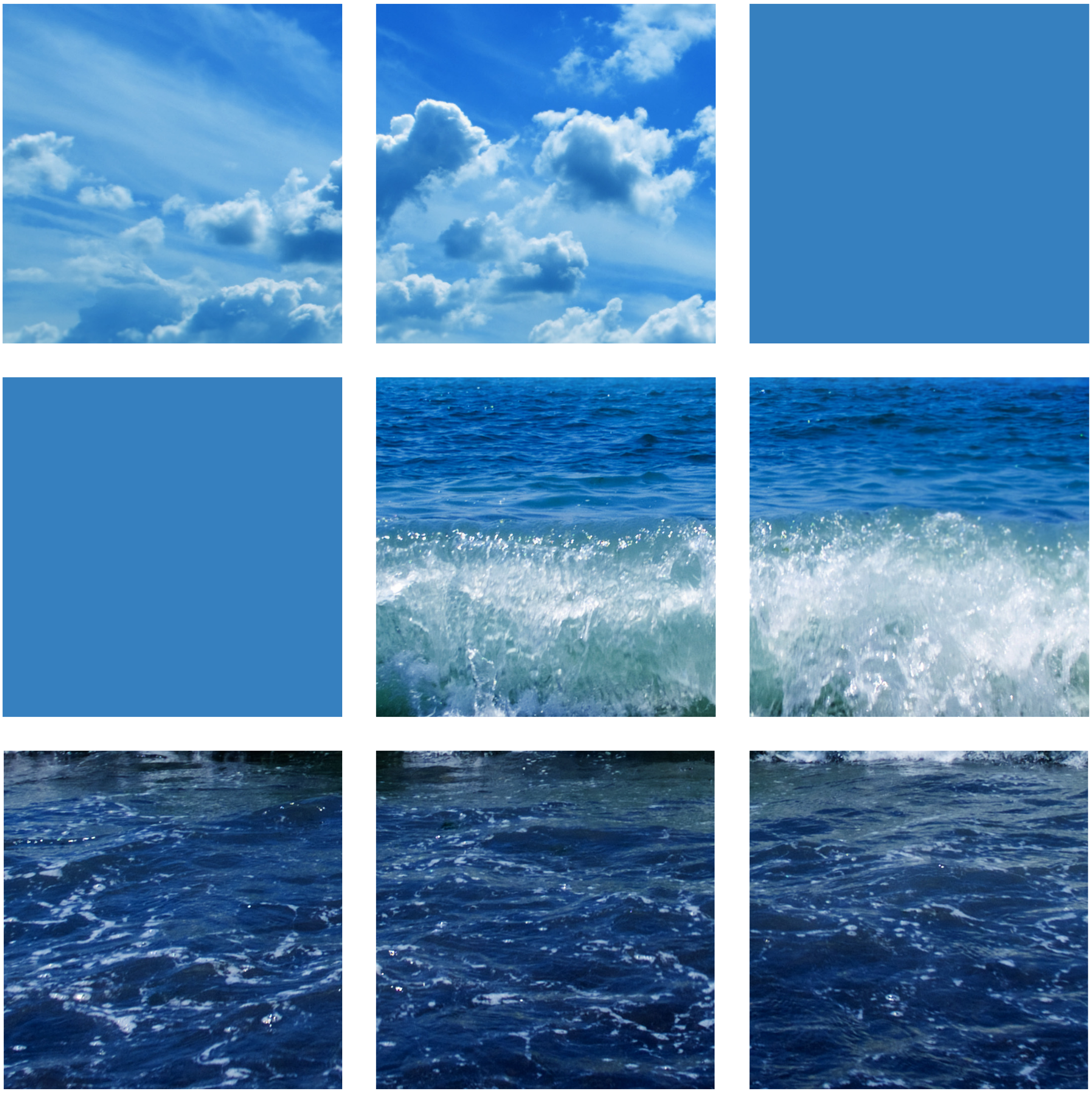
Water Quality Modelling for all existing & currently proposed salmon farm sites in Bantry Bay

IBE0744/R07/Rev02/NS Marine Harvest Ireland November 2015



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1 EXECUTIVE SUMMARY

A commission was undertaken by RPS, on behalf of Marine Harvest Ireland (MHI), to investigate the effects on water quality of further development of salmon farming activities in Bantry Bay, County Cork, to include the addition of a 3,500 tonne biennial production site at Shot Head, draft licence now granted, plus a harvesting site, maximum stranding stock 300 tonnes at Waterfall in Berehaven. A comprehensive numerical modelling study was carried out to this end. The study was undertaken in two phases; firstly the hydrodynamic model development and validation phase and secondly, the water quality modelling phase. The second phase utilised the hydrodynamic model established in the first phase.

In the primary phase of the study a pre-existing hydrodynamic model of Bantry Bay was updated from rectangular to flexible mesh technology. In the process the bathymetry data was also revised to include the latest available data. The model was validated using a wide range of hydrodynamic field data, which was collated for this purpose from a variety of sources. This report demonstrates that the model is validated as 'fit for purpose' for water quality modelling.

Once validated, the hydrodynamic model was used to assess the effects of all potential discharges into Bantry Bay as a result of all existing and proposed fish farming activities. This was undertaken in line with the European Communities (Control of Dangerous Substances in Aquaculture) Regulations, Scottish Environmental Protection Agency (SEPA) guidelines and Environmental Quality Standards (EQS's) for salmon farming and SI 272 of 2009, the Irish SI which brings the European Framework Directive (2000/60/EC) in to Irish law.

There are two finfish farmer operators in Bantry Bay. MHI have two licensed and operational sites in the bay, a grower site at Roancarrig and a smolts site at Ahabeg, which lie relatively close together just to the east of Bere Island. The current commission relates to provision of a harvest site at Waterfall to the north of Bere Island and also takes account of new production at Shot Head, where a new site has already been applied for . The proposed Waterfall site will comprise of six 100m diameter pens, which will hold salmon for a maximum period of one month prior to harvest to help maintain consistent market supply. The study was undertaken to examine both the potential impact of the Waterfall harvest site alone, and in combination with other sites operating (or potentially operating) within the Bay. The analysis includes the full range of discharges derived from salmon farming activities, from both MHI sites and other producers' sites.

Nitrogen, Phosphorus and Biological Oxygen Demand (BOD) discharges arising from fish feeds, from both ingested and waste feed sources, were modelled. A worst-case scenario was investigated; with the total discharges (both settled and soluble) being discharged. A 24 month, alternating production schedule was examined incorporating all sites in the Bay for the appropriate stocking level of each individual site to derive the largest combined discharge impacts. The results of this modelling exercise showed that the discharges of Nitrogen, Phosphorus and BOD, the three main pollution indicators, due to the proposed fish farming activity, were typically lower than the existing background conditions within Bantry Bay. The model also shows that established quality standards never even approached being breached, even taking account of all salmon production increases proposed.

The settleable solids discharges arising from both projected waste feed and faecal matter from the proposed Waterfall site and all other sites in the bay were also modelled. The sheltered nature of the Waterfall site meant that effects in combination with those from other sites would be inconsequential. It was found that any accumulation of salmon farm-origin sediments occurred in the immediate area under the proposed pens at Waterfall, with very little alteration to benthic communities beyond the pens themselves.

Salmon farming has associated treatment residues arising mainly from anti lice medications. These were also examined using the model. Irish salmon farm sites are constantly monitored for lice. If the densities of adult female ovigerous slice stages exceed Government-set trigger levels, then the lice are treated. As a harvest site, Waterfall would only be used to stock fish clear of lice prior to harvest, and fish would not be on the site for more than one month, which is shorter than the cycle time for lice maturation from first settlement. However, lice monitoring would still be undertaken. That said it is not anticipated that lice treatments would be carried out on the site. Nonetheless, for the sake of completeness, both in-feed and bath lice treatments are investigated in the study, in order to assess their appropriateness and potential for impacts should they ever be considered. The Slice® in-feed treatment was examined and determined to be unsuitable for use at Waterfall, due to the sheltered nature of the site and limited dispersion. The bath treatment Alphamax® was also examined in accordance with the EU protocol and may be applicable given a suitably designed treatment cycle.

Although not required by any established standard, the migration of sea lice within Bantry Bay was also examined, to ascertain any potential risk to wild salmonid stocks in the general vicinity. A series of dispersion scenarios were modelled, based on the range of the numbers of lice larvae that might be released from the sites. Under all scenarios tested, the concentrations of infestive copepodid stages throughout Bantry Bay were found to be sufficiently low that augmentation of natural sources of infestation are considered unlikely to occur as a result of the presence of MHI's proposed salmon farming operations. Dispersal of wild lice from local river sources were also examined to ensure that the locations of the proposed site and other sites would not be susceptible to, or lead to augmentation of wild lice populations.

In all areas of Bantry Bay, the impact of the proposed increases in salmon production would fall within the acceptable limits set out by SI 272 in respect of surface water quality and by the Scottish Environmental Protection Agency in their Environmental Quality Standards for salmon farming. The Environmental Quality Standards adopted by SEPA are well-tested, long-established parameters which have been very widely adopted, not just in the context of salmon farming. Indeed they represent an important international benchmark in the field of environmental quality management as a whole.

2 INTRODUCTION

Marine Harvest Ireland (MHI) commissioned RPS to investigate the potential effects on water quality of existing and further proposed development of salmon farming activities in Bantry Bay, County Cork. There are two salmon farm operators in Bantry Bay. MHI currently have two licensed sites in the bay; a grower site at Roancarrig and a smolt site at Ahabeg, which lie quite close together on the northern shore, just east of Bear Island. An application was made in May 2011, for a further grower site licence at Shot Head, 7km east of Roancarrig. MHI also wish to apply for a licence to convert a licensed rainbow trout grower site at Waterfall, in Berehaven into a farmed salmon harvest site of the same maximum standing stock (300T). Murphy's Irish Seafoods (also known as Fastnet Irish Seafoods) also has two licensed salmon farm sites at Gearhies, on the southern shore of the bay, west of Whiddy Island. All these sites are shown in Figure 2.1.

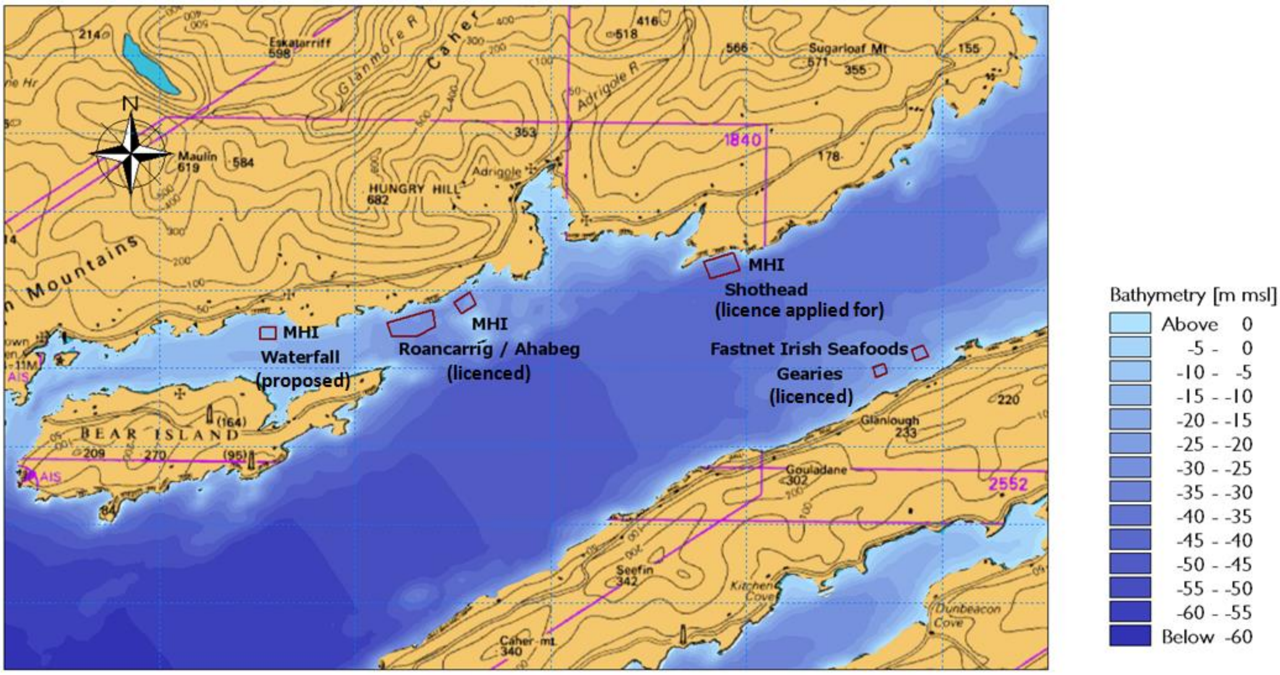


Figure 2.1: Location of all existing and currently proposed salmon farm sites / licences in Bantry Bay.

The brief for this study includes the following:-

1) Updating and calibration of the RPS tidal model of Bantry Bay, developed with the MIKE21 HD software, validated using all available current data for the region.

2) Simulation of the dispersion and fate of soluble and solid discharges arising from the feeding of the salmon on all existing and currently proposed sites in the bay, in order to quantify their likely impacts on the bay and its environment.

3) Simulation of the dispersion and fate of residues arising from both in-feed and bath lice treatments that may be used on all existing and currently proposed sites in the bay.

4) Modelling the dispersion of sea lice infestive stages from all existing and currently proposed salmon farm sites in the bay using particle-tracking simulations, to include the modelling of the influence of wind as a forcing factor on the dispersion of sea lice infestive stages released from the sites.

5) Modelling of the dispersion and dilution of infestive lice stages arising from wild sources.

This report outlines the processes used to develop the calibrated model of Bantry Bay and documents the model validation. The results of the water quality and lice migration studies are also included.

3 BANTRY BAY: MODELLING SYSTEM

3.1 MIKE 21/3 COUPLED MODEL FM

The MIKE 21/3 Coupled Model FM model has recently been introduced by its developers, the Danish Hydraulics Institute (DHI). It is a truly dynamic modelling system for application within coastal and estuarine environments. It can be used for investigating the morphological evolution of the nearshore bathymetry, due to the impact of engineering works (coastal structures, dredging works etc.). The engineering works may include breakwaters (surface-piercing and submerged), groynes, shore-face nourishment, harbours etc. MIKE 21/3 Coupled Model FM can also be used to study the morphological evolution of tidal inlets.

MIKE 21/3 Coupled Model FM is composed of following modules:

- Hydrodynamic Module
- Transport Module
- ECO Lab Module
- ABM Module
- Mud Transport Module
- Sand Transport Module
- Particle Tracking Module
- Spectral Wave Module

The Hydrodynamic Module is the basic computational component of the modelling system. Using MIKE 21/3 Coupled Model FM it is possible to simulate the mutual interaction between waves and currents using a dynamic coupling between the Hydrodynamic Module and the Spectral Wave Module. The MIKE 21/3 Coupled Model FM also includes a dynamic coupling between the Mud Transport, Particle Tracking and Sand Transport models and the Hydrodynamic Module and the Spectral Wave Module. Hence, a full feedback of the bed level changes on the waves and flow calculations can be included.

The main features of the MIKE 21 Coupled Model FM are as follows:

- Dynamic coupling of flow and wave calculations
- Full feedback of bed level changes on flow and wave calculations
- Easy switch between 2D and 3D calculations (hydrodynamic module and process modules)
- Optimal degree of flexibility in describing bathymetry and ambient flow and wave conditions using depth-adaptive and boundary-fitted unstructured mesh

3.2 THE HYDRODYNAMIC MODEL

The tidal flow simulations, which form the basis for the dispersion simulations conducted, were undertaken using DHI's MIKE21 FMHD hydrodynamic flow model. This provides the hydrodynamic basis for the computations performed in the modules for Nutrient Dispersion and Environmental Hydraulics; that is the transport, ABM (Agent Based Modelling) and particle tracking modules.

The Hydrodynamic Module simulates water level variations and flows in response to a variety of forcing functions in lakes, estuaries and coastal regions. The effects and facilities include:

- Flooding and drying
- Momentum dispersion
- Bottom shear stress
- Coriolis force
- Wind shear stress
- Barometric pressure gradients

- Ice coverage
- Tidal potential
- Precipitation/evaporation
- Wave radiation stresses
- Sources and sinks

The Hydrodynamic Module can be used to solve both three-dimensional (3D) and two-dimensional (2D) problems. In 2D, the model is based on the shallow water equations; the depth-integrated incompressible Reynolds averaged Navier-Stokes equations.

3.3 IRISH SEA MODEL

Tidal flow in Bantry Bay was simulated by a model driven by the RPS Irish Seas Surge model, which was used to derive boundary data. The Irish Sea model itself stretches from the northwestern end of France, including the English Channel to Dover, to 16° West into the Atlantic, including the Porcupine Bank and Rockall. To the South, it stretches from the Northern part of the Bay of Biscay to just south of the Faeroes Banks in the North. Overall, the model covers the Northern Atlantic Ocean to a distance of 600km from the Irish Coast, as illustrated in Figure 3.1.

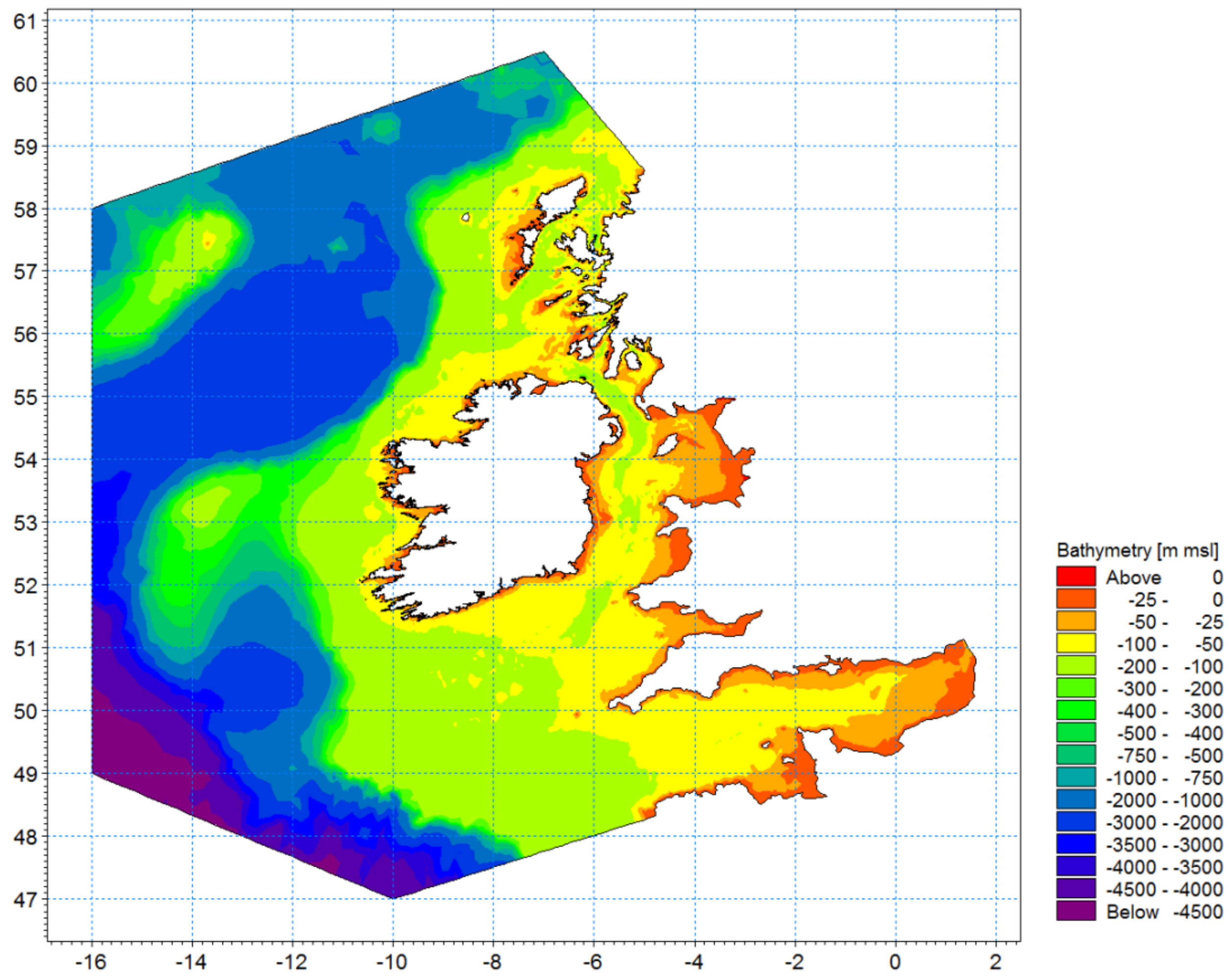


Figure 3.1: Extent of Irish Sea Tidal Surge Model

The Irish Sea model was constructed using flexible mesh technology. This allows the size of the computational cells to vary, depending on user requirements. Along the Atlantic boundary, the model features a mesh size of 13.125' (24km). The Irish Atlantic coast has been discretised, using cells of an average size of 3km. In the Irish Sea the maximum cell size is limited to 3.5 km, decreasing to less than 200m along most of the Irish coastline.

The bathymetry of the model was generated from a number of different sources. The model was constructed using the most up-to-date and highest resolution data available, including the entire INFOMAR database, which incorporates the OSI LiDAR datasets; the coverage of which is shown in Figure 3.3 (the OSI extents are indicated by pale blue areas). This includes detailed LiDAR data in Bantry Bay (Figure 3.2), in addition to individual site surveys, carried out for numerous projects. Surveys of Dublin Bay and adjacent areas carried out by Geological Survey Ireland (GSI) were also incorporated into the model, along with data from surveys carried out by GSI to the West of Ireland as part of the Irish National Seabed Survey (INSS).

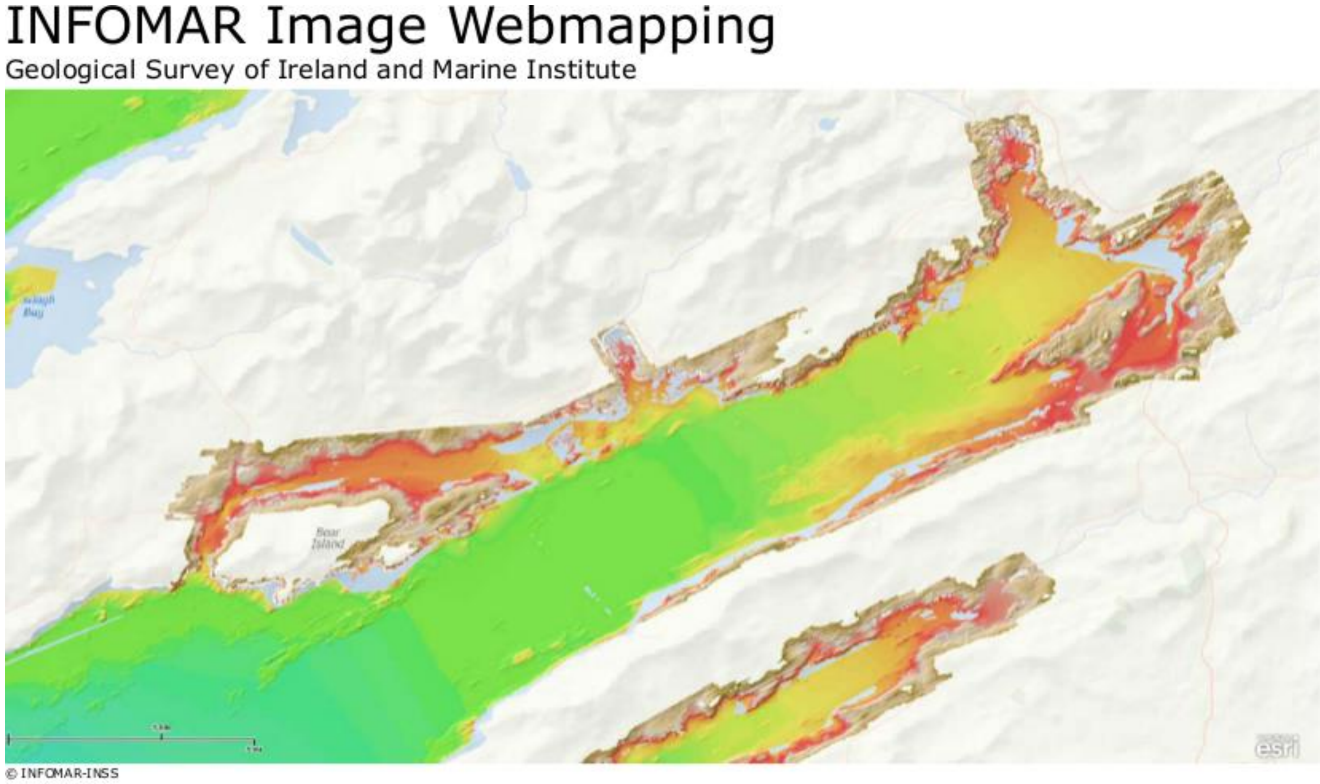


Figure 3.2: INFOMAR datasets used for the Irish Seas model & Bantry tidal model – Bantry Bay

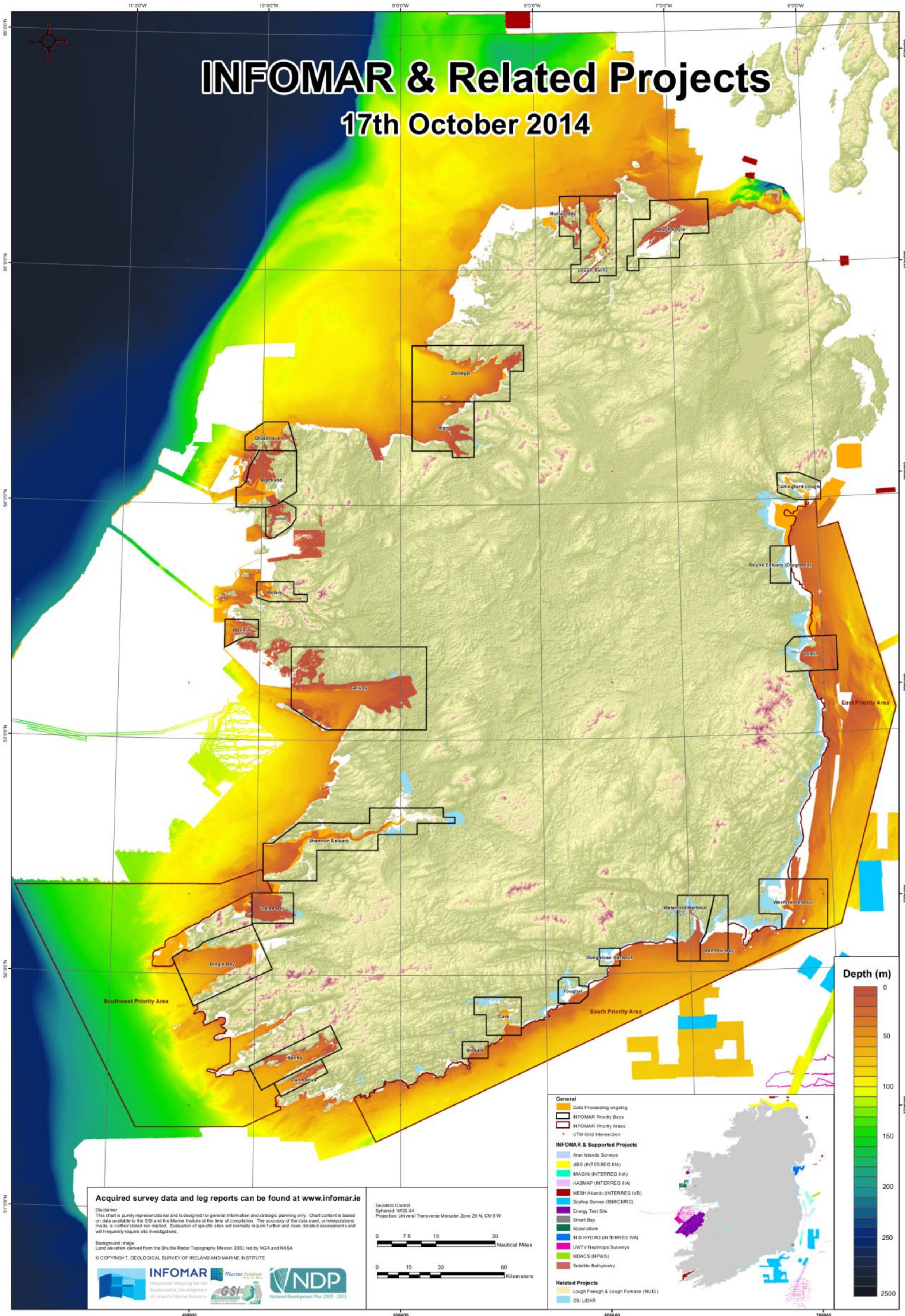


Figure 3.3: INFOMAR datasets used for the Irish Seas model & Bantry tidal model

Additional information was obtained from chart data available digitally. Surveys of several banks and coastal areas have been included in the model, covering in parts or all of the following:-

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

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 Models have six open boundaries, five in the Atlantic and one in the English Channel. The time series of tidal elevations along these boundaries are generated using a global tidal model designed by a team at the National Space Institute, Demark (DTU10). The DTU10 global tidal model is based on the prediction of tidal elevations using 10 semi-diurnal and diurnal tidal harmonic constants (as opposed to the United Kingdom Hydrographic Office approach which uses 4-6 harmonic constants). These constants were derived through the simulation of the effect of astronomic forces due to the sun and moon on the water surfaces. Figure 3.4 shows the amplitude of the M2 semi-diurnal (12.25hour) tidal harmonic constituent over the global model domain.

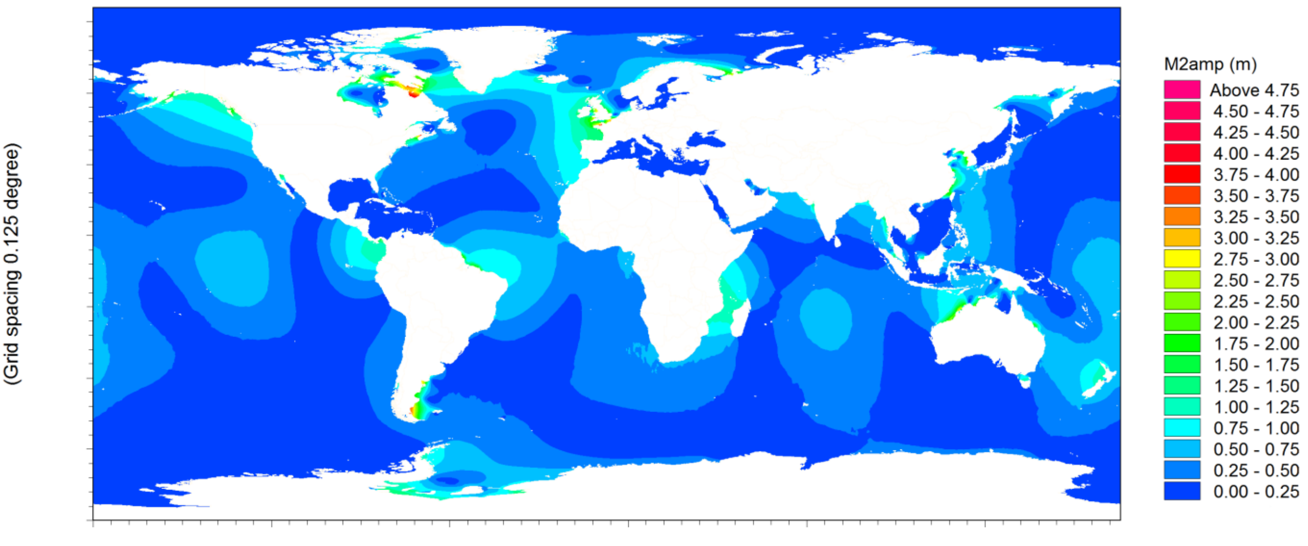


Figure 3.4: Tidal harmonic for M2 amplitude for the DTU10 global model

3.4 BANTRY BAY MODEL

The hydrodynamic model for the Bantry Bay study extended from just south of Great Skellig on the west coast and as far east as Toehead Bay westerly of The Stags on the south coast, as illustrated in Figure 3.5. A relatively large domain was required to simulate the complex convergence of tides which occurs offshore of the southwest coast of Ireland. The bathymetry was derived from the same datasets as used for the Irish Sea model and discussed in the previous section, Section 3.3.

The mesh size for the model region varied greatly across the domain in order to both delineate the large scale tidal gyres and also to be suited to the small scale dispersion characteristics whilst maintaining computational efficiency. Offshore cells were in the order of kilometres^2 whilst at each of the farm sites cells were in the order of 20m^2 so that discharges from individual salmon pens could be discerned. Figure 3.6 shows the location of the existing and currently proposed farm sites included in the model bathymetry, with the bathymetry level being given relative to mean sea level, which varies with chart datum, depending on the location. In the Bantry region mean sea level is 1.83m above chart datum (Lowest Astronomical Tide) at Castletownbere and 1.9m at Bantry Harbour.

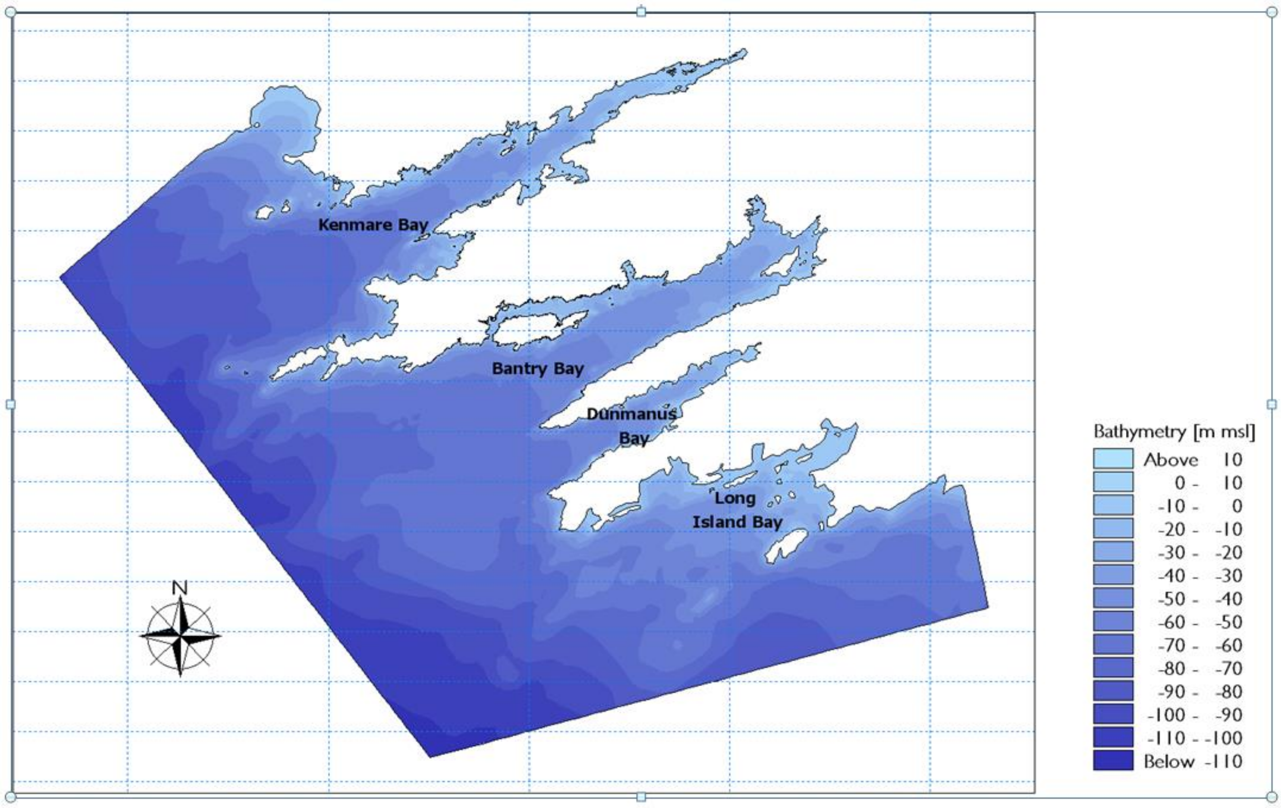


Figure 3.5: Extent of tidal model bathymetry (MSL)

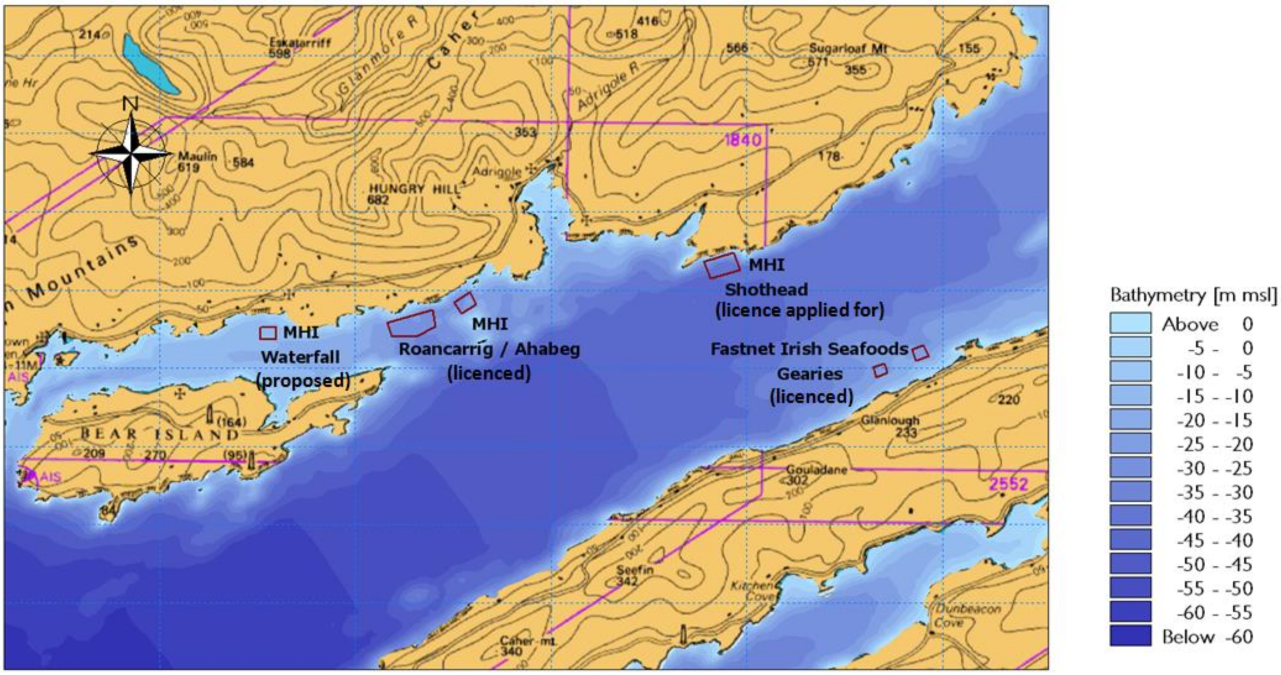


Figure 3.6: Location of all existing and currently proposed salmon farm sites / licences in Bantry Bay.

The model was used to simulate tidal flow patterns for a period of 22 days, in order to include both neap and spring tidal cycles in the simulation. Typical tide patterns for mean spring tides are presented in Figure 3.7 to Figure 3.14. Figure 3.7 shows the flood tide pattern for Bantry Bay as a whole whilst Figure 3.8 to Figure 3.10 show mean spring flood tide flow around Bear Island, and the Roancarrig and Shot Head site areas respectively. Figure 3.11 and Figure 3.12 to Figure 3.14 show the corresponding ebb tide pattern plots for mean spring ebb tide.

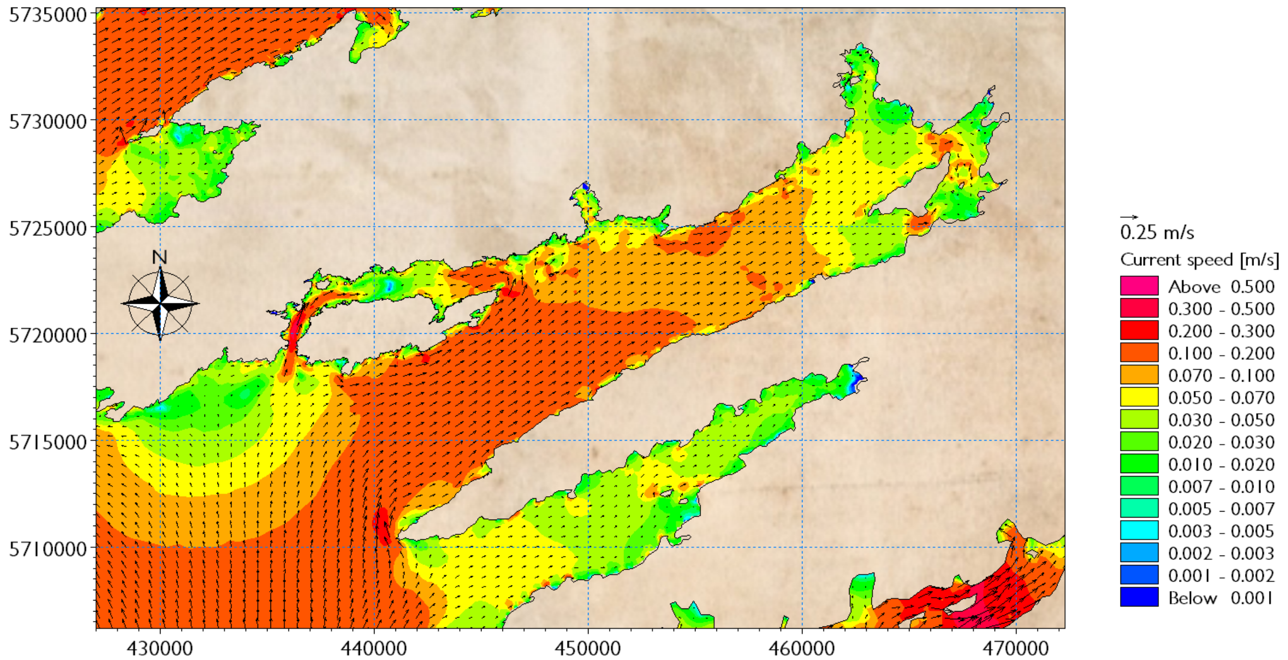


Figure 3.7: Flood tide pattern for Bantry Bay – Mean Spring Tide

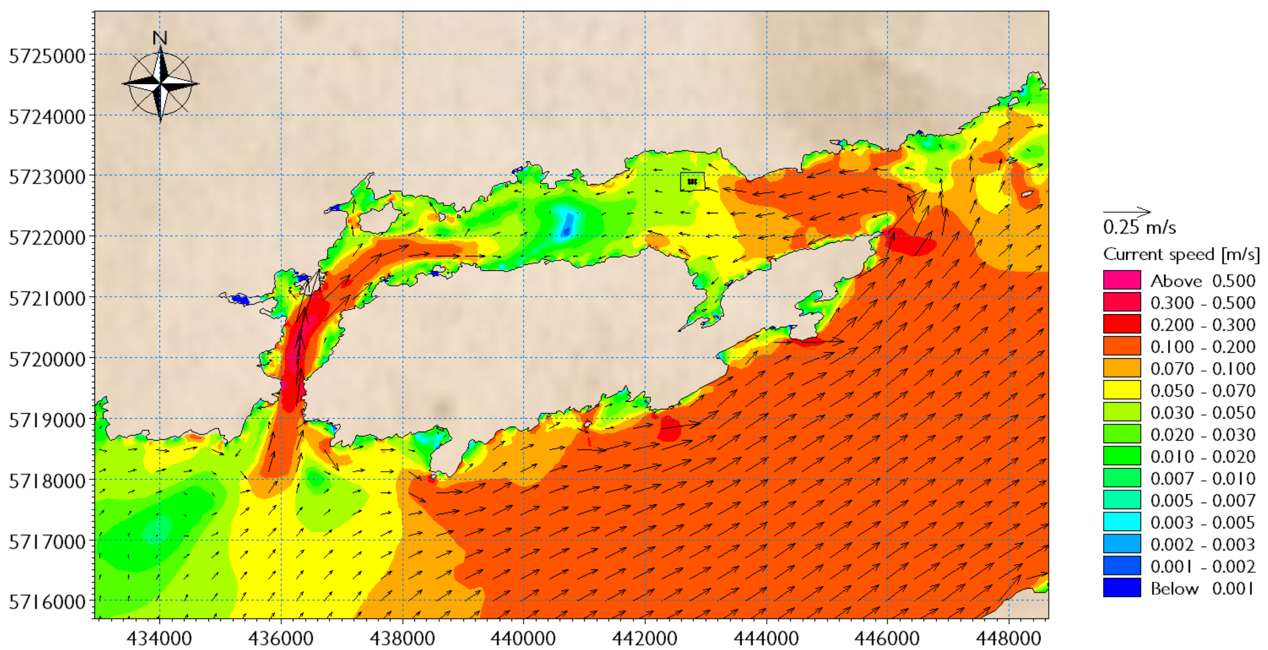


Figure 3.8: Flood tide pattern for Bear Island – Mean Spring Tide

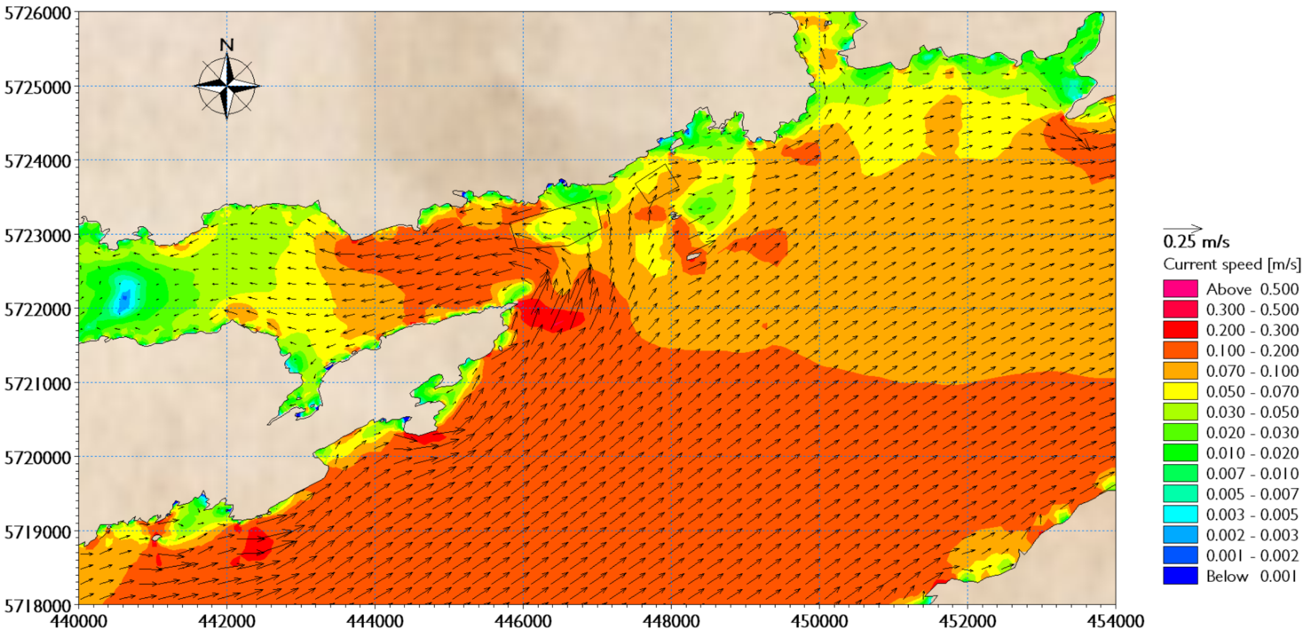


Figure 3.9: Flood tide pattern for Roancarrig area – Mean Spring Tide

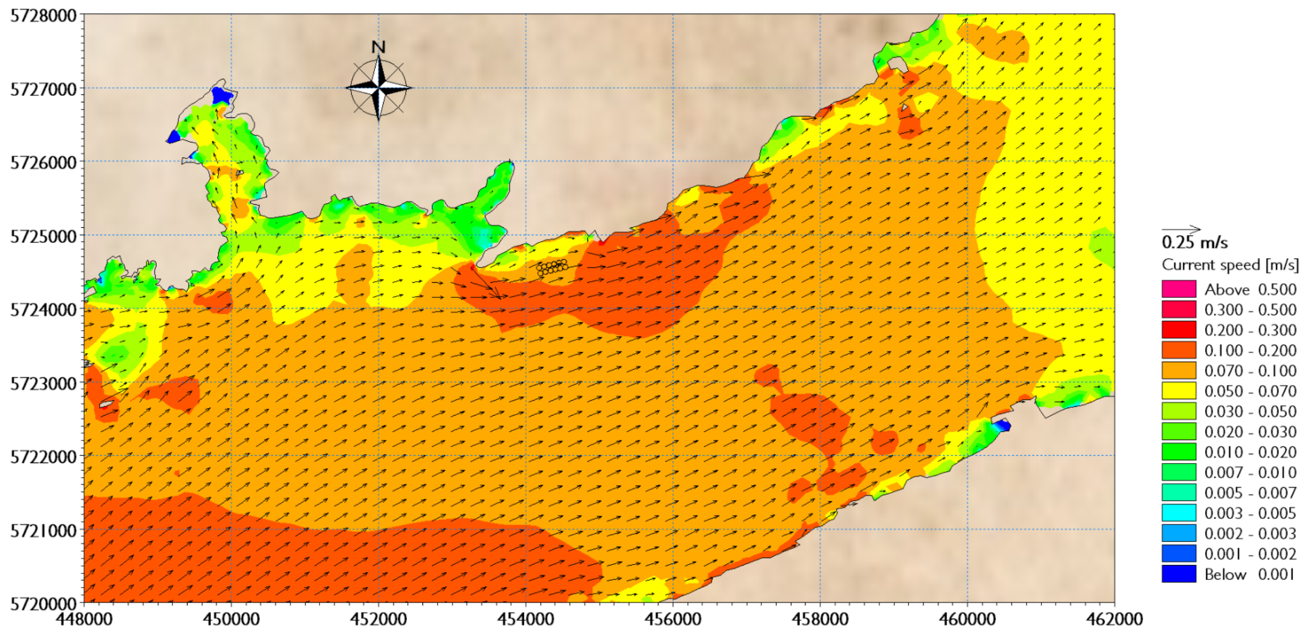


Figure 3.10: Flood tide pattern for Shot Head area – Mean Spring Tide

These plots demonstrate the complex nature of flow within the bay, which has been known of for up to 200 years or possibly longer. The New British Channel Pilot by J W Norie, Eleventh Edition, published in 1839, states of Bantry Bay that *"The stream of the tide is scarcely sensible in any part of it."* The general magnitude of ebb end current speeds are generally less than 0.1m/s as the convergence of tides in the outer domain limit the prevailing currents. The tidal flows are also complicated further by the presence of Bear and Whiddy Islands – in both cases the tide ingresses and egresses from both sides of these island with neutral current areas being formed in their lee.

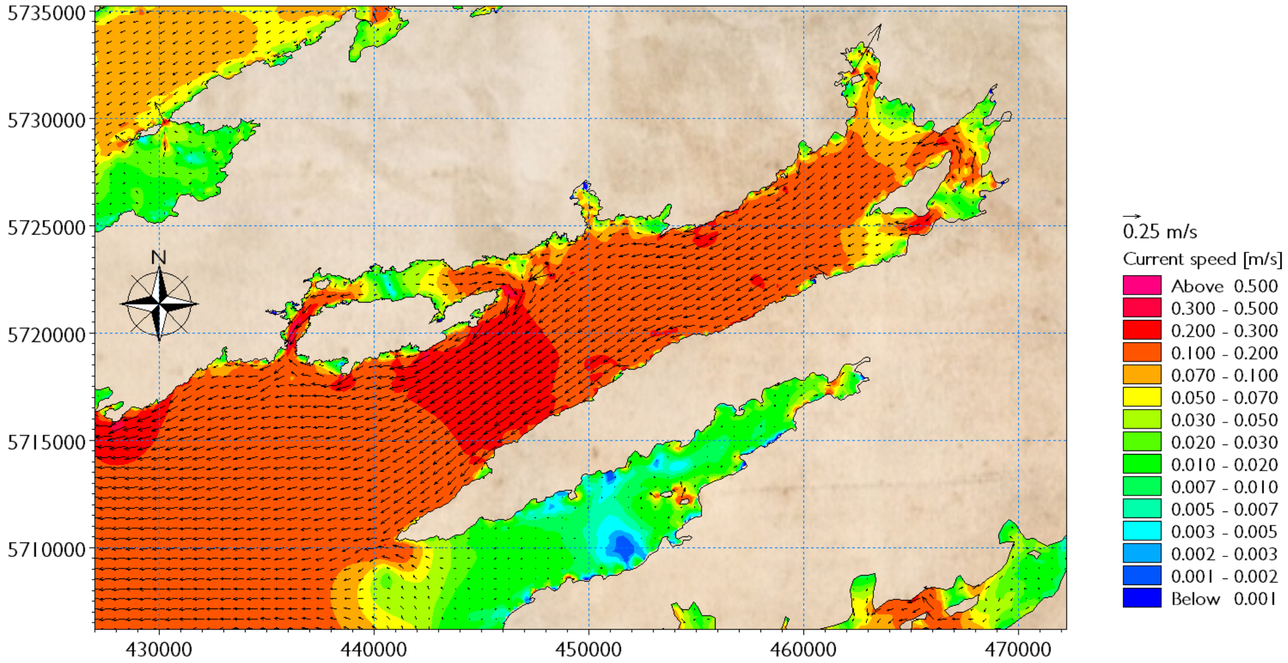


Figure 3.11: Ebb tide pattern for Bantry Bay – Mean Spring Tide

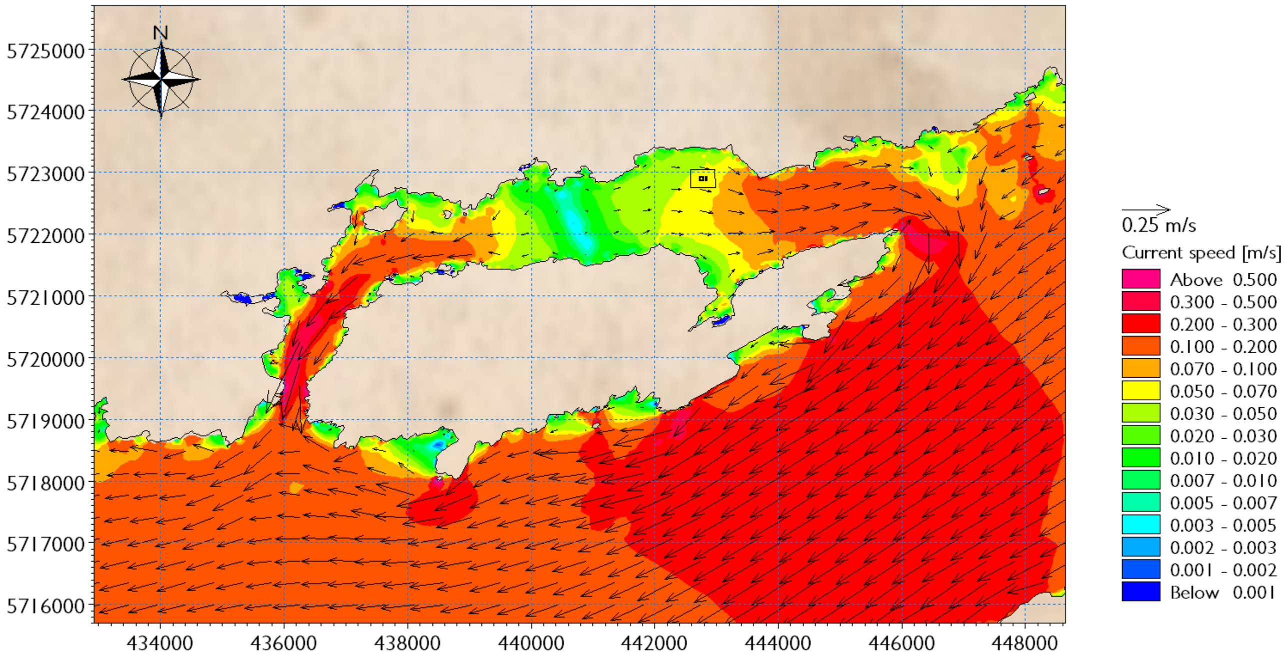


Figure 3.12: Ebb tide pattern for Bear Island – Mean Spring Tide

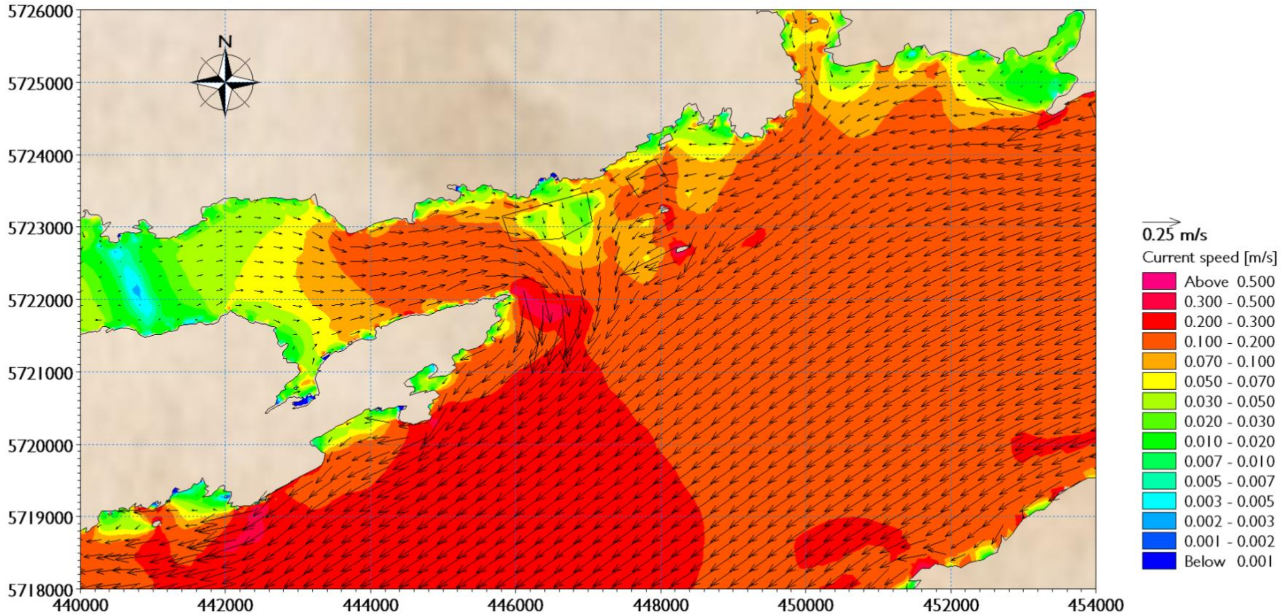


Figure 3.13: Ebb tide pattern for Roancarrig area – Mean Spring Tide

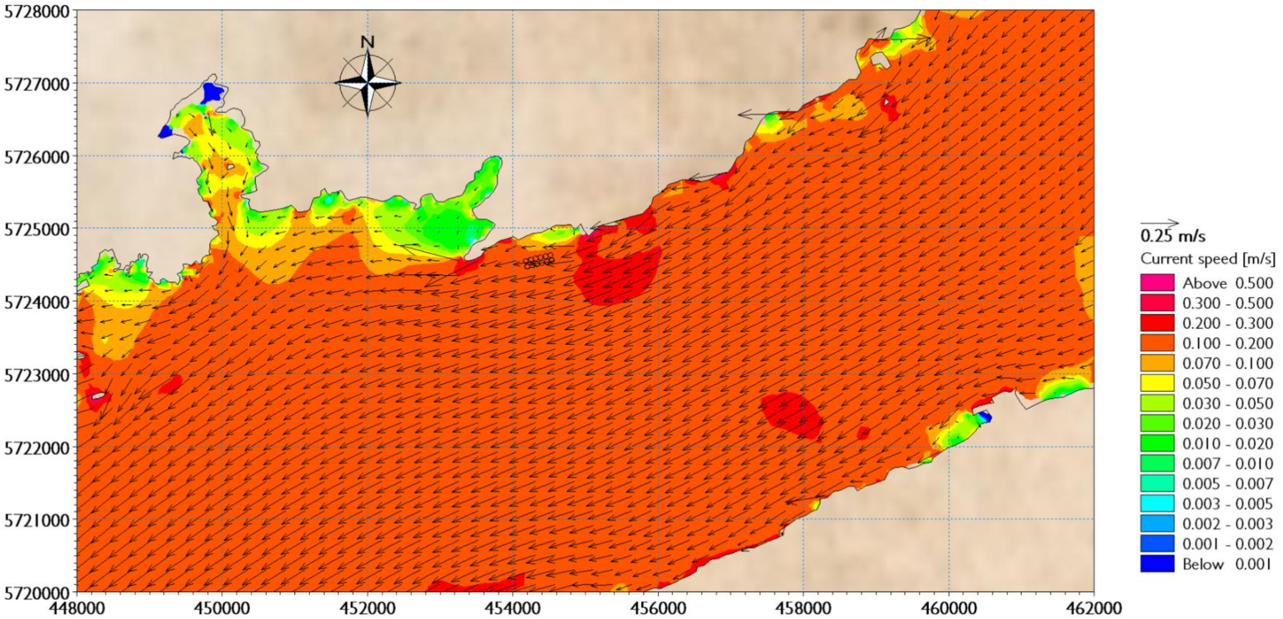


Figure 3.14: Ebb tide pattern for Shot Head area – Mean Spring Tide

Flow characteristics and particularly dispersion potential in an area may be assessed by the examination of residual currents. Residual currents can be calculated by considering the vector components of tidal currents over the course of complete tide cycles. As a general rule, areas showing little or no residual current are characterised by tide which ebb and flood along the same axis and at a similar magnitude. In such a situation, any released material may be carried back on the returning tide to the release site. In contrast, residual currents through an area increase as the difference between the ebb and flood currents increases.

Figure 3.15 shows that residual currents are relatively low in the main body of Bantry Bay. However, around most islands and promontories, and in particular around Bear Island, much higher residual currents are generated, as shown in Figure 3.16. In regions such as this, residual currents provide enhanced mixing and dispersion. Good residual currents are evident around the salmon farm sites in Bantry Bay such as at Waterfall, Roancarrig and Shot Head. Thus, although relatively low tidal currents in these areas may suggest reduced dispersion, the dispersion models in this report show that the presence of good residual currents diminish solids accumulation and enhance dispersal and dilution of both solid and soluble wastes at the sites. This encourages and encourage the carriage of wastes out of the bay and into the Atlantic circulation.

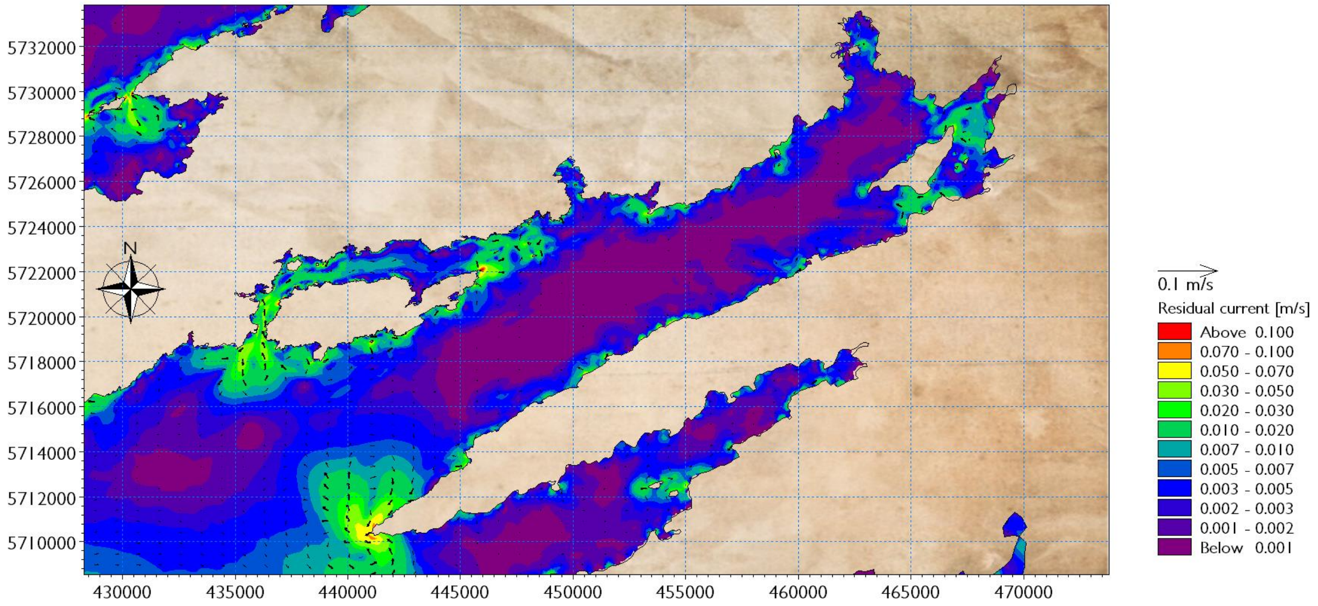


Figure 3.15: Residual current for Bantry Bay – Mean Spring Tide

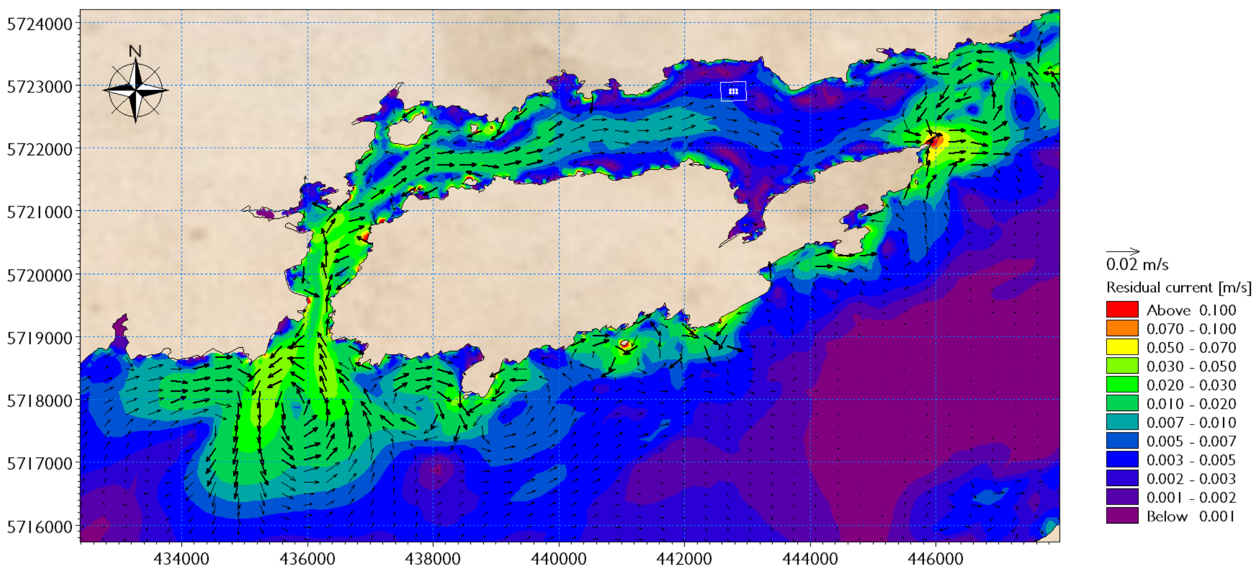


Figure 3.16: Residual current for Bear Island area – Mean Spring Tide

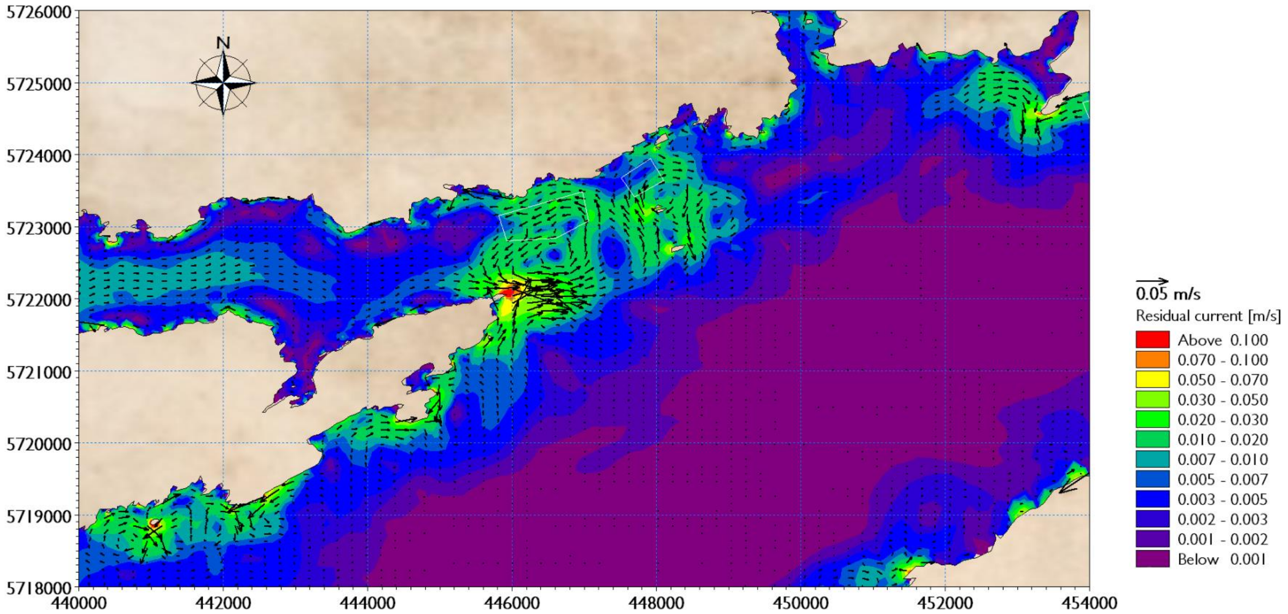


Figure 3.17: Residual current for Roancarrig area – Mean Spring Tide

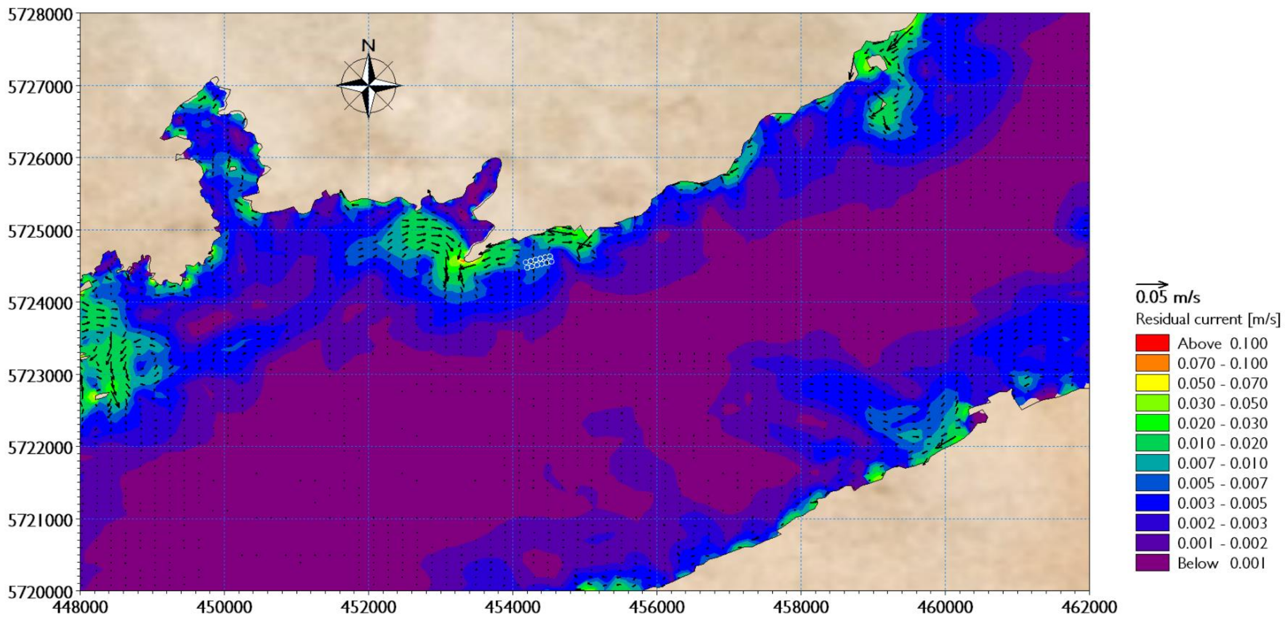


Figure 3.18: Residual current for Shot Head area – Mean Spring Tide

3.5 BANTRY BAY MODEL VERIFICATION

RPS have been involved with a variety of projects and have carried out a large number of studies in the Bantry Bay area. Therefore a variety of calibration data were available from other MHI studies, beach nourishment studies and coastal engineering projects. In total the model was verified using current metering data collected from over 15 deployments, including those directly related to the Waterfall study. Most datasets were derived from Acoustic Doppler Current Profilers (ADCP) also referred to as Recording Doppler Current Profiler (RDCP). Figure 3.19 shows the locations of the deployments whilst Table 3.1 provides the co-ordinates and a link to where figures are provided in this report.

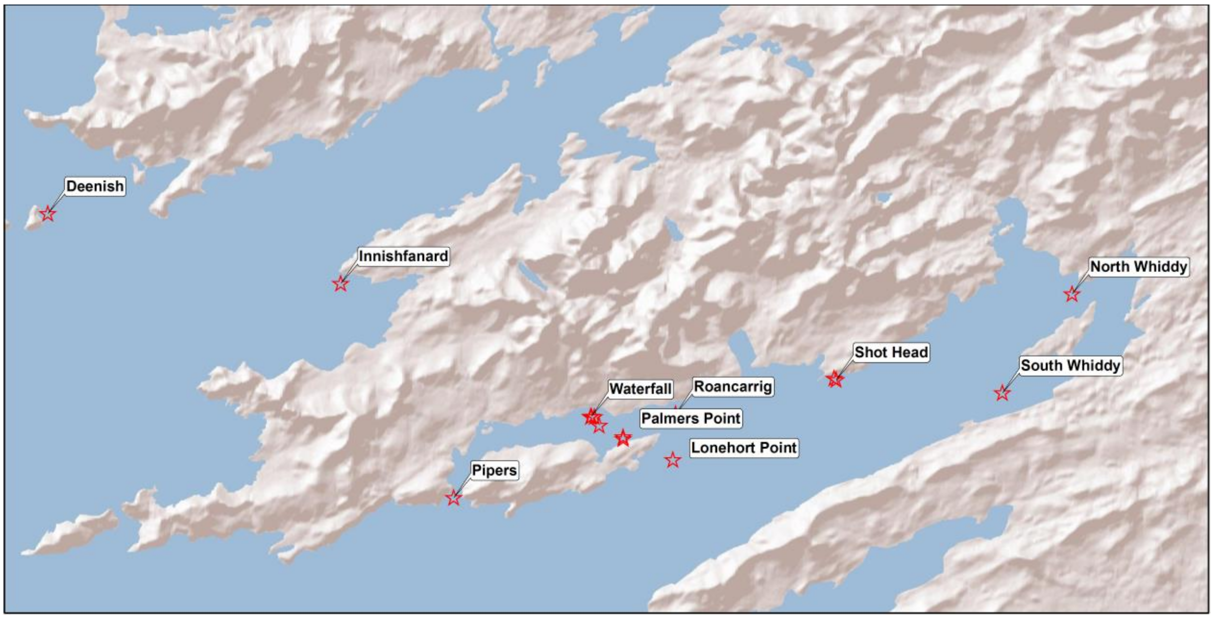


Figure 3.19: Location of current survey data

Table 3.1: Location of current survey data

Location		Co-ordinates ING (m)		Measurement	Figure	
Code	Name	Easting	Northing	period	link	location
fid_00	Lonehort Point	77352	44024	19/09/2012	Figure A.1	Appendix
fid_01	Waterfall	73453	46175	31/08/2012	Figure 3.21	Report
fid_02	Waterfall	73425	46153	20/09/2012		
fid_03	Deenish	47398	56313	01/04/2010	Figure A.5	Appendix
fid_04	Inishfarnard	61463	52744	01/04/2010	Figure A.7	Appendix
fid_05	Palmers Point	74968	45069	22/12/2009	Figure A.13	Appendix
fid_06	Shot Head	85280	47781	05/12/2009	Figure 3.23	Report
fid_07	Shot Head	85178	47837	13/01/2010	Figure A.15	Appendix
fid_08	North Whiddy	96699	51755	26/08/2010	Figure A.17	Appendix
fid_09	South Whiddy	93284	47034	26/08/2010	Figure A.19	Appendix
fid_10	The Pipers	66770	42342	10/11/2010	Figure 3.25	Report
fid_11	Roancarrig	73832	45735	16/07/2010	Figure 3.27	Report
fid_12	Roancarrig	77513	46238	05/12/2009	Figure A.25	Appendix
fid_13	Waterfall	73600	46150	22/08/2001	Figure A.27	Appendix
fid_14	Palmers Point	74981	45150	22/08/2001	Figure A.29	Appendix

With such a large number of datasets, with variable time spans from a matter of days to one month, not all periods could be simulated Therefore, for modelling purposes, the period of simulation was not the same as the monitoring periods. As it was important to simulate the full range of velocities experienced within the bay for the assessment of water quality, the model validation period was chosen for spring and neap tides, which encompasses the range of flow conditions experienced at the sites. This also aided the calibration / verification process as the comparison period was chosen on the basis of tidal excursion. The range of tidal elevations occurring during the modelling is shown in Figure 3.20.

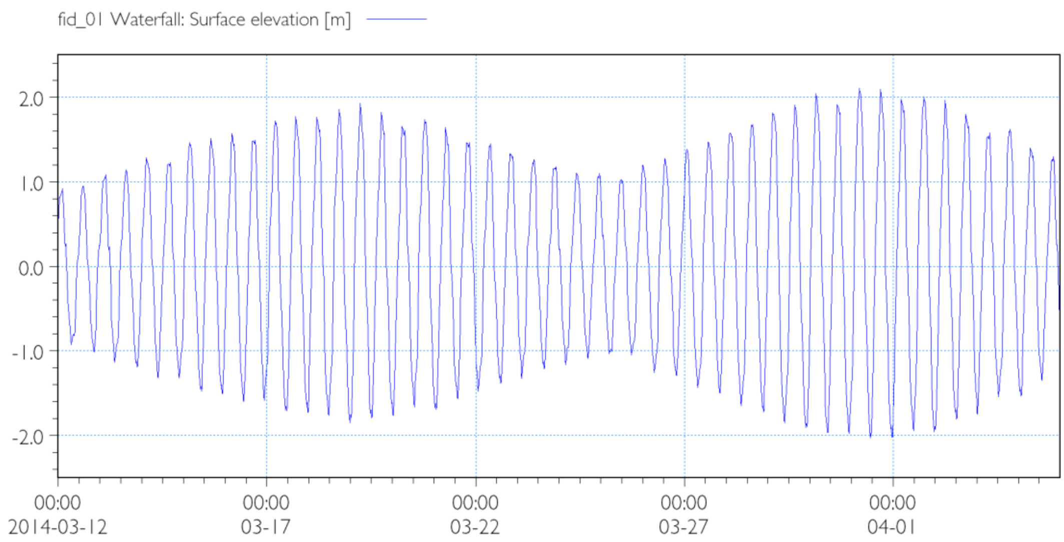


Figure 3.20: Surface elevation at Waterfall

With such an extensive dataset, it was not possible that all comparisons could be reported. Therefore representative plots are provided for each of the deployment sites. These range across both spring and neap cycles and data is aligned on the basis of tidal excursion. Four sites are shown in the body of this report whilst examples for all sites are provided as an Appendix to the report.

In each case, two figures are presented; the first relating to current direction and the second to current speed. On the left axis the monitored data is shown. Where locations through the water column were measured, then a representative sample is shown for near bed, mid depth and near surface. The modelled data is presented on the right axis (to the same scale). As the model is depth averaged, only a single trace is provided.

Figure 3.21 and Figure 3.22 provide an example of the current direction and speed data for the Waterfall site. The measured current directions for near bed (black trace), mid depth (red trace) and near surface (green trace) can be seen to vary and in some case are in opposing directions. In areas where there is strong wind forcing, surface currents are often in a different direction to the main body of water, however this is not the case for Waterfall, where it is the near bed current direction which differs. This apparent mismatch may be explained by the Waterfall site, which is located in the region where the tidal flows meet in the lee of Bear Island. This confluence is not necessarily characterised by a vertical stratum but would be described by the dominant flows at particular heights within the water column. It should be noted that a depth-averaged model would not replicate this stratification and therefore calibration should be assessed on the basis that the principle characteristic flow is replicated as demonstrated by the model blue trace. The modelled current speed (black trace) falls within the range of those measured at the bed (dark blue), mid depth (pink) and near surface (blue) shown on the lower plot.

Figure 3.23 presents the measured (red trace) and modelled (blue trace) current direction at the Shot Head site. It can be seen that the measured directions are quite erratic and a model driven from harmonic data will not provide such an erratic response without fluctuating forcings being applied, such as meteorological variations. However the modelled trace does correspond with the trends in current direction. Figure 3.24 shows the corresponding data for the current speed. Even taking into account the inconsistent nature of the flow at this site and variation across the water depth, the modelled current speed falls within the range of those measured. A number of datasets collected at Shot Head were used in the calibration and validation of the model, further details are provided in Appendix A of this document.

The next data location considered is situated in the Western Entrance at The Pipers. Similarly to the preceding regions this location experiences variations in current patterns. The ebb and flood occur in an asymmetrical formation and the entrance is prone to eddy formation; the exact location of these circulations is dependent on the dominant flows and may vary through the spring-neap cycle. Figure 3.25 and Figure 3.26 show the current direction and speed plots respectively. The direction plot clearly demonstrates how the site is not bi-directional but varies throughout the relatively short, three-day, sample presented; whereas the model data is harmonic in nature with a north-north-east and south-south-west bi-directionality. The modelled current speed does correlate with that measured during some of the monitoring period, if the extraction location is varied then other periods are also replicated. Therefore the general flow patterns and current magnitudes may be said to be simulated.

The final location reported in the body of this document is at Roancarrig, within the site of the nearest salmon farm. Once again, the surface flow may be exposed to wind-driven currents and the flow directions are quite erratic but the model replicates these conditions well, as shown in Figure 3.27. Figure 3.28 presents the corresponding current speed data and again the modelled trace falls within the measured range, giving confidence that subsequent water quality simulations will provide a good representation of the dispersion of material released from the licensed and candidate salmon farm sites into the Bay.

Further figures are provided in Appendix A relating to all sites for which data was available. Table 3.1 provides links to each set of figures. The first two Waterfall datasets are provided as a combined figure as it was an ADCP deployment in which technical issues occurred and a split dataset was provided.

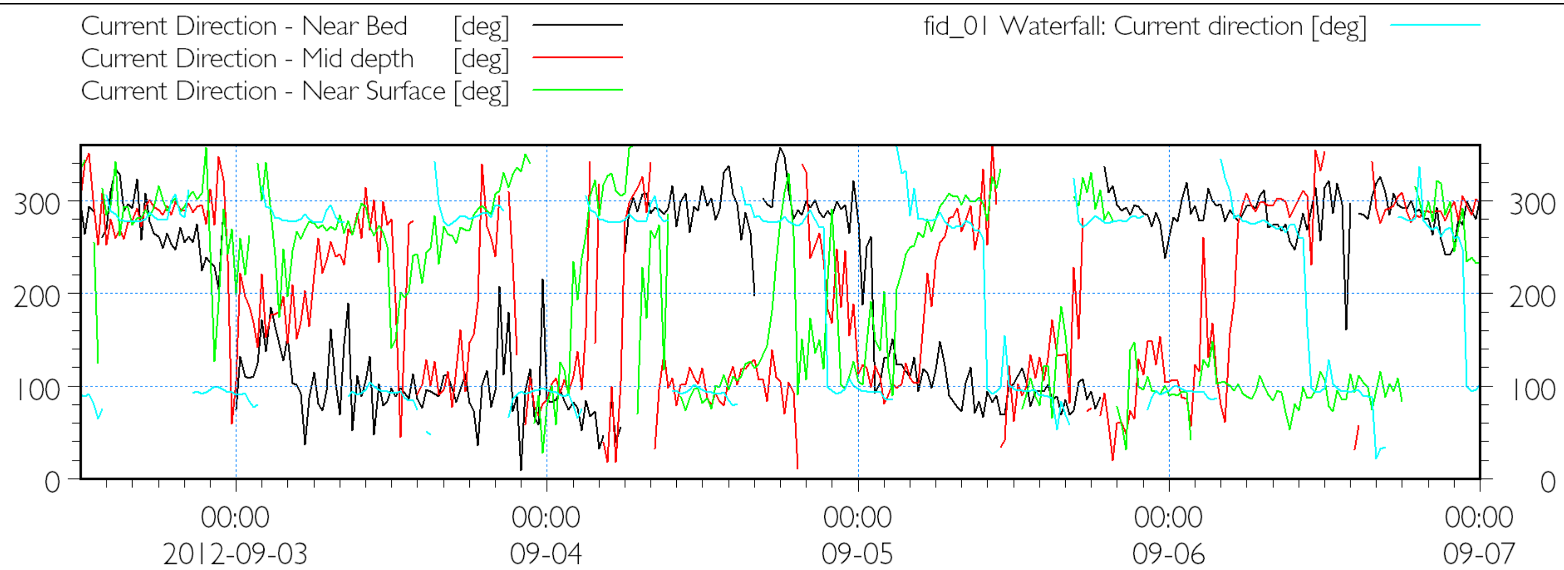


Figure 3.21: Measured (left axis) and modelled (right axis) current direction – fid_01/02 Waterfall

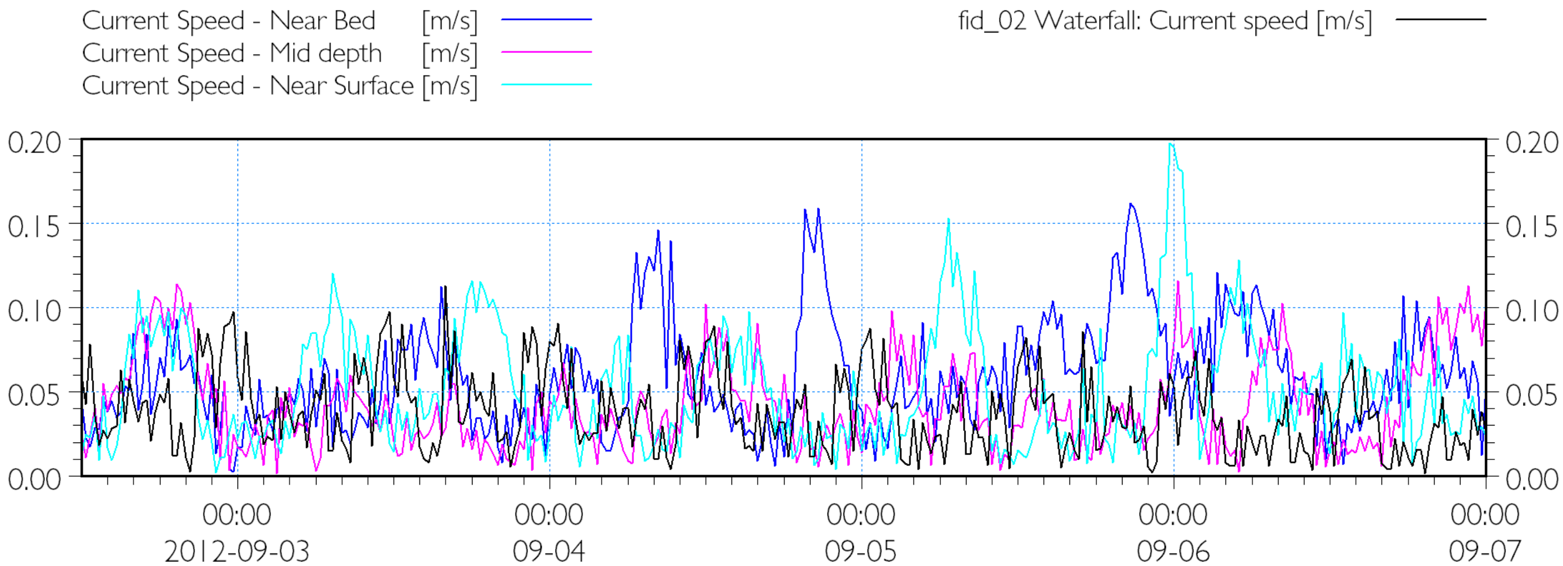


Figure 3.22: Measured (left axis) and modelled (right axis) current speed – fid_01/02 Waterfall

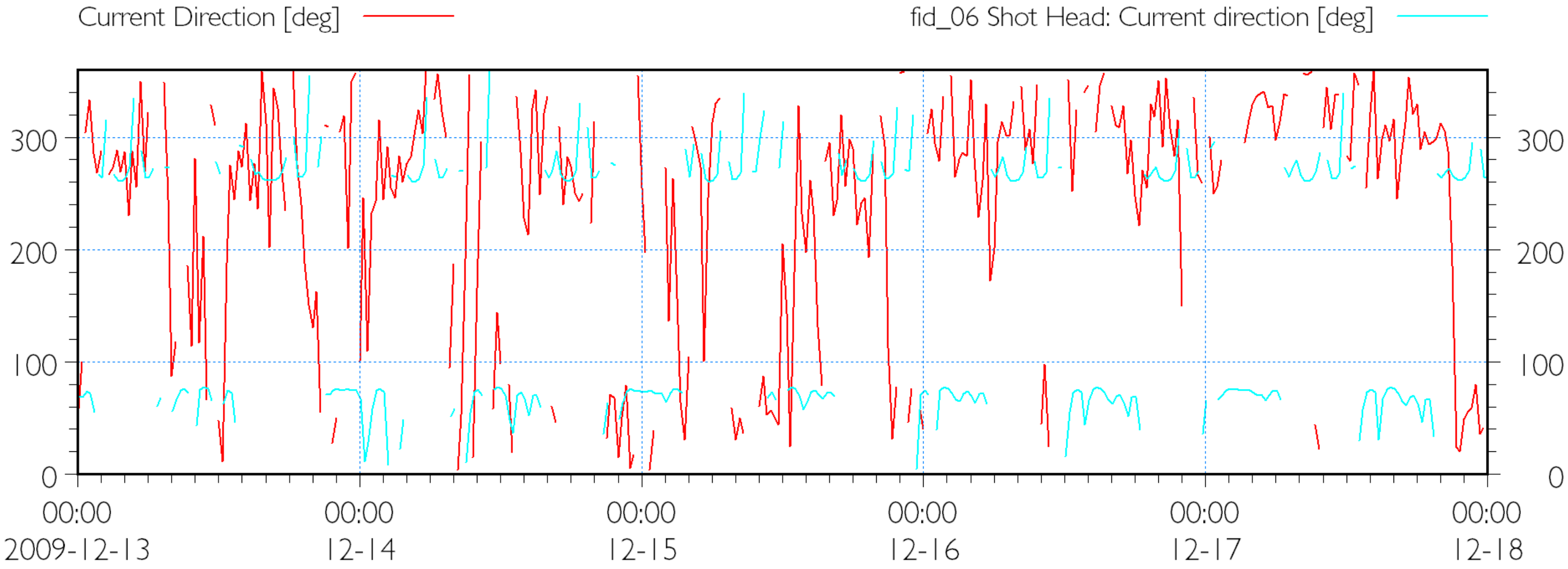


Figure 3.23: Measured (left axis) and modelled (right axis) current direction – fid_06 Shot Head

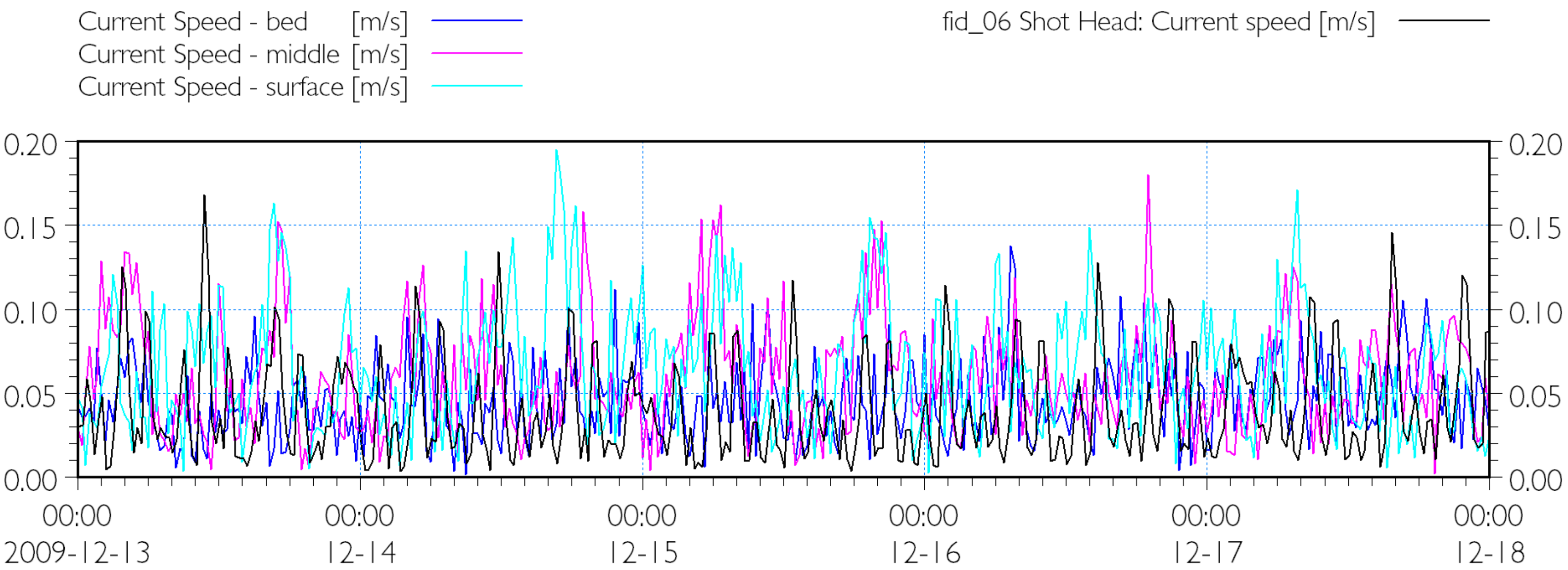


Figure 3.24: Measured (left axis) and modelled (right axis) current speed – fid_06 Shot Head

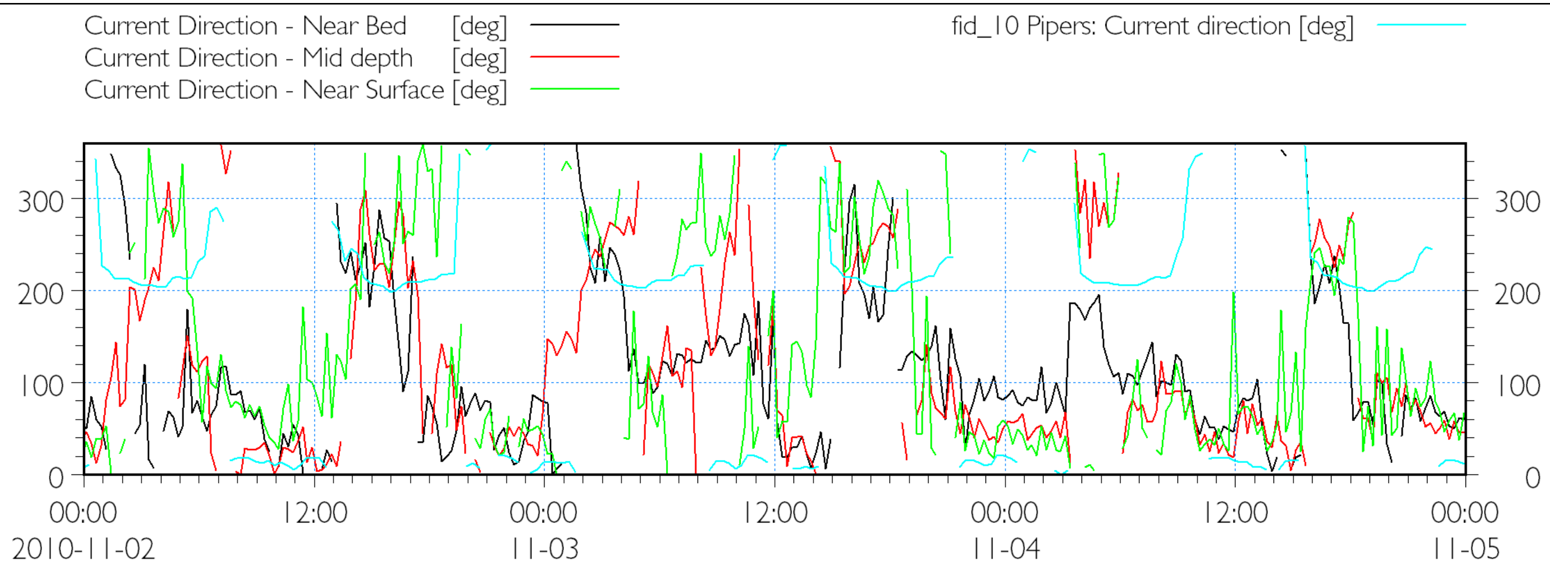


Figure 3.25: Measured (left axis) and modelled (right axis) current direction – fid_10 The Pipers

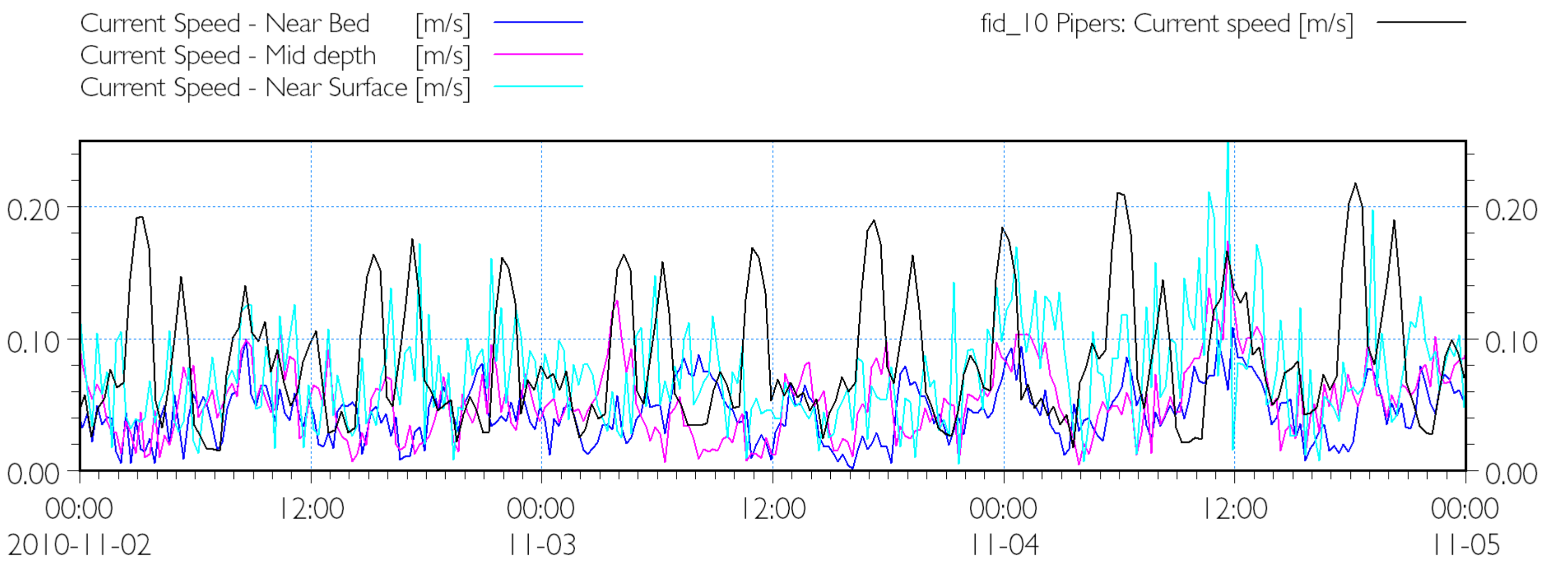


Figure 3.26: Measured (left axis) and modelled (right axis) current speed – fid_10 The Pipers

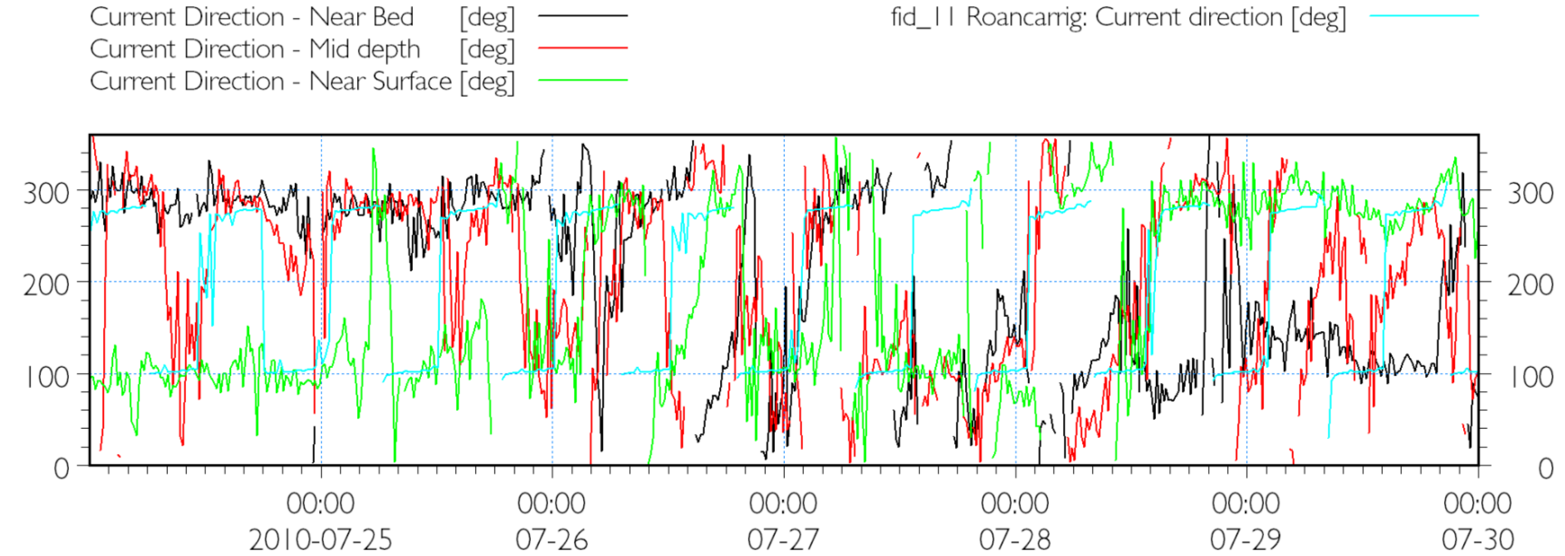


Figure 3.27: Measured (left axis) and modelled (right axis) current direction – fid_11 Roancarrig

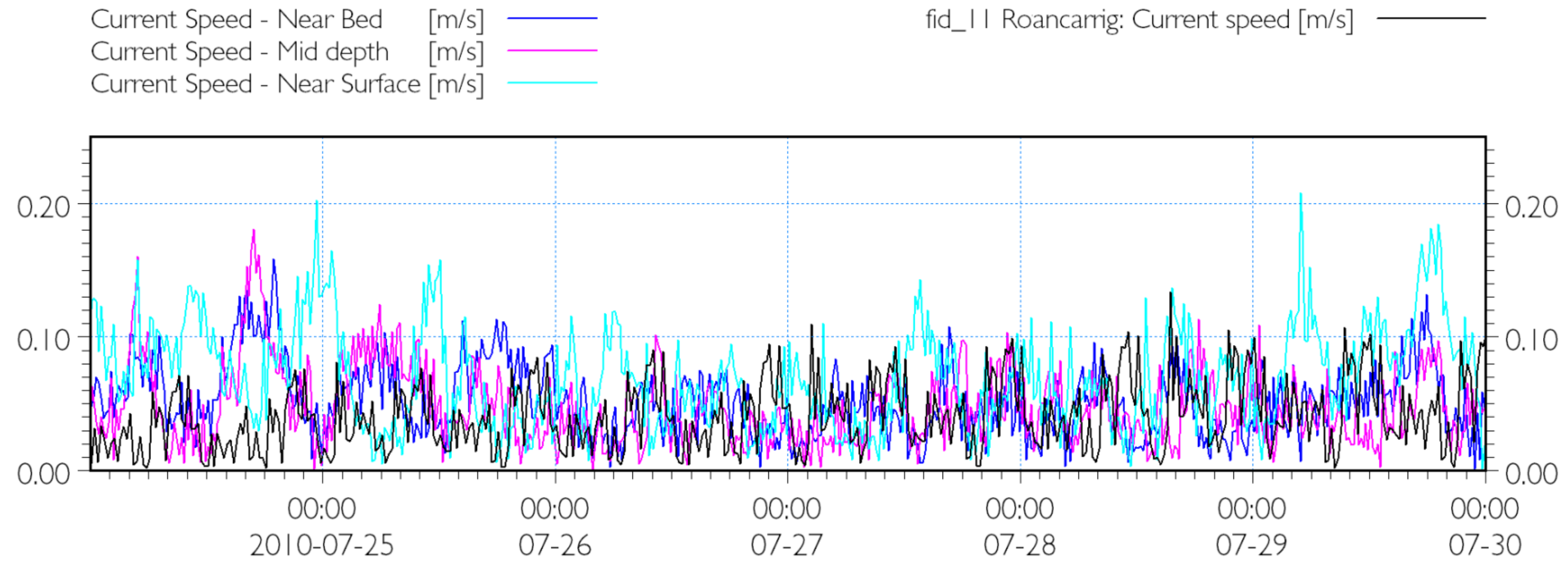


Figure 3.28: Measured (left axis) and modelled (right axis) current speed – fid_11 Roancarrig

4 WATER QUALITY MODELLING.

Water quality modelling was undertaken to establish the dispersal and fate of waste solutes and solids, along with lice production and dispersal and lice treatments associated with fish production at all existing and currently proposed sites in the bay. Two modelling methods were employed during the study – particle analysis and advection/dispersion modelling. An overview of each method is given in the following sections. In subsequent sections, each water quality parameter (nitrogen, phosphorus etc.) is considered in turn. For each parameter, the modelling method is given along with details of how the loading was applied and the results of the model simulation. The locations of all sites included in the study is given in Figure 4.1. Figure 4.2 shows the proposed arrangement of the fish pens at Shot Head, as used to define dispersion sources.

4.1 PARTICLE TRACKING.

The first method used for dispersion simulations was the DHI MIKE 321 Particle Tracking model, which describes the transport and fate of solutes or suspended matter. This uses data from the hydrodynamic model, described in Section 3, to provide information on the general movement of the water body.

Within MIKE 321 PT, the transported substance is considered as a mass of particles, being advected within the surrounding water body and dispersed as a result of random processes in a 2-Dimensional or 3-Dimensional regime, using the Lagrangian approach. Hence, the resolution of the plume is not restricted by the cell size of the current field.

In this case, the model can be used to determine the fate of suspended or dissolved matter that is discharged into the Bay or is transported to the open sea. The model may simulate the effects of wind-driven currents and includes a mechanism to deal with overturning currents (waves) along the shoreline. The loss of active material from the water column through either settlement or decay can also be included within the model simulations if so desired.

Although the model uses data from the 2-Dimensional depth-averaged hydrodynamic flow model, the MIKE321 PT model generated for Bantry Bay applies bed shear to represent the vertical velocity profile to provide a more accurate assessment of the displacement of particles located at different depths in the water column. Employing this facility in the dispersion simulations provides a more realistic representation of the dispersion at full scale.

4.2 ADVECTION DISPERSION MODELLING.

The DHI MIKE 21 AD advection / dispersion module is an extension of the MIKE 21 HD model and simulates the spreading of dissolved substances, subject to the influence of the fluid transport and associated natural dispersion processes. MIKE 21 AD solves the advection-dispersion equation for dissolved or suspended substances in two dimensions. This is, in reality, the mass-conservation equation. The substance may be treated conservatively or under linear decay as required. Discharge quantities and compound concentrations at source and at sink points are included, together with a decay rate if appropriate.

Implementation of the AD module was undertaken using the tailorable EcoLab module. This is known as Agent-Based Modelling (ABM). In a similar way to the hydrodynamic (HD) module, the concentration of the substance is calculated in the AD model at each point of the mesh, covering the area of interest. Information on the transport, (that is the currents and water depths at each point), is provided by the HD module. The system solves the equation of conservation of mass for a dissolved or suspended substance using a two-dimensional finite difference scheme.

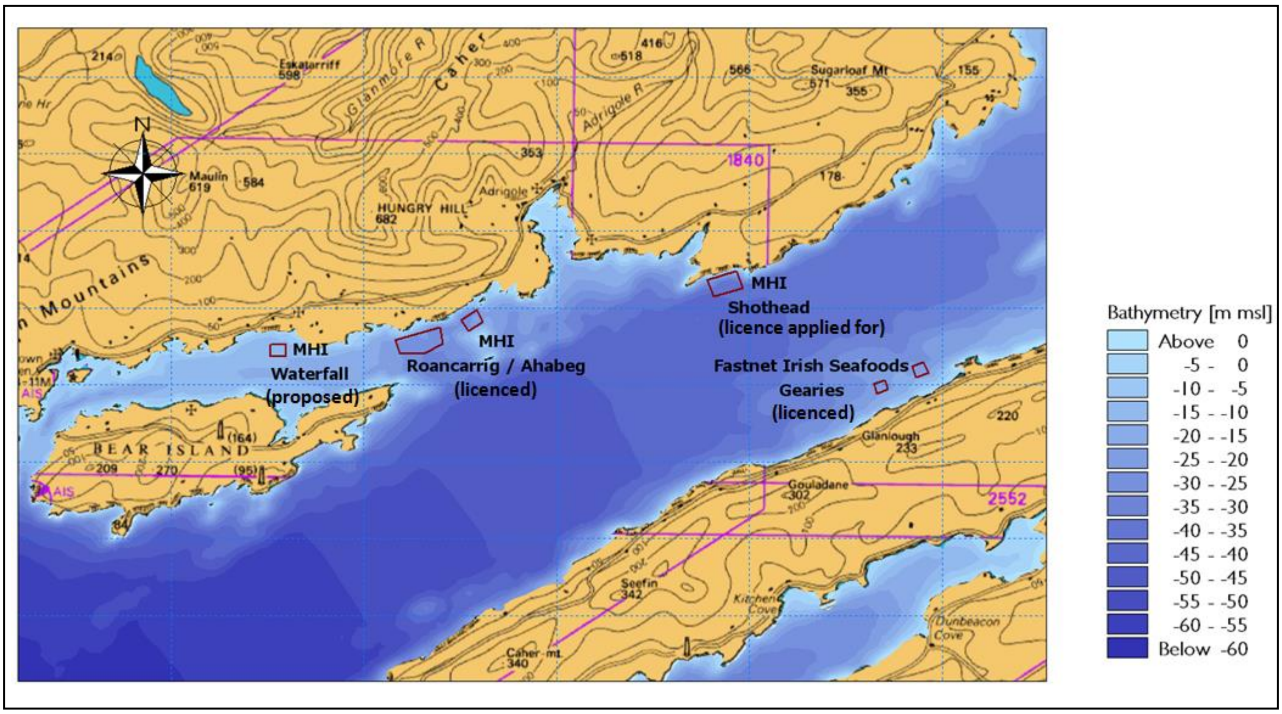
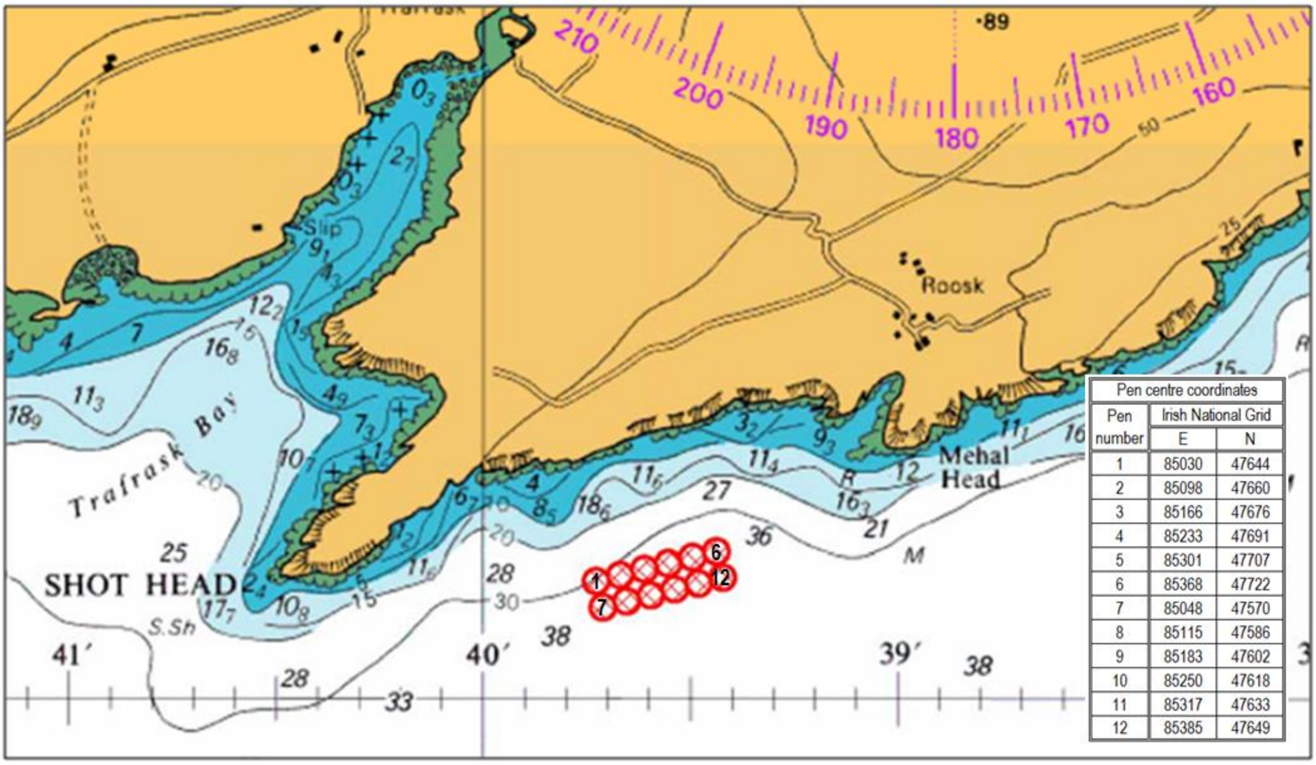


Figure 4.1: Location of all existing and currently proposed salmon farm sites / licences in Bantry Bay.



Pen centre coordinates

Pen number	Irish National Grid E	N
1	85030	47644
2	85098	47660
3	85166	47676
4	85233	47691
5	85301	47707
6	85368	47722
7	85048	47570
8	85115	47586
9	85183	47602
10	85250	47618
11	85317	47633
12	85385	47649

Figure 4.2: Proposed pen locations, Shot Head, Bantry Bay.

5 WATER QUALITY PARAMETERS

5.1 OVERVIEW

5.1.1 Introduction

For the purposes of estimating the potential for salmon farm-derived impacts on water quality parameters in Bantry Bay, the EQO / EQS (Environmental Quality Objectives / Environmental Quality Standards) approach has been adopted in this study. This approach has been widely used in the quantification and qualification of the environmental impact of a wide range of individual anthropogenic discharges. It was first proposed in the context of salmon farming by the then Scottish Office Agriculture and Fisheries Department (SOAFD) in 1992 and has subsequently been adopted by the Scottish Environmental Protection Agency (SEPA), which is the regulator in Scotland of the UK Control of Pollution Act 1974 (superseded by the Controlled Activities Regulations in April 2006), under which all industrial pollution, including that arising from aquaculture, is regulated. Scotland is the world's third largest producer of farmed salmon so it is considered appropriate to employ the standard adopted for salmon farming waters in Scotland and indeed further afield for this present analysis.

SI 272 2009, the European Communities Environmental Objectives (Surface Waters) Regulations 2009 is the main national legislation transposing the European Water Framework Directive 2000/60/EC into Irish law. This introduced a range of standards for all surface waters in Ireland, including coastal waters for their achievement of good ecological status or maintenance of high status. In general, the relevant standards in SI 272 are in agreement with SEPA EQS's for example, whilst SEPA's EQS for Nitrogen (DIN) is 168µgN/l, the SI DIN standard for high status coastal waters in 0.17Nmg/l (=170µgN/l).

The thinking behind the EQO / EQS approach to salmon farming and the environment is succinctly described in the Manual on Marine Cage Fish Farming produced and regularly updated by SEPA. SEPA's primary EQO's in respect of marine pen farming are:-

- Protection of the consumer (ensuring that edible aquatic species may be eaten safely by man and other animals).
- Protection of aquatic life including plants and animals of commercial or conservation importance.
- Protection of the aesthetic quality and recreational value of the water body.
- Safeguarding of water quality for industrial use.

SEPA's selected EQS's have been established to protect the given EQO's. EQS's are often concentration limits for specific substances in solution. Many such substances may be perfectly normal constituents of fresh or marine waters (for example inorganic nitrogen and phosphorus) where, nonetheless, a safe upper concentration limit is set as the EQS value in order to avoid the potential effects of "unnaturally" high concentrations or other tolerance limits, for example the occurrence of eutrophication and "unnatural" levels of primary production, which can result from elevated inorganic nitrogen and phosphorus levels. As well as concentration limits for both natural and unnatural substances in solution, for example toxins of industrial origin or aquaculture medicinal treatments, a number of biological standards have also been adopted as EQS's.

The derivation and adoption of EQS's is a lengthy process. Each new EQS has been standardised and reported in the scientific literature for at least 15 years. The process involves extensive and ongoing review and assessment of data on the behaviour, fate and effects of each substance in the environment. This generally results in the derivation of a draft standard, prior to the final approval of an EQS. In respect of the water quality parameters assessed in the following sections, (Sections 5.2 to 5.6), the EQS's used are taken directly from SEPA's Manual on Marine Cage Fish Farming, where further information on each can be found.

5.1.2 Definition of Terms

The simulations for each of the parameters considered were carried out using a model mesh for the extent of Bantry Bay, with a variable time-step of typically less than 10 seconds and simulations lasting for periods of up to 22 days, depending on the specific parameter. Models of this resolution generate huge amounts of data. In order to condense the results for analysis and presentation, four types of graphical output have been generated:

- Maximum Concentration Plume Envelope
- Average Concentration Plume Envelope
- Typical Ebb Concentration Plume Envelope
- Typical Flood Concentration Plume Envelope

Maximum Concentration Plume Envelope

The purpose of the Maximum Concentration Plume Envelope is to show the maximum concentration of the given parameter reaches at each nominal $20m^2$ cell location in any ≤10-second time step during the entire course of each simulation (22 days = ≥ 190,000 time steps). All the maximum values recorded are then plotted as concentration contours in the graphical output. It is most important for the observer to appreciate that, whilst the resulting diagram is of use in showing the *maximum* values that can be reached at any point throughout the area covered and throughout the simulation, it does not represent a real situation in space or time because there is little likelihood of any of the maximum values recorded occurring simultaneously. In fact, in most cases, this is very unlikely as each plume passes through the domain over the time period concerned, with the maximum concentration at its centre, undergoing dispersion and dilution as it moves in the prevailing currents. Additionally, whilst the time for which the maximum value persists in any given mesh cell will vary and, overall, the percentage frequency of occurrence will be low due to tidal oscillation.

Average Concentration Plume Envelope

The purpose of the Average Concentration Plume Envelope is to show the average concentration of the given parameter reached in each cell during the entire course of each simulation (22 days). This was generated by averaging all the values recorded in all ≤10 second time steps in each cell over the course of the simulation. Once again, the resulting diagram is not related to a given point in time but it is useful when used in conjunction with the maximum plume envelope for gauging the 'typical' values in any area and to indicate how often the maximum values occur. For example, a high concentration may be recorded at one location and presented on the maximum envelope, but when the average plot is interrogated the value is much lower at this location. This indicates that the maximum value obtained was only experienced for a short period of time.

Typical Ebb and Flood Concentration Plume Envelopes

In order to give an indication of the actual dispersion pattern within the Bay for each parameter, the typical flood and ebb contour plots have also been included. These are 'snapshots' from the model for a typical mid-flood or mid-ebb tide situation. Unlike the previous plots, these values can be related to real moments in time.

It is worth considering the scales that have been used to present the results of the simulations. For ease of comparison, the same scales and colour palette are used for maximum and average plot sets and for individual and combined site model output. Likewise the same scale is used for the flood and ebb pairs. However the range of values under consideration is often very great and, in order to portray the dispersion pattern within the context of the EQS, a sliding or log scale is often used. This means that, for example, in the case of nitrogen in Figure 5.1 a range of 0-200 μg/l (0 - 0.2mg/l) was used but all maximum values outside of the farm site were of the order of 5 μg/l; little detail would be shown if a linear 0-200μg/l scale had been used. However a log scale allows discharges from all existing and currently proposed Bantry Bay sites, including Waterfall, to be viewed directly and compared in context, for example in Figure 5.3. In a logarithmic scale, each increment is approximately double that of the previous step. A similar approach has been taken with the other parameters modelled.

5.1.3 Site characteristics & modelling rationale

The primary purpose of this report is to investigate the likely impacts of discharges from the Shot Head site, for which an application was lodged in May 2011 and a draft licence issued (subject to appeal) in October 2015. At the time of the writing of the Shot Head EIS in 2010, the development of water quality modelling for aquaculture as it is now understood was still in development. In addition to this, since Bantry Bay is not in an SAC area it was considered that the use of box modelling was an adequate way to assess the impacts of soluble wastes from Shot Head, both singly and in combination with all other sites in the bay and this was the approach taken in the EIS. However, observations during the consultation period of the application process prompted MHI to commission this study from RPS. This study considers the worst case in the context of soluble and solids discharges and the potential for impacts of lice dispersal, both from Shot Head alone and also in combination with all existing and currently proposed site in the bay.

In terms of modelling rationale, several issues had to be addressed in investigating possible interactions of the Shot Head site with other sites within Bantry Bay. The in-combination effects were established using the alternating 24 month cycle for the production sites, operated by MHI. Full licensed production at each site was also assumed, as a worst-case scenario from the point of view of discharges. In this case, the ‘worst case’ month was used where the Shot Head site was dominant and the Roancarrig/Ahabeg site was on the alternate year in the cycle. Dominance of the Shot Head and Fastnet / Murphy's Irish Seafoods sites is likely to have the worst-case impacts on the eastern end of the bay; for comparison, Roancarrig-dominant dispersals are graphed in the sister report issued by RPS to MHI for the Waterfall site[1]. The stocking months which provided the greatest discharges were chosen for the assessment. For parameters such as feed and faecal waste, this will be related to peak biomass whereas peak lice larval production and dispersal is more closely related to fish numbers in the second production year.

5.2 NITROGEN DISCHARGE

Inorganic nitrogen is the first limiting nutrient for primary production (i.e. plant growth) in open marine conditions. Inorganic nitrogen is therefore widely regarded as a primary indicator of water quality in relation to fish farming. In fish, nitrogen discharges arise from the ingestion, digestion and metabolism of feed, which results in the excretion of soluble nitrogen, primarily as ammonia in solution in the urine, through the gills. Nitrogen is also discharged in indigestible solids from ingested feed, which are voided as faeces via the anus. Nitrogen waste also arises from uneaten (waste) feed. Approximately 43% of the nitrogen content of ingested feed is retained by the salmon for growth; the remainder is discharged into the water column. Waste feed, which remains uneaten and passes into the water column and to the seabed comprises approximately 3% of the feed offered to the fish. Note that, in the models and simulations that follow, waste feed is accounted for by a 3% allowance in the Feed Conversion Rate (FCR), which is built into both the growth models and discharge models used.

The sum of nitrogen discharges from a salmon farm site comprise both settleable and soluble fractions. The proportions of each can be calculated from the quantity of feed used on the site, the feed conversion rate (the ratio of the feed utilised as dry weight over the increase in salmon wet weight resulting), the protein digestibility of the feed (in this case about 87%) and the proportion of nitrogen retained by the fish for growth (in this case about 43%). The projected loadings for total, settleable and soluble nitrogen are given for all existing and currently proposed salmon farm sites Bantry Bay in Table 5.1. This table is extracted from the full production and discharge models for the sites, which are expanded and described in Section 6 of the EIS document which accompanied the Shot Head the licence application. Although the total nitrogen discharge can be separated by calculation into soluble and settleable fractions, the total quantity of nitrogen discharged has been used for the purposes of the modelling of nitrogen dispersion from the sites in this exercise. This gives a worst-case scenario in respect of the proportion of discharged nitrogen available for immediate dispersion form the sites (that is 100%).

The monthly nitrogen discharge model given in Table 5.1 shows that the amount of nitrogen discharged from each site varies throughout the farming cycle, with only the Waterfall harvest site remaining constant in this

1 IBE0744_R06_Rev01_NS_WaterfallWQ (1), RPS Consulting Engineers Belfast October 2015.

respect. As the fish grow on the other Bantry Bay sites, which are all production sites, the feeding demands of the stock increase, resulting in increased discharges. Discharges then decrease as the fish are harvested and total biomass reduces, ultimately to zero. The fate of the nitrogen discharged from the farm sites was simulated using the advection / dispersion modelling process outlined in Section 4.2. The peak combined monthly discharges of all sites was used for January in cycle year 2; see highlight in Table 5.1, which is when the Shot Head and Fastnet sites are dominant, and reach their discharge peak.

Discharges were incorporated into the model as arising from a point source at each pen centre, i.e. Shot Head and Roancarrig / Ahabeg 12 pens each and Waterfall and the Fastnet sites 6 pens each. This provides a realistic worst-case scenario for dispersion, since, in reality, discharges would occur across each pen and therefore be more dispersed and dilute at the outset of the simulation than in the scenario selected.

The worst-case principle was further applied in that all nitrogen discharged was treated as conservative; that is no decay rate for nitrogen was applied within the model. In reality, nitrogen is readily and rapidly assimilated through primary production (plant and bacterial growth) in the water column. The period used for the simulation was 22 days, which is discussed further in Section 3.4 This allows for the discharges to both develop and to stabilise and also covers the full range of spring to neap tidal conditions to which dispersing substances are exposed in Bantry Bay.

Table 5.1: Total proposed Nitrogen loading for all currently proposed and existing Bantry Bay salmon farm sites; Shot Head / Fastnet dominant.

Month	Nitrogen discharge N Tonnes / month											
	Shot Head			Fastnet			Roancarrig			Waterfall		
	Total	Settleable	Soluble	Total	Settleable	Soluble	Total	Settleable	Soluble	Total	Settleable	Soluble
Sep	Fallow site			Fallow site			9.65	0.89	8.76	0.13	0.01	0.11
Oct							11.58	1.07	10.51	0.13	0.01	0.11
Nov	0.72	0.09	0.64	0.18	0.02	0.16	12.69	1.17	11.52	0.13	0.01	0.11
Dec	1.14	0.14	1	0.29	0.03	0.25	14.15	1.31	12.84	0.13	0.01	0.11
Jan	1.66	0.22	1.45	0.42	0.05	0.36	15.26	1.41	13.85	0.13	0.01	0.11
Feb	2.68	0.35	2.32	0.67	0.09	0.58	13.84	1.28	12.56	0.13	0.01	0.11
Mar	4	0.53	3.48	1	0.13	0.87	13.42	1.24	12.18	0.13	0.01	0.11
Apr	5.18	0.68	4.49	1.29	0.17	1.12	9.15	0.85	8.31	0.13	0.01	0.11
May	6.15	0.86	5.29	1.54	0.22	1.32	4.85	0.45	4.4	Fallow site		
Jun	7.91	1.11	6.8	1.98	0.28	1.7	1.98	0.18	1.79			
Jul	9.37	1.32	8.06	2.34	0.33	2.01	1.25	0.12	1.13	0.13	0.01	0.11
Aug	8.48	0.78	7.69	2.12	0.2	1.92	0.18	0.02	0.16	0.13	0.01	0.11
Sep	9.65	0.89	8.76	2.41	0.22	2.19	Fallow site			0.13	0.01	0.11
Oct	11.58	1.07	10.51	2.89	0.27	2.63				0.13	0.01	0.11
Nov	12.69	1.17	11.52	3.17	0.29	2.88	0.72	0.09	0.64	0.13	0.01	0.11
Dec	14.15	1.31	12.84	3.54	0.33	3.21	1.14	0.14	1	0.13	0.01	0.11
Jan	15.26	1.41	13.85	3.82	0.35	3.46	1.66	0.22	1.45	0.13	0.01	0.11
Feb	13.84	1.28	12.56	3.46	0.32	3.14	2.68	0.35	2.32	0.13	0.01	0.11
Mar	13.42	1.24	12.18	3.36	0.31	3.05	4	0.53	3.48	0.13	0.01	0.11
Apr	9.15	0.85	8.31	2.29	0.21	2.08	5.18	0.68	4.49	0.13	0.01	0.11
May	4.85	0.45	4.4	1.21	0.11	1.1	6.15	0.86	5.29	Fallow site		
Jun	1.98	0.18	1.79	0.49	0.05	0.45	7.91	1.11	6.8			
Jul	1.25	0.12	1.13	0.31	0.03	0.28	9.37	1.32	8.06	0.13	0.01	0.11
Aug	0.18	0.02	0.16	0.04	0	0.04	8.48	0.78	7.69	0.13	0.01	0.11
Sep	Fallow site			Fallow site			9.65	0.89	8.76	0.13	0.01	0.11
Oct							11.58	1.07	10.51	0.13	0.01	0.11
Nov	0.72	0.09	0.64	0.18	0.02	0.16	12.69	1.17	11.52	0.13	0.01	0.11
Dec	1.14	0.14	1	0.29	0.03	0.25	14.15	1.31	12.84	0.13	0.01	0.11
Jan	1.66	0.22	1.45	0.42	0.05	0.36	15.26	1.41	13.85	0.13	0.01	0.11
Feb	2.68	0.35	2.32	0.67	0.09	0.58	13.84	1.28	12.56	0.13	0.01	0.11
Mar	4	0.53	3.48	1	0.13	0.87	13.42	1.24	12.18	0.13	0.01	0.11
Apr	5.18	0.68	4.49	1.29	0.17	1.12	9.15	0.85	8.31	0.13	0.01	0.11
May	6.15	0.86	5.29	1.54	0.22	1.32	4.85	0.45	4.4	Fallow site		
Jun	7.91	1.11	6.8	1.98	0.28	1.7	1.98	0.18	1.79			
Jul	9.37	1.32	8.06	2.34	0.33	2.01	1.25	0.12	1.13	0.13	0.01	0.11
Aug	8.48	0.78	7.69	2.12	0.2	1.92	0.18	0.02	0.16	0.13	0.01	0.11
Sep	9.65	0.89	8.76	2.41	0.22	2.19	Fallow site			0.13	0.01	0.11
Oct	11.58	1.07	10.51	2.89	0.27	2.63				0.13	0.01	0.11
Nov	12.69	1.17	11.52	3.17	0.29	2.88	0.72	0.09	0.64	0.13	0.01	0.11
Dec	14.15	1.31	12.84	3.54	0.33	3.21	1.14	0.14	1	0.13	0.01	0.11
Jan	15.26	1.41	13.85	3.82	0.35	3.46	1.66	0.22	1.45	0.13	0.01	0.11
Feb	13.84	1.28	12.56	3.46	0.32	3.14	2.68	0.35	2.32	0.13	0.01	0.11
Mar	13.42	1.24	12.18	3.36	0.31	3.05	4	0.53	3.48	0.13	0.01	0.11
Apr	9.15	0.85	8.31	2.29	0.21	2.08	5.18	0.68	4.49	0.13	0.01	0.11
May	4.85	0.45	4.4	1.21	0.11	1.1	6.15	0.86	5.29	Fallow site		
Jun	1.98	0.18	1.79	0.49	0.05	0.45	7.91	1.11	6.8			
Jul	1.25	0.12	1.13	0.31	0.03	0.28	9.37	1.32	8.06	0.13	0.01	0.11
Aug	0.18	0.02	0.16	0.04	0	0.04	8.48	0.78	7.69	0.13	0.01	0.11

It is emphasised that, at every point where a choice was available, the worst case input option was selected for simulation. This results in a 4-stage compounding of worst case in the simulations made, as a result of the following selections:-

- As a result of the protein digestibility of the 12mm pelleted feed fed, at the time of peak N discharges, approximately 12% of Total N, is insoluble and organically bound in the faeces and waste feed discharged. It is therefore not part of dissolved organic N in the water column. 38% of Total P is similarly organically bound. Whether insoluble N and P, bound in the solid wastes, settles to the seabed or remains in suspension due to tidal currents, neither will be immediately released as part of the DIN and DIP loads but will be more slowly assimilated by bacteria or via consumption by benthic or water column fauna. However, this is not taken into account in the N and P dispersal simulations modelled, which disperse Total N and Total P discharges. This increases DIN and DIP discharges in the peak month modelled by up to 13.6% N and 61.3% P respectively. In reality, these amounts of N and P would not contribute to peak month DIN and DIP but would be mineralised and contribute to soluble dispersals over subsequent, non-peak production months.

- Table 5.1, Table 5.3 and Table 5.5 for Total N, Total P and BOD discharges respectively indicate that discharges at the production sites vary from zero (when a site lies fallow) to Cycle Year 2 January peaks. Only the harvest site at Waterfall is expected to have consistent discharge levels over each year. Despite the fact that resulting peak values for the bay as a whole are only reached during a single month in each cycle, only these peak values have been modelled in the in-combination dispersal simulations.

- Pen centre point sources were used for dispersal simulations from all sites. In reality, discharges occur through the full volume of each pen and therefore would be more dispersed and dilute at the outset of dispersal than portrayed in the simulation scenarios selected. Thus the models show higher concentrations of wastes close to the pen centres than would occur in reality.

- No decay rate for N or P was implemented in the model. In reality, soluble N and P are readily and rapidly assimilated through primary production (plant and bacterial growth) in the water column, in particular during the late spring to summer months, when discharges peak.

The results for four sets of nitrogen discharge simulations are given, in two groups, in Figure 5.1 to Figure 5.4 and Figure 5.5 to Figure 5.8 respectively. All figures show the nitrogen concentration resulting from dispersal of discharges from the farm sites only, i.e. concentration contours given do not include the value of ambient background nitrogen concentration.

5.2.1 Simulation Group 1 – Maximum & Average Nitrogen Concentration

The contour plots of the projected maximum and average concentrations of total nitrogen in Bantry Bay due to total nitrogen discharges from the Shot Head site alone and from all existing and proposed farm sites in the bay are given in Figure 5.1 to Figure 5.4. Each maximum plume plot shows the maximum value recorded within each nominal $20m^2$ cell during the entire simulation period. Therefore, the concentrations shown in the maximum plots (Figure 5.1 and Figure 5.3) would not all occur simultaneously. Each average plot (Figure 5.2 and Figure 5.4) shows the average concentration in each cell over the course of each simulation. This gives an indication of how frequently the maximum values given could occur.

The Scottish Environmental Agency (SEPA) sets an environmental quality standard (EQS) for the maximum ambient nitrogen concentration in seawater of 168µg/l, equivalent to the SI 272 quality standard of 0.17mg/l (=170µg/ml). The EQS comprises the sum of the concentrations resulting from the discharge (which SEPA terms Equilibrium Concentration Enhancement, or ECE), plus the existing ambient nitrogen concentration, which is presented for control sites (where background Nitrogen data is regularly collected by MHI is the general area) in Table 5.2. (Note that it is felt that peak N levels at the Boatyard control site (very close to the Waterfall site) appear elevated relative to those collected off Lamb's Head in Kenmare Bay. This is thought to be due to nitrogen discharges in the locality of the control site, from Castletownbere town and port).

Table 5.2: Mean Background Nitrogen.

Month	Inorganic N Monthly Mean Ambient Concentration	
	Lambs Head control site	Boatyard control site
	N µg/l	N µg/l
Jan	88.0	125.11
Feb	63.0	114.87
Mar	96.0	84.08
Apr	40.5	53.95
May	10.3	6.49
Jun	4.7	3.22
Jul	16.6	1.59
Aug	3.8	2.43
Sep	23.1	19.83
Oct	37.7	38.13
Nov	72.9	76.14
Dec	80.0	93.29

As a result of this ambient value and EQS, the maximum and average contour plots in Figure 5.1 to Figure 5.4 are presented with a scale range which extends to 0.2mg/l which (= 200µg/l), so that the range includes the maximum allowable discharge under the SEPA EQS. It should be noted that the contour levels are closer at lower concentrations in order to better highlight the dispersal of the discharges. Given that the average winter background level is circa 100µg/l then a discharge resulting in an increase of less than 70µg/l would be acceptable; this doesn't take any account that existing farming activities (such as Roancarrig and the existing Waterfall trout site, during the period in which it operated) will already be contributing to the background and thus are 'double counted' in the combined sites scenario presented.

Figure 5.1 and Figure 5.2 show the Nitrogen concentrations arising from the Shot Head site only, as Maximum and Average Concentration plumes during production. All concentrations for both outputs are below 10µg/l (0.01mg/l) and are typically less than a tenth of this value. Similarly, Figure 5.2 and Figure 5.3 show Maximum and Average Concentration plumes from the combined sites in the combined peak discharge month of January of alternate years.

The plots in Figure 5.1 to Figure 5.4 all show a disparity between the maximum and average plots of around one to two contour levels in each case, which equates to maxima being two to four times the average values. In that the average plots represent the mean of the values which fall between the maximum values (given) and the minimum value (not given) in each case, this suggests that the maximum values given in the Maximum Concentration Plume Envelope plots do frequently occur or persist for long periods.

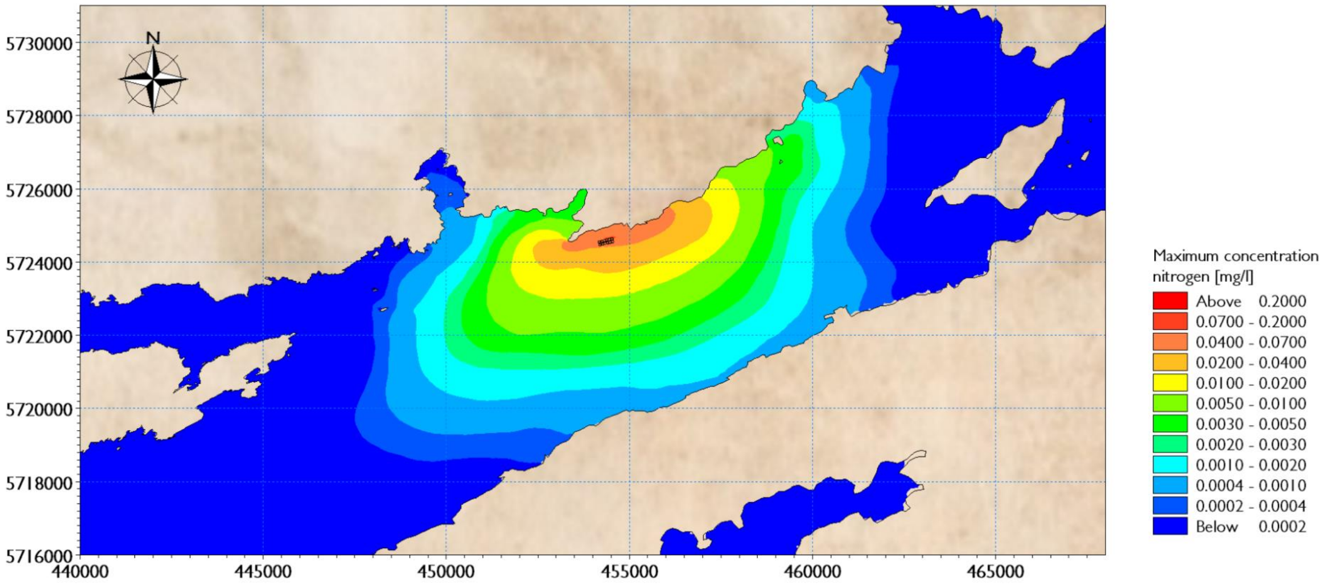


Figure 5.1: Maximum Plume Envelope of Nitrogen Concentration arising from the Shot Head site only.

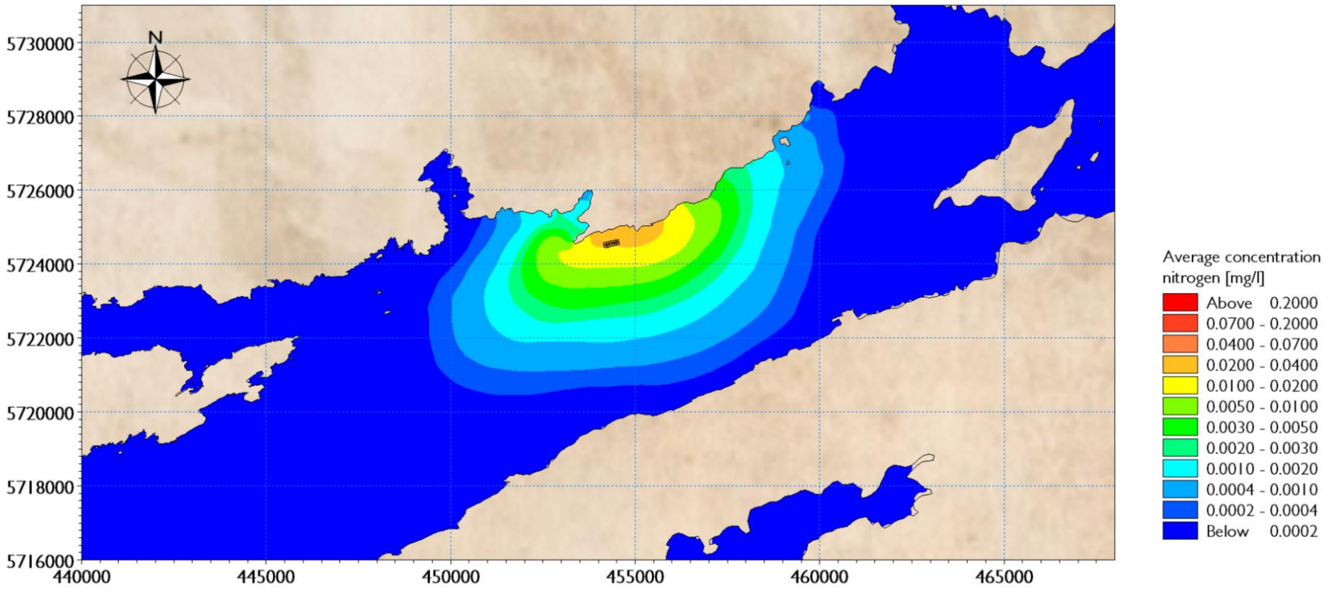


Figure 5.2: Average Nitrogen Concentration arising from arising from the Shot Head site only.

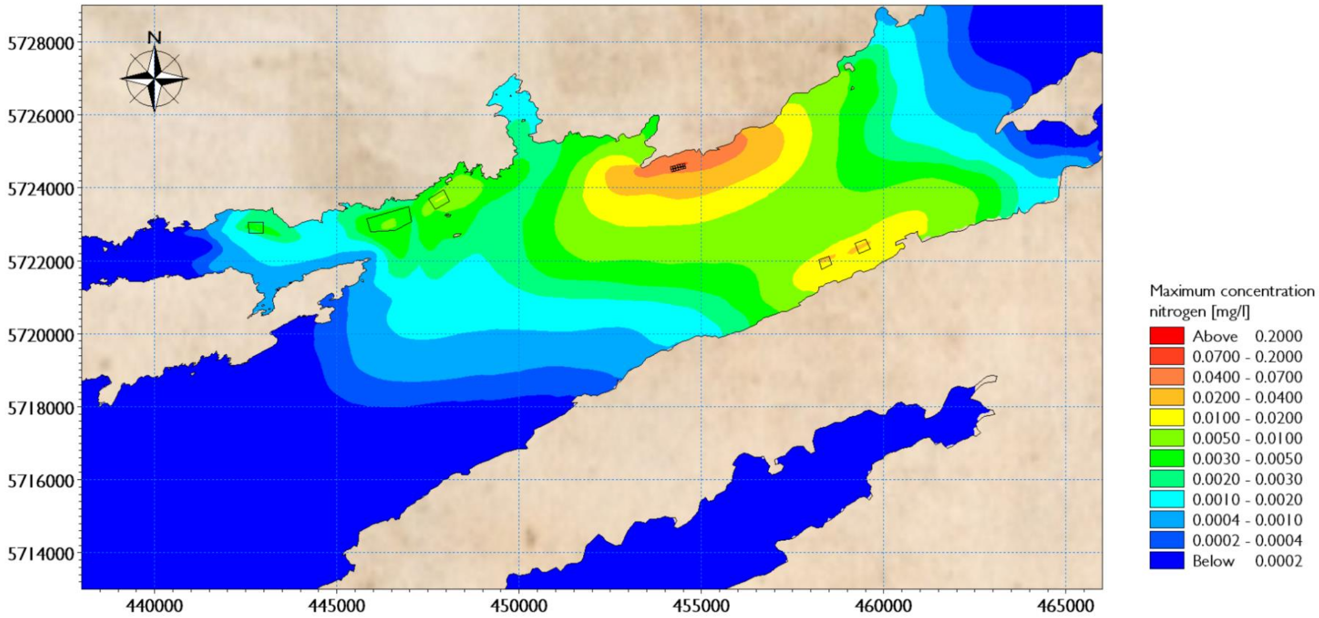


Figure 5.3: Maximum Plume Envelope of combined Nitrogen Concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

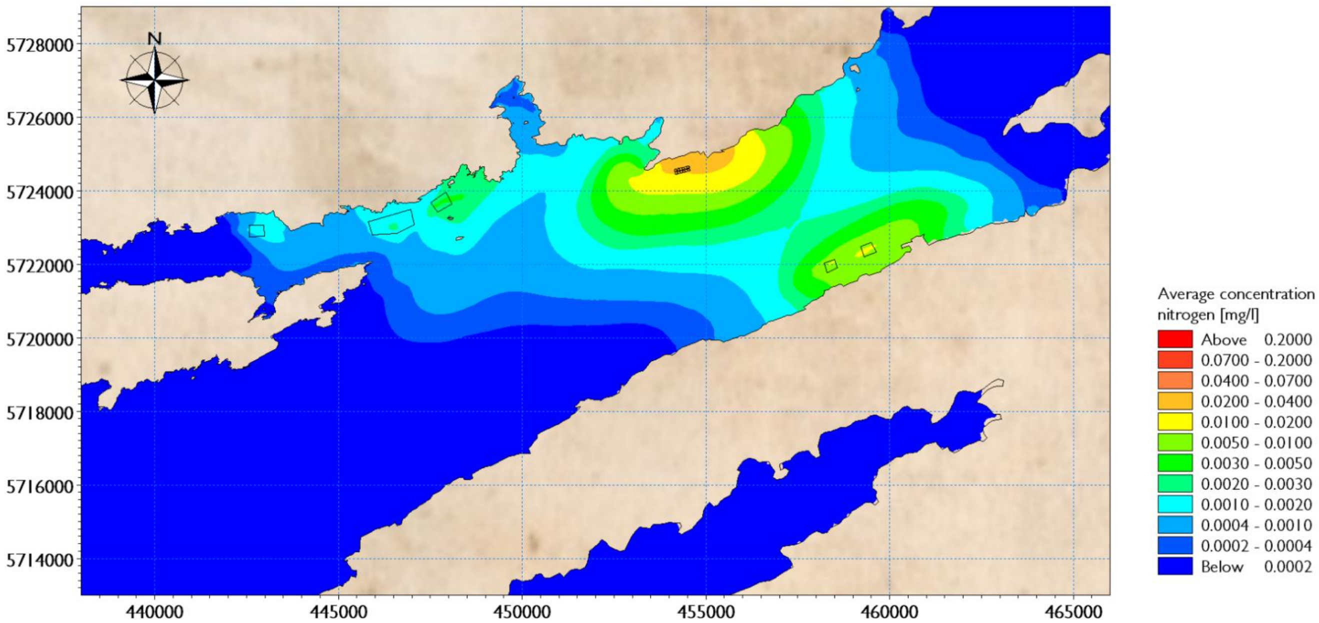


Figure 5.4: Average combined Nitrogen Concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

5.2.2 Simulation Group 2 – Typical Nitrogen Concentration

The second set of contour plots for discharged Nitrogen concentrations relates to typical concentrations resulting from discharges from the Shot Head site on ebb and flood tides (Figure 5.5 and Figure 5.6) and the combined discharges from all currently proposed and existing salmon farm sites in the bay on ebb and flood tides (Figure 5.7 and Figure 5.8). Typically, the N concentration elevation at the Shot Head site itself lies between 10µg/l to 40µg/l and falls 10-fold within 1km of the site in both ebb and flood conditions. It is notable that the typical combined-site plumes do not appear to augment each other and that, once beyond the immediate influence of the sites, the N elevation in open waters is generally below 20µg/l which is well within the range of fluctuation in background levels. Figure 5.1 to Figure 5.8 all indicate that, under all circumstances, dispersal of nitrogen from the sites has a limited impact on dissolved nitrogen levels in Bantry Bay as a whole by way of Equilibrium Concentration Enhancement, even where simulations are based on a high level of worst-case expectation.

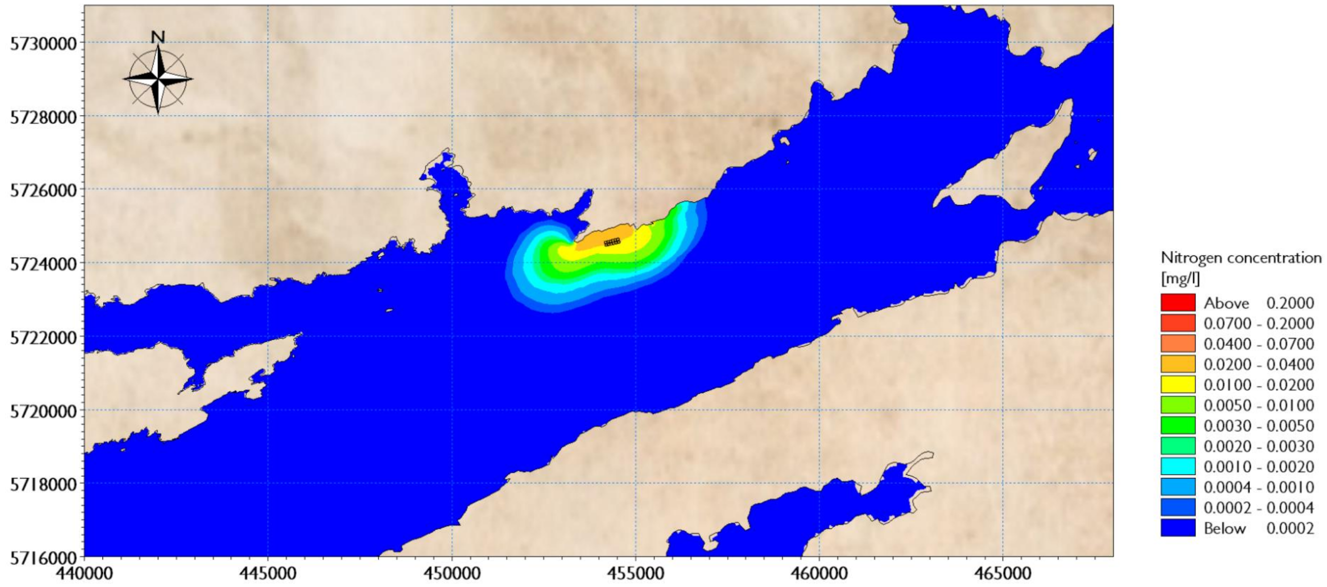


Figure 5.5: Typical Ebb Plume of Nitrogen Concentration arising from the Shot Head site only.

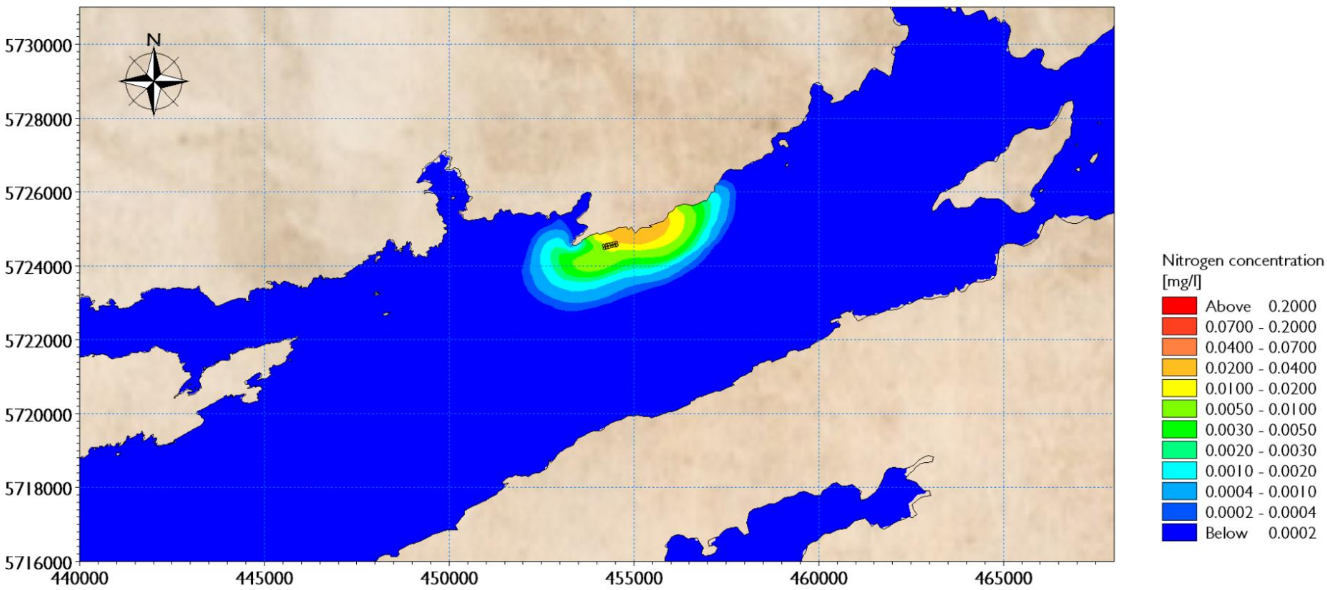


Figure 5.6: Typical Flood Plume of Nitrogen Concentration arising from the Shot Head site only.

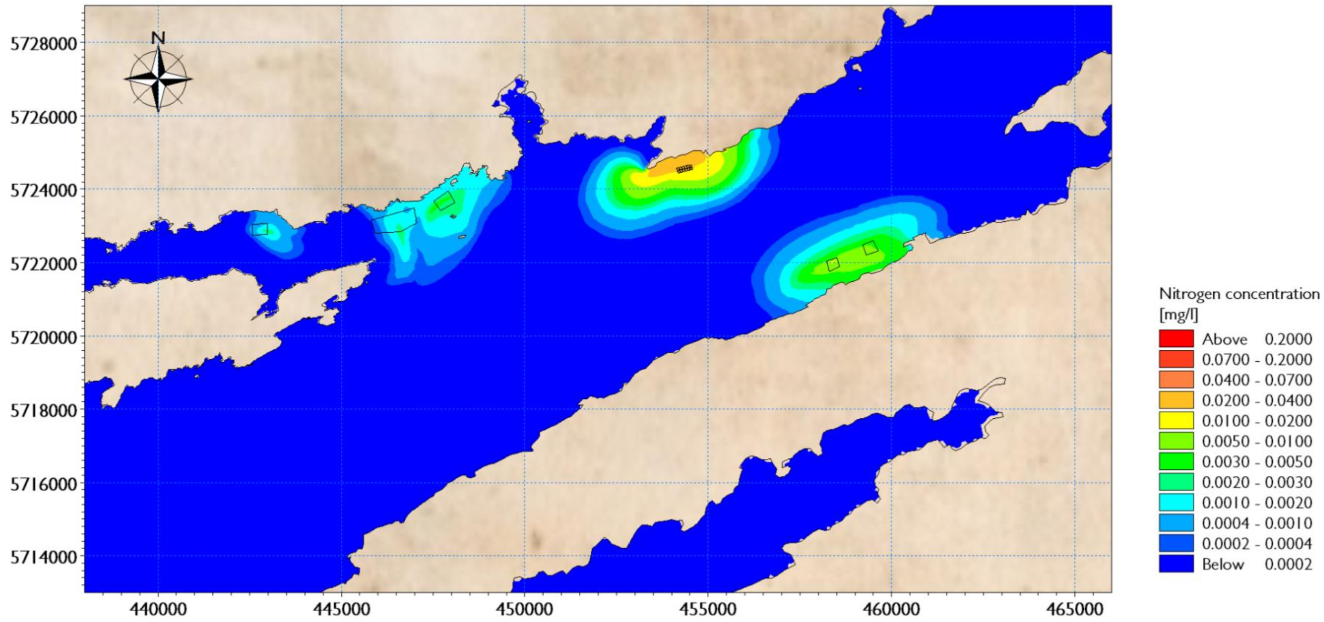


Figure 5.7: Typical Ebb Plume of combined Nitrogen Concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

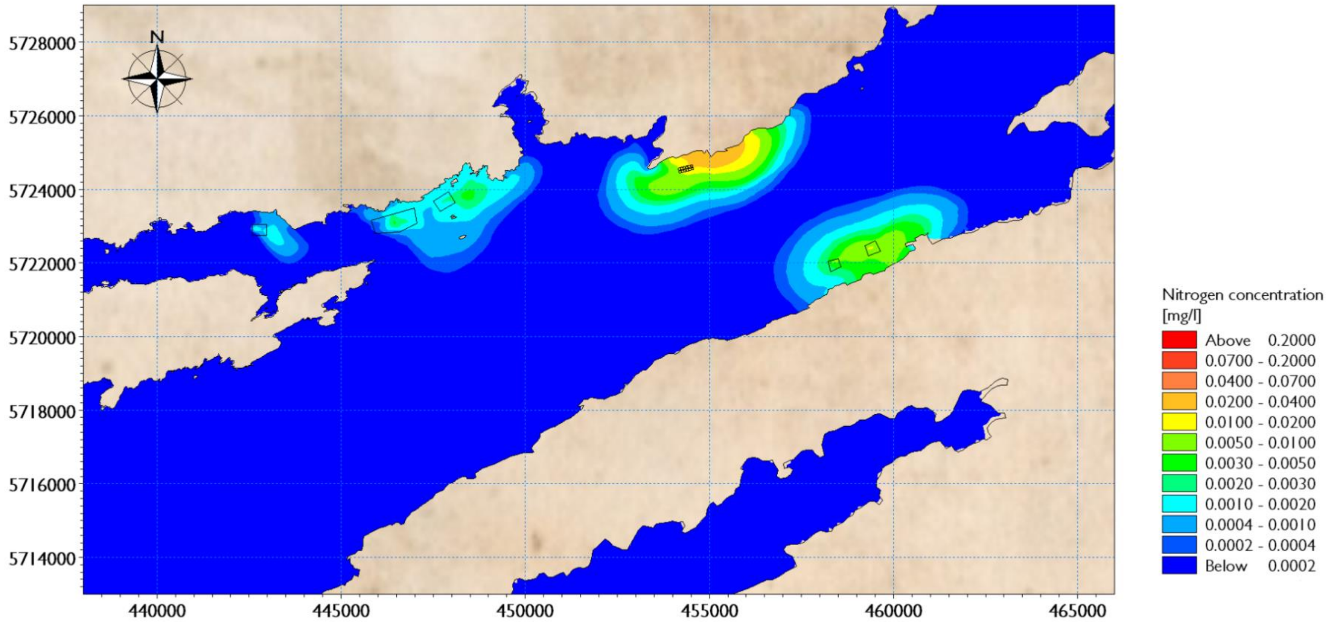


Figure 5.8: Typical Flood Plume of combined Nitrogen concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

Even in the worst case, there is no significant elevation of N concentration towards the head of the bay, where N concentration can be expected to remain within its existing seasonal ambient concentration range.

5.3 PHOSPHORUS DISCHARGE

Phosphorus is a secondary indicator of water quality in relation to marine aquaculture. Similar to nitrogen, the source of phosphorus is the fish feed, in fish meal, also supplemented with mineral phosphorus. Of the phosphorus within the feed (about 1% by weight, depending on ration size), approximately 62% is soluble. Approximately 49% of feed phosphorus is taken up by the fish. That part which is excreted passes directly into the water column, in solution, via the gills. The remaining indigestible phosphorus is voided via the anus in the faeces. A further small quantity of phosphorus enters the environment from uneaten, waste feed.

As for nitrogen, the total phosphorus waste load can be calculated from the settleable faecal waste and the soluble load, plus the phosphorus content of the waste feed. Again, to provide the worst-case scenario, the total phosphorus waste is assumed to be in solution for the purposes of dispersion modelling. The projected loadings for total, settleable and soluble phosphorus are given for all existing and currently proposed Bantry Bay sites in Table 5.3.

Phosphorus discharges were simulated using the advection dispersion model described in Section 4.2. The peak combined monthly discharges from all sites was used for January in cycle year 2; see highlight in Table 5.3, which is when the Shot Head and Fastnet sites are dominant. As for the nitrogen model, the discharge was included within the model from a source at each pen centre. The total phosphorus loading was introduced as a (worst case scenario) conservative discharge and the simulation was run for 22 days to allow for full plume development and to cover the range of tidal conditions, from neap to spring tide. Again, phosphorus discharges were treated as conservative although in reality, phosphorus is rapidly assimilated in the process of primary production, like nitrogen.

Table 5.3: Total proposed Phosphorus loading for all currently proposed and existing Bantry Bay salmon farm sites; Shot Head / Fastnet dominant.

Month	BOD5 Tonnes / month			
	Shot Head	Fastnet	Roancarrig	Waterfall
Sep	Fallow site	Fallow site	201.922	2.617
Oct			242.205	2.617
Nov	8.724	2.181	265.419	2.617
Dec	13.726	3.432	295.982	2.617
Jan	22.376	5.594	319.289	2.617
Feb	38.025	9.506	289.469	2.617
Mar	59.074	14.768	280.792	2.617
Apr	76.36	19.09	191.792	2.617
May	100.423	25.106	101.453	Fallow site
Jun	129.869	32.467	41.337	
Jul	154.566	38.641	26.052	2.617
Aug	177.282	44.32	3.672	2.617
Sep	201.922	50.48	Fallow site	2.617
Oct	242.205	60.551		2.617
Nov	265.419	66.355	8.724	2.617
Dec	295.982	73.995	13.726	2.617
Jan	319.289	79.822	22.376	2.617
Feb	289.469	72.367	38.025	2.617
Mar	280.792	70.198	59.074	2.617
Apr	191.792	47.871	76.36	2.617
May	101.453	25.363	100.423	Fallow site
Jun	41.337	10.334	129.869	
Jul	26.052	6.513	154.566	2.617
Aug	3.672	0.918	177.282	2.617
Sep	Fallow site	Fallow site	201.922	2.617
Oct			242.205	2.617
Nov	8.724	2.181	265.419	2.617
Dec	13.726	3.432	295.982	2.617
Jan	22.376	5.594	319.289	2.617
Feb	38.025	9.506	289.469	2.617
Mar	59.074	14.768	280.792	2.617
Apr	76.36	19.09	191.792	2.617
May	100.423	25.106	101.453	Fallow site
Jun	129.869	32.467	41.337	
Jul	154.566	38.641	26.052	2.617
Aug	177.282	44.32	3.672	2.617
Sep	201.922	50.48	Fallow site	2.617
Oct	242.205	60.551		2.617
Nov	265.419	66.355	8.724	2.617
Dec	295.982	73.995	13.726	2.617
Jan	319.289	79.822	22.376	2.617
Feb	289.469	72.367	38.025	2.617
Mar	280.792	70.198	59.074	2.617
Apr	191.792	47.871	76.36	2.617
May	101.453	25.363	100.423	Fallow site
Jun	41.337	10.334	129.869	
Jul	26.052	6.513	154.566	2.617
Aug	3.672	0.918	177.282	2.617

The results for the simulations for phosphorus discharges are presented in the same format used for nitrogen discharge simulations.

5.3.1 Simulation Group 1 – Maximum & Average Phosphorus Concentration

The first set of contour plots, given in Figure 5.9 - Figure 5.12 relate to the maximum and average concentrations simulated for the Shot Head and combined site phosphorus discharges respectively. As with the nitrogen discharges the combination simulation relates to the dominance of the Shot Head / Fastnet sites (which occurs in January of cycle year 2). The Maximum Concentration Plume Envelope plots give the maximum value recorded within each cell during the entire simulation period whilst the Average Concentration Plume Envelope plots indicate the average value in each nominal 20m^2 model cell.

SEPA refers to the OSPAR EQS standard for total phosphorus, of 119μg P/l in Atlantic and Irish Sea coastal waters. A phosphorus EQS is rarely applied because nitrogen and phosphorus have a common source. Thus, if the nitrogen standard is met the phosphorus standard, which is more liberal, will also generally be met. This is likely to be why there is no phosphorus standard in SI 272. The EQS includes both the background ambient (SEPA's Equilibrium Constant) and discharge (SEPA's Equilibrium Constant Elevation) levels. The average background phosphorus levels for the Bantry Bay / Kenmare Bay control sites are presented in Table 5.4.

Table 5.4: Mean Background Phosphorus

Month	Inorganic P Monthly Mean Ambient Concentration	
	Lambs Head control site P µg/l	Boatyard control site P µg/l
Jan	23.4	22.03
Feb	21.9	18.91
Mar	20.5	17.34
Apr	9.9	17.57
May	7.4	3.10
Jun	4.5	4.55
Jul	5.5	5.43
Aug	6.1	5.37
Sep	11.0	11.26
Oct	11.4	9.92
Nov	15.9	16.12
Dec	20.7	19.30

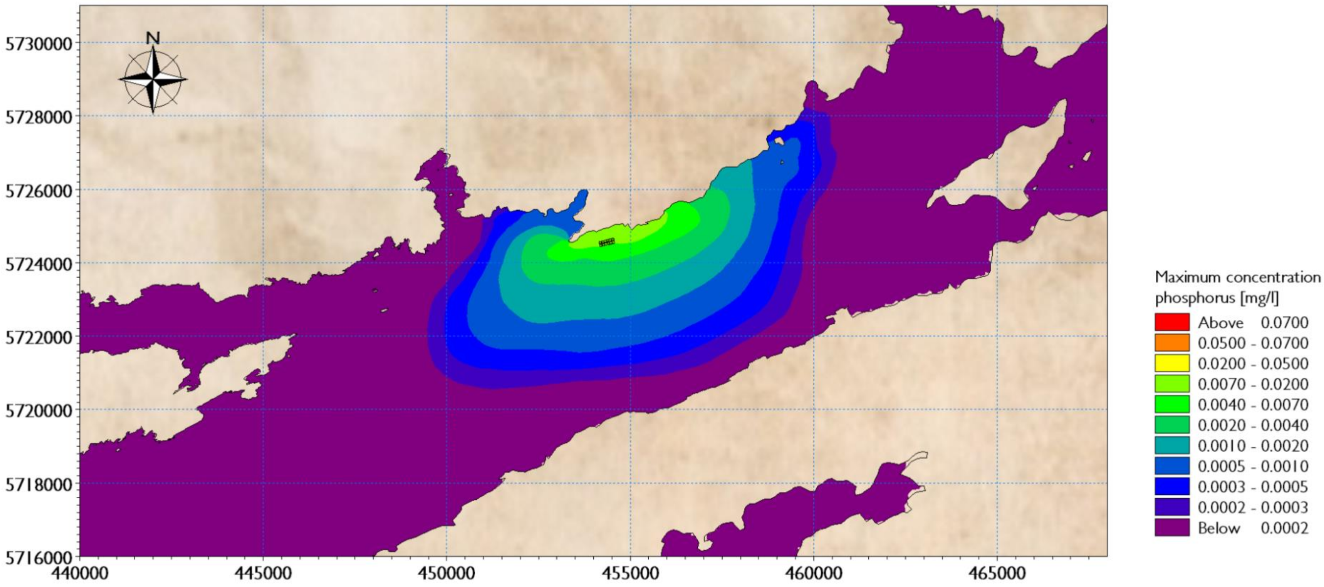


Figure 5.9: Maximum Plume Envelope of Phosphorus Concentration arising from Shot Head only.

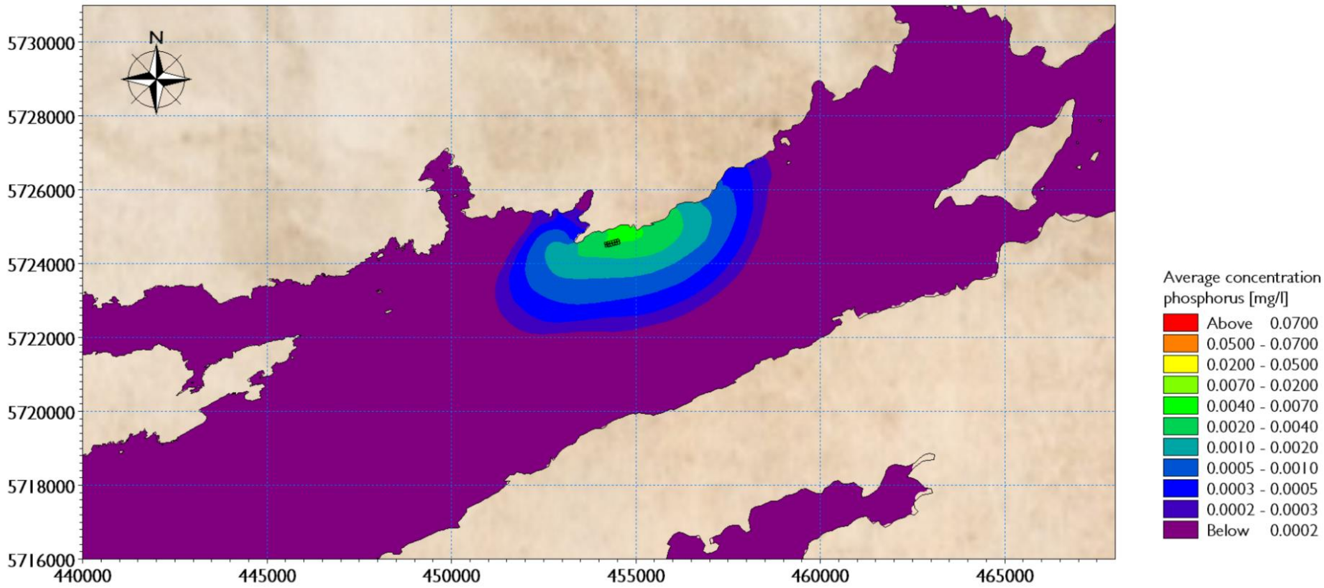


Figure 5.10: Average Phosphorus Concentration arising from Shot Head only.

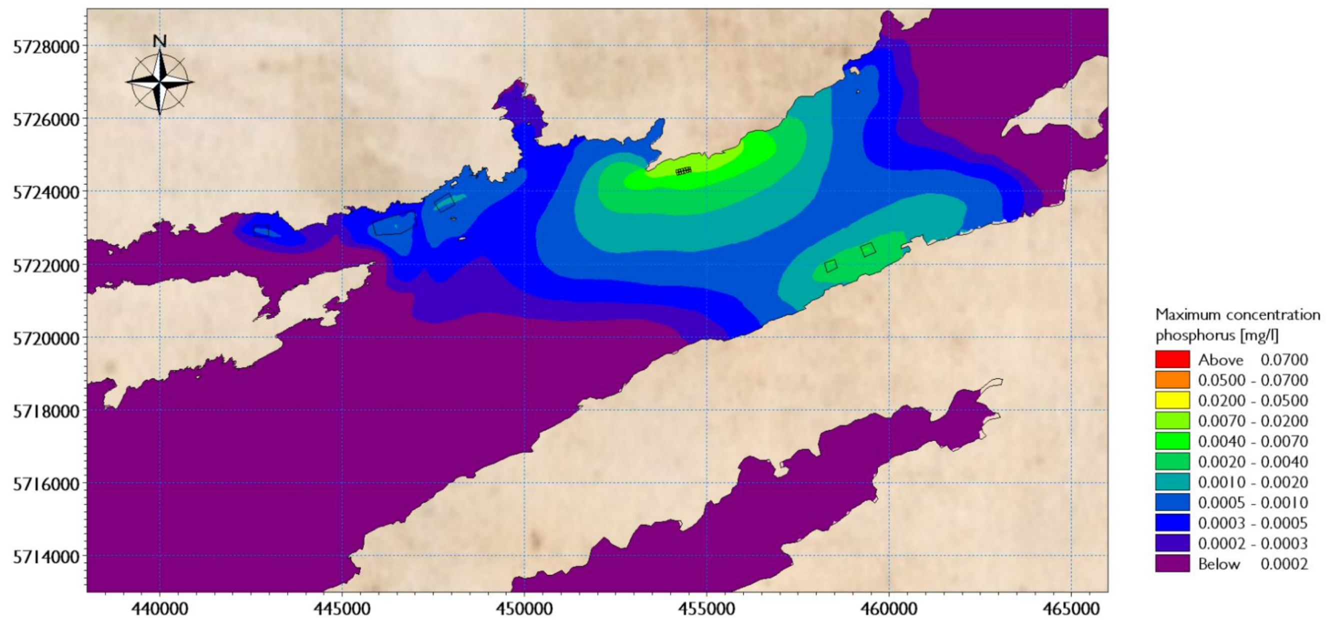


Figure 5.11: Maximum Plume Envelope of combined Phosphorus Concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

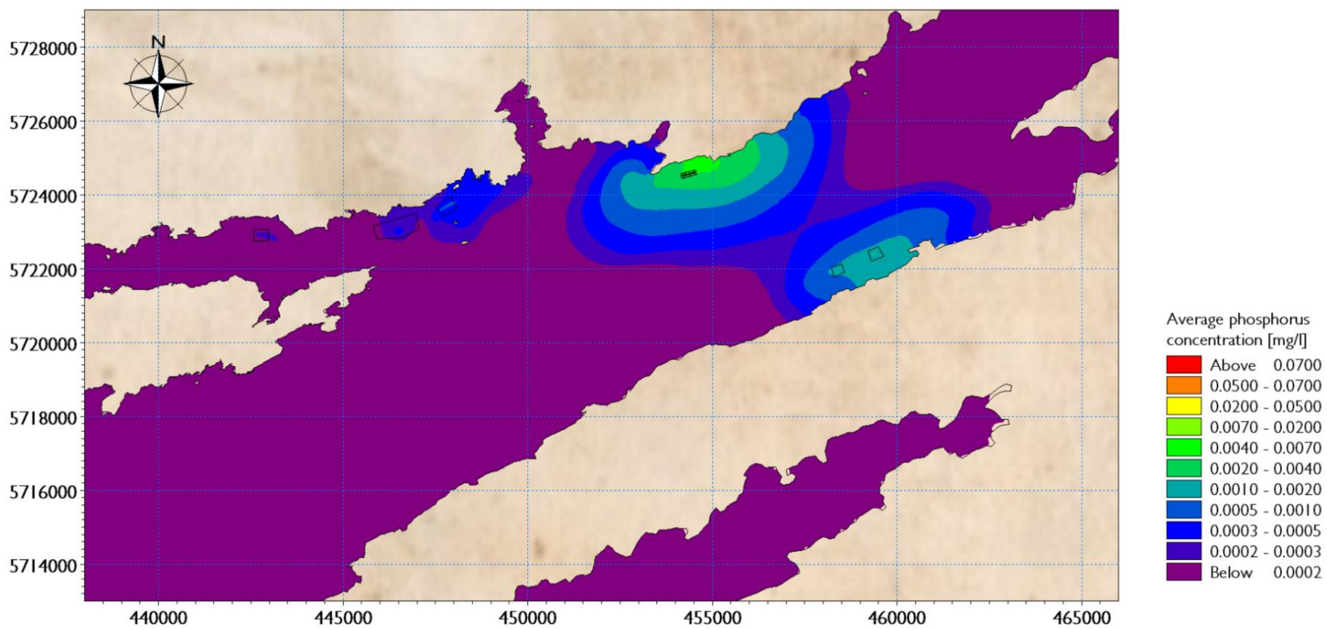


Figure 5.12: Average combined Phosphorus Concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

As with nitrogen, the phosphorus plots in Figure 5.9 to Figure 5.12 all show a disparity between the maximum and average plots in the order of four times. In that the average plots represent the mean of all values in a given cell, which lie between the maximum values (given) and the minimum value (not given) in each case, this suggests that maximum values given in the Maximum Concentration Plume Envelope plots do not persist. The maximum ambient value for background phosphorus levels is around 25μg/l and the allowable standard set out by SEPA and the OSPAR standards is 119µg/l The EQS condition will thus be met if discharge plumes remain below 90µg/l. The fish farm contributions are typically smaller than the background levels, both of which fall well below the allowable standards. Again it should be noted that measured background levels will also include contributions from farm sites already operational within the Bay, which are therefore double accounted-for by the model.

5.3.2 Simulation Group 2 – Typical Phosphorus Concentration.

The second set of contour plots for Phosphorus (Figure 5.13 - Figure 5.16) relate to typical phosphorus concentrations for discharges dispersed from the Shot Head site and the combined sites during flood and ebb tides. As in the case of nitrogen, Figure 5.13 to Figure 5.16 all indicate that, under all circumstances, dispersal of phosphorus from the proposed site will have an inconsequential impact on dissolved phosphorus levels in the open waters of Bantry Bay by way of Equilibrium Concentration Enhancement, relative to the EQS. This also applies where simulations are based on a combination of the proposed site and the high level of worst-case expectation employed for combined sites operating in Bantry Bay.

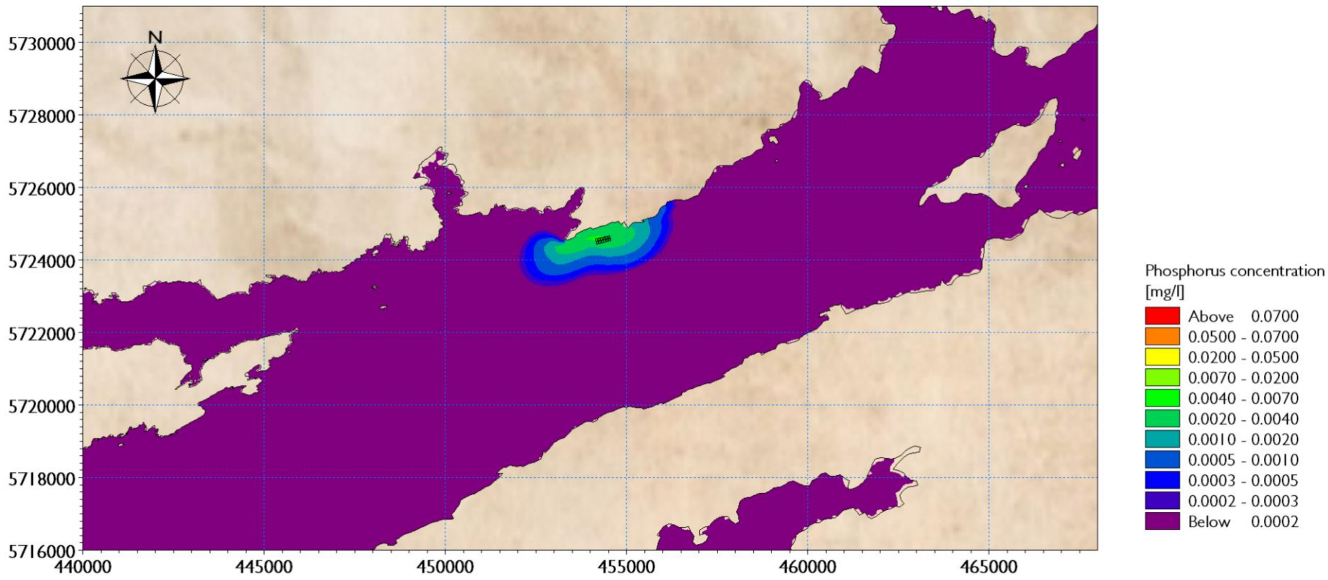


Figure 5.13: Typical Ebb Plume of Phosphorus Concentration arising from Shot Head only.

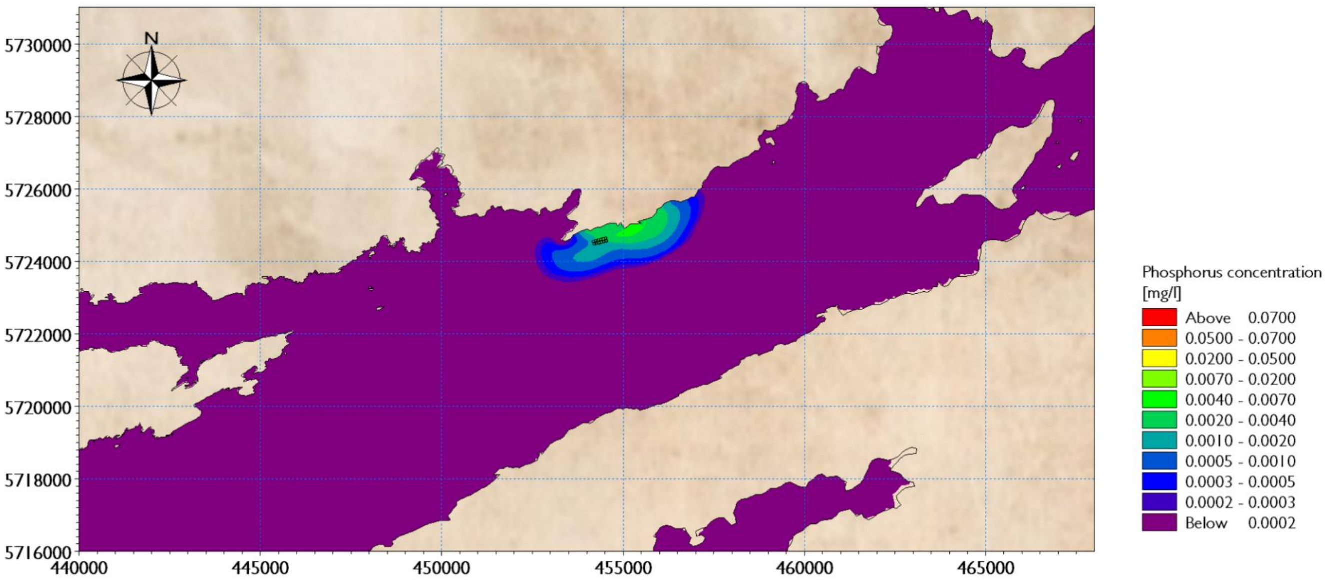


Figure 5.14: Typical Flood Plume of Phosphorus Concentration arising from Shot Head only.

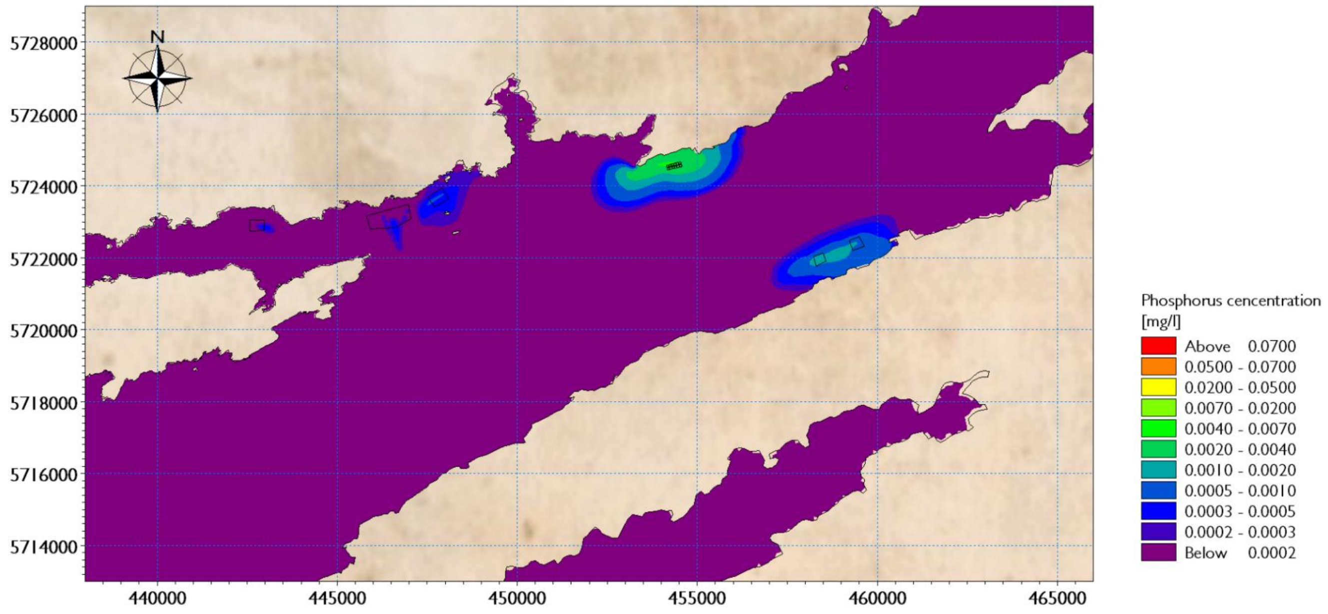


Figure 5.15: Typical Ebb Plume of combined Phosphorus Concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

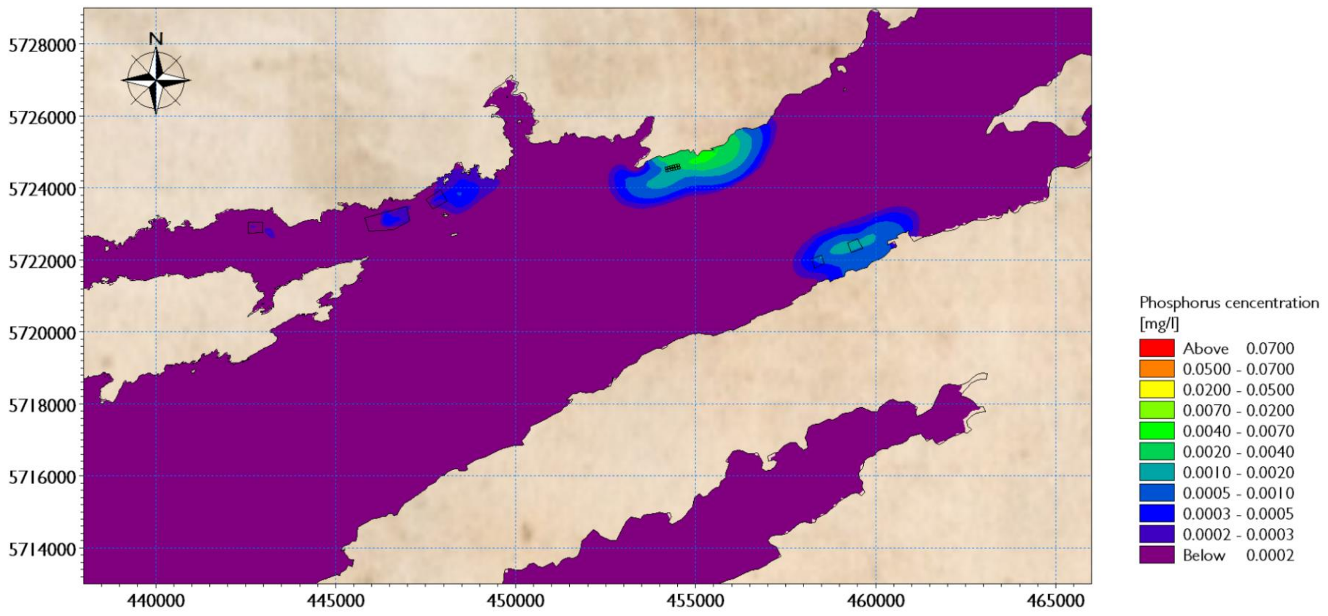


Figure 5.16: Typical Flood Plume of combined Phosphorus Concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

It should be noted that, as for Nitrogen, all Phosphorus plumes modelled demonstrate a rapid dilution of the Phosphorus discharged from the sites, to less than 0.0002mgP/l, both upstream and downstream of the area occupied by the sites. There is no tendency for farm origin P to persist in the bay. Thus, to all intents and purposes, even in the worst case, there is insignificant elevation of P concentration to the head of the bay, where P concentration can be expected to remain within its existing seasonal ambient concentration range.

5.4 BOD DISCHARGE

Biological Oxygen Demand (BOD) is the amount of oxygen used (mainly by bacteria) to assimilate the molecular components of organic waste to their most oxidised state. This is the point at which such wastes can no longer deplete ambient dissolved oxygen saturation levels. BOD emanating from salmon farms is mainly contained in the carbon and nitrogen wastes resulting from the feeding of the stock.

In a similar manner to the Nitrogen and Phosphorus loads generated by all existing and currently proposed farm sites in Bantry Bay, the Biological Oxygen Demand (BOD) load can be calculated from the contribution from Total Nitrogen and Carbon derived from the farm feed specifications and nutrient content. Again, to take the worst case, the BOD load is assumed to be fully in solution in the water column for the dispersion modelling exercise and was simulated using the advection dispersion model described in Section 4.2, with the BOD source introduced at each pen centre. The BOD loading was introduced as a conservative discharge and the simulation was run for 22 days to allow for full plume development and to cover the range of tidal conditions, from neap to spring tide. The projected loadings for BOD are given for each of the sites in Table 5.5

Neither the EU nor the SEPA standards apply EQS values for BOD in coastal waters. However, for the purposes of this study, the transitional and inland water values were assessed to give a context to the BOD arising from the proposed farming activities. The EU standards for transitional waters set an EQS value for BOD of 4mg/l on a 95%'ile basis, (i.e. may be exceeded on occasion provided this does not constitute more than 5% of the time). The UK Environment Agency (EA) / SEPA standards provide Guidance Values for inland waters; these are 3mg/l and 6mg/l where the latter may be applied in areas were less sensitive receptors are located. These are also applied on a 95%'ile basis. Dissolved oxygen saturation (DO) background values, which include the effects of the operational farm discharges, range between 8 and 10 mg/l.

Table 5.5: Total proposed BOD loading for all currently proposed and existing Bantry Bay salmon farm sites; Shot Head / Fastnet dominant.

Month	BOD5 Tonnes / month			
	Shot Head	Fastnet	Roancarrig	Waterfall
Sep	Fallow site	Fallow site	201.922	2.617
Oct			242.205	2.617
Nov	8.724	2.181	265.419	2.617
Dec	13.726	3.432	295.982	2.617
Jan	22.376	5.594	319.289	2.617
Feb	38.025	9.506	289.469	2.617
Mar	59.074	14.768	280.792	2.617
Apr	76.36	19.09	191.792	2.617
May	100.423	25.106	101.453	Fallow site
Jun	129.869	32.467	41.337	
Jul	154.566	38.641	26.052	2.617
Aug	177.282	44.32	3.672	2.617
Sep	201.922	50.48	Fallow site	2.617
Oct	242.205	60.551		2.617
Nov	265.419	66.355	8.724	2.617
Dec	295.982	73.995	13.726	2.617
Jan	319.289	79.822	22.376	2.617
Feb	289.469	72.367	38.025	2.617
Mar	280.792	70.198	59.074	2.617
Apr	191.792	47.871	76.36	2.617
May	101.453	25.363	100.423	Fallow site
Jun	41.337	10.334	129.869	
Jul	26.052	6.513	154.566	2.617
Aug	3.672	0.918	177.282	2.617
Sep	Fallow site	Fallow site	201.922	2.617
Oct			242.205	2.617
Nov	8.724	2.181	265.419	2.617
Dec	13.726	3.432	295.982	2.617
Jan	22.376	5.594	319.289	2.617
Feb	38.025	9.506	289.469	2.617
Mar	59.074	14.768	280.792	2.617
Apr	76.36	19.09	191.792	2.617
May	100.423	25.106	101.453	Fallow site
Jun	129.869	32.467	41.337	
Jul	154.566	38.641	26.052	2.617
Aug	177.282	44.32	3.672	2.617
Sep	201.922	50.48	Fallow site	2.617
Oct	242.205	60.551		2.617
Nov	265.419	66.355	8.724	2.617
Dec	295.982	73.995	13.726	2.617
Jan	319.289	79.822	22.376	2.617
Feb	289.469	72.367	38.025	2.617
Mar	280.792	70.198	59.074	2.617
Apr	191.792	47.871	76.36	2.617
May	101.453	25.363	100.423	Fallow site
Jun	41.337	10.334	129.869	
Jul	26.052	6.513	154.566	2.617
Aug	3.672	0.918	177.282	2.617

The results for the BOD simulations are presented in the same format as the previous simulations, as follows.

5.4.1 Simulation Group 1 – Maximum & Average BOD Concentration

The first set of contour plots, given in Figure 5.17 to Figure 5.20 give the maximum and average BOD concentration simulations for the Shot Head site only and for combined-site BOD discharges respectively. As with previous discharge simulations, the combined sites outputs relate to the dominance of the Shot Head and Fastnet sites (year 2 of growth cycle) as highlighted in Figure 5.5. Roancarrig / Ahabeg-dominant outputs are given in the related Waterfall report[2]. Since the Shot Head and Fastnet sites are the further upstream, the plots indicate the greatest likely impacts from all existing and currently proposed salmon farm sites towards the head of the bay. The Maximum Concentration Plume Envelope plots give the maximum value recorded within each nominal 20m^2 cell during the entire simulation period, however short-lived, whilst the Average Concentration Plume Envelope plots indicate the average value in each cell over the simulation period.

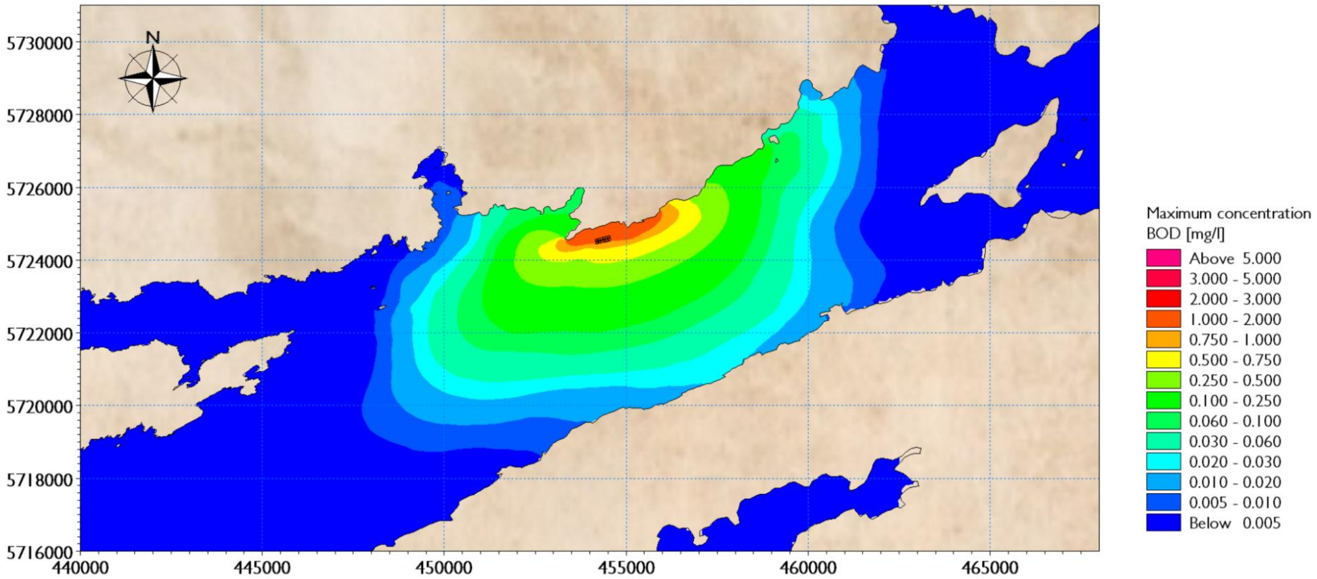


Figure 5.17: Maximum Plume Envelope of BOD Concentration arising from the Shot Head site only

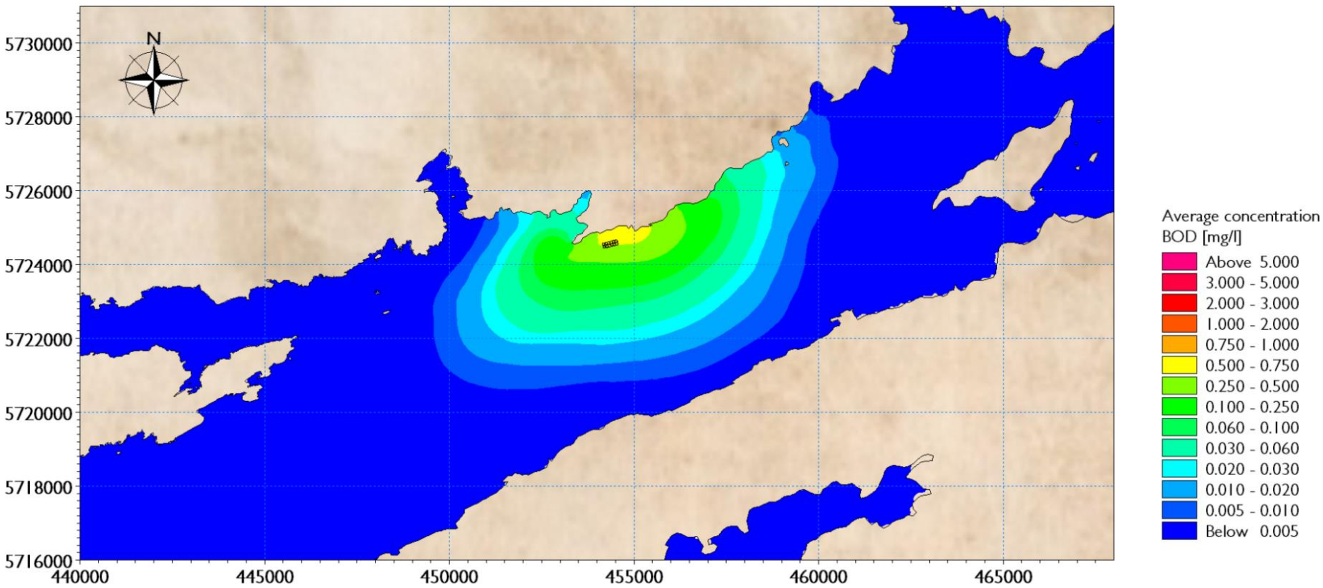


Figure 5.18: Average BOD Concentration arising from the Shot Head site only.

2 IBE0744_R06_Rev01_NS_WaterfallWQ (1), RPS Consulting Engineers Belfast October 2015.

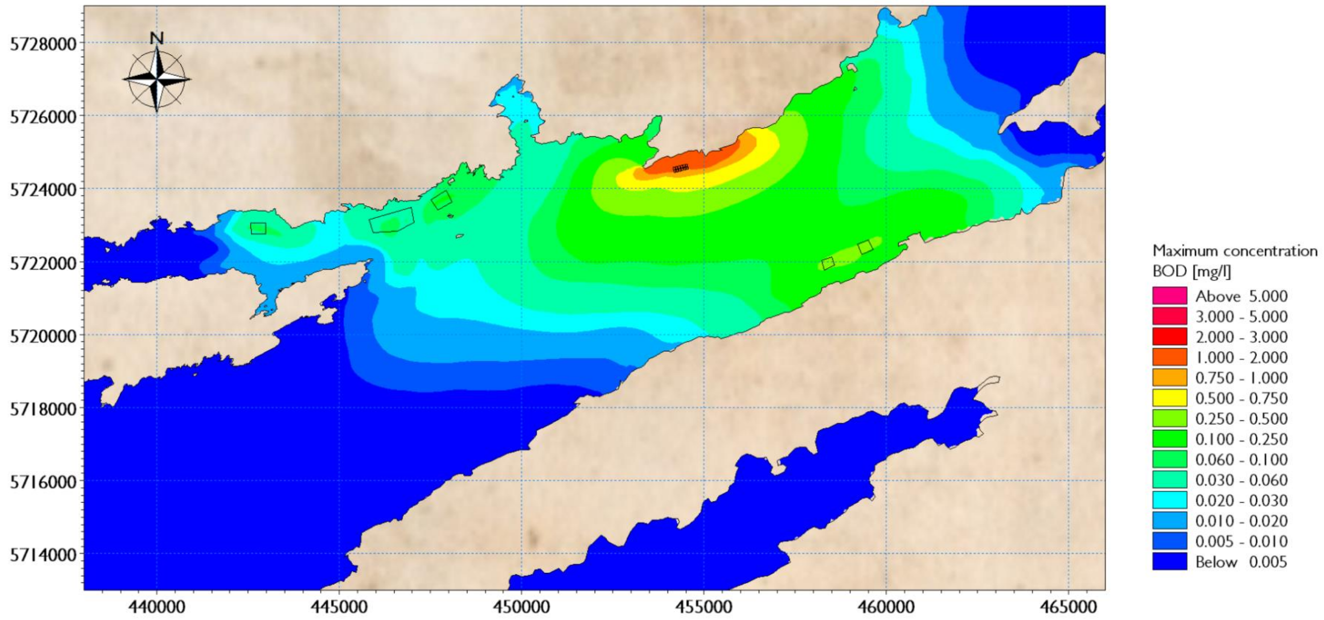


Figure 5.19: Maximum Plume Envelope of combined BOD Concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

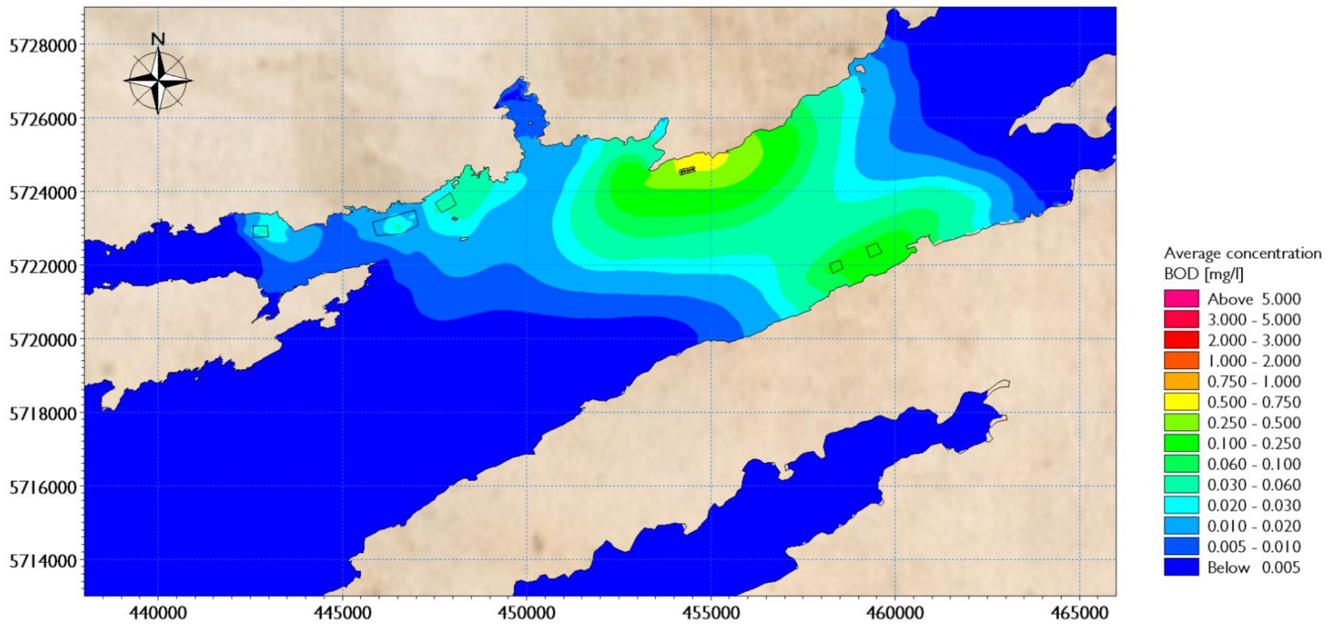


Figure 5.20: Average combined BOD Concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

In all cases, even in the combined sites scenario, the BOD remains below 2mg/l and well within the set Environmental Quality Standards, even close to its sources, both for the Shot Head site only for the combined sites scenario. It should be noted that, should a statistical analysis be carried out to remove the 5% highest values for direct comparison with the guidance, then the margin by which the standards are met would be much greater.

5.4.2 Simulation Group 2 – Typical BOD Concentration.

The second set of contour plots (Figure 5.21 - Figure 5.24) relate to typical BOD levels for discharges dispersed from Waterfall and the combined sites during ebb and flood tides.

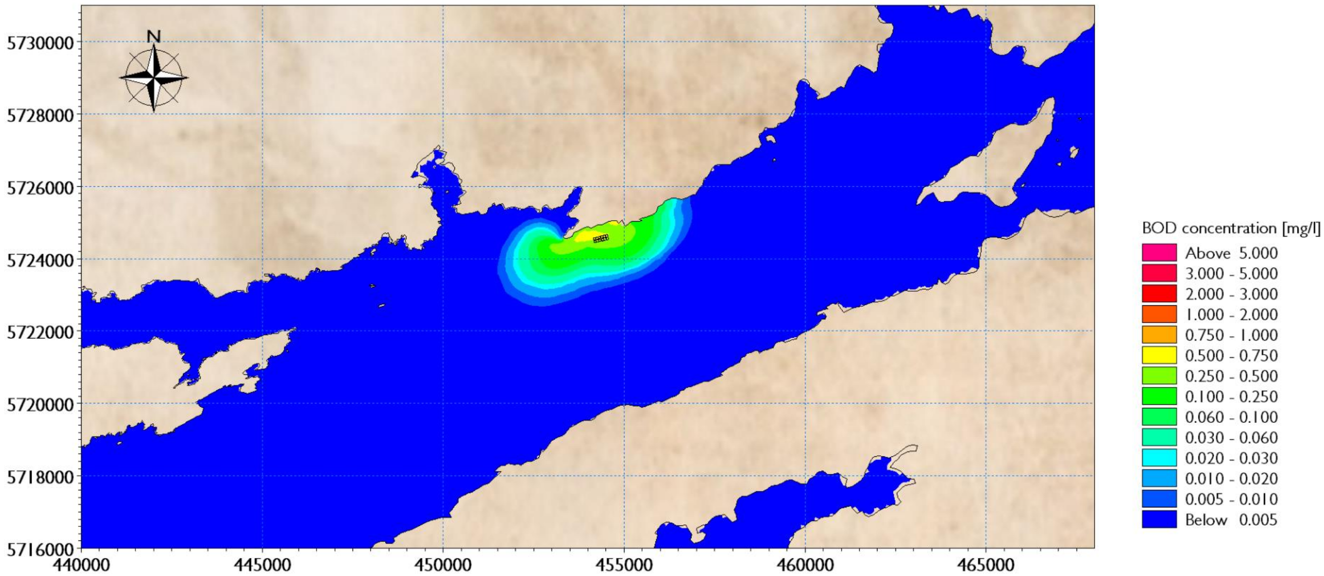


Figure 5.21: Typical Ebb Plume of BOD Concentration arising from the Shot Head site only.

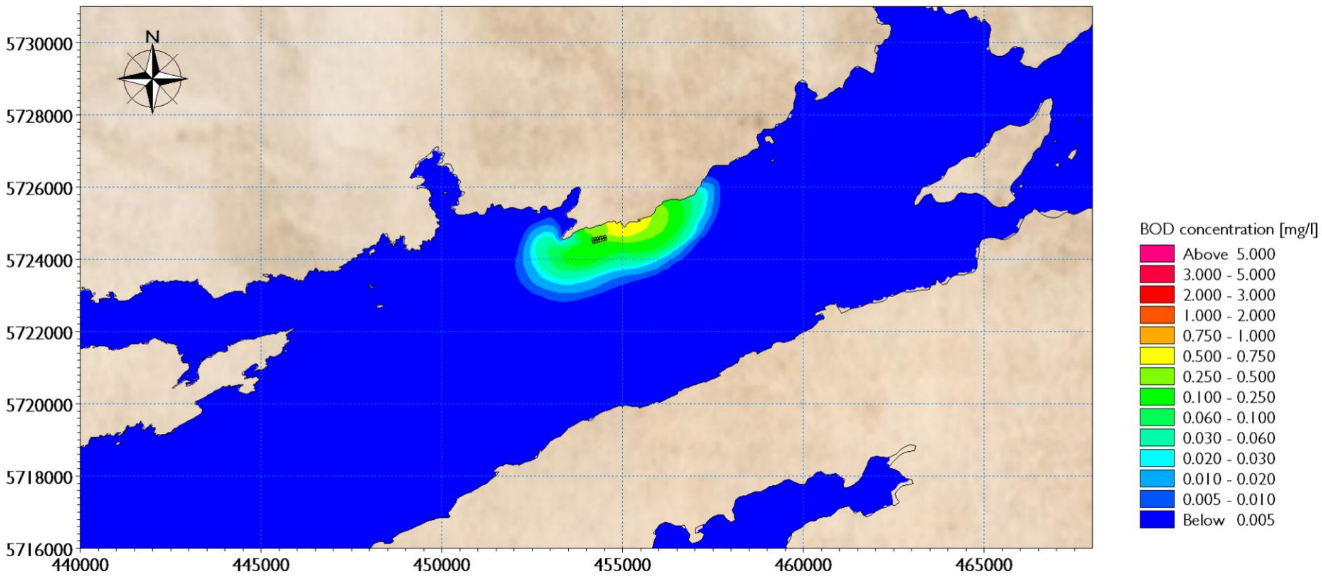


Figure 5.22: Typical Flood Plume of BOD Concentration arising from the Shot Head site only.

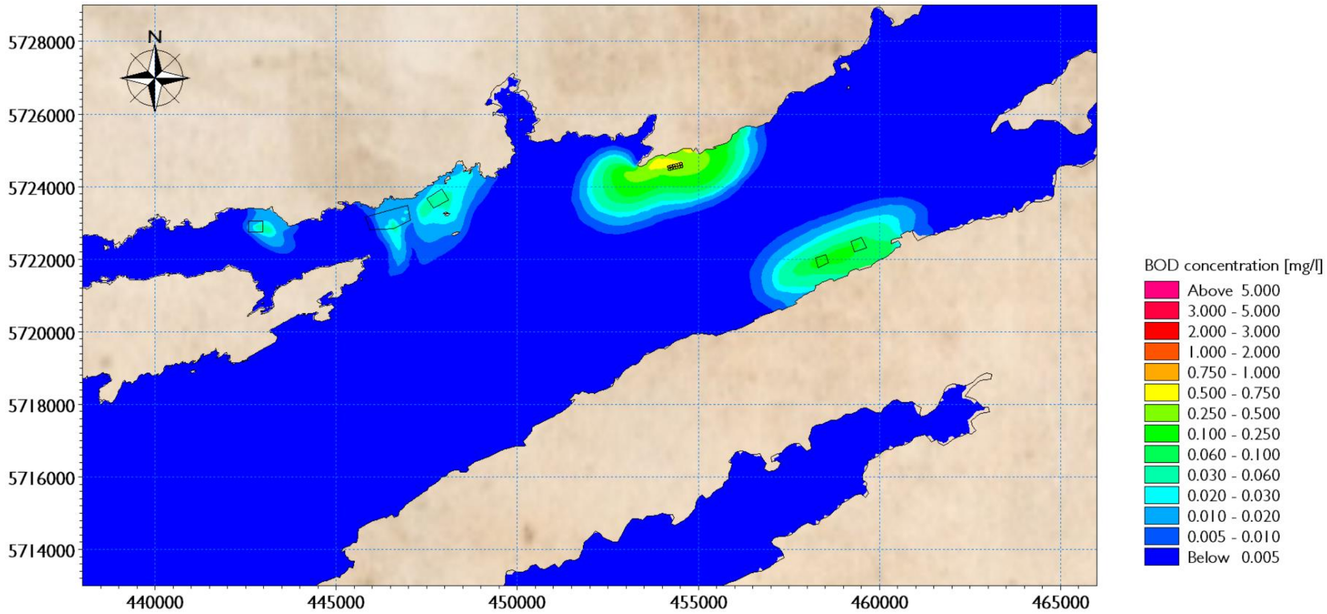


Figure 5.23: Typical Ebb Plume of combined BOD Concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

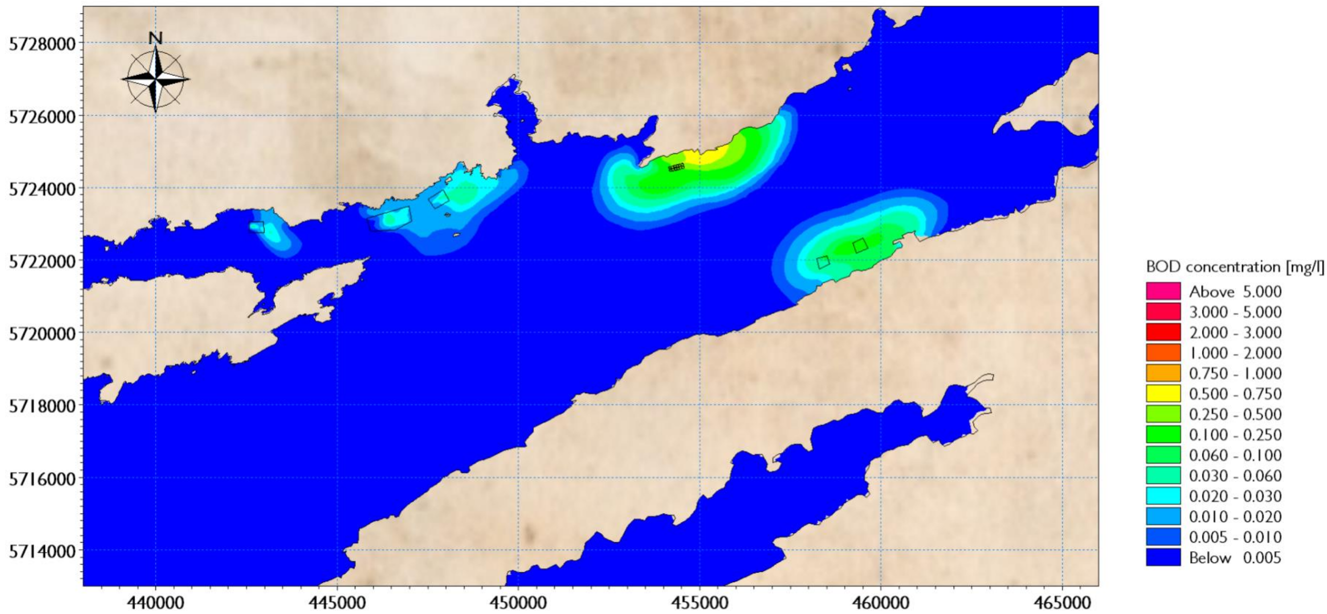


Figure 5.24: Typical Flood Plume of combined BOD Concentration arising from all currently proposed and existing Bantry Bay sites - January, year 2 - Shot Head / Fastnet dominant.

As with the preceding parameters, the typical discharged BOD concentration values are around one quarter of those observed in the maximum concentration plots. In all cases, including the combined discharges, concentrations remain below 1mg/l. In addition, it is observed that there is no cumulative interaction between the plumes from any of the existing or currently proposed site groups. It is further noted that, as for Nitrogen and Phosphorus, the BOD plumes modelled demonstrate a rapid dilution of the BOD discharged from the sites, to less than 0.005mg/l, both upstream and downstream of the area occupied by the sites. There is no tendency for farm origin BOD to persist in the bay. Thus, to all intents and purposes, even in the worst case, there is no evidence that BOD discharges will have any significant impact on dissolved oxygen saturation concentration at the head of the bay, where DO saturation can be expected to remain within its existing seasonal ambient concentration range.

5.5 SETTLEABLE SOLIDS.

The settleable solids discharged from fish farm sites comprise two components:-

- Salmon faeces.
- Waste feed pellets.

Particles of both these components may be dispersed variable distances and may or may not settle to the seabed, depending on their settlement velocities and the current regime to which they are subjected. Solids settlement modelling is required to ascertain the degree and extent of settlement and the consequential impact on benthic communities in the vicinity of the proposed site. SEPA standards use a method to calculate the effects of settled solids on the benthic community over a period of one year known as the Infaunal Trophic Index (ITI). The basis of ITI calculation is the classification of the organisms found in the seabed in terms of their population density and the classification of the feeding (trophic) group into which they fall. A fuller explanation of ITI can be found in Section 2.9 of the main EIS document for Shot Head. Figure 5.25 below shows the relationship between solids settlement and ITI. An ITI of between 30 and 60 is indicative of an altered benthic community; ITI values above 60 indicate an unaltered benthic community and therefore absence of impact, whilst values below 30 indicate a degraded benthic community, a result of high impact.

Some organic loading and consequent benthic degradation in the immediate locality of the farm (i.e. directly beneath the pens) is regarded as acceptable by the regulatory authorities. SEPA applies a biological EQS within an Allowable Zone of Effect (AZE), which is set as a contour, bounding an area of ITI < 30. The shape of the AZE is site specific, as bathymetry and tidal currents vary between sites, but it is taken to be represented by an area within a boundary line running 25m beyond the footprint of the fish pens. This method was commonly used before the introduction of DEPOMOD depositional modelling software by SEPA but it was thought to be over-simplistic given that sedimentation, when it occurs, does so in an elongated form, stretching in the direction of the dominant current direction[3]. In the application of SEPA EQS's either a near-field or a far-field AZE is now applied as required, the former being equivalent to an area bounded by a line 25m beyond the pen footprint and the latter being equivalent to an area bounded by a line 100m beyond the pen footprint.

3 ADRIS (1991). Report of the ADRIS Technical Group on the Monitoring of Caged Fish Farms. Part 1: Current Practice. Unpublished Report. Association of Directors and river Inspectors of Scotland. Dumfries.

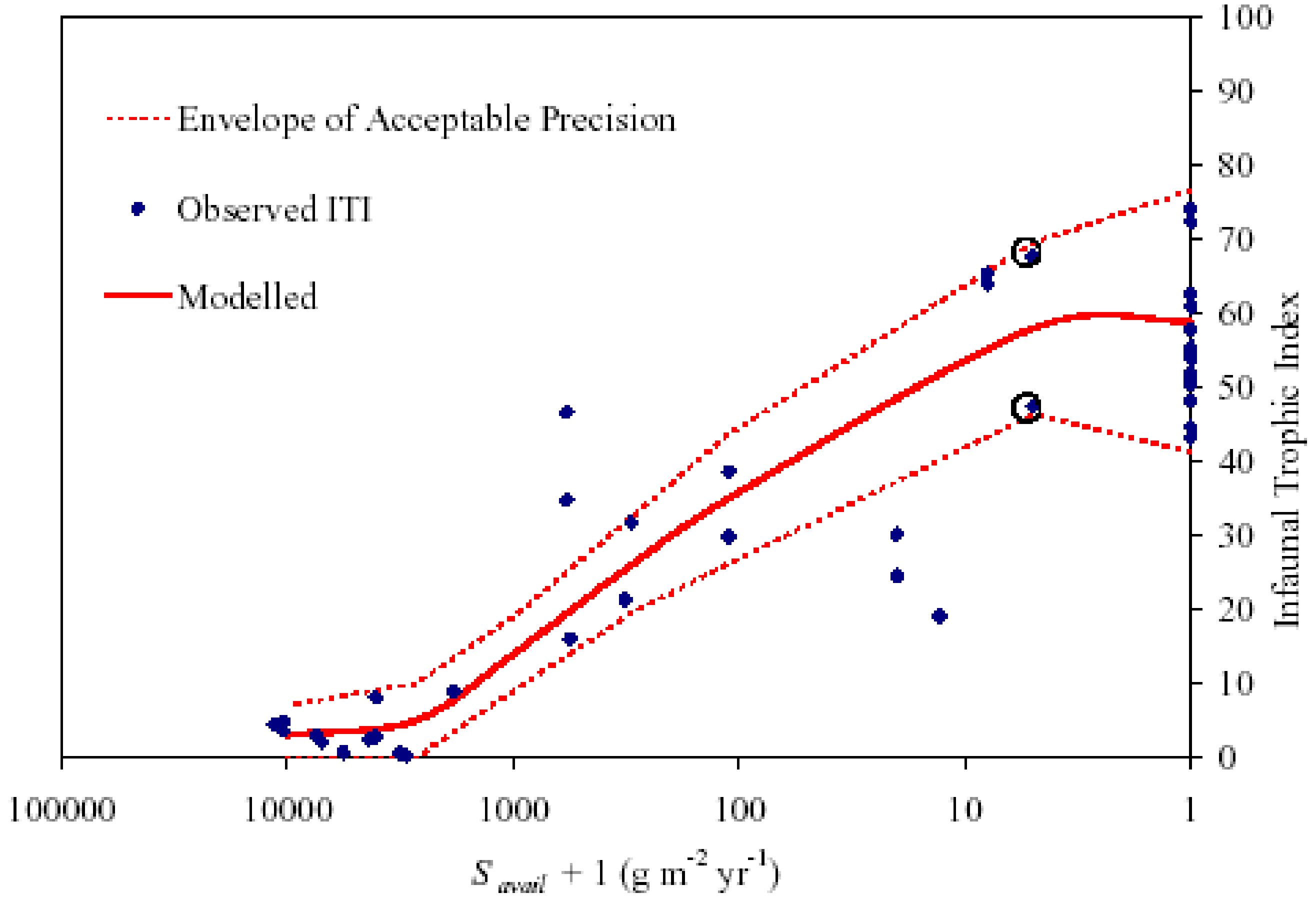


Figure 5.25: Infaunal Trophic Index - Source SEPA Fish Farm Manual, Annex H, 2005

The amount of faeces discharged by a salmon farm site is dependent on the biomass of the stock held and the Feed Conversion Rate (FCR), which itself is dependant of many factors, including the mean fish weight, amount of feed supplied and the feed formulation and digestibility. Of the feed supplied an estimated 97% is consumed by the fish whilst the remaining 3% is uneaten and wasted directly to the environment. Given figures for FCR, which are abstracted from historical production data, along with manufacturers' data on whole feed digestibility (85.32%) and feed water content (5%), the dry weight loading of faeces that arises from all existing and currently proposed sites in the bay may be calculated on a monthly basis, as shown in Table 5.6, abstracted from the production and discharge models for the sites (see Section 4 of the Shot Head EIS document). For the present study, a settling velocity for faecal particles of 0.032m/sec is used, as recommended by SEPA.

The quantity of uneaten (waste) feed pellets discharged from the site can be estimated as 3% of the total feed fed. The loading calculated to arise from waste feed throughout the farming cycle is given on a monthly basis in Table 5.6, alongside faecal loadings. The settling properties of the feed pellets are dependent on the feed pellet shape, size and density. For the first 12 months of each cycle a range of pellet sizes is used, increasing from 3 - 9mm. For the remainder of the production period (including the pre-harvest period) only 12mm pellets are used. Each of the pellets has an associated settling velocity, examples are given below.

9mm pellets - 0.12246m/s
12mm pellets - 0.15554m/s

Note that the waste arising from the Waterfall harvest site is of a much smaller magnitude than for all other sites in the bay, which are production sites. This is because stock at the Waterfall site will, even at worst case, only be fed on maintenance rations or will, otherwise, not be fed, to clear the gut prior to harvest.

Table 5.6: Total projected Settleable Solids for all existing and currently proposed salmon farm sites in Bantry Bay.

Month	Settleable Solids Tonnes / month							
	Shot Head		Fastnet		Roancarrig		Waterfall	
	Feed waste	Faecal waste	Feed waste	Faecal waste	Feed waste	Faecal waste	Feed waste	Faecal waste
Sep	Fallow site		Fallow site		7.93	41.52	0.1	0.54
Oct					9.52	49.8	0.1	0.54
Nov	0.53	2.86	0.13	0.72	10.43	54.57	0.1	0.54
Dec	0.84	4.5	0.21	1.13	11.63	60.86	0.1	0.54
Jan	1.27	7.04	0.32	1.76	12.55	65.65	0.1	0.54
Feb	1.89	10.49	0.47	2.62	11.38	59.52	0.1	0.54
Mar	2.66	14.77	0.66	3.69	11.03	57.73	0.1	0.54
Apr	3.44	19.09	0.86	4.77	7.52	39.37	0.1	0.54
May	4.35	24.77	1.09	6.19	3.99	20.86	Fallow site	
Jun	5.52	31.43	1.38	7.86	1.62	8.5		
Jul	6.48	36.86	1.62	9.22	1.02	5.36	0.1	0.54
Aug	6.97	36.45	1.74	9.11	0.14	0.75	0.1	0.54
Sep	7.93	41.52	1.98	10.38	Fallow site		0.1	0.54
Oct	9.52	49.8	2.38	12.45			0.1	0.54
Nov	10.43	54.57	2.61	13.64	0.53	2.86	0.1	0.54
Dec	11.63	60.86	2.91	15.21	0.84	4.5	0.1	0.54
Jan	12.55	65.65	3.14	16.41	1.27	7.04	0.1	0.54
Feb	11.38	59.52	2.84	14.88	1.89	10.49	0.1	0.54
Mar	11.03	57.73	2.76	14.43	2.66	14.77	0.1	0.54
Apr	7.52	39.37	1.88	9.84	3.44	19.09	0.1	0.54
May	3.99	20.86	1	5.22	4.35	24.77	Fallow site	
Jun	1.62	8.5	0.41	2.12	5.52	31.43		
Jul	1.02	5.36	0.26	1.34	6.48	36.86	0.1	0.54
Aug	0.14	0.75	0.04	0.19	6.97	36.45	0.1	0.54
Sep	Fallow site		Fallow site		7.93	41.52	0.1	0.54
Oct					9.52	49.8	0.1	0.54
Nov	0.53	2.86	0.13	0.72	10.43	54.57	0.1	0.54
Dec	0.84	4.5	0.21	1.13	11.63	60.86	0.1	0.54
Jan	1.27	7.04	0.32	1.76	12.55	65.65	0.1	0.54
Feb	1.89	10.49	0.47	2.62	11.38	59.52	0.1	0.54
Mar	2.66	14.77	0.66	3.69	11.03	57.73	0.1	0.54
Apr	3.44	19.09	0.86	4.77	7.52	39.37	0.1	0.54
May	4.35	24.77	1.09	6.19	3.99	20.86	Fallow site	
Jun	5.52	31.43	1.38	7.86	1.62	8.5		
Jul	6.48	36.86	1.62	9.22	1.02	5.36	0.1	0.54
Aug	6.97	36.45	1.74	9.11	0.14	0.75	0.1	0.54
Sep	7.93	41.52	1.98	10.38	Fallow site		0.1	0.54
Oct	9.52	49.8	2.38	12.45			0.1	0.54
Nov	10.43	54.57	2.61	13.64	0.53	2.86	0.1	0.54
Dec	11.63	60.86	2.91	15.21	0.84	4.5	0.1	0.54
Jan	12.55	65.65	3.14	16.41	1.27	7.04	0.1	0.54
Feb	11.38	59.52	2.84	14.88	1.89	10.49	0.1	0.54
Mar	11.03	57.73	2.76	14.43	2.66	14.77	0.1	0.54
Apr	7.52	39.37	1.88	9.84	3.44	19.09	0.1	0.54
May	3.99	20.86	1	5.22	4.35	24.77	Fallow site	
Jun	1.62	8.5	0.41	2.12	5.52	31.43		
Jul	1.02	5.36	0.26	1.34	6.48	36.86	0.1	0.54
Aug	0.14	0.75	0.04	0.19	6.97	36.45	0.1	0.54

Solids discharges were simulated using separate point discharge sources for the feed and faeces, located at the centre of each pen and at mid-pen depth, with the appropriate release rate and settlement characteristics. At Waterfall and Fastnet, where 6 pens are proposed, a total of 12 sources were used at each site whilst at the other sites in the bay, where 12 pens are used / proposed, a total of 24 sources were used, i.e. one source per pen relating to feed and a second relating to faeces. The modelling approach used was by particle tracking as outlined in Section 4.1. A period of 22 days was simulated to cover all tidal conditions. A worst-case scenario was adopted in that the discharged solids are treated as conservative throughout the simulation and no allowances are made for their biological decomposition or assimilation by the local epifauna and infauna, whilst both take place naturally in such circumstances.

The hydrodynamic model that forms the basis of the model is 2-dimensional. However (as with all the simulations in this study) a parabolic velocity profile has been adopted to improve the simulation of conditions within Bantry Bay, as near-bed velocities are clearly important in sediment deposition. The re-suspension of sediment was controlled using the critical shear stress associated with the material properties.

It should be noted that the values for sedimentation and deposition used by SEPA should be compared with those values measured on site. The critical re-suspension speed used by DEPOMOD is 0.095m/sec whilst the critical deposition speed is 0.045m/sec (measured 1.8m from the seabed). From the results presented previously in the model verification section, (Section 3.5), it can be seen that both the modelled and measured current speeds across the Shot Head site and for much of the main body of Bantry Bay are of low magnitude. As a result, current speeds remain below those required to maintain suspension of solids for much of the tidal cycle. Equally, this also indicates that re-suspension of settled material would be unlikely to occur. The results from the settleable solids simulations are given in the following section. The model also indicates that no in-combination effects between sites in terms of solids sedimentation will occur and therefore only Shot Head results are presented in this report.

The following two plots, Figure 5.26 and Figure 5.27, show the sedimentation depth at the end of a simulation following one month with the maximum stocking density. It can be seen that, both figures are very similar. This shows that, as anticipated, the solids have settled in the vicinity of the pens and have not become resuspended. It should be noted that even directly under the pens, the accumulation depth is relatively small when compared with other (low current) sites; this is due to the low stocking density, at a maximum of 10kg/m^3, required by the organic standard, within the large 126m diameter pens.

Although the model results demonstrate that the distribution of suspended solids will be limited, as the waste falls to the bed, the results relating to suspended sediment concentration are presented here for completeness. Two regions of the water column are investigated, firstly, the 0.5m closest to the bed was considered and secondly, the water column as a whole. The former is of importance when looking at the impact on seabed flora and fauna such as mussel beds. The latter is of importance when considering more general water quality parameters such as turbidity and the impact on fishing.

The maximum and average concentrations in the near bed region are shown in Figure 5.28 and Figure 5.29 respectively. The maximum plots illustrate the maximum concentration experienced within each 30m model cell over the one month period and therefore these levels may not occur instantaneously. Similarly Figure 5.30 and Figure 5.31 across the entire water column. These figures illustrate that the concentrations are limited as the settling occurs relatively quickly, due to the low current speed and particles do not remain in suspension for a sustained period.

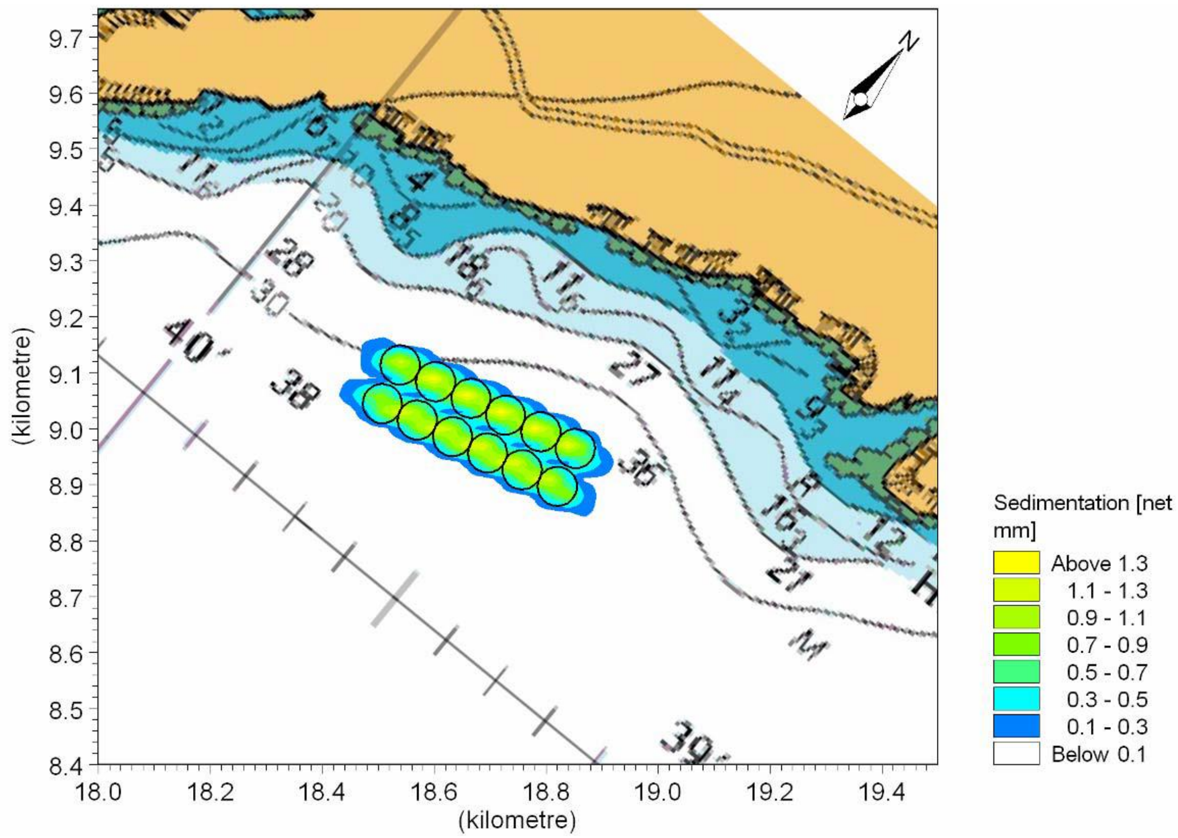


Figure 5.26: Sedimentation following month of greatest stocking level

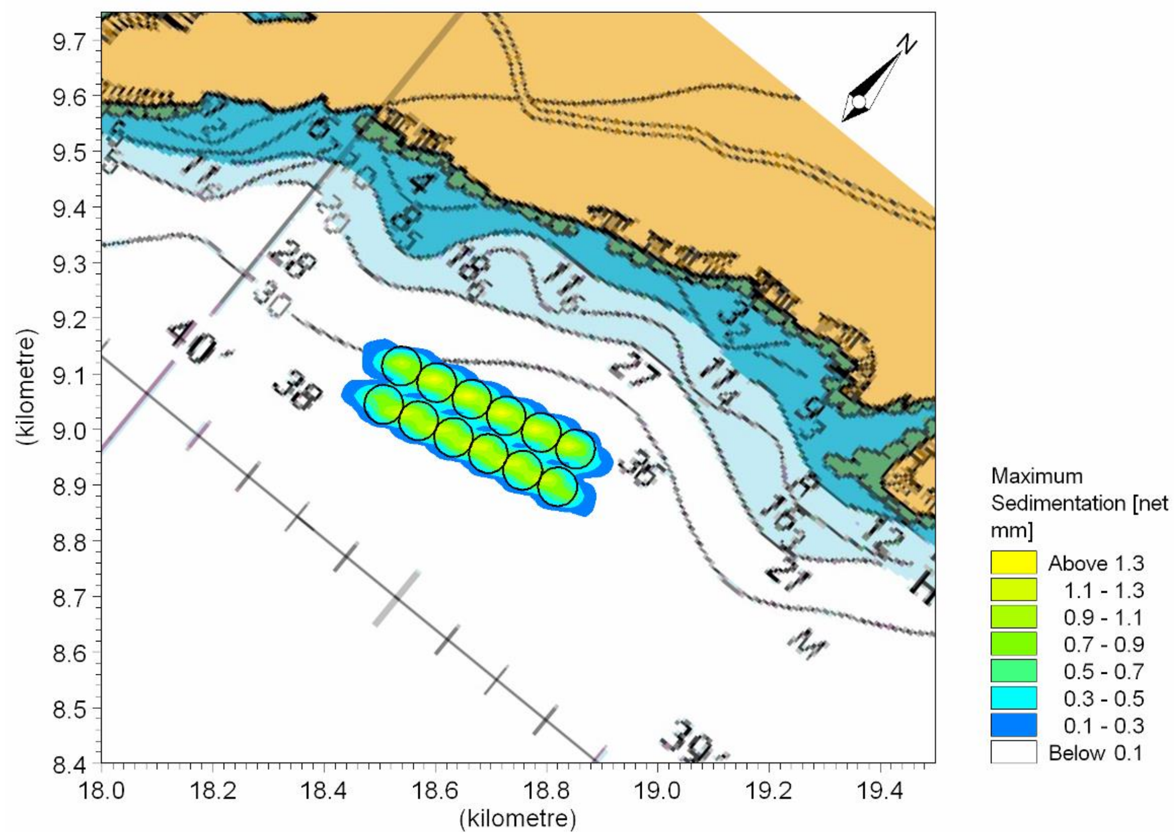


Figure 5.27: Maximum sedimentation during month of greatest stocking level

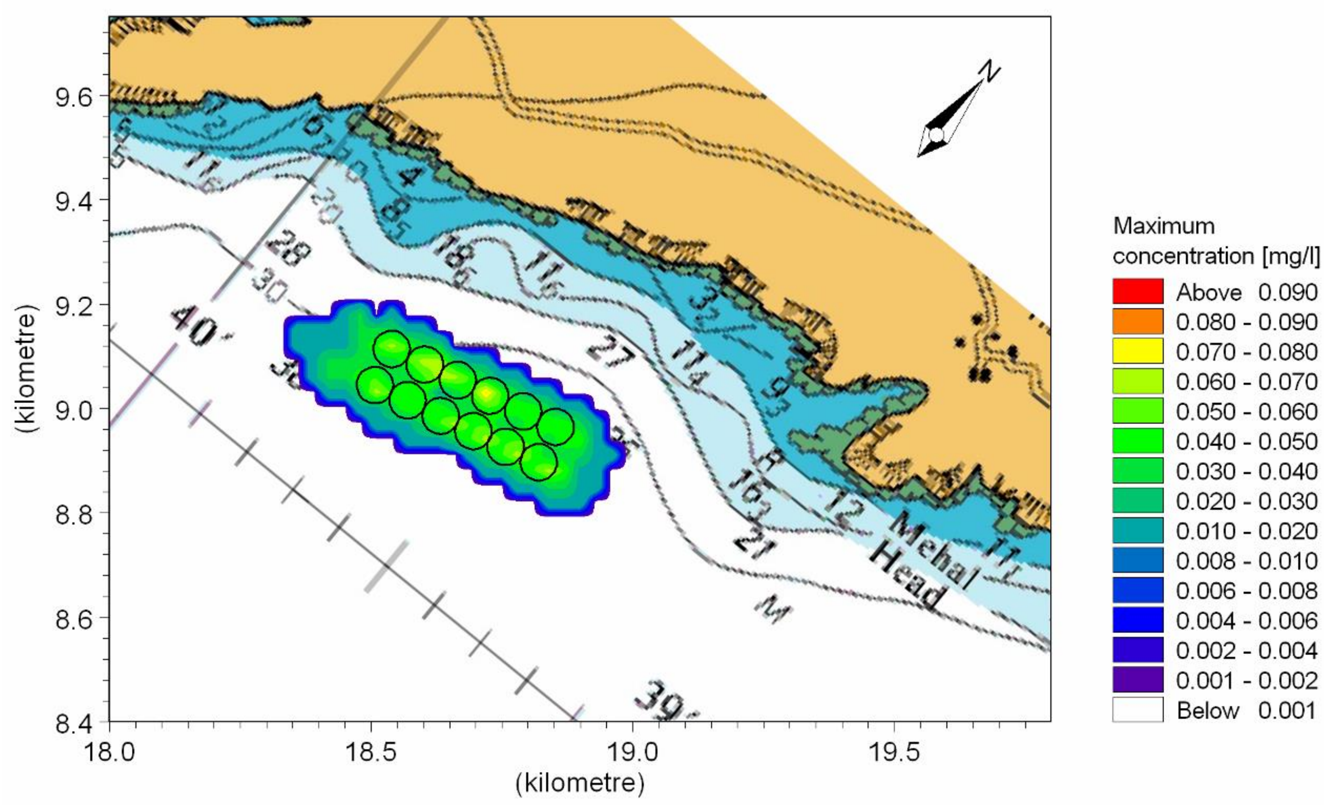


Figure 5.28: Maximum concentration near bed during month of greatest stocking level

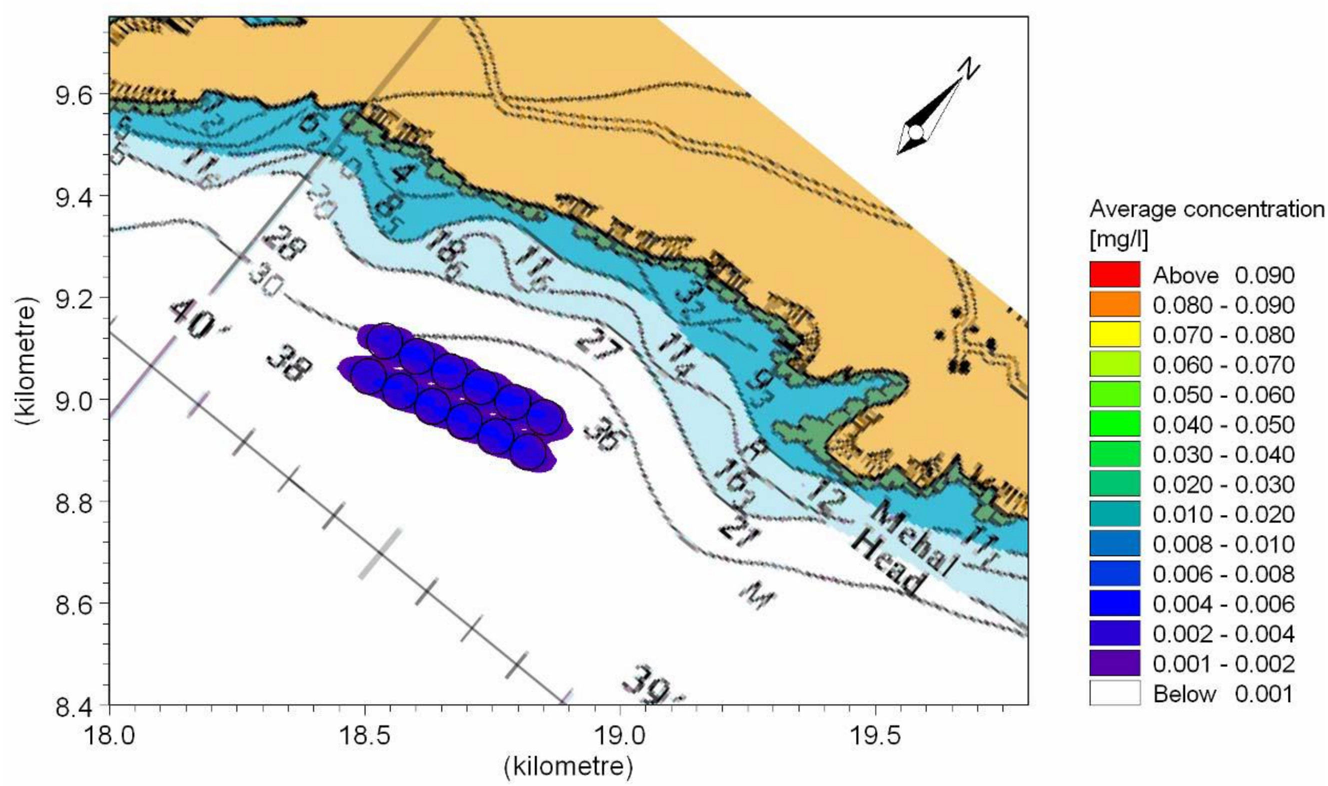


Figure 5.29: Average concentration near bed during month of greatest stocking level

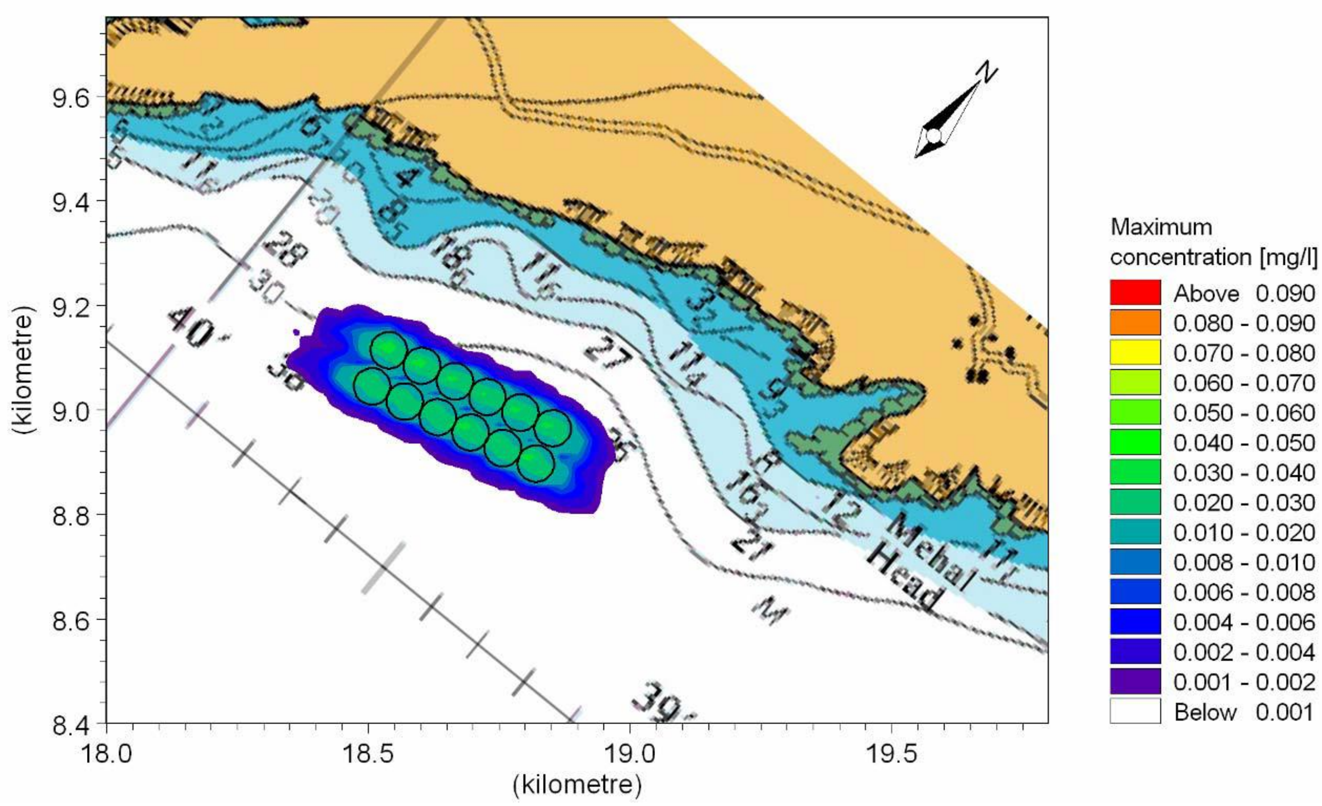


Figure 5.30: Maximum concentration through water column during month of greatest stocking level

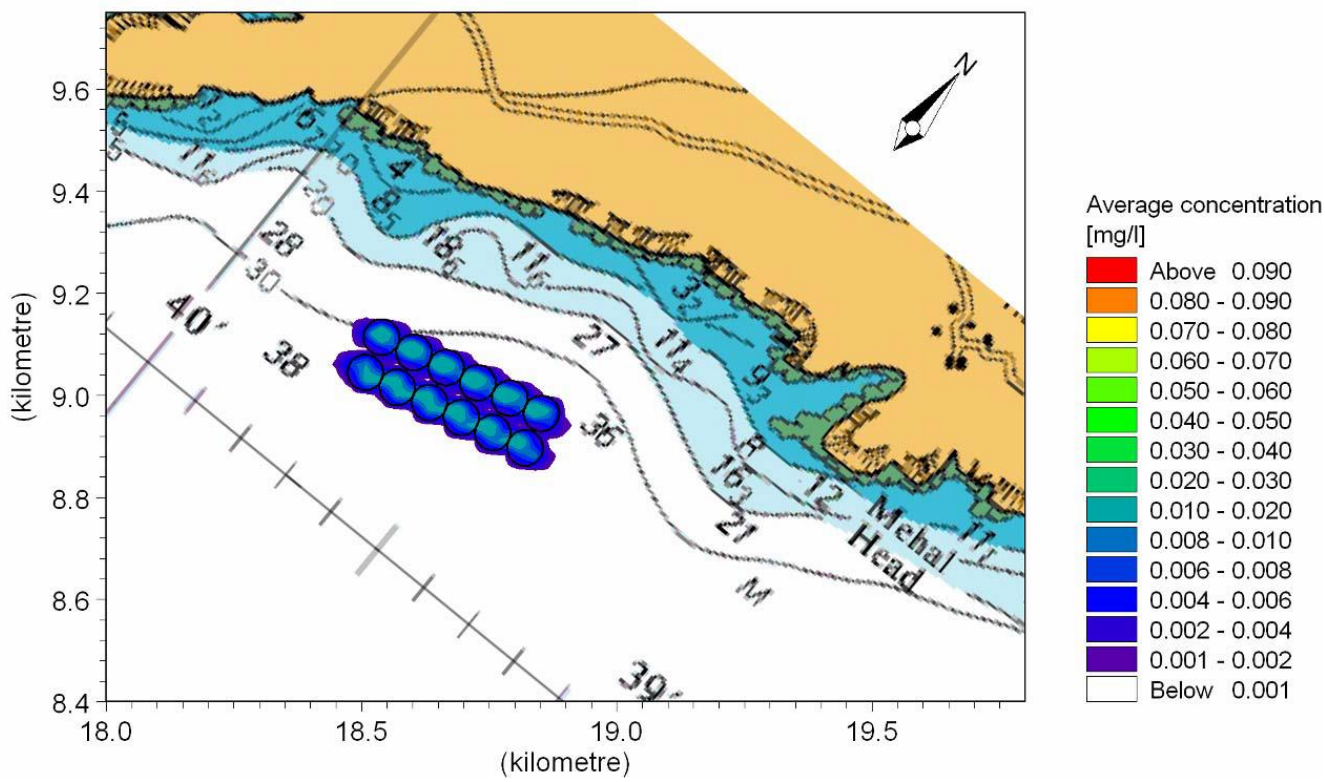


Figure 5.31: Average concentration through water column during month of greatest stocking level

The results of the settlement modelling for the month of maximum stocking density were scaled to represent a full year of the farming cycle. It should be noted that the scaling applied used a period of 12 consecutive months with the highest waste production given by Table 5.6, providing a 'worst case' scenario. In reality a more typical year may include periods where the production is winding down or the site is completely fallow. The scaling also retained the conservative assumption that material deposited would not degrade or be drawn into the bed sediments and taken up by opportunist species; this in reality would be the case and indeed the site is likely to be 'clean' following the fallow periods.

The ITI criteria outlined in Figure 5.25 were applied to the model results and the area for which the ITI was less than 30 was identified. Figure 5.32 shows this region shaded in grey; it also indicates the near-field AZE (hatched in black) the outline of the far-field AZE (dashed line). This indicates that the majority of the deposition occurs within the AZE's and is, as anticipated, elongated in the direction of the principle tidal flows. Figure 5.33 shows sedimentation depth which these areas may undergo. The 25m buffer is shown by the dashed line and the deposition beyond this limited is less than 2mm over the hypothetical worst case one year period. Indeed, under these hypothetical conditions, the peak sediment depth reached even under the centres of the pens is only 13mm. Figure 5.33 clearly demonstrates that deposition from the site would have a minimal or insignificant impact on benthic communities beyond the immediate vicinity of the pens themselves.

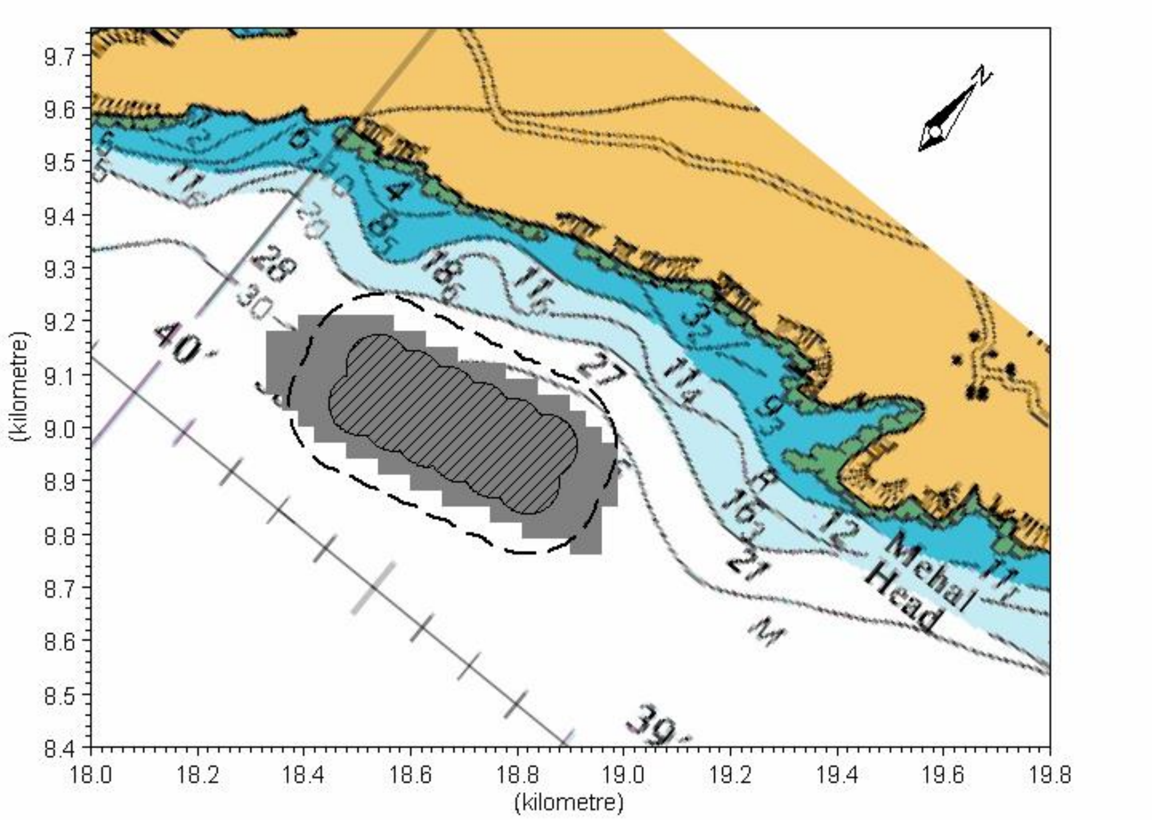


Figure 5.32: Area of AZE outline versus area ITI < 30 (far-field indicated by dashed line)

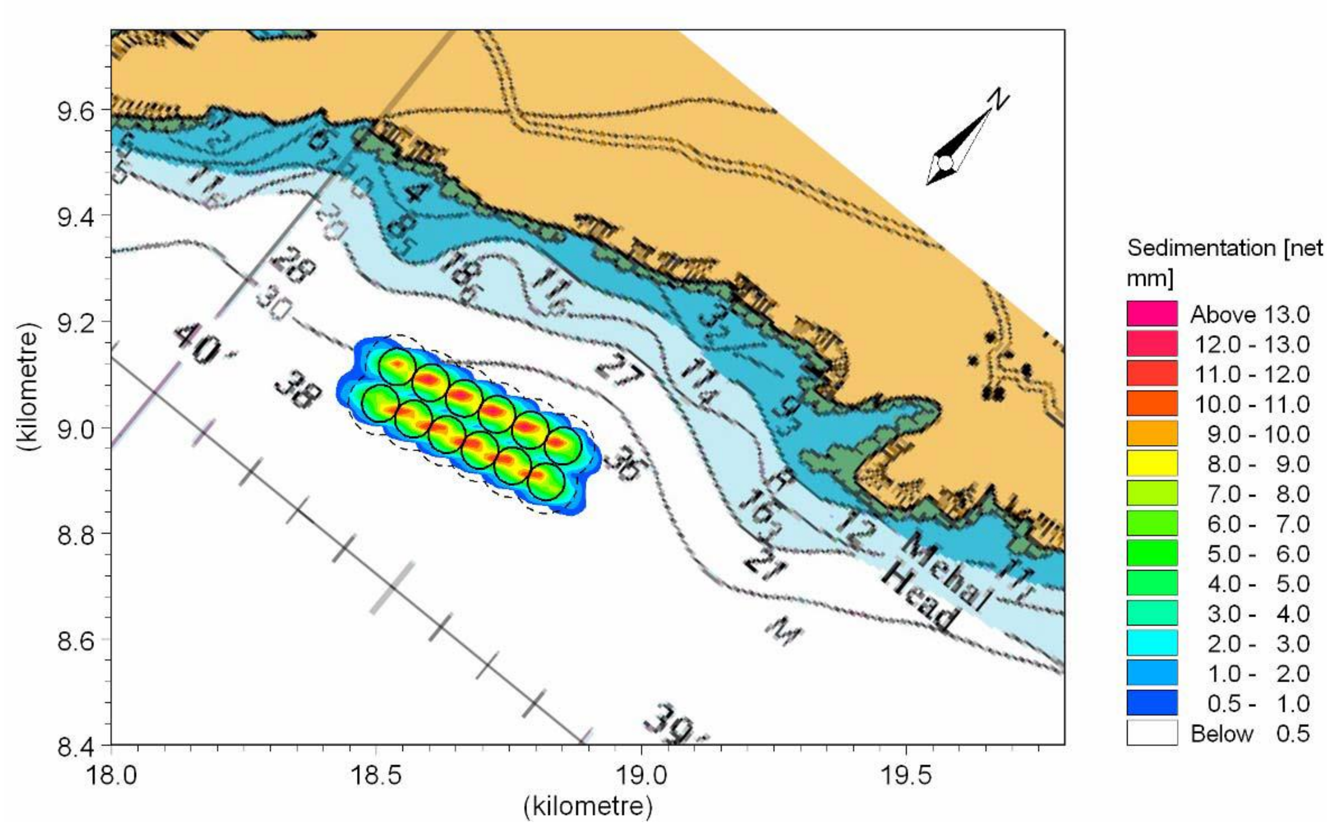


Figure 5.33: Sedimentation following operation for one year (worst case)

4.3 WAVE INDUCED TRANSPORT

Given the low tidal current speeds at the proposed site, the mechanism by which material is most likely to be dispersed is due to wave action. Two aspects of the impact of waves at the site were considered, firstly an examination of the conditions under which deposited material may become re-suspended and secondly the impact of the wave climate on the settling of material as it passes down through the water column. For both investigations the wave climate assessment carried out by RPS on the Shot Head site in 2009 (IBE0368/AKB/Bantry) was used as the primary source of wave climate data.

An analysis of wave characteristics using the horizontal wave equation showed that, for this water depth, a wave with a period of approximately 7 seconds with a significant wave height of 2m would be required to re-suspend material from the bed. This would more commonly occur under the influence of swell waves. The average wave climate at the site showed that such swell conditions would occur for around 15% of the time in summer and in excess of 30% of the time in winter. Modelling was then undertaken to assess the excursion of particles which may be resuspended by such wave action and transported by subsequent tidal flows.

Particle tracking was carried out by releasing a neutrally buoyant particle at each cage centre and plotting the course of the particle over the following 96 hours. A series of particle releases were carried out to examine the excursion of the particles during spring and neap tides and also with the release at different tidal stages. Figure 5.34 and Figure 5.35 show the results for the particle releases which travelled furthest from the site under the influence of the tide alone, that is at high water and low water during spring tide. It can be seen that the limited tidal current speeds mean that particles do not travel a great distance before being carried back on the returning tide. In reality, the particles are unlikely to stay in suspension for this 96-hour period and will be re-deposited on the sea bed at some point along the trajectory, unless the wind or wave conditions influence the current magnitude or direction.

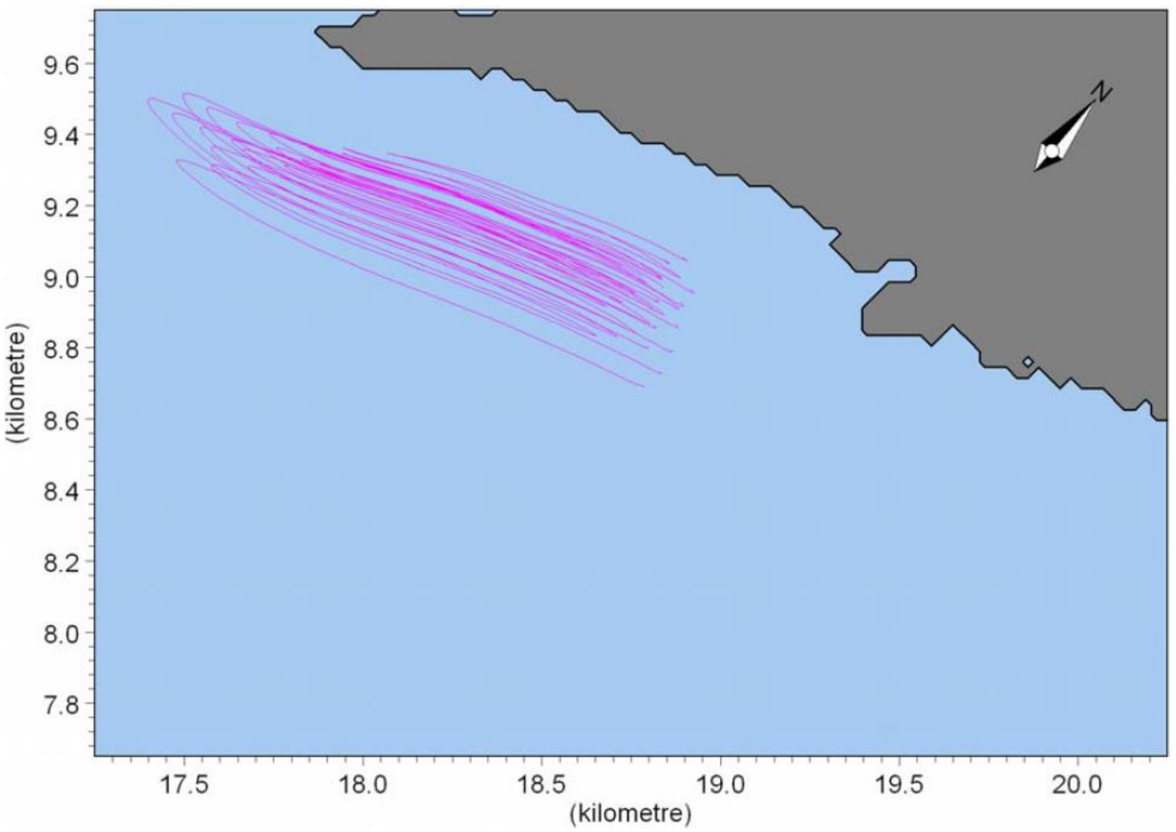


Figure 5.34: Sediment transport patterns - re-suspension spring high water

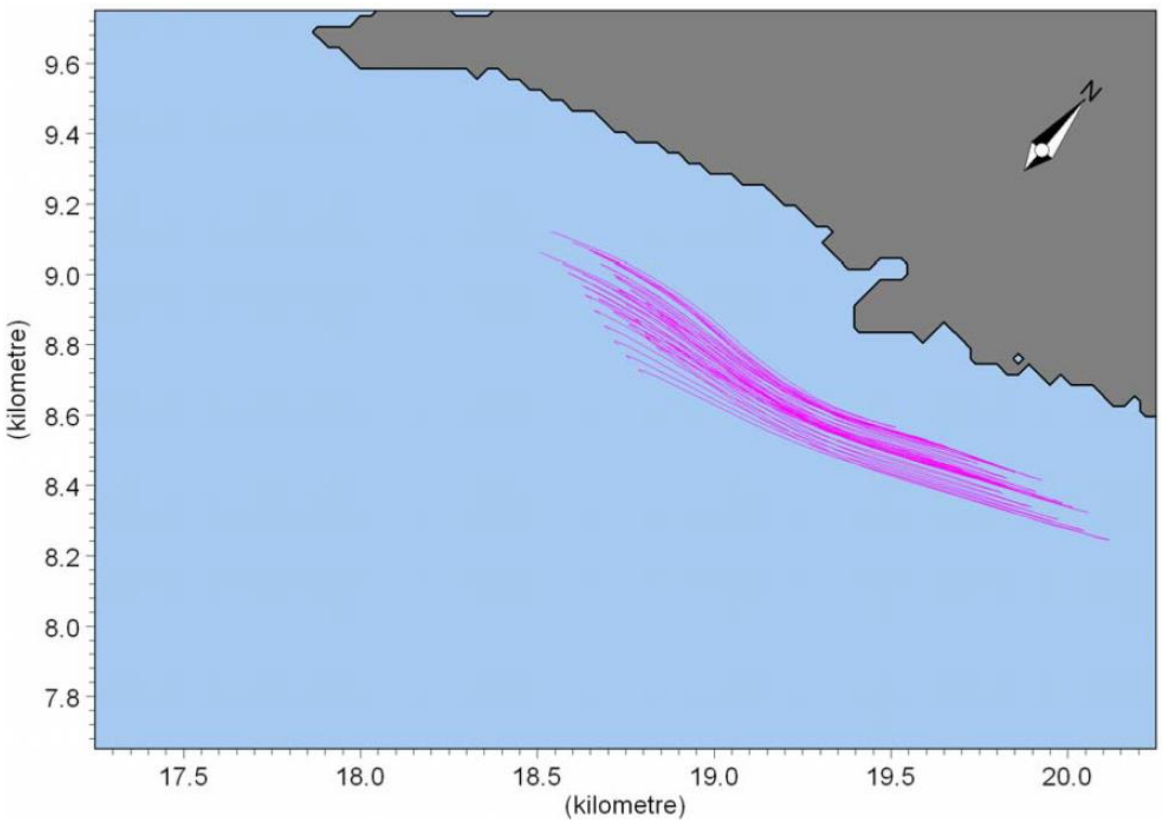


Figure 5.35: Sediment transport patterns – re-suspension spring low water

The second aspect of wave induced sediment transport that was investigated relates to the impact that wave climate may have on current speeds, where tidal currents are weak. Although the Shot Head site is relatively well-sheltered from waves from most sectors, it is open the southwest and relatively large swell waves may reach the site from this sector as this is the prominent swell direction from the Atlantic. Figure 5.36 and Figure 5.37 illustrate the wave climate at the mouth of the Bay.

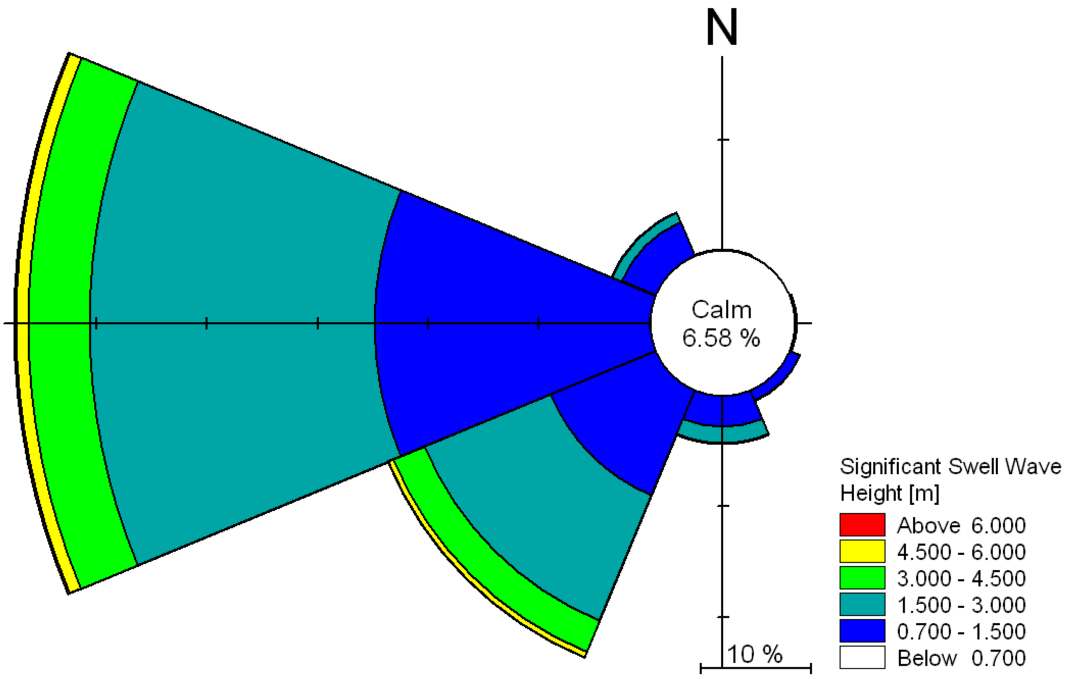


Figure 5.36: Swell wave climate at the mouth of Bantry Bay

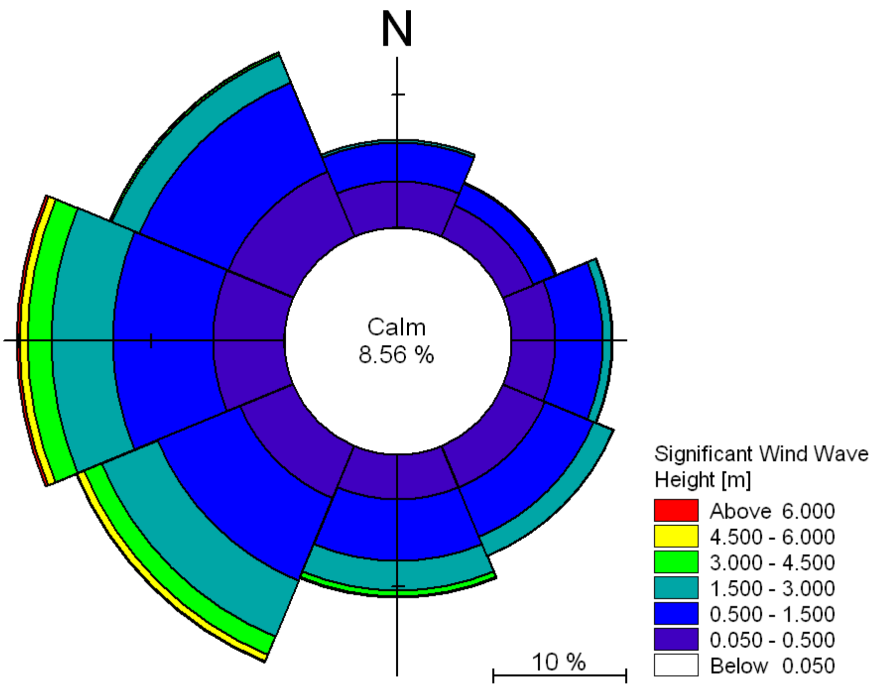


Figure 5.37: Wind wave climate at the mouth of Bantry Bay

The average wave climate derived as part of the 2009 RPS wave climate analysis was examined to assess the proportion of time during which wave-induced flow would dominate over the tidal flow at the site. The horizontal wave equation was used to assess when the flow beneath the pens, i.e. at over 15m depth, was larger than the average tidal current of around 0.05m/s. From the analysis of the wind waves, occurrences in excess of 15% and 40% were found for summer and winter months respectively. For swell waves, occurrences were in excess of 25% in the summer and almost 40% during the winter months.

It may therefore be concluded that the settlement pattern of material below the Shot Head pens is likely to differ from that derived due to tidal conditions alone, shown in Section 4.2 of the EIS, during the periods when wave induced flow dominates. Since such conditions dominate for almost 40% of the time during the winter months, this is likely to have a considerable effect in reducing settlement and promoting dispersal precisely when solids production reaches its peak (October to March, peaking in January in the second year of the growth cycle; see Table 5.6. Since the peak January solids production figure alone was used in the generation of Figure 5.26 to Figure 5.33, some reduction can be expected to be seen in the settlement levels as presented, which are under tidal influence alone.

5.6 TREATMENT RESIDUES

5.6.1 Slice® Lice Treatment

Slice® is a licensed in–feed treatment for sea lice which, where hydrographic conditions suit its application, is commonly chosen in preference to bath treatments as it is considered more effective, in that it kills all lice stages and is more environmentally benign. Slice® is a proprietary pre-mix containing 0.2% Emamectin Benzoate (EmBZ), for surface coating onto salmon feed, at a rate of 5kg Slice® / tonne of feed (that is 10g EmBZ / tonne of feed). It is manufactured by Merck Animal Health Inc. The treatment is applied, on veterinary prescription, as a surface dressing to salmon feed, prior to use. The course of treatment lasts 7 days.
SEPA has determined that 10% of the EmBZ dose ingested is excreted during this treatment period. Of the remaining 90% of the chemical, approximately 99% is excreted over the subsequent 216 days. This excretion has an exponential decay profile such that 50% of the chemical remaining in the fish is released, on average, over each ensuing 36 – 37 day period. It has also been determined that EmBZ breaks down into “non-toxic” sub-compounds with a half-life period of 250 days.

On the basis of SEPA’s calculations, an Excel spreadsheet was developed for a Slice® treatment schedule, derived from the biomass of fish held and the quantity of Slice® required to treat it on the proposed sites. The spreadsheet also takes account of any EmBZ, that could be wasted with uneaten feed on the basis of a feed wastage of 3% of total feed fed; as discussed in Section 5.4 and is further explained in Section 4 of the EIS document. The efficacy of a Slice® treatment against lice infestation lasts 120 days.

In line with MHI Special Operating Procedures (SOP), a period of 1,000 degree days (approximately 4 months at Bantry Bay winter temperatures) is observed between Slice® treatment and fish harvesting. This ensures that the body load of EmBZ has been largely excreted and only remains in insignificant / undetectable quantities within treated salmon tissues. (Although there is no legislative requirement for this practice). The stock biomass of the site is the regulatory factor and, therefore, with harvesting of S0 fish commencing in late February of year 2, the latest Slice® could be administered would be the previous October. This pertains to a maximum treated stock of a nominal 1,300T biomass. This was therefore the maximum stock biomass tested in the first EmBZ dispersal models.

The Irish Parliament has adopted the European Communities (Control of Dangerous Substances in Aquaculture) Regulations 2008, known as SI No. 466 of 2008. These regulations set standards for a range of aquaculture medicines. In respect of the in-feed lice medication Slice® in which the active ingredient is Emamectin benzoate (EmBZ), the SI states that:-

The following standards shall apply 24 hours post treatment at 100m from the site	
Emamectin benzoate (Slice)	0.22ηg/l

This is the only EQS that applies for EmBZ in Ireland, under SI 466 2008. The quality standard in this instance relates only to water column concentrations. Therefore the excreted body load was modelled as being purely in solution to ensure that the upper bound load was released directly into the water column. The release of EmBZ associated with the wasted feed containing the medication was modelled as being bound to the solid pellets which would settle with a potential for resuspension, considered in Section 5.5.

The modelling approach used for EmBZ was similar to that employed for settled solids modelling. Particle Tracking was used over a series of stages (see Section 4.1). During the treatment period, particles were released from the pen centres on the surface for the feed and mid-pen depth for the excreted load. The settling and re-suspension parameters used to describe the movement of waste feed pellets are the same as those described in Section 5.5 for settleable solids. Whilst the excreted concentration was in solution and given neutral buoyancy; this would be applicable both to the proportion of EmBZ which is soluble in saline water and also the insoluble fraction that would become attached to suspended particles within the water column.

During the period following treatment, discharge of EmBZ continues via excretion alone, with a decreasing EmBZ body load. The model was used to simulate the 7 days of treatment, plus the following 24 hours, until the point of the EQS assessment. Figure 5.38 shows the excreted EmBZ levels 24 hours following the treatment of 1,300 tonnes of fish. The 100m boundary from the site required by the EQS is indicated by the black outline around the pens.

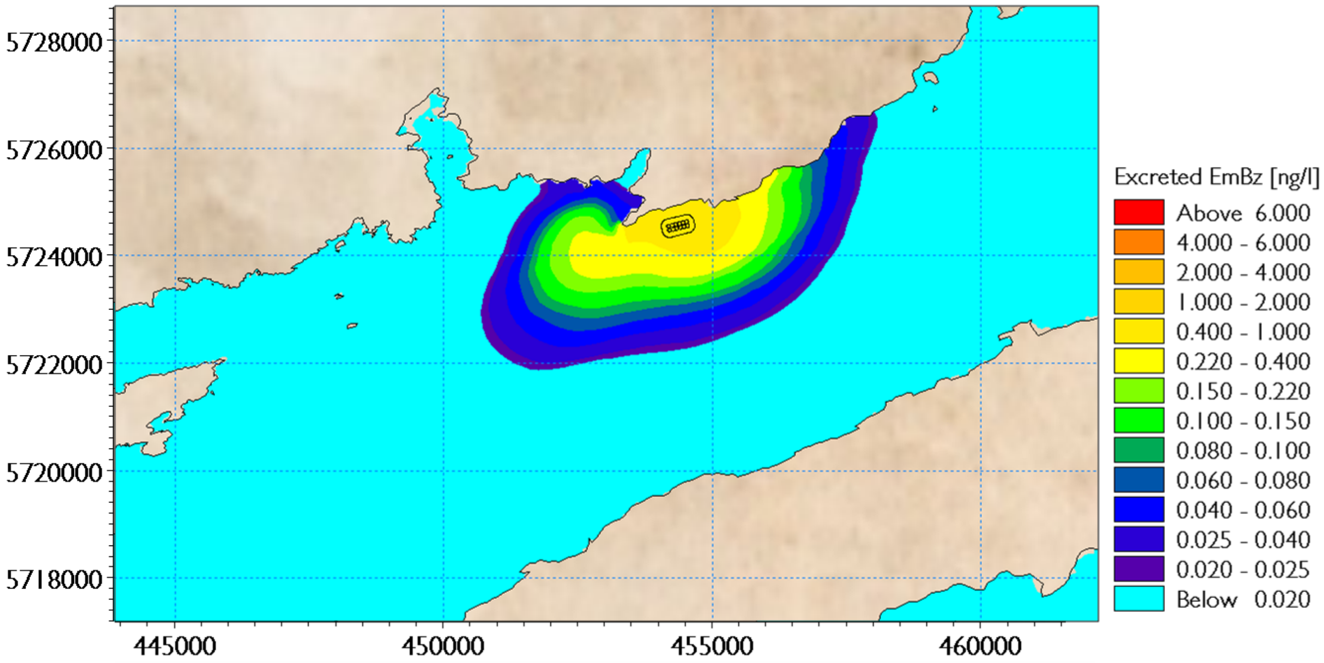


Figure 5.38: Plume Envelope of excreted EmBZ Concentration at the Shot Head stocked with 1,300 tonnes salmon, 24 hours post-treatment

The plot shows that, in fact, the EQS is exceeded 24 hours post treatment, although the EQS concentration can be reached after two further tides (say at 36 hours post-treatment). However, the EQS is breached at the EQS time point so EmBZ cannot be used at this dose rate at the Shot Head site. By calculation and further modelling it has been ascertained that the maximum standing stock that could be treated at the Shot Head site is 440 tonnes, which the site reaches at month 7 post smolt transfer, in May of the first growth year. It should be noted that this would enable strategic treatment with Slice prior to the first sea winter to protect the fish into the "Susceptible Period" under the mandatory lice inspection and treatment protocols, when wild salmon and sea trout smolt are migrating. Alternatively, treatment of 440 tonners of stock at month 7 would protect the farm stock for 120 days until about September, should this be required

In considering this proposal it should be borne in mind that lice levels on salmon farms in Bantry Bay have remained sufficiently low that treatment with Slice® has never proved to be necessary.

For completeness, the study also considered the SEPA approach to EmBZ which examines the accumulation of EmBZ in sediments rather than within the water column. For settlement, the SEPA EQS is 0.763µgEmBZ/kg wet weight of settled particles, averaged over the top 5cm outside the AZE (Allowable Zone of Effects) and 7.63µgEmBZ/kg wet weight within the AZE.

The modelling approach was similar to that employed for water column modelling. However it was assumed that the excreted body load was actually voided and therefore bound to faeces to ensure worst case settlement. As previously, Particle Tracking was used with the properties of treated feed waste and excretion of EmBZ in faeces, both the sediment volume and EmBZ concentrations were modelled in order to assess the composition of the 5cm top layer. The settling and re-suspension parameters used to describe the movement of waste feed pellets and faeces are the same as those described in Section 5.5 for settleable solids.

During the period following treatment, discharge of EmBZ continues via faecal excretion alone, with a decreasing EmBZ load but at the same volume flux. Also the waste feed discharge continues but with no EmBZ component (since the treatment period is over). The initial treatment model was used to simulate the first 22 days of discharge whilst further models were used, with depleting faecal EmBZ discharges, to model subsequent periods. In this way accumulated sediment could be calculated to take account of the half-life of the EmBZ in faecal particles, arising from the treatment. When the depth of sediment and EmBZ concentrations were examined they were found to comply with the SEPA standards on the outer 100m AZE boundary but for compliance on the inner 25m boundary sedimented values are required to be below circa 0.648 x 10^{-6} kg/m^2. Therefore Figure 5.39 demonstrates that Slice® is unsuitable for use at this site.

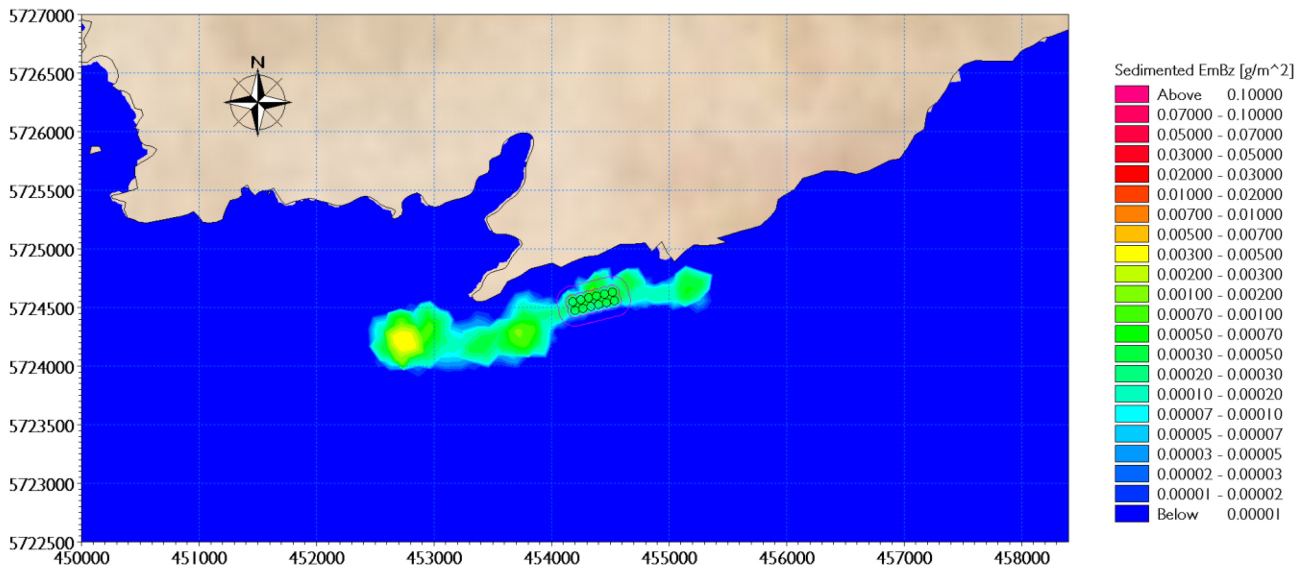


Figure 5.39: Sedimented EmBZ Concentration at the Shot Head site after 200 days – body load shed

5.6.2 Alphamax® Lice Treatment

Alphamax® is licensed for the bath treatment of sea lice and is manufactured by Pharmaq Limited. Its active ingredient is the synthetic pyrethroid Deltamethrin. Alphamax® comes in liquid form, containing 10mg/ml (i.e. a 1% solution) of Deltamethrin. Pyrethroids are a group of natural and synthetic chemicals which act on insects and related organisms (such as sea lice) by blocking neural transmission pathways. Bath treatments can be carried out in pens using a tarpaulin skirt around the pen to contain the treatment. A preferred treatment method, normally used by MHI, is to use well boat tanks to which the fish are pumped for treatment and then returned to clean pens.

Deltamethrin does not bioaccumulate in fish and, if released into the environment, less than 10% persists (and this part widely dispersed) after 10 days, whilst its half life in sediments under treated pens has been found to be 140 days, with 90% biodegraded by 12 months. However these are not issues for MHI who use enclosed well boat tanks for bath treatments.

For well boat treatments, treatment dosage and time is 0.2ml Alphamax® (=2µg Deltamethrin) per m^3 seawater in the well tank for 40-45 minutes. The well boat MV Grip Transporter that would be used for Alphamax® treatment in Bantry Bay, should a treatment be required, has two $600m^3$ tanks. These would require a total dose of 120ml of Alphamax®, containing 1,200µg (1.2mg) of Deltamethrin, per tank, per treatment. The well boat tanks have the combined capacity to treat 100 tonnes of fish per treatment. Thus the total tonnage of fish for treatment is material to the total dosage of Alphamax® to be used. Alphamax® treatment is applied on a 24-hour-day basis and generally pens are treated consecutively. Well boat treatment uses less medication than in-pen treatment because the fish can be held in good condition at higher densities for the treatment duration.
As with the Slice® treatment, the Irish Parliament has adopted the European Communities (Control of Dangerous Substances in Aquaculture) Regulations 2008, known as SI No. 466 of 2008. These regulation state that:

The following standards shall apply 24 hours post treatment at 100m from the site	
Alphamax (Deltamethrin)	2ηg/l

In-pen Alphamax® treatment, whist now generally superseded by treatment in well boat tanks, requires a larger quantity of Deltamethrin per unit fish weight treated. Dispersion from pens is modelled here since it provides a worst case. The advection dispersion modelling approach was applied as discussed in Section 4.2. Within the modelling, a source consistent with the raised pen volume was introduced, the source was then moved to the next consecutive pen and a similar process was followed until the entire stock had been treated. Total weight of fish treated for the simulation was the proposed Maximum Allowable Biomass (MAB) for the site, of 2,800 tonnes, which occurs in January in the second production year. Again this provides a worst case scenario. The number and temporal spacing of treatments means that discharges occurred at various times through the tidal cycle, including slack water. Therefore the simulation results are independent of the initial tidal state.

Figure 5.40 shows the resulting plume arising from Alphamax® treatment from the Shot Head site at the EQS point, 24 hours post treatment. The solid line around the pens demotes the EQS boundary. It can be seen that Deltamethrin concentration at the EQS point lies between the 0.8ng and 2.0ng contours, and therefore meets the EQS requirement.

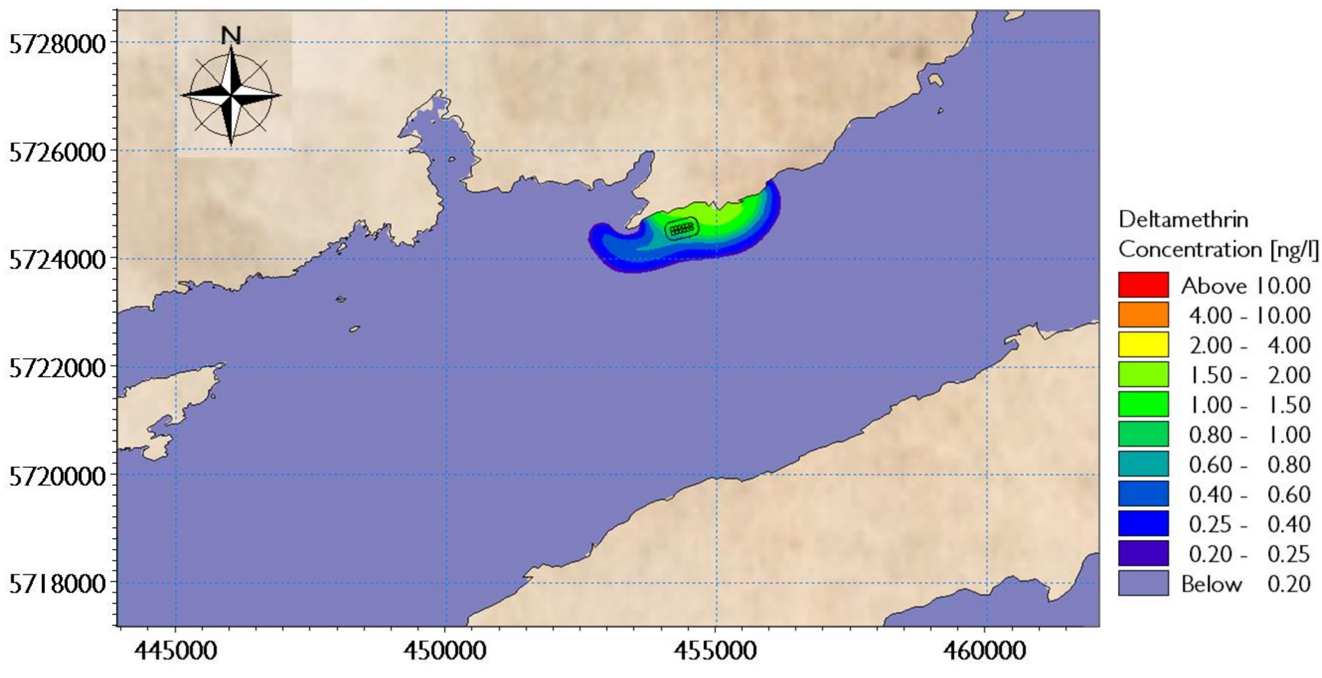


Figure 5.40: Deltamethrin Concentration 24 hours Post Treatment at the Shot Head site.

5.7 SEA LICE

5.7.1 Background

The salmon louse, *Lepeophtheirus salmonis*, is a parasite of wild and farmed salmonids, which can lead to unsightly lesions, loss of growth and mortality. Farmed salmon begin life in freshwater hatcheries and are transferred to seawater, as smolts. The salmon louse only exists in marine conditions and farmed salmon smolts, just as wild salmonid smolts, are free of lice when first transferred to the sea. However, once transferred, they can become infested with the spread of lice, either from infested wild or farmed salmon stock "upstream" of them, in the prevailing current regime. Because farmed fish are held at relatively high densities and at fixed locations, it is a simple matter for very small numbers of free-living copepodid larvae (the infestive stage of the salmon louse), to drift into salmon pens, if local currents cause them to drift in that direction. Once there, they settle, reproduce and thereby have the potential to spread rapidly within a farm site, if not treated.

Whilst it is evident, therefore, that farmed fish can become infested with lice from wild sources, there is an ongoing debate as to whether or not wild salmonids can become infested with lice from farmed sources. Doubts arise primarily because *Lepeophtheirus* has evolved a highly specialised infestation strategy, which probably requires that ovigerous (egg-bearing) female lice hatch their young in relatively close proximity to maximum concentrations of their target hosts, so that copepodid stages are concentrated in or near the estuaries in which their hosts congregate prior to their seawards migration each spring. Such an evolutionary process does not involve salmon farms, which are a very recent event on the evolutionary timescale. Thus, it is hypothesised that, whilst such an infestation strategy leaves drifting wild larvae (that failed to find wild hosts upstream) with some possibility of drifting into a farm site, or farm-hatched larvae able to infest the farmed salmon immediately around them, it is less likely to provide a means by which farm-origin larvae can locate new wild hosts, in or near estuaries, for the following reasons:-

- Farm-origin infestive copepodid larvae are not equipped to control their dispersal away from salmon farms since they are planktonic and, therefore, largely at the mercy of prevailing currents. Copepodids have no known means of "steering" a course from farms to wild salmonid estuaries and, in open waters, will drift and disperse downstream in the prevailing current regime.
- Copepodid larvae have a short lifespan, which limits the range over which they can disperse, via the ambient current regime to locate new hosts, in particular if the hosts are upstream in the prevailing current regime. Wild salmonid estuaries are generally located upstream, relative to salmon farms.
- In order to effect successful, or pathogenic levels of infestation, copepodid larvae must be present in sufficiently high densities, coincident in time and space with critical densities of their host species.
- The numbers of copepodids that can congregate in order to infest their hosts is, by definition, inversely proportional to the distance and time through which they have been dispersed. Thus maintenance of high densities and efficient infestation are dependent on a relative lack of dispersive forces, as well as rapid host location.
- Lice infestation of salmon on Irish salmon farms is monitored by government. Therefore, enumeration and treatment of lice tends to occur before their numbers become critical to either farmed or wild stocks in the locality. The low numbers / density of Irish salmon farm sites in any given area does much to reduce ambient lice infestation pressures and the risk, if any, to wild stocks.
- Some counter-arguments in the past decade or so have mainly been based on a variety of statistical analyses of large quantities of data gathered from releases of tagged salmon smolts, a proportion of which have been treated with Slice®, to protect them from lice infestation, and recaptures of the resultant returning salmon. These studies indicate that survival of Slice®-protected fish can be higher than that of unprotected fish, suggesting that infestation by copepodids as they migrate may have a direct impact on marine survival of unprotected fish. However such studies do not distinguish the source of lice in their findings as being of "wild" or "farmed" origin and indeed the causal link between lice on salmon farms and in wild fisheries has never been demonstrated empirically. In addition to this, there are contradictory views on the contribution that such mortalities make to overall marine mortality of wild salmon, which has increased markedly in recent years, for a variety of reasons not associated at all with lice infestation.

- Some such arguments have been prompted by observations in Norway, where it has been shown that salmon smolts migrating down fjords towards the open sea can become infested with high numbers of copepodids. However conditions found in Norway are somewhat different to those in Ireland:-

  - Farmed salmon populations and site numbers in such fjords can be extremely high (up to four times greater than the entire Irish salmon farming industry in one particular fjord which has been studied)
  - Fjords are very long, narrow and deep. Tidal range is quite low so they are very poorly flushed relative to Irish bays and loughs, where tidal amplitude is generally much greater.
  - Migrating smolt pass very close to many salmon farm pens, where dispersal of farm-origin copepodids is minimal. Hence copepodid densities at the point of infestation are likely to be high and not reduced in their infestation potential by dispersion and age.
  - Historically lice numbers may have been less well-controlled in Norway than in Ireland. In consequence, copepodid populations close to such farms could have been high, coincident with high numbers of migrating smolt. This has the potential to create "unnatural" infestation scenarios, arising from farm-origin copepodids, not dissimilar to the natural scenario found close to salmonid river estuaries.
  - High numbers of feral salmon (originally escapees) boost wild populations in some Norwegian rivers. These may also have a role in augmenting the natural infestation pressure on wild stocks.

5.7.2 Lice dispersal modelling

As with salmonid migration routes, salmon louse dispersal, either from wild sources or from salmon farms, differs between river and coastal water systems, subject to area-specific topography, hydrography, the location of salmon farm installations relative to rivers, and a number of other variables. Although designed as a harvest site to be stocked with fish clear of lice, lice dispersal from the proposed Waterfall site was modelled as part of the present modelling exercise, to test the infestation hypotheses set out above and to investigate whether or not, in the specific case of Bantry Bay, lice larvae hatched on the Waterfall or adjacent sites are:-

- Capable of reaching estuaries around the Bay in sufficiently high numbers to infest emerging wild salmonids.

- Capable of maintaining sufficiently high numbers across relatively large sea areas in the Bay in order to infest wild salmonids migrating past proposed farm sites towards the open sea.

The following scenarios and assumptions, based on the current understanding of the life cycle and behaviour of *Lepeophtheirus* were incorporated into the model:-

1. Fecundity and life cycle
   For the purposes of modelling larval lice dispersal from the salmon farm sites, it is assumed that farmed-origin ovigerous (egg-bearing) adult female lice release 250 viable Nauplius I larvae on each hatch, which are then dispersed by the ambient currents. Nauplius I larvae metamorphose into Nauplius II larvae, which metamorphose again, into infestive Copepodid larvae about four days post-hatch. All three larval stages are free-living, in the water column. If a host is located, Copepodids undergo further metamorphoses whilst living on the host salmon, where they mature and reproduce. Salmon and sea trout smolt migrate from rivers to the sea in the spring and this is known as the "susceptible " period for their lice infestation. During Irish spring (susceptible) temperature conditions, lice generation time is approximately one month.

2. Longevity
   Copepodids do not feed and, as a result, have a maximum longevity of 10 days at springtime temperatures, by which time their internal yolk supply is used up. They must therefore find a host within their 10-day lifespan, that is, between days 4 to 14 post-hatch. The mortality of free-swimming lice larvae during their potential lifespan is also generally regarded as considerable, in particular when they metamorphose from one stage to the next, in addition to which their ability for host attachment is thought to decline with age. These characteristics were allowed for in the model as an exponential decay curve from hatch to day 14 post-hatch, with 3.42% of the hatch enabled to reach the full 14-day lifespan. Maximum lifespan was limited within the model by prescribing a maximum particle age of 14 days. (see also Amundrud and Murray 2009[4])

[4] Amundrud, T. L. & Murray, A. G. 2009 Modelling sea lice dispersion under varying environmental forcing in a Scottish sea loch. J. Fish Dis. 32, 27–44. (doi:10.1111/ j.1365-2761.2008.00980.x)

3. Discharge numbers
   The number of lice discharged from each site relates firstly to the trigger levels for treatment set as part of the Government's lice monitoring program. The government-set trigger level during the susceptible spring period, when wild salmonids migrate (March to May inclusive each year), is 0.5 ovigerous female lice per fish although MHI protocol uses a lower more precautionary value of 0.3 ovigerous female lice per fish. The government lice monitoring program is bi-weekly during this period. At all other times of year, when monitoring frequency is monthly, the trigger level is two ovigerous lice per fish. For the base simulations, ovigerous female lice numbers were set at 1 louse per fish. A simple multiplier can then be used to estimate Copepodid dispersion numbers from higher mean ovigerous farm lice counts from the plots generated. The second factor controlling lice numbers is the size of the fish stock. In reality, a uniform infestation of an entire site is unlikely, but this assumption was made to reinforce the worst-case scenario modelled.

An Excel spreadsheet was used to calculate the likely numbers of copepodid larvae that may be released from each farm at any time. This was undertaken for all existing and currently proposed salmon farm sites in Bantry Bay. Both the susceptible and non-susceptible periods were considered, along with the characteristics of infestation, i.e. stocks placed on a site either from smolt sites or moved to a harvest site are free of lice and a minimum period of 12 weeks is required for an infestation to establish on a site. Therefore the data from all operational sites needed to be analysed to select the largest total lice release under these circumstances. To clarify this selection, a colour palette was applied to each summary table for lice discharge. The key to the colours used is given in Table 5.7, whilst the maximum nauplius production for all existing and currently proposed Bantry Bay sites, from 1 ovigerous louse per fish) are shown in Table 5.8. It should be noted that the proposed Waterfall harvest site has been added into the model, even though the possibility of occurrence of ovigerous female lice at the site is regarded as remote (because the Waterfall stock is not excepted on the site for long enough for ovigerous lice to develop).

Table 5.7: Lice larvae Table Key

Lice Release Key	
Shade/fill	**Description**
Standard text	Non-susceptible period
Grey text	Fresh site stocking – no lice present
White text	Conditions selected for simulation
Hatched period	Susceptible migration period

4. Density of lice for dispersal
   It was assumed in the modelling that hatching of farm-origin lice Nauplii takes place during the flood tide and that the Nauplii larvae are released at mid-cage depth, with sources placed in the centre of each pen. In the simulation, the effect on water courses both up and down stream of the farm site were considered. The full range of possible tidal states and dispersion mechanisms were also incorporated.

The numerical model utilises particle analysis to simulate the dispersal of the lice larvae from the farm sites. The modelling methodology is as outlined in Section 4.1. In order to satisfy the above assumptions, the larvae were modelled as neutrally buoyant particles. As in the case of other dispersion simulations, the model was run for a period of 22 days to offer the full range of tidal conditions from spring to neap. This also allowed dispersed lice numbers to develop and to become stable in the water column (over 44 tides).

The models were run for two scenarios over the 22 day period. Firstly the full larval life cycle to Copepodid settlement with mortality and secondly the Nauplius stage only with mortality, where extinction occurred after 4 days. The two datasets were then used to compute the fate and dispersion for the (infestive) Copepodid lice stage only; i.e. by subtraction of the (non-infestive) Nauplii from the full lice population.

Figure 5.41 and Figure 5.42 show the resulting maximum and average copepodid only densities for the complete lifecycle. As with previous assessments, the maximum larval concentration to occur in each model grid cell at any time during the simulations is presented in the Maximum Concentration Plume. It is emphasised that the maxima for each cell do not occur simultaneously. The average value makes it apparent that during the

Nauplii stage the maximum lice excursion is around 1km from the site. Whilst Figure 5.43 and Figure 5.44 shows the corresponding maximum and average density for the entire lice population i.e. Nauplii + Copepodids.

Table 5.8: Lice larvae statistics used for simulation of larval lice dispersal from all existing and currently proposed Bantry Bay salmon farm sites; 1 ovigerous louse per fish and a monthly hatch of 250 larvae per clutch.

Month	Lice statistics for lice dispersal simulations; 1 ovigeorus louse per fish											
	Shot Head			Fastnet			Roancarrig			Waterfall		
	Average fish number	Ovigerous lice (1 per fish)	Nauplii per month (250/clutch)	Average fish number	Ovigerous lice (1 per fish)	Nauplii per month (250/clutch)	Average fish number	Ovigerous lice (1 per fish)	Nauplii per month (250/clutch)	Average fish number	Ovigerous lice (1 per fish)	Nauplii per month (250/clutch)
Sep	Fallow site			Fallow site			732,492	732,492	183,122,973	28,992	28,992	7,247,875
Oct							723,662	723,662	180,915,518	28,992	28,992	7,247,875
Nov	825,435	825,435	206,358,863	206,359	206,359	51,589,716	717,156	717,156	179,288,912	28,992	28,992	7,247,875
Dec	808,874	808,874	202,218,625	202,219	202,219	50,554,656	709,975	709,975	177,493,858	28,992	28,992	7,247,875
Jan	799,551	799,551	199,887,762	199,888	199,888	49,971,941	704,649	704,649	176,162,298	28,992	28,992	7,247,875
Feb	794,349	794,349	198,587,287	198,587	198,587	49,646,822	697,961	697,961	78,520,574	28,992	28,992	7,247,875
Mar	790,377	790,377	197,594,351	197,594	197,594	49,398,588	647,086	647,086	72,797,077	28,992	28,992	7,247,875
Apr	786,426	786,426	196,606,379	196,607	196,607	49,151,595	538,021	538,021	60,527,357	28,992	28,992	7,247,875
May	780,924	780,924	195,231,120	195,231	195,231	48,807,780	406,217	406,217	45,699,388	Fallow site		
Jun	772,730	772,730	193,182,517	193,183	193,183	48,295,629	283,304	283,304	31,871,685			
Jul	762,305	762,305	190,576,302	190,576	190,576	47,644,076	174,219	174,219	19,599,630	28,992	28,992	7,247,875
Aug	747,844	747,844	186,961,113	186,961	186,961	46,740,278	59,323	59,323	6,673,744	28,992	28,992	7,247,875
Sep	732,492	732,492	183,122,973	183,123	183,123	45,780,743	Fallow site			28,992	28,992	7,247,875
Oct	723,662	723,662	180,915,518	180,916	180,916	45,228,880				28,992	28,992	7,247,875
Nov	717,156	717,156	179,288,912	179,289	179,289	44,822,228	825,435	825,435	206,358,863	28,992	28,992	7,247,875
Dec	709,975	709,975	177,493,858	177,494	177,494	44,373,465	808,874	808,874	202,218,625	28,992	28,992	7,247,875
Jan	704,649	704,649	176,162,298	176,162	176,162	44,040,575	799,551	799,551	199,887,762	28,992	28,992	7,247,875
Feb	697,961	697,961	174,490,303	174,490	174,490	43,622,576	794,349	794,349	198,587,287	28,992	28,992	7,247,875
Mar	647,086	647,086	161,771,419	161,772	161,772	40,442,855	790,377	790,377	197,594,351	28,992	28,992	7,247,875
Apr	538,021	538,021	134,505,374	134,505	134,505	33,626,344	786,426	786,426	196,606,379	28,992	28,992	7,247,875
May	406,217	406,217	101,554,331	101,554	101,554	25,388,583	780,924	780,924	195,231,120	Fallow site		
Jun	283,304	283,304	70,826,100	70,826	70,826	17,706,525	772,730	772,730	193,182,517			
Jul	174,219	174,219	43,554,868	43,555	43,555	10,888,717	762,305	762,305	190,576,302	0	28,992	7,247,875
Aug	59,323	59,323	14,830,674	14,831	14,831	3,707,669	747,844	747,844	186,961,113	0	28,992	7,247,875
Sep	Fallow site			Fallow site			732,492	732,492	183,122,973	0	28,992	7,247,875
Oct							723,662	723,662	180,915,518	0	28,992	7,247,875
Nov	825,435	825,435	206,358,863	206,359	206,359	51,589,716	717,156	717,156	179,288,912	0	28,992	7,247,875
Dec	808,874	808,874	202,218,625	202,219	202,219	50,554,656	709,975	709,975	177,493,858	0	28,992	7,247,875
Jan	799,551	799,551	199,887,762	199,888	199,888	49,971,941	704,649	704,649	176,162,298	0	28,992	7,247,875
Feb	794,349	794,349	198,587,287	198,587	198,587	49,646,822	697,961	697,961	174,490,303	0	28,992	7,247,875
Mar	790,377	790,377	197,594,351	197,594	197,594	49,398,588	647,086	647,086	161,771,419	0	28,992	7,247,875
Apr	786,426	786,426	196,606,379	196,607	196,607	49,151,595	538,021	538,021	134,505,374	0	28,992	7,247,875
May	780,924	780,924	195,231,120	195,231	195,231	48,807,780	406,217	406,217	101,554,331	Fallow site		
Jun	772,730	772,730	193,182,517	193,183	193,183	48,295,629	283,304	283,304	70,826,100			
Jul	762,305	762,305	190,576,302	190,576	190,576	47,644,076	174,219	174,219	43,554,868	0	28,992	7,247,875
Aug	747,844	747,844	186,961,113	186,961	186,961	46,740,278	59,323	59,323	14,830,674	0	28,992	7,247,875
Sep	732,492	732,492	183,122,973	183,123	183,123	45,780,743	Fallow site			0	28,992	7,247,875
Oct	723,662	723,662	180,915,518	180,916	180,916	45,228,880				0	28,992	7,247,875
Nov	717,156	717,156	179,288,912	179,289	179,289	44,822,228	825,435	825,435	206,358,863	0	28,992	7,247,875
Dec	709,975	709,975	177,493,858	177,494	177,494	44,373,465	808,874	808,874	202,218,625	0	28,992	7,247,875
Jan	704,649	704,649	176,162,298	176,162	176,162	44,040,575	799,551	799,551	199,887,762	0	28,992	7,247,875
Feb	697,961	697,961	174,490,303	174,490	174,490	43,622,576	794,349	794,349	198,587,287	0	28,992	7,247,875
Mar	647,086	647,086	161,771,419	161,772	161,772	40,442,855	790,377	790,377	197,594,351	0	28,992	7,247,875
Apr	538,021	538,021	134,505,374	134,505	134,505	33,626,344	786,426	786,426	196,606,379	0	28,992	7,247,875
May	406,217	406,217	101,554,331	101,554	101,554	25,388,583	780,924	780,924	195,231,120	Fallow site		
Jun	283,304	283,304	70,826,100	70,826	70,826	17,706,525	772,730	772,730	193,182,517			
Jul	174,219	174,219	43,554,868	43,555	43,555	10,888,717	762,305	762,305	190,576,302	0	28,992	7,247,875
Aug	59,323	59,323	14,830,674	14,831	14,831	3,707,669	747,844	747,844	186,961,113	0	28,992	7,247,875
Sep	Fallow site			Fallow site			732,492	732,492	183,122,973	0	28,992	7,247,875
Oct							723,662	723,662	180,915,518	0	28,992	7,247,875

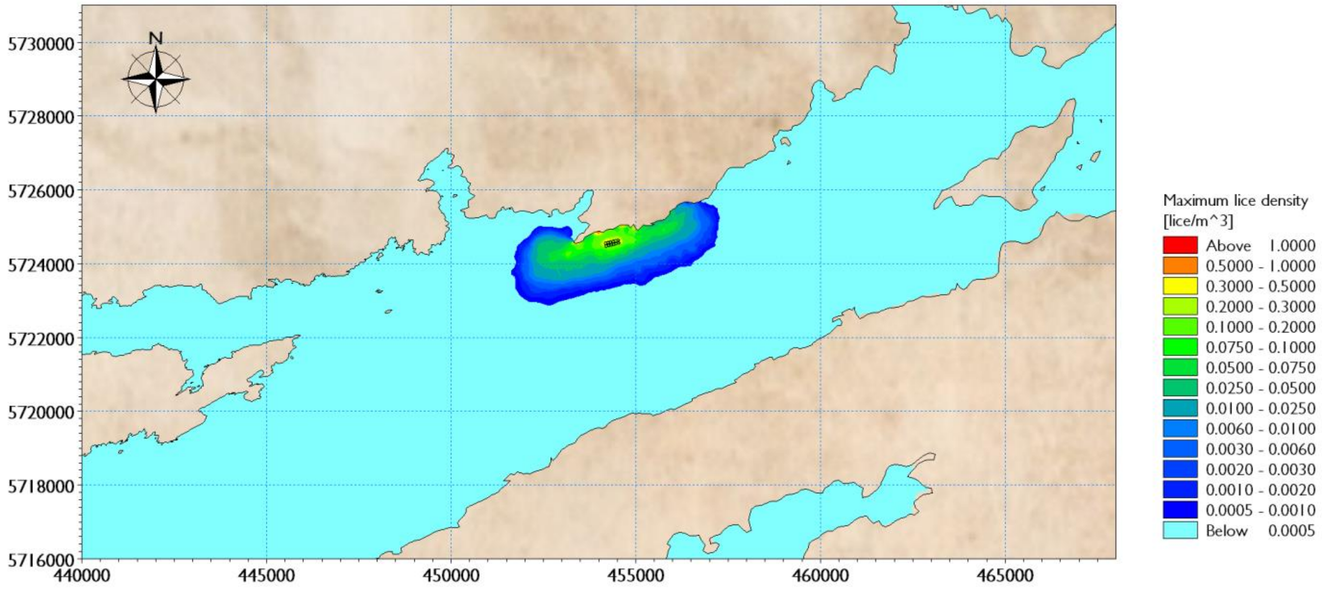


Figure 5.41: Maximum Plume Envelope, copepodid population from 1 ovigerous louse/fish for the Shot Head site only, non susceptible period

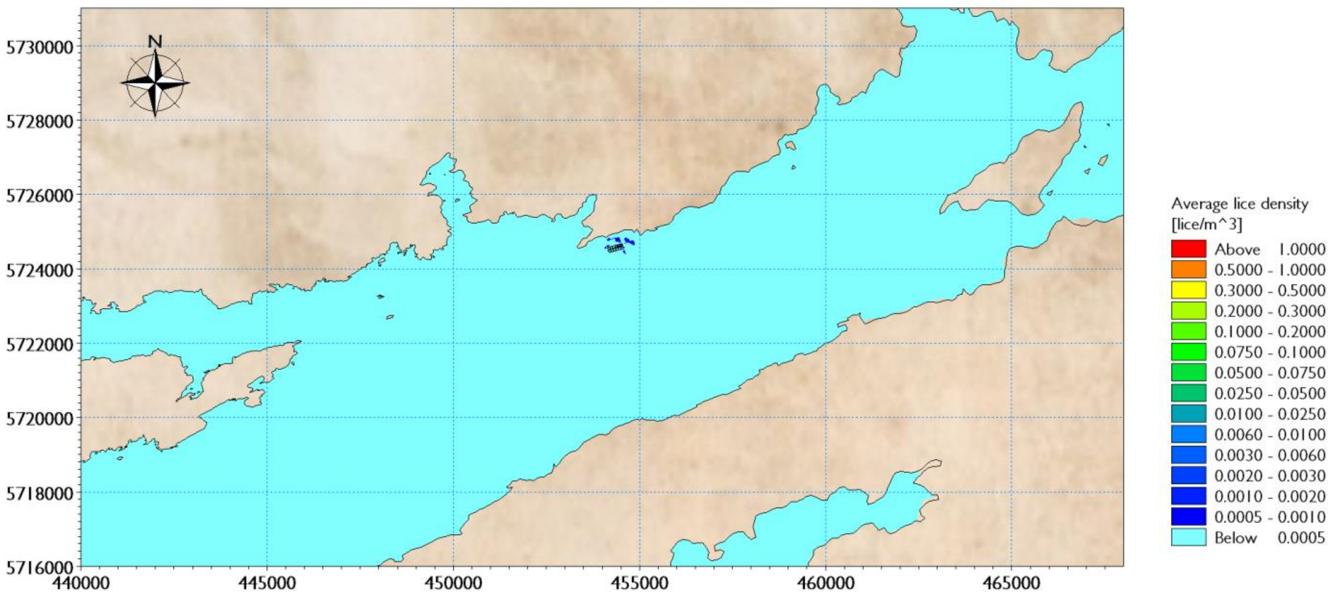


Figure 5.42: Average Plume Envelope, copepodid population from 1 ovigerous louse/fish for the Shot Head site only, non-susceptible period

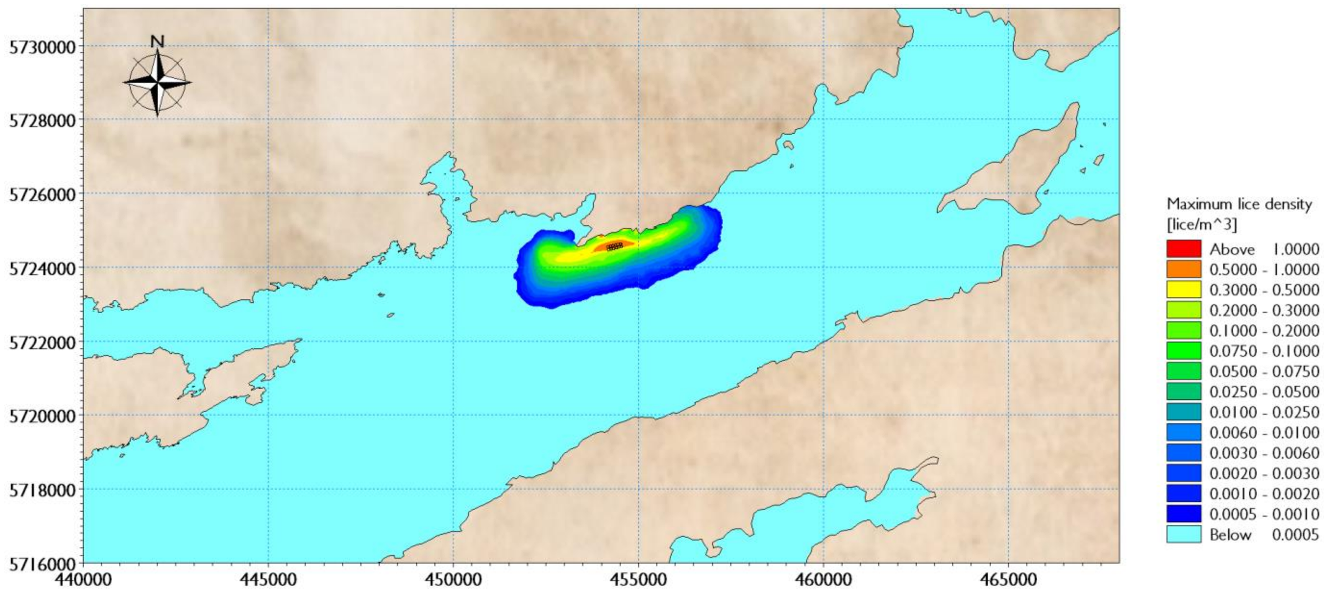


Figure 5.43: Maximum Plume Envelope, total population (i.e. Nauplii + Copepodids) from 1 ovigerous louse/fish for the Shot Head site only, non-susceptible period

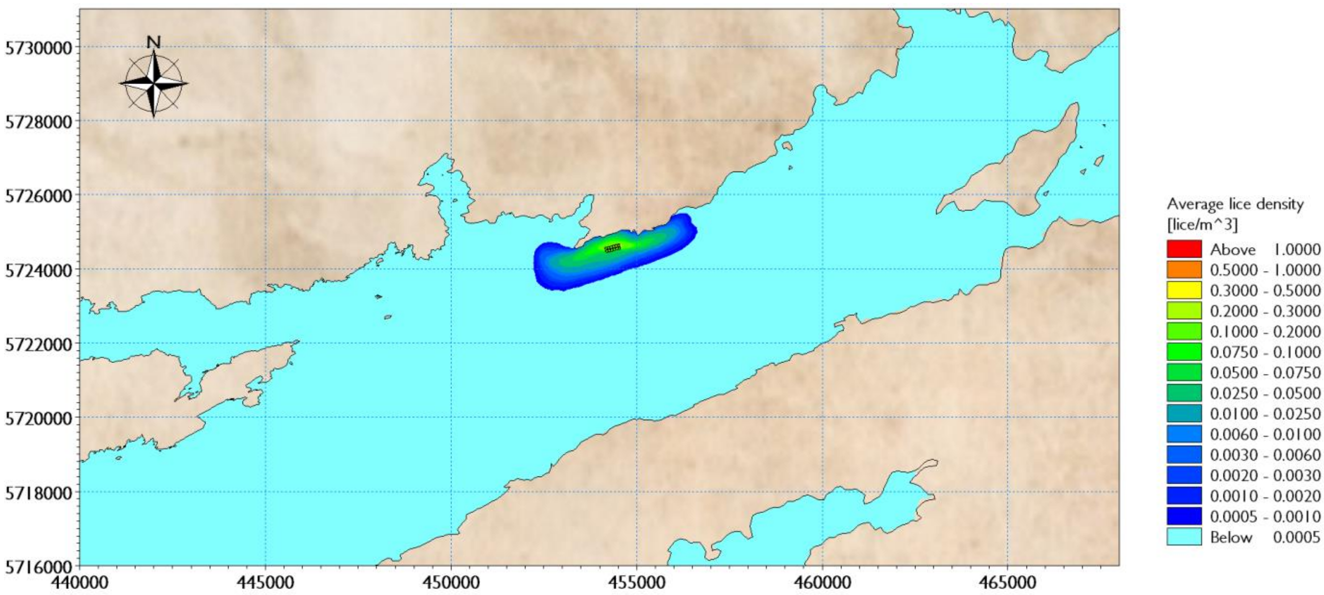


Figure 5.44: Average Plume Envelope, total population (i.e. Nauplii + Copepodids) from 1 ovigerous louse/fish for the Shot Head site only, non-susceptible period

The nauplii release was then simulated for the all sites, with Shot Head / Fastnet dominant. This indicates worst case for lice dispersal towards the estuaries at the head of the bay, based on the numbers of fish resident on all the sites during the non-susceptible period and a mean count of one ovigerous female louse per salmon and a lice larval hatch rate of 250 Nauplii per ovigerous female; see Table 5.8. The release occurred over the course of each flood tide during the simulation period, again to give a worst case scenario of advection towards estuaries, which are mainly at the head of the bay.

The maximum copepodid density for all the sites in Bantry Bay, under non-susceptible conditions is shown in Figure 5.45 whilst the average value is shown in Figure 5.46. Note that the plumes from each site do not intersect with adjacent sites, therefore limiting cross-infection. Figure 5.47 and Figure 5.48 show the maximum and average lice density for all planktonic lice stages (i.e Nauplii plus Copepodids).

The average value outputs makes it apparent that the reduced tidal currents within the Bay mean that lice excursion is limited during the naupliar stage.

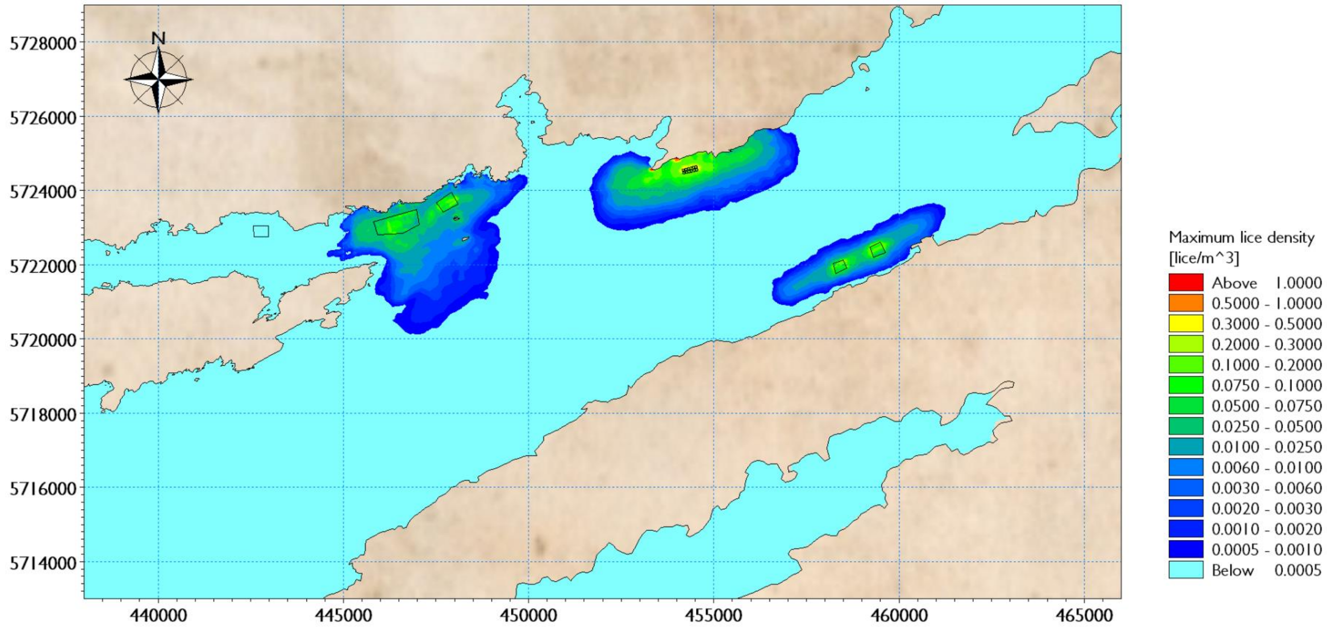


Figure 5.45: Maximum sites Combined Plume Envelope, copepodid population from 1 ovigerous louse/fish per Bantry Bay farm site Shot Head / Fastnet dominant

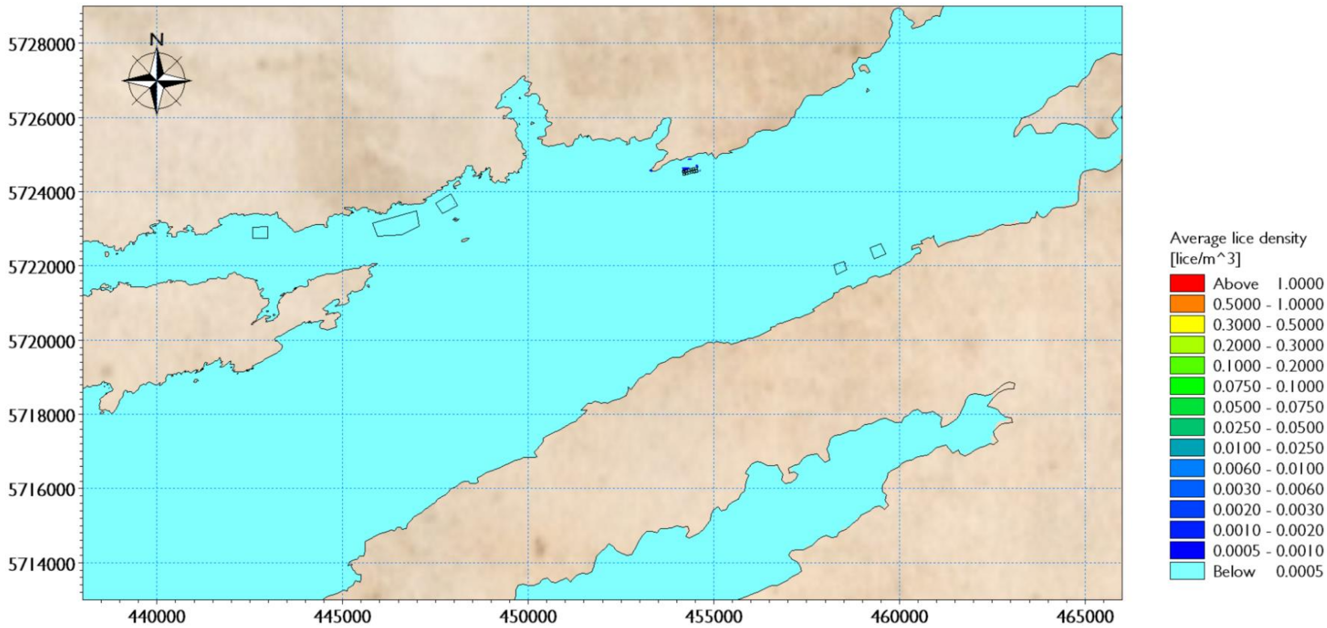


Figure 5.46: Average Combined sites Plume Envelope, copepodid population from 1 ovigerous louse/fish per Bantry Bay farm site Shot Head / Fastnet dominant

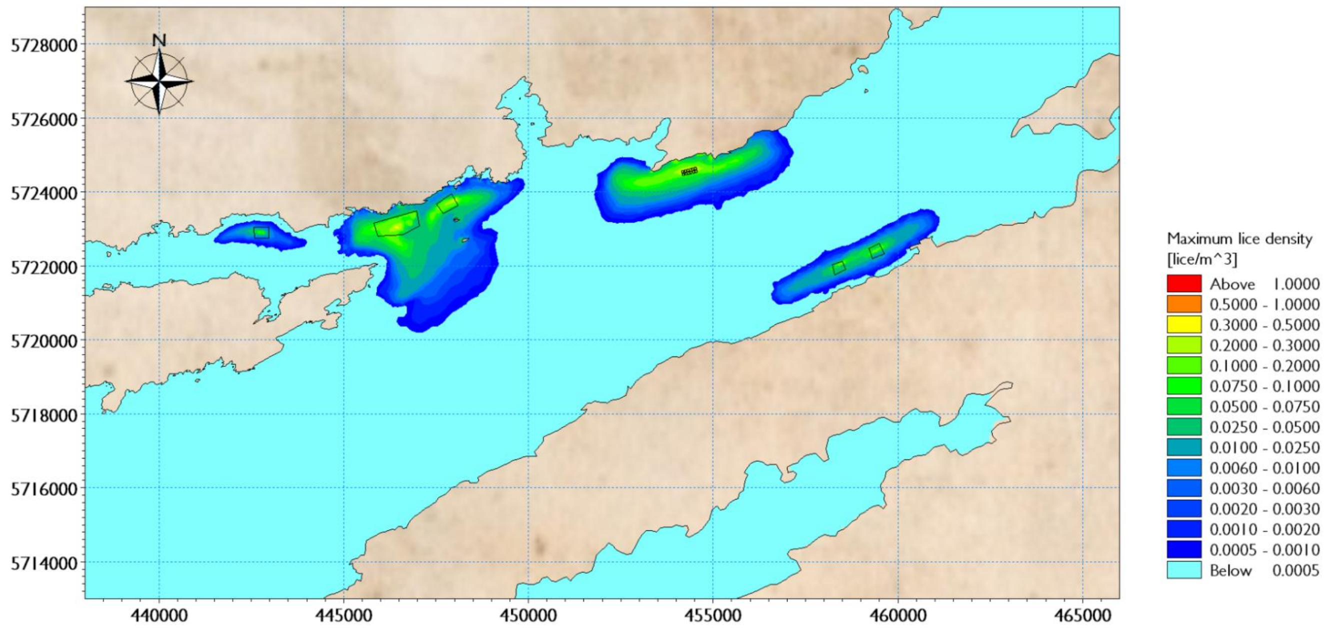


Figure 5.47: Maximum Combined Plume Envelope, total population of planktonic lice stages (Nauplii and Copepodids) from 1 ovigerous louse/fish per Bantry Bay farm site Shot Head / Fastnet dominant

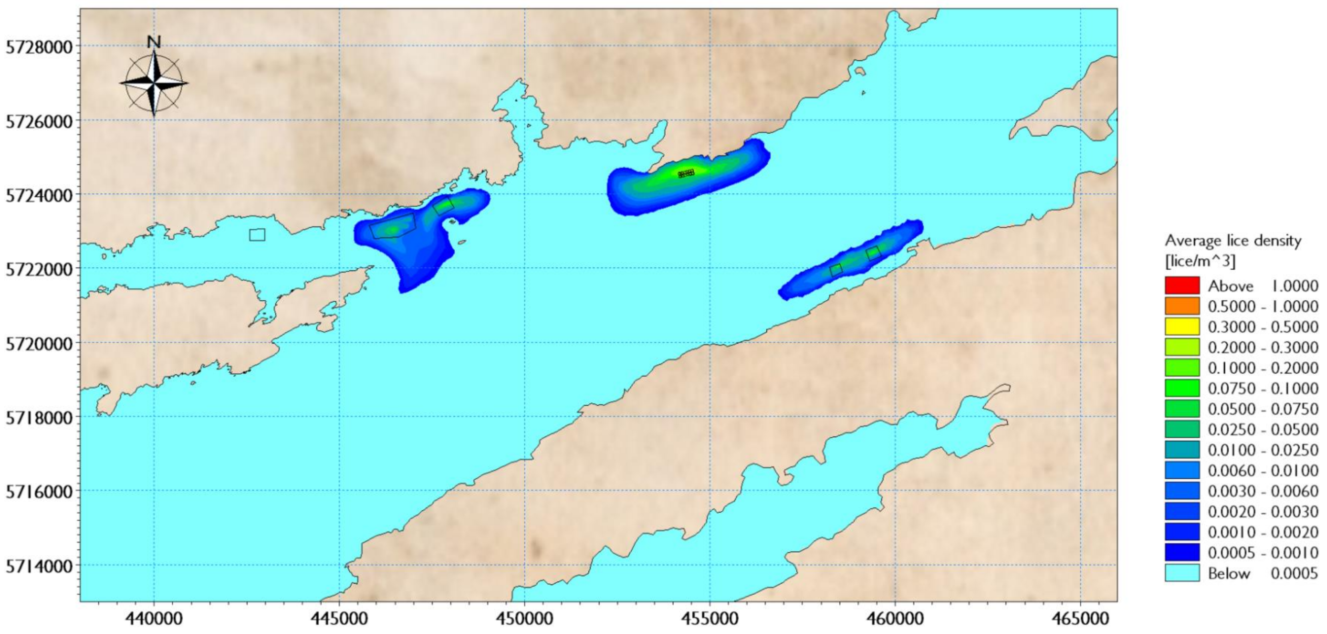


Figure 5.48: Average Combined Plume Envelope, total population of planktonic lice stages (Nauplii and Copepodids) from 1 ovigerous louse/fish per Bantry Bay farm site Shot Head / Fastnet dominant

The Nauplii release was then simulated for Shot Head alone and for all sites, Shot Head / Fastnet dominant, site based on the maximum numbers of fish resident on the sites during the susceptible period and a mean count of 0.3 ovigerous female louse per salmon and a lice larval hatch rate of 250 Nauplii per ovigerous female; see Table 5.9. The release occurred over the course of each flood tide to give a worst case scenario of advection towards estuaries.

Table 5.9: Lice larvae Waterfall Site – 0.3 louse per fish & monthly hatch of 250 larvae per clutch

Month	Lice statistics for lice dispersal simulations; 0.3 ovigeorus louse per fish											
	Shot Head			Fastnet			Roancarrig			Waterfall		
	Average fish number	Ovigerous lice (0.3 per fish)	Nauplii per month (250/clutch)	Average fish number	Ovigerous lice (0.3 per fish)	Nauplii per month (250/clutch)	Average fish number	Ovigerous lice (0.3 per fish)	Nauplii per month (250/clutch)	Average fish number	Ovigerous lice (0.3 per fish)	Nauplii per month (250/clutch)
Sep	Fallow site			Fallow site			732,492	219,748	54,936,900	28,992	8,698	2,174,400
Oct							723,662	217,099	54,274,650	28,992	8,698	2,174,400
Nov	825,435	247,631	61,907,625	206,359	61,908	15,476,925	717,156	215,147	53,786,700	28,992	8,698	2,174,400
Dec	808,874	242,662	60,665,550	202,219	60,666	15,166,425	709,975	212,993	53,248,125	28,992	8,698	2,174,400
Jan	799,551	239,865	59,966,325	199,888	59,966	14,991,600	704,649	211,395	52,848,675	28,992	8,698	2,174,400
Feb	794,349	238,305	59,576,175	198,587	59,576	14,894,025	697,961	209,388	52,347,075	28,992	8,698	2,174,400
Mar	790,377	237,113	59,278,275	197,594	59,278	14,819,550	647,086	194,126	48,531,450	28,992	8,698	2,174,400
Apr	786,426	235,928	58,981,950	196,607	58,982	14,745,525	538,021	161,406	40,351,575	28,992	8,698	2,174,400
May	780,924	234,277	58,569,300	195,231	58,569	14,642,325	406,217	121,865	30,466,275	Fallow site		
Jun	772,730	231,819	57,954,750	193,183	57,955	14,488,725	283,304	84,991	21,247,800			
Jul	762,305	228,692	57,172,875	190,576	57,173	14,293,200	174,219	52,266	13,066,425	28,992	8,698	2,174,400
Aug	747,844	224,353	56,088,300	186,961	56,088	14,022,075	59,323	17,797	4,449,225	28,992	8,698	2,174,400
Sep	732,492	219,748	54,936,900	183,123	54,937	13,734,225	Fallow site			28,992	8,698	2,174,400
Oct	723,662	217,099	54,274,650	180,916	54,275	13,568,700				28,992	8,698	2,174,400
Nov	717,156	215,147	53,786,700	179,289	53,787	13,446,675	825,435	247,631	61,907,625	28,992	8,698	2,174,400
Dec	709,975	212,993	53,248,125	177,494	53,248	13,312,050	808,874	242,662	60,665,550	28,992	8,698	2,174,400
Jan	704,649	211,395	52,848,675	176,162	52,849	13,212,150	799,551	239,865	59,966,325	28,992	8,698	2,174,400
Feb	697,961	209,388	52,347,075	174,490	52,347	13,086,750	794,349	238,305	59,576,175	28,992	8,698	2,174,400
Mar	647,086	194,126	48,531,450	161,772	48,532	12,132,900	790,377	237,113	59,278,275	28,992	8,698	2,174,400
Apr	538,021	161,406	40,351,575	134,505	40,352	10,087,875	786,426	235,928	58,981,950	28,992	8,698	2,174,400
May	406,217	121,865	30,466,275	101,554	30,466	7,616,550	780,924	234,277	58,569,300	Fallow site		
Jun	283,304	84,991	21,247,800	70,826	21,248	5,311,950	772,730	231,819	57,954,750			
Jul	174,219	52,266	13,066,425	43,555	13,067	3,266,625	762,305	228,692	57,172,875	28,992	8,698	2,174,400
Aug	59,323	17,797	4,449,225	14,831	4,449	1,112,325	747,844	224,353	56,088,300	28,992	8,698	2,174,400
Sep	Fallow site			Fallow site			732,492	219,748	54,936,900	28,992	8,698	2,174,400
Oct							723,662	217,099	54,274,650	28,992	8,698	2,174,400
Nov	825,435	247,631	61,907,625	206,359	61,908	15,476,925	717,156	215,147	53,786,700	28,992	8,698	2,174,400
Dec	808,874	242,662	60,665,550	202,219	60,666	15,166,425	709,975	212,993	53,248,125	28,992	8,698	2,174,400
Jan	799,551	239,865	59,966,325	199,888	59,966	14,991,600	704,649	211,395	52,848,675	28,992	8,698	2,174,400
Feb	794,349	238,305	59,576,175	198,587	59,576	14,894,025	697,961	209,388	52,347,075	28,992	8,698	2,174,400
Mar	790,377	237,113	59,278,275	197,594	59,278	14,819,550	647,086	194,126	48,531,450	28,992	8,698	2,174,400
Apr	786,426	235,928	58,981,950	196,607	58,982	14,745,525	538,021	161,406	40,351,575	28,992	8,698	2,174,400
May	780,924	234,277	58,569,300	195,231	58,569	14,642,325	406,217	121,865	30,466,275	Fallow site		
Jun	772,730	231,819	57,954,750	193,183	57,955	14,488,725	283,304	84,991	21,247,800			
Jul	762,305	228,692	57,172,875	190,576	57,173	14,293,200	174,219	52,266	13,066,425	28,992	8,698	2,174,400
Aug	747,844	224,353	56,088,300	186,961	56,088	14,022,075	59,323	17,797	4,449,225	28,992	8,698	2,174,400
Sep	732,492	219,748	54,936,900	183,123	54,937	13,734,225	Fallow site			28,992	8,698	2,174,400
Oct	723,662	217,099	54,274,650	180,916	54,275	13,568,700				28,992	8,698	2,174,400
Nov	717,156	215,147	53,786,700	179,289	53,787	13,446,675	825,435	247,631	61,907,625	28,992	8,698	2,174,400
Dec	709,975	212,993	53,248,125	177,494	53,248	13,312,050	808,874	242,662	60,665,550	28,992	8,698	2,174,400
Jan	704,649	211,395	52,848,675	176,162	52,849	13,212,150	799,551	239,865	59,966,325	28,992	8,698	2,174,400
Feb	697,961	209,388	52,347,075	174,490	52,347	13,086,750	794,349	238,305	59,576,175	28,992	8,698	2,174,400
Mar	647,086	194,126	48,531,450	161,772	48,532	12,132,900	790,377	237,113	59,278,275	28,992	8,698	2,174,400
Apr	538,021	161,406	40,351,575	134,505	40,352	10,087,875	786,426	235,928	58,981,950	28,992	8,698	2,174,400
May	406,217	121,865	30,466,275	101,554	30,466	7,616,550	780,924	234,277	58,569,300	Fallow site		
Jun	283,304	84,991	21,247,800	70,826	21,248	5,311,950	772,730	231,819	57,954,750			
Jul	174,219	52,266	13,066,425	43,555	13,067	3,266,625	762,305	228,692	57,172,875	28,992	8,698	2,174,400
Aug	59,323	17,797	4,449,225	14,831	4,449	1,112,325	747,844	224,353	56,088,300	28,992	8,698	2,174,400
Sep	Fallow site			Fallow site			732,492	219,748	54,936,900	28,992	8,698	2,174,400
Oct							723,662	217,099	54,274,650	28,992	8,698	2,174,400

The maximum copepodid density for the Shot Head site, under susceptible conditions is shown in Figure 5.49 whilst the average value is shown in Figure 5.50. Figure 5.51 and Figure 5.52 shows the maximum and average lice density for the complete lifecycle.

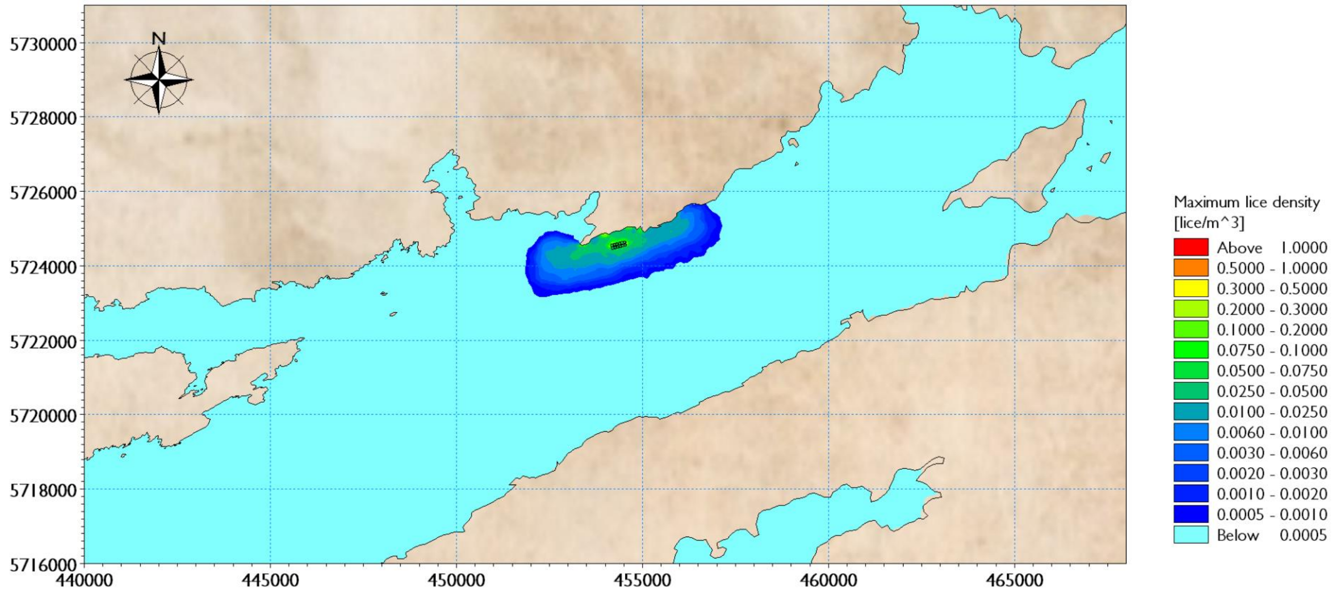


Figure 5.49: Maximum Plume Envelope, copepodid population from 0.3 ovigerous louse/fish for the Shot Head site only

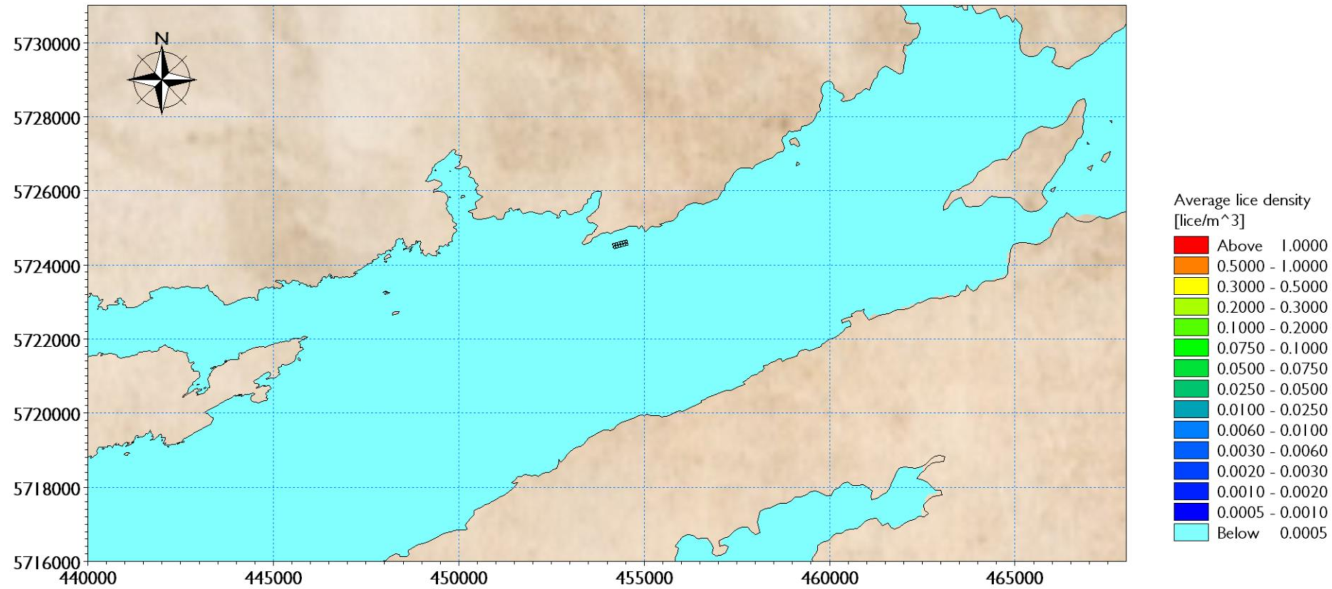


Figure 5.50: Average Plume Envelope, copepodid population from 0.3 ovigerous louse/fish for the Shot Head site only

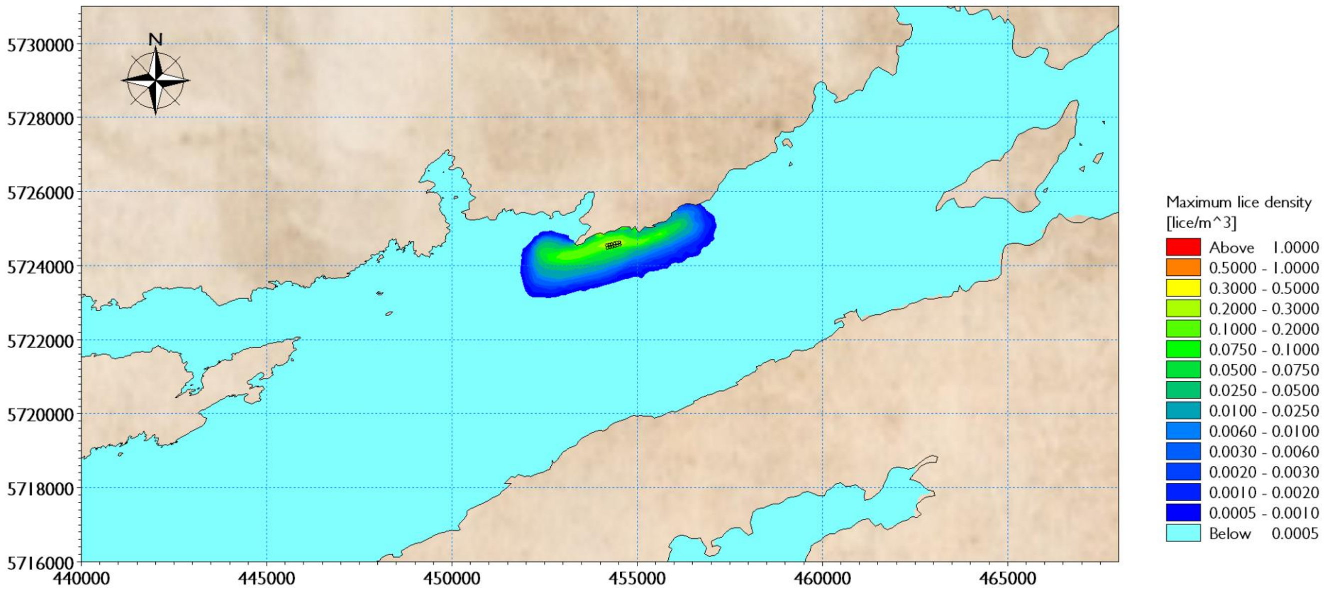


Figure 5.51: Maximum Plume Envelope, total population (i.e. nauplii plus copepodids) 0.3 louse/fish for the Shot Head site only

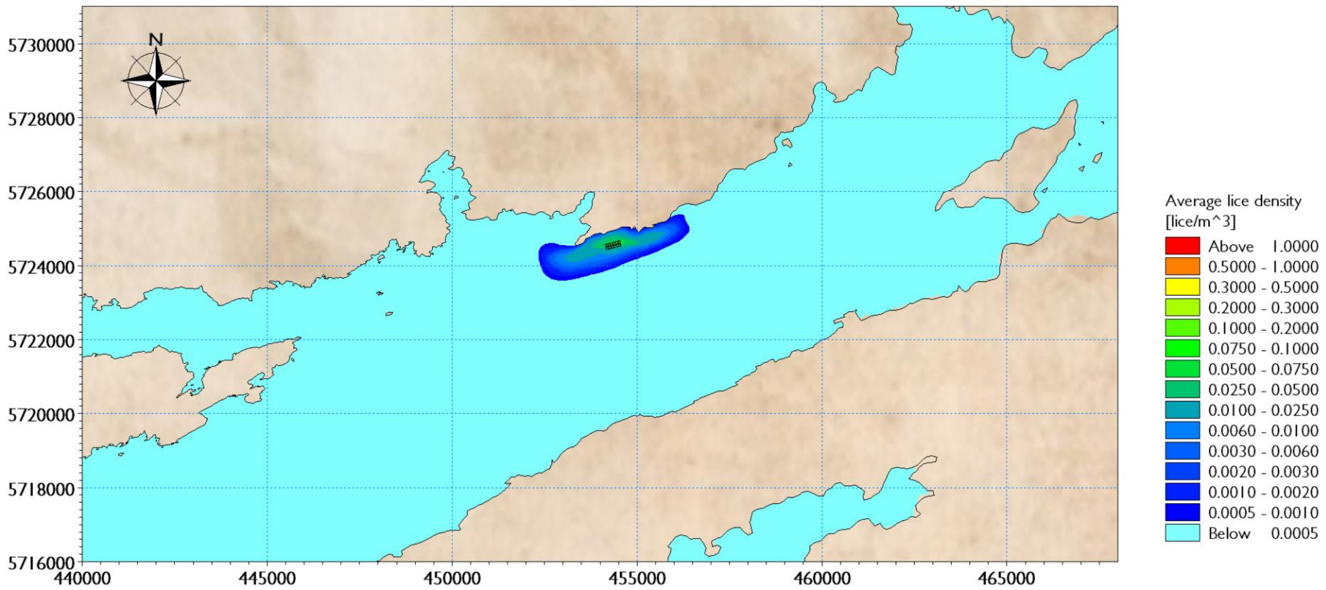


Figure 5.52: Maximum Plume Envelope, total population i.e. nauplii plus copepodids)0.3 louse/fish for the Shot Head site only

The Nauplii release was the simulated for all existing and currently proposed Bantry Bay sites, based on the numbers of fish resident on the site during the susceptible period and a mean count of 0.3 ovigerous female louse per salmon and a lice larval hatch rate of 250 Nauplii per ovigerous female; see again Table 5.9. The release was set to occur over the course of each flood tide to give a worst case scenario of advection towards estuaries, which are mainly at the head of the bay..

The maximum copepodid density for the combined sites, under susceptible conditions is shown in Figure 5.53 whilst the average value is shown in Figure 5.54. Figure 5.55 and Figure 5.56 shows the maximum and average lice density for Nauplii and Copepodids combined, respectively. As anticipated, maintenance of lice at a lower trigger level of 0.3 ovigerous lice per farmed fish gives rise to a lower lice densities on dispersion and, generally, maximum lice densities are below 0.1 lice per m^3. To give this context within a 1000m of the largest site (with a typical water depth of 10m) there may have been a single lice present in any 1m by 1m area at some point over the 22 day period.

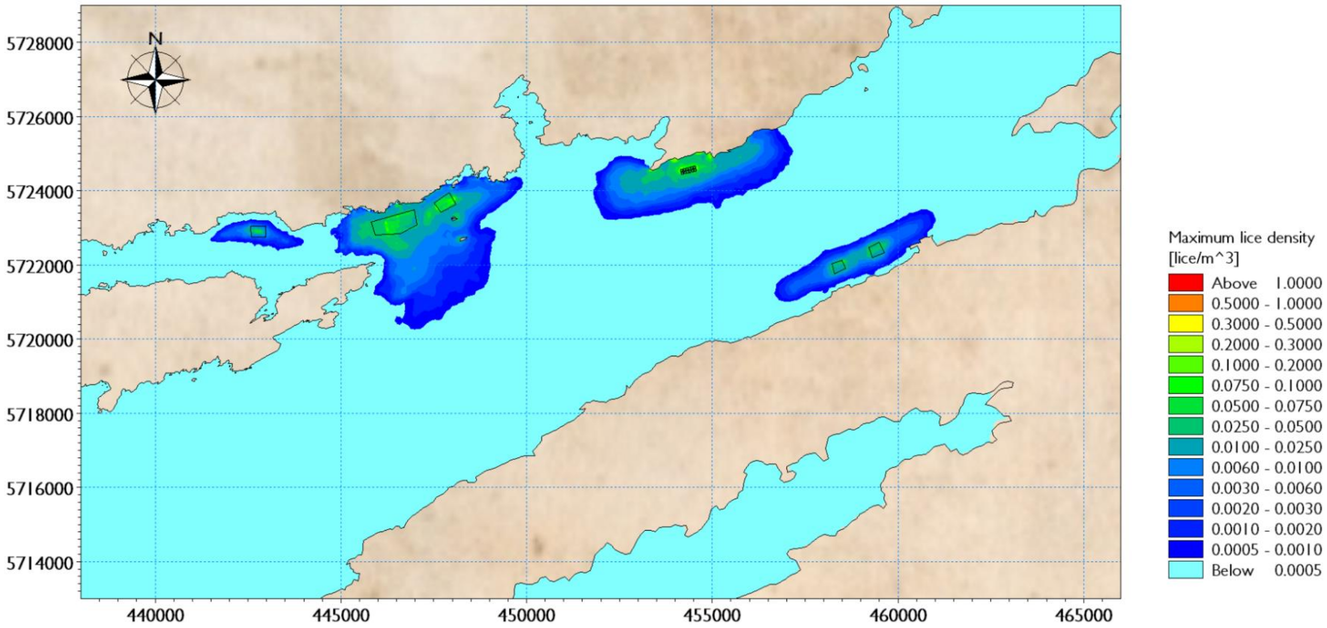


Figure 5.53: Maximum Combined Plume Envelope, copepodid population 0.3 louse/fish per Bantry Bay farm site Shot Head / Fastnet dominant

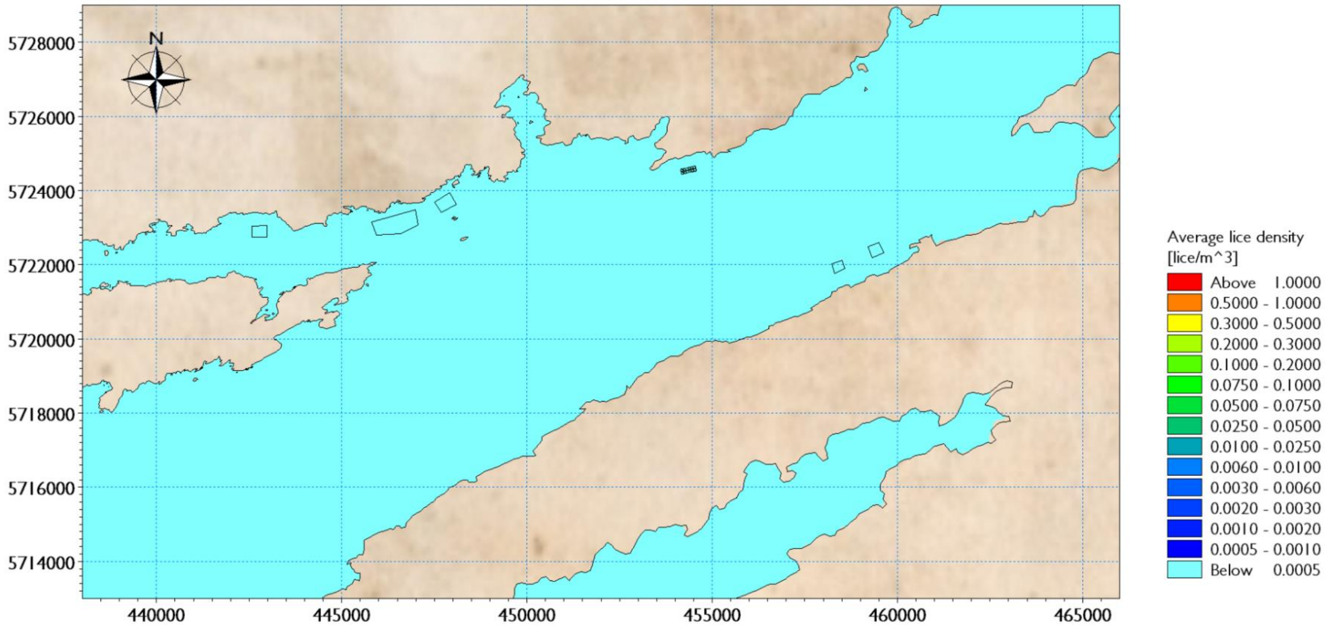


Figure 5.54: Average Combined Plume Envelope, copepodid population 0.3 louse/fish per Bantry Bay farm site Shot Head / Fastnet dominant

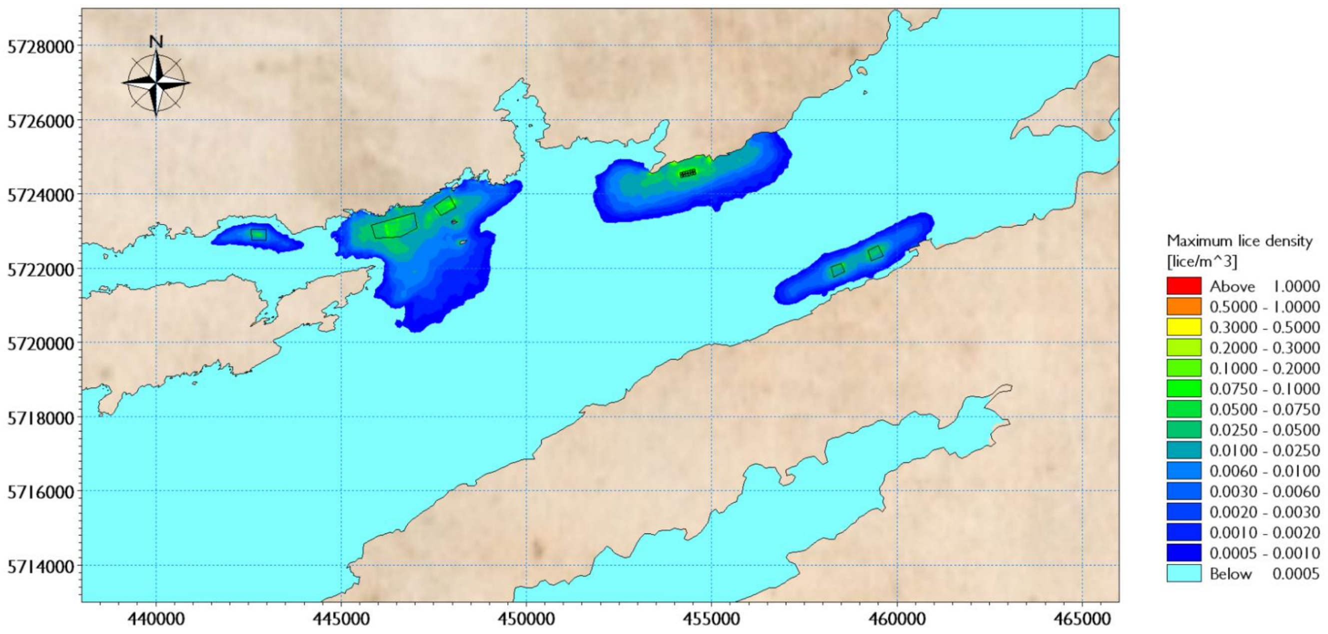


Figure 5.55: Maximum Combined Plume Envelope, total population (i.e. nauplii and copepodids) 0.3 louse/fish per Bantry Bay farm site Shot Head / Fastnet dominant

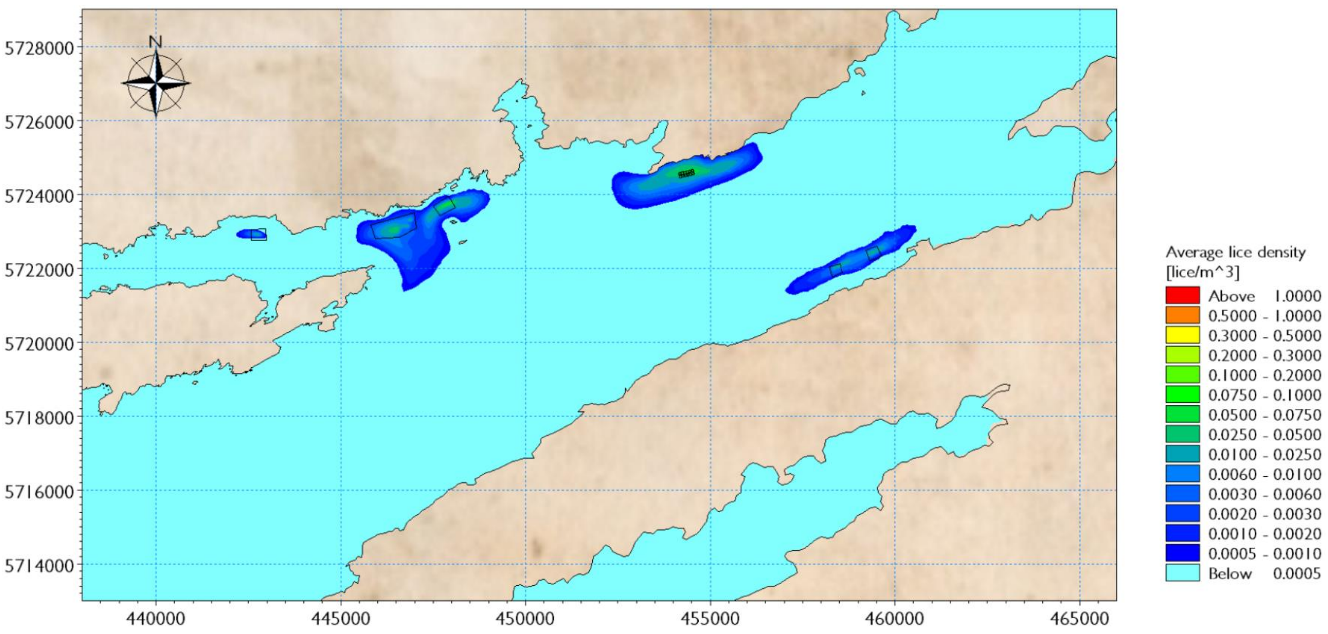


Figure 5.56: Average Combined Plume Envelope, total population (i.e. nauplii and copepodids) 0.3 louse/fish per Bantry Bay farm site Shot Head / Fastnet dominant

5.7.3 Wind induced lice dispersion

As part of the study an examination was undertaken into the effect of wind on lice transport and dispersion to investigate concerns that onshore wind may cause lice to congregate in shallow water and impact upon wild fish populations. Two scenarios were tested; the first simulated transport in response to a south westerly wind of Beaufort Force 5 and secondly a south easterly wind of Force 4. The former was designed to Represent storm conditions which are likely to occur on an annual basis and the latter was selected to give the largest realistic onshore condition perpendicular to the shore. Although the wind speeds were within the likely range it is very improbable that they would persist for a period of two weeks as applied in the model scenarios. As in the previous studies both the copepodid and total lice populations were examined and these were released on flood tide for the duration of the simulation.

Figure 5.57 presents the maximum copepodid lice density during the two week period whilst Figure 5.58 shows the average value for the same period. It can be seen that although maximum concentrations increase towards the shoreline the average plot confirms that the lice do not remain or re-concentrate and by the end of the four day maturation period the lice are dispersed. Figure 5.59 and Figure 5.60 show the same data but relating to the whole life cycle and again demonstrates that the nauplii are driven onshore on release but quickly dispersed prior to reaching maturity.

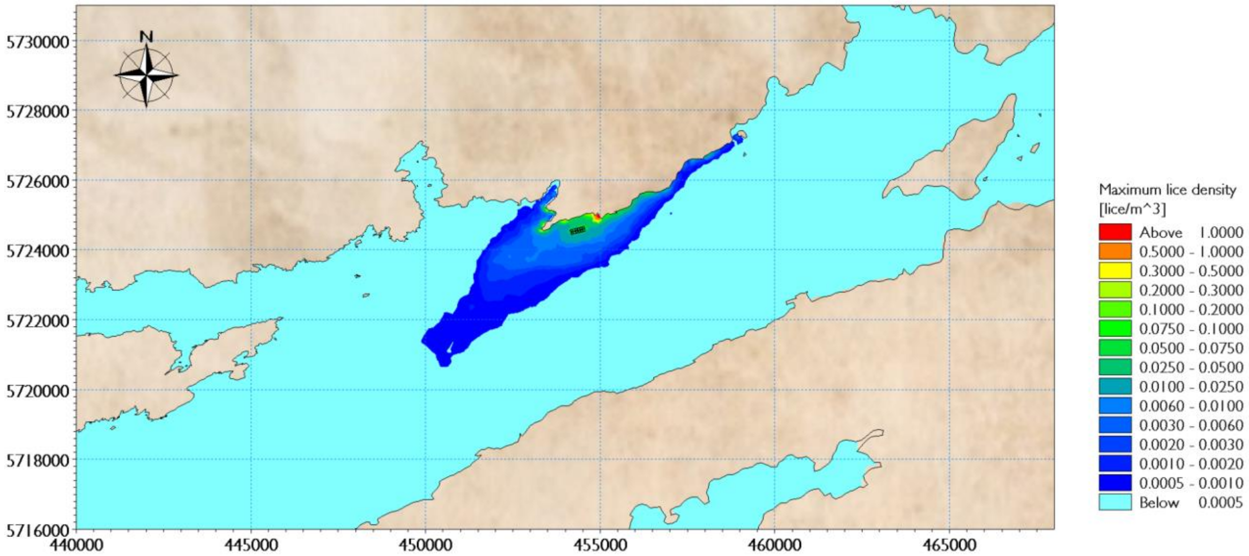


Figure 5.57: Maximum Plume Envelope, copepodid population F5 South Westerly wind

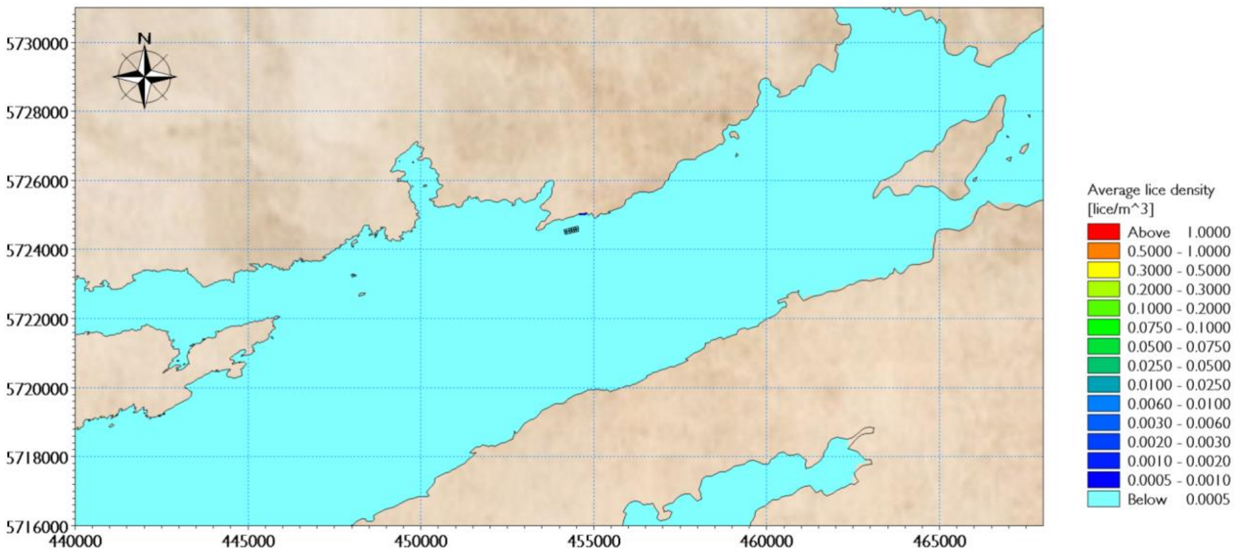


Figure 5.58: Average Plume Envelope, copepodid population F5 South Westerly wind

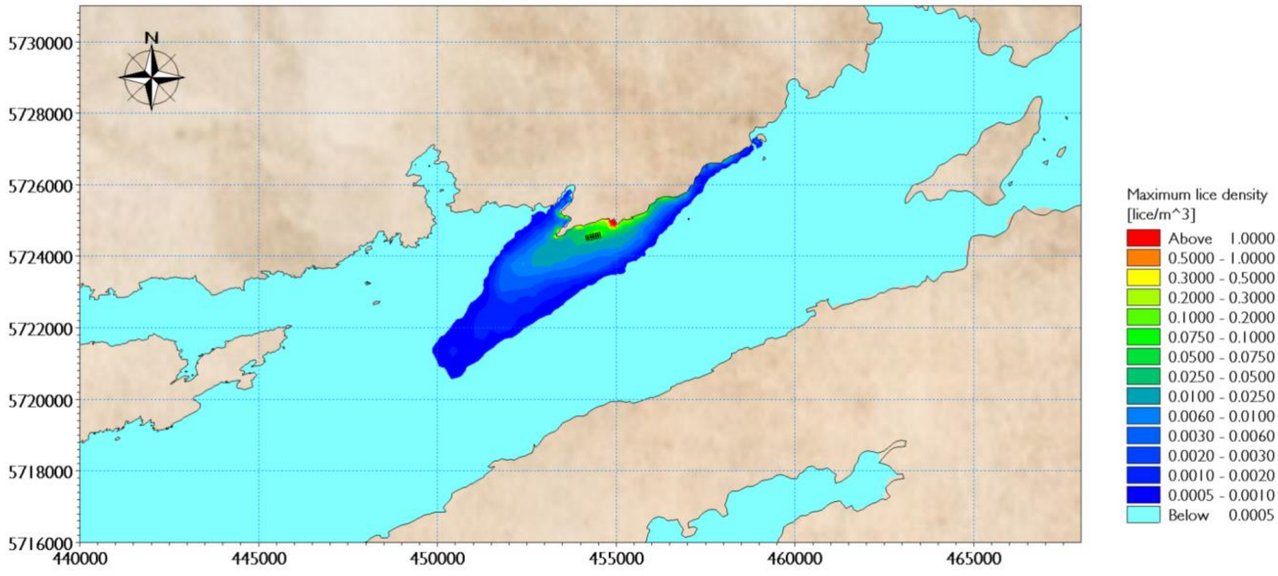


Figure 5.59: Maximum Plume Envelope, total population F5 South Westerly wind

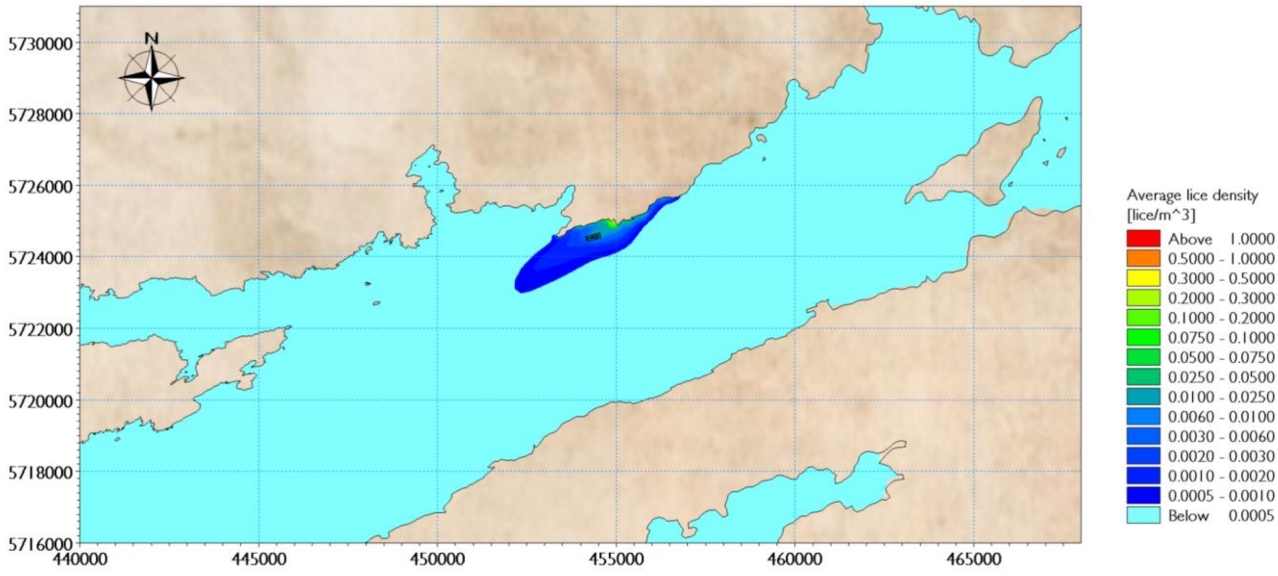


Figure 5.60: Average Plume Envelope, total population F5 South Westerly wind

The second scenario investigated an onshore wind perpendicular to the shoreline. Figure 5.61 and Figure 5.62 show the maximum and average copepodid densities respectively whilst Figure 5.63 and Figure 5.64 show the entire population. As with the stronger south westerly scenario the lice are driven inshore, however they are readily dispersed and prior to reaching maturity. It is noteworthy that the dispersion throughout the Bay in an offshore direction greater than that without wind forcing due to the overturning currents.

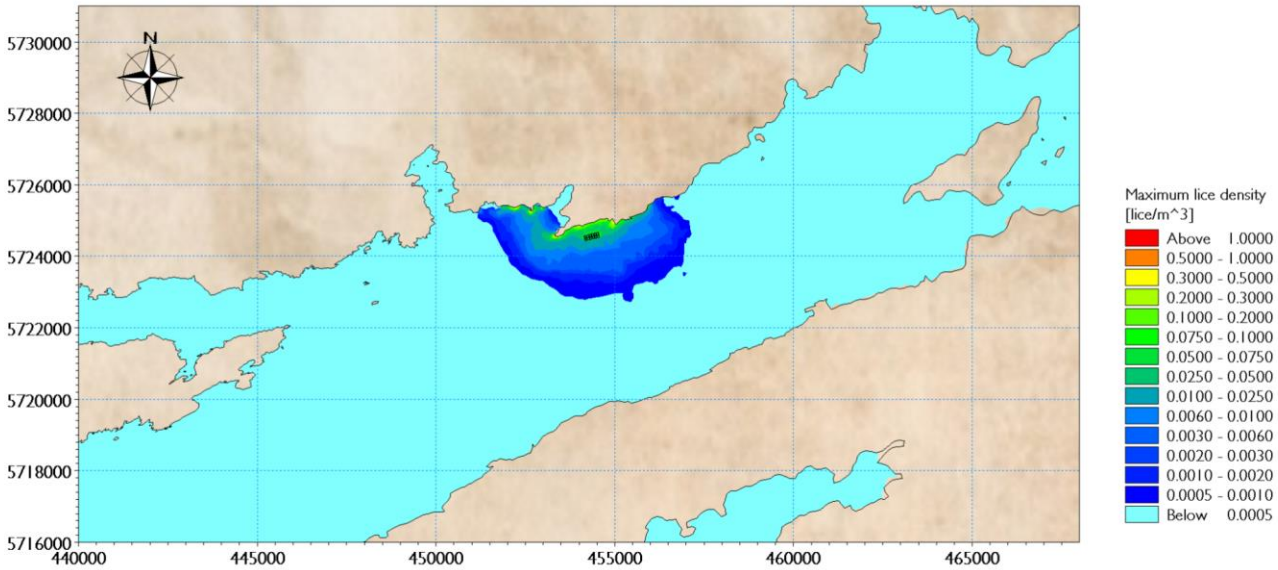


Figure 5.61: Maximum Plume Envelope, copepodid population F4 South Easterly wind

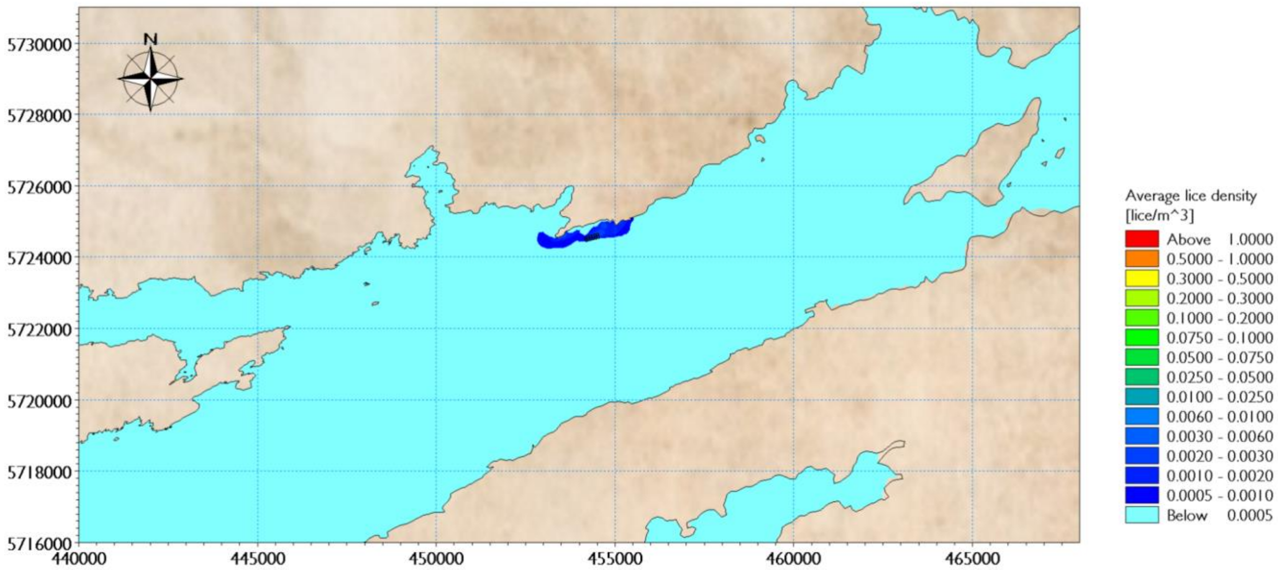


Figure 5.62: Average Plume Envelope, copepodid population F4 South Easterly wind

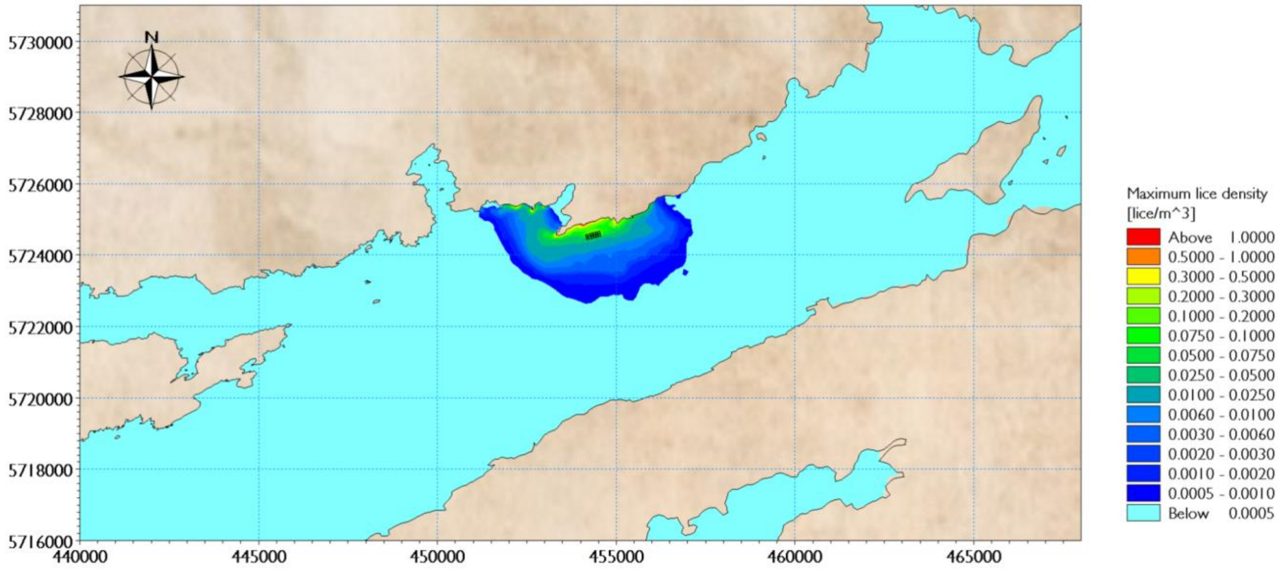


Figure 5.63: Maximum Plume Envelope, total population F4 South Easterly wind

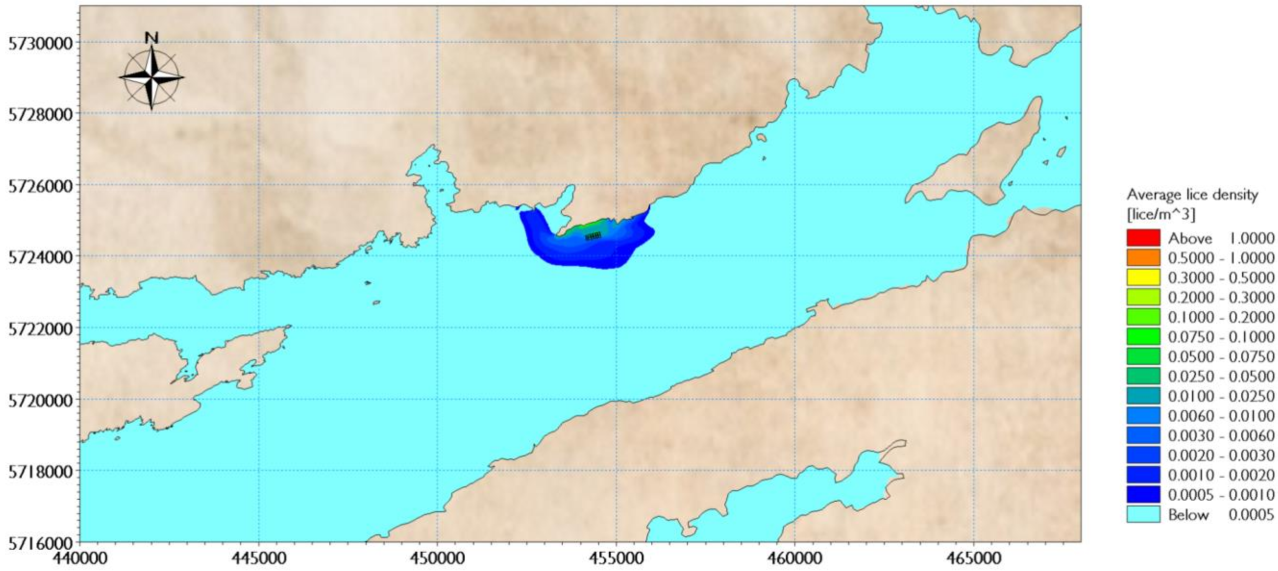


Figure 5.64: Average Plume Envelope, total population F4 South Easterly wind

The behaviour of the lice dispersion and the fact that they do not congregate under onshore wind conditions may be explained by examining the nearshore current profile. Wind friction will act on the water surface and drive the upper portion of water towards the shore, however this shoreward flow will limited by the depth of the influence of the wind. In shallow water when the influence reaches close to the bed the bed friction will counteract this and an overturning current is formed, as illustrated in Figure 5.65. The wind driven current cannot continuously drive fluid (and particles carried within it) to the shore without a return flow or flooding would continuously occur. Conditions of wind setup or seiching may occur where water levels are altered by the influence of the wind however neutrally buoyant media, such as lice, cannot by definition re-concentrate/congregate. Only by the release of further lice into populated waters can the density of lice be increased.

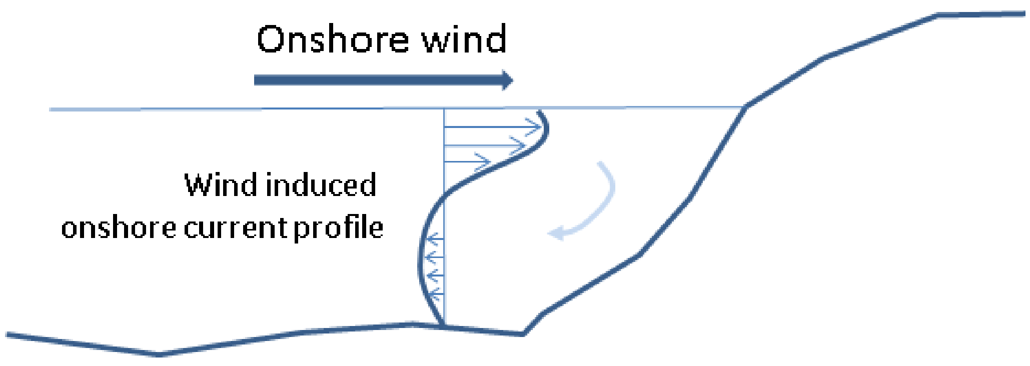


Figure 5.65: Wind induced overturning current profile

Although the hydrodynamic model used within the study was two dimensional, the particle tracking module enabled the application of logarithmic current profile. The particles therefore also have a position within the water column (i.e. those near the surface will be subject to greater current speeds). Within the wind simulations the wind induced currents were also enable wind the onshore current profile being applied by use of a wind coefficient such as the formulation shown in Figure 5.66.

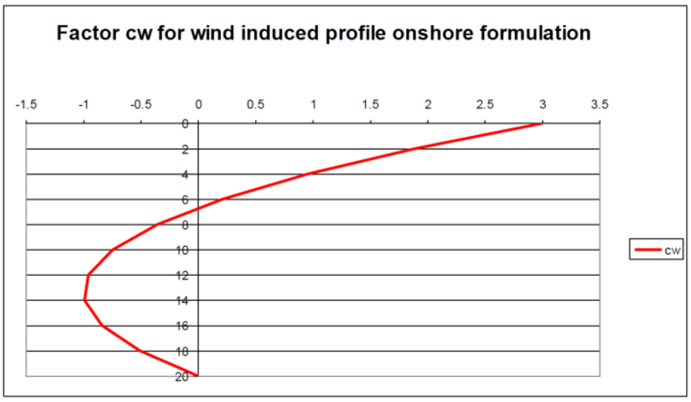


Figure 5.66: Formulation of wind induced overturning current profile

It should be noted that the wind simulation were performed on the basis of the effect of the tidal currents and wind alone. In reality the prolonged wind speeds of F4 and above would be accompanied by wave action. The combined littoral currents would provide a much more energetic mixing environment and increase the dispersion of lice enormously. These are also conditions which migrating fish are likely to avoid in favour of more sheltered estuarine locations.

In addition to the simulating the possible dispersion of lice larvae from all existing and currently proposed Bantry Bay salmon farm sites, detailed analysis was also undertaken at each of the sensitive river receptors around the shores of the bay, all of which are detailed in Figure 5.67 and Table 5.10. At each location the number of both the total and infestive stage lice were examined over the simulation period. In all but one case, no lice either nauplii or copepodids reached the river estuaries. The exception was the Owengarriff River located in close proximity to the Waterfall site; however the maximum concentration was less than 0.0025 lice/m^3 therefore very unlikely to impact on wild salmon migration.

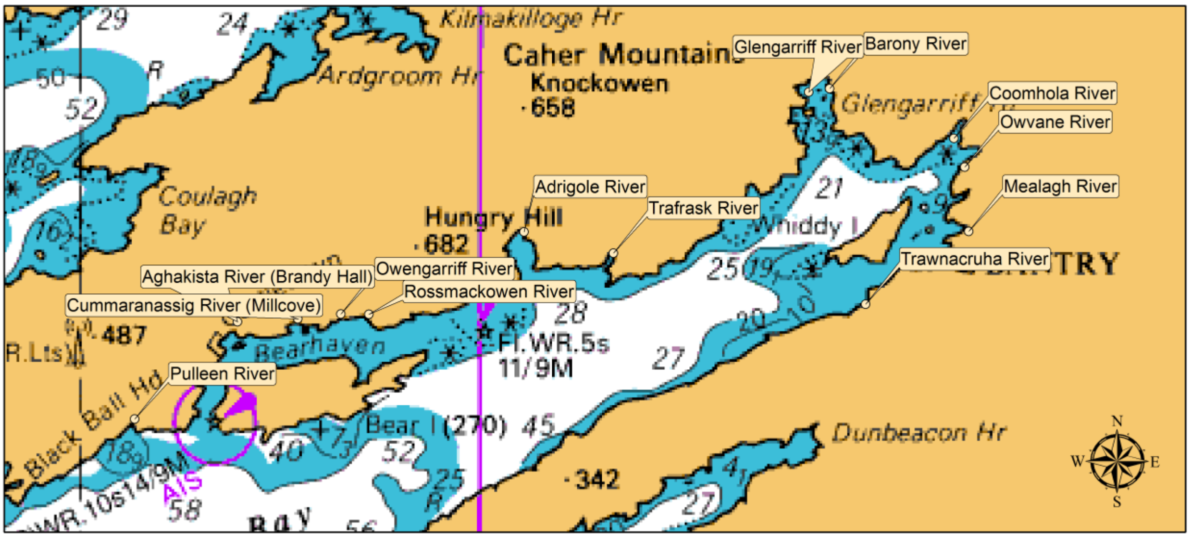


Figure 5.67: Estuaries in the Bantry Bay Region

Table 5.10: Estuaries in the Bantry Bay region

River / Bay	Irish National Grid Easting / Northing	WGS84
Pulleen River	63764 / 42193	51.61634N / -9.96766W
Aghakista River (Brandy Hall)	68287 / 46328	51.65456N / -9.90396W
Cummaranassig River (Millcove)	70911 / 46423	51.65601N / -9.86610W
Owengarriff River	72782 / 46609	51.65811N / -9.83915W
Rossmackowen River	73998 / 46573	51.65807N / -9.82151W
Adrigole River	80790 / 50047	51.69075N / -9.72492W
Trafrask River (Dromogowlane R)	84663 / 49073	51.68281N / -9.66835W
Glengarriff River	93249 / 55920	51.74603N / -9.54635W
Barony River	94161 / 56050	51.74737N / -9.53319W
Coomhola River	99530 / 53835	51.72845N / -9.45484W
Owvane River	99983 / 52587	51.71733N / -9.44793W
Mealagh River	100110 / 49800	51.69230N / -9.44529W
Trawnacruha River	95588 / 46722	51.66383N / -9.50975W

In this context, it is necessary to offer some perspective on what a "critical concentration for infestation" by *Lepeophtheirus* copepodids might be. Copepodids have been observed to dart 10cm to reach a host. Thus each copepodid has a maximum potential "infestation zone" equivalent to a sphere of diameter 20cm, of which 125 can be close-packed into 1m^3. Thus, although only true when the copepodids are evenly spread through the volume in question (as might be expected in active dispersion), it might be said that infestation by at least one copepodid when a host passes through 1m^3 of water is only 100% certain when minimum copepodid density is 125/m^3 [5]. Under these circumstances, the confidence level for infestation when a single host passes through 1m^3 of water containing between 0.1 to 1.0 larvae/m^3 can be calculated to lie between 0.08% and 0.8%. This confidence level, which is low by any standard will fall proportionately lower at larval concentrations of less than 0.1/m^3, a copepodid density which applies

A further observation is that the lice populations on wild sea trout sampled by the CFB over many years broadly comprise lice at the same life stage (in particular Chalimus I larvae). It is argued that such infestations can only have arisen from single, essentially simultaneous infestation events by many copepodids, which then metamorphose into Chalimus I larvae more or less simultaneously. Such a homogeneous population could not be the result of an extended infestation event, where copepodids attach to a host as it swims through low densities of lice over a number of days or longer, since such infestations would comprise a heterogeneous mix of settled lice life stages.

5.7.4 Wild lice dispersion

The second area of sensitivity which was investigated was the susceptibility of the proposed site operations to infestation from wild lice sources. It is known that lice are carried by wild fish stocks into estuaries and rivers. Subsequently, nauplii will hatch and be released and carried with riverine and tidal flows. The purpose of the study was to initially establish the dispersion routes. Therefore the assessment was carried out using theoretical numbers of infestive fish and released nauplii.

At each river mouth location, a constant flux of lice was released over the flood tide, the 14-day life cycle of planktonic lice larvae with decay was applied over the 22-day simulation. Two datasets for copepodid and full lifespan i.e. the nauplius stage was not removed as it could not be assumed that hatching occurs at the release location and may occur further upstream and the lice may have metamorphosed into Copepodids by the time that they reach the river mouth.

Figure 5.68 shows the maximum lice density for the copepodid stage whilst Figure 5.69 shows the full lifecycle for all the rivers in the locality of the operation and proposed farm sites. The largest concentrations will generally occur at the source of the nauplii release at the mouth of the estuaries which is seen to be circa 0.5 lice/m^3. It can be seen that in most cases the lice become widely dispersed within close proximity to the river mouth. The exception being the Waterfall site where the tidal currents are at the lowest due to the confluence of tides around Bear Island. In more detail Figure 5.70 shows the maximum lice density for the copepodid stage whilst Figure 5.71 shows the full lifecycle in this area. The maximum density to reach the outer boundary of the site is less than one fiftieth of the source value and no lice from wild origins pass through any of the pens. The modelling demonstrates that even the Waterfall site is not susceptible to the wild lice population and therefore would not exacerbate their prevalence.

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[5] It should be noted that the figure of 125 larvae / m^3 is somewhat higher than the 31 to 54 larvae/m^3 calculated for the commencement of the dispersion of the larvae resulting from the presence of trigger level of 1 ovigerous adult female per farmed salmon and also higher than the 70 larvae per m^3 collected by Costelloe et al in the vicinity of the salmon farm in Killary Harbour in 1994).

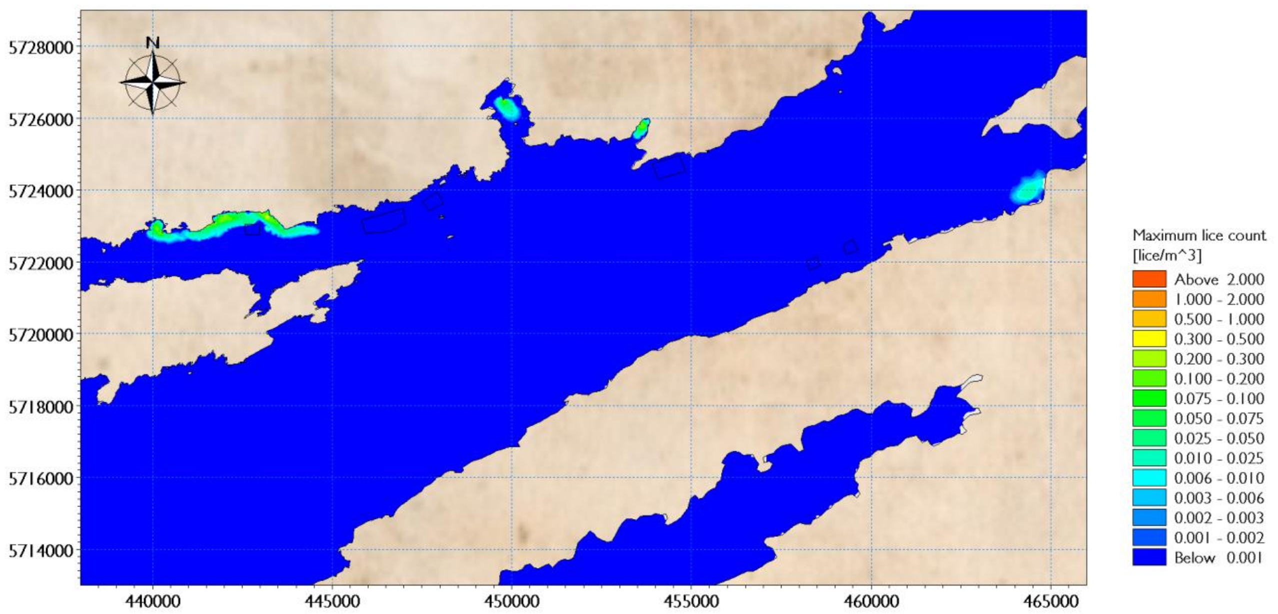

Figure 5.68: Maximum wild copepod lice density

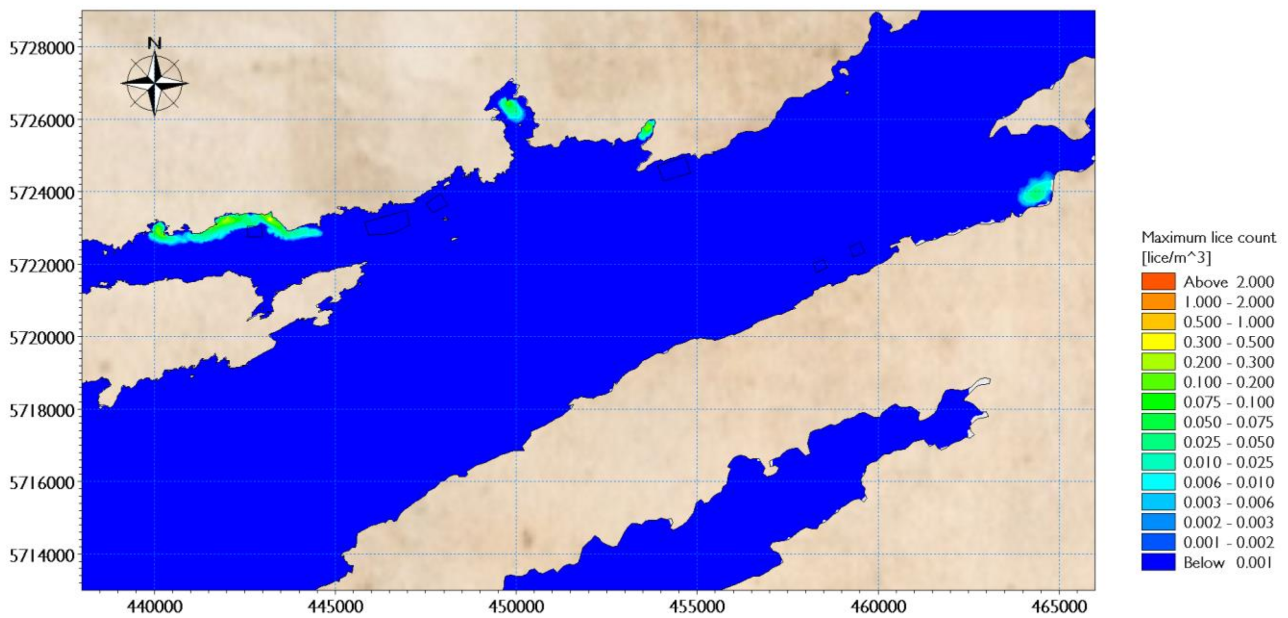

Figure 5.69: Maximum wild total lice density

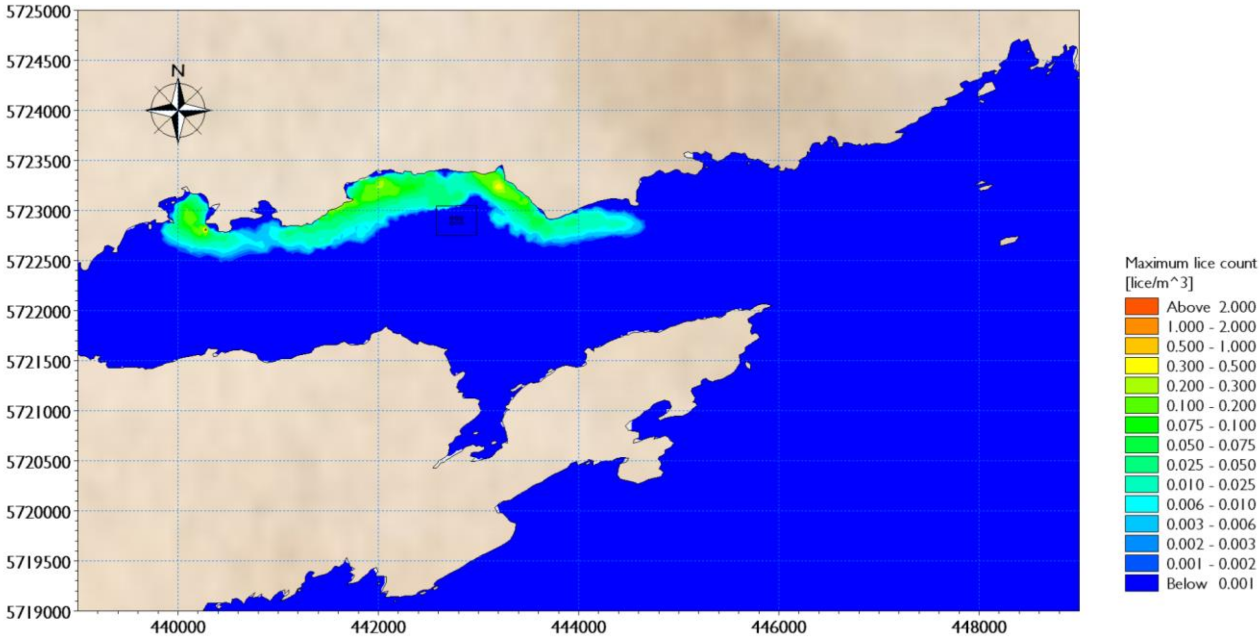

Figure 5.70: Maximum wild copepod lice density for rivers in the vicinity of Waterfall

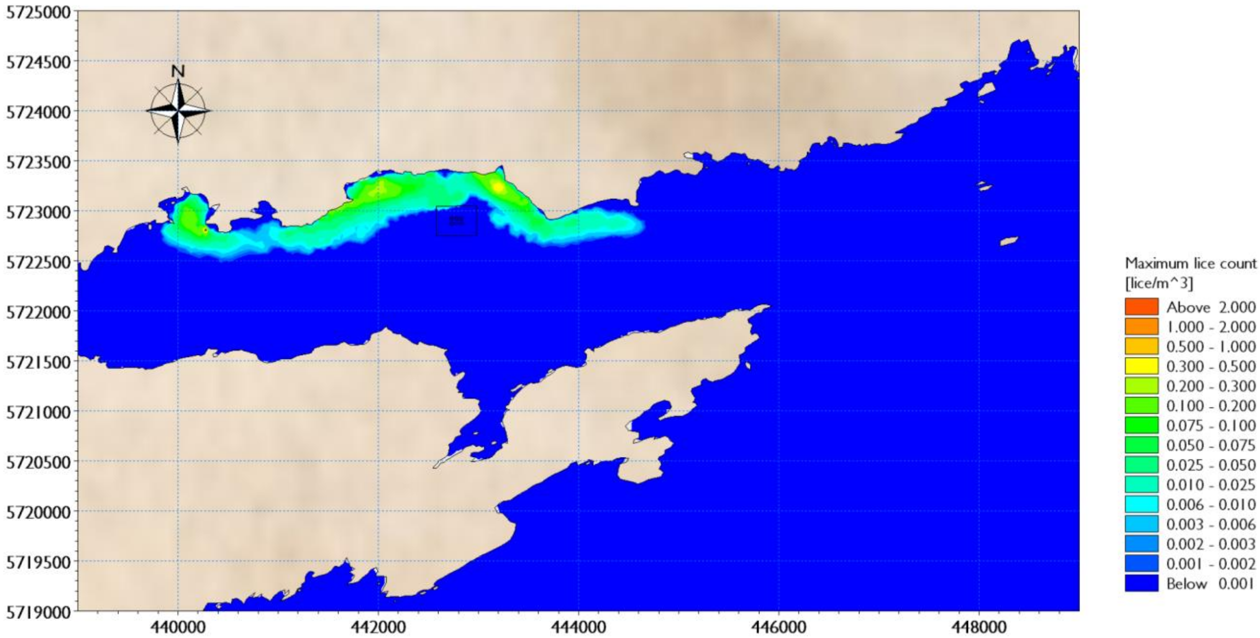

Figure 5.71: Maximum wild total lice density for rivers in the vicinity of Waterfall

6 SUMMARY

A commission was undertaken by RPS, on behalf of Marine Harvest Ireland (MHI), to investigate the effects on water quality of the development of salmon farming activities in Bantry Bay, County Cork. To this end a comprehensive numerical modelling study was undertaken. During the first phase of the modelling study an existing hydrodynamic model of Bantry Bay was updated and validated using hydrodynamic field data, which was collected and collated for this purpose.

The model output showed a good level of correlation with the measured data and the model is therefore deemed suitable for water quality and dispersion modelling. The calibrated hydrodynamic model was then used in the second phase to assess the effects of all potential discharges into the Bay as a result of the proposed fish farming activities in line with the European Communities (Control of Dangerous Substances in Aquaculture) Regulations and Scottish Environmental Protection Agency (SEPA) guidelines and Environmental Quality Standards (EQS's) for salmon farming. This utilised the database of background levels of the major water quality indicators that have been monitored by MHI over the past number of years.

Nitrogen, and Phosphorus discharges along with Biological Oxygen Demand (BOD) arising from fish feeds, from both ingested feed and from waste feed sources, were modelled. The discharges at the maximum monthly stocking density were evaluated. Additionally a worst-case in-combination scenario was investigated; with the total discharges (both settled and soluble) being discharged for the stocking level of each individual site for the largest combined site discharge (during the 24-month, alternating production schedule) for the licensed and proposed sites within Bantry Bay. The results of this modelling exercise showed that, for Nitrogen, Phosphorus and BOD, the discharges due to the proposed fish farming activity was typically lower than the existing background conditions and that established quality standards were not breached.

The settleable solids discharges arising from both projected waste feed and faecal matter from the farm sites were also modelled. It was found the no accumulation of salmon farm-origin sediments occurred beyond the immediate vicinity of each site, due to the low current speeds and sheltered locations. As a result, benthic communities remain "unchanged" and defined by the Infaunal Trophic Index at the outer Allowable Zone of Effect (AZE) 100m from the pens. At the inner AZE with a distance of 25m from the pens, the benthic communities may be “altered”, but not “degraded” which is within the legislative standards, as communities would recover during fallow periods. At Shot Head, within the cage limits the maximum depth was found to be around 12mm, this is due to the large diameter (70m) cage design which have a lower stocking density when compared with other sites. An investigation was undertaken to assess the role which wave induced currents may have on sedimentation patterns. It was found that wave conditions which may re-suspend material would have an average occurrence of around 20% and the flow at the site may be dominated by waves for up to 40% of the time. Therefore the influence of wave induced transport should be considered.

Irish salmon farm sites are constantly monitored for lice and if they are detected above Government-set levels the lice are treated; either by an in-feed *or* a bath treatment. Potentially these salmon farming activities may have associated treatment residues and these were also examined. Both types of treatments were investigated in order to assess their suitability and potential impact within Bantry Bay. The Slice® in-feed treatment was examined and determined to be unsuitable for use at the Shot Head site during the latter parts of the production cycle due to the sheltered location; however it may be appropriate to provide protection during the first susceptible period. The bath treatment Alphamax® (active ingredient Deltamethrin) was also examined in accordance with the EU protocol. The modelling concluded that it may be applied under application using either well boat or tarpaulin.

Although not required by any established standard and infestation being unlikely, the migration of sea lice within the Bay was examined to ascertain any potential risk to wild salmonid stocks. A series of dispersion scenarios was modelled, based on a range of the numbers of lice larvae that might be released from both the proposed site and including the effect of other salmon farming activities within the Bay. Under all scenarios tested, the concentrations of infestive copepodid stages throughout the Bay were found sufficiently small that augmentation of natural sources of infestation are considered unlikely to occur as a result of the presence of MHI's proposed salmon farming operations. This is due primarily to the limited lifespan and high mortality rate of lice larvae and the low fish numbers associated with a harvest site. Additionally, wind induced transport and wild lice sources were examined to ensure that the location of the proposed site would not be unduly susceptible to infestation by wild-origin lice populations or vice versa.

In all areas of Bantry Bay, the impact of the proposed increase in salmon production would fall well within the acceptable limits set out by the Scottish Environmental Protection Agency in their Environmental Quality Standards for salmon farming. The Environmental Quality Standards adopted by SEPA are well-tested, long-established and very widely adopted, not just in the context of salmon farming. Indeed they represent an important international benchmark in the field of environmental quality management as a whole. The apparent lack of impacts that this study projects will arise from the proposed salmon farming operations at Waterfall on Bantry Bay is felt to be due to the low production tonnage proposed and the alternating production plan that MHI proposes.

A. APPENDIX

Additional Calibration Figures

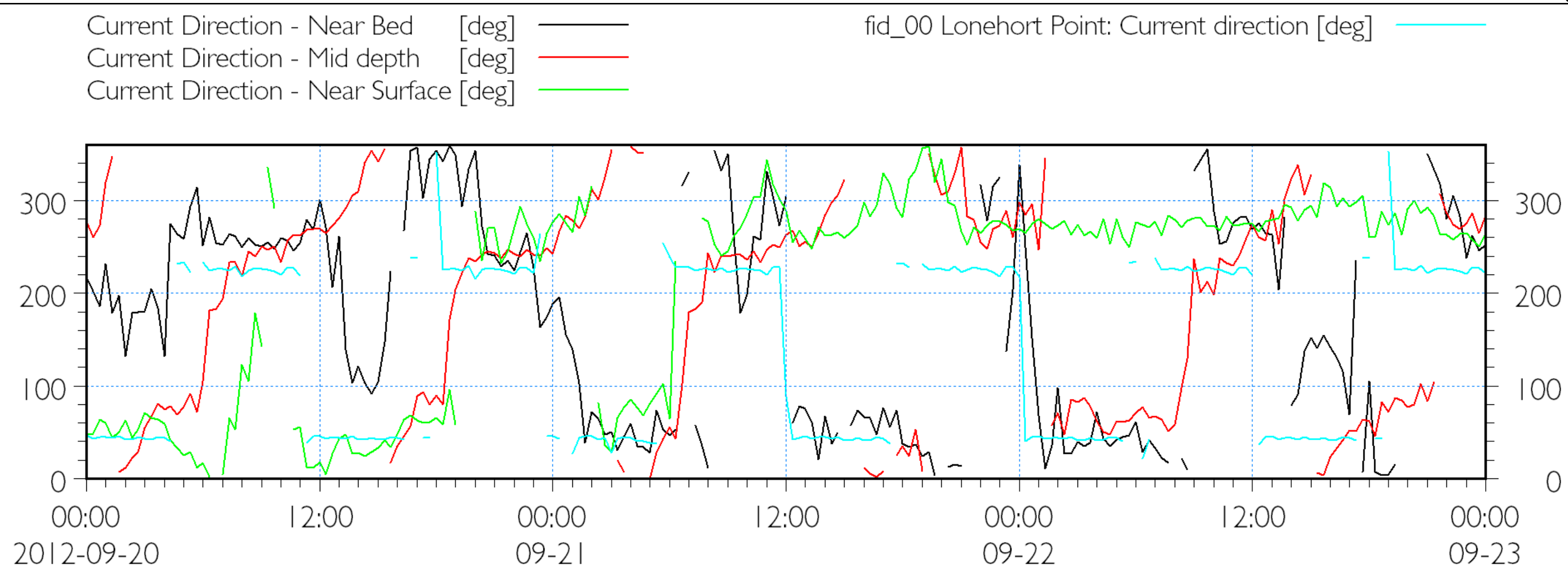

Figure A.1: Measured (left axis) and modelled (right axis) current direction – fid_00 Lonehort Point

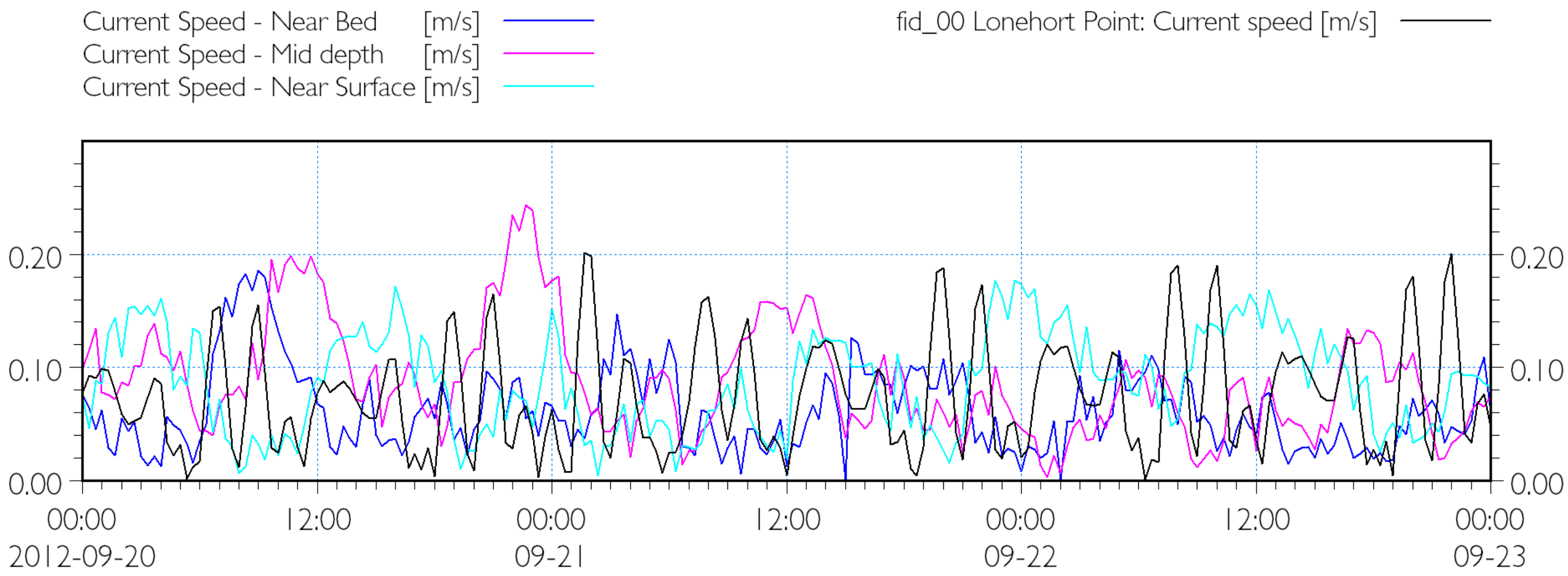

Figure A.2: Measured (left axis) and modelled (right axis) current speed – fid_00 Lonehort Point

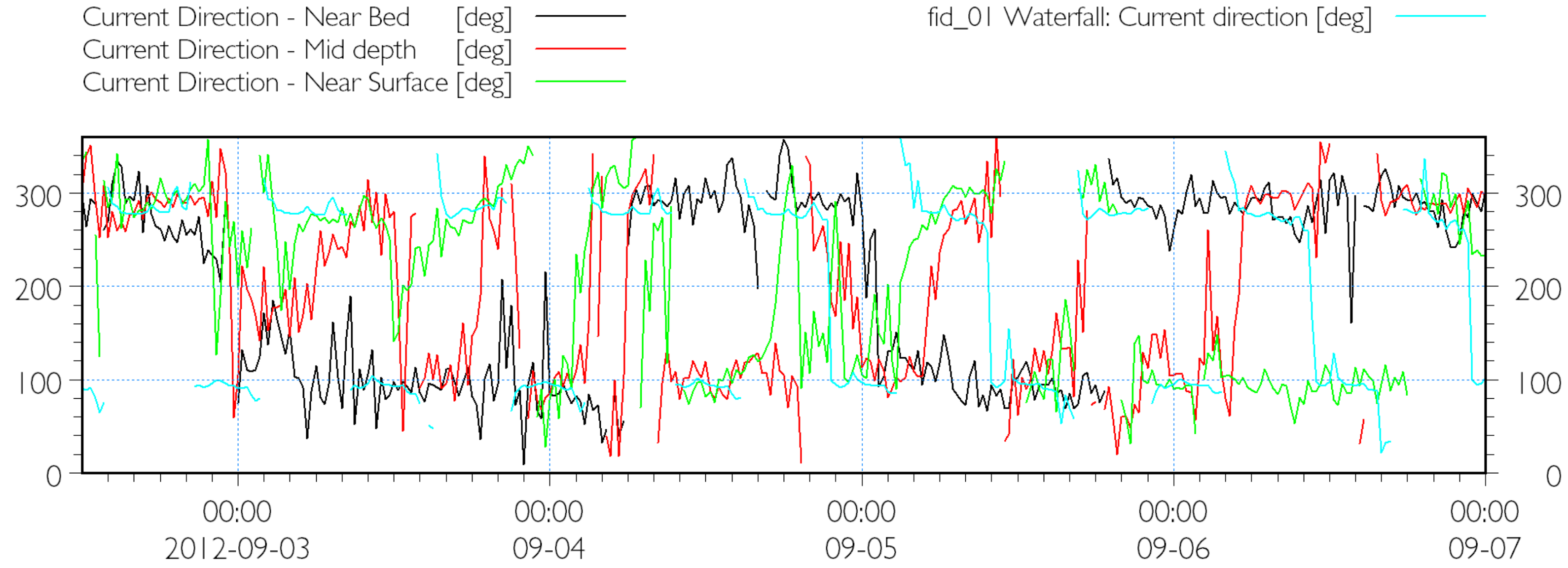

Figure A.3: Measured (left axis) and modelled (right axis) current direction – fid_01/02 Waterfall

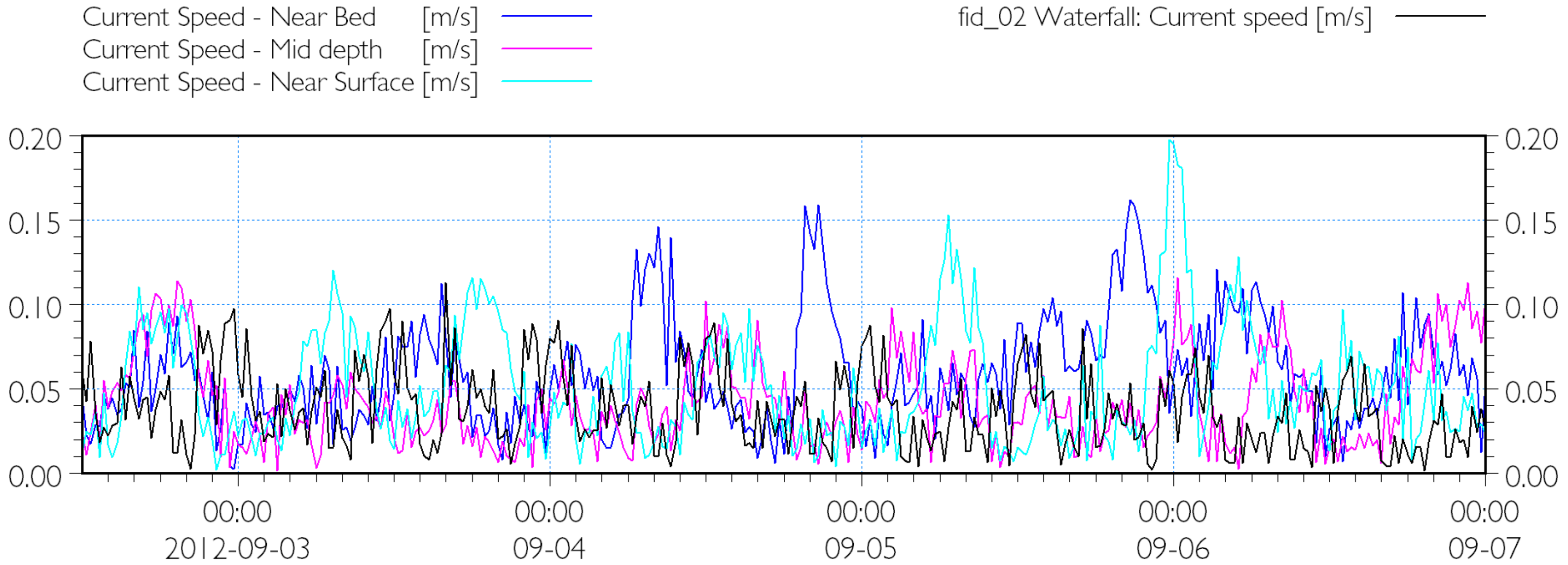

Figure A.4: Measured (left axis) and modelled (right axis) current speed – fid_01/02 Waterfall

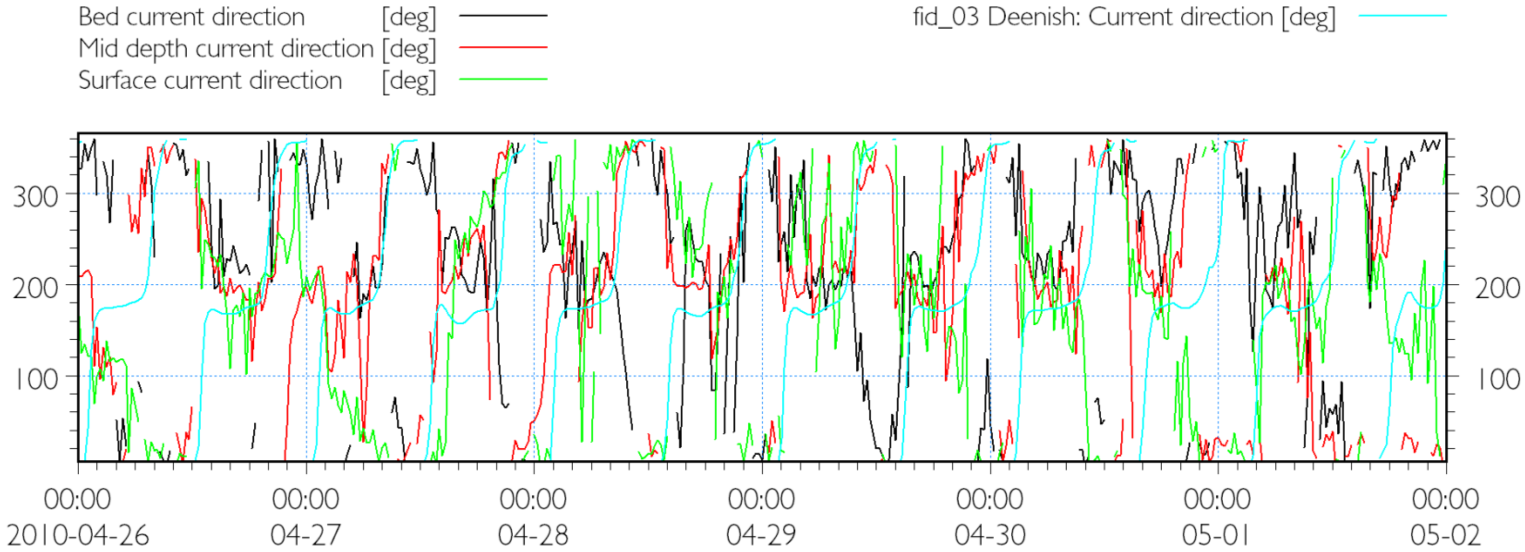

Figure A.5: Measured (left axis) and modelled (right axis) current direction – fid_03 Deenish

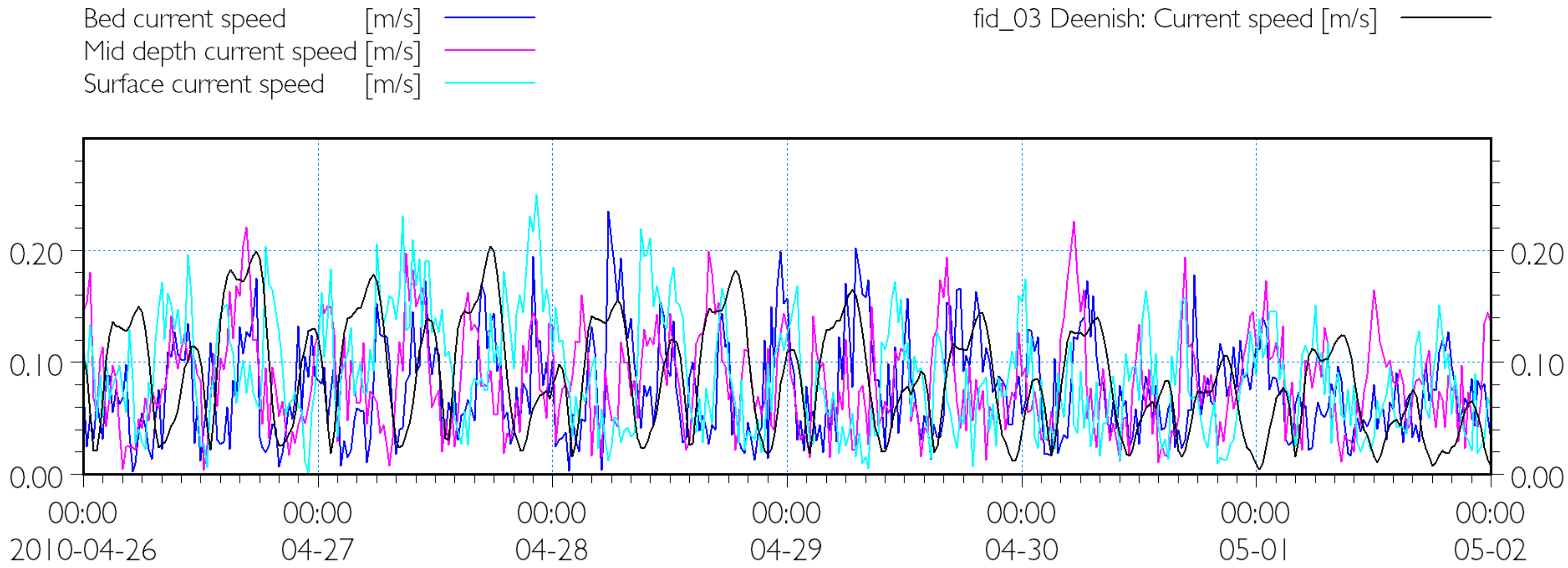

Figure A.6: Measured (left axis) and modelled (right axis) current speed – fid_03 Deenish

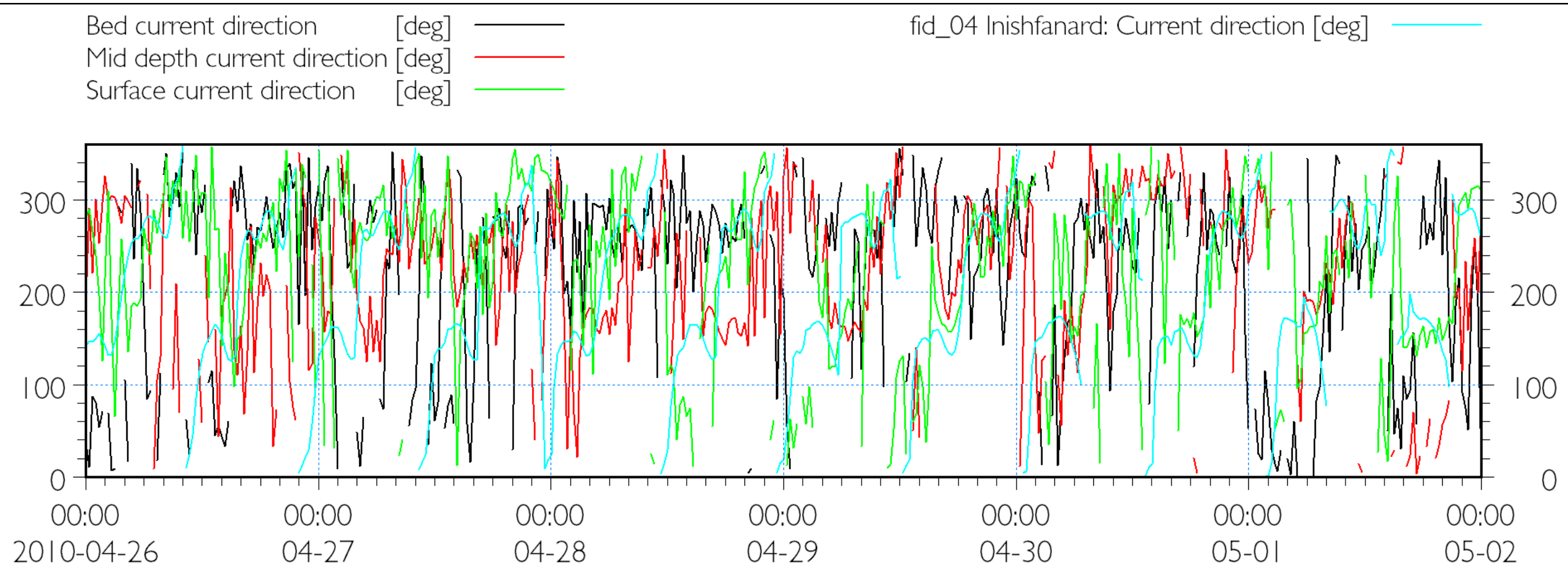

Figure A.7: Measured (left axis) and modelled (right axis) current direction – fid_04 Inishfarnard

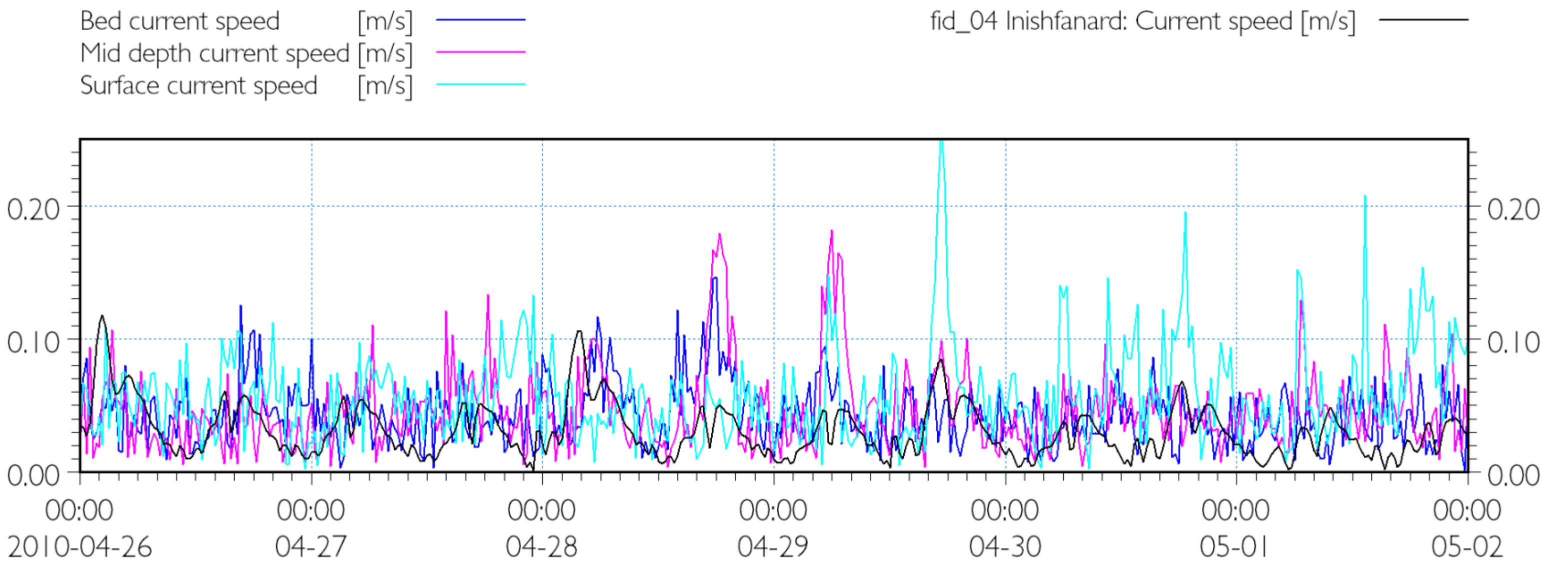

Figure A.8: Measured (left axis) and modelled (right axis) current speed – fid_04 Inishfarnard

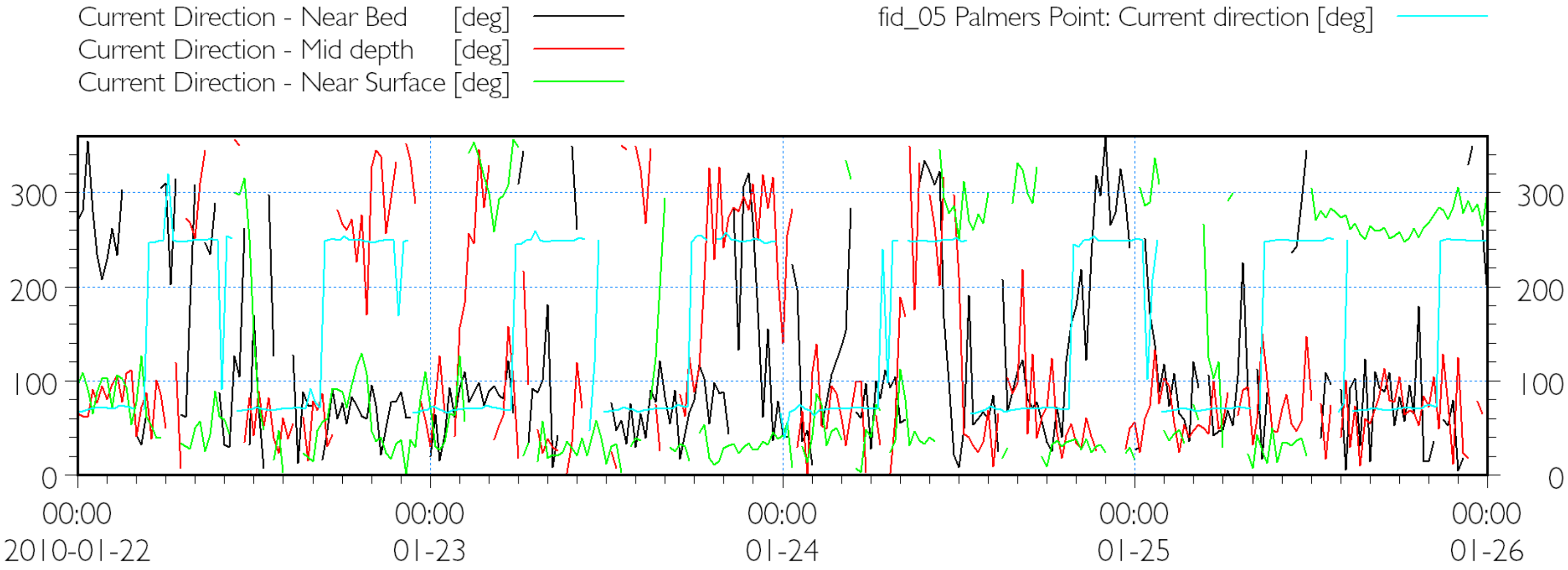

Figure A.9: Measured (left axis) and modelled (right axis) current direction – fid_05 Palmer's Point

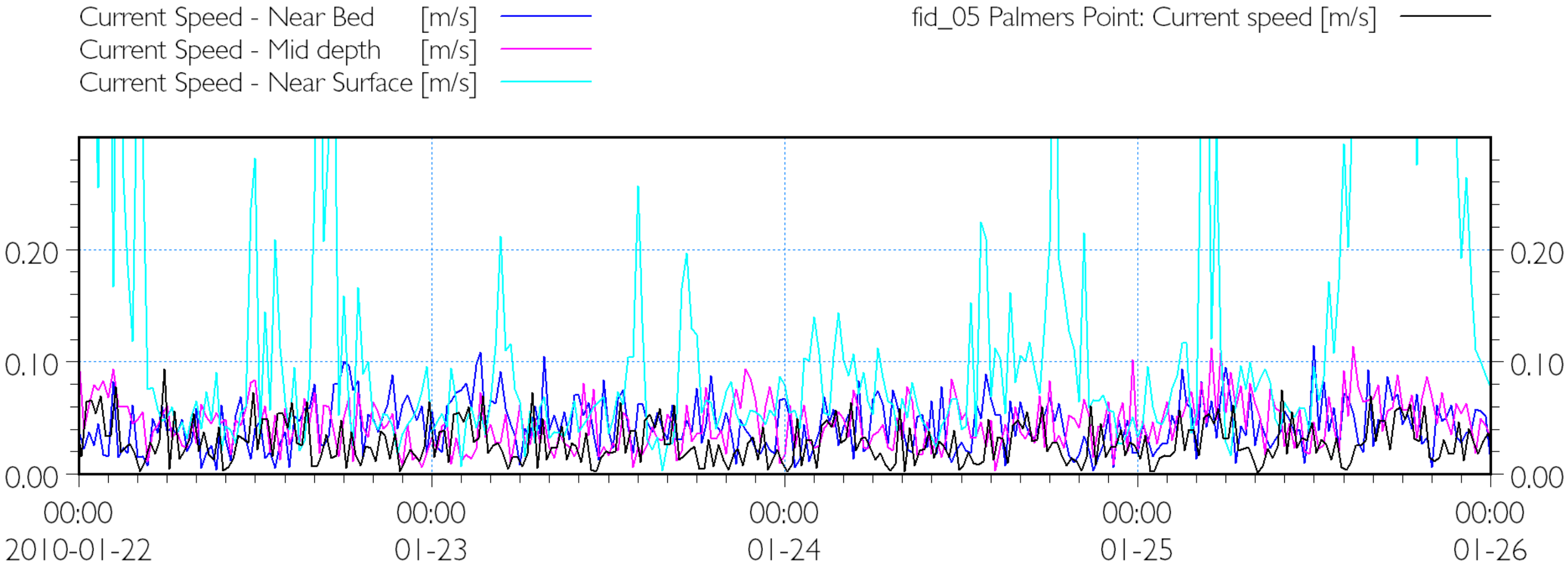

Figure A.10: Measured (left axis) and modelled (right axis) current speed – fid_05 Palmer's Point

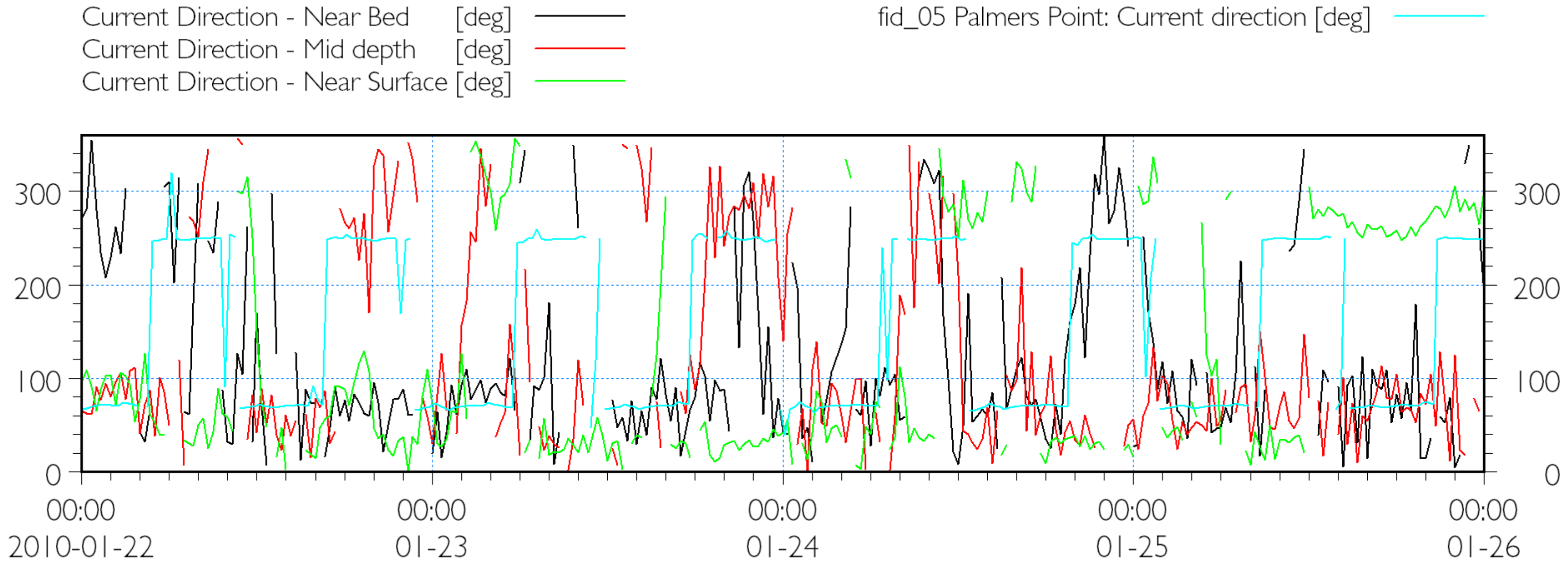

Figure A.11: Measured (left axis) and modelled (right axis) current direction – fid_05 Palmer's Point

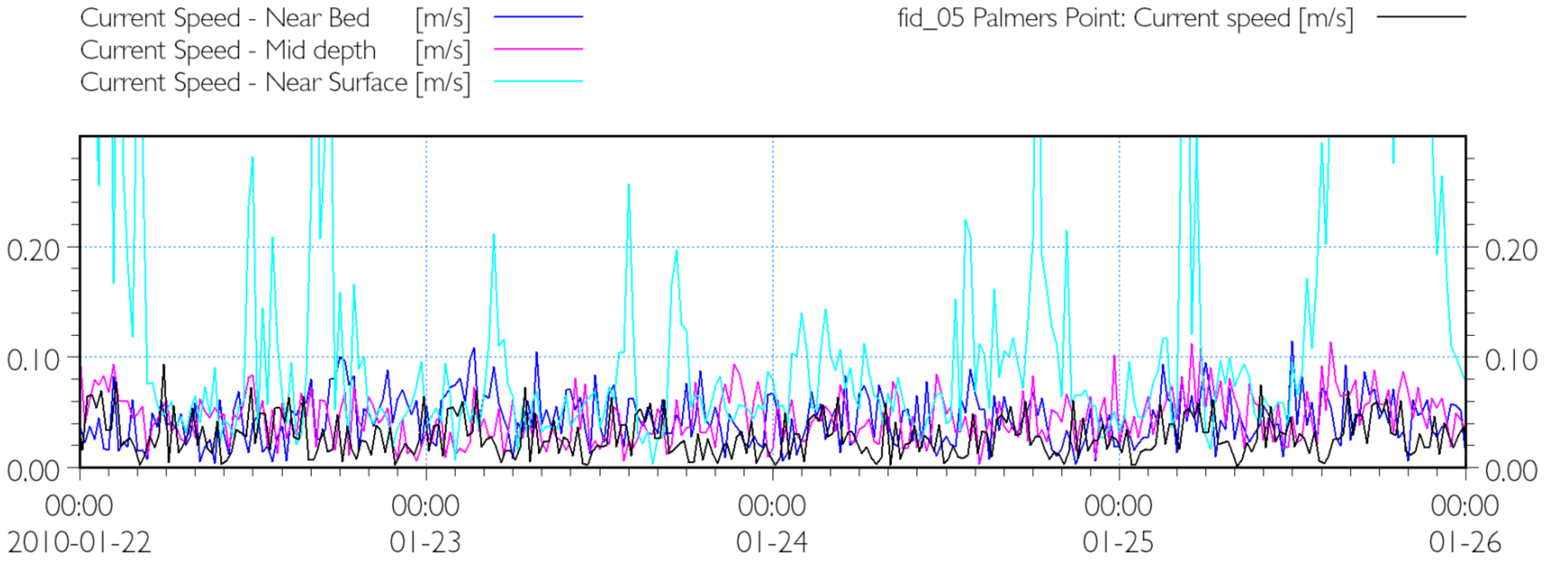

Figure A.12: Measured (left axis) and modelled (right axis) current speed – fid_05 Palmer's Point

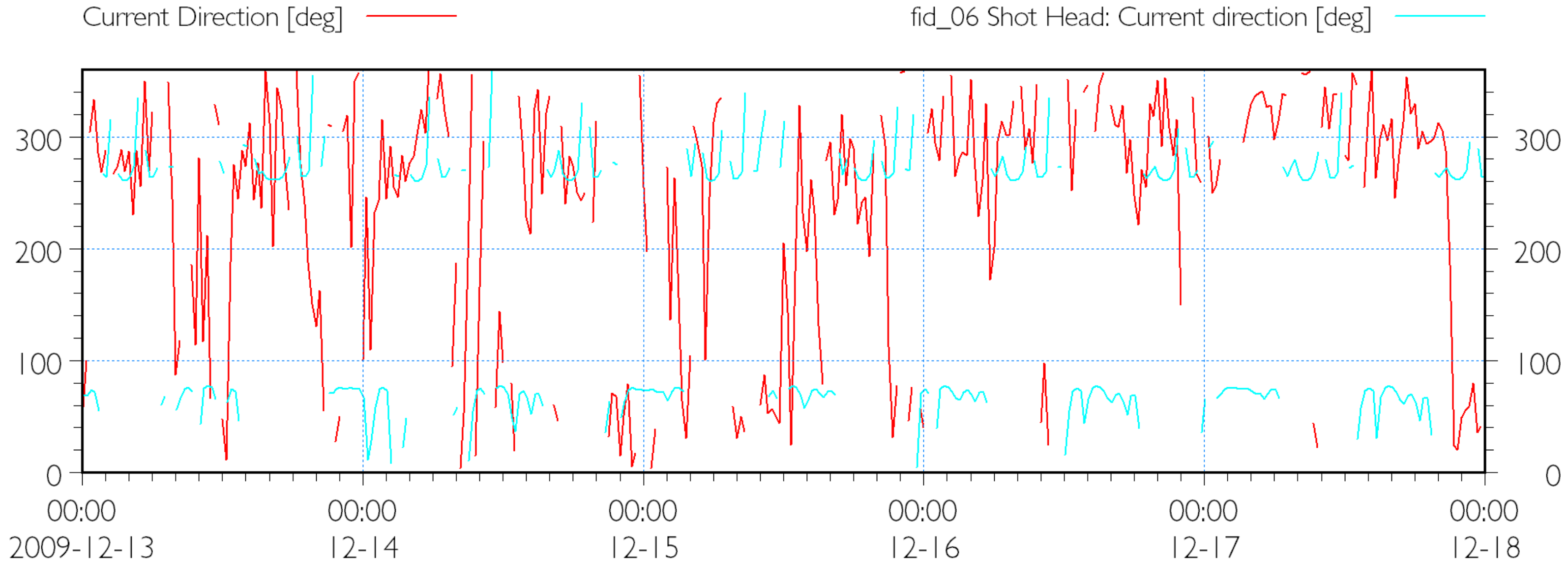

Figure A.13: Measured (left axis) and modelled (right axis) current direction – fid_06 Shot Head

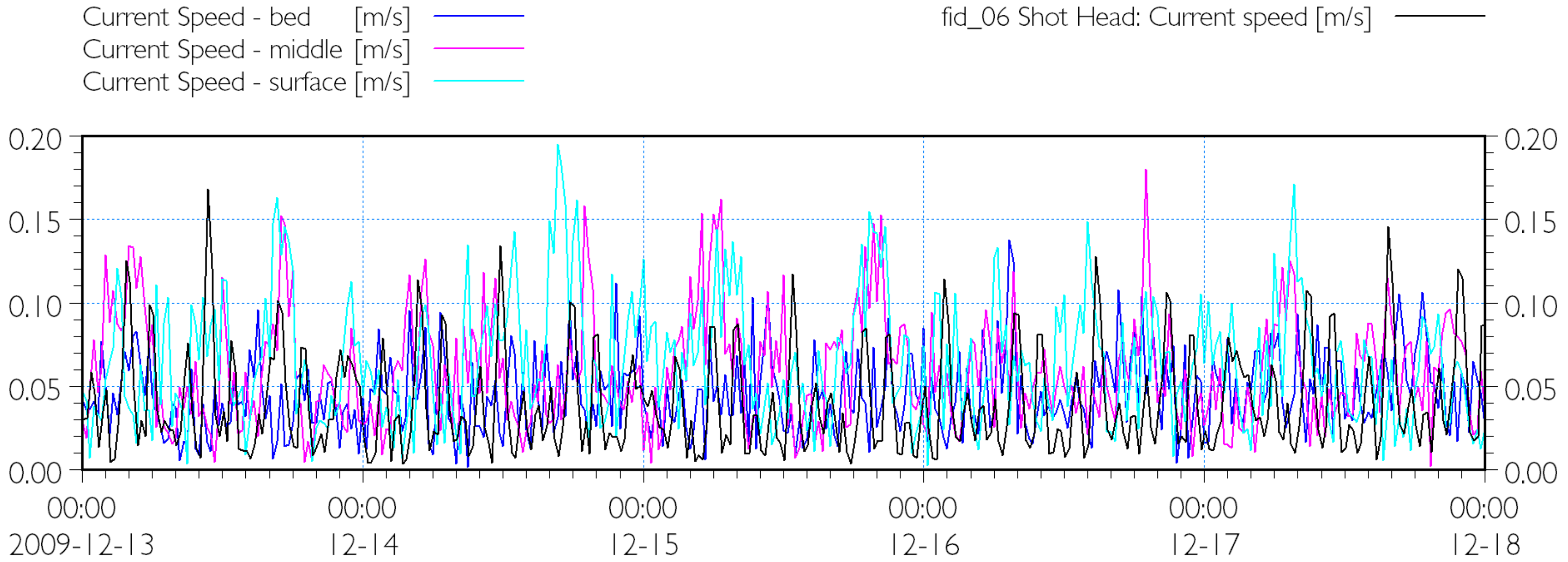

Figure A.14: Measured (left axis) and modelled (right axis) current speed – fid_06 Shot Head

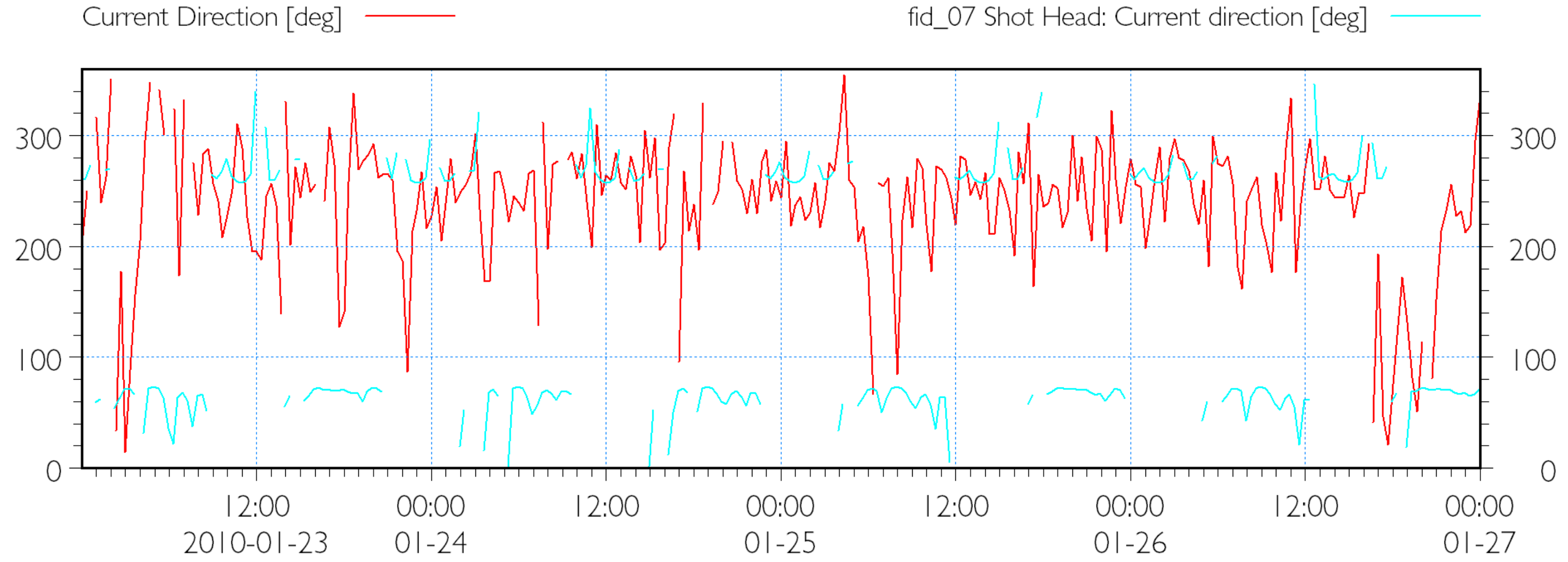

Figure A.15: Measured (left axis) and modelled (right axis) current direction – fid_07 Shot Head

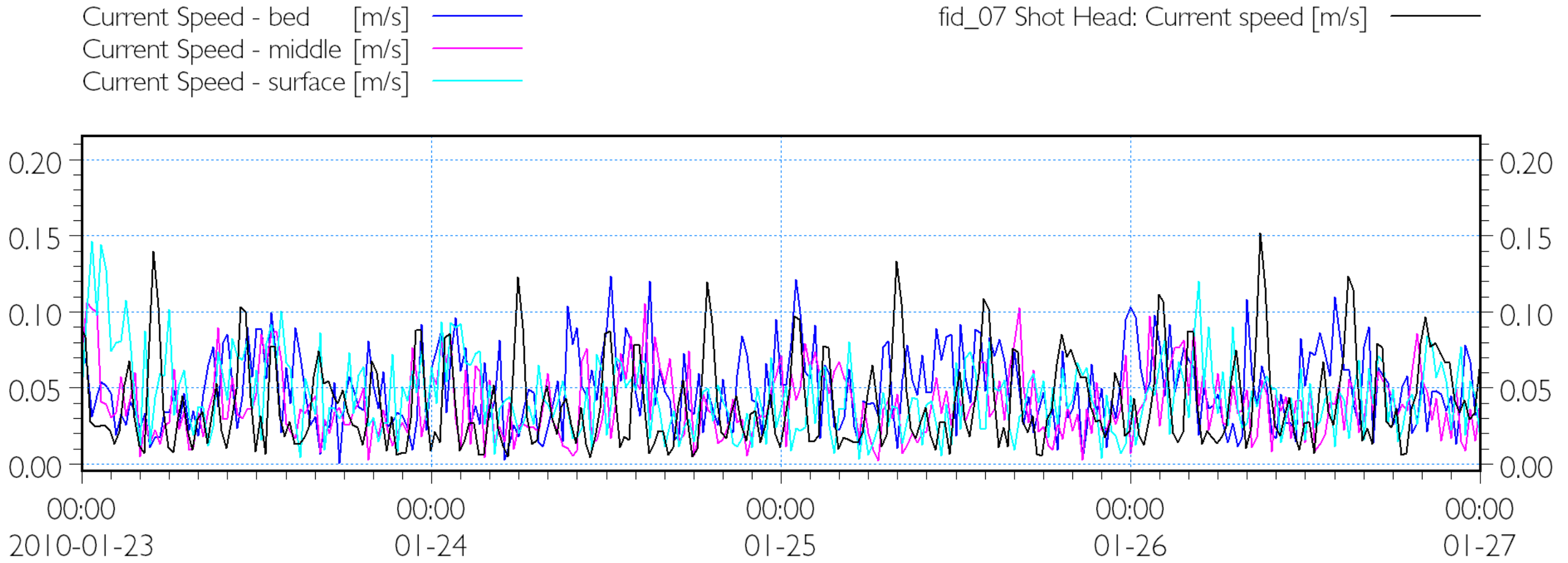

Figure A.16: Measured (left axis) and modelled (right axis) current speed – fid_07 Shot Head

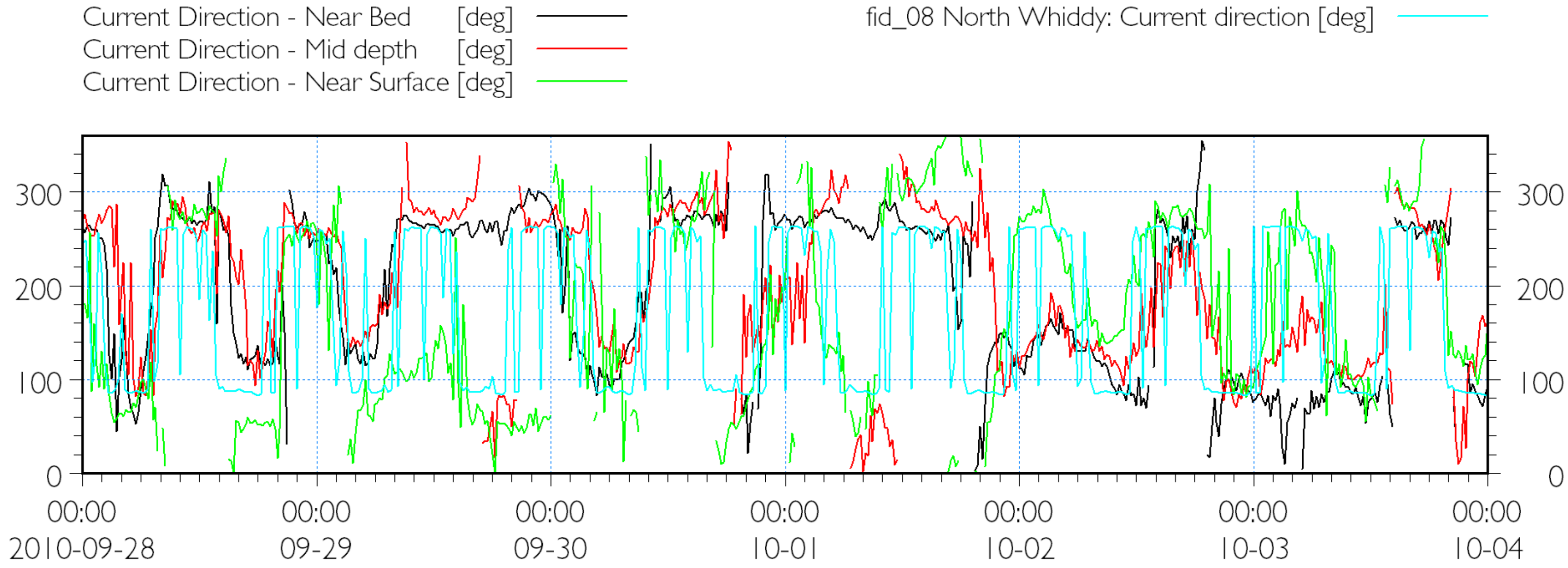

Figure A.17: Measured (left axis) and modelled (right axis) current direction – fid_08 North Whiddy

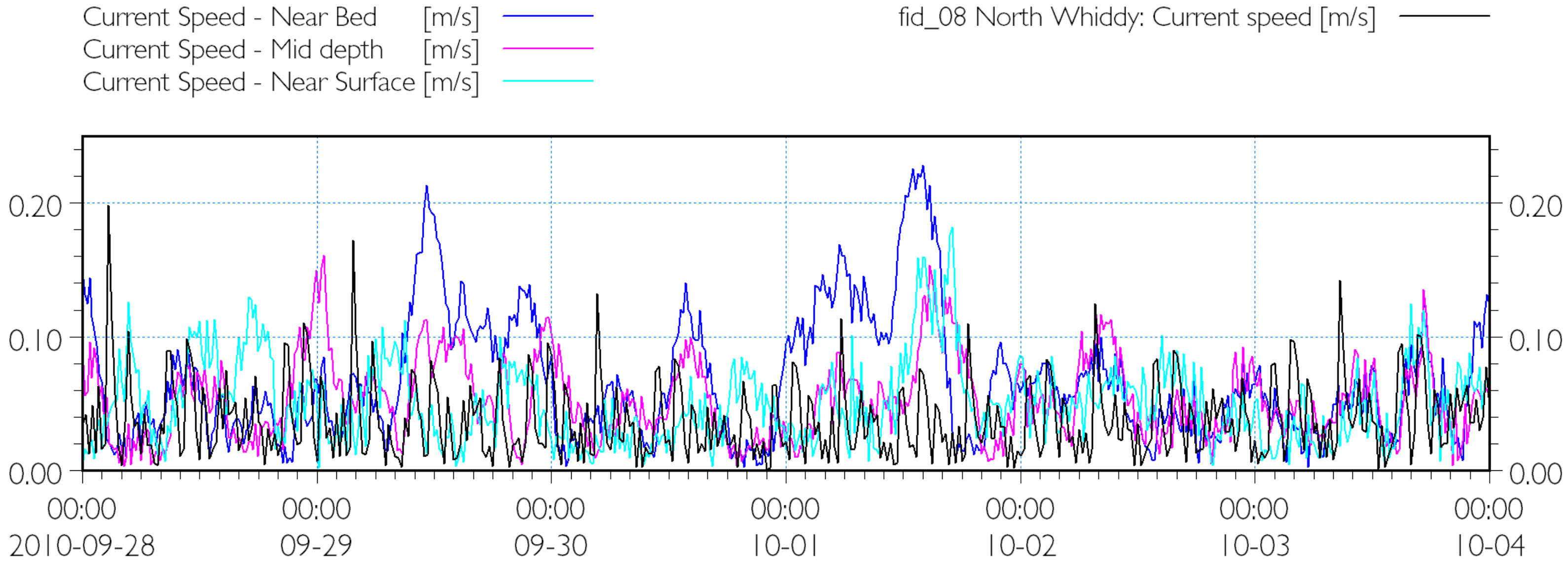

Figure A.18: Measured (left axis) and modelled (right axis) current speed – fid_08 North Whiddy

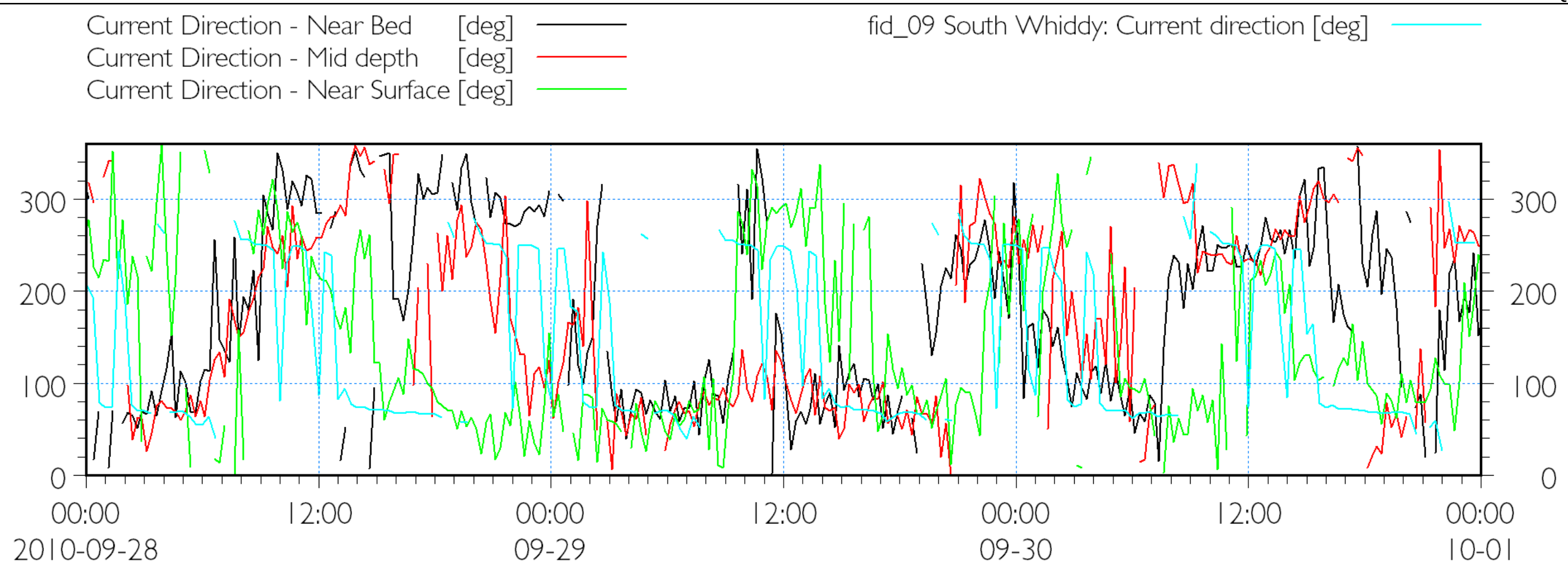

Figure A.19: Measured (left axis) and modelled (right axis) current direction – fid_09 South Whiddy

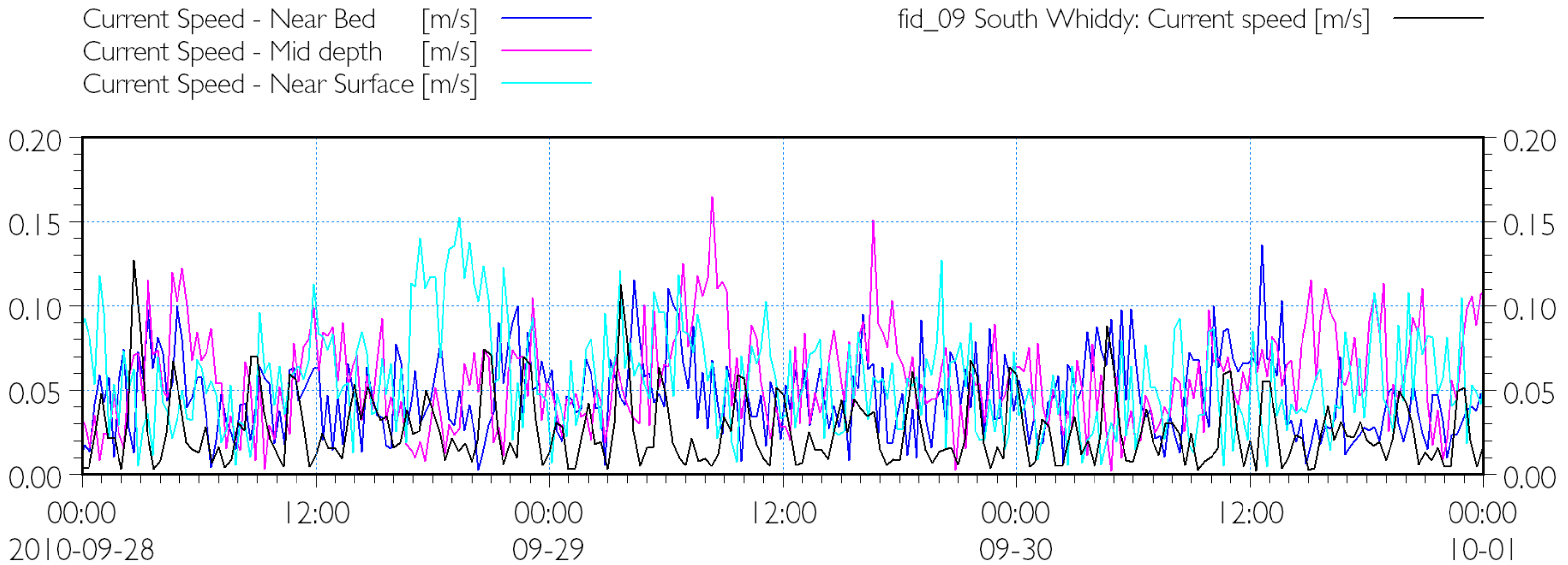

Figure A.20: Measured (left axis) and modelled (right axis) current speed – fid_09 South Whiddy

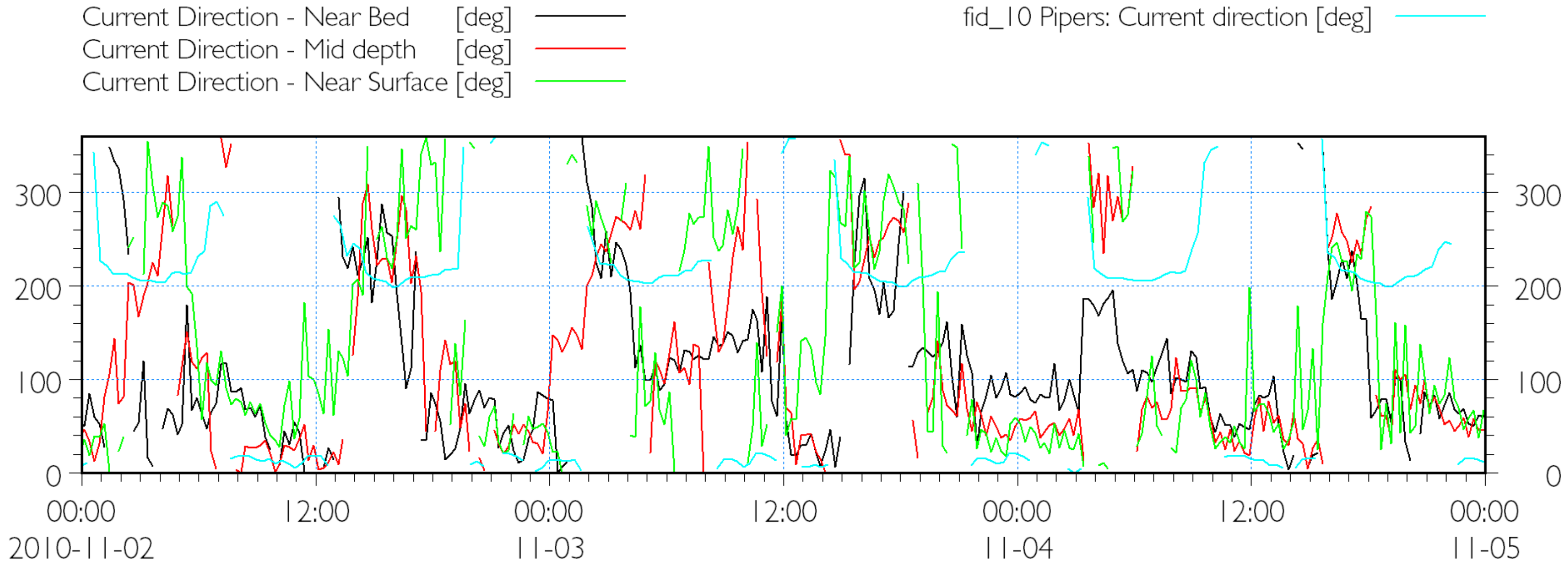

Figure A.21: Measured (left axis) and modelled (right axis) current direction – fid_10 The Pipers

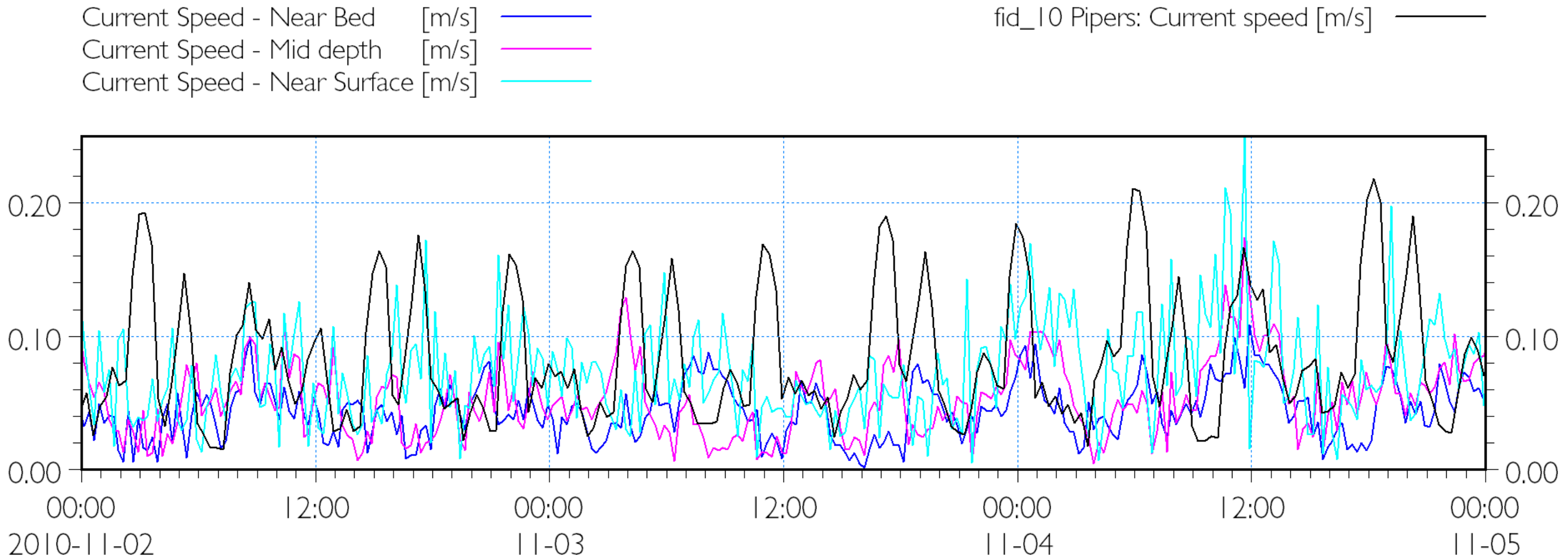

Figure A.22: Measured (left axis) and modelled (right axis) current speed – fid_10 The Pipers

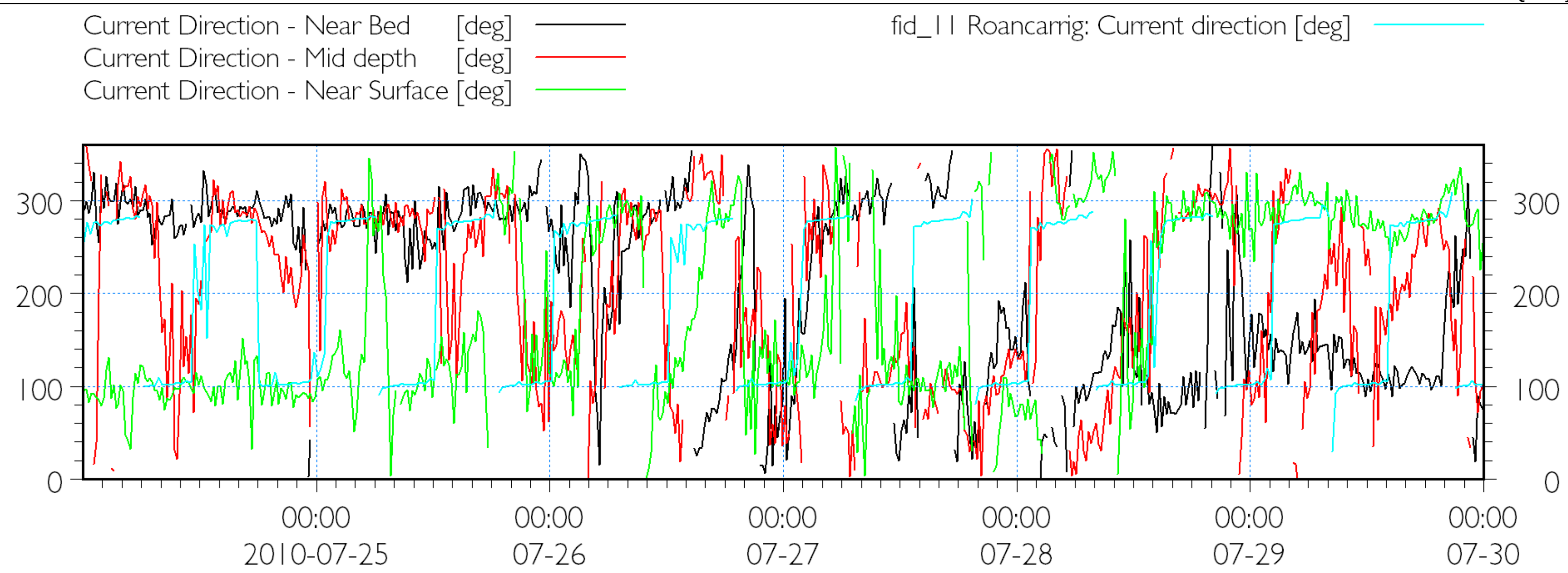

Figure A.23: Measured (left axis) and modelled (right axis) current direction – fid_11 Roancarrig

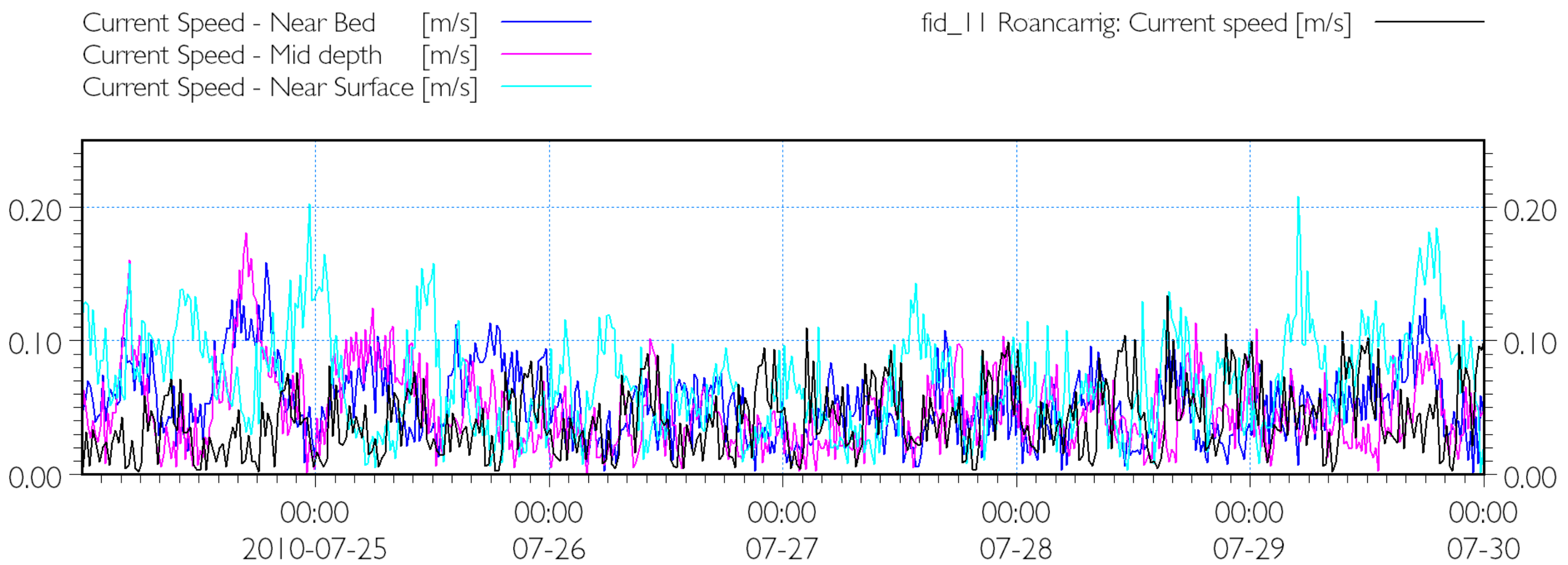

Figure A.24: Measured (left axis) and modelled (right axis) current speed – fid_11 Roancarrig

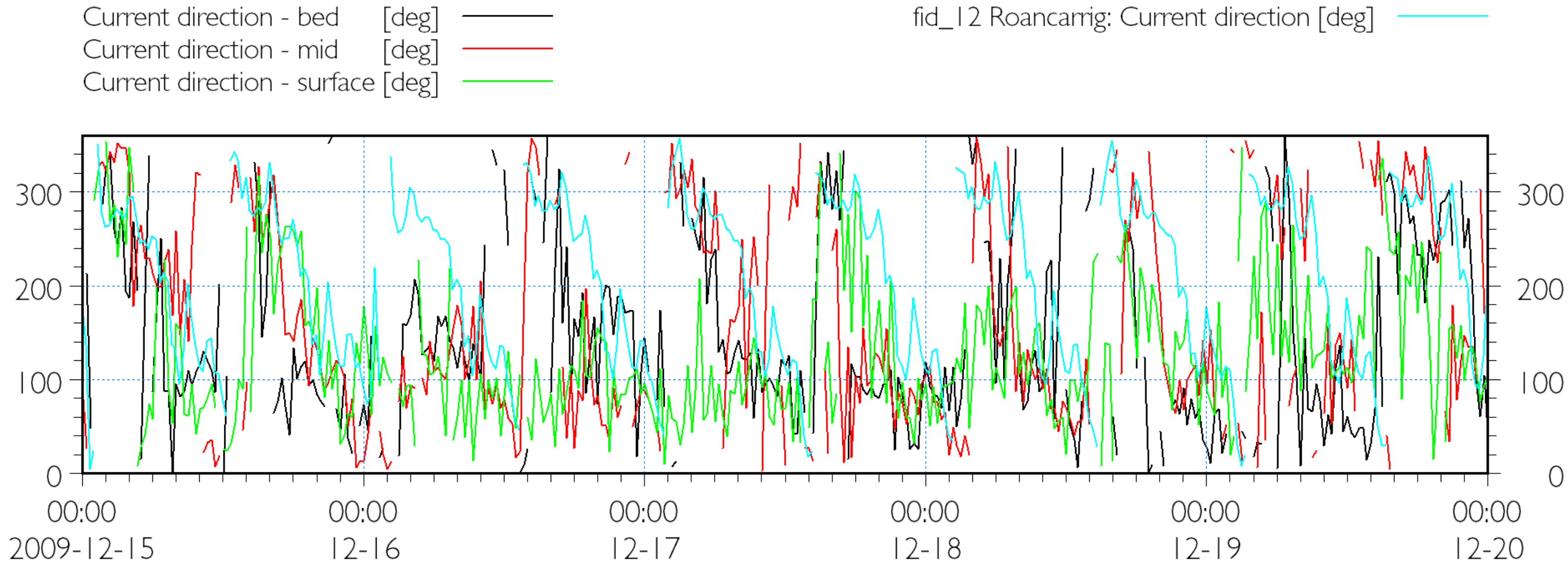

Figure A.25: Measured (left axis) and modelled (right axis) current direction – fid_12 Roancarrig

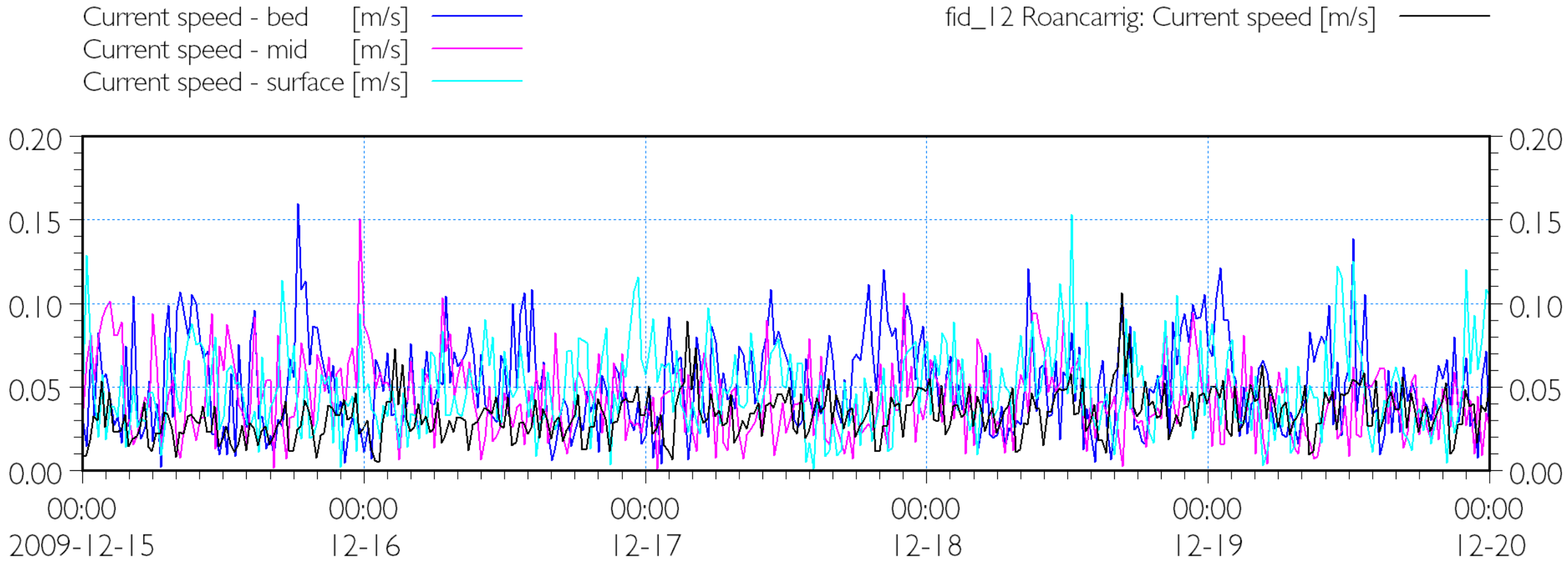

Figure A.26: Measured (left axis) and modelled (right axis) current speed – fid_12 Roancarrig

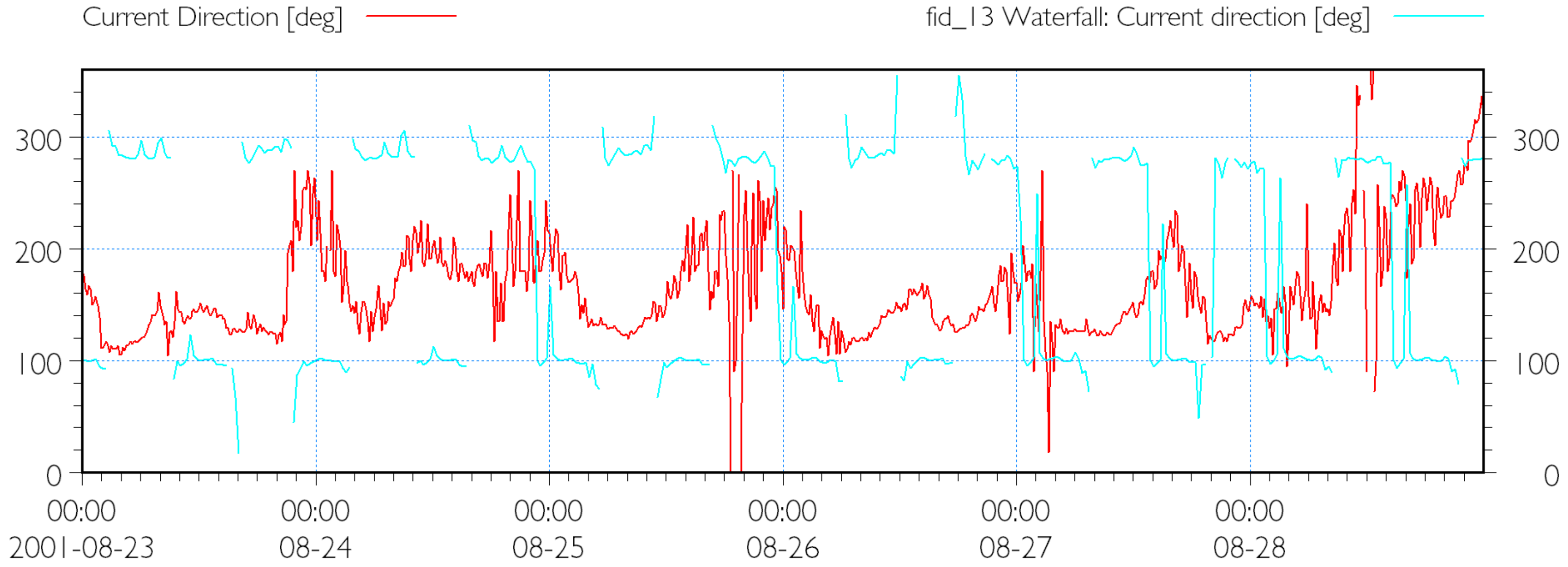

Figure A.27: Measured (left axis) and modelled (right axis) current direction – fid_13 Waterfall

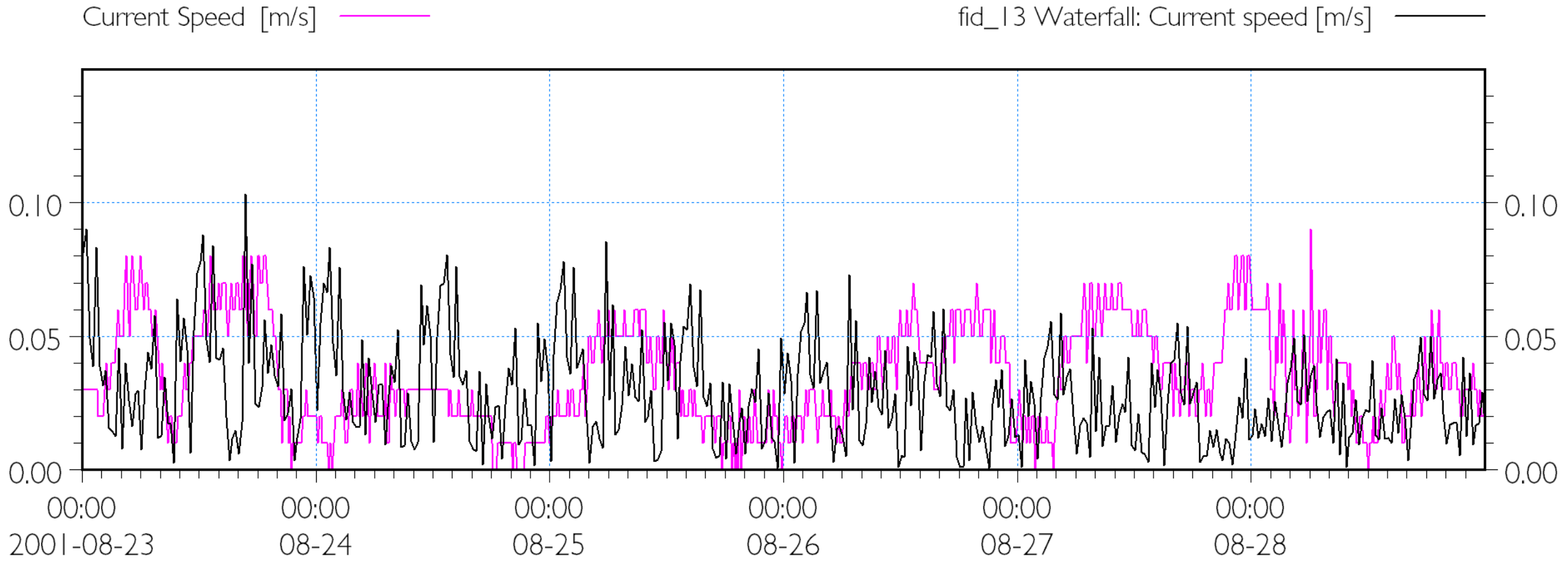

Figure A.28: Measured (left axis) and modelled (right axis) current speed – fid_13 Waterfall

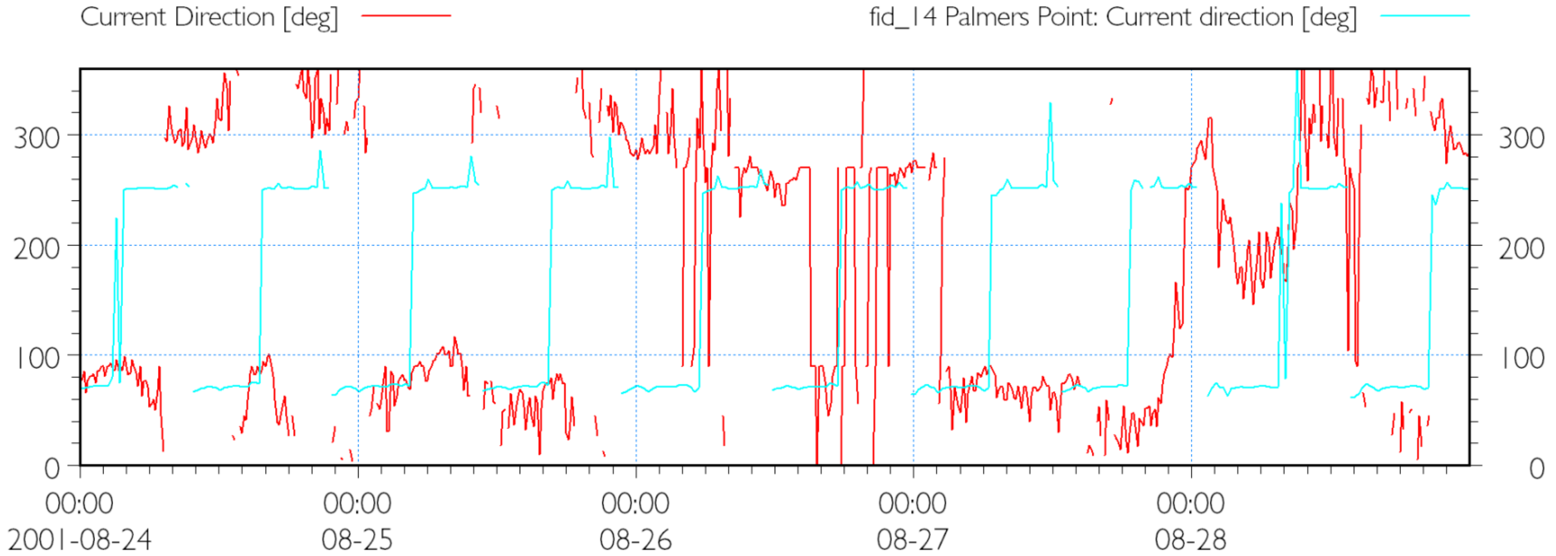

Figure A.29: Measured (left axis) and modelled (right axis) current direction – fid_14 Palmers Point

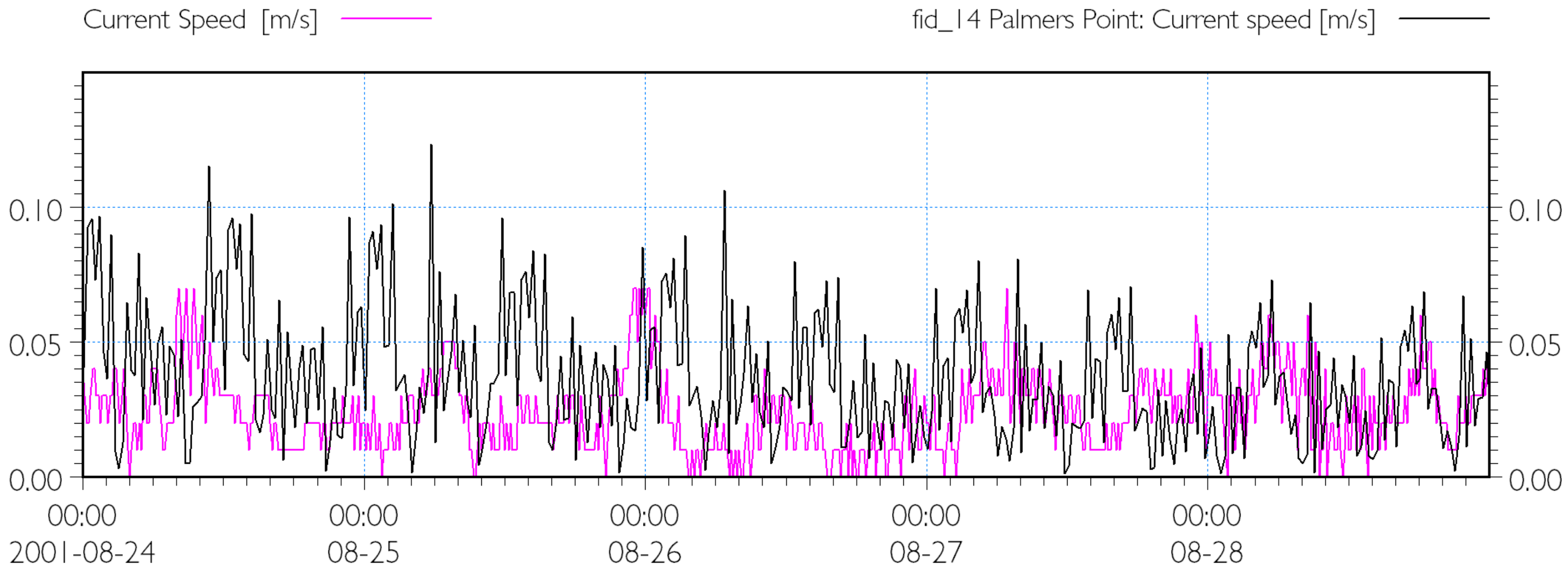

Figure A.30: Measured (left axis) and modelled (right axis) current speed – fid_14 Palmers Point