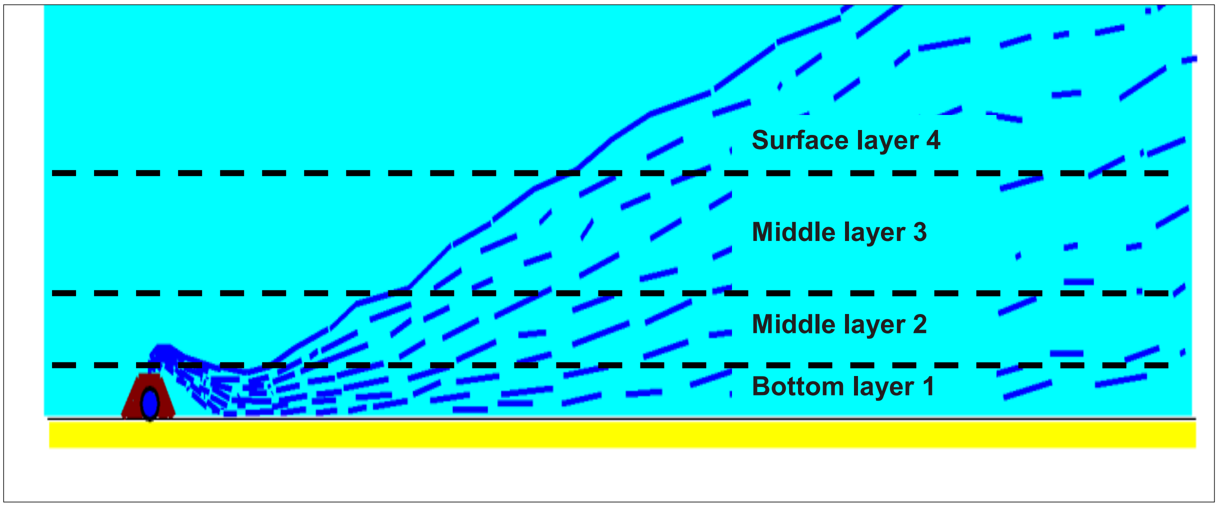


Figure 5-1: Modelling zones implemented for medium and far field brine dispersion

5.1.1 Far Field Brine Dispersion during Neap Tides

Figure 5-2 shows the maximum salinity envelope for the bottom layer in which concentrations are greatest during the neap tidal cycle for the 250m^3/hour discharge from a single port. Similar plots of the maximum bottom layer salinities for the 500m^3/hour and 1,000m^3/hour discharges are presented in Figure 5-3 and

Figure 5-4 respectively. In all figures presented the colour contour bands are not linear with smaller intervals used at the lower salinity and the 36 psu threshold is shown in yellow.

The salinity increases predicted beyond the initial mixing zone in all cases are relatively small; the contour intervals plotted representing very small increases of 0.25-0.50 psu. A maximum far field increase in salinity of less than 4 psu i.e. total salinity <38 psu, was recorded throughout all the simulations which is commensurate with the levels predicted for the concept design considered at planning stage.

The baseline salinity data obtained from AFBI and NIEA at the initial project development stage indicated that background salinities in this part of the North Channel off Islandmagee can range between circa 30.5 psu and 34.8 psu. Even with an assumed background salinity of 34.2 any salinity increase in excess of the range normally experienced in seasonal variations (34.8 psu) is expected to be restricted to an area less than 300 metres from the outfall.

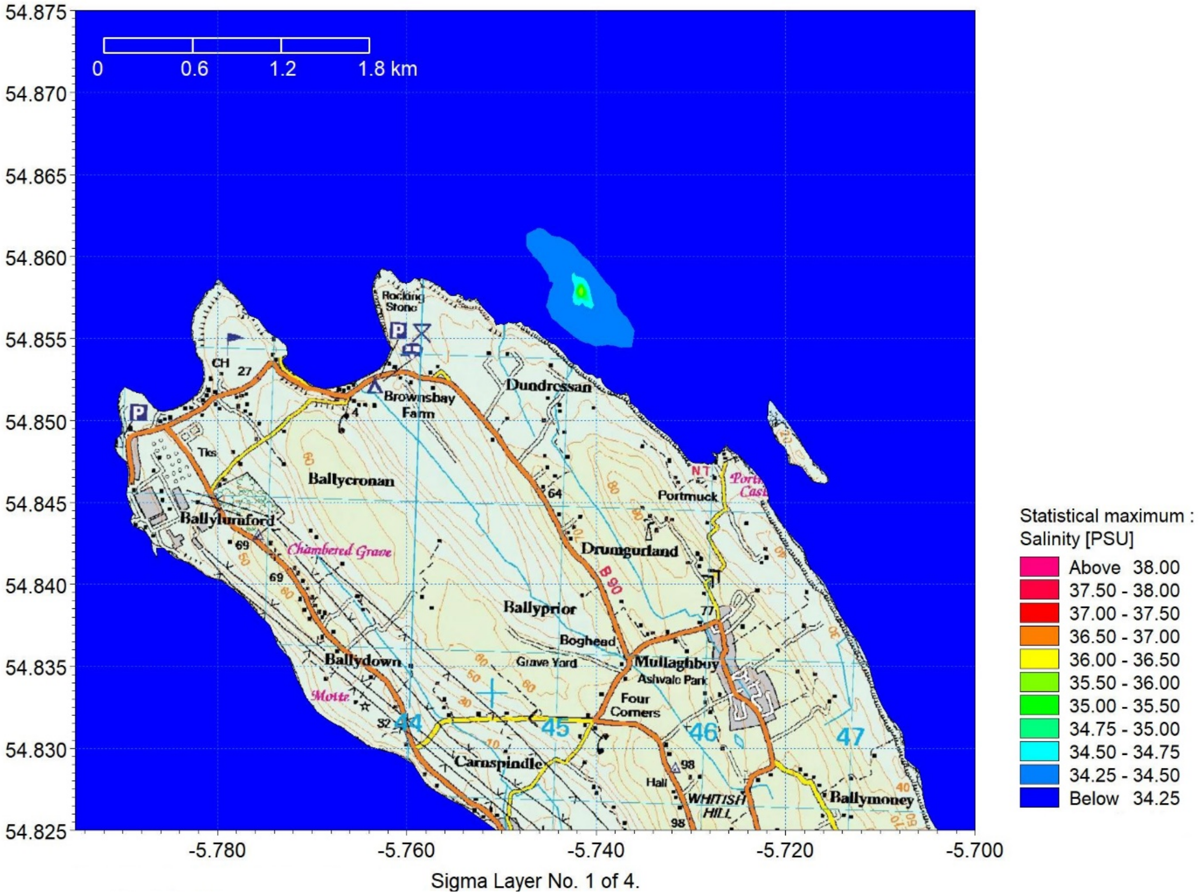


Figure 5-2: Maximum Seabed Salinity during a Neap Tidal Cycle – 250m^3/hour Discharge

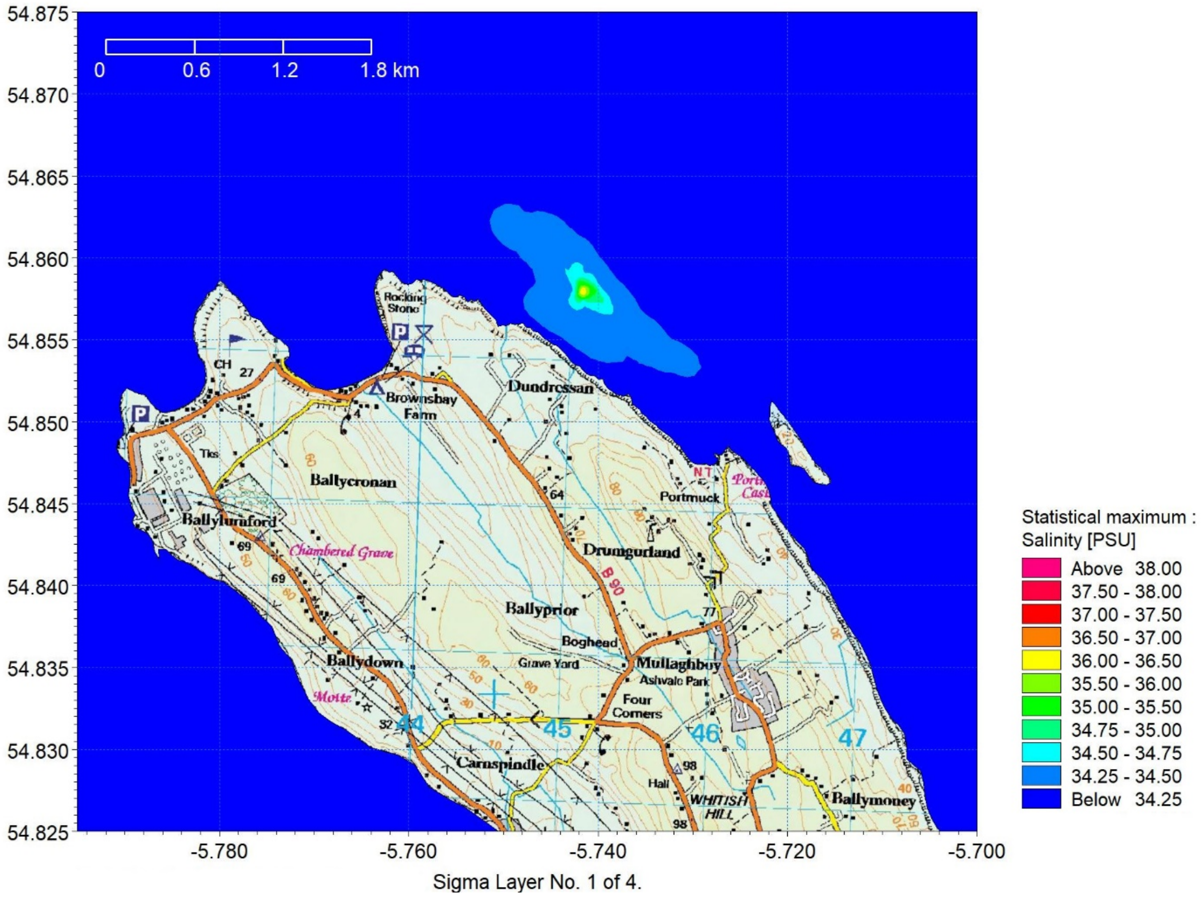


Figure 5-3: Maximum Seabed Salinity during a Neap Tidal Cycle – 500m^3/hour Discharge

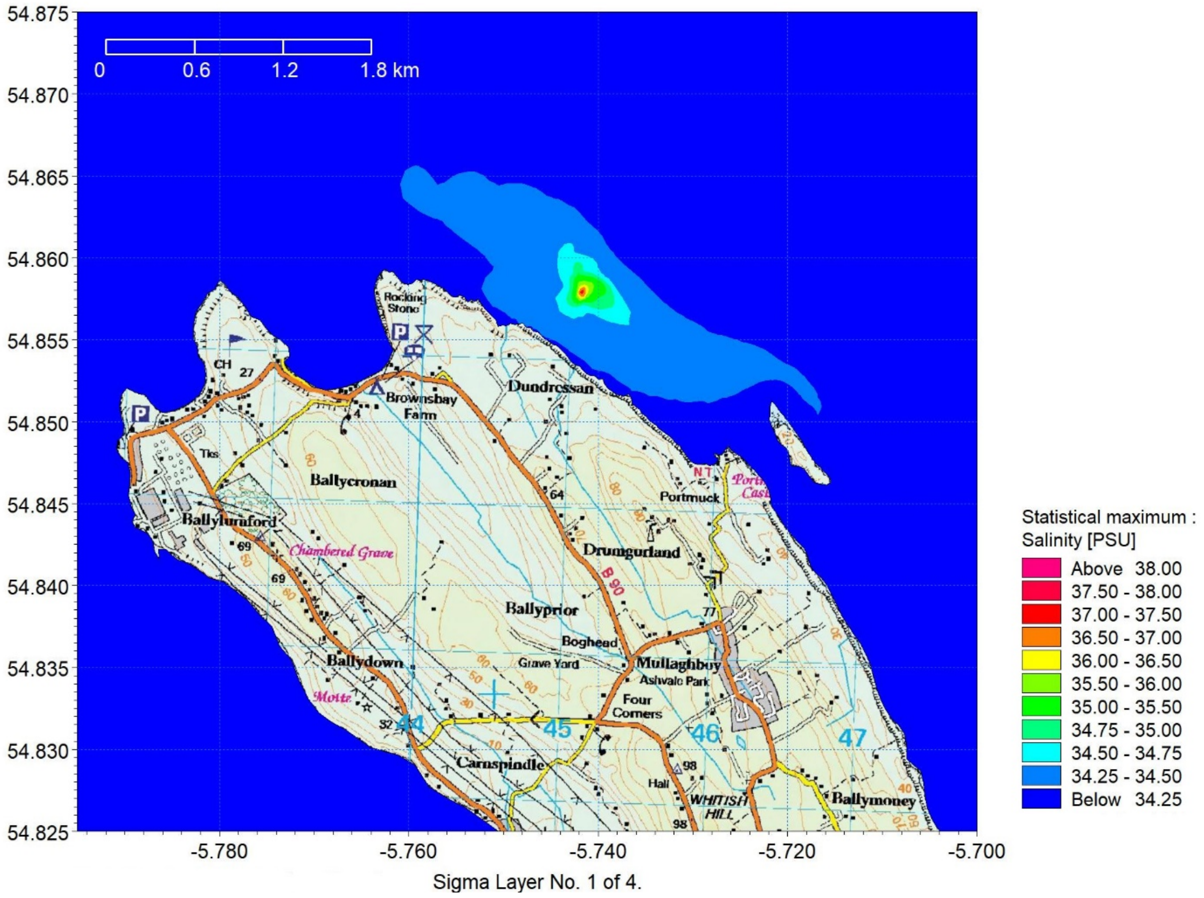


Figure 5-4: Maximum Seabed Salinity during a Neap Tidal Cycle – 1,000m^3/hour Discharge

5.1.2 Far Field 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 was minimal, therefore during spring tides, where peak tidal velocities are typically double those of the neaps, the impact would be expected to be further reduced.

For completeness the maximum concentration envelope for the bottom layer during spring tides under the maximum 1,000m^3/hour scenario is presented in Figure 5-5.

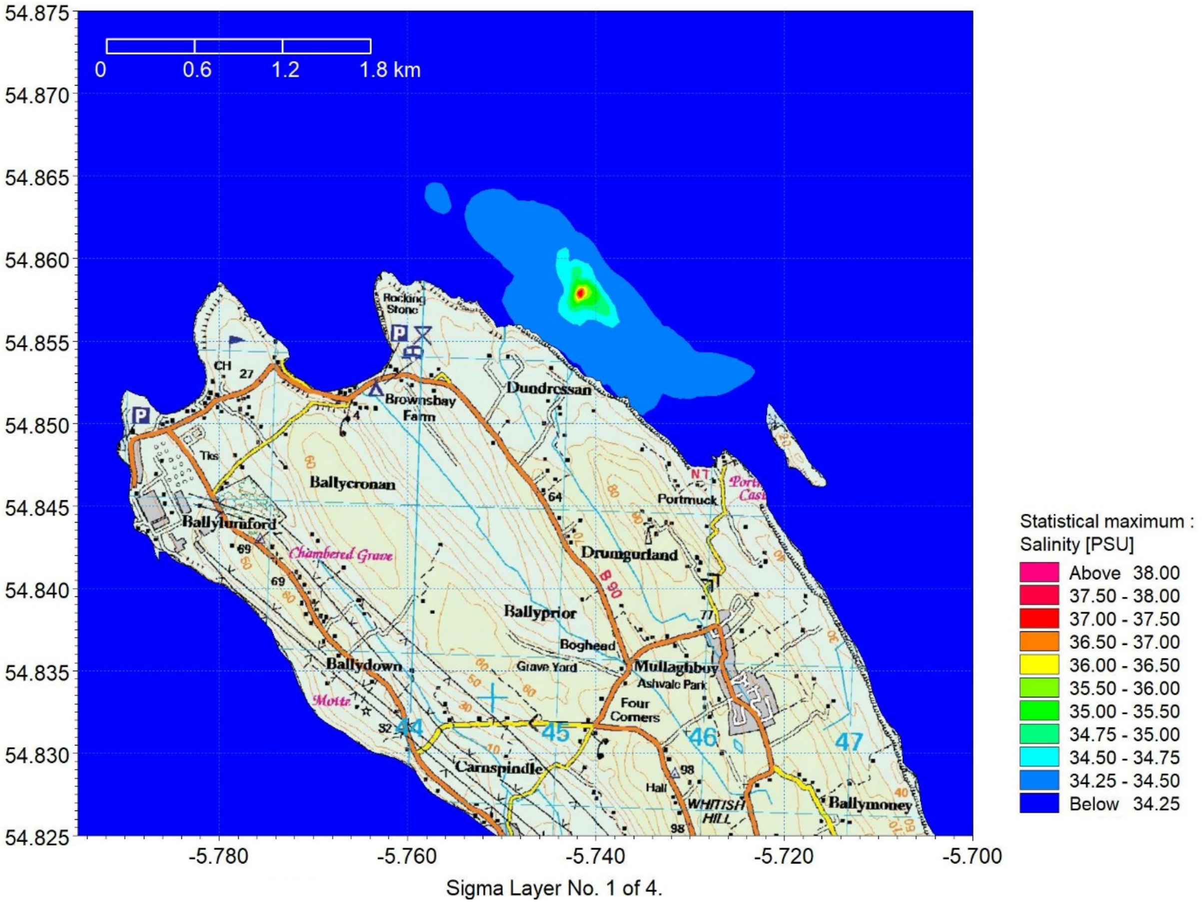


Figure 5-5: Maximum Seabed Salinity during a Spring Tidal Cycle – 1,000m^3/hour Discharge

5.1.3 Maximum Brine Plume Envelope

The results presented previously show the anticipated salinity levels during standard spring and neap tidal cycles, however the overall model simulation period selected for this study also included a period of very small neap tides with tidal ranges approaching 1m. When the overall results were examined it was noted that slightly elevated salinity levels, circa 34.25PSU or 0.05 psu above background were shown to extend further from the discharge than indicated by the standard neap tide simulations. The maximum extent of influence of these slightly elevated salinities in illustrated in Figure 5-6. While it must be emphasised that this situation would only occur if a period of very small neap tides coincided with the leaching plant operating at maximum capacity, even under these conditions any elevation in salinity levels by more than 0.5 psu is still restricted to the immediate vicinity of the discharge and is flushed with the subsequent spring tides.

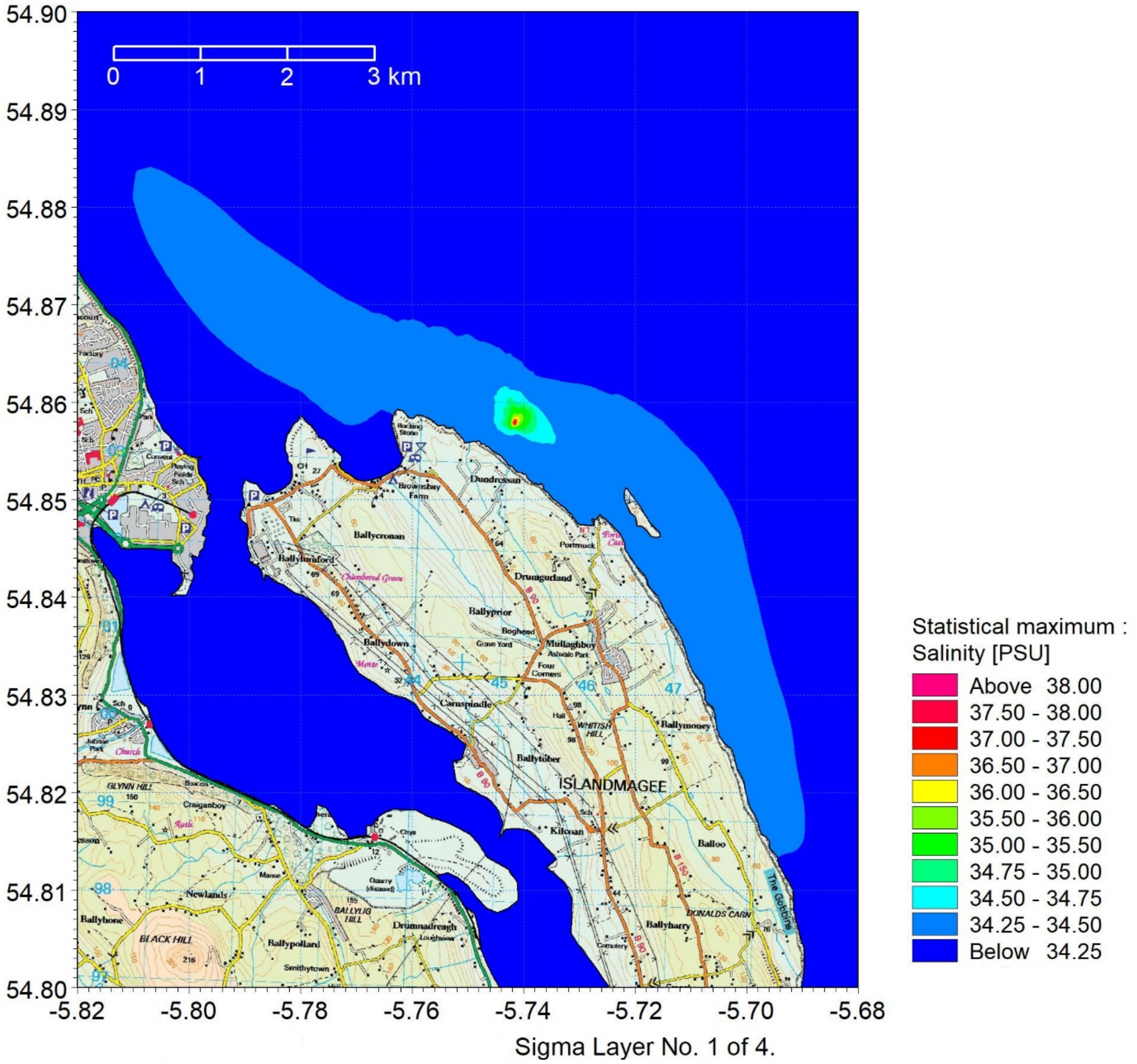


Figure 5-6: Maximum Seabed Salinity - Spring – Neap Tidal Cycle – 1,000m^3/hour Discharge

6 OTHER IMPURITIES IN THE BRINE

When the Islandmagee Gas Storage Facility (IGSF) was initially proposed no site specific salt samples had been obtained from the local Permian salt sequence and hence the consideration of other impurities that could be present in the brine discharge was based on data from the nearest comparable UK site at Aldbrough. However following the successful granting of planning consent for the IGSF a confirmation well was drilled at Islandmagee and salt cores retrieved for subsequent analysis to establish the validity of the original assumption that the Permian salt sequence at Islandmagee would be similar to that encountered at Aldbrough.

Four rock salt samples were selected from the stratigraphic interval of salt sequences in which the IGSF caverns will be created and dissolved in seawater collected from the North Channel at Port Muck to produce a saturated brine of the composition anticipated to be discharged from the IGSF outfall. The resulting concentrations of various non-salt compounds in the Aldbrough and Islandmagee brines and the North Channel seawater are presented in Table 6-1 below along with the corresponding EQS limit for seawater.

Table 6-1: Comparison of Non-Salt Components in Brine

Parameter	Concentration in Brine µg/l		Concentration in seawater	EQS in seawater µg/l
	Aldbrough	Islandmagee		
Arsenic	<5	<1.8	0.1	25
Boron	<20	<3,810	4,300	7,000
Cadmium	<2	<0.36	<0.05	2.5
Chromium	<2	<1	<1.0	15
Copper	<12	<1.5	10.8	5
Lead	<25	<2.2	<0.1	25
Mercury	<0.25	<0.024	<0.02	0.3
Nickel	<5	<3.4	0.3	30
Zinc	<20	<4.4	4.8	40

Examination of the results of the analysis presented in Table 6-1 demonstrates that none of the identified parameters in either the Aldbrough or Islandmagee brines will exceed the relevant EQS limit prior to discharge. Thus with the initial dilution available from the ISGF diffuser concentrations of these parameters within the receiving water of the North Channel can be expected to be well below the relevant EQS level.

It is noteworthy that with the exception of Boron the concentrations of the various compounds in the Islandmagee brine are lower than those observed at Aldbrough thus the original assumptions have been proven to be conservative. In the case of Boron the difference appears to be attributable to higher levels of Boron in the seawater of the North Channel rather than anything in the salt sequence at Islandmagee.

7 CONCLUSIONS

The initial dilution and far-field dispersion likely to be achieved by brine discharge from the proposed Islandmagee Gas Storage Facility (IGSF) diffuser under a range of flow condition has been assessed using accepted computational modelling techniques.

The ambient conditions employed in terms of water depths, tidal flows and salinities were identical to those adopted for the earlier work associated with the original consenting process for the IGSF. Similarly the salinity of the brine was also assumed to be unchanged from those adopted for the earlier work.

However the FEED stage assessment identified that the excess temperature of the brine will be lower than was originally assumed at only around 2°C above the temperature of the intake water, consequently this lower brine temperature was used for all model simulations presented in this study. The sensitivity of the model results to the excess temperature of the brine was assessed using the initial dilution model and the results indicated that the difference in initial dilution achieved between a brine discharge at 2°C above ambient and the same discharge at 10°C above ambient was minimal, amounting to less than one additional dilution i.e. a dilution of 12:1 at 2°C above ambient might be increased to 13:1 if the brine was at 10°C. Thus it was concluded that using the lower excess temperature for all analysis would yield a conservative estimate of salinity levels.

The initial dilution modelling results presented in this document show that for a diffuser with 6" ports the salinity of the brine at first contact with the seabed will be between 50.5 psu and 37.6 psu depending on the discharge flow and number of active ports on the diffuser. This can be compared to the 49.4 psu to 38.5 psu range of salinities predicted for first contact with the seabed in the original assessment of the concept design.

The medium to far-field dispersion assessment completed using the latest version of the MIKE3 FM software that incorporates a representation of initial dilution not available at the time that the original assessment was undertaken, has confirmed that the discharge of up to 1,000m^3/hour of saturated brine via the proposed IGSF outfall will have minimal impact on salinity levels beyond the immediate vicinity of the outfall. Maximum salinity increases of more than 0.5 psu are not anticipated to occur more than a few hundred metres from the diffuser and salinities of in excess of 36 psu are not predicted to occur more than 100m from the diffuser under normal operating conditions. It is important to note that during operation it is very unlikely that maximum flow will coincide with maximum salinity increase as conservatively assumed for this study. These conclusions apply over the range of discharges considered in this study, 250m^3/hour to 1,000m^3/hour provided the diffuser is operated in the way reported with one port used for discharges of less than 500m^3/hour and two port for the larger discharges.

Cores from the proposed salt sequences at Islandmagee within which the IGSF caverns will be created have been recovered and dissolved in North Channel seawater to produce a saturated brine representative of the brine that will be produced by the cavern creation process at Islandmagee. Comparison of the concentration of non-salt compounds in the Islandmagee brine to levels of the same compounds in the Aldbrough brine and applicable EQS levels for marine waters has established that the concentrations in the Islandmagee brine are generally lower than those recorded at Aldbrough and in all cases are lower than the relevant EQS. Thus with the dilution and dispersion that will occur after discharge the non-salt components in the IGSF brine discharge do not pose a significant threat to marine water quality at Islandmagee.

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