Sediment Modelling Report

EirGrid Cross-Shannon 400kV Cable Project

22 November 2019

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Executive summary

Mott MacDonald Ireland was appointed by EirGrid plc as a lead consultant for the Cross-Shannon 400 kV Cable Project (Capital Project Reference CP0970). The Project involves the installation of four 400kV cables beneath the Shannon Estuary between Moneypoint Power Station, Co. Clare and Kilpaddoge Substation, Co. Kerry.

In order to assess the environmental impacts of sediment resuspension and dispersion during and after the cable installation operations, numerical modelling has been used to simulate the hydrodynamic processes and sediment dispersion and deposition in the estuary. In order to capture important three-dimensional (3D) processes associated with tidal flows and density gradients in the estuary, the hydrodynamic model was built using the MIKE3 flexible mesh (FM) hydrodynamic (HD) module. The resuspension of the bed sediments during cable installation and their subsequent dispersion and deposition over several days was simulated using the outputs from the MIKE3 FM/HD module and the MIKE Particle Tracking (PT) module. The modelling study followed an indicative but likely cable installation procedure for the Project by: (a) simulation sediment resuspension by a mass flow excavation (MFE) cable installation method in real time; (b) defining changes in sediment properties along the cable route; and (c) simulating each cable installation sequentially over a period of four days.

In the PT model run it was assumed that the MFE operated at 0.208m^3/s during spring tide for 24-hr to complete the first of four cable installations. It was assumed also that the second cable will be installed directly after the completing the first cable installation and similarly for the third and fourth cables. This continuous cable installation programme was considered to give rise to the maximum bed disturbance and thus is considered the worst-case scenario with regards to suspended sediment release, dispersion and deposition in the estuary environment.

With regards to the total suspended sediment concentration (TSSC) attributable to the worst-case scenario cable installation works, the PT modelling showed that during the 155-hour simulation:

- The percentage of time TSSC values exceeded 50mg/l in the middle of the channel was around 10%;
- The finer sediments remained in suspension longer than larger sediments and were dispersed over a wider area; and
- The highest TSSC values were recorded in the small sheltered bay area to the south east of the Project site.

With regards to suspended sediment deposition attributable to the worst-case scenario cable installation works, the PT modelling showed that during the 155-hour simulation:

- The amount of sediment deposited by the end of the simulation is less than 1mm for most estuary locations;
- Deposited sediments are likely to re-mobilise and disperse more widely in the Shannon Estuary except in areas exposed to low tidal currents; and
- Relatively large and localised deposition depths of the order of 20mm were predicted in the sheltered small bay area to the south east of the Project site.

Using OSPAR (2008, 2009) as a guide, sediment deposition of around 20mm is five times less that the values likely to have any detrimental impact on marine benthos. Further, the area where sediment deposition depths of 20mm are predicted is intertidal and it would be expected that the local flora and fauna would be the adaptive strategies to accommodate modest sediment deposition without any significant detrimental impact.

The model results show that even for the worst-case scenario considered, the sediment released into the estuarine environment during cable installation operations is - unlikely to have any detrimental environmental consequences. It remains possible to reduce impacts further for example by changing the cable installation programme. Undertaking the cable installation during neap tides when the tidal flows are smaller is likely to result in the settling of sediment more rapidly and less dispersion of suspended sediment.

1 Introduction

1.1 Project background and objectives

Mott MacDonald Ireland has been appointed by EirGrid plc as lead consultant for the Cross Shannon 400 kV Cable project (Capital Project Reference CP0970), hereafter called “the Project”. At Step 4 of EirGrid’s Framework for Grid Development, a best performing subsea cable option has been identified, and the key stakeholders and the public have been consulted (Figure 1.1). The Project comprises installation of four subsea power cables across the Shannon Estuary from Moneypoint Power Station, Co. Clare to Kilpaddoge Substation, Co. Kerry (located approximately 1.5km northwest of Tarbert).

The numerical modelling described in this report provides an understanding of the amount of sediment placed into suspension by the cable laying operation and the potential impacts of related sediment deposition on the marine benthos in the Shannon estuary.

Figure 1.1: Shannon Estuary location and indicative route of proposed crossing

Source: Mott MacDonald, 2019 & Google Earth

1.2 Site description

The Shannon River and its 97km long estuary with a tidal range at the mouth and head of the estuary during normal spring tides of approximately 5.0m and 6.5m, respectively. These tides induce peak currents of up to 3m/s in water depths of 35m.

The estuary is characterised by extensive mudflats, saltmarshes and low-lying reclaimed coastal land. If the discharges from all the rivers and streams into the Shannon Estuary (including the rivers Feale, Maigue, Fergus and Deel) are added, the total discharge of the River Shannon at its mouth at Loop Head reaches approximately 300m^3/s.

This freshwater input to the estuary is relatively small compared with the volume of the estuary. A turbidity maximum (5‰) is located approximately halfway between Shannon Airport and Limerick City (Wilson et al. 1993).

Seabed sediment characteristics along the proposed cable route have been established by the surveys undertaken by SM Pelorus (2008) and RINA (2018). It is reported that the seabed cable route comprises: (a) sands underlain with sandy silts on the southern side of the estuary; and (b) glacial till with sands, silts and clay which extend from the deepest parts to the northern shore.

At this early design stage of the Project it is considered likely that a mass flow excavation (MFE) method is likely to be used to install four cables at the site. The same method was used to install cables at the same location for the 220kV Moneypoint to Kilpaddoge project. In the previous study by RPS (2009) for said project, the median grain size (D50) of the bed sediments was defined as being in the range 0.1mm to 0.002mm (SM Pelorus, 2008), and simulations assumed the resuspension of 0.25m^3 of sediment per metre of cable during the installation process.

In the worst-case scenario in the present study, the MFE is assumed to resuspend 0.208m^3 of sediment per metre of cable. The estimated MFE excavation rate is based on information provided by James Fisher SubSea Excavation[1] (a leading specialist and provider of MFE solutions). The sediment characteristics are defined by the data from the intrusive sampling points with D50 values of 0.15mm, 0.05mm and 0.003mm for sand, silt and clay materials, respectively.

1.3 Report structure

The report comprises the following Chapters:

Chapter 2: Describes the modelling approach.

Chapter 3: Describes the data and setup of the MIKE3 hydrodynamic model of the Shannon Estuary.

Chapter 4: Presents the MIKE3 hydrodynamic model calibration and validation.

Chapter 5: Describes the MIKE particle tracking model and presents results on the dispersion and deposition of sediments released into the estuary by the cable installation operations.

Chapter 6: Summarises the key results from the study and draws conclusions.

[1] http://www.jfsubseaexcavation.com/

2 Modelling approach

2.1 Hydrodynamic modelling

In the Shannon estuary, fresh water discharges from the fluvial drainage network are less dense than the saline estuarine water leading to stratification where the river water 'floats' above the denser estuarine water. During the ebb tide, the fresh water and the sea water flows in the same direction with varying degrees of mixing between the two water bodies. However, during the flood tide, the fresher water will remain above the incoming flow of denser seawater. In some circumstances the effect is to 'squeeze' the denser seawater towards the bed, thereby increasing the near-bed current speeds. The increase in current speed (and bed shear stress) during the flood tide can affect the sediment transport regime. In a secondary effect, the freshwater near the surface may be preferentially pushed to one side of the estuary causing changes to the lateral currents.

For these reasons, it was considered from the outset that a standard two-dimensional (2D) depth-averaged hydrodynamic model would not fully-capture density driven circulations that could impact the overall sediment transport regime and potentially underestimate the quantity and the spatial dispersion of sediments released into the estuary waters during cable installation activities.

In order to simulate the complex hydrodynamic conditions in the Shannon Estuary, a 3D model was built using MIKE3 by DHI flexible mesh (FM) hydrodynamic (HD) software. This approach allowed simulation of the vertical water column behaviour and characteristics associated with tidal-induced movement of water in the estuary, freshwater inputs, and the associated effect of density gradients.

2.2 Sediment modelling approach

There are a range of numerical modelling approaches that can be used to simulate the behaviour of sediments released in the water column during cable installation. The MIKE3 Particle Tracking (PT) module used in the present study enables modelling of suspended sediment transport from point or line sources and is especially well-suited to environmental impact assessments concerned with sediment spreading from bottom disturbances such as by sediment dispersion techniques and cable laying. The PT module is driven by the flow data from the MIKE3 FM/HD model.

In the PT modelling approach, sediment released into the water column by a MFE sediment dispersion method is represented by particles with defined sediment grading and mass at a defined height above the bed. Released particles are then tracked as they are carried by the tidal currents and deposited in the various parts of the estuary when conditions allow.

3 Hydrodynamic model setup

The use of a flexible mesh (FM) in the MIKE3 HD model for the Shannon Estuary allows the resolution to be varied across the model domain, thereby allowing higher-resolution in the areas of interest and reduced resolution further away or in areas with less variability in the bathymetry. This approach makes the model computationally more efficient than a regular fixed mesh size.

3.1 Bathymetry

The performance of any hydrodynamic model is closely related to the accuracy of the bathymetry/topography and boundary conditions that are used in the model. Care has been taken to ensure natural conditions are represented as accurately as possible within the constraints imposed by the data available to the study.

The bathymetric data used to build the model originates from survey, hydrographic charts and open source data. In order to include only the most up-to-date bathymetry, the available data were reviewed, collated and transformed to mOD Malin and included:

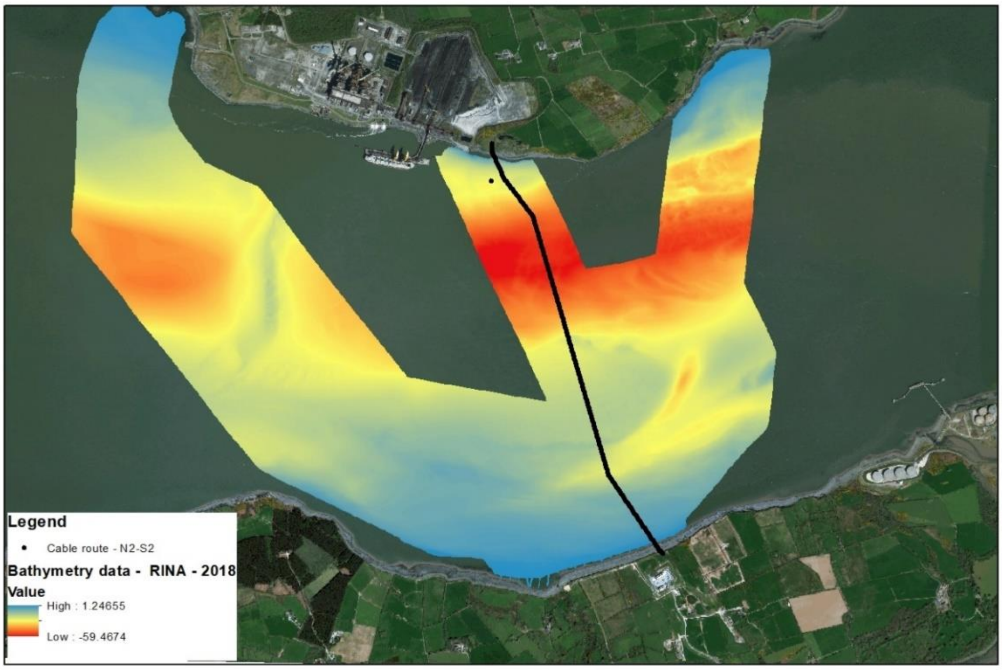
- Marine survey (RINA, 2018) – A detailed marine survey of the site was undertaken in 2018 by RINA. The bathymetric survey had a horizontal resolution of 50cm (Figure 3.1) and it is referred to Chart Datum at Tarbert;
- INFOMAR[2] data – All surveys available for the Shannon estuary were downloaded from INFOMAR Interactive Web Data Delivery System. The survey available for the Shannon estuary were the main bathymetric source used to detail the bathymetry of the model. the resolution of the data depended on the survey used, varying from 1m to 5m;
- Emapsite[3] data – Vector data was purchased from emapsite. The data, derived from Electronic navigation Charts, was used to provide additional coverage to the upper Shannon estuary. The data is referred to Chart Datum;
- Seazone data – Similar to the emapsite data, the Seazone data is derived from navigational chart. The data was used to provide additional coverage for the upper estuary. The data is referred to Chart Datum; and
- EMODnet[4] data (2019) – Freely available data covering the wider offshore area. The data has a resolution of 1/16 arc minutes and it is referred to Mean Sea Level vertical datum.

[2] https://www.infomar.ie/

[3] https://www.emapsite.com/

[4] http://www.emodnet.eu/

Figure 3.1: Bathymetry data from the marine survey of the study area, undertaken by RINA, 2018. The black line is indicating the proposed cable route.



Source: Mott MacDonald, 2019. Contains RINA data, 2018

It is noted that the available data for the upper estuary was limited to the chart contours available from Emapsite and SeaZone. No LiDAR was used to define the elevation of the intertidal areas of the upper Shannon estuary.

3.2 Water levels

Only limited measurements of water level were available to the study. Figure 3.2 shows the location of the tide stations in the Shannon Estuary. The water level data included:

- Shannon and Foynes Port Company – The port authority operates two tide gauges within the confines of the Shannon Estuary: Foynes and Carrigaholt. Data for 2008 was obtained for both sites. Figure 3.3 shows part of Foynes measured data. The water level data at Carrigaholt was not used in this study, since the exact location metadata was unavailable, and the data was not matching, in terms of levels, to the rest of the datasets;
- Irish National Tide Gauge[5] – Kilrush water level data was available for this site from 2017 onwards;
- Marine survey 2008 (Soil Mechanics – Pelorus Survey, 2008) – Water level data recoded in April and June 2008 by Soil Mechanics – Pelorus Survey, at Kilimer Ferry Pier. Part of the recorded data is shown in Figure 3.3. No metadata was available. It was assumed that the data was recorded in Chart Datum and that the reader was deployed at the end of Pier;
- Office of Public Works (OPW)/Hydro-data[6] – Limited tidal data was available for the estuary. Recorded water level at Bridge Ball (Limerick) station, from 2002 onwards, were

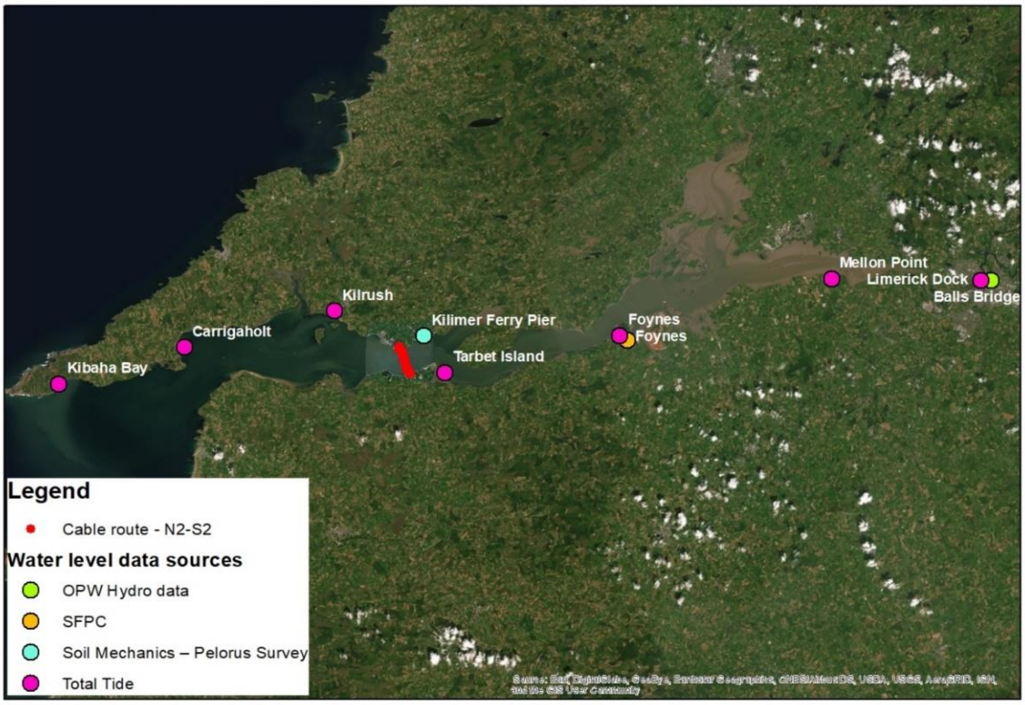
[5] http://www.marine.ie/Home/site-area/data-services/real-time-observations/tidal-observations

[6] http://waterlevel.ie/hydro-data/home.html

downloaded. The data, partially displayed in Figure 3.3, clearly shows the river discharge component; and

- Total Tide (UKHO, 2019) – Harmonic tide data was available from the UK Hydrographic Office Total Tide software for several station, including Kibaha Bay, Carrigaholt, Kilrush, Tarbert island, Foynes Island, Mellon Point and Limerick (Figure 3.2). Water level timeseries at some of these stations are shown in Figure 3.3.

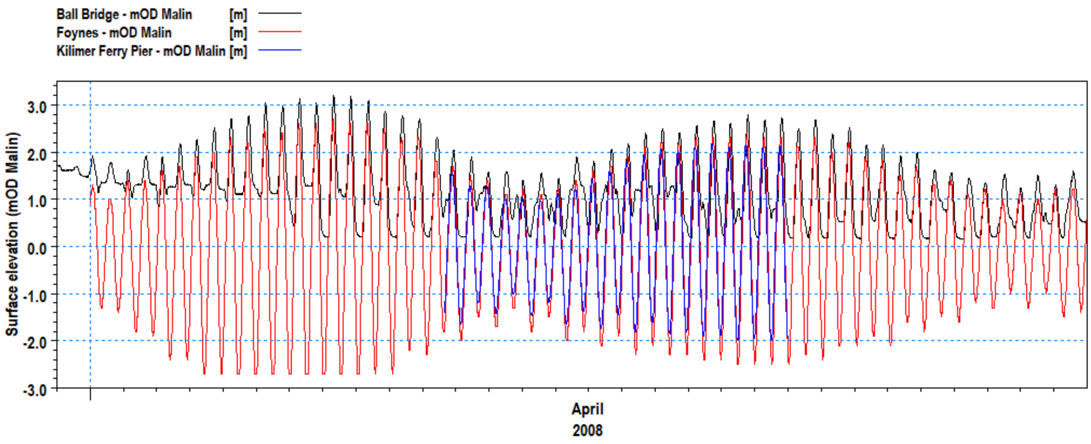
Figure 3.2: Location of the water level data available in the Shannon Estuary. This includes measures and predicted datasets.



Source: Mott MacDonald, 2019

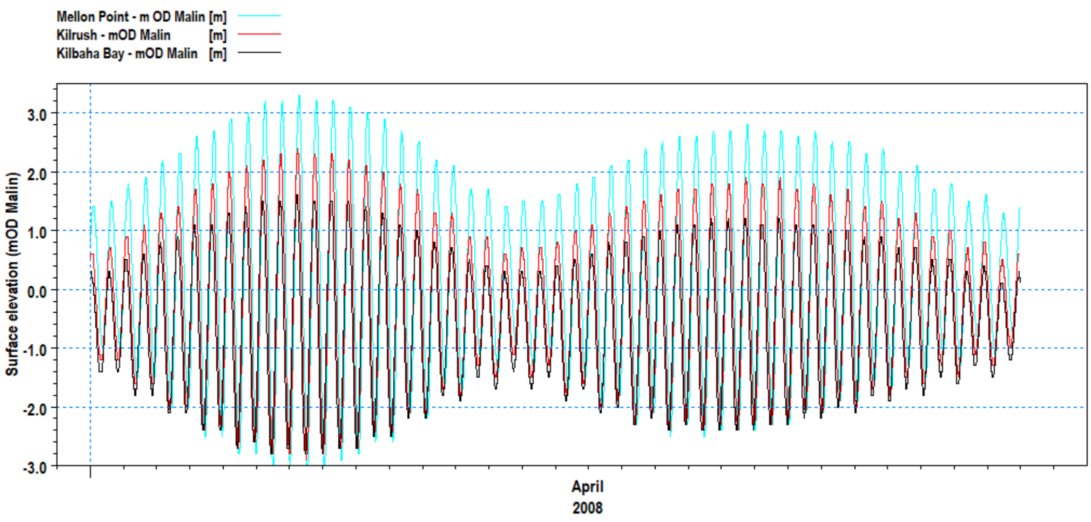
The water level data shows an increase in tidal range from the mouth of the estuary, at Kibaha Bay, towards the upper estuary, at Limerick. Spring tidal range increases from 4.45m at Kibaha Bay, to 6.25m at Limerick. In the measured data at Ball Bridge, the effect of the river discharges is evident.

Figure 3.3: Measured data in the Shannon Estuary available for the present study. (The data is plotted for April 2008 only).



Source: Mott MacDonald, 2019. Contains Office of Public Works (OPW) data, Soil Mechanics – Pelorus Survey data and Shannon and Foynes Port Company data.

Figure 3.4: Predicted TotalTide data for selected stations in the Shannon Estuary. Note the change in the tidal range from the estuary mouth (Kibaha Bay) to the upper estuary (Mellon Point). (The data is plotted for April 2008 only).



Source: Mott MacDonald, 2019. Contains UKHO Total Tide data, 2019

3.3 Tidal current speed and direction

3.3.1 ADCP data

Measurements of current speed and direction were available at the Project site for a Spring and Neap tide in April 2008. These data were obtained by Soil Mechanics – Pelorus Survey, using an RDI Workhorse Sentinel ADCP.

Measurements of current speed and direction were obtained through the whole water column in vertical bins of 0.5m over a 12-hour period on both a Spring and Neap tide. The data were acquired during cross-estuary profiling along Alternative Route 3 once every 30 minutes. Alternative Route 3 is located approximately 400m to the west of the proposed route on this study. Further information about the ADCC survey and results is provided in the Soil Mechanics – Pelorus Survey (2009) report.

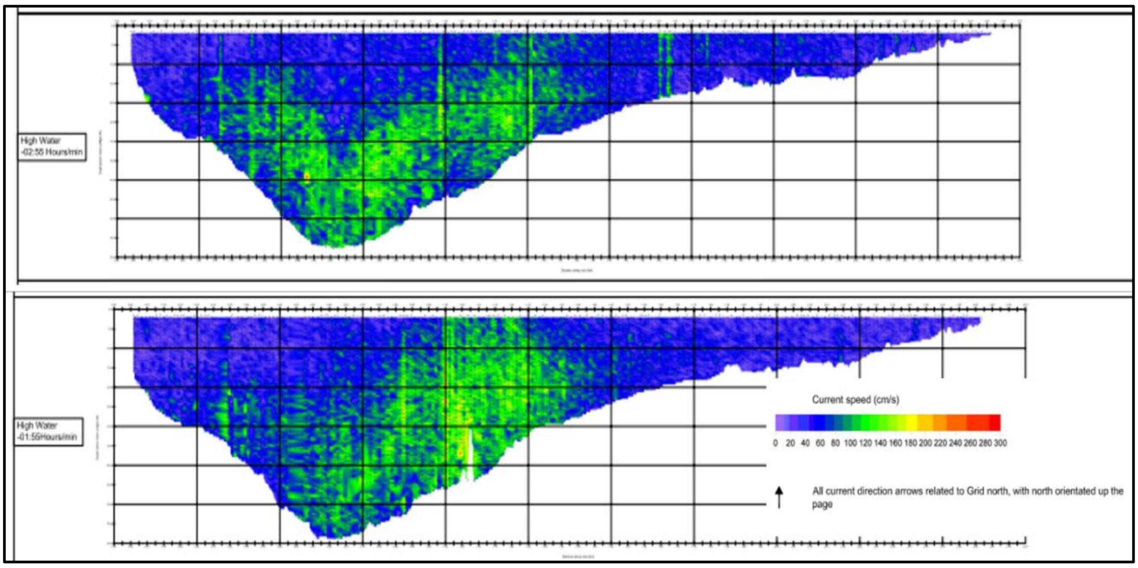
In summary the ADCP data shows that:

- The flood tide propagates up the estuary, mainly flowing through the deeper section of the estuary channel, with faster velocities measured at greater depth; and
- Higher current velocities at the surface are observed during ebb tides.

The ADCP data also show density effects, with denser saline water moving up the estuary in the lower part of the water column during the flood tide. During the ebb tide, the fresh and saline water move in the same direction, and higher current speeds are observed in the upper water column.

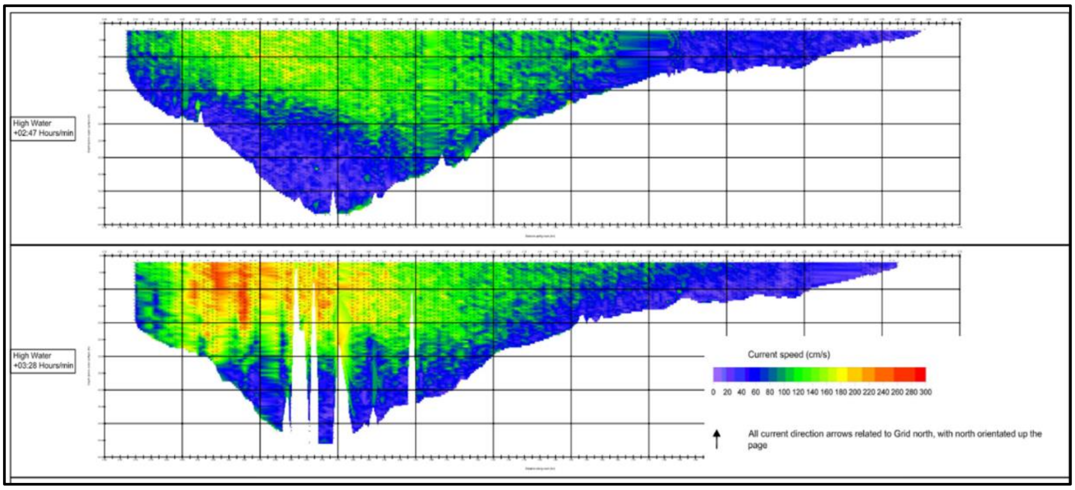
This flow behaviour is shown in Figure 3.5 and Figure 3.6 which show flood and ebb current profiles across the study site, respectively. For further ADCP results, please refer to the Soil Mechanics – Pelorus Survey, 2009 report.

Figure 3.5: Example of flood tide current speed and direction measured by the ADCP survey in April 2008. Please note that the left site represents the northern edge of channel, while the right one is the southern edge.



Source: Modified from Soil Mechanics – Pelorus, 2008

Figure 3.6: Example of ebb tide current speed and direction measured by the ADCP survey in April 2008. Please note that the left site is representing the northern edge of channel, while the right one is the southern edge.



Source: Modified from Soil Mechanics – Pelorus, 2008

For the purpose of MIKE3 FM/HD model calibration in the present study, the ADCP data were processed and extracted at 6 points (Figure 3.7).

Figure 3.7: Location of the points extracted from the ADCP data for this modelling study.

Source: Mott MacDonald, 2019. Contains Soil Mechanics – Pelorus data, 2008

3.3.2 TotalTide data

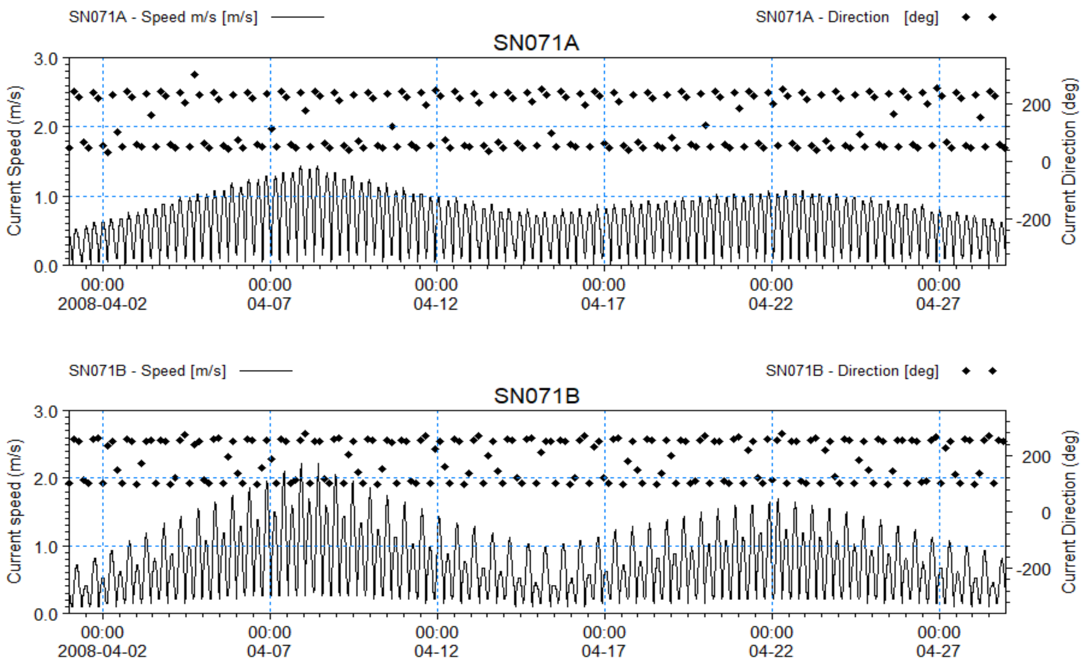
UK Hydrographic Office TotalTide tidal diamond data were available at two locations in the estuary, as shown in Figure 3.8.

Figure 3.8: Location of the tidal current data available in the Shannon Estuary.

Source: Mott MacDonald, 2019. Contains UKHO Total Tide data

Figure 3.9 shows a portion of the available current speeds and direction data. These data are temporally coincident with the ADCP data collected in the Soil Mechanics – Pelorus Survey.

Figure 3.9: Total tide current speed and direction for April 2008 for the two available points in the estuary.



Source: Mott MacDonald, 2019. Contains UKHO Total tide data.

It is noted that the specific details about tidal diamond data are not always clear and the data can have several issues that add uncertainty. These include:

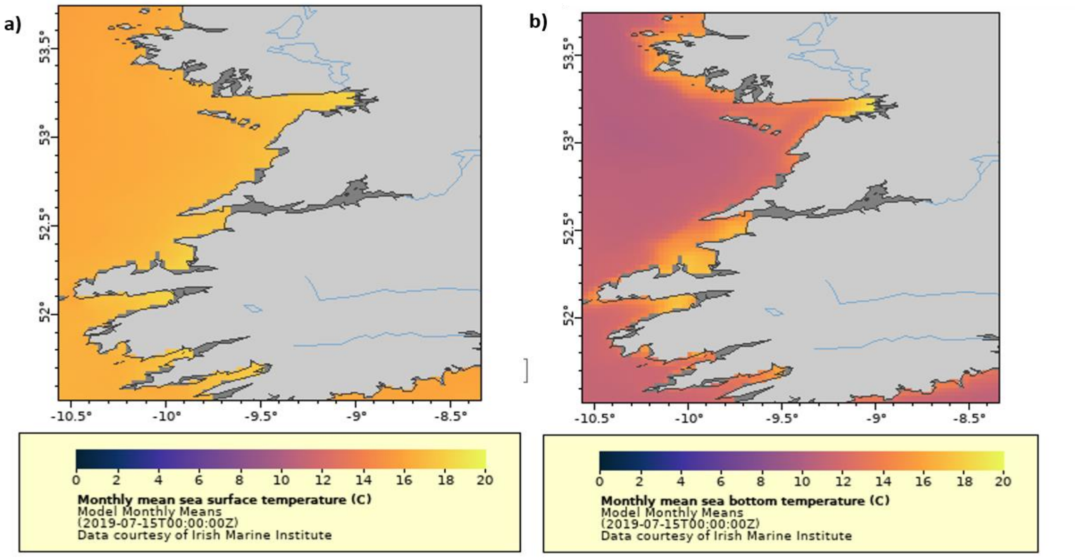
- The duration of the measurements used to derive the tidal diamond data is unknown. Often the two tides in a day have slightly different peak speeds, with one being larger than the other due to the asymmetry in the water levels. This is not always evident in tidal diamond data;
- The actual date of the data recording is often unknown. It could be the case that significant bathymetric changes could have taken place since the data was recorded both due to natural or anthropogenic changes;
- It is not known at what depth the measurements were made. They may be near surface (for navigation reasons) or recorded at greater depths;
- Wind, wave or river flow effects can be measured in some coastal or estuarine regions and it is not known if these have been removed from the tidal diamond current speeds and directions; and
- Location accuracy can mean that there is some potential for a discrepancy in the location of the tidal diamond. This is especially important if it is located near an area with large gradients in current speed where a small horizontal distance can make a large difference in current speed.

Despite these uncertainties, tidal diamonds are still useful for model calibration in the absence of other data, especially in the case where several sites together show that the agreement between the data is good.

3.4 Temperature and salinity

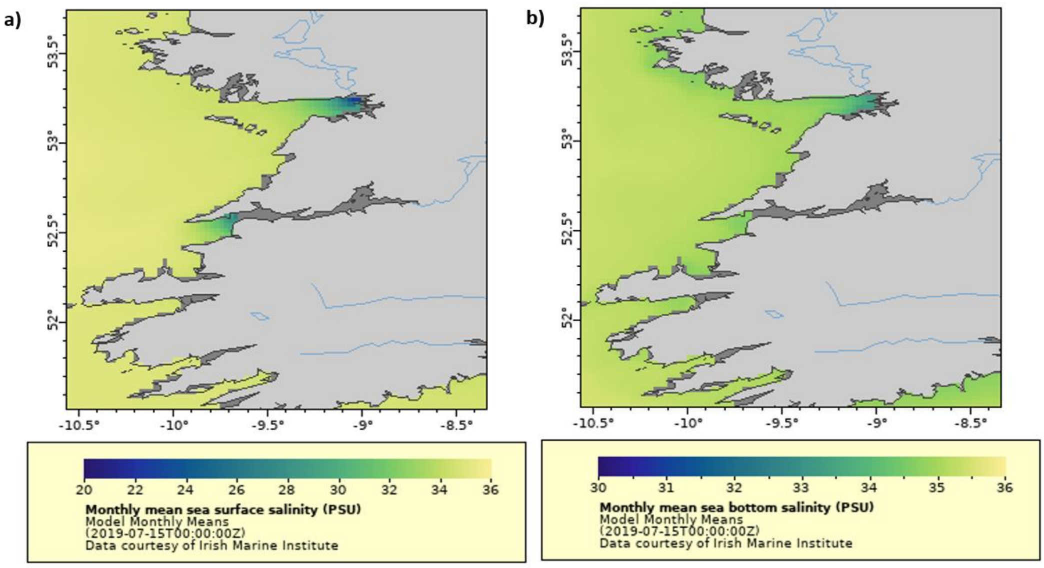
Very limited information regarding salinity and temperature for the Shannon Estuary was available. The Irish Marine Institute models provide monthly temperature and salinity at the surface and bottom for the offshore area of Ireland. An example of the available data is shown in Figure 3.10 and Figure 3.11 for July 2019, when the data was accessed. The raw data from the models was not available, and the model-derived information for the site was only used as a guide. The offshore salinities are around 35 PSU and generally well-mixed through the vertical layers.

Figure 3.10: Monthly mean sea surface (a) and bottom (b) temperature for July 2019.



Source: Mott MacDonald, 2019. Contains Irish Marine Institute data, 2019.

Figure 3.11: Monthly mean sea surface (a) and bottom (b) salinity for July 2019.



Source: Mott MacDonald, 2019. Contains Irish Marine Institute data, 2019.

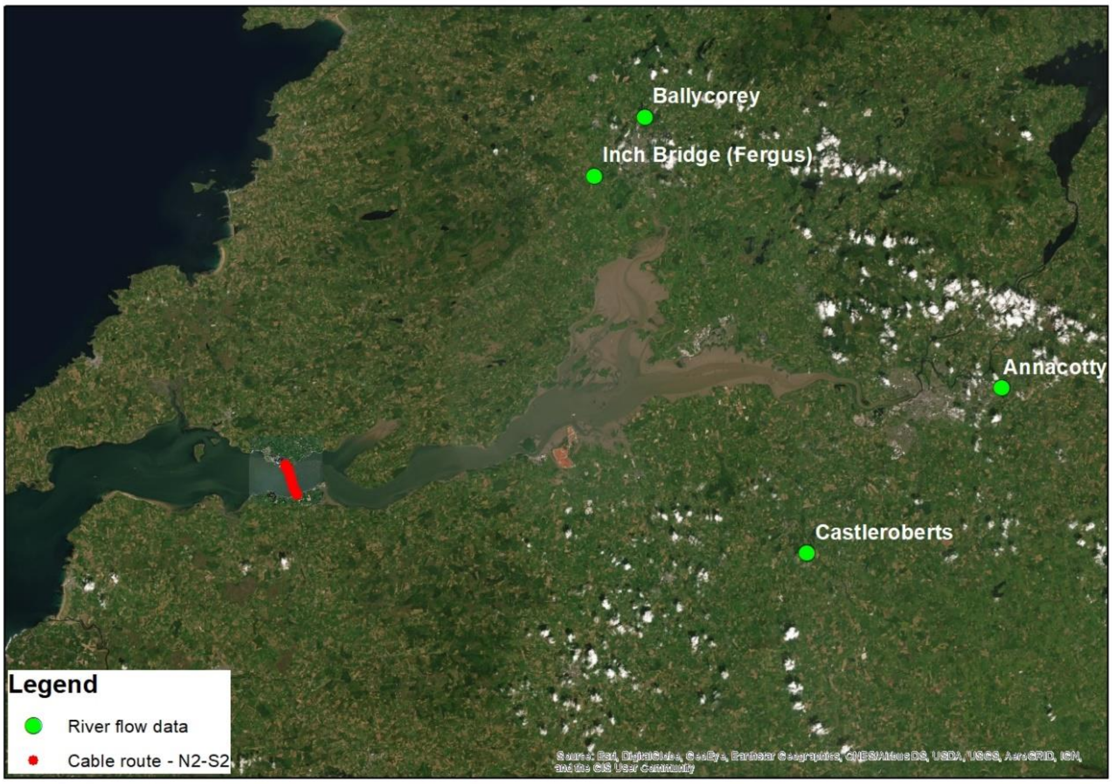
3.5 Fluvial discharge

Mean daily fluvial discharge data were obtained from the Office of Public Works (OPW)/Hydro-data for all the available site, including:

- Annacotty station (25001) – data available from 1972 onwards;
- Ballycorey station (27002) – data available from 1954 onwards;
- Castleroberts station (24008) – data available from 1979 onwards; and
- Inch Bridge (Fergus) station (27001) – data available from 1972 onwards.

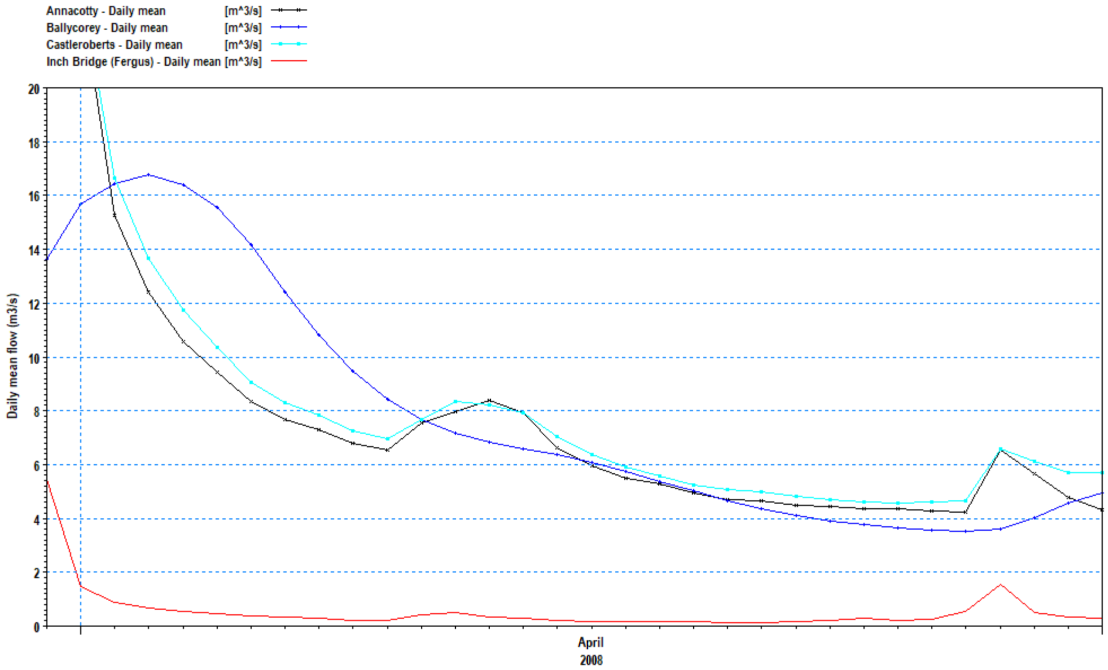
Figure 3.12 shows the location of the river discharge stations. Figure 3.13 shows the daily mean discharges for the stations during April 2008.

Figure 3.12: Location of the available river flow measurements.



Source: Mott MacDonald, 2019. Contains OPW data.

Figure 3.13: Daily mean river discharge for April 2008.



Source: Mott MacDonald, 2019. Contains OPW data

3.6 Model setup

3.6.1 Horizontal and vertical references

The model was set up using Geographic Coordinate System, (Lat/Long), based on the WGS84 horizontal datum. The vertical reference datum for the model bathymetry and boundary conditions is referred to metres above Ordnance Datum Malin[7] (mOD Malin) which is defined as being 3m above Chart Datum at Carrigaholt.

3.6.2 Horizontal model mesh and extent

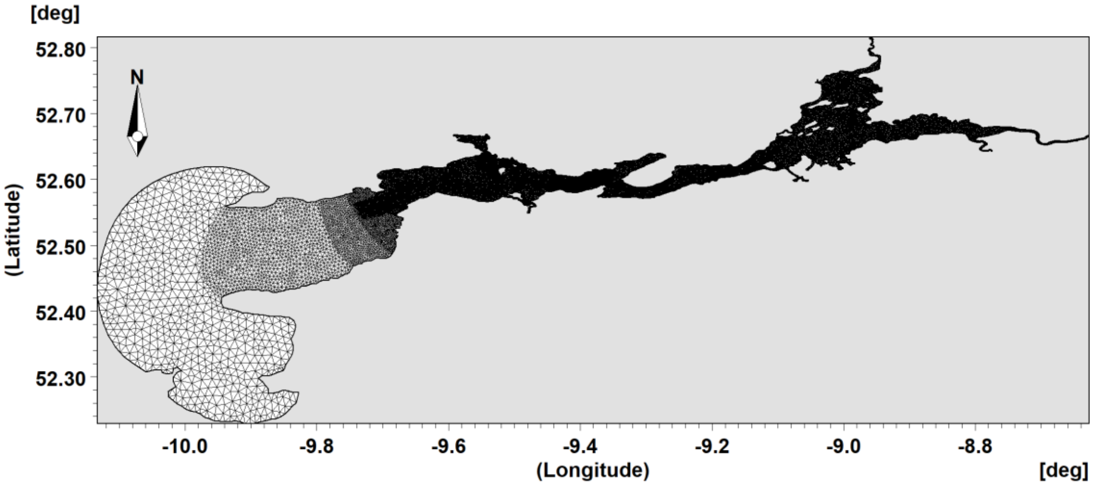
The MIKE3 flexible mesh comprises triangular elements. The resolution of the model mesh is coarser in the offshore region, with elements of approximating 1000m in side length. The mesh resolution was refined moving into the estuary in the following way:

- At the Project site the elements range from 20 to 30m in the nearshore to 50 to 60m in the center of the channel;
- Small elements, of the order of 20 to 30m were selected for the nearshore areas with steep bathymetry gradients; and
- The upper estuary was also refined in order to ensure that all the intertidal channel systems were captured with a resolution of 60 to 100m.

Figure 3.14 and Figure 3.15 shows the overall model mesh and details of the high resolution around the Project site respectively.

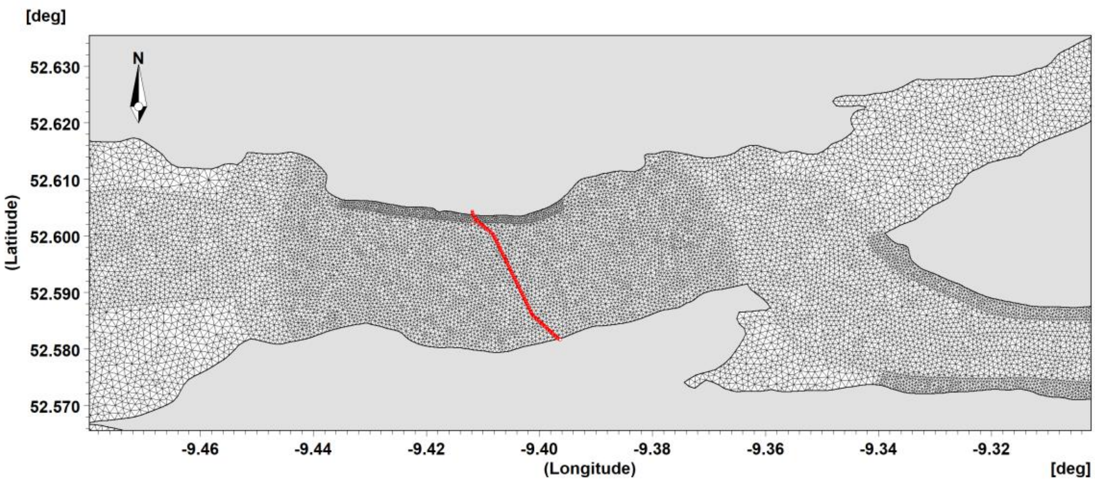
[7] Please note that Ordnance Datum Malin is the same as Ordnance Datum Belfast; and Ordnance Datum Dublin, also called Poolbeg datum, is 2.7m below Ordnance Datum Belfast.

Figure 3.14: Overall model mesh



Source: Mott MacDonald, 2019

Figure 3.15: Refined model mesh in study area. The red line represents the proposed cable route.



Source: Mott MacDonald, 2019

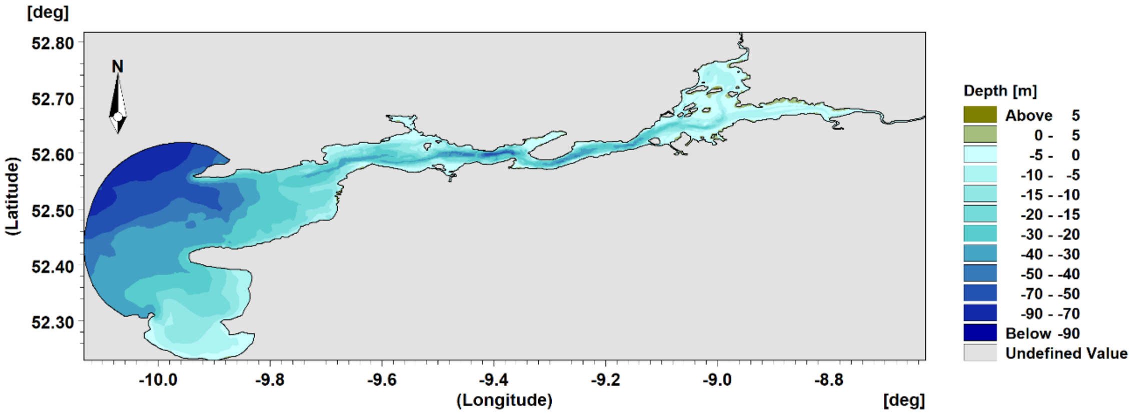
3.6.3 Vertical model mesh

To represent the water column structure the 3D vertical model domain is defined using 10 sigma layers with variable vertical thickness. In a sigma layer mesh, the number of active layers in the water column will always be the same in any point in the domain irrespective of the water depth. This approach provides the detailed information about near-bed flows required in the subsequent sediment modelling.

3.7 Model bathymetry

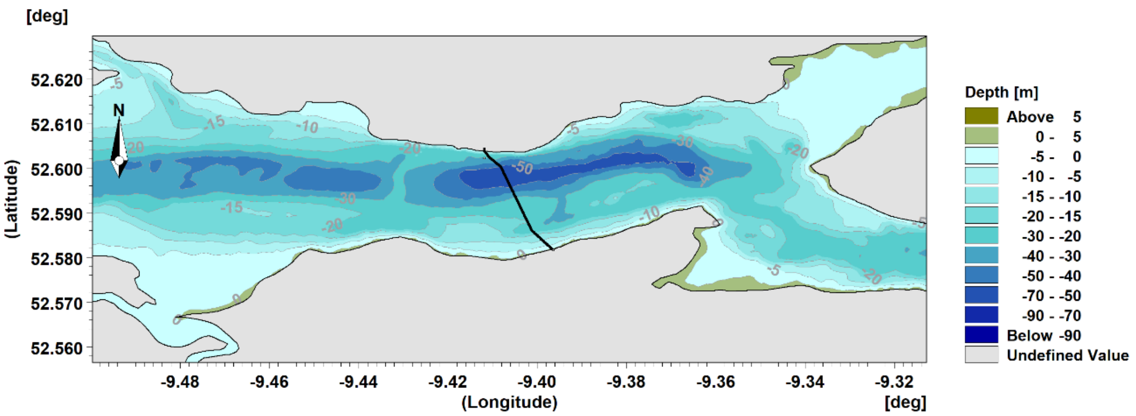
In order to use the most up-to-date and detailed bathymetric data in the model build all the data from the sources described in Section 3.1 were combined and transformed to Ordnance Datum Malin (ODM) and the WGS84 geographic coordinates system. These data were then interpolated into the model mesh to define the bathymetry across the model domain. Figure 3.16 and Figure 3.17 show the model bathymetry of the estuary and the detailed bathymetry in the study area.

Figure 3.16: Model bathymetry for the entire model domain.



Source: Mott MacDonald, 2019

Figure 3.17: Detailed model bathymetry in study area. The black line represents approximately the proposed cable route.



Source: Mott MacDonald, 2019

Figure 3.16 and Figure 3.17 show that the Shannon Estuary is deep (depth >-60mODM) and narrow, and is constrained upstream from the estuary entrance, where the width of the estuary reduces from 12km to 4km, with very steep channel edges. At the Project site, the depths of the central area are of the order of -60mODM. The bathymetry here is complex, with large sand waves, smaller channels and a ridge on the west side known locally as 'the Bridge' (Figure 3.17). The narrow sections of the estuary are characterised by limited or absent intertidal areas and very steep channel edges, while the upper estuary has extensive intertidal areas and intertidal channels.

3.8 Model boundary conditions

To ensure that the tidal flows and water levels are represented correctly in the Shannon Estuary model domain the offshore boundary of the model was defined approximately 10km offshore from the estuary mouth. Tests were undertaken to select the most appropriate open boundary conditions including: (a) Mike 3D generator; (b) Mike Global Tide model; and (c) Kibaha Bay harmonic tide predictions.

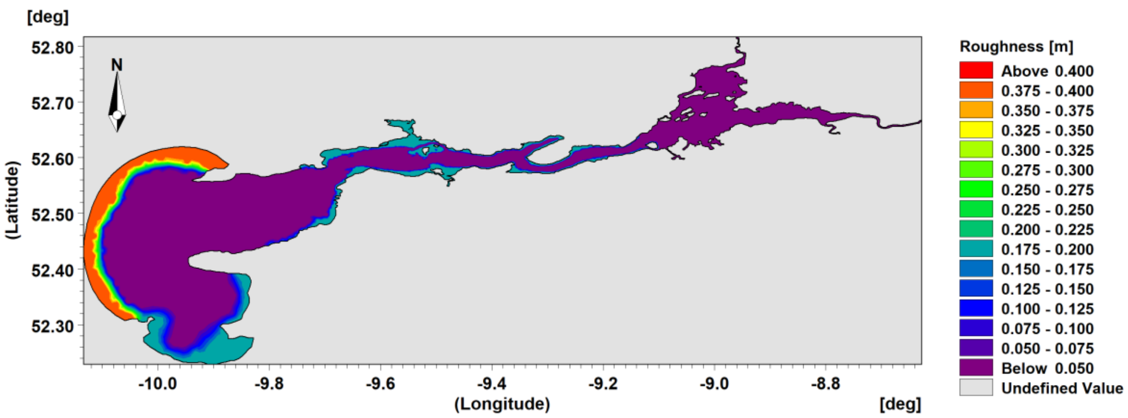
Test showed that the water level predictions from the Mike 3D generator did not reproduce the observed tidal conditions in the estuary well and consequently was not used. Similarly, water levels from the Mike Global Tide model, with a resolution of 0.125deg, deviated from the observations are were therefore also not used. However, harmonic tide predictions from TotalTide for Kibaha Bay were found to match the observations reasonably well are were selected as the preferred boundary conditions for the model. A constant salinity of 35 PSU was also applied at the boundary.

3.9 Bed resistance

Bed roughness creates friction between the moving water and the bed of the estuary the influences the current speed and water level. Following the normal modelling procedure several iterative sensitivity tests were undertaken in which the bed roughness was varied between 0.001 to 0.04m.

In the final bed roughness map, higher bed roughness values were applied to the edges of the channels (0.2m roughness) to achieve the best calibration and model stability. To ensure the correct propagation of the tide in the estuary a roughness of 0.01m was applied in the deeper areas and the upper estuary. Figure 3.18 shows the final roughness map for the calibrated model.

Figure 3.18: Roughness (m) in the model domain



Source: Mott MacDonald, 2019

3.10 Eddy viscosity

Eddy viscosity expresses the distribution of shear stress in a fluid and is related to the amount of flow turbulence. In the present model the horizontal eddy viscosity was selected with a constant Smagorinsky (CS) formulation with the recommended CS value of 0.28. The vertical eddy viscosity is defined in the k-epsilon formulation of the model.

3.11 River flows

The freshwater input of the rivers was included into the model as sources, with a salinity of 0 PSU and discharging in the upper vertical layer. The daily mean flow data described in Section 3.5 was used for the calibration period.

4 Hydrodynamic model calibration and validation

4.1 Introduction

In order to demonstrate good model performance, it is important that the water level and current speed predictions made by the MIKE3 FM/HD model compare well with the measured data. The agreement between predicted and observed values is optimised through the model calibration and validation process.

Noting the constraints imposed by the specific model application and data limitations, the process of model calibration involves varying model parameters, boundary conditions, bathymetry, bed roughness etc. to reproduce as accurately as possible measured data at key locations within the model domain. By keeping the same model parameters/setup derived during the calibration, model validation is progressed to establish that the model can replicate the hydrodynamic processes from a different period and/or location with the required accuracy. This approach is widely accepted as demonstrating that the model is robust enough to be applied in subsequent simulations of different periods or input conditions.

4.2 Model performance criteria

The evaluation of whether an established model provides a sufficiently accurate description of the environment depends in general on the specific objective for the individual model. Traditionally, the evaluation of performance has been based on visual comparisons, e.g. by time-series plots or instantaneous plan/transect plots of modelling results and monitoring data.

More recently, a quantitative approach for the performance control has been introduced, where the general discrepancy (or match) between model and monitoring data is expressed numerically. Simple statistics that demonstrate the level of agreement between measured/observed data and model prediction at a chosen location in the model domain include the mean and peak differences (often expressed as a percentage) and the standard deviation. Several quality indices can be used to demonstrate the statistical agreement between model predictions and observations including:

- Root Mean Square Error (RMSE) - RMSE is a measure of the residuals between the model prediction and measured observation. Smaller value indicates better agreement;
- Bias – Bias expresses the difference between an estimator's expectations and the true value of the parameter being estimated and can be defined as being equal to the mean error statistics in the data;
- Standard deviation of residuals (STD) - STD is a measure of the dynamical correspondence between measurements and simulations;
- Pearson product-moment coefficient (R^2) – The R^2 measures the best linear fit between observed and simulated values. It ranges from 0 to 1 with larger values indicating a better fit. Please note that the measure is insensitive to bias and proportional, and hence large R^2 values may actually be obtained for models that have serious errors. Another drawback of the R^2 measure is that it is more sensitive to outliers than values close to the mean; and
- Index of Agreement (Scatter Index) – Agreement between measured and model prediction. It ranges from 0 to 1 with large values indicating a better fit.

Following the specifications for the present study, the "*Guidance on Setup, Calibration, and Validation of Hydrodynamic, Wave, and Sediment Models for Shelf Seas and Estuaries*" (Williams & Esteves, 2018), is utilised to assess the calibration and validation performance of the hydrodynamic model.

Table 4-1 shows a summary of a minimum level of performance for coastal and estuarine models.

Table 4-1 Statistical guidelines to establish calibration standards for a minimum level of performance for coastal and estuarine hydrodynamic and sediment models

Predictions	RMSE	Bias	R^2	SI
Water level (coast)	± 10% of the measured level.	< 0.10	> 0.95	< 10%
Water level (estuary)	± 10% (mouth); ± 25% (head) of the measured level.	< 0.20	> 0.95	< 15%
Water level phase (coast)	± 15% of the measured phase.	< 0.20	> 0.90	< 20%
Water level phase (estuary)	± 15% (mouth); ± 25% (head) of the measured phase.	< 0.25	> 0.90	< 20%
Average current speed	± 10% to 20% of the measured speed.	< 0.10	> 0.95	< 10%
Peak current speed	Within <0.05m/s (very good), <0.1m/s (good); <0.2m/s (moderate) & < 0.3m/s (poor) of the measured peak speed.	< 0.15	> 0.90	< 15%
Current direction (coastal)	± 10° of the measured direction.	< 0.25	> 0.90	< 20%
Current direction (estuary)	± 15° of the measured direction.	< 0.30	> 0.90	< 20%
Bed shear stress	± 10% N/m^2 of the measured mean stress.	< 0.10	> 0.95	< 10%
Mean SPM concentration	± 20% of the mean measured SPM concentration	< 0.20	> 0.90	< 20%

Source: Williams & Esteves, 2018

4.3 Model Calibration

To be coincident with the time of the ADCP and water level surveys undertaken at the site by Soil Mechanics – Pelorus Survey in April 2008 the model calibration was undertaken using TotalTide data for the period covering some spring and neap tide conditions between 11th to 21st April 2008. Please note that slightly larger spring tides could be expected in other months of the year, increasing the tide range by approximately 8%.

During the calibration process values of bed roughness, eddy viscosity, bathymetry and boundary conditions were adjusted iteratively to obtain the best model performance against the metrics in Table 4-1 .

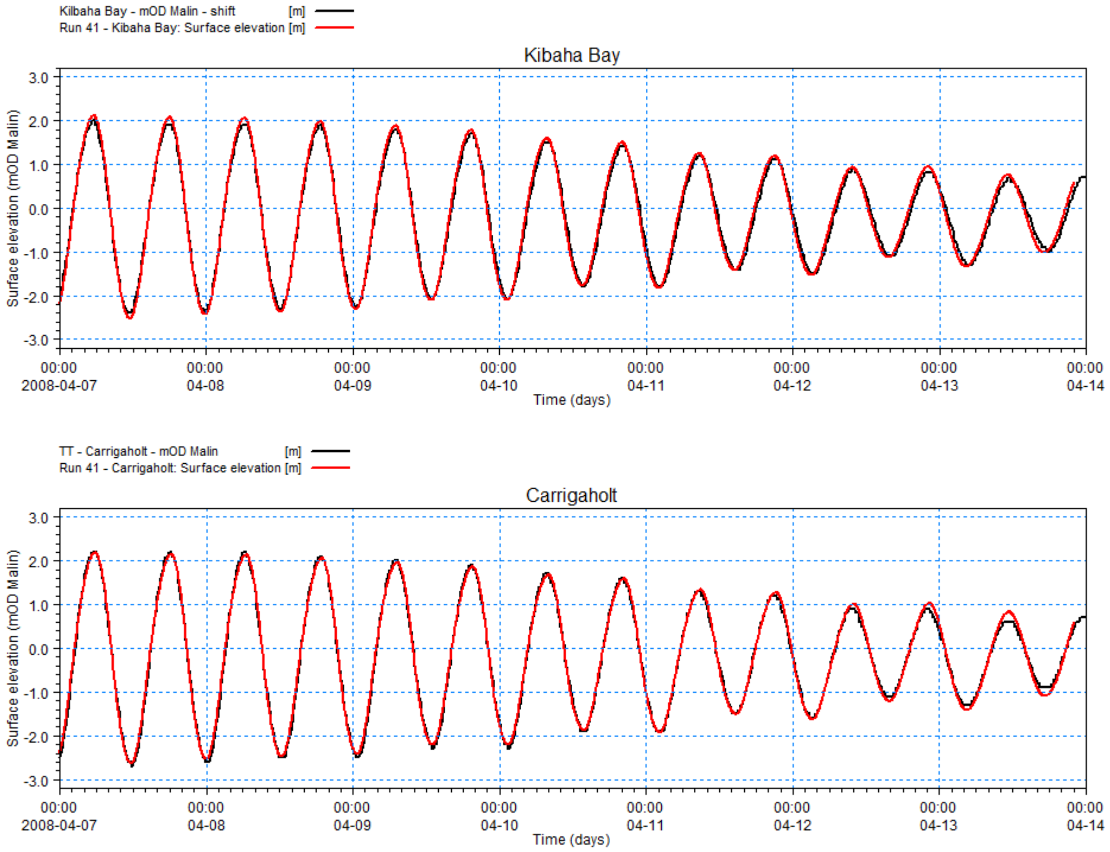
4.3.1 Water levels

The model water levels were compared to measured water level data at Kilmer Ferry Pier and Foynes Island, as well as the predicated astronomical tides for the TotalTide stations (Figure 3.2). The error statistics expression agreement between the observed and simulated water levels are shown in Table 4-2.

Model prediction of water level at stations closer to the mouth of the estuary (Figure 4.1) show very good levels of agreement with TotalTide data for the spring and neap tides. Both Kibaha

Bay and Carrigaholt have a small RMSE and bias values, with an R^2=0.99. The error in the tide spring tide range at Carrigaholt is smaller than 2% (0.08m), Table 4-2.

Figure 4.1: Comparison between Total Tide data (black line) and simulated water levels (red line) for the station located closer to the mouth of the Shannon Estuary.



Source: Mott MacDonald, 2018. Contains Total Tide data, 2019.

Kilrush is located to the west of the study site. The simulated tide range is slightly smaller, by 6% (0.29m) on the spring tide range, while during the neap tide, the range is overestimated by 14% (0.28m). The tide propagation is also slightly different. Figure 4.2 shows that the ebb tide is slightly quicker than the observed data, low water in the model is reached approximately 30 minutes before the available data, while both observed and simulated high waters are in phase (Figure 4.2).

The differences between the modelled and observed water levels at Kilrush are potentially related to the bathymetry in the area and the model resolution. The model resolution in this area is a compromise between the computational time and the required details outside the area of interest. However, the results obtained at Kilrush are complying with the guidance described in Table 4-2.

At Kilmer Ferry Pier, the modelled and measured data is compared for a smaller period of time, mainly covering the neap tide period (Figure 4.2). There was no metadata provided for this measured data or any information regarding the survey and how the data was processed. However, because the survey was located very close to the site, it was decided that this data should be used. The results indicate that there is a vertical difference/shift between the modelled and measured data. According to the calculated statistics, there is an average bias (mean error) of +0.15m in the results. When the mean level of the measured data is shifted using the bias, the results indicate a considerable improvement in the comparison, both visually and statistically (Figure 4.2 and Table 4-2).

At Tarbert Island, the modelled and observed water levels are showing a very good visual and statistical agreement (Figure 4.2). The spring tide tidal range is overpredicted by 1% (0.05m), indicating a very good model agreement with the observed data. The range is slightly more overpredicted during the neap tides, by 16% (0.3m). All the statistical values are complying with the guidance of Table 4-1.

At Foynes Island (Figure 4.3) the model tends to overestimate the HW, from Total Tide, during spring tides (30cm), and therefore, the tidal range is overestimated by approximately 6% (0.3m). During the neap tides, both modelled high water and low water are overestimated, compared to Total Tide data, with the model tide range 27% larger than the Total Tide data. However, the statistics are showing an average RSME of 0.26m and an average bias of -0.07m, complying with the modelling guidance.

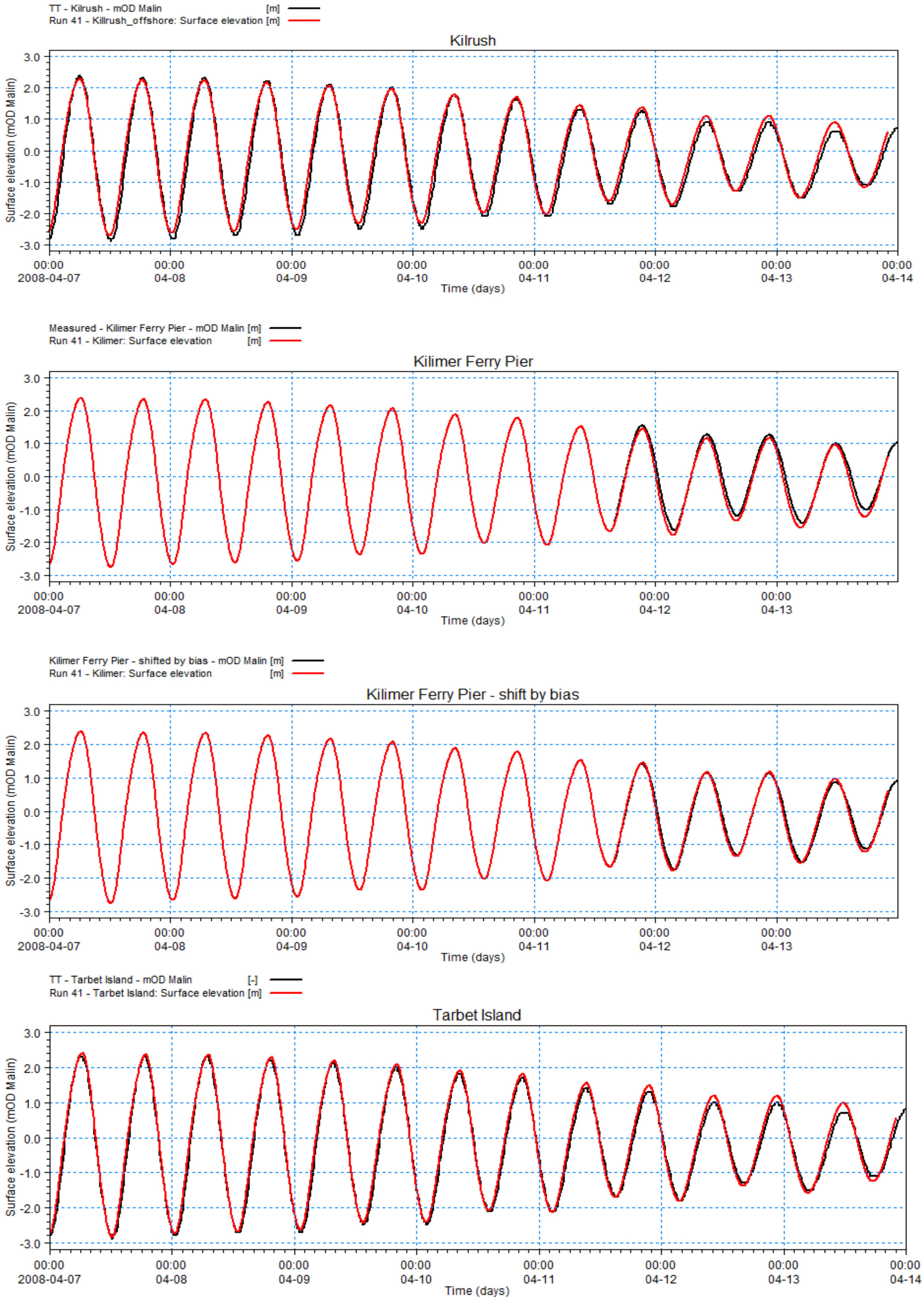
When the modelled data at Foynes Island is compared to the measured data from the SFPC data (green line - Figure 4.3) the visual comparison between the datasets considerably improves. There are significant differences between the measured data and the total tide dataset at this location, however the model seems to be reproducing water levels closer to the SFPC measured data than the total tide data.

In the upper part of the estuary, at Mellon Point and Limerick, the model is showing predictions of the water levels which are not quite so good when compared to the observed data (Figure 4.3). This is most likely due to the lack of high-quality bathymetry data. The main focus of the model is to correctly reproduce the hydrodynamic conditions at the study site.

The modelled high water at Mellon Point is underestimated, while the low water is generally overestimated. The tidal range however, is only underestimated by 2% (0.12m) during spring tides. The average bias is +0.23m, while the spring/neap RSME is 0.42m.

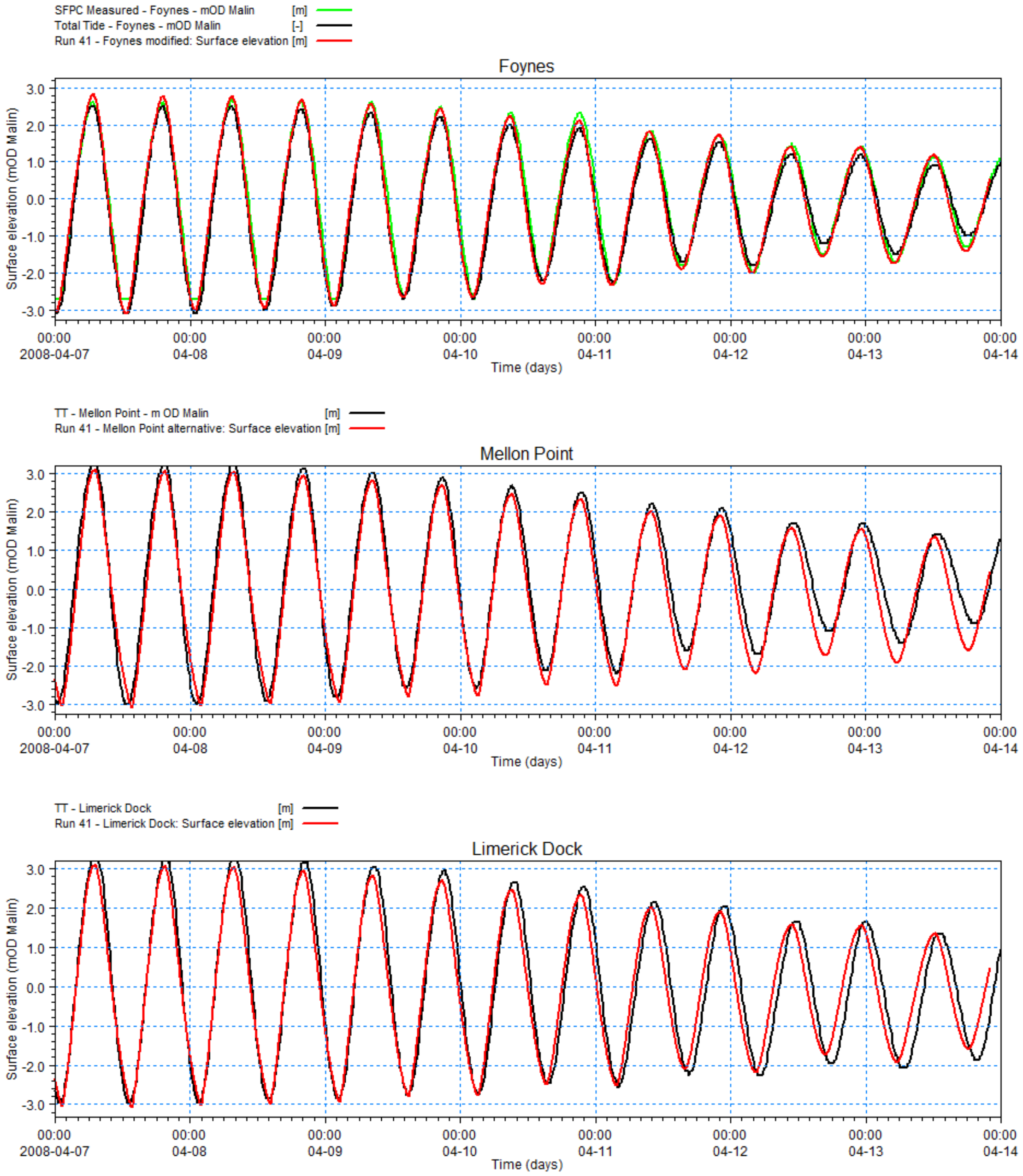
At Limerick, on the other hand, the spring range is underestimated by 0.37m (6%), while during the neap tides the range is underestimated only by 10cm (2%). At this station, the modelled ebb tide is too slow, probably due to the limited bathymetry data, reaching the low water with 2hrs delay, compared to the Total Tide data. Please note that the bathymetry data in this area was extremely limited, which has affected the calibration in these upper reaches of the estuary. However, since the station is a considerable distance away from the study area, the model performance in the upper part of the estuary is not significantly affecting the hydrodynamic conditions at the study site.

Figure 4.2: Comparison between observed data (black line) and simulated water levels (red line) for the station located closer to the study site.



Source: Mott MacDonald, 2018. Contains Total Tide data and Soil Mechanics – Pelorus Survey data, 2019.

Figure 4.3: Comparison between observed data (black line) and simulated water levels (red line) for the station located in the upper Shannon Estuary.



Source: Mott MacDonald, 2018. Contains Total Tide data and SFPC data, 2019

Table 4-2 Summary of model calibration statistics for the water levels in the Shannon Estuary

Station	RMSE (m)	Bias (m)	STD (m)	R^2	SI
Kibaha Bay	0.114	-0.024	0.112	0.994	0.998
Carrigaholt	0.083	-0.013	0.082	0.996	0.999
Kilrush	0.204	-0.098	0.179	0.985	0.995
Kilmer Ferry Pier	0.181	0.148	0.105	0.988	0.990
Kilmer Ferry Pier – shifted by bias (0.15m)	0.106	0.018	0.105	0.988	0.997
Tarbert Island	0.227	-0.085	0.210	0.983	0.995
Foynes – Total Tide	0.200	0.094	0.176	0.988	0.996
Foynes – SFPC Measured	0.137	-0.081	0.111	0.994	0.998
Mellon Point	0.418	0.229	0.349	0.960	0.985
Limerick	0.579	0.019	0.579	0.904	0.973

Source: Mott MacDonald, 2019

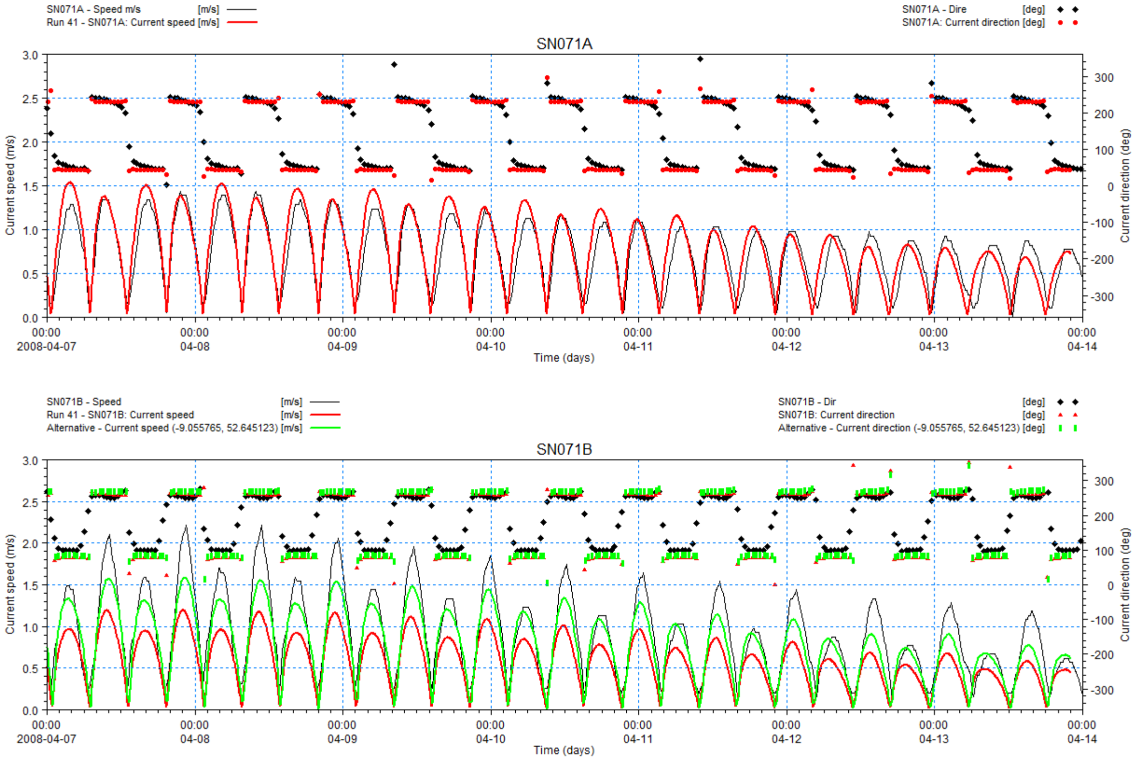
4.3.2 Tidal current speed and direction – Tidal diamonds

In addition to the measured and predicted water levels, tidal diamond-derived current speed and direction data (Figure 3.8) were used to calibrate the MIKE3 FM/HD model. These data were compared with the depth-averaged current speed and direction from the model at the same location. The results are shown in Figure 4.4 and model performance statistics are given in Table 4-3.

Figure 4.4 and Table 4 3 demonstrate that the model reproduces the current speed and direction of tidal diamond SN071A very well compared with the TotalTide data (Figure 3.8). The results show that the model tends to slightly overpredict the current speed, mainly during the flood tide, by 0.1m/s to 0.3m/s, approximately 10% to 20%.

In the case of tidal diamond SN071B, the model underpredicts the ebb and flood currents during the spring tide. If the location of the tidal diamond is adjusted slightly, the agreement is improved, especially during the flood tide. However, the ebb tide is still underpredicted by the model, especially during the spring tides. It is noted that the specific details about tidal diamond data are not always clear and the data can have several issues that add uncertainty. Please refer to previous section 3.3.2 for further details.

Figure 4.4: Comparison between the tidal diamonds data (black line) and simulated current speed (red line) for the Shannon Estuary



Source: Mott MacDonald, 2019. Contains UKHO Total Tide data, 2019

Table 4-3 Summary of model calibration statistics for the total tide diamonds current speeds in the Shannon Estuary

Station	RMSE (m/s)	Bias (m/s)	STD (m/s)	R^2	SI
SN071A	0.177	-0.042	0.173	0.816	0.944
SN071B	0.41	0.334	0.238	0.864	0.778

Source: Mott MacDonald, 2019. Contains UKHO Total Tide data, 2019

4.4 Model validation

Model validation is normally undertaken after calibration using either observed data from a different date or location to test that the model still predicts water levels and/or tidal currents correctly. In the present study validation was undertaken using the ADCP data from the Project site described in Section 3.3.1.

4.4.1 ADCP data

Data processing was required to obtain ADCP data suitable for model validation. Since the start and end time of each ADCP transect was determine, it was then possible to estimate the location of the survey boat using information on the recorded time and direction of the vessel during each survey transect. It was assumed that the boat was surveying continuously, and at the same speed. Since it was impractical to process all the data collected during the survey, a series of measurement points along the survey transect were selected (Figure 3.7) and the current speed and direction data was extracted at locations 1, 1a, 2 and 3, representing the northern and central deeper section of the channel.

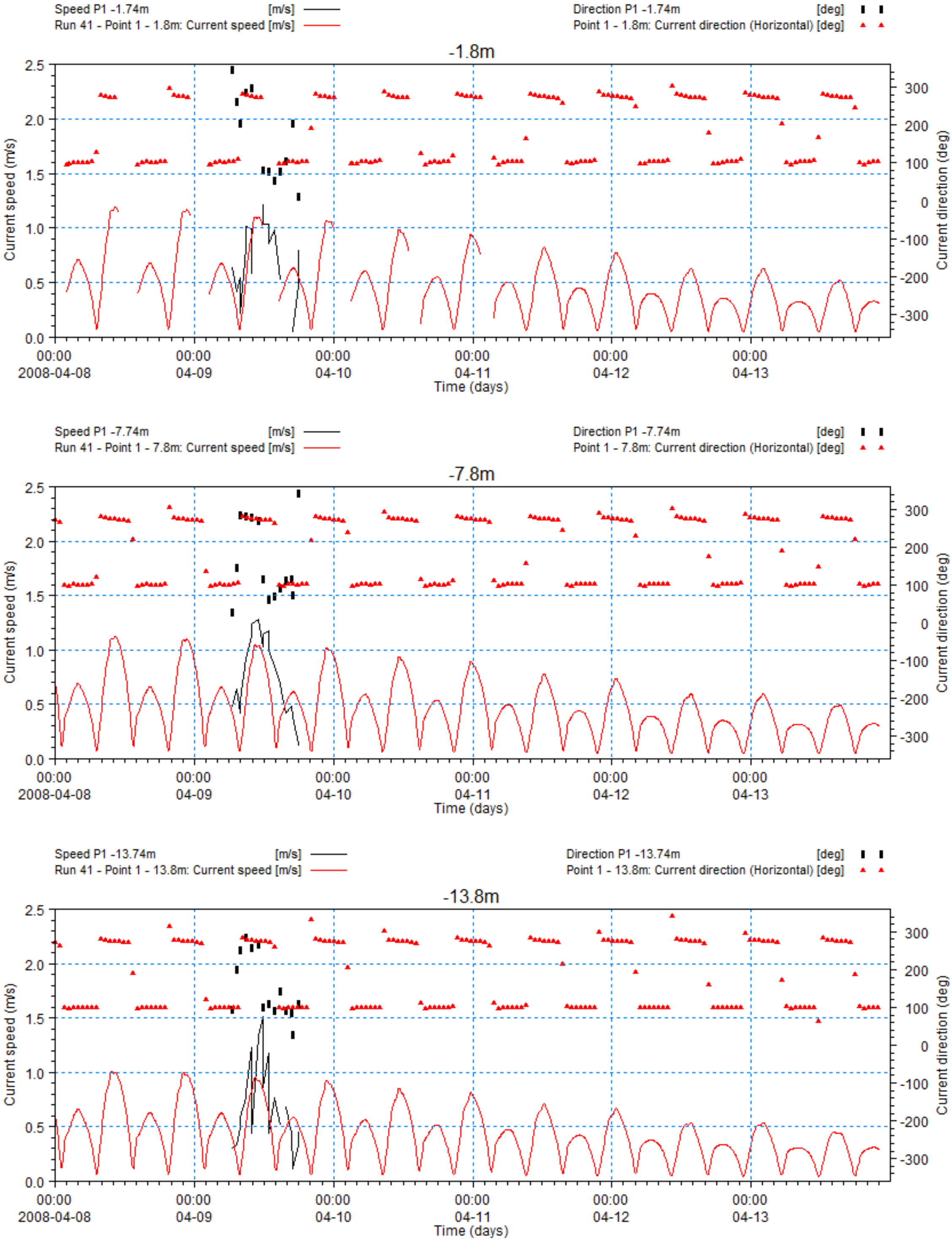
4.4.1.1 Velocity profile model validation

At each location, current speed and direction data were available in vertical slices through the water column separated by 0.5m. For model calibration purposes data from several depths were selected at each location and used to build an observed current speed and direction data set.

An example of the model calibration achieved at Point 1 is shown in Figure 4.5. The figure demonstrates that model reproduces the measured current speed and direction very closely at different depths. While the figure also shows that the model tends to slightly underpredict the current speed towards the bottom, the model predicts well the near-bed currents (of most importance for this project) and slightly underpredict the currents closer to the surface. In general, the main features, timings and magnitudes of the ADCP data are reproduced by the model.

Similar comments apply to calibrations undertaken at the other ADCP data extraction locations 1a, 2 and 3, and the reader if referred to Appendix A where the results are shown.

Figure 4.5: Comparison between the current speed and direction from the ADCP survey (black line) and the simulated current speed and direction (red line) for several depths at Point 1.



Source: Mott MacDonald, 2019. Contains Soil Mechanics – Pelorus Survey data, 2019

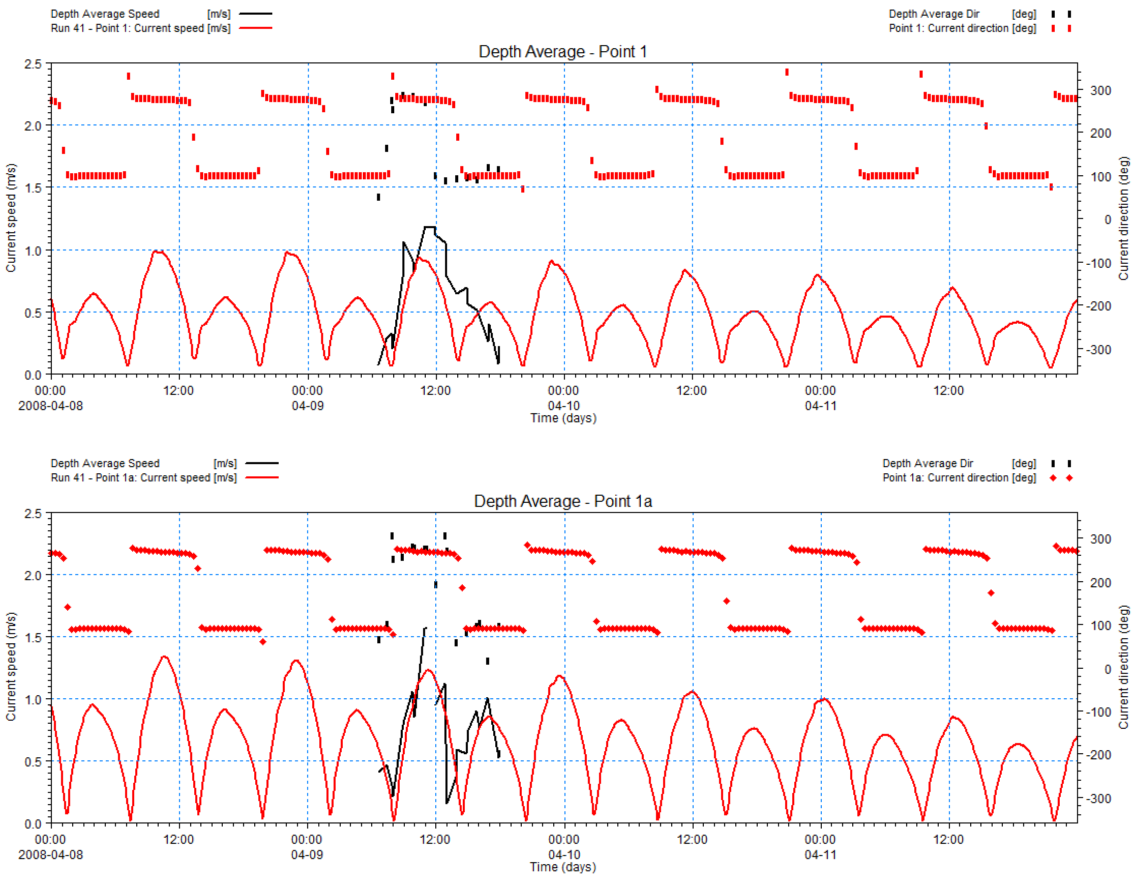
4.4.1.2 Depth-average model validation

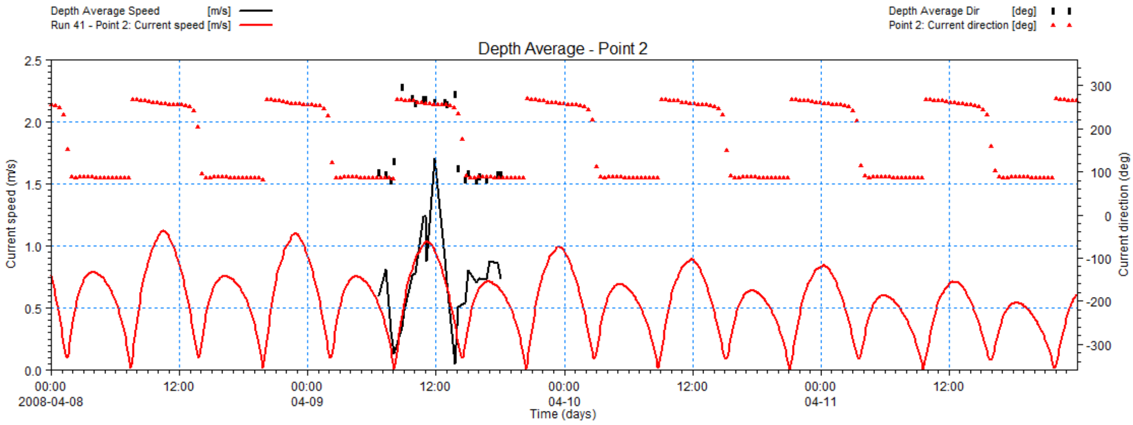
The current speed and direction measured by the ADCP, at each location, through the depth, were used to calculate a depth-average current speed and direction for each location. This derived data was compared to the depth average current speed and direction simulated by the model.

Figure 4.6 shows the comparison between modelled depth average (red line) and derived depth average current speed and direction (black line) for the ADCP data points located towards the northern and deeper section of the channel (Point 1, Point 1a and Point 2). Depth average current speeds are, for this section of the channel, between 1.0 to 1.5m/s.

Figure 4.7 shows the comparison between modelled depth average (red line) and derived depth average current speed and direction (black line) for the points located towards the southern and shallower section of the channel (Point 3 and Point 4). Depth average current speed are smaller than in the deeper section of the channel, with values not higher than 1m/s.

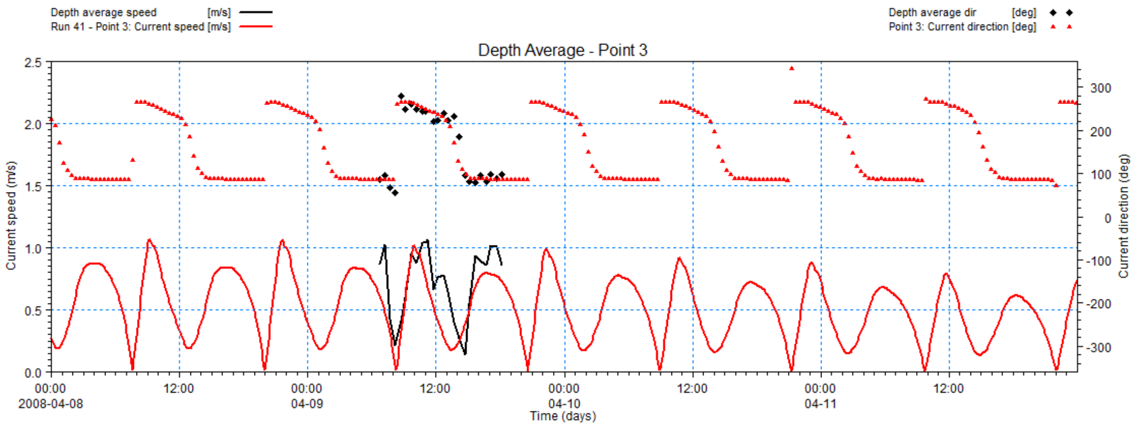
Figure 4.6: Comparison between the depth-average current speed and direction from the ADCP survey (black line) and the simulated current speed and direction (red line) at Point 1, Point 1a and Point 2.

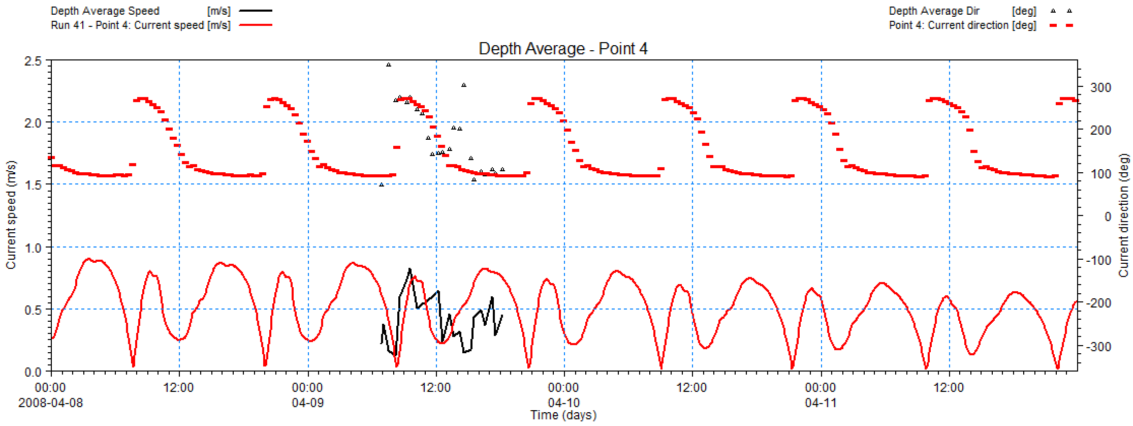




Source: Mott MacDonald, 2019. Contains Soil Mechanics – Pelorus Survey data, 2019

Figure 4.7: Comparison between the depth-average current speed and direction from the ADCP survey (black line) and the simulated current speed and direction (red line) at Point 3 and Point 4.





Source: Mott MacDonald, 2019. Contains Soil Mechanics – Pelorus Survey data, 2019

Error statistics for the derived data, compared to the modelled depth-average current data are shown in Table 4-4. It is seen that some of the statistics do not meet the model performance criteria in Table 4-1. This is mainly attributable to spikes and noise in the measured data which were not removed.

Table 4-4 Summary of model calibration statistics for depth-average current speeds in the Shannon Estuary

Station	RMSE (m/s)	Bias (m/s)	STD (m/s)	R^2	SI
Point 1	0.302	0.123	0.275	0.422	0.728
Point 1a	0.370	0.023	0.370	0.271	0.735
Point 2	0.254	0.129	0.219	0.621	0.837
Point 3	0.251	0.176	0.179	0.613	0.798
Point 4	0.281	-0.104	0.261	0.029	0.496

Source: Mott MacDonald, 2019

4.5 Summary

Together the model calibration and validation results show that the hydrodynamic model reproduces well the hydrodynamic conditions in the Shannon Estuary, especially in the study area. In all regards the model performance is commensurate with the performance metrics specified by Williams and Esteves (2018).

The differences between the data and the model results are explained by:

- Insufficiently accurate bathymetric data for the upper estuary;
- Out-dated bathymetry failing to capture recent morphological changes;
- The accuracy of the data used to calibrate the model (TotalTide and ADCP); and
- The assumption undertaken to process the available ADCP datasets.

The tendency of the model to underpredict flows velocities from the tidal diamonds, especially during the ebb tide is considered to be related primarily to the errors in the model representation of the upper estuary bathymetry. This is thought to have a small influence affecting the whole estuary. The underprediction by the model of the peak ebb current speeds is also demonstrated by the ADCP data at the Project site.

However, when considering sediment dispersion processes, the slight underestimation of current velocities represents the worst-case scenario, whereby sediments brought into suspension by the cable installation process will be dispersed less widely in the estuary and thus represent a more conservative situation as greater sedimentation could potentially occur. Based upon this argument it is concluded that the calibrated MIKE3 FM/HD model reproduces the hydrodynamic processes of the Shannon Estuary with enough accuracy and confidence to be used in simulations of suspended sediment plume behaviour during and after the cable installation operations.

5 Sediment modelling

5.1 Introduction

The Particle tracking (PT) module in the MIKE3 software enables modelling of suspended sediment transport discharged from point or line sources in estuaries such as the River Shannon. The PT module in MIKE3 is especially well-suited to environmental impact assessments concerned with sediment spreading associated with bottom disturbances by sediment dispersion techniques and cable laying. The particle model can simulate the near-field release of sediment into the water column and the released particles are not constrained by the resolution of the hydrodynamic model mesh. A detailed description of the PT model background and its formulation is given in (DHI, 2017).

The PT model simulation for this project has considered a worst-case scenario in which a 24-hr period was assumed for the installation of each of the four cables using the Mass Flow Excavation (MFE) method. It has been assumed that the worst-case for this project is represented by a shorter and continuous time period of disturbance rather than lower rates of dispersion over a longer, stop start, time period. The estimated MFE excavation rate provided by James Fisher SubSea Excavation[8] (a leading specialist and provider of MFE solutions) was between 0.139 to 0.208 m^3/s (500-750 m^3/hr). To be conservative, and to represent the worst-case scenario, it has been assumed that the MFE operates at its highest rate of 0.208m^3/s for 24-hr to complete the first cable installation. It was further assumed that the second cable will be installed (after 25-hr) directly after the completion of the first cable installation and similarly for the third and fourth cables. In addition, the other cable installation techniques such as cable plough and installation of additional cable protection were not considered in this study as these methods are assumed not to have any significant impact on the sediment regime at the site.

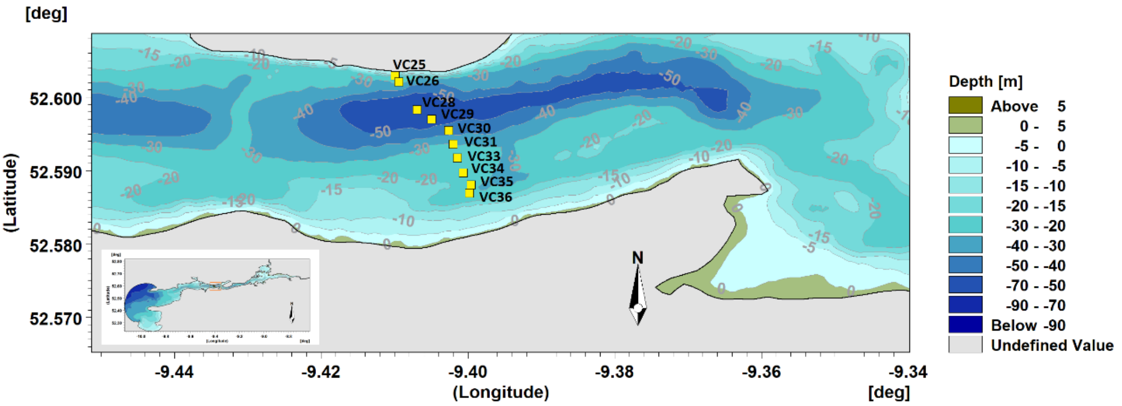
The sediments released into the water column from the MFE during the cable installation were represented by particles with defined sediment types and mass flux at 1m above the bed. The many thousands of released particles were tracked as they are carried by the tidal currents, dispersed and deposited in the various parts of the estuary. With regards to the sediment types of the particles released into the water column, the PT modelling was carried out based on the intrusive samples along the N2-S2 cable route. An overview of the sediment materials used in the PT model is presented in the next section.

5.2 Sediment data

Figure 5.1 shows an overview of the intrusive sample points along the proposed N2-S2 cable route and Table 5-1 summarises sediment properties at each location. A more detailed summary of the intrusive sample results is presented in the marine survey results by RINA (RINA, 2018).

[8] http://www.jfsubseaexcavation.com/

Figure 5.1: Overview of intrusive sample points



Source: RINA (2018)

Table 5-1 Summary of sediment material

	Sediment type					
Station	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Bulk Density (kg/m^3)[9]	Dry Density (kg/m^3)
VC25	42.0	25.0	19.4	13.5	1506	779
VC26	63.5	31.9	2.3	2.3	1506	779
VC28	31.2	18.7	35.6	14.5	1506	779
VC29	1.4	0.8	54.9	43.6	1362	543
VC30	0.0	0.2	40.1	59.8	1362	543
VC31	0.0	94.5	2.8	2.8	1362	543
VC33	0.1	66.2	27.3	6.7	1362	543
VC34	0.9	72.8	16.2	10.1	1362	543
VC35	0.6	15.7	66.1	17.9	1362	543
VC36	24.3	23.4	45.5	6.9	1506	779

Source: RINA (2018)

Based on the data in Table 5-1, four main sediment types were identified at the Project site comprising mixtures of gravel, sand, silt and clay with an average D50 of 3.25mm, 0.15mm, 0.05mm and 0.003mm, respectively. For modelling purposes two representative dry bulk densities of 779 kg/m^3 and 543kg/m^3 were defined for the mixture of gravel/sand/silt/clay and sand/silt/clay, respectively. Gravel was excluded in the model as this material will not move very far from the release point compared to the sand, silt and clay sediment.

[9] https://structx.com/Soil_Properties_002.html

5.3 Model setup and execution

Figure 5.2 shows an overview of the procedure to setup and run the PT model. This comprises:

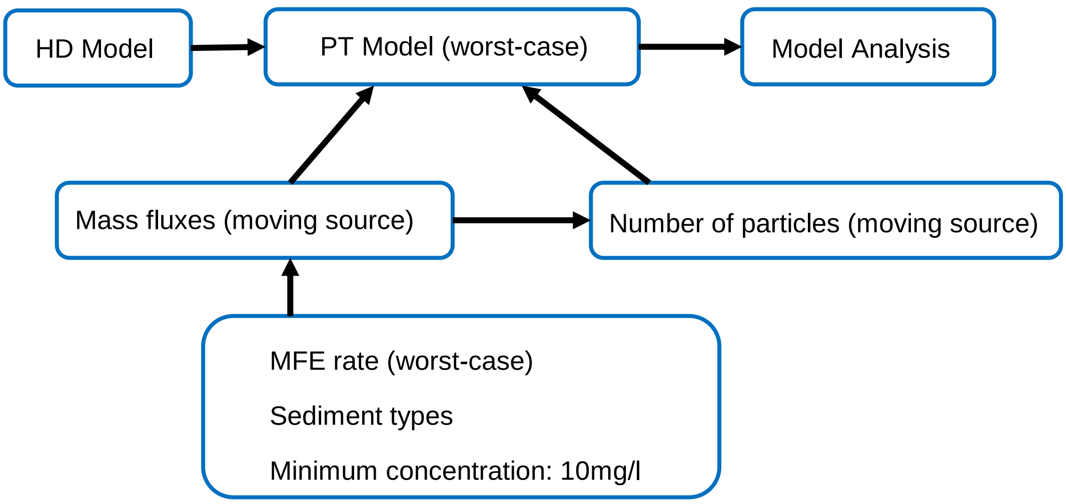
- Providing to the PT model the calibrated HD model results to define hydrodynamic flows during the simulation;
- Provision of input files defining mass fluxes and number of particles based on the highest MFE rate of 0.208m^3/s for the worst-case scenario and sediment types at the site as described in the previous section; and
- Setting the minimum concentration to 10mg/l to define the number of particles to be released in the model. This value is based on best practise.

To represent the worst-case scenario for dispersion of sediments around the estuary, the simulation of one cable installation using the MFE method was undertaken for a spring tide. Cable installation is more likely to be planned to commence on neap tides due to the strength of spring tide currents, hence this is considered to represent the worst-case scenario. The sediments were released in the bottom layer (1m above the sea bed) of the model as a moving source along the proposed N2-S2 cable route and supplied as a mass flux (kg/s) with the number of particles per timestep (and per sediment type) calculated to produce a maximum mass per particle. This allowed small suspended sediment concentrations to be simulated.

In order to represent accurately the proportions of each sediment fraction in the water column, sand, silt and clay were modelled separately. The characteristic of the release mixed sediment was changed according to the location along the N2-S2 cable route based on the sediment data from the intrusive sample points (Figure 5.1). The first sediments were released during the ebb flow on the spring tide where the current speed magnitude was higher than during the flood flow, again to represent the worst-case scenario.

After a period of 24-hours, sediment releases were stopped and the model run was continued for a further 72-hours in order to observe the sediments in suspension as they are transported, deposited and eroded within the estuary.

Figure 5.2: Modelling approach



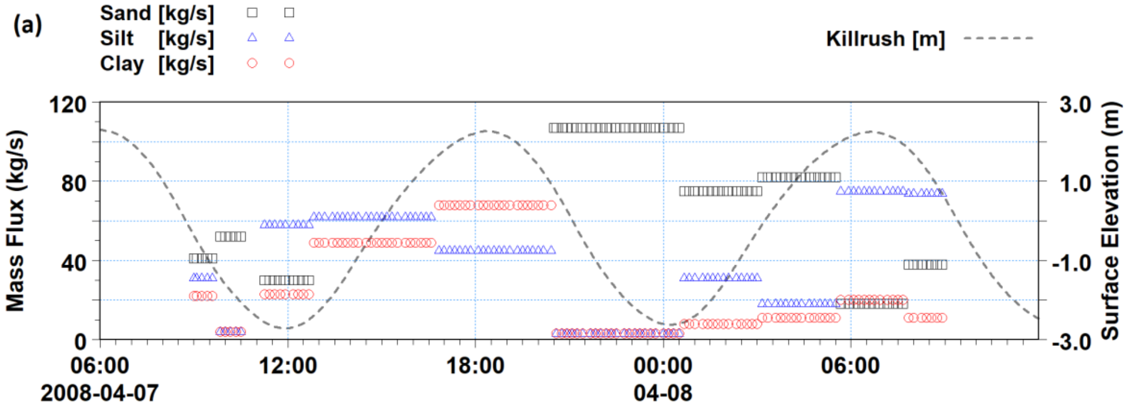
Source: Mott MacDonald, 2019.

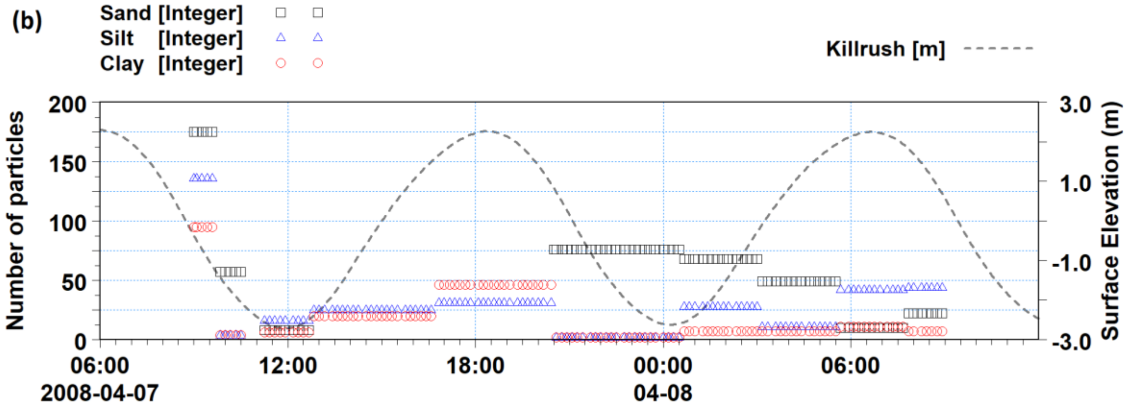
Figure 5.3(a) shows a time-series of the moving source mass flux of sand, silt and clays. The sediments were released every 5 minutes (i.e. the output resolution of the HD model). Figure

5.3(b) shows the number of particles for each sediment type during the 24-hour MFE operation. The water level at Kilrush extracted from the HD model is also shown in both figures to show when the first sediments were released during the ebb tidal cycle.

It is noted that while the sediment types were modelled individually, the analysis of sediment suspension and deposition considered sand, silt and clay materials together using a dry bulk density value of 543kg/m^3 to compute sediment deposition depths. This conservative approach results in greater sediment deposit depths than would be the case if a dry bulk density value of 779kg/m^3 was used (Table 5-1).

Figure 5.3: Mass flux and number of particles. Figure(a) represents the masses for each sediment type. Figure(b) shows number of particles for each sediments type. The masses and number of sediments vary along seabed/cable route in which the sediment type and thickness varies.





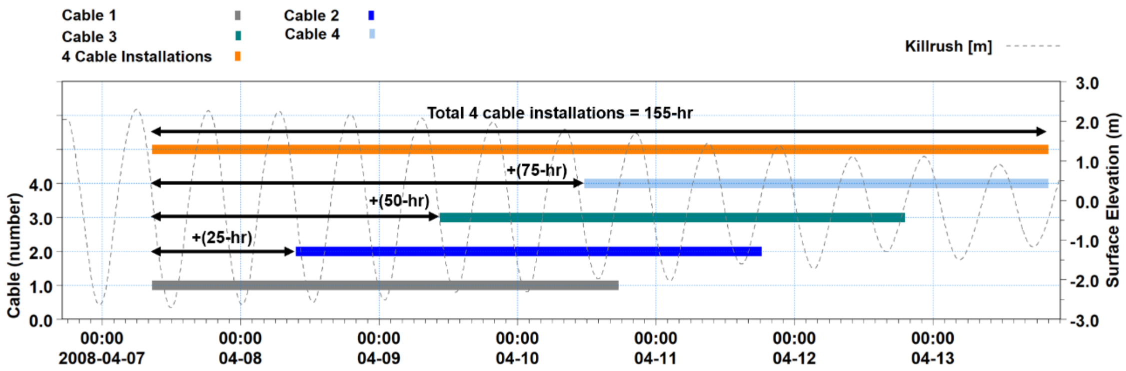
Source: Mott MacDonald, 2019.

For efficiency, the model was run to simulate one cable only. However, the results were scale-up to represent the combined impact of four cable installations. In this approach the first cable was assumed to be installed completely after a 24-hr MFE operation with the model run until 155-hr to understand the sediment dispersion with time. The second cable was assumed to commence installation on the next ebb tide after the first cable installation completed (1 hour after the completion of the first cable installation, or 25 hours after the commencement of the first cable installation). The third and fourth cables were assumed to commence installation at 50-hr and 75-hr, respectively (see Figure 5.4).

Figure 5.4 shows the worst-case scenario approach to simulate sediment dispersion arising during installation of four cables. The resulting 96-hr simulation was obtained by considering the first 24-hour cable installation and shifting cable installations two, three and four by 25, 50 and 75-hr, respectively.

The total suspended sediment concentration and sediment deposition depths for four cable installations was then obtained by summing the individual results over a period of 155-hr. The water level at Kilrush extracted from the HD model results is shown in the figure to demonstrate that during the simulation the beginning of each cable deployments was during the ebb tide.

Figure 5.4: Four cable installations analysis diagram



Source: Mott MacDonald, 2019.

To estimate the settling velocity for sand the PT model applies Stokes Law based on particle size. The settling velocity for silt and clay (fine grained cohesive sediments) is calculated using the Richardson-Zaki (1954) formula. This approach also accounts for flocculation rate and hindered settling of cohesive silt and clay particles when the concentration of suspended sediment is high (i.e. > 500mg/l).

A critical bed shear stress for bed erosion (τ_{crit}) was also supplied to the model for sand, silt and mud. The selected values of τ_{crit} are based on the sediment types. For silt and mud, the values are related to D50 and an assumption of how consolidated the sediments are. For sand, τ_{crit} is estimated using the Shields curve. The values selected and shown in Table 5-2 are those recommended by DHI (2017).

Table 5-2 Sediment properties defined in the PT model

Sediment type	Average D50 (mm)	Critical sheer stress of erosion (τ_{crit}) (N/m^2)	Settling velocity (m/s)
Sand	0.15	0.1	0.02
Silt	0.05	0.5	0.003
Clay	0.003	0.3	0.001

Source: Mott MacDonald, 2019.

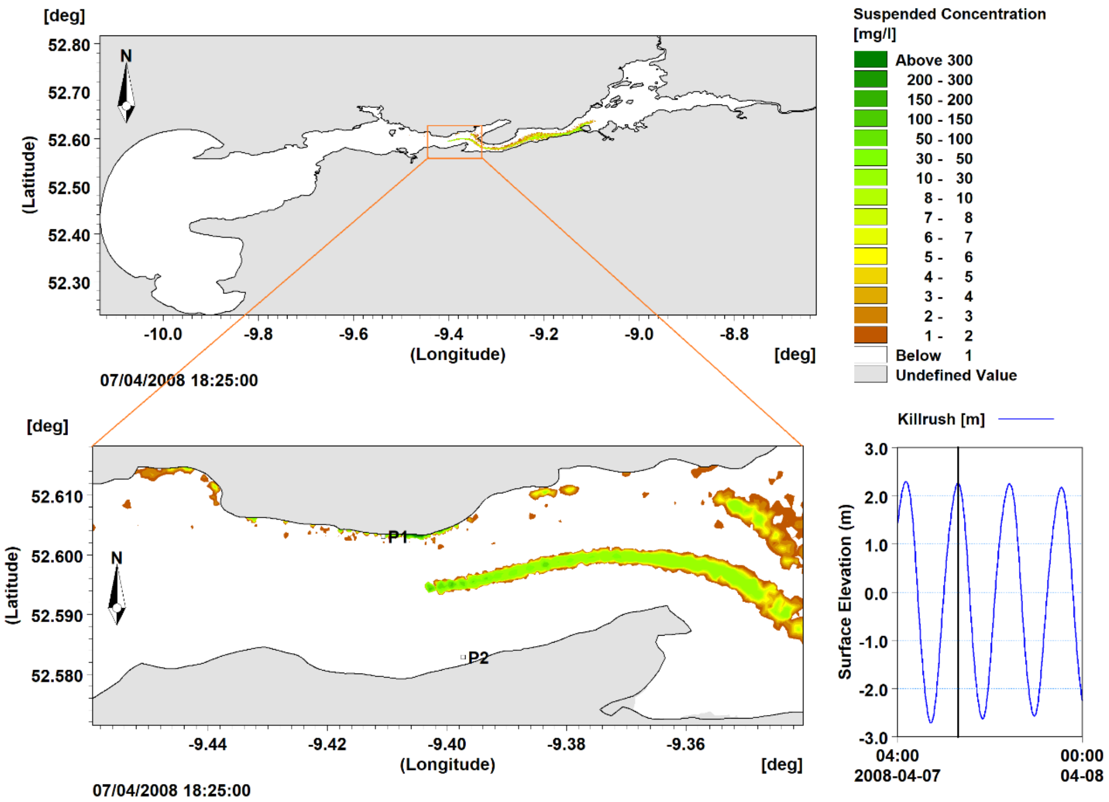
6 Results

6.1 Total suspended sediment concentration, TSSC

The total suspended sediment concentration (TSSC) resulting from the cable installation works was defined by the sum of the sand, silt and clay fractions for the four cable installations during the 155-hr PT model simulation period. Figure 6.1 and Figure 6.2 show the spatial distribution of TSSC at high water following the flood tide, and at low water following the ebb, respectively.

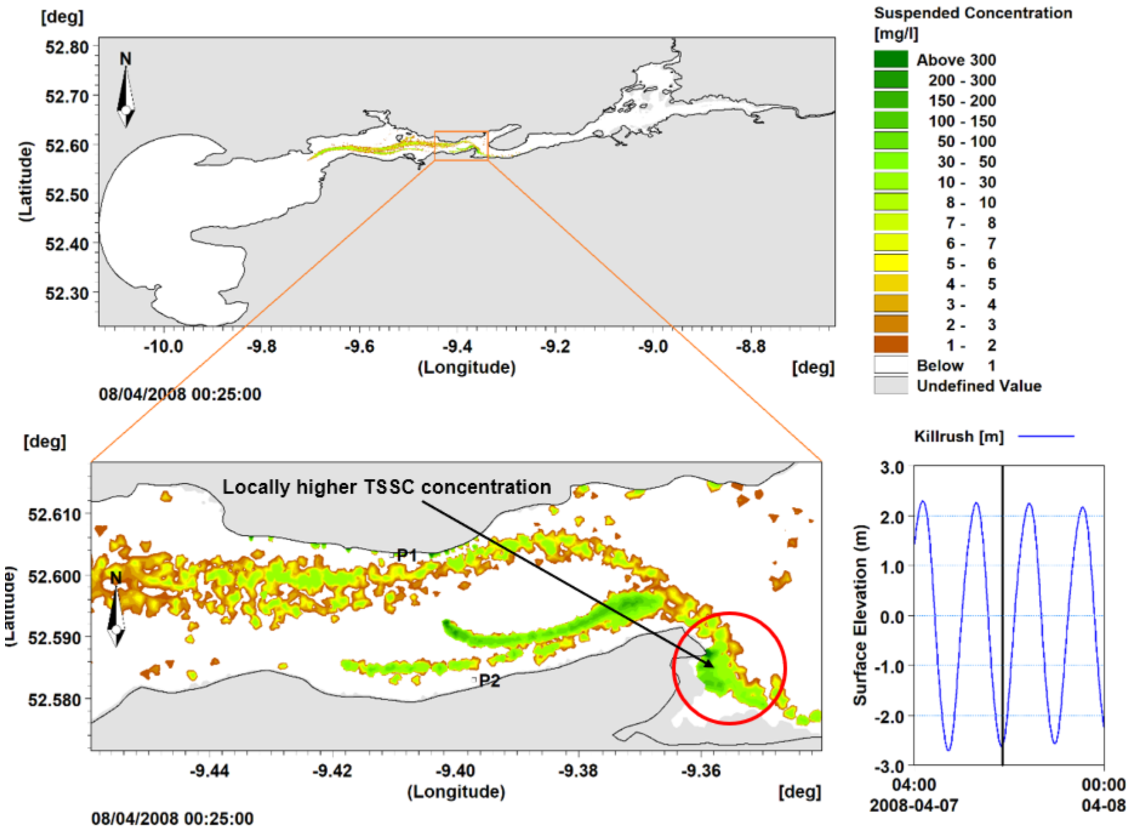
While in most cases these figures show that TSSC values are higher at the point of release into the PT model (see inset within Figure 6.2) these also show that TSSC values are higher (up to 300mg/l) near to the small bay area located at around -9.36E,52.58N. Sediment accretion would be expected at this location due to the relatively high TSSC values during the tidal cycle, and the sheltered nature of this small bay with a headland, shallow water depths and low current speeds.

Figure 6.1: Suspended concentration at high water (flood flow)



Source: Mott MacDonald, 2019.

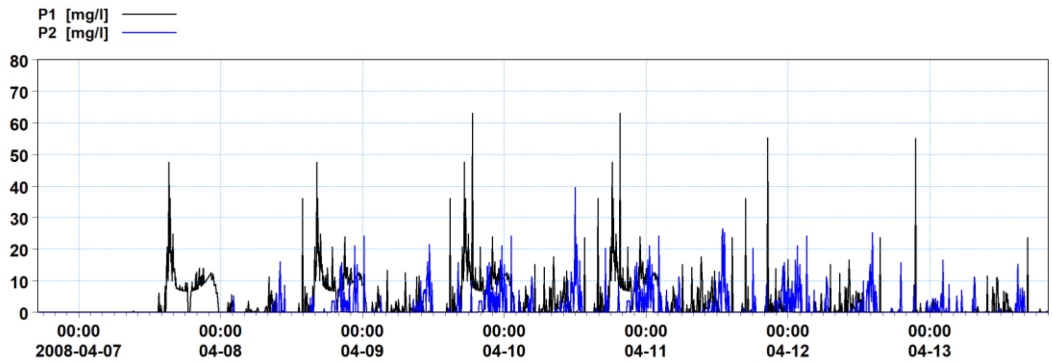
Figure 6.2: Suspended concentration at low water (ebb flow)



Source: Mott MacDonald, 2019.

To examine the temporal variation in TSSC over 155-hr, TSSC time-series were extracted at locations north and south of the proposed N2-S2 cable route (P1 and P2, Figure 6.1). These results, are presented in Figure 6.3 where the TSSC at P1 is higher (>60mg/l) than at P2 (>39mg/l) due to the higher sediment release rate.

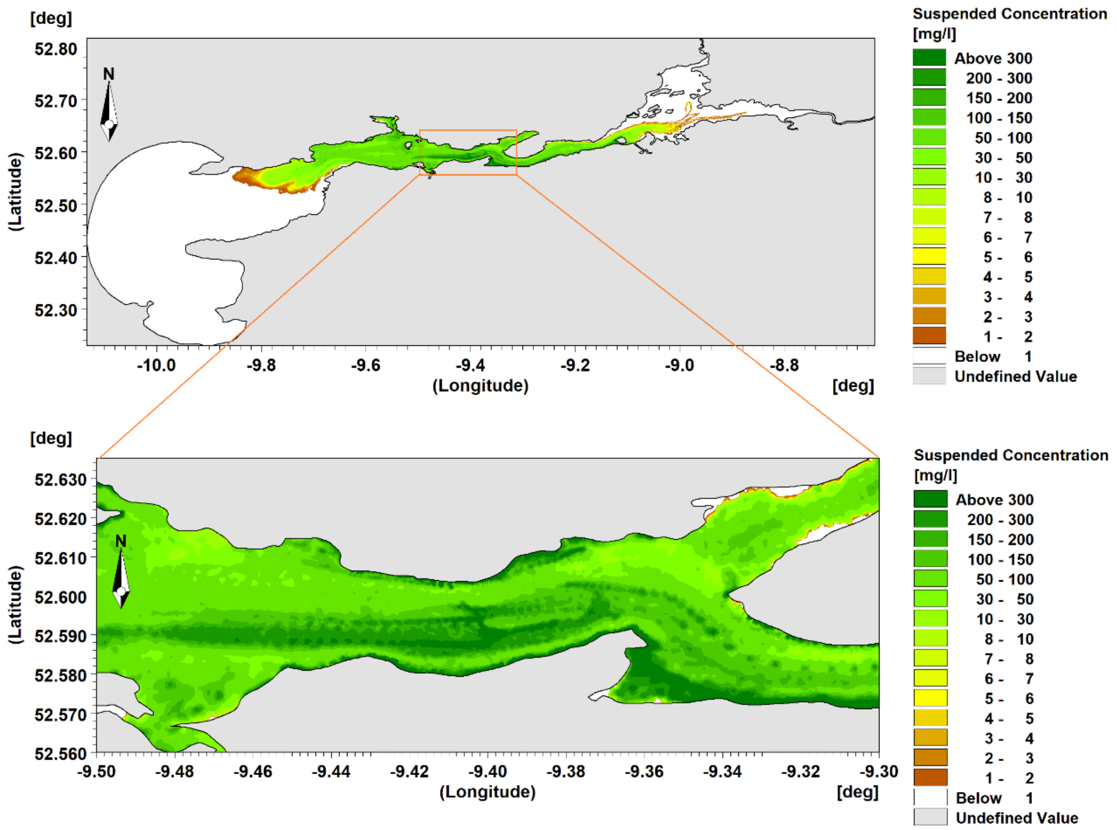
Figure 6.3: Total suspended concentration at P1 and P2



Source: Mott MacDonald, 2019.

The PT modelling indicates a short-term estuary-wide peak in TSSC during cable installation works. Figure 6.4 shows the spatial distribution of the maximum TSSC during the 155-hour simulation period. The figure shows that the short-term maximum TSSC values are higher in the middle of the channel close to the moving source of sediment. It shows also that high values occur in the small bay area as previously identified in Figure 6.2. It must be noted carefully that these relatively high TSSC values are short-lived and are considered to be only marginally above the normal background TSSC in the Shannon Estuary at most locations.

Figure 6.4: Maximum short-term suspended sediment concentration



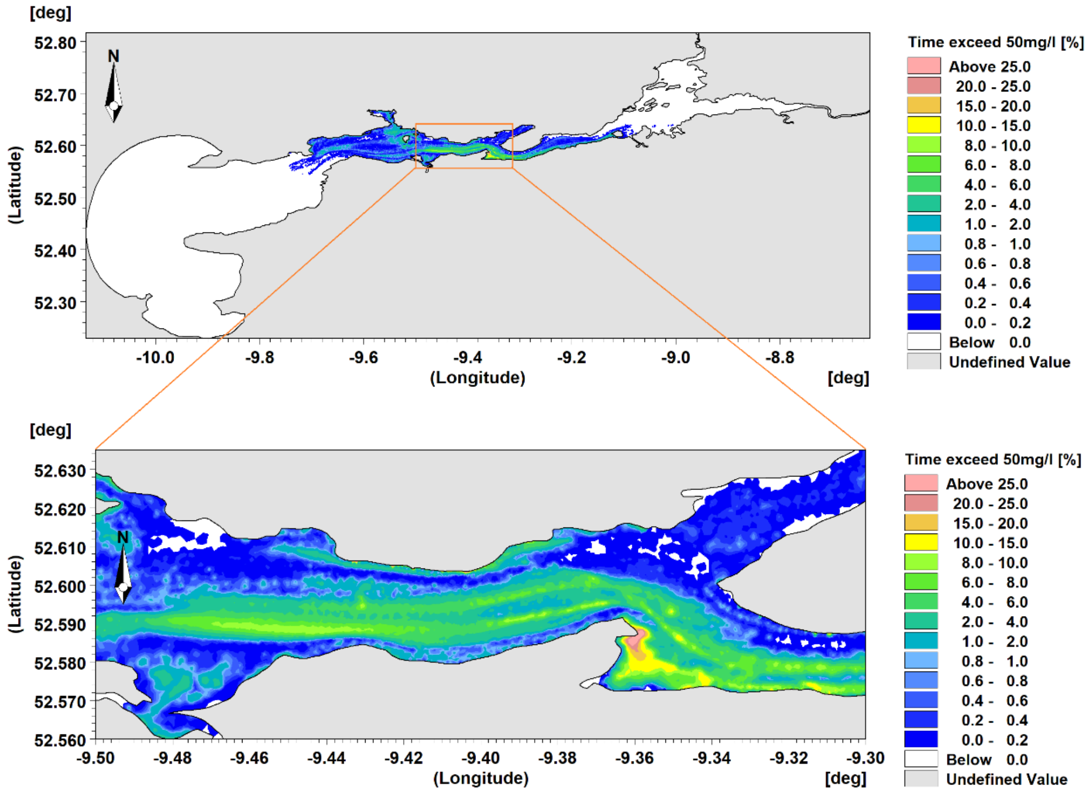
Source: Mott MacDonald, 2019.

Figure 6.5 shows spatially the percentage of time TSSC values exceed 50mg/l over the 155-hr PT model run. The figure shows that, as expected, TSSC values exceeded 50mg/l for over 10% of the time in the middle of the channel close to cable installation location and that sediments are dispersed over a wide area owing to the presence of the silt/mud fraction that remains in suspension much longer than sand. Figure 6.5 also shows that TSSC values in excess of 50mg/l occur for less that 2% of the 155-hour PT model run at most locations in the estuary.

The region of high TSSC values in the embayment noted above (Figure 6.2) is also evident in Figure 6.5 where TSSC values exceeding 50mg/l are observed for around 25% of the total PT run time. This reflects the sheltered nature of this location that tends to reduce mixing and dispersion of the suspended sediments.

It is noted that the MIKE3 FM/HD bed shear stress predictions showed that tidal currents alone are competent to mobilise and resuspend the bed sediment in the estuary and thus contribute to TSSC values predicted by the PT model.

Figure 6.5: Percentage of time TSSC exceeds 50mg/l during the 155-hour PT model run



Source: Mott MacDonald, 2019.

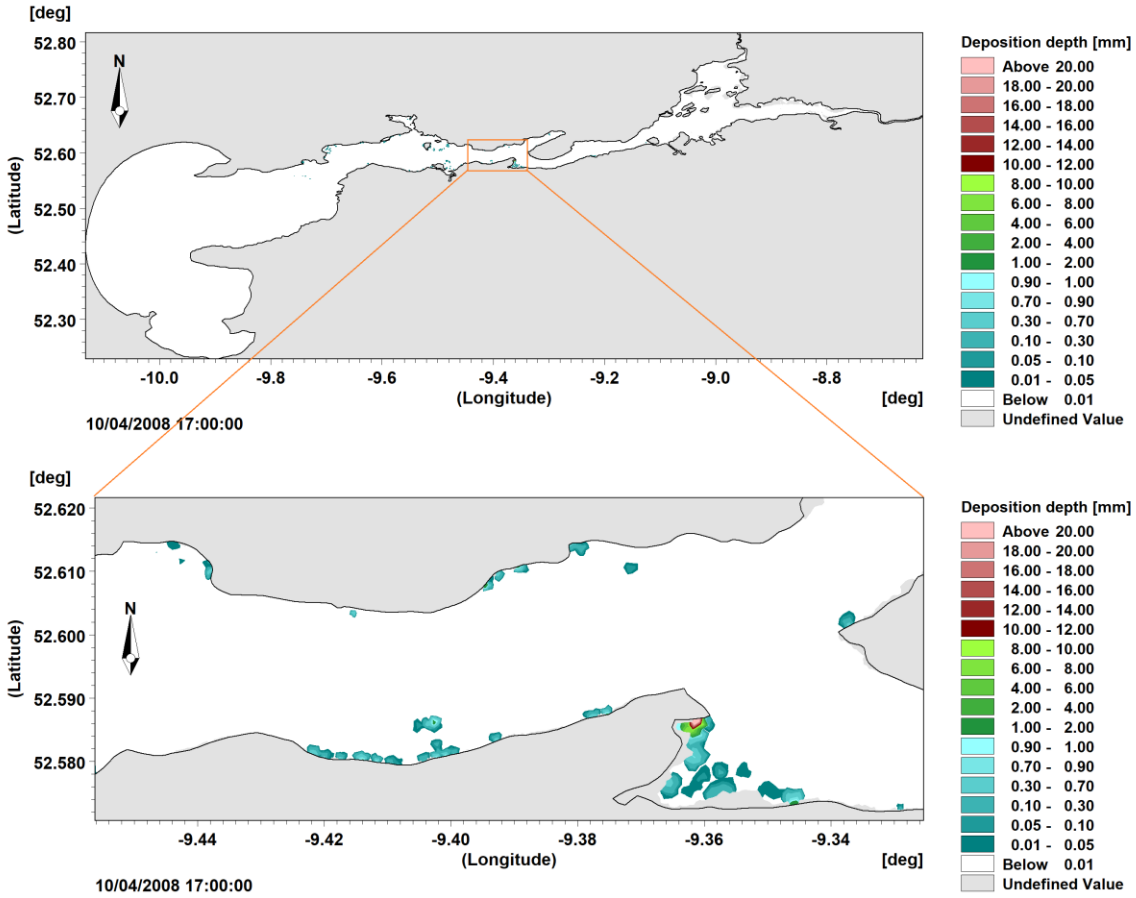
6.2 Sediment deposition

In common with the analysis of TSSC, the assessment of sediment deposition predicted by the PT model considered the combined effect of the four cable installations during the 155-hr PT model simulation period. Figure 6.6 shows the predicted sediment deposition depths after completion of the cable installation. The figure shows that sediment deposition depths are:

- Up to 2mm towards the south of the cable route;
- Generally less than 1mm and located towards the shoreline where flow speeds are lower than in the central part of the estuary; and
- Up to 20mm inside the small bay to the south east of the cable route (Figure 6.2).

The relatively high sediment deposition in the small bay is not unexpected given the relatively high TSSC values previously identified in this area. However, it is noted that the OSPAR Commission (OSPAR 2008, 2009) state that marine life can survive rapid sediment deposition up to depths of 100mm, five times the depth predicted by the PT model for the worst-case scenario. Further, OSPAR (2008, 2009) also state that negative impacts to marine life are only expected when sediment deposition depths exceed 150mm.

Figure 6.6: Total deposition depth at the end of cable installation

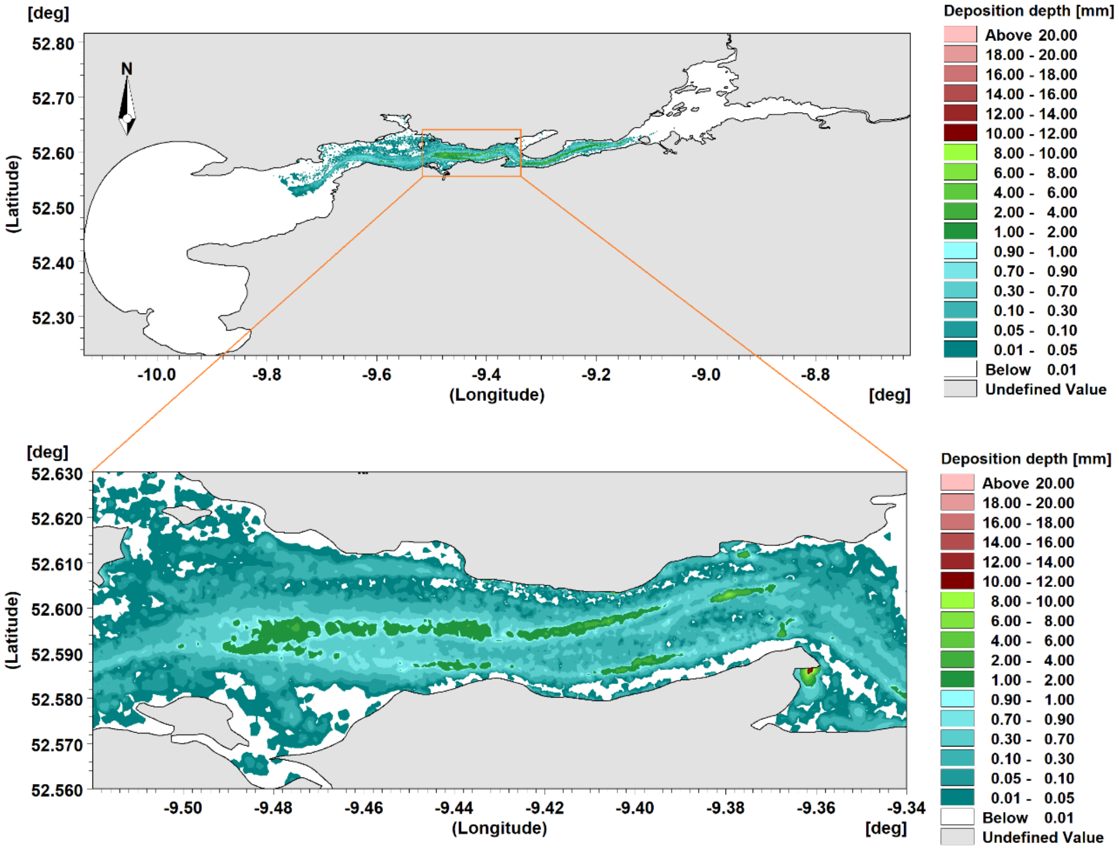


Source: Mott MacDonald, 2019.

During the PT model run sediment deposition was predicted more widely across the Shannon Estuary due to the temporarily deposition of sediments in suspension during the low flow velocity conditions between the ebb and flood tidal flows. To illustrate this Figure 6.7 shows the maximum sediment deposition depth predicted by the PT model at any time during the simulation period. Figure 6.7 again shows sediment deposition depths up to 20mm inside the small bay (Figure 6.2). The maximum sediment deposition depth in the middle of the channel varies between 2mm and 8mm while the remaining areas in the estuary shows low sediment deposition depths.

The PT model showed that sediments deposited temporary during periods of slack water during the tidal cycle were re-mobilised and further dispersed in the estuary during the next tidal cycle. Further, the temporary deposits are highly localised and around a factor of 5 less than the sediment deposition depths likely to stress marine life.

Figure 6.7: Maximum short-term deposition depths



Source: Mott MacDonald, 2019.

7 Summary and Conclusions

The tidal flows in the Shannon estuary, influenced by freshwater inputs from the fluvial network, has been simulated and using a calibrated and validated MIKE3 FM/HD model. To simulate the sediment dynamics at the Project site the outputs from the MIKE3 FM/HD model have been used to drive a particle tracking (PT) model.

In the PT model run it was assumed that the MFE operated at 0.208m^3/s for 24-hr to complete the first cable installation during spring tide. It was assumed also that the second cable will be installed directly after the completing the first cable installation and similarly for the third and fourth cables (see Figure 5.4). This continuous cable installation programme was considered to give rise to the maximum bed disturbance and thus is the worst-case scenario with regards to suspended sediment release, dispersion and deposition in the estuary environment.

With regards to the TSSC attributable to the worst-case scenario cable installation works, the PT modelling showed that during the 155-hour simulation:

- The percentage of time TSSC values exceeded 50mg/l in the middle of the channel was around 10%;
- The finer sediments remained in suspension longer than larger sediments and were dispersed over a wider area; and
- The highest TSSC values were recorded in the small sheltered bay area to the south east of the Project site (Figure 6.2).

With regards to suspended sediment deposition attributable to the worst-case scenario cable installation works, the PT modelling showed that during the 155-hour simulation:

- The amount of sediment deposited by the end of the simulation is less than 1mm for most estuary locations;
- Deposited sediments are likely to re-mobilise and disperse more widely in the Shannon Estuary except in areas exposed to low tidal currents; and
- Relatively large and localised deposition depths of the order of 20mm were predicted in the sheltered small bay area to the south east of the Project site (Figure 6.2).

Using OSPAR (2008, 2009) as a guide, sediment deposition of around 20mm is five times less that the values likely to have any detrimental impact on marine benthos. Further, the area where sediment deposition depths of 20mm are predicted is intertidal and it would be expected that the local flora and fauna would possess the adaptive strategies to accommodate modest sediment deposition without any significant detrimental impact.

The model results show that even for the worst-case scenario considered, the sediment released into the estuarine environment during cable installation operations is unlikely to have any detrimental environmental consequences. Please note that slightly larger spring tides could be expected in other months of the year, increasing the tide range by approximately 8% and therefore will potentially increase the TSSC and deposition if the cable installation is undertaking during these periods. It remains possible to reduce impacts further for example by changing the cable installation programme. Undertaking the cable installation during neap tides when the tidal flows are smaller is likely to result in the settling of sediment more rapidly and less dispersion of suspended sediment.

8 References

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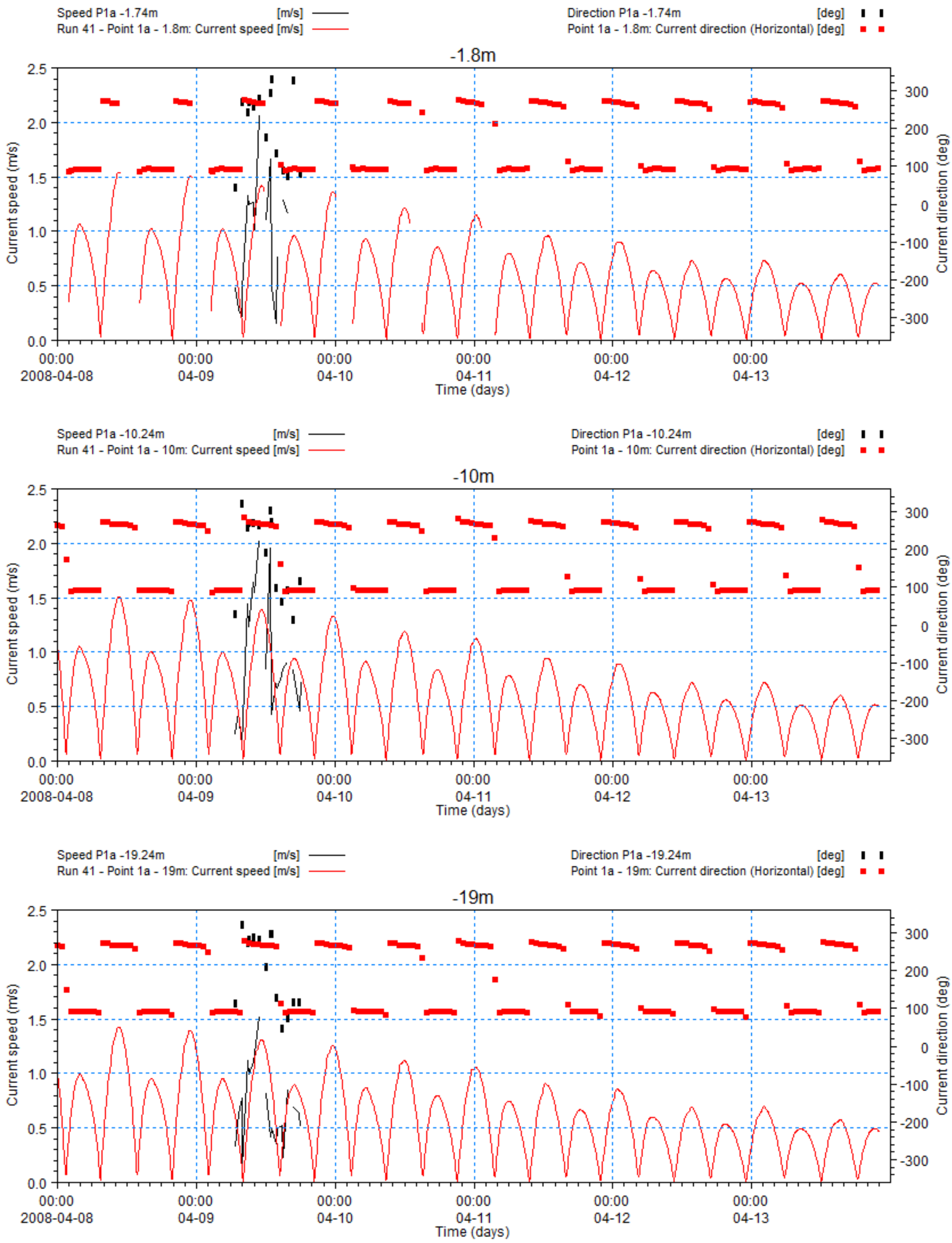
Appendices

A. Model validation results 48

A. Model validation results

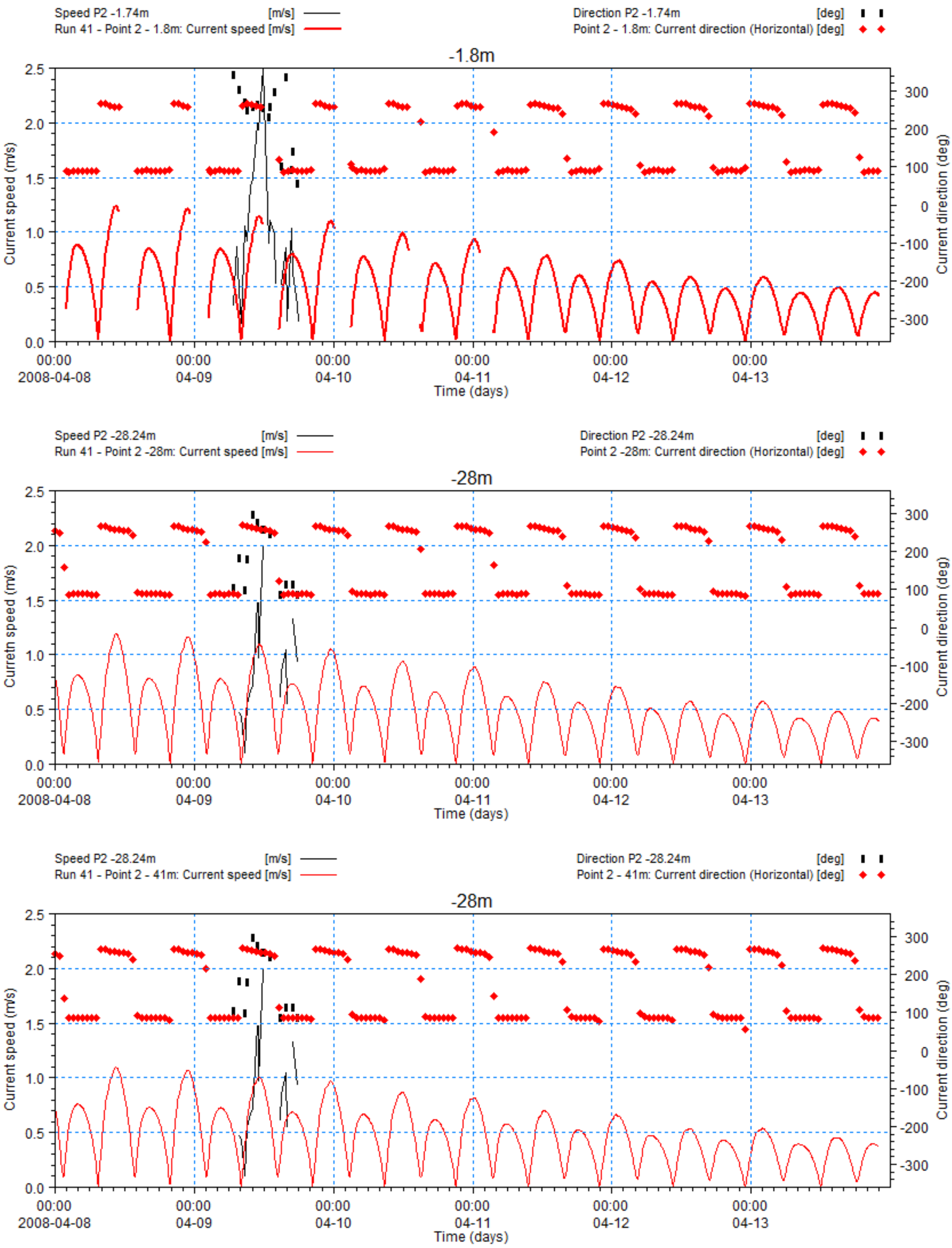
The following plots demonstrate the MIKE21 FM/HD model validation results at different depths for at locations 1a, 2 and 3 along the ADCP survey transect (Figure 3.7).

Figure 8.1: Comparison between the current speed and direction from the ADCP survey (black line) and the simulated current speed and direction (red line) for several depth at Point 1a.



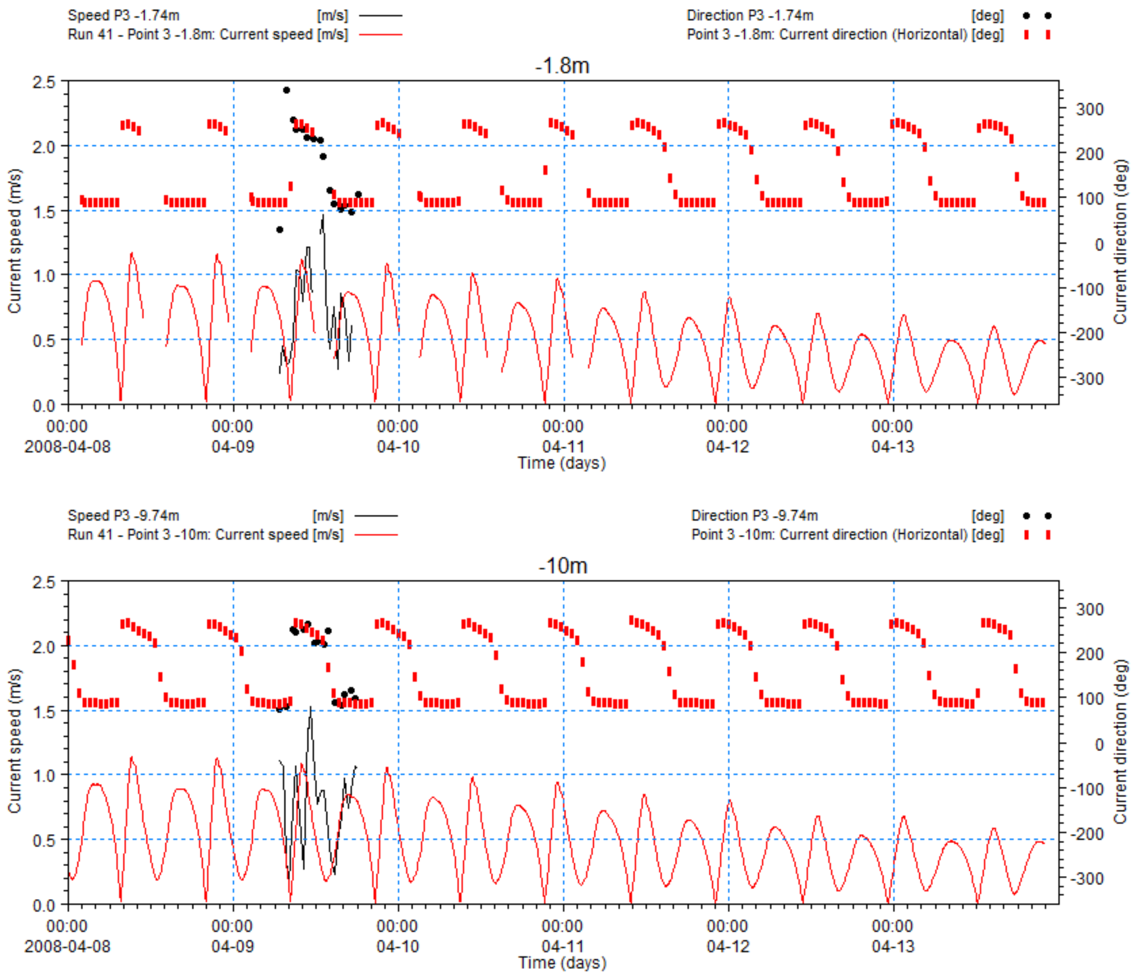
Source: Mott MacDonald, 2019. Contains Soil Mechanics – Pelorus Survey data, 2019

Figure 8.2: Comparison between the current speed and direction from the ADCP survey (black line) and the simulated current speed and direction (red line) for several depth at Point 2.



Source: Mott MacDonald, 2019. Contains Soil Mechanics – Pelorus Survey data, 2019

Figure 8.3: Comparison between the current speed and direction from the ADCP survey (black line) and the simulated current speed and direction (red line) for several depth at Point 3.



Source: Mott MacDonald, 2019. Contains Soil Mechanics – Pelorus Survey data, 2019

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