Balliemeanoch Pumped Storage Hydro

Environmental Impact Assessment Report

Volume 5: Appendices

Appendix 18.1 Tidal Model Calibration

ILI (Borders PSH) Ltd

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Quality information

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1. Tidal Model Calibration

1.1 Introduction

This Appendix describes the setting-up and calibration of a hydro-dynamic (HD) model used to provide a description of water movement in the upper reaches of Loch Fyne. After it is demonstrated that the model has been calibrated using suitable data, it can then be used to predict potential effects on the physical marine environment for key stages (i.e. construction and operation) in the development of the proposed Marine Facility required to facilitate construction of the Balliemeanoch PSH Development.

1.2 Hydrodynamic model set-up

1.2.1 Model domain

The hydro-dynamic model was developed using the MIKE21 modelling software from MIKE by DHI. The model domain covers the Firth of Clyde extending into the Irish Sea, as shown in Figure 0-1.

The spatial resolution of the model mesh is approximately 5m, which was chosen to accurately resolve local current patterns in the immediate vicinity of the proposed Marine Facility. The mesh resolution gradually increases reaching 5 km at the offshore limits of the model domain. By varying the mesh resolution, the model run-time is reduced to a minimum while providing the required level of detail in the main areas of interest.

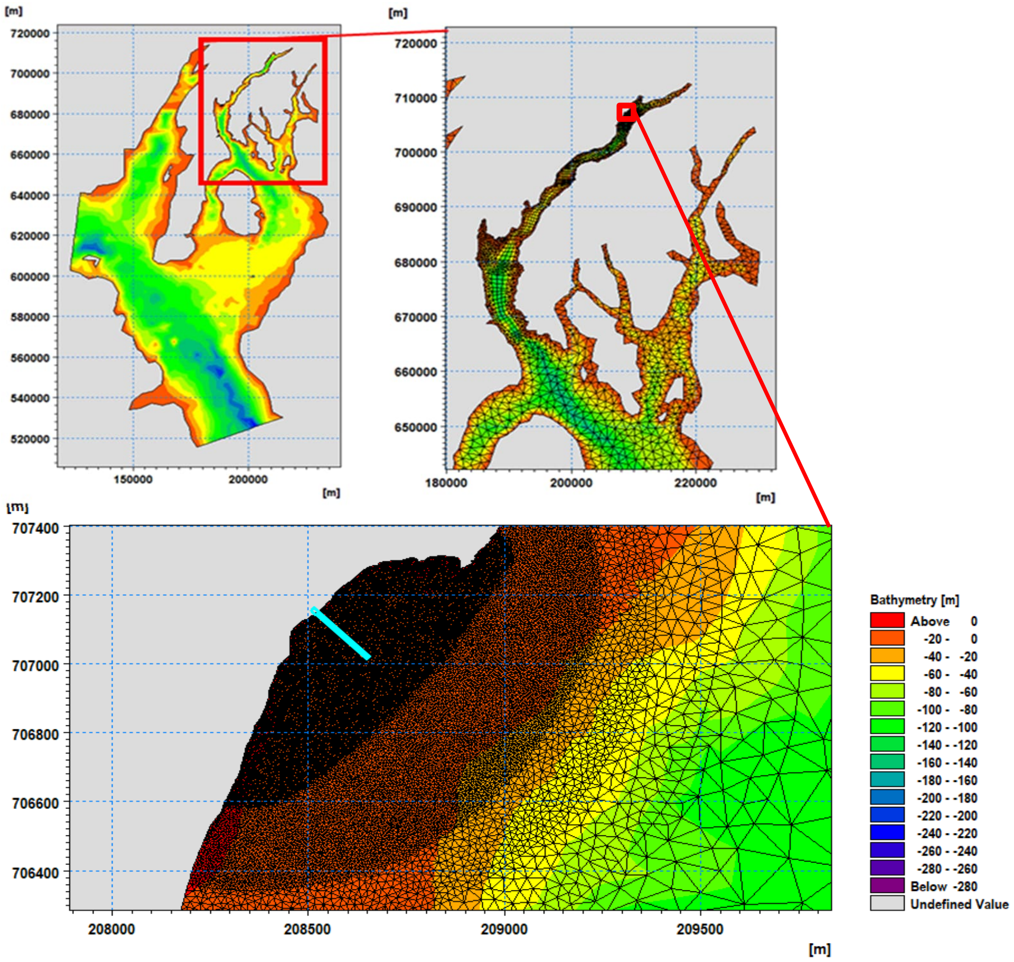

Figure 0-1. Model extent and spatially varying cell resolution

1.2.2 Bathymetry

For the majority of the model domain, bathymetric data is derived from digitised Admiralty Chart data from the C-Map database. In 2023 a project-specific bathymetry survey was undertaken which was used to provide high-resolution data covering the area where the Marine Facility is proposed to be located. This data has been used in the area where the mesh resolution is most refined thus enabling any features on the seabed and their effect on the flow regime to be represented in the model. The bathymetry data was merged with high-resolution LiDAR data and used to provide an accurate representation of intertidal areas within the model. Any gaps between datasets were covered by manually digitizing data from navigation charts.

The bathymetric datasets were converted to a common datum, MSL (Mean Sea Level) so that these were then consistent with the datum used for the seaward model boundary conditions. Table 1 provides a summary of the bathymetry datasets used to populate the model domain.

Table 1. Bathymetry Datasets

Name	Coverage	Applied Resolution
CMap Digital Bathymetry	Outer domain	250 m / contours
2017 LiDAR Survey	Local shoreline	2 m
2023 Bathymetric Survey	Marine Facility	5 m

1.2.3 Boundary Conditions

4.2.3.1 Water Levels

Water levels along the seaward boundary of the model were taken from the Danish Hydraulic Institute's (DHI) DTU10 Global Tidal Model. Predicted tides were used to identify suitable periods including mean spring (3.2 m range) and neap (2.4m range) tides, as required for model calibration and validation, respectively. The selected tides are shown in Figure 0-2 and Figure 0-3, as predicted using the Admiralty's TotalTide software. Astronomic tidal constituents are applied along the offshore boundaries of the model with data provided at approx. 15km intervals.

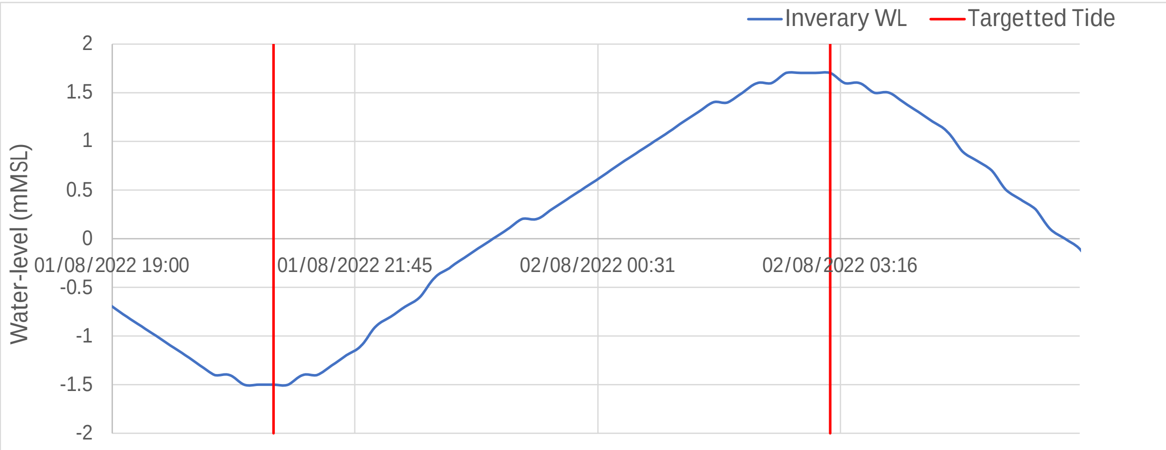

Figure 0-2. Spring tide selected for model calibration

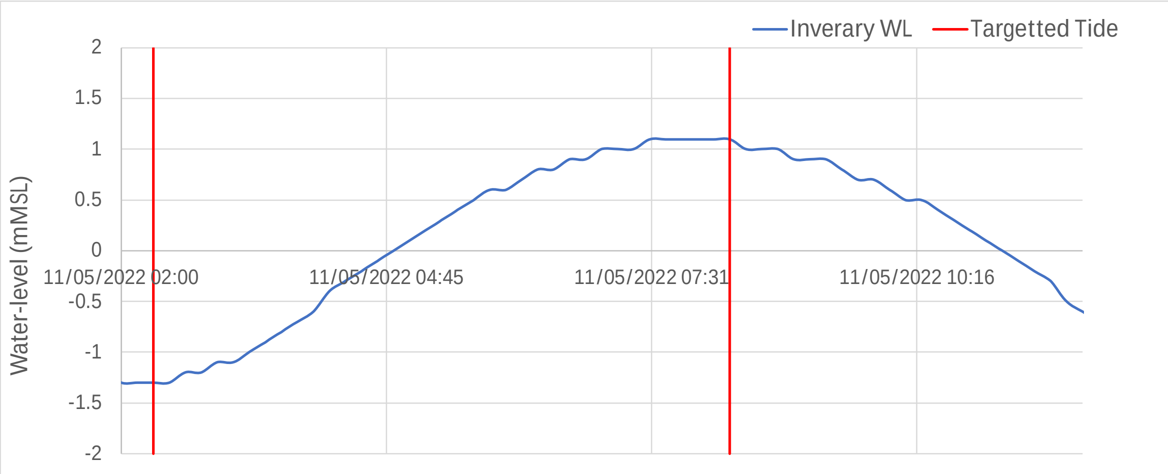

Figure 0-3. Neap tide selected for model validation

1.3 Model Calibration

As part of the model calibration process, a series of tests were carried out to understand the sensitivity of the model to alternative set-up parameters. A summary of the results from these tests is provided below.

1.3.1 Bed Roughness

Bed roughness is applied in the model to represent frictional energy losses as a result of interaction between the tidal flow and the seabed substrate. Roughness is represented by the Manning's 'm' value with a higher value denoting lower frictional resistance. A range of constant bed roughness values were tested as well as spatially varying values using a depth related approach. Due to significant depths in the main body of the loch, bed roughness was found to have minimal influence on water levels and currents and on this basis it was decided to adopt a constant, mid-range value of 32 $m^{1/3}/s$.

1.3.2 Model Dimensionality

A 'cut-down' version of the 2D model, limited to the extent of Loch Fyne, was configured as a 3D model with a water level boundary condition taken from the 2D model. The 3D model was used to investigate the potential development of a significant vertical flow structure, in particular during extended periods of high wind blowing from a south-westerly direction, along the axis of the loch. The results of the 3D model tests confirmed that variations in water levels and currents were almost identical when compared to results from the 2D model set-up. A 3D model with 10 vertical layers involves model run-times that are 10 times longer. Given that there was no justification for operating the model in 3D mode, it was therefore decided to 2D model production runs would be adequate.

1.3.3 Tidal Phasing

During initial tests a slight phase shift was noted between the timing of predicted and modelled high and low waters. A phase shift of 30 minutes was therefore applied to the model boundary conditions in an attempt to provide improved agreement between the model and predicted datasets. However, due to the asymmetry of the tides in the Firth of Clyde, any improvements to the timing of high water were offset by an increase in the phase difference at low water. It was therefore decided to leave the phasing of the model boundary conditions unchanged.

1.3.4 Water Levels

During the calibration process, modelled water levels were compared to predicted water levels for three tidal stations within the model domain. This approach was used to ensure that the model performs well not just at the area of interest, but across the whole model domain. The location of the tidal stations used are shown in Figure 0-4, with the water-level comparison for each location presented in Figure 0-5 to Figure 0-7.

From the figures it can be seen that the model replicates the magnitude and phasing of the flood and ebb tide water levels across all stations. The tides predicted using the TotalTide software show a diurnal influence with an alternating high/low pattern in successive high tide levels which is also reproduced by the model for the spring tides at each location.

There are minor differences between the modelled and predicted water levels (phasing and magnitude) which can be attributed to the following factors:

- The C-Map digital chart data is relatively coarse.
- Depths on published charts typically underestimate available depths for navigation safety reasons.
- Both Inveraray and Tarbert are classified as 'Secondary Ports' with tide levels derived from Greenock rather than site-specific measurements. The accuracy of predicted tide curves is therefore uncertain.

The model is therefore considered to perform well taking the above limitations. Most importantly, the model is demonstrated to perform well at Inveraray which is closest to the proposed Marine Facility.

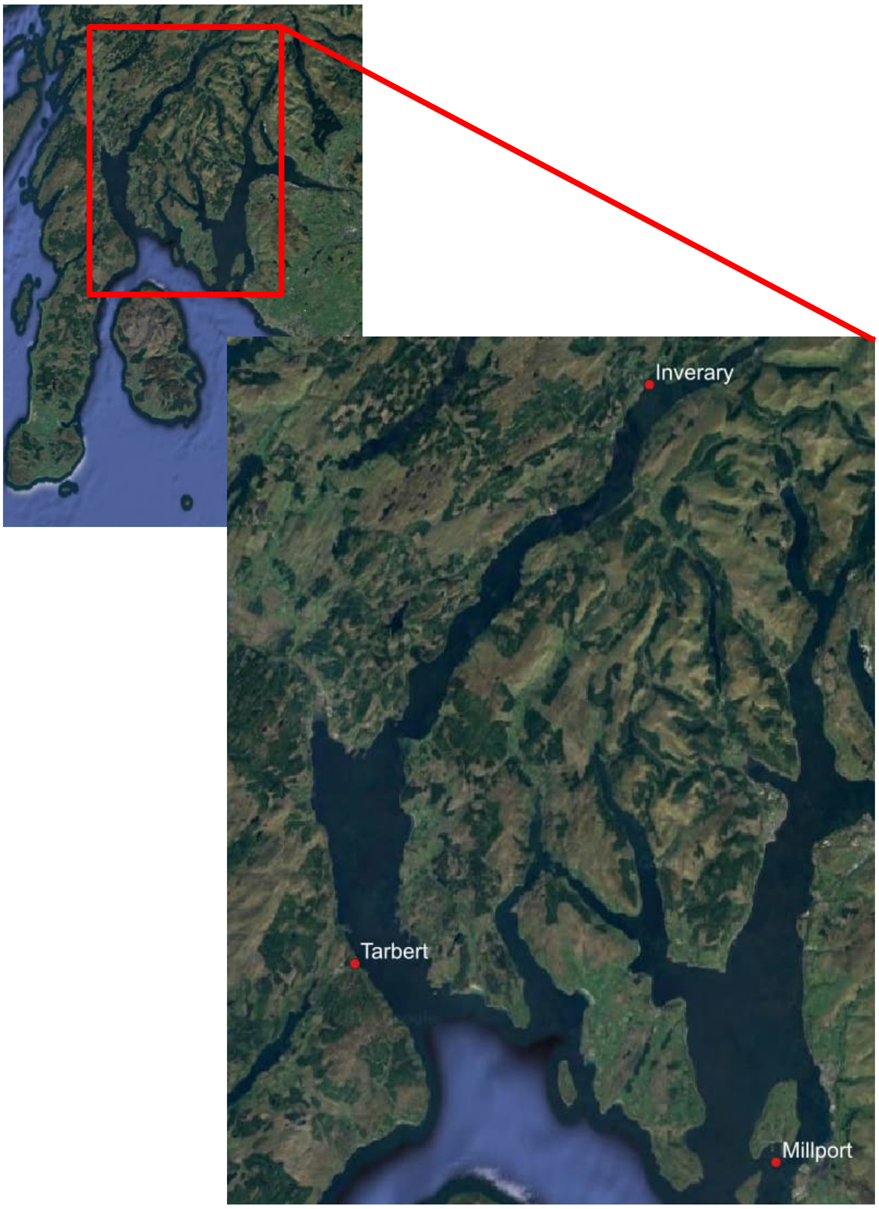

Figure 0-4. Location of Tidal Stations

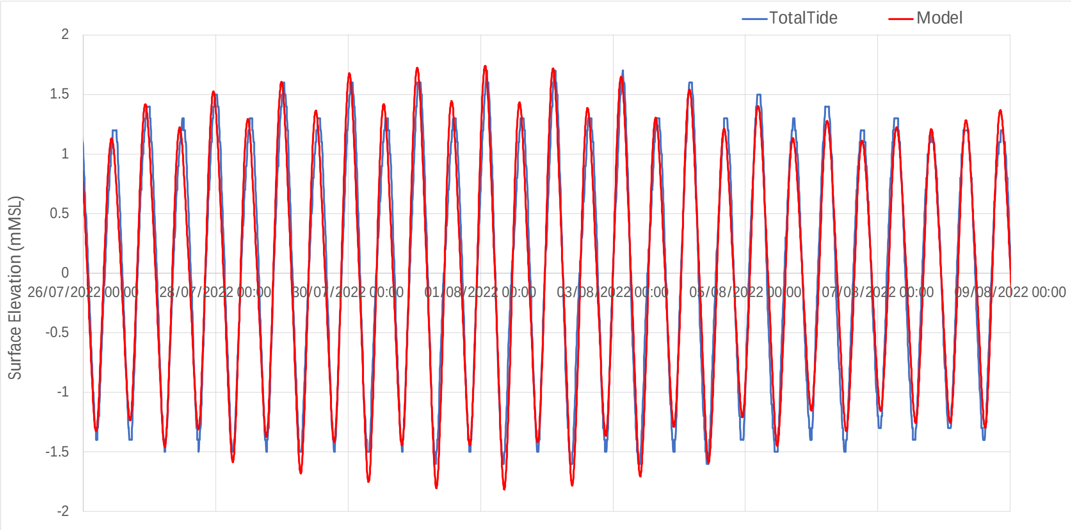

Figure 0-5. Calibration of tidal water levels at Inveraray

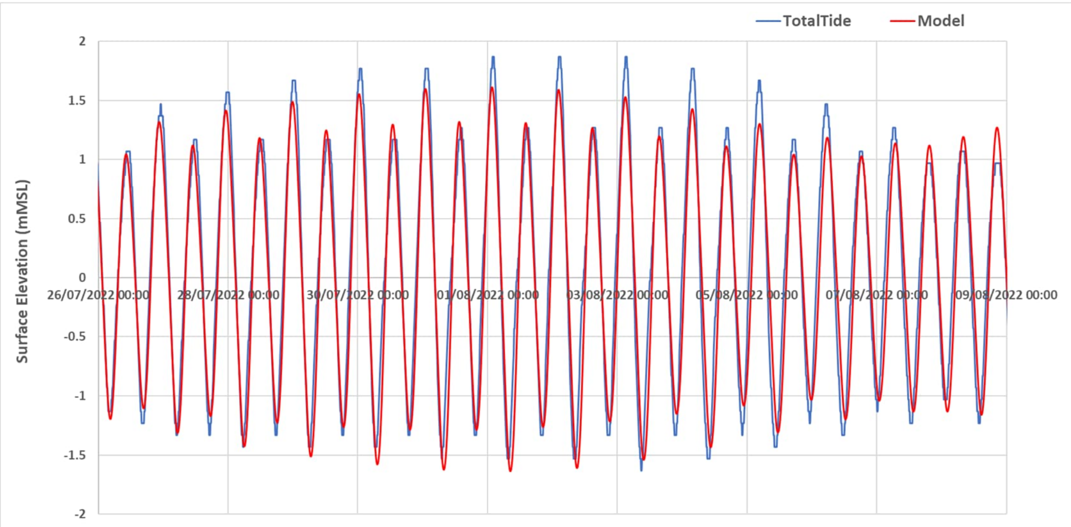

Figure 0-6. Calibration of tidal water levels at Tarbert

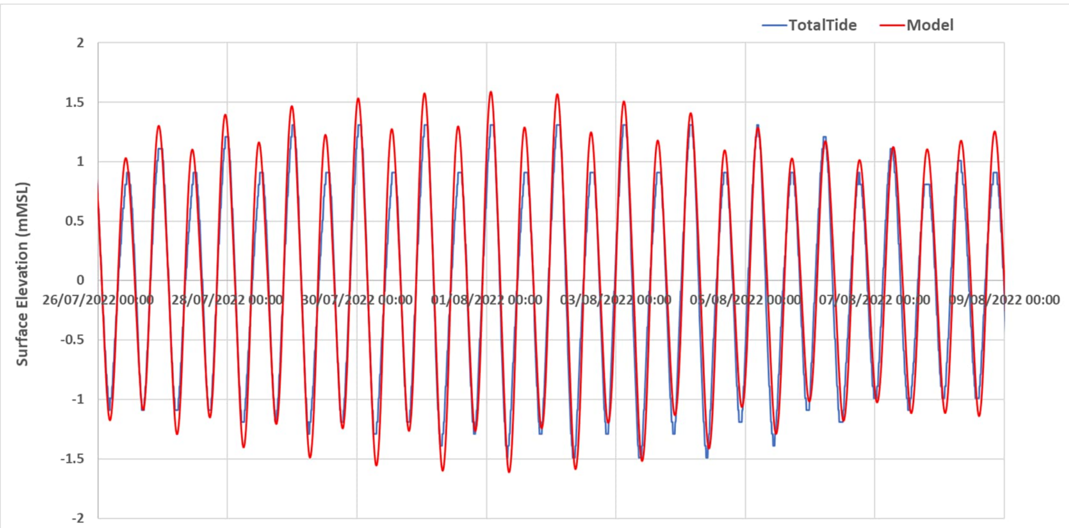

Figure 0-7. Calibration of tidal water levels at Millport

1.3.5 Currents

Measured current data was obtained from the British Oceanography Data Centre (BODC) for the purposes of calibrating currents predicted by the model. Two sub-surface current meter datasets (443163 & 88123) were obtained for the two locations identified on Figure 0-8 and were subject to harmonic analysis. This process removes non-tidal components of the signal and allows the tidal currents to be predicted for the model calibration period. The comparison of model and predicted current speeds and directions at the BODC locations is presented in Figure 0-9 and Figure 0-10.

The model is shown to match the magnitude of the peak currents speeds well event though these are of very low magnitude with peak values of just over 0.1 m/s. The magnitude of these currents are at the limit of what can be modelled and measured with any degree of certainty, as demonstrated by the poorer correlation shown in Figure 0-9 for location 446163. The currents are slightly stronger in Figure 0-10 which provides a better fit between the two datasets.

The modelled current speeds are shown to be similar in magnitude to the measured data and the directions follow the alignment of the main channel, as expected, at each location, with the flood currents heading in northerly directions and ebb currents to the south.

Figure 0-8. Location of current measurements (orange dots)

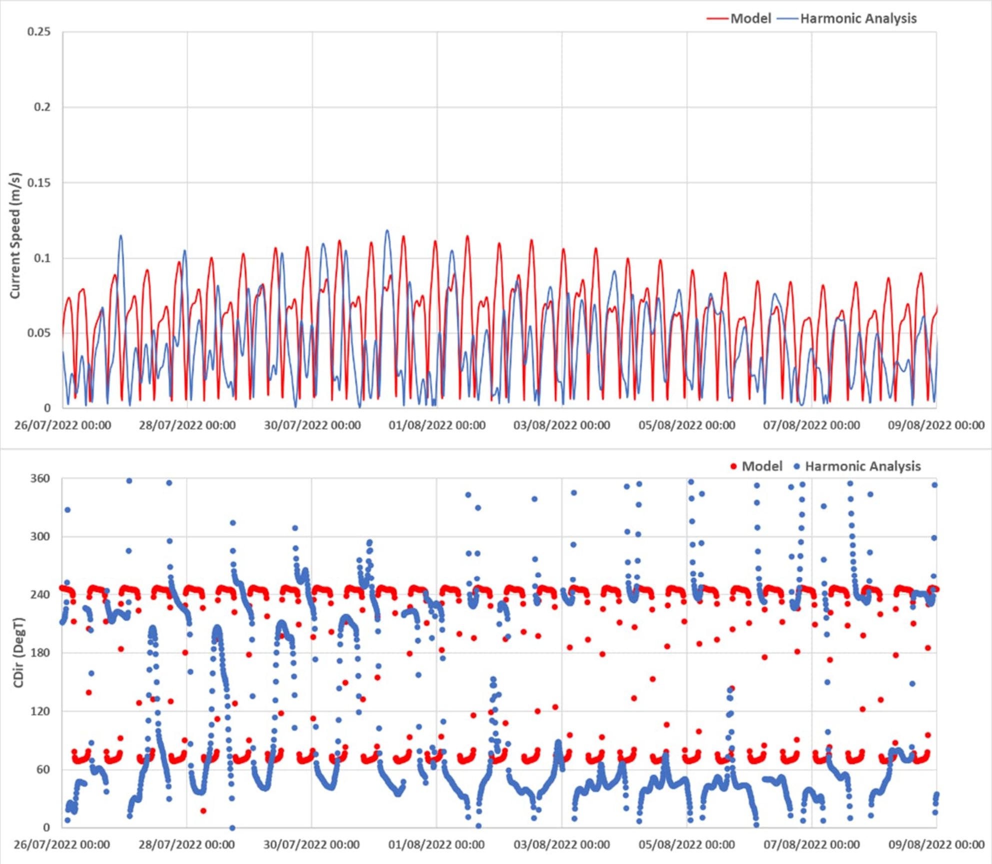

Figure 0-9. Comparison of modelled and measured current speed (top) and direction (bottom) at location 446163.

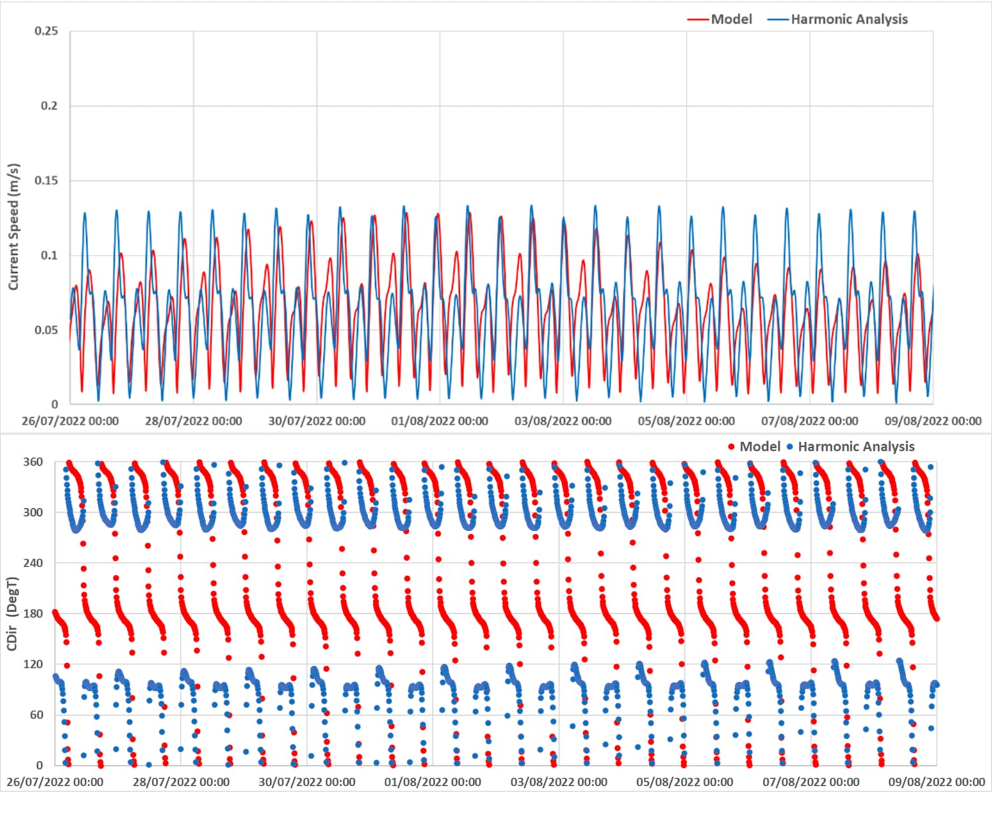

Figure 0-10. Comparison of modelled and measured current speed (top) and direction (bottom) at location 88123.

1.4 Validation of Flow Patterns

As part of the model validation process, current vectors from the model have been overlaid on predicted tidal streams calculated using the TotalTide software to provide a comparison of general flow patterns. A total of 5 tidal diamonds have been included in this assessment with the locations of each of these as shown on Figure 0-11.

The vectors are compared at 2-hourly intervals for a mean spring tide and are presented in **Error! Reference source not found.** to Figure 0-17. In each case the model output is represented by the black vectors with the TotalTide data shown in red and the timing relative to high water, as indicated, refers to the tide at Greenock.

The TotalTide vectors are calculated using tidal constituents derived from historical measurements and are therefore best suited to providing a high-level comparison. From this comparison it can be concluded that the model provides a realistic representation of tidal flow patterns across the model domain throughout a tidal cycle. In particular the timing of transitions between the flood/ebb and slack water phases are shown to be well reproduced in the model.

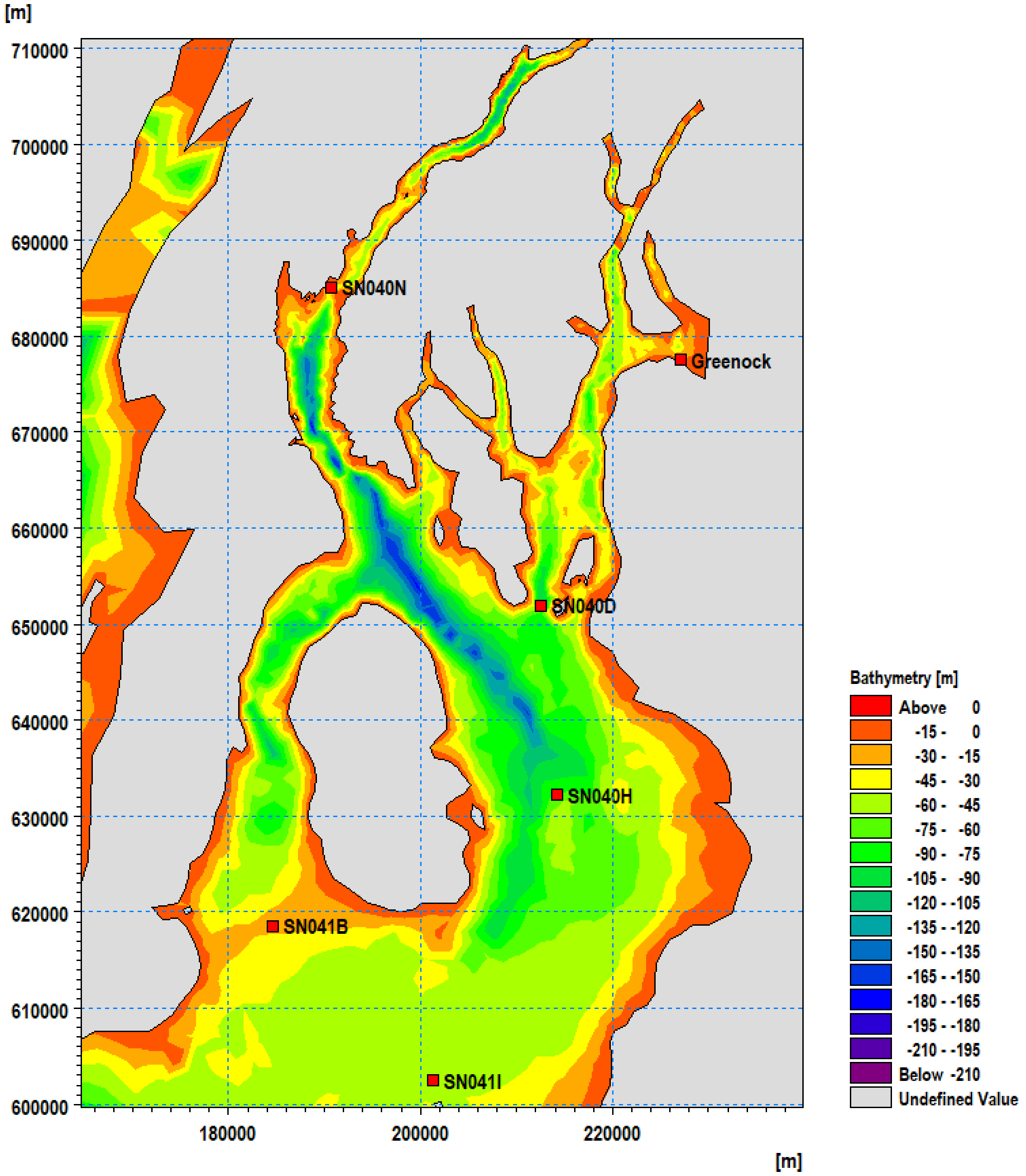

Figure 0-11. Location of tidal stream data

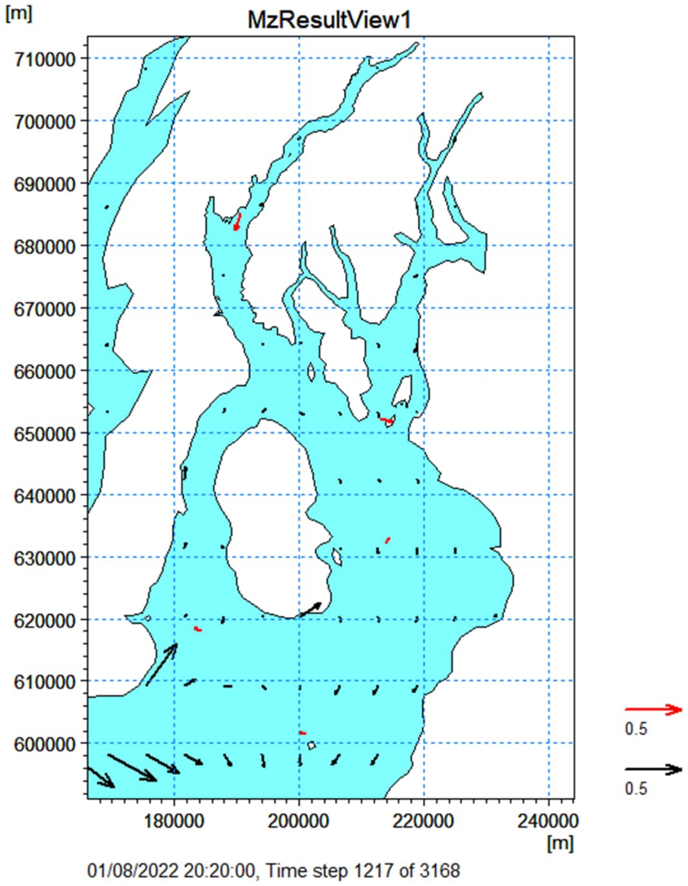

Figure 0-12. Comparison of modelled currents (black) and predicted tidal streams (red) at LW

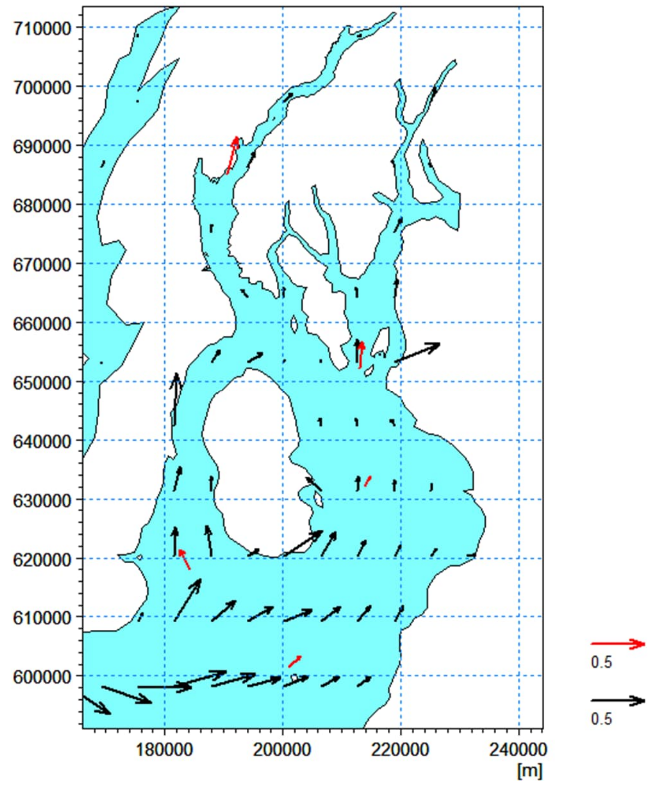

Figure 0-13. Comparison of modelled currents and predicted tidal streams at 4hrs before HW

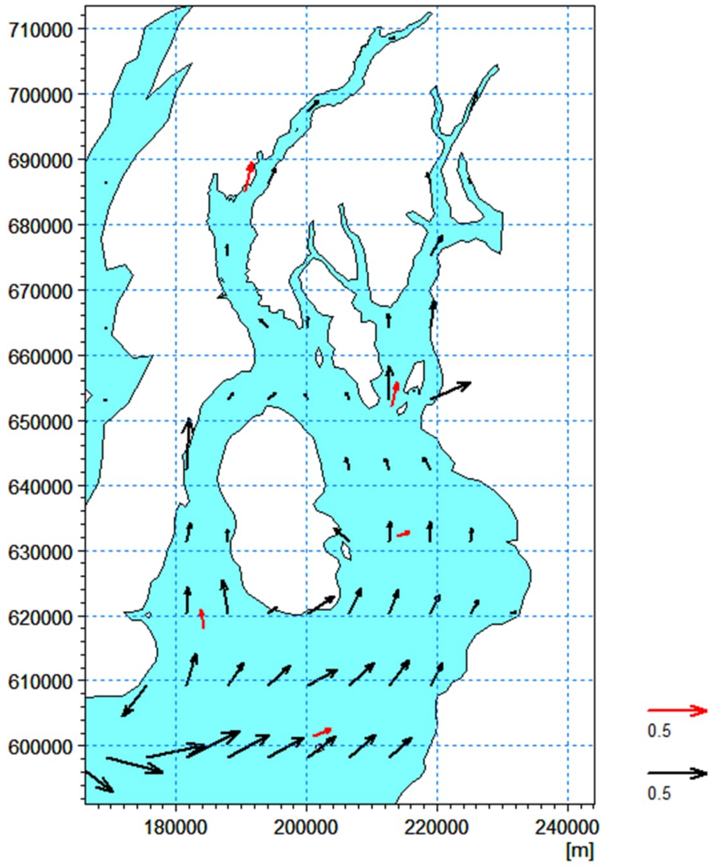

Figure 0-14. Comparison of modelled currents and predicted tidal streams at 2hrs before HW

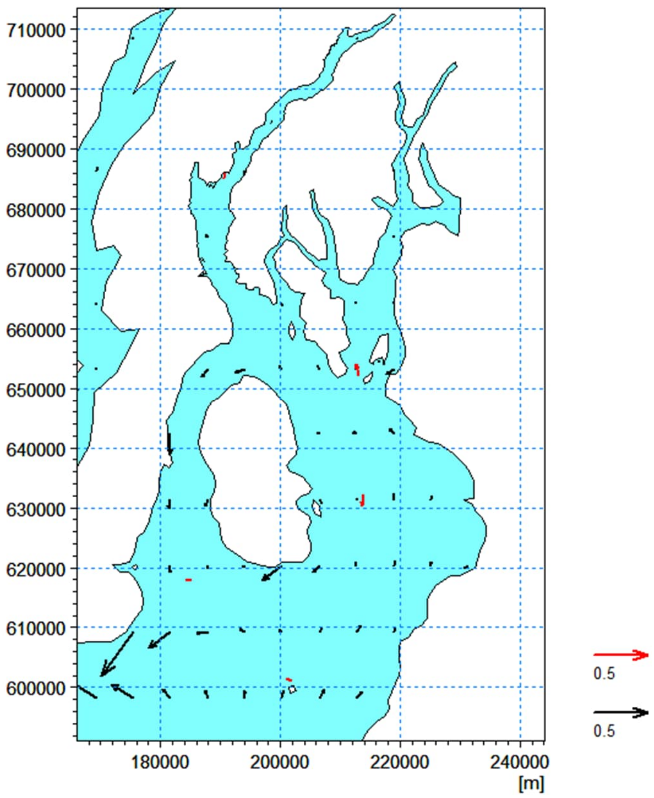

Figure 0-15. Comparison of modelled currents and predicted tidal streams at HW

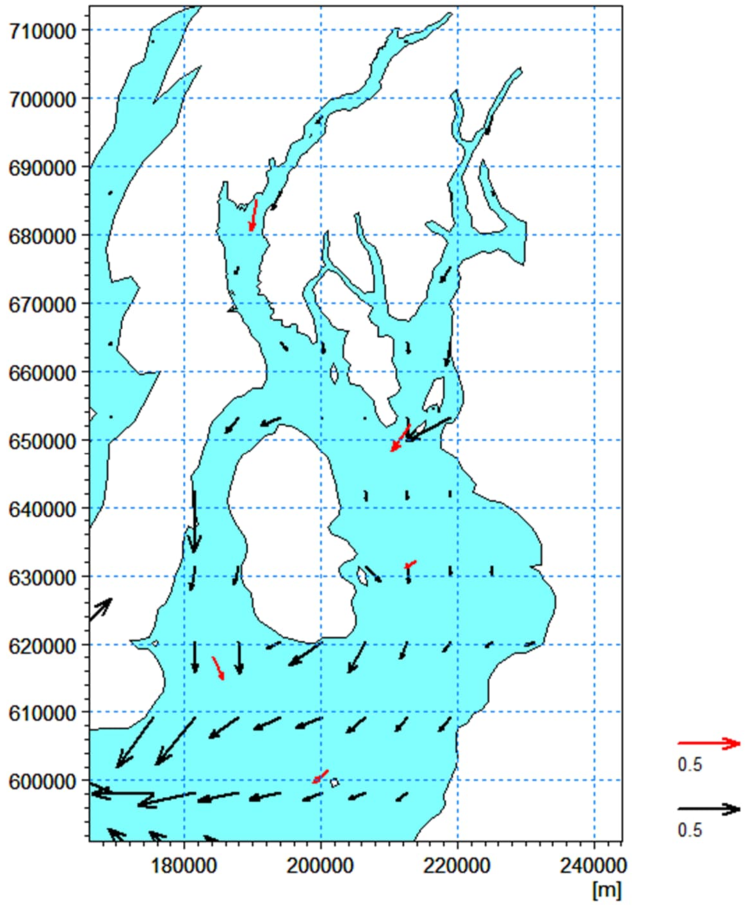

Figure 0-16. Comparison of modelled currents and predicted tidal streams at HW +2hrs

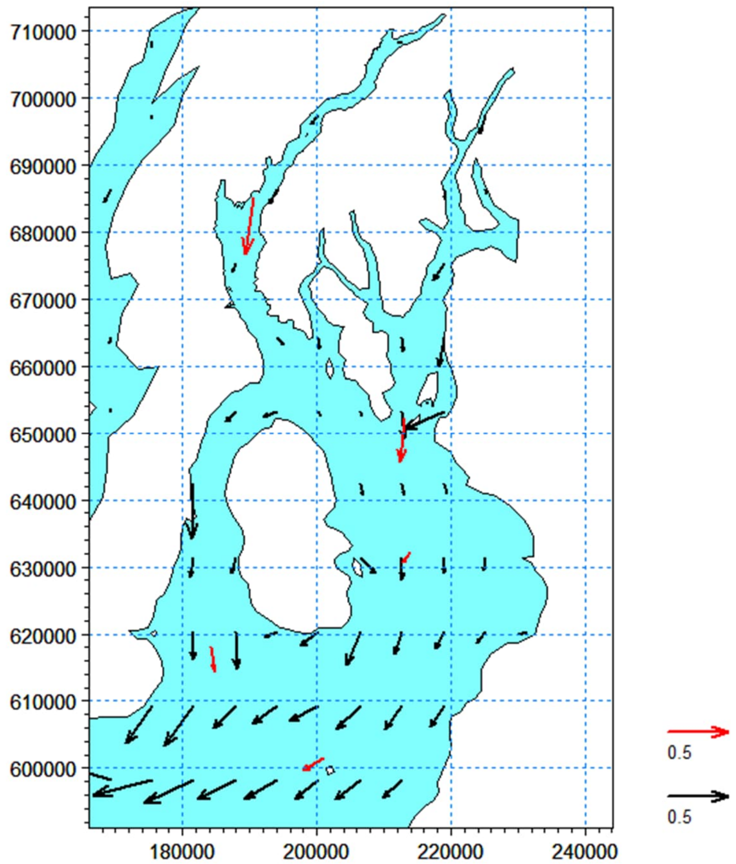

Figure 0-17. Comparison of modelled currents and predicted tidal streams at HW +4hrs

1.5 Model Validation

1.5.1 Water levels

During the validation process, the model settings are kept the same as applied during calibration with model outputs now compared for a mean neap tide instead. This process is designed to establish how good the model is at describing hydro-dynamic conditions for periods of time other than that considered for model calibration.

The same three tidal stations as used for the calibration of water levels have been used for validation with the results presented in Figure 0-18 to Figure 0-20. The figures show that the magnitude and phasing of the time-varying water levels is well replicated, with the model capturing variations in the tide as it transitions from neap to spring tides. There are minor differences in the water levels that vary between the sites which can be attributed to the same factors as identified during calibration.

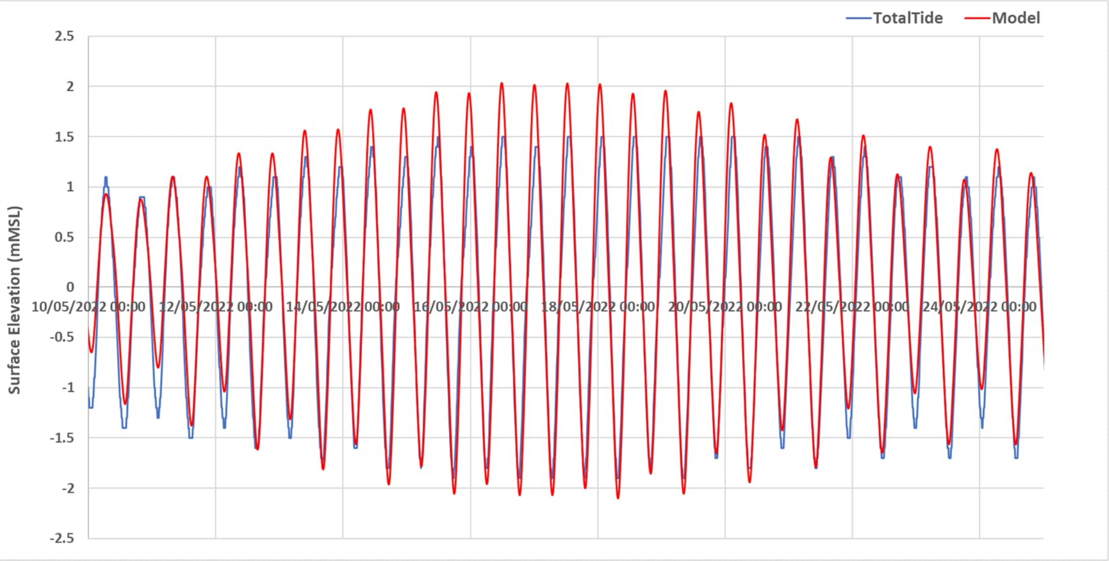

Figure 0-18. Validation of water levels at Inveraray

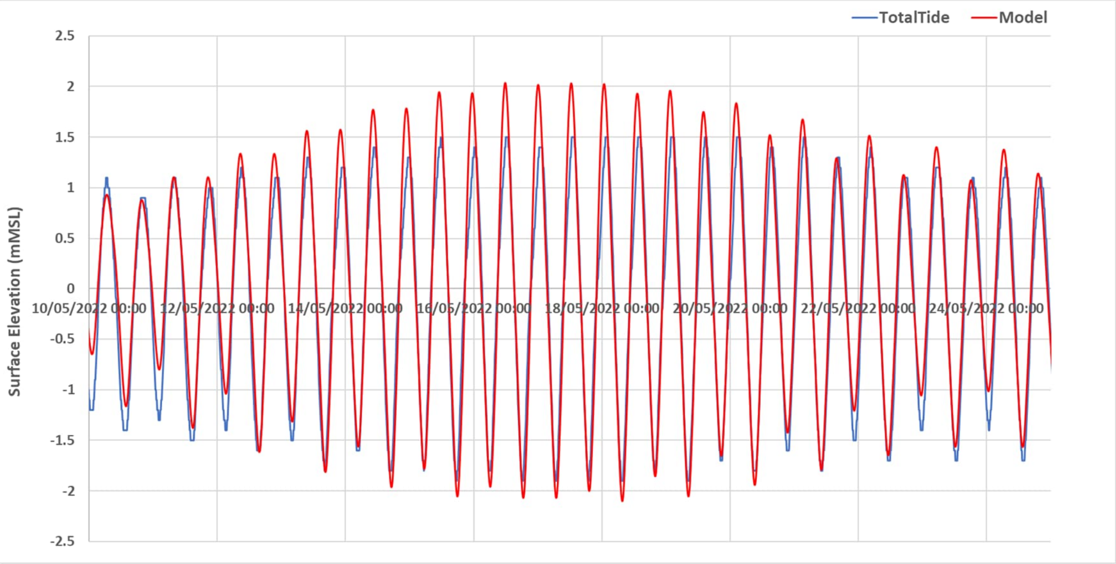

Figure 0-19. Validation of water levels at Tarbert

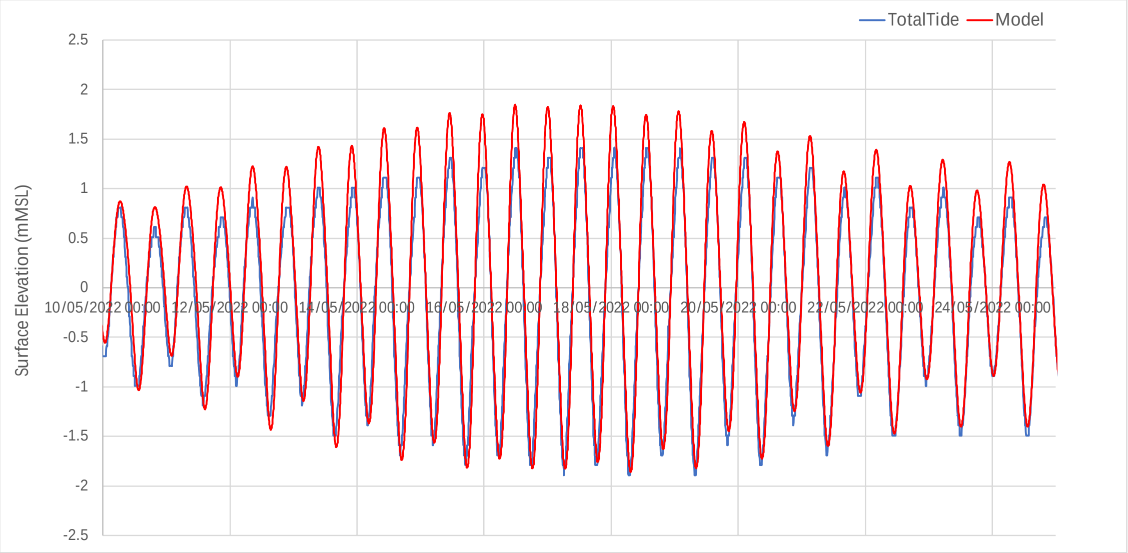

Figure 0-20. Validation of water levels at Millport

1.5.2 Tidal currents

The same approach as applied during calibration was used to predict tidal current speeds and directions for the model validation period. The comparison of model and predicted currents at the two sites is presented in Figure 0-21 and Figure 0-22. Figure 0-21 shows oscillations in the predicted dataset at location 443163 that do not appear to be related to a tidal signal. This suggests that the accuracy of the harmonic analysis approach may be an issue when attempting to predict such low magnitude current speeds. However, the peak current speeds in both datasets appear to be consistent.

The model shows a distinctive variation in current speed as it transitions from neap to spring tides, consistent with the variation in tidal range but not apparent in the predicted current speeds shown in Figure 0-22 for location 88123. The model results therefore appear to be more consistent with typical behaviour in estuarine environments and suggests that the tidal signal in the original measured dataset is possibly too weak to provide a reliable analysis of harmonic constituents at this location.

The current speed comparison at location 88123 (Figure 0-8) shows that the model replicates the shape of the harmonically predicted data much better than at location 443163, presumably due to the stronger tidal signal at the location further offshore.

The current directions are again influenced by noise, particularly at location 443163, most likely due to the weak currents. The modelled and predicted directions show a northerly flood direction and a rotation through to a southerly direction during the ebb phases of the tide. This is consistent with expected behaviour confirming that the model simulates flooding and ebbing of the tide with the axis of flow aligned with the deep-water channel of the loch.

To summarise, it is concluded that the model behaviour is consistent with observed conditions and has therefore been successfully validated. The model is therefore suitable for the investigation of potential hydro-dynamic impacts associated with the proposed developments of a new Marine Facility near Inveraray.

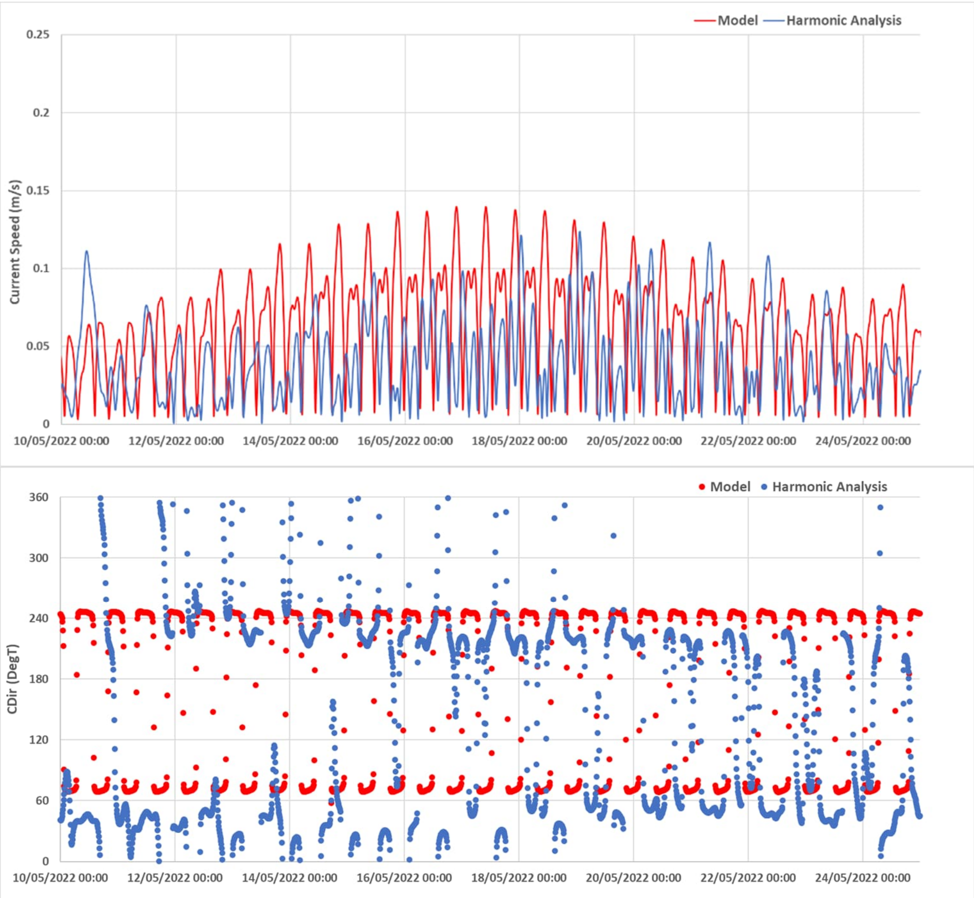

Figure 0-21. Validation of current speed (top) and direction (bottom) at location 443613

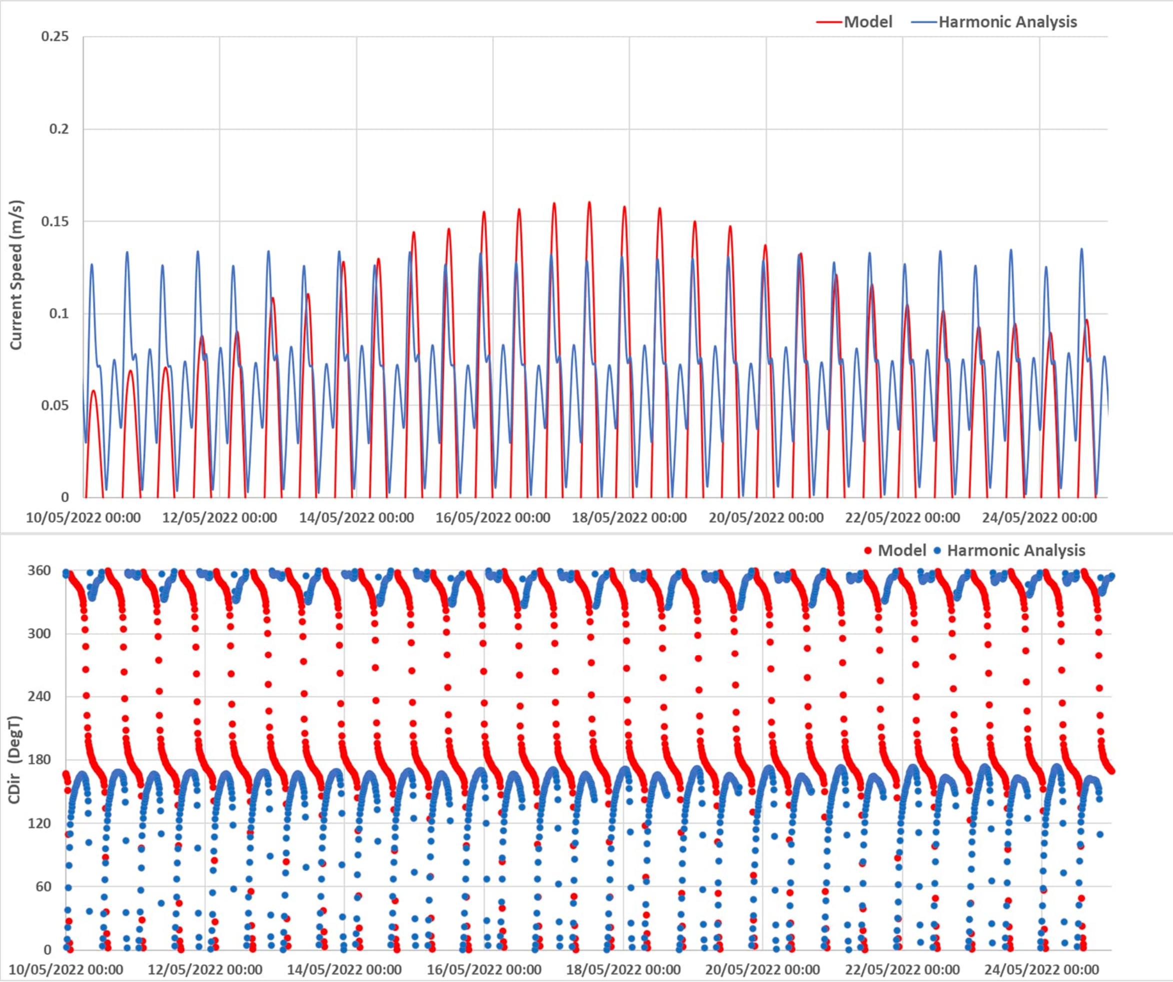

Figure 0-22. Validation of current speed (top) and direction (bottom) at location 88123

1.6 Sensitivity testing

Due to the tidal currents at Inveraray shown to be of very small magnitudes (<0.1 m/s for peak spring tides near the Marine Facility), the local wind-generated surface currents are likely to have an important influence on the currents and the initiation of sediment transport. A set of sensitivity tests have therefore been conducted to assess the influence of local wind on hydro-dynamic conditions.

No suitable source of long-term local wind data could be identified therefore data from the ERA5 global atmospheric model was downloaded for the nearest output point. The data was processed using a directional Extreme Value Analysis (EVA) approach for directional sectors aligned with the longitudinal axis of Loch Fyne. The direction sectors included were centred on the north-east (75°N) and south south-west (190°N) directions.

These selected directions provide the longest fetch lengths along Loch Fyne therefore allowing the maximum influence on currents to be assessed. Wind speeds were calculated for a 1 in 1 year return period which gave values of 9.4 m/s and 11.6 m/s for the north-east and south south-west directions, respectively. To assess the sensitivity, water levels and currents speeds were extracted from a point close to the proposed Marine Facility. The results extracted data were then compared against baseline values (i.e. model run with no wind included) to allow the effect of wind on local hydro-dynamic conditions to be quantified, as presented in Figure 0-24 and Figure 0-25.

In both cases it can be seen that the applied wind has a noticeable affect when blowing from either direction. The water levels show a phase shift of approximately 40 minutes and are generally raised by 0.2-0.3 m. The current speeds are also shown to be sensitive to the imposed wind field with increases in both cases, most significantly when the wind is from the south south-west (**Error! Reference source not found.**) and current speeds are increased by a factor of 10, although they are still only just above 0.1 m/s at the proposed Marine Facility location.

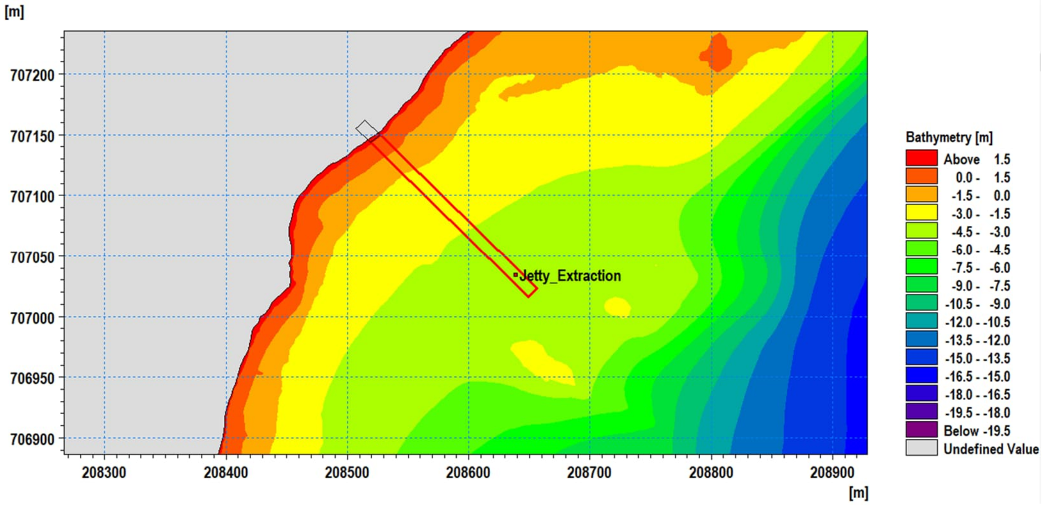

Figure 0-23. Extraction location for wind sensitivity tests.

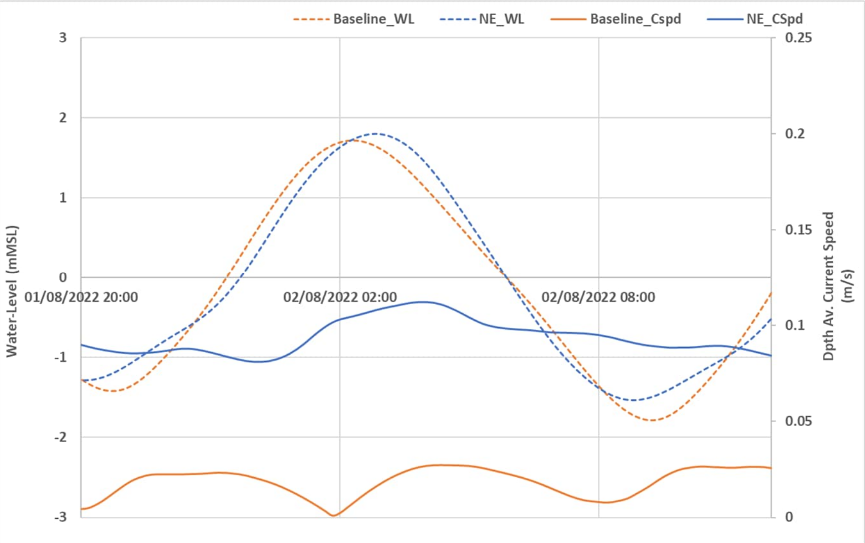

Figure 0-24. Effect of wind from the north-east.

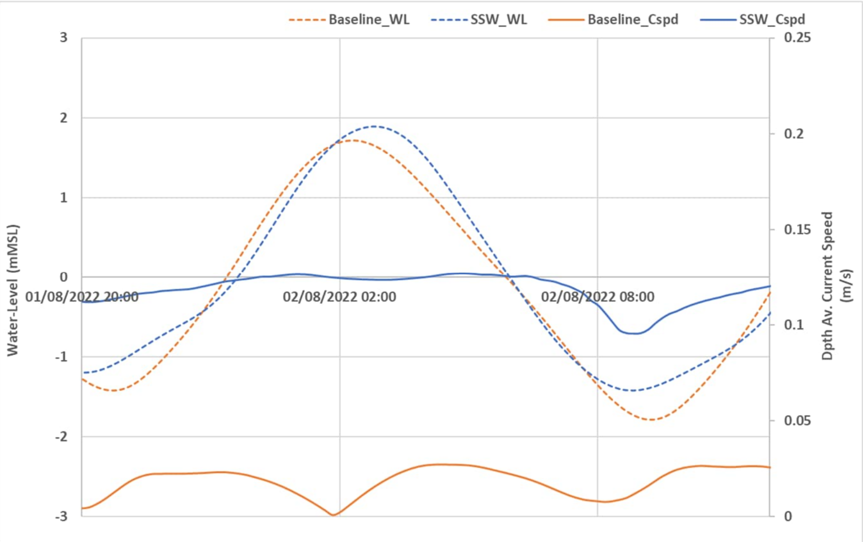

Figure 0-25. Effect of wind from the south-west.

Given that currents at the location of the Marine Facility are shown to be sensitive to wind, the assessment of potential impacts on the physical marine environment therefore needs to account for the enhancing effect of a superimposed wind field.

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