Chapter 3 The Models

All our work makes use of the well-known MIKE 21 modelling system supplied under license by the Danish Hydraulic Institute (DHI)[51]. DHI provides very extensive documentation on this system and is not included in this report.

This section discusses the model parameters in the RP and OH models. The acronyms refer to the location of the seaward boundary in each case. RP and OH indicate the boundary is at Roches Point, and at the Old Head of Kinsale, respectively.

3.1 Set-up of the Roches Point (RP) model

The development of every numerical model involves a compromise between a high resolution grid which resolves the flows in great detail and the time it takes for a computer to calculate the results[52]. The model run time is a function of the number of grid points in a model[53] and the timestep. Generally if the grid spacing is halved the model runtime increases by a factor of 8. Given that the run time for models such as the RP could be in the order of days, and not hours, the issue of resolution and run time is always of concern.

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Nested grids are the means by which this problem can be overcome. A nested grid implies that different areas of the model are resolved with different grid spacing. Areas that are of great importance to the study may be resolved with a high resolution while the area surrounding it may be resolved with a lower resolution. The higher resolution grid must sit inside (hence the 'nested' term) the coarser grid. At the boundary the water level and fluxes are passed from one grid to the next so that a single unified model is developed. For MIKE 21 the

[51] http://www.dhigroup.com/

[52] The size of the generated result files is also a concern. High resolution grids generate larger result files than those with a lower resolution. Files larger than 4GB are quite problematic for any personal computer today.

[53] Determined by the extent of the model and the grid spacing

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nested grid must be exactly 3 times smaller than the coarser grid. A 30m grid can be nested within a 90m grid but not a 100m grid. The 90m grid may then be nested within a 270m grid. MIKE 21 allows up to 9 grids to be successively nested within each other. Both the RP and OH models have used the nested grids.

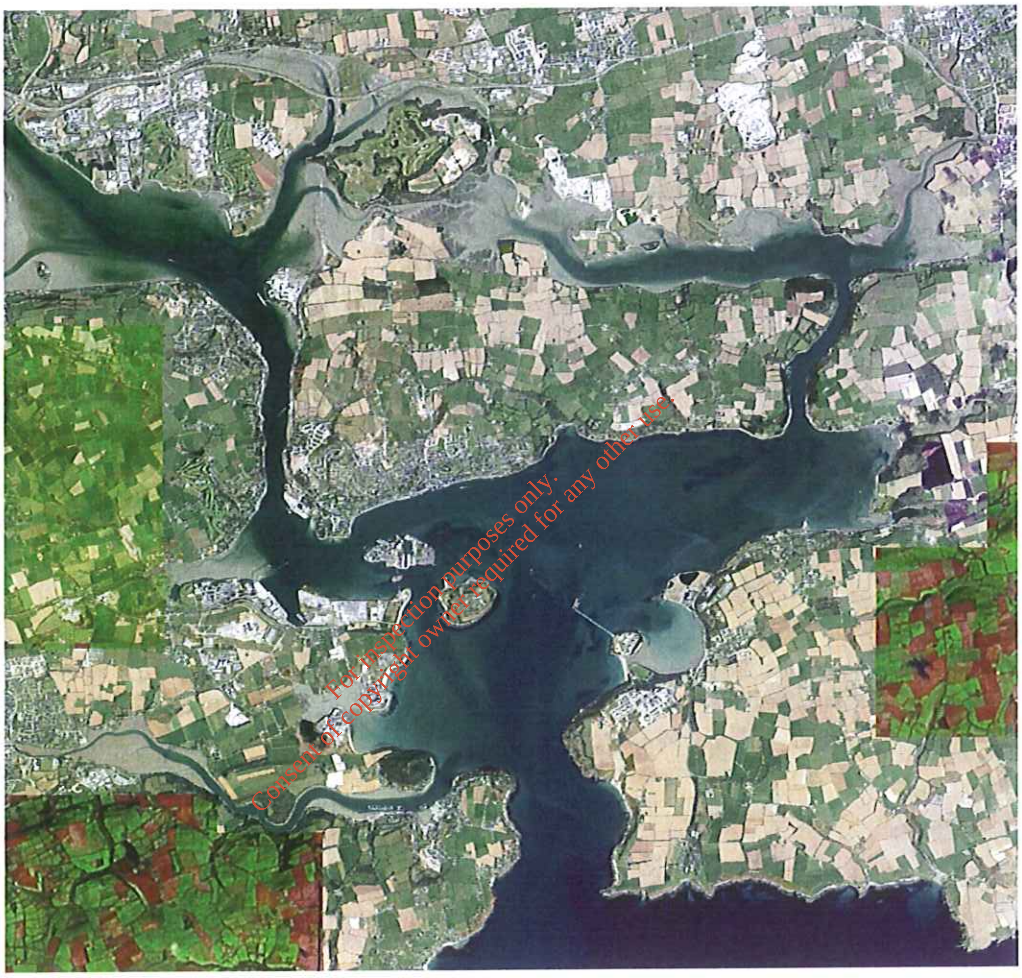
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Fig. 3.1 Image of Cork Harbour at low water - from the Quickbird Data

The Roches Point (RP) model has three separate grids each of varying resolution (Fig. 3.2). The outer grid has a grid spacing of 54m and covers the outer harbour. The inner harbour is resolved with an 18m grid. The area around the Belvelly Bridge has the highest resolution of 6m. The OH also contains these three grids but has an additional 162m grid in which the 54m grid is nested. This model is described in Chapter 6.

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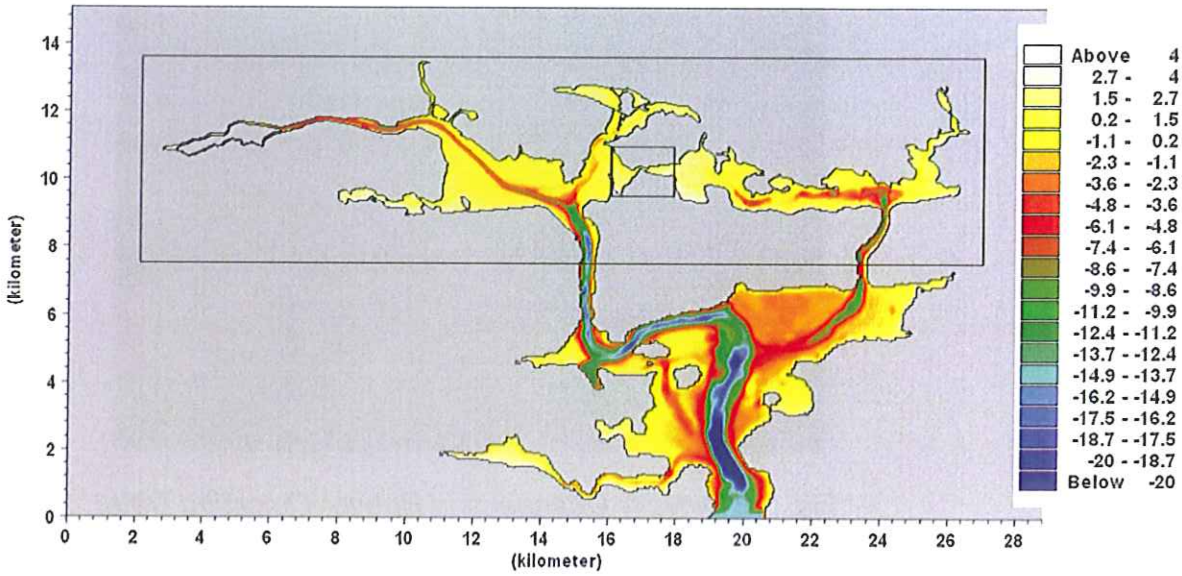

Fig. 3.2 RP bathymetric plot – 54m, 18m & 6m nested grids. The colour palette on the right-hand-side indicates the depth of the harbour bed in metres.

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Accurately resolving the flow through the Belvelly channel (Fig. 3.3) is important because viruses discharged from the city, or into Lough Mahon, have a much shorter route to the Oyster Farm through Belvelly, compared to the path around Cobh Island[54]. A computational grid with a spacing of 6m (Δx = 6m) is necessary to resolve the flow through the Belvelly Bridge openings (Fig. 3.4 and Fig. 3.5). The widths of the openings are 6.1m, 8.1m and 6.1m. The run-time of the models increases as the cube of the grid spacing i.e. a grid of 2m would take 27 times as long as a 6m grid to simulate the same historical period. This limitation is the reason why we have used a set of nested horizontal grids with spacings that match the necessary resolution to the computational speed of our computers.

[54] The distance from the outfalls at Kennedy/Horgans Quay to the Oyster Farm in the North Channel through the Belvelly channel is approximately 17km. The distance from the same locations measured around Cobh Island is approximately 28km.

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Fig. 3.3 Belvelly Channel and Bridge (Quickbird Data)

Fig. 3.4 The Belvelly Bridge at low tide

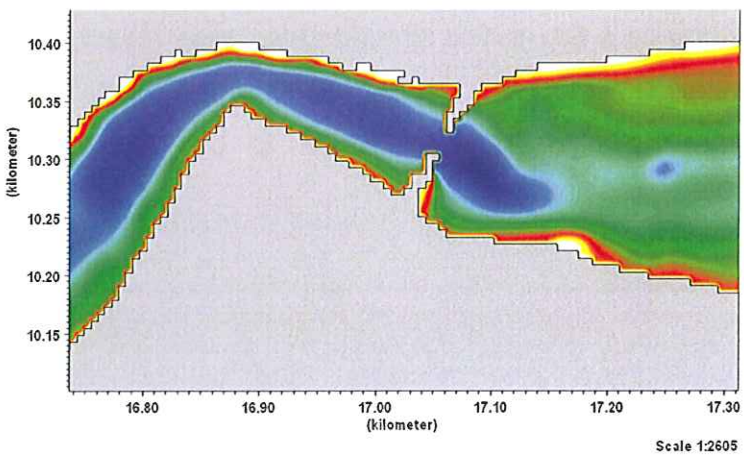

Fig. 3.5 Close-up view of the Belvelly opening in the 6m grid. The distance from the bridge to the outfall at Kennedy Quay is approx. 12km along the deep channel

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The results presented in Chapter 5 indicate that a very significant number of model *Norovirus* pass through the Belvelly channel when a reasonably strong wind (8 – 10m/s) blows from the west. The relative contribution of the outfalls located in the western side of the harbour is therefore increased. For this reason it is critical to the results of the study that the flow through Belvelly is well resolved.

There are 7 other bridges in Cork Harbour which exert an influence on the flow. These bridge openings were adjusted on the 18m grid to match the survey data as closely as possible.

The individual piers of the bridges were not explicitly included. MIKE 21 allows the user to account for this through the use of a pier resistance formula in the momentum equation. Trial runs of the model indicated that the effect of pier resistance on concentrations of contaminant was insignificant.

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3.2 Model Parameters

The Roches Point (RP) model has two parts. The first is the hydrodynamic model, which predicts the numerical variation in water level and the speed and direction of currents throughout Cork Harbour. Coupled with this is the Advection-Dispersion (AD) model, which describes the dispersal and decay of *Norovirus* discharged at any location in the Harbour. Numerous parameters are required for each model. Some of the values used in the RP model were obtained through calibration. Some were chosen based on experience and guidance from the literature.

3.2.1 Hydrodynamic Model Parameters

The main parameters in the RP model are listed as:

- **Δx – grid resolution.** 3 different resolutions were used in the RP model as described in the last section.
- **Δt – timestep.** A timestep of 4 seconds was used for the model. This low value was found necessary to ensure the Advection Dispersion model remained stable.

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- **Eddy Viscosity.** A flux-based formulation of the eddy viscosity, which varies over the entire grid has been used. The eddy viscosity parameter is shown in Fig. 3.6. These values were determined from the calibration of the model.

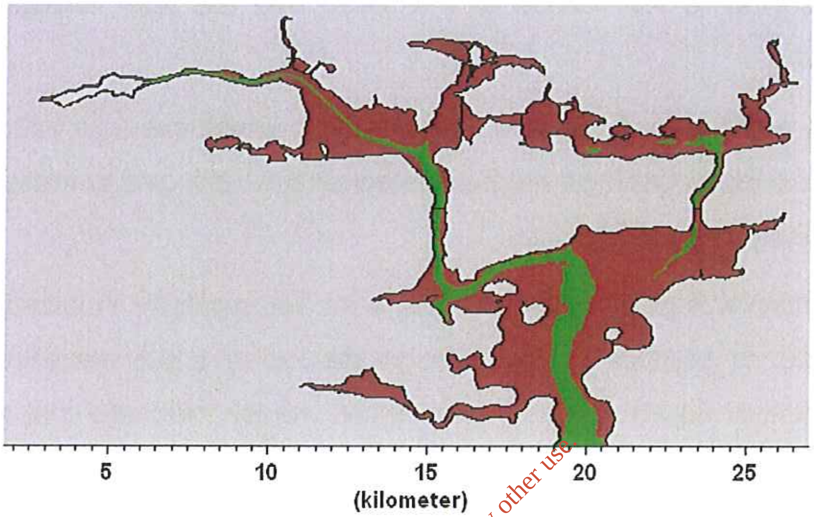

Fig. 3.6 Flux-based Eddy Viscosity Parameters.

Green = 0.5 m^2/s, Brown = 1m^2/s

- **Bed Resistance.** The bed resistance was defined using the Manning's M number. The parameter varied over the entire grid as can be seen in Fig. 3.7. These values were determined from the calibration of the model.

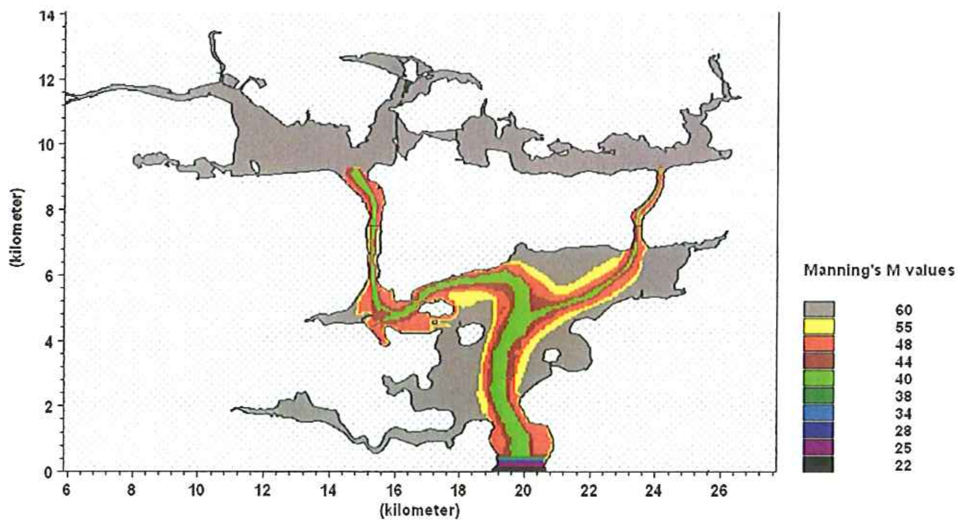

Fig. 3.7 Manning's M value used in model. Manning's M ($m^{1/3}$/s) is the reciprocal of Manning's n.

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- **Flooding and Drying depths.** MIKE 21 allows the simulation of flow in areas that are subject to flooding and drying. When an area dries out the grid cells are removed from the computations. When the tide returns and floods the area the grid cells are included in the computations again. The flooding and drying depths control this inclusion and exclusion of computational points. The default values in MIKE 21 are 0.2m (drying) and 0.3m (flooding). Therefore when the depth of water in a grid cell is less than 0.2m the cell is removed from the computations. When the tide is on the flood and the water level is calculated to be above 0.3m, the grid cell is once again included in the computations. The default values of 0.2 and 0.3 were used for the main outfalls in the study. Reduced values of 0.05m and 0.1m were used for the Houses model. Values of 0.1m and 0.2m were used for the stormwater overflows.

3.2.2 AD Model Parameters

There are a number additional parameters required for the Advection dispersion model.

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These parameters are:

- **Initial conditions.** These were set to zero across the entire grid.
- **Boundary Conditions.** The boundary conditions at the mouth were set to zero for the duration of the simulations.
- **Decay specification.** The viruses decay exponentially with time. We have assumed that *Norovirus* in winter has a T90 of 30 days while *Norovirus* in summer has a T90 of 7days.
- **Dispersion Coefficient.** The dispersion coefficients in MIKE 21 may be defined as either independent of the current or proportional to the current. The results presented in Chapter 5 use the independent option. A value of 1m^2/sec in both the x- and y-direction has been used across all three grids in the RP model. Extremely high values are considered in the sensitivity analysis as well as the "proportional to the current" option.

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- **Feedback.** By including the HD density terms in the advection dispersion model, horizontal density gradients become another forcing function in the hydrodynamic model[55]. The influence of salinity and temperature may be included in this way. The results presented in Chapter 5 do not include feedback. It is however included in the sensitivity analysis in Chapter 7.

3.3 Calibration of the Roches Point HD model

The model was calibrated and validated using the data from the 1992 survey by Irish Hydrodata. As discussed in section 2.2 six automatic water level recorders were deployed at sites in the Inner and Outer harbour on three separate occasions in December 1991 and January/February 1992, as well as two current speed and direction recorders. Data from the Fort Camden gauge was used to drive the hydrodynamics of the RP model by acting as the boundary condition at Roches Point. Data from the Pfizer (water level), Lough Mahon (water level and current speed/direction), Belvelly (water level) and Spit Bank (current speed/direction) gauges were used to calibrate and validate the hydrodynamic model.

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The model was calibrated using spring tides over a four day period from the 19th to the 20th of January. This involved adjusting the bed resistance until an acceptable match between the modelled and recorded water levels was achieved. Further adjustments to the resistance and the eddy viscosity parameters were then made until there were good agreements between the modelled and recorded currents.

The calibrated model was then validated using a different set of inputs. The water level validation was from the 15th of February to the 10th of March. The current speed and current direction validation was from the 25th of January to the 8th of February. The 1993 dataset collected by Irish Hydrodata as part of the MCOS study was also used for the calibration of the model.

[55] In addition to the tide, wind and river flows.

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3.3.1 Water Level Calibration Plots – 1992 dataset

The water level calibration plots are shown below. The modelled data is plotted with a green line while the recorded is shown with a red line. We can see from the figures that there is a very good match between the recorded and modelled data for all three gauges. There a number of erroneous readings present in the recorded Lough Mahon timeseries (Fig. 3.9). We can also see from the figures that there is a slight mis-match between the timeseries immediately after the high water. This can be attributed to minor errors in the Fort Camden gauge, which are propagated into the model. No adjustments of the Fort Camden data were made in this respect.

From these figures we can conclude that the RP model can reproduce the observed tides in Cork Harbour.

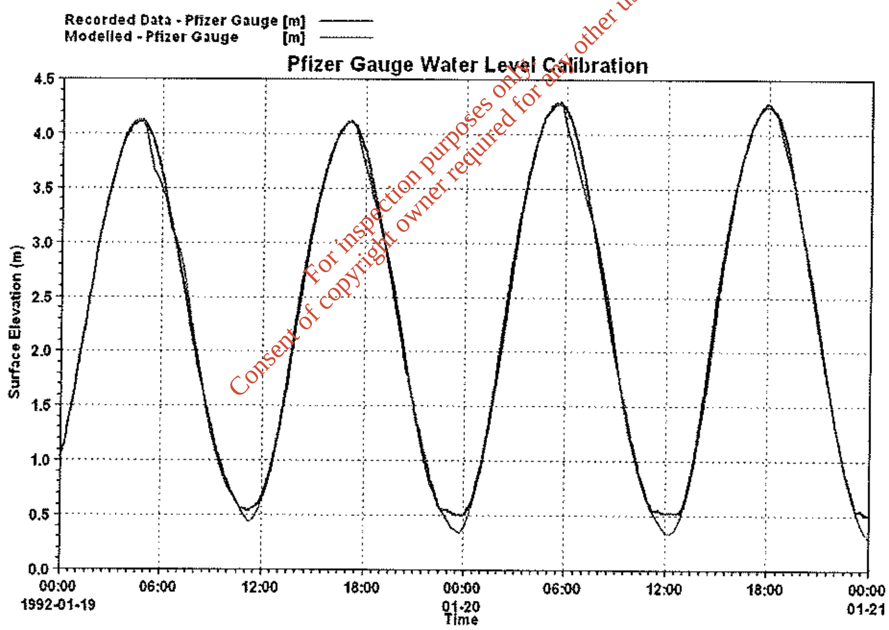

Fig. 3.8 Pfizer Gauge Calibration Plot

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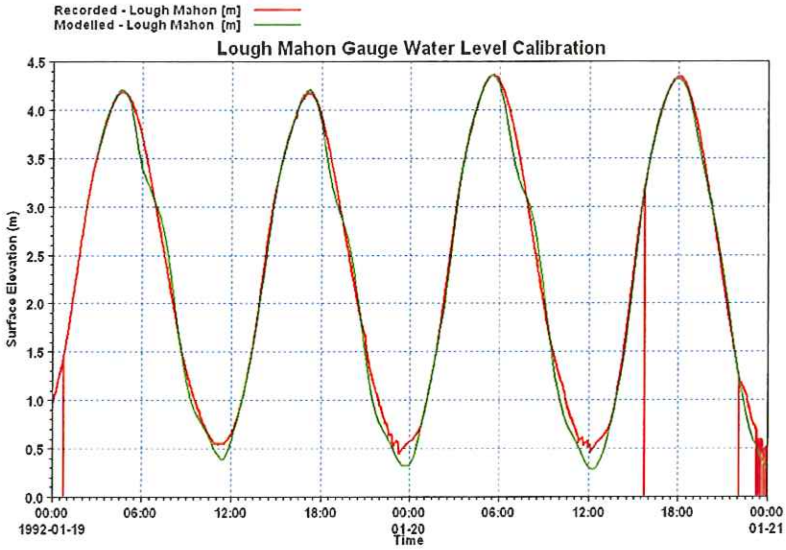

Fig. 3.9 Lough Mahon Gauge Calibration Plot

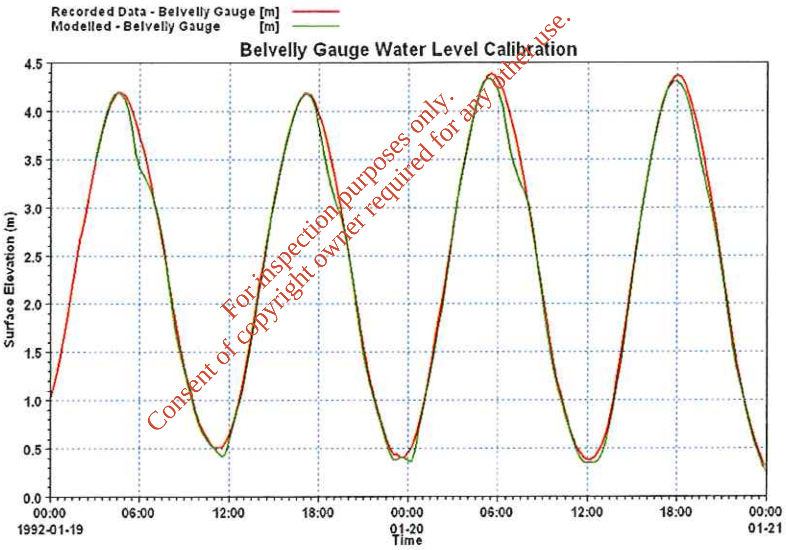

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Fig. 3.10 Belvelly Gauge Calibration Plot

3.3.2 Current Speed and Direction Calibration Plots

The current speed and direction calibration plots are presented in the following set of figures. We can see from the figures that there is an excellent match between the modelled and the measured data for the Spit Bank gauge in the outer harbour. The current speeds on the ebb tide for this gauge are very well matched with the modelled data. There is slight underestimation on the flood tide (0.1 – 0.15m/s). The time at which slack water occurs is also in very good agreement in both the model and the data.

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We can see from Fig. 3.12 that there is a very good agreement between the measured and modelled current direction for this location as well. The figure is slightly confusing however. The direction of the flow on the ebb tide is approximately due south which, as a direction, corresponds to both 0 and 360 degrees. When plotted the slight variations in direction are shown as lines which alternate up down the figure leading to confusion. Fig. 3.13 provides a close-up view to highlight the problem.

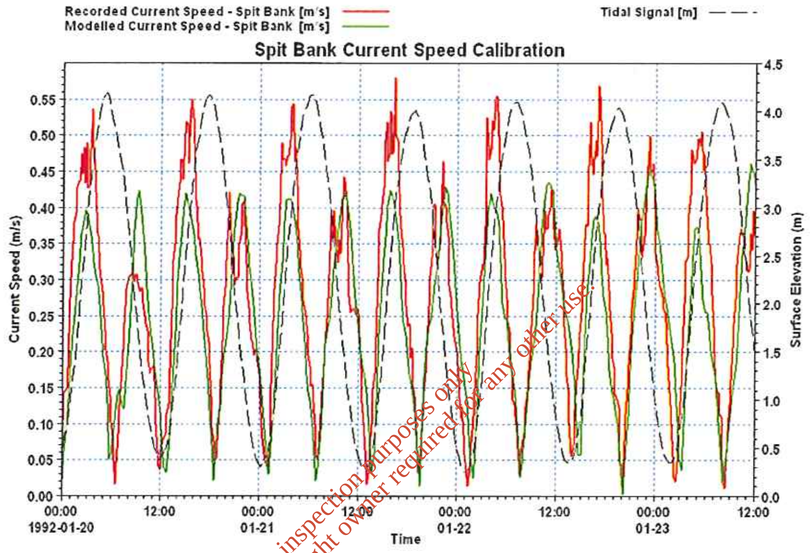

Fig. 3.11 Spit Bank Current Speed Calibration

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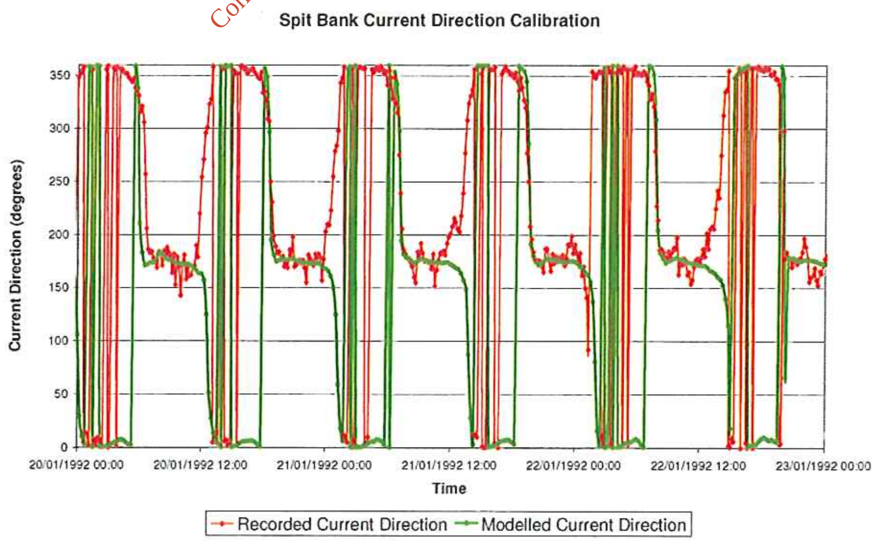

Fig. 3.12 Spit Bank Current Direction Calibration

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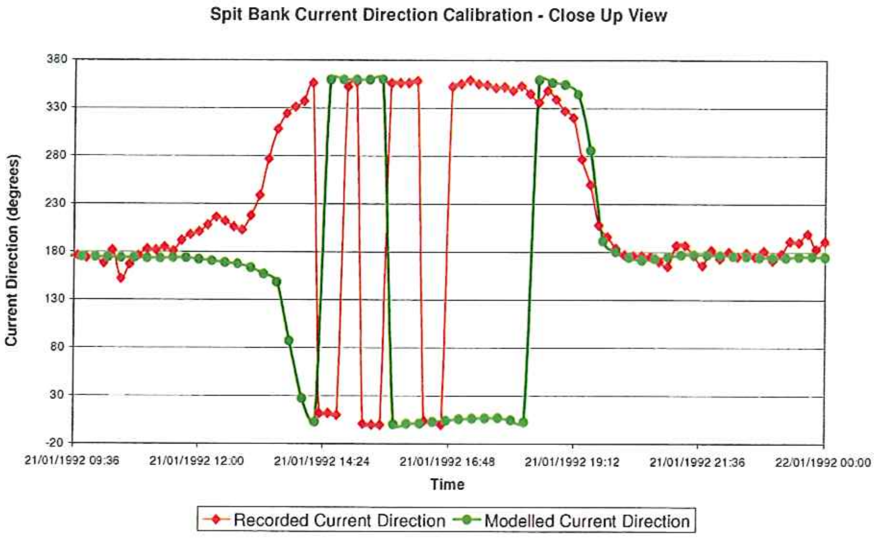

Fig. 3.13 Spit Bank Current Direction Calibration – Close Up View

The current speed and direction calibration plots for the gauge in Lough Mahon are presented in figures Fig. 3.14 and Fig. 3.15. We can see from the figures that there is a slight underestimation of the current speed on both the flood and ebb tides. We can see that the difference is not consistent for the different tides. It varies from 0.05 to 0.25m/s. The general directions on the flood and ebb tides of the model are in agreement with the measured but there is a slight variation in the timing of the turning of the tide when it switches from ebb to flood.

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The gauge in Lough Mahon is located in the centre of the Lough at the point where the shallow mudflat meets the dredged channel. The flow here is quite complicated with strong localised, subgrid hydrodynamics. Capturing this is quite difficult because the modelled currents are averaged over an 18m grid cell. The calibration is well within an acceptable limit of error.

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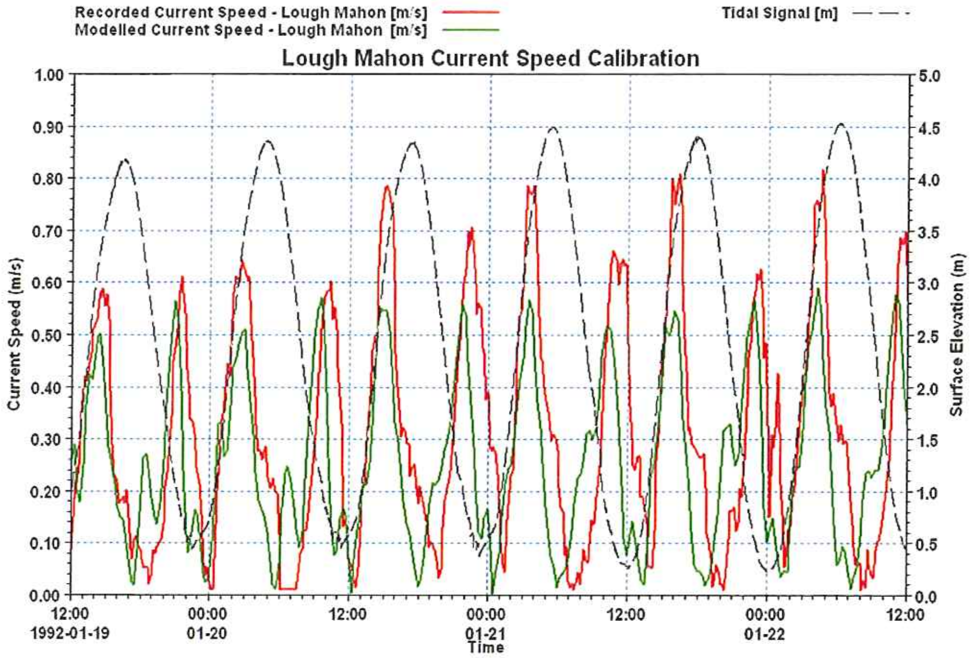

Fig. 3.14 Lough Mahon Current Speed Calibration

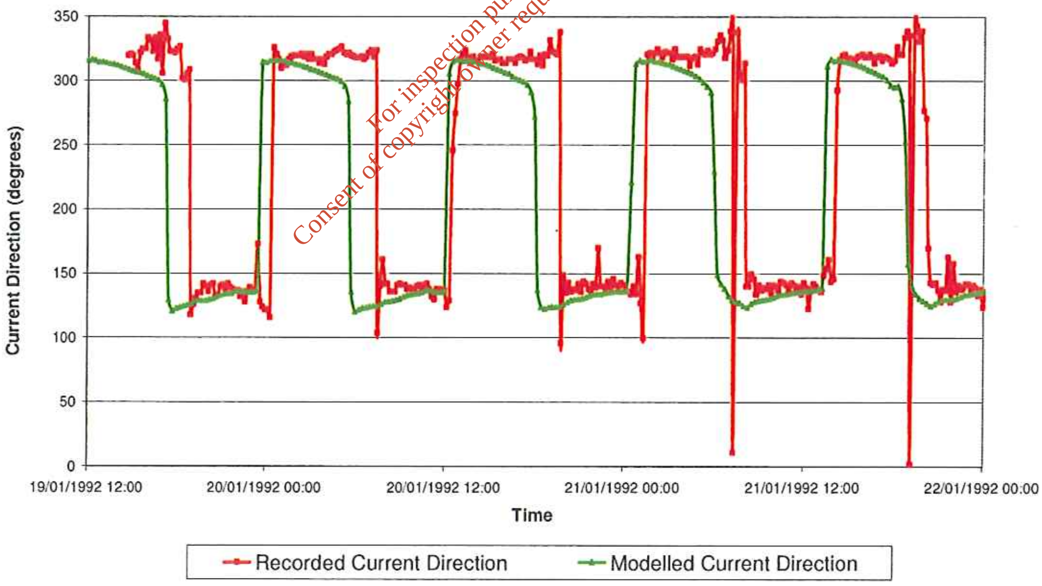

Fig. 3.15 Lough Mahon Current Direction Calibration

3.4 1993 Dataset – North Channel Calibration

The model was also calibrated with the 1993 dataset obtained from Irish Hydrodata. As stated in Chapter 2 the domain of the RP model was altered to

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account for the fact that the boundary condition of this model is provided by data recorded at East Ferry.

3.4.1 Water Level at Ashgrove Castle

The water level calibration at Ashgrove Castle is shown in the figure below. We can see from the figure that there is an excellent match between the measured and modelled data sets. This confirms the ability of the RP model to reproduce the tides in the North Channel of Cork Harbour.

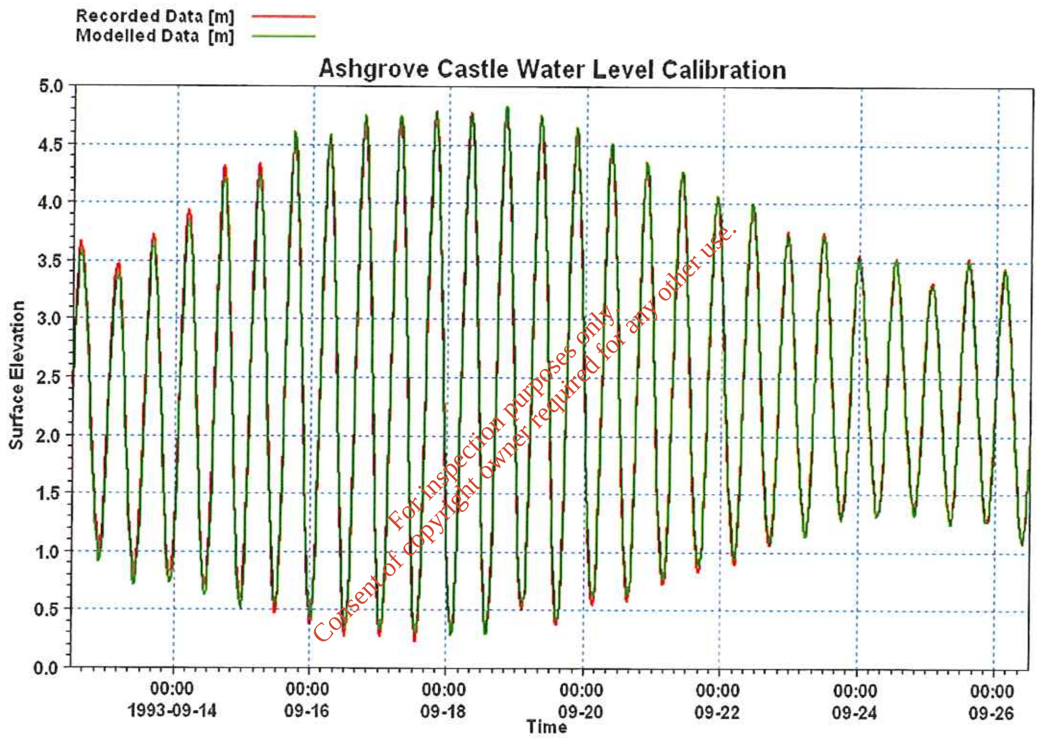

Fig. 3.16 Ashgrove Castle Water Level Calibration

3.4.2 Brown Island Current Speed and Direction

The following six figures present the current speed and direction plots for the gauge at Brown Island. 12 days of comparison are presented split into 4 day periods for both the current speed and direction.

We can see from the figures that there is a very good agreement between current speeds throughout the 12 day period. There is a slight underestimation on the ebb tides as the neaps tides approach but it is small.

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The current directions are also well matched with obvious errors in the recorded dataset towards the end of the 12 day period.

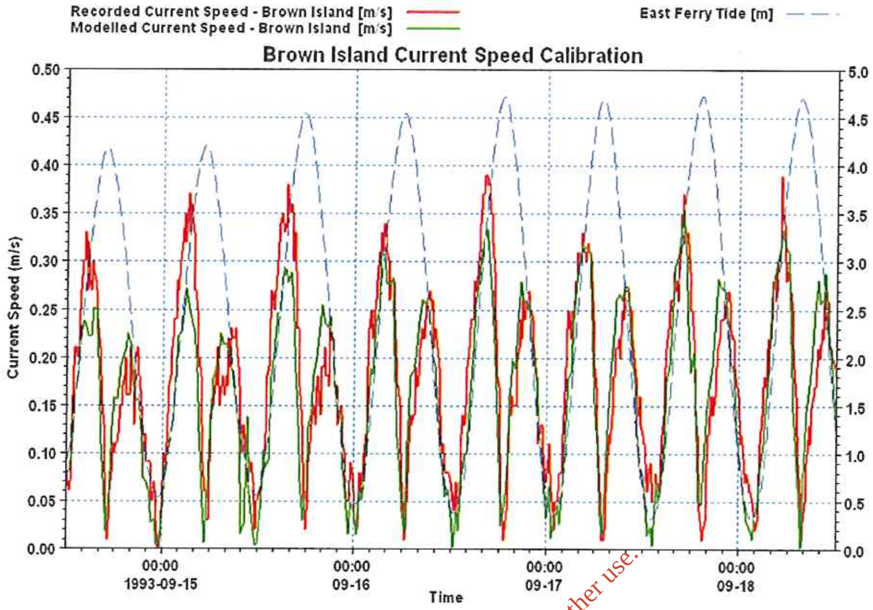

Fig. 3.17 Brown Island Current Speed – first 4 day period

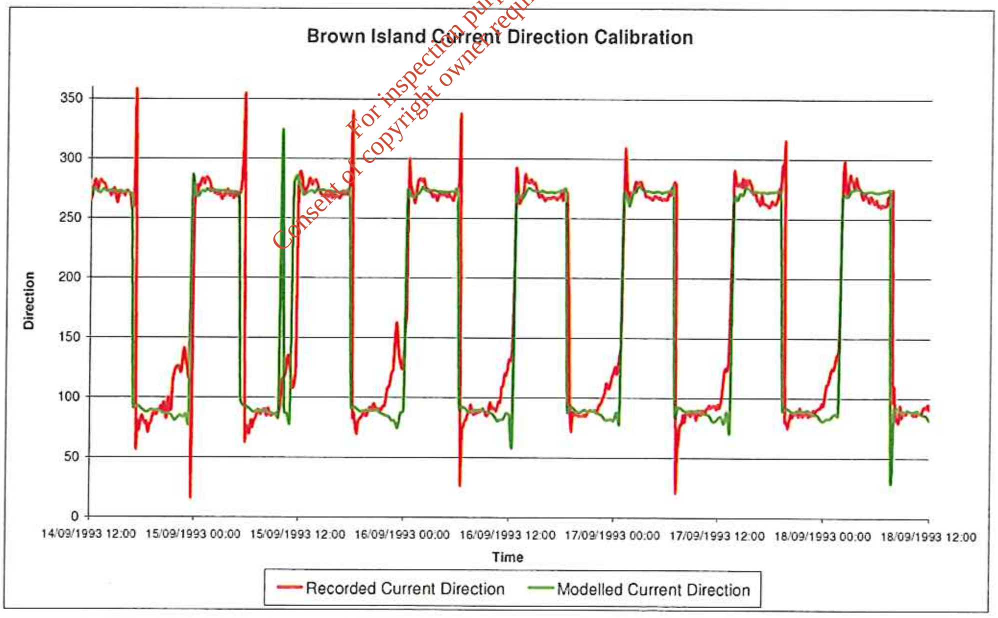

Fig. 3.18 Brown Island Current Speed Calibration – first 4 day period

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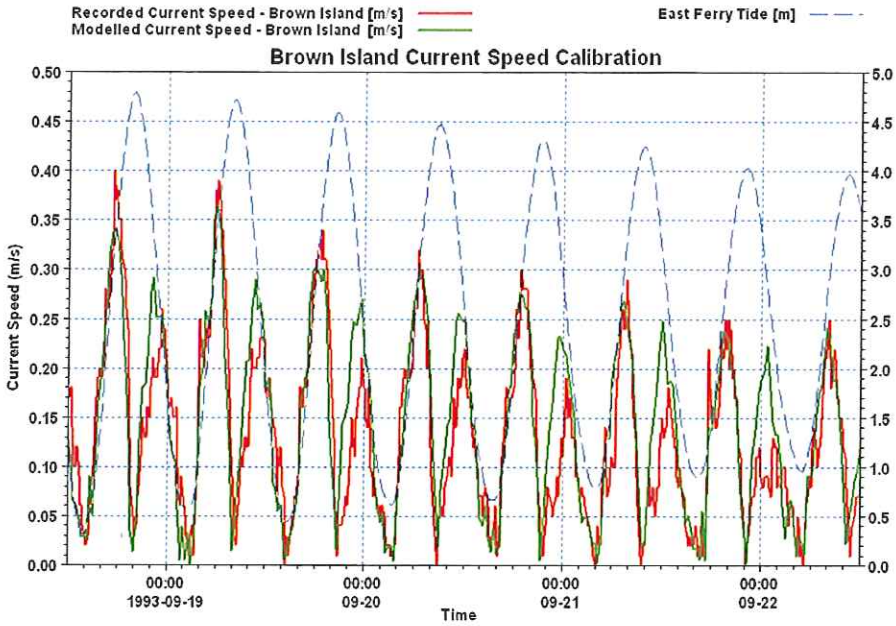

Fig. 3.19 Brown Island Current Speed Calibration – second 4 day period

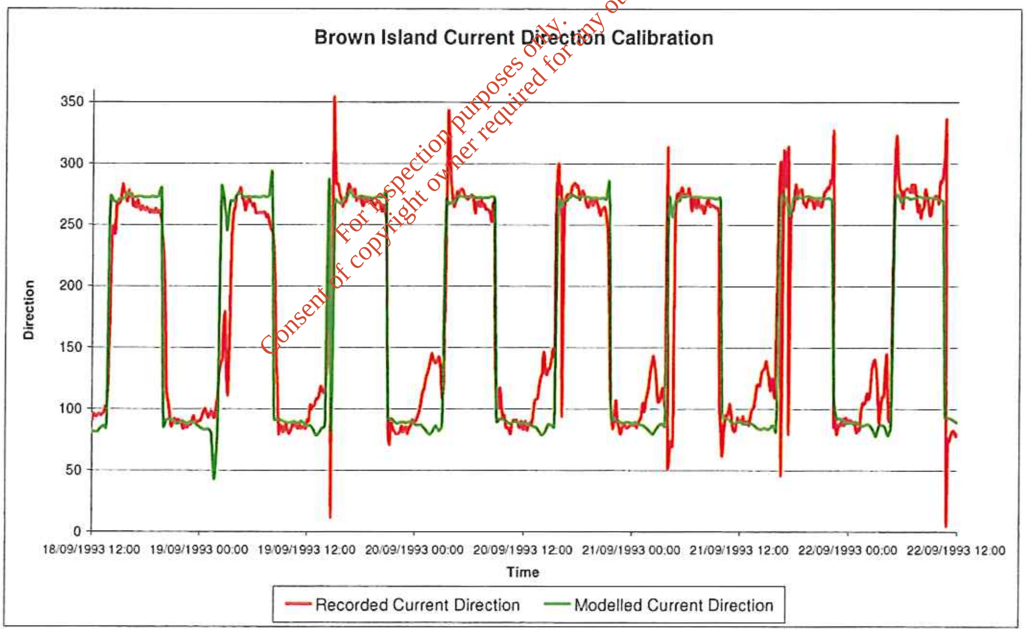

Fig. 3.20 Brown Island Current Speed Calibration – second 4 day period

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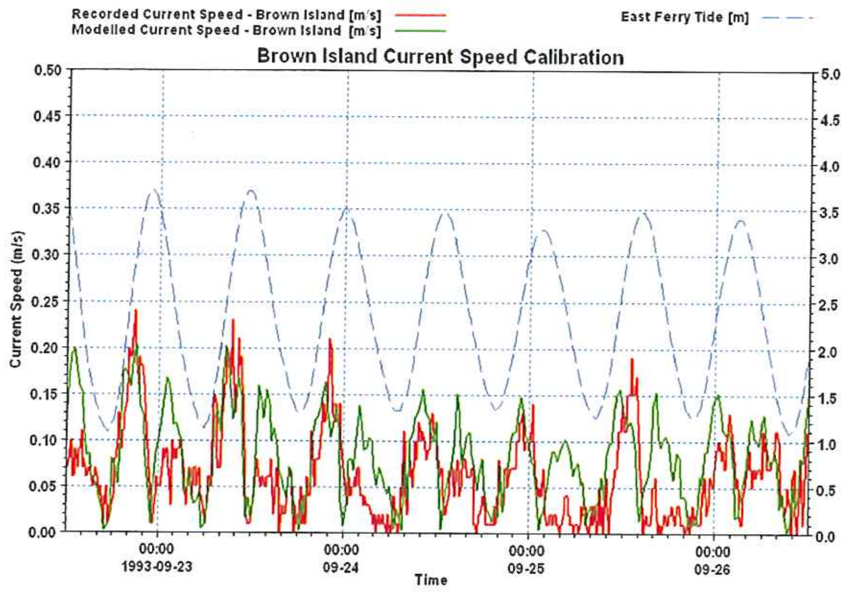

Fig. 3.21 Brown Island Current Speed Calibration – third 4 day period

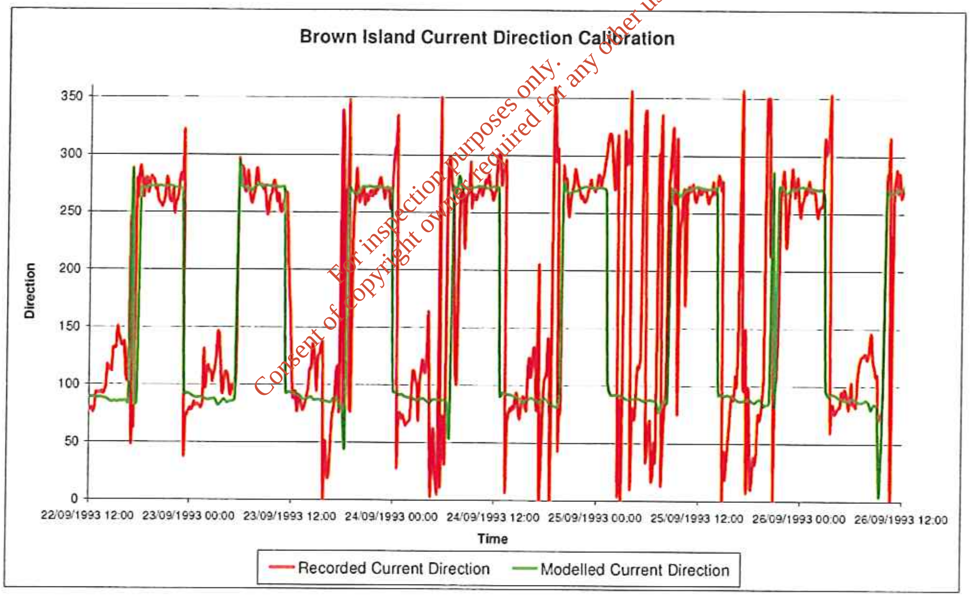

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Fig. 3.22 Brown Island Current Speed Calibration – third 4 day period

3.4.3 Bagwell Hill Current Speed and Direction

The following six figures present the current speed and direction plots for the gauge at Bagwell Hill. Ten and a half days of comparison are presented, split into 3.5 day periods for both the current speed and direction.

We can see that there is a very good match between the measured and modelled current speeds for the ebb tide throughout the entire period. There is

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however a constant mismatch on the flood tide. This mismatch is also evident in the current direction calibration. This difference between the datasets may be attributed to the eddy that forms to the left of the entrance to the North Channel from the East Passage[56].

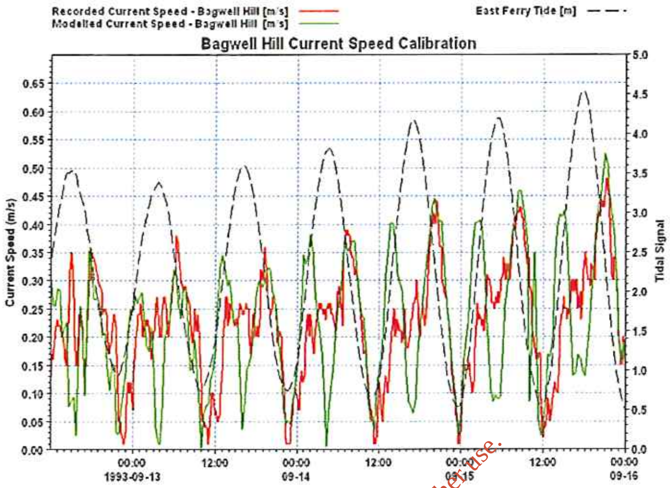

Fig. 3.23 Bagwell Hill Current Speed Calibration – first 4 day period

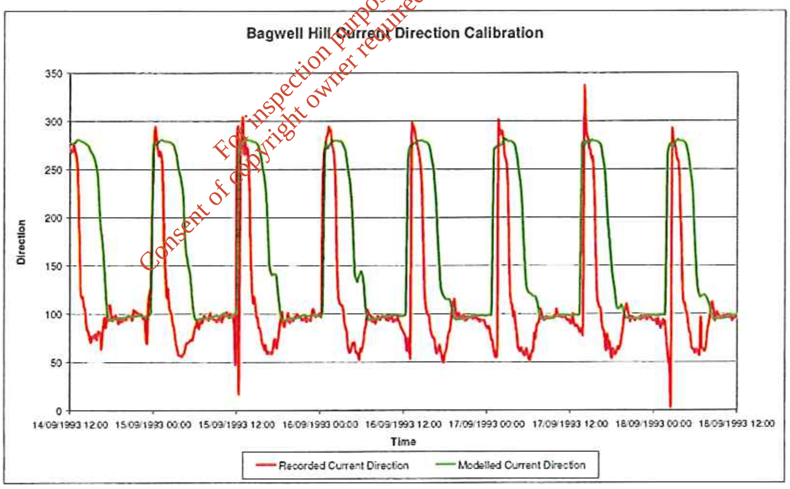

Fig. 3.24 Bagwell Hill Current Direction Calibration – first 4 day period

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[56] Numerous transient eddies form at different stages of the tide in Cork Harbour. Four large eddies form in the outer harbour while numerous smaller eddies develop in the East and West Passage and in the North Channel. These eddies have been simulated in a previous modelling study of Cork (Barry, K., 2005. Surface Waters of the Lee Catchment, Case Studies in Hydroinformatics. MEngSc thesis, University College Cork). These eddies have been "socially calibrated". Harbour pilots and sailors have indicated to the authors that the eddies occur in nature at the location and time simulated by the models.

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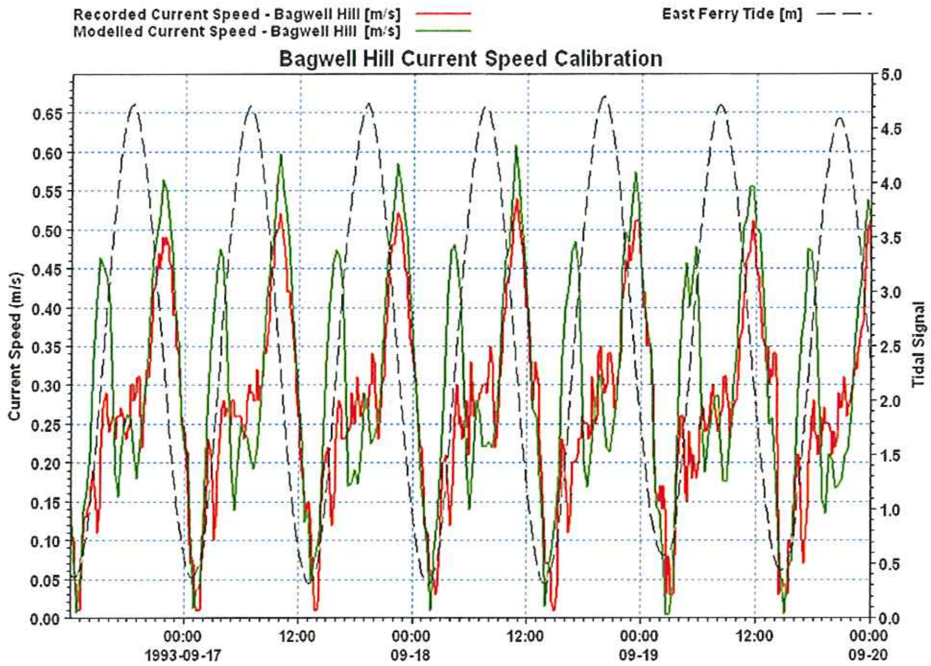

Fig. 3.25 Bagwell Hill Current Speed Calibration – second 4 day period

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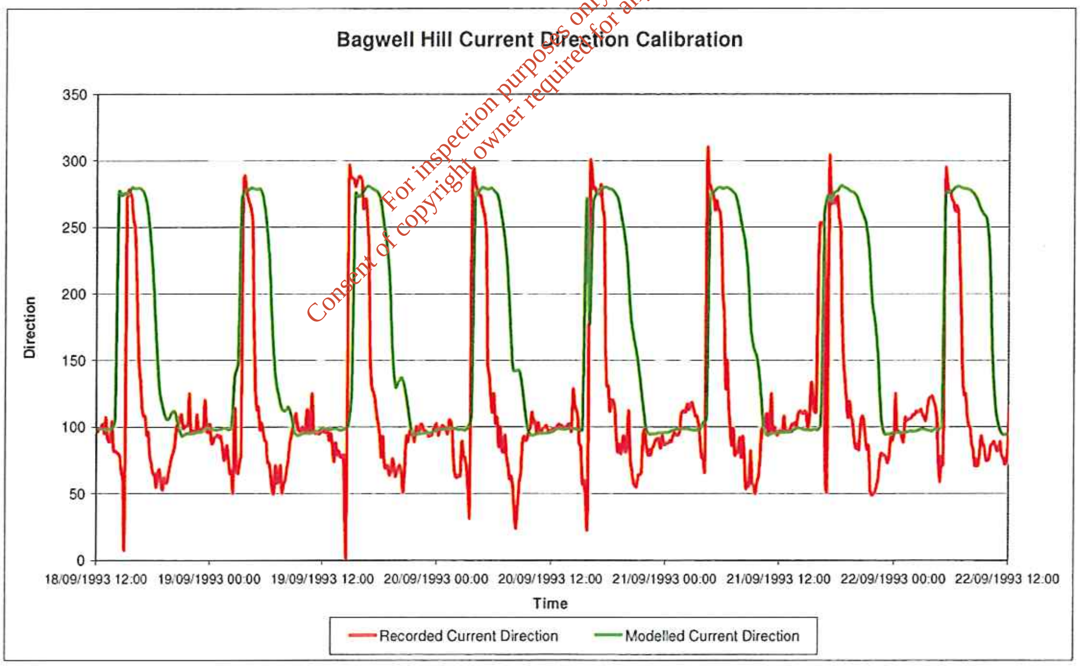

Fig. 3.26 Bagwell Hill Current Dir. Calibration – second 4 day period

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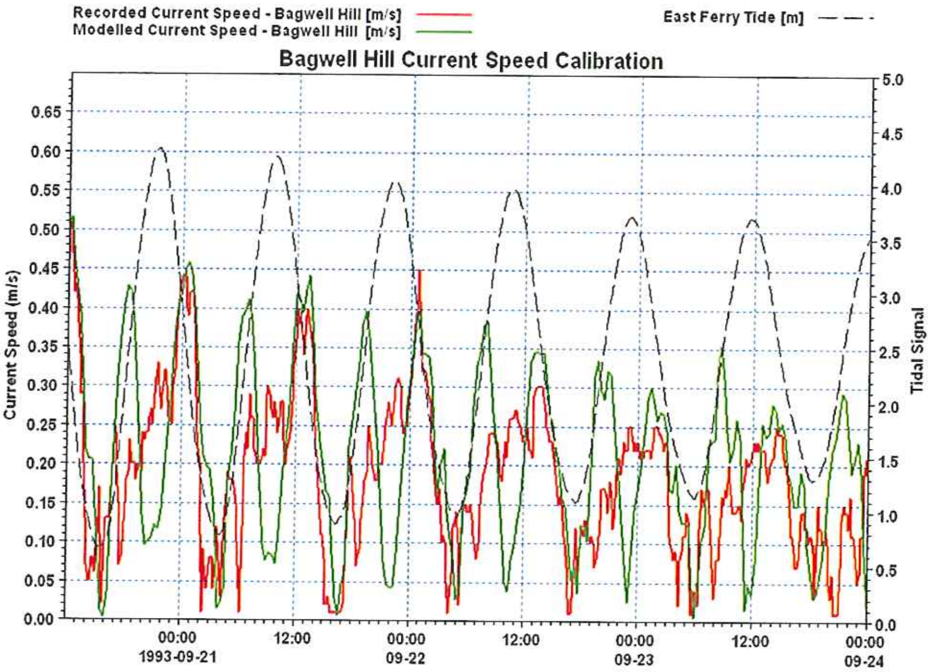

Fig. 3.27 Bagwell Hill Current Speed Calibration – third 4 day period

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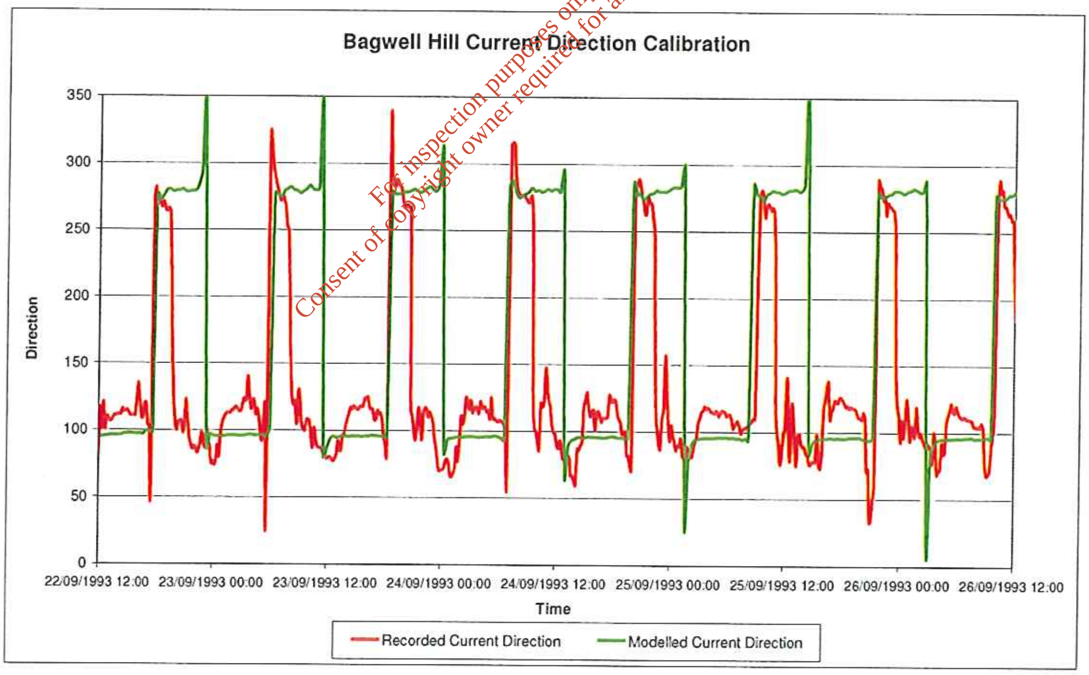

Fig. 3.28 Bagwell Hill Current Direction Calibration – third 4 day period

3.5 Water Level Validation Plots

The water level validation plots are presented in this section. The recorded data is plotted with a blue line while the modelled data is shown with a red one. The

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difference between the modelled and the measured, the error, is plotted on the secondary axis on the left-hand-side with a green line. The scaling on this secondary axis varies slightly for each plot.

We can see from Fig. 3.29 that there is a very close agreement for the Pfizer gauge. The error varies between 5 and 15cm. There is an obvious mismatch at the start of the neap cycle on the 27th of February. This error is consistent in each of the three validation plots. The source of this error was found to occur in the boundary condition where a few erroneous readings were recorded during this particular tidal cycle.

We can also see a slight bias in the gauge by the fact that the recorded data is consistently above the modelled data. This bias is reflected in the error plot. The error is, with only a few exceptions, consistently positive. No adjustments were made to the recorded dataset. This would reduce the errors in the model.

Fig. 3.30 presents a close up view of the error associated with the bottoming out of the Pfizer gauge as discussed in chapter 2.

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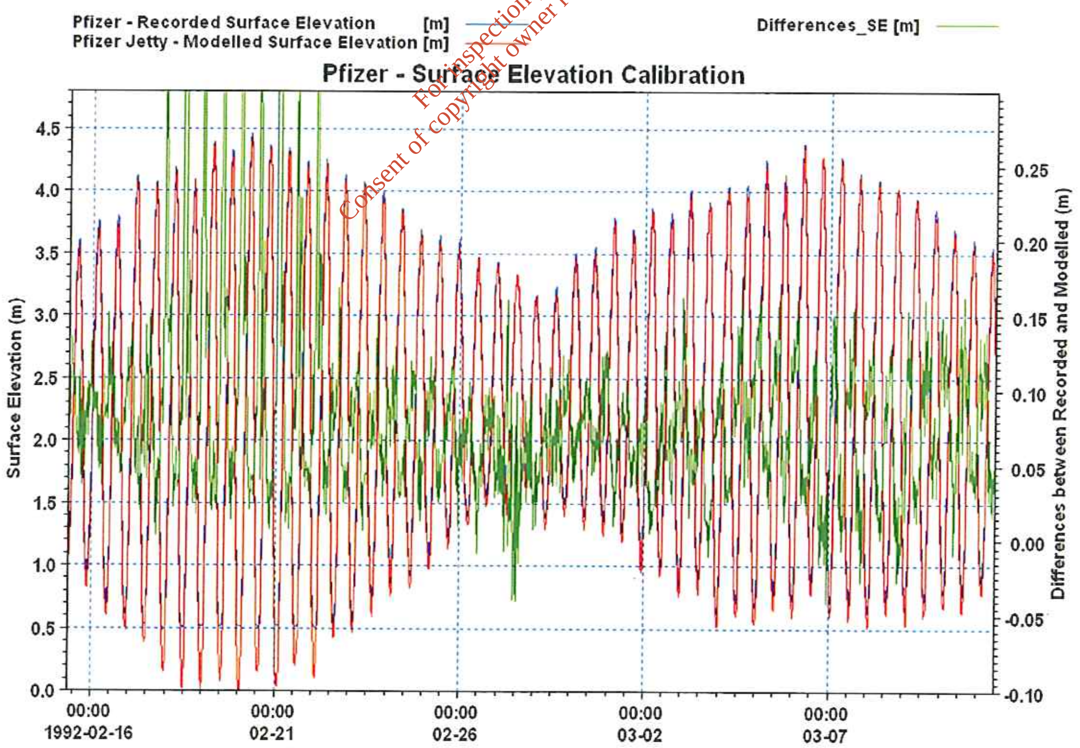

Fig. 3.29 Pfizer Gauge Water Level Validation

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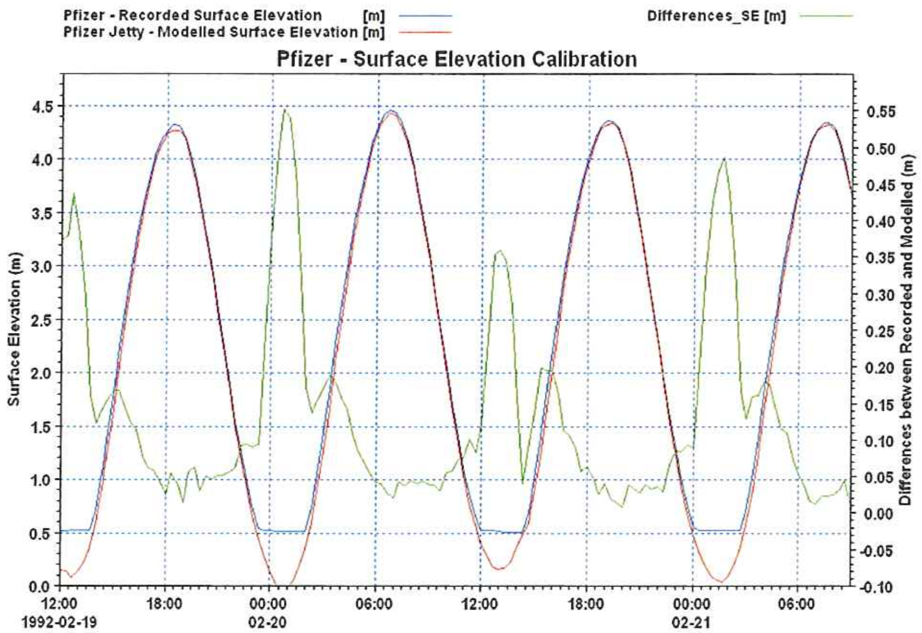

Fig. 3.30 Pfizer Gauge Validation – error with Pfizer Gauge

The validation for the gauge in Lough Mahon is presented in Fig. 3.31. Again we can see that the error is between 5 and 15 cm. There is also a slight bias in the error as the recorded data is consistently above the modelled data. As with the Pfizer gauge no adjustments were made to the recorded dataset.

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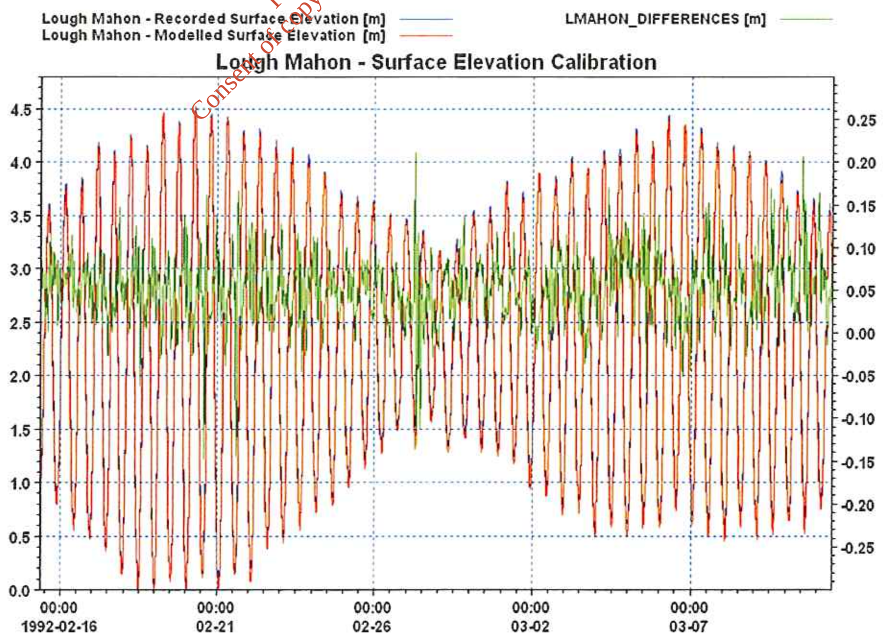

Fig. 3.31 Lough Mahon Gauge Validation

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The validation for the Belvelly gauge is presented in Fig. 3.32. We can see that the error is between 5 and 18 cm. There is also a slight bias in the error as the recorded data is consistently above the modelled data. As with both of the pervious gauges no adjustments were made to the recorded dataset.

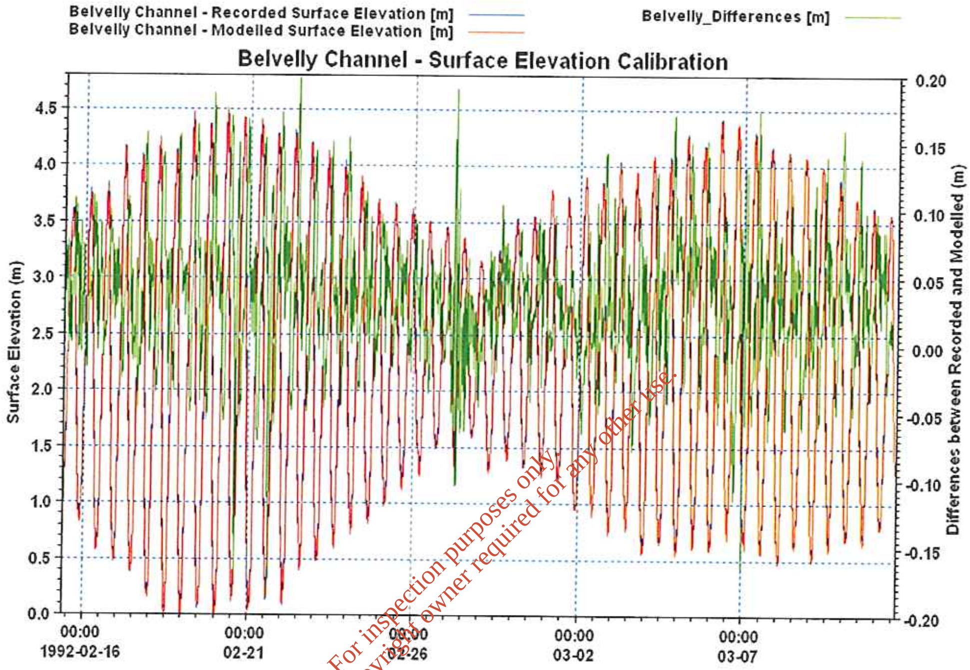

Fig. 3.32 Belvelly Gauge Validation

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3.6 Current Speed and Direction Validation

The current speed and direction validation for the Spit Bank are presented in the following 8 figures. The validation covers a 2-week period. We can see from the plots that overall a very good agreement between the datasets is achieved with the RP model. For the first 8 days, covering neap tide, the maximum current speeds are underestimated for the flood and ebb tides. As the neap cycle moves to spring, the difference between the datasets decreases.

The current direction validation follows a similar pattern. Overall it can be stated that there is a very good match between the modelled and measured datasets.

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3.6.1 Spit Bank

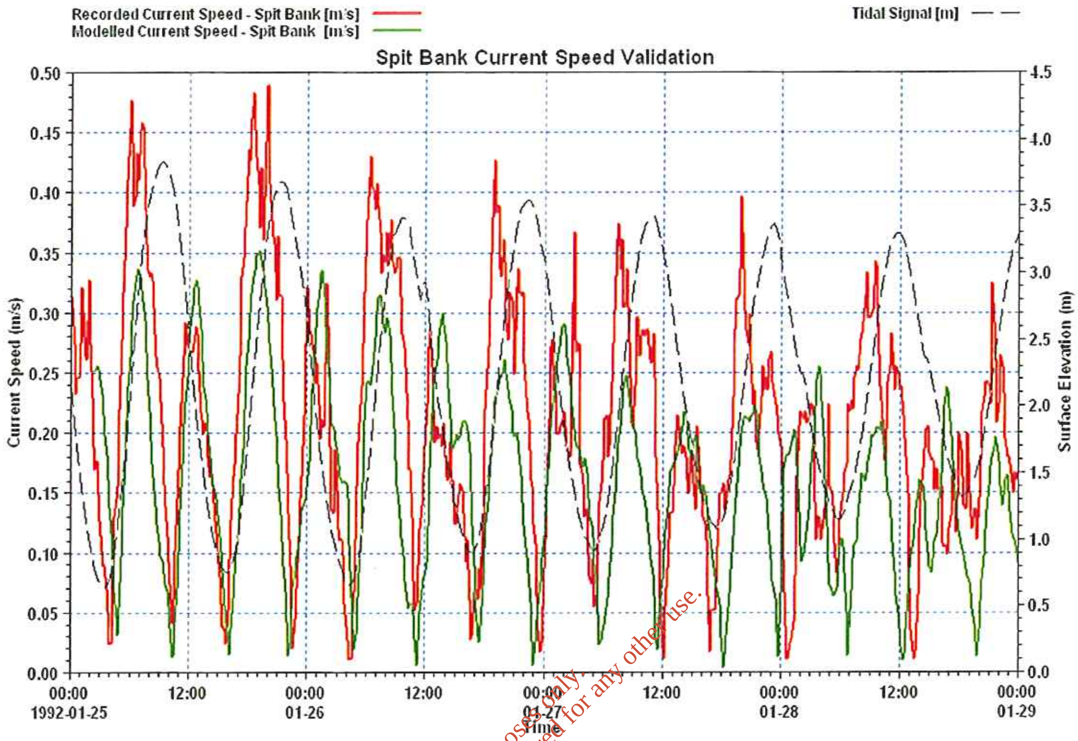

Fig. 3.33 Spit Bank Current Speed Validation -25th to 29th

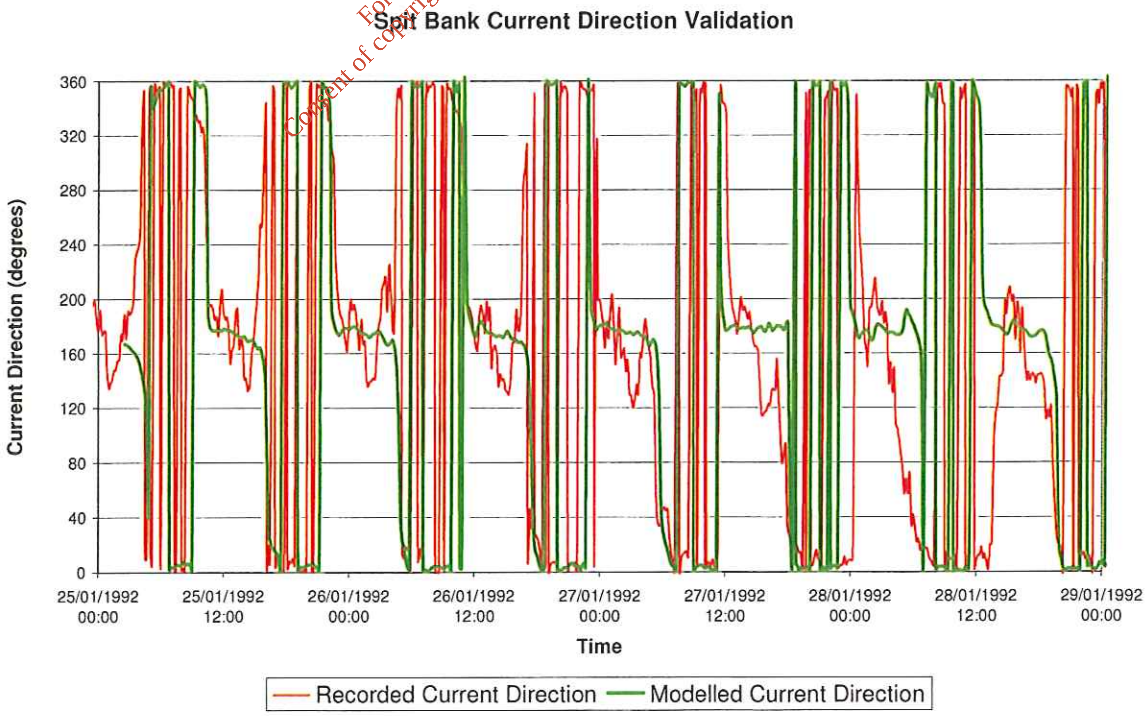

Fig. 3.34 Spit Bank Current Direction Validation -25th to 29th

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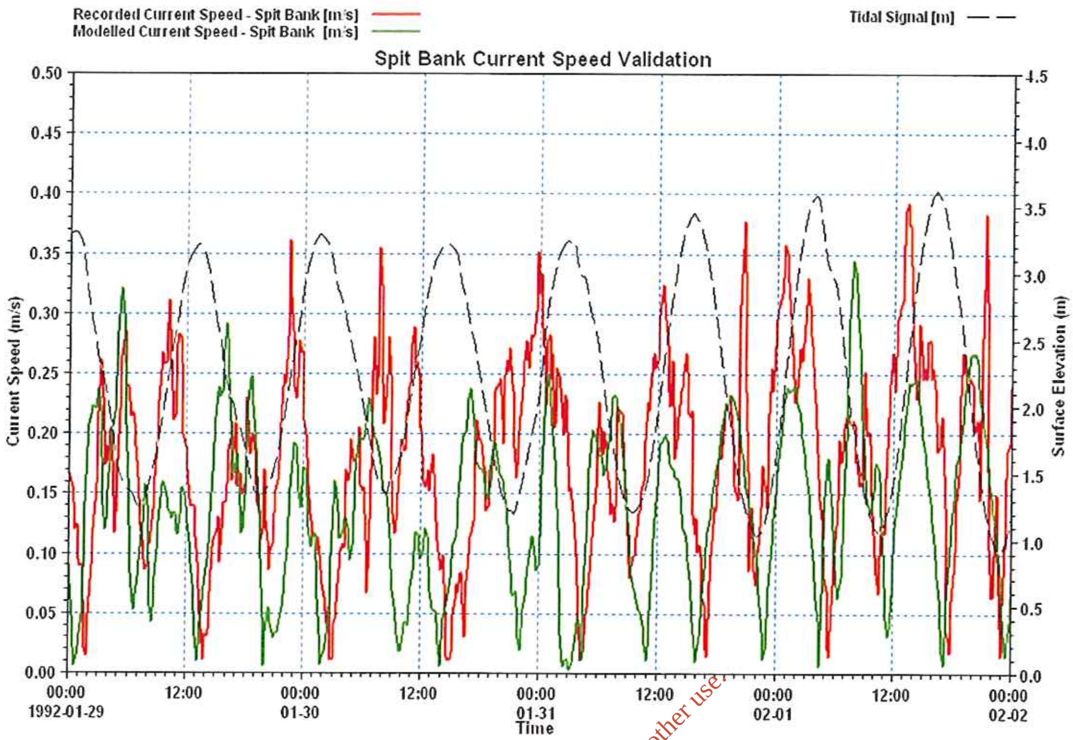

Fig. 3.35 Spit Bank Current Speed Validation -29th to 2nd Feb

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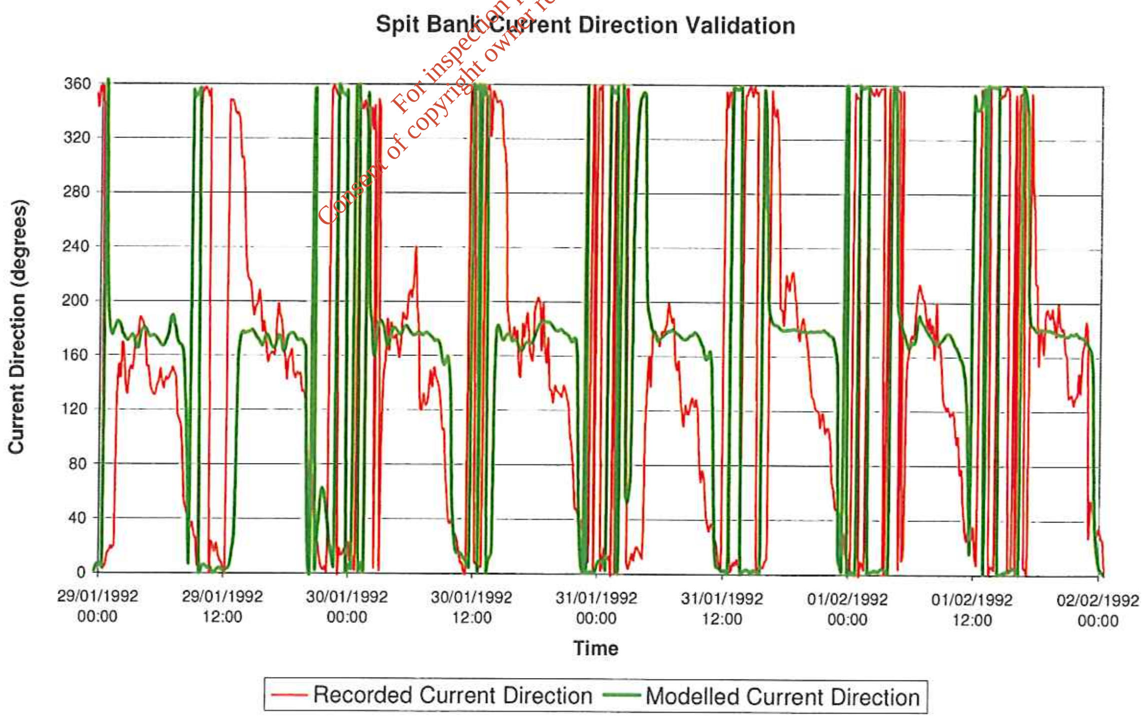

Fig. 3.36 Spit Bank Current Direction Validation -29th to 2nd Feb

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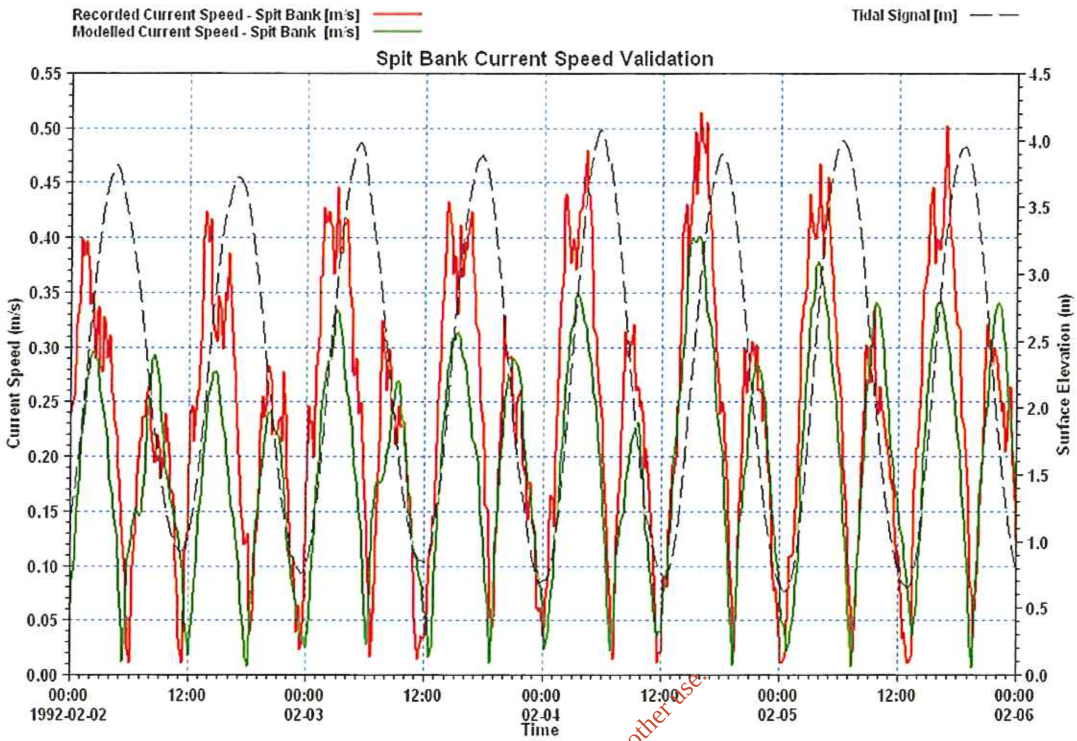

Fig. 3.37 Spit Bank Current Speed Validation - 2nd to 6th

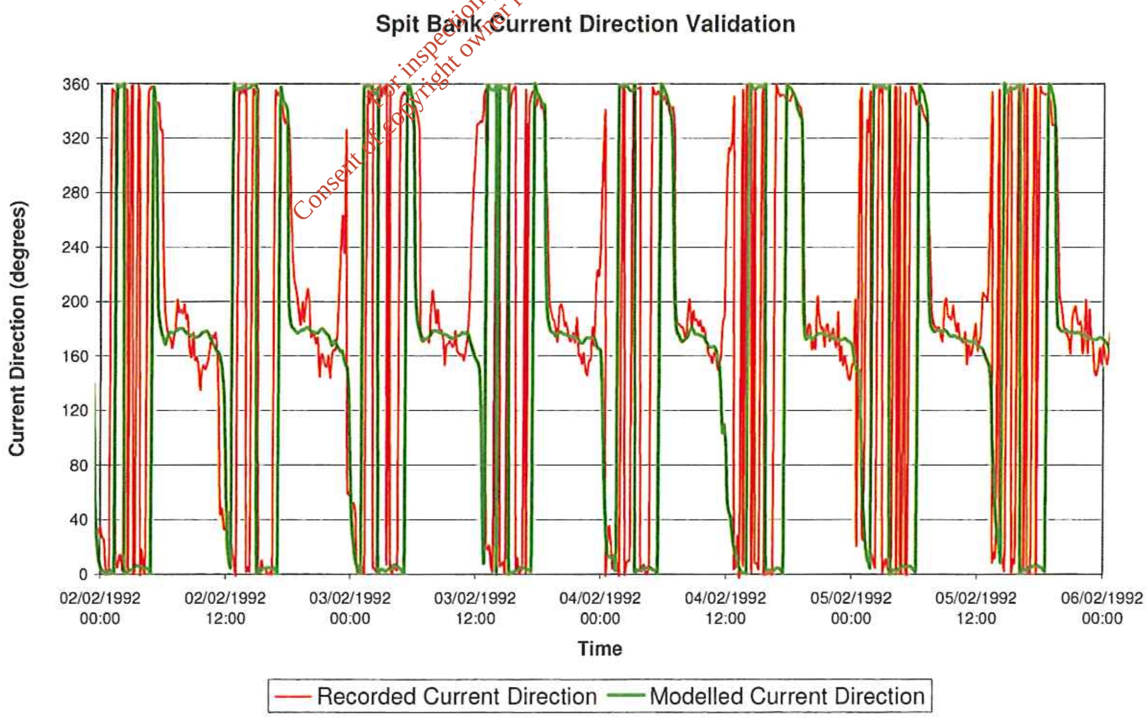

Fig. 3.38 Spit Bank Current Direction Validation - 2nd to 6th

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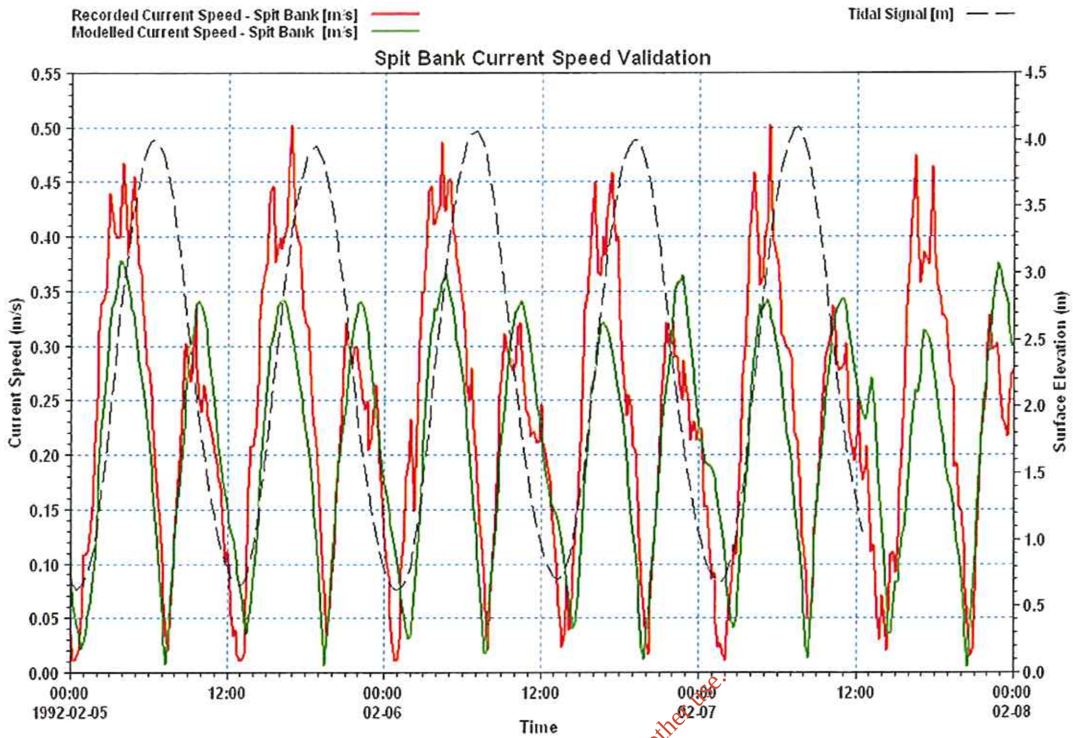

Fig. 3.39 Spit Bank Current Speed Validation – 5^th to 8^th

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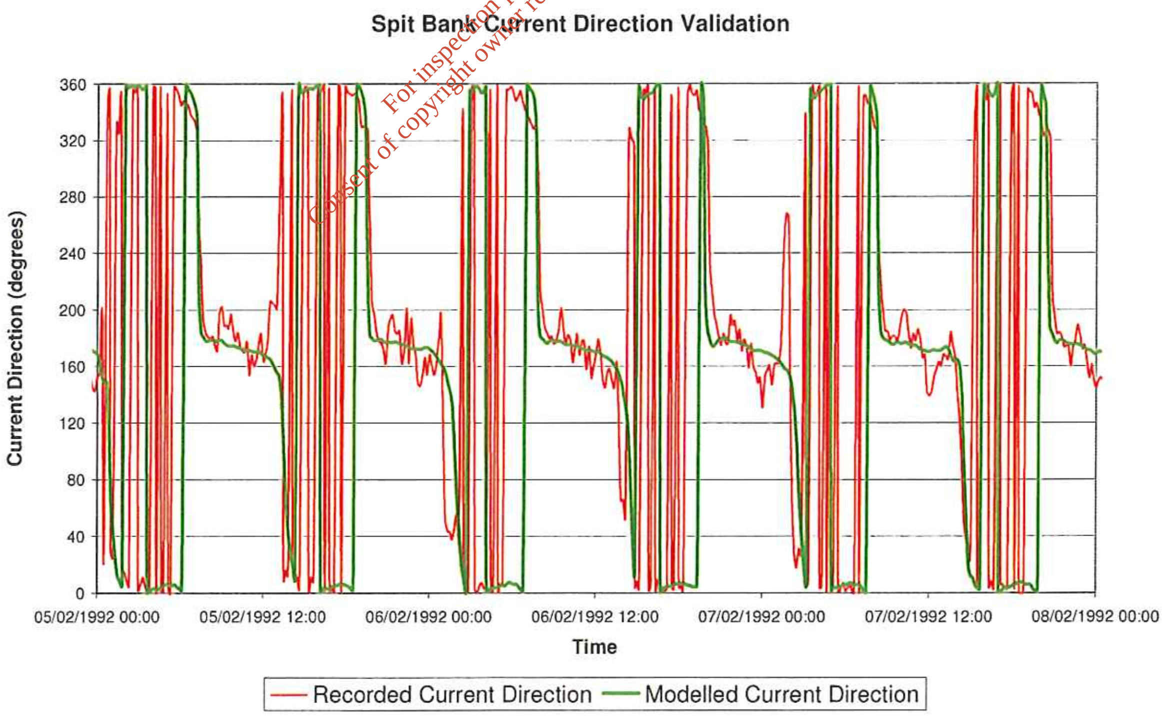

Fig. 3.40 Spit Bank Current Direction Validation – 5^th to 8^th

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3.6.2 Lough Mahon Current Speed and Direction Validation

The current speed and direction validation for the Lough Mahon gauge are presented in the following 8 figures. The validation covers a 2-week period.

We can see that the difference between the modelled and measured current speeds is very good for some periods while less good for others. For the first 2 days there is a very good agreement between the datasets. After this the differences increase. We can see from Fig. 3.41 that the gauge failed at the start of the 27th of January which would tend to cast doubt on the validity of the recorded data for these few days. Differences continue to occur between the modelled and measured data for the next few days through the neap cycle period. By the first of February however there is again a very good match between the model and the data.

The same pattern occurs with the current direction calibration.

Overall however we can state that there is a very good agreement between the modelled and measured datasets for Lough Mahon.

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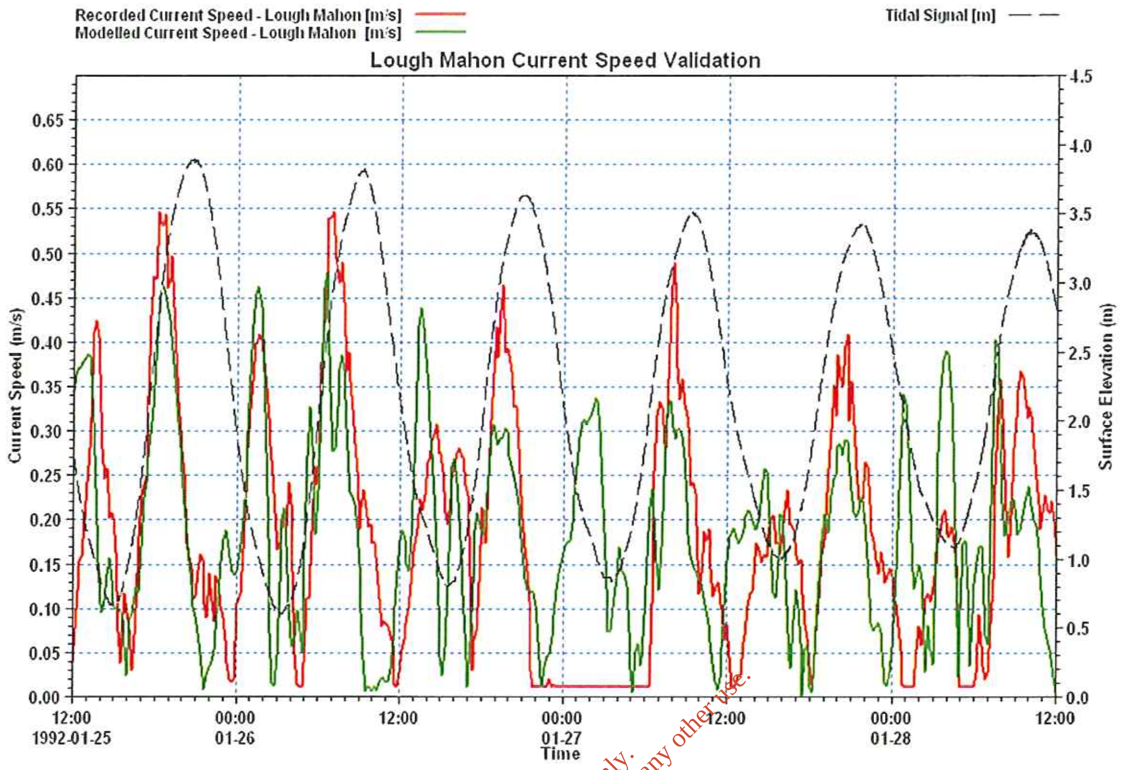

Fig. 3.41 Lough Mahon Current Speed Validation – 25th to 29th

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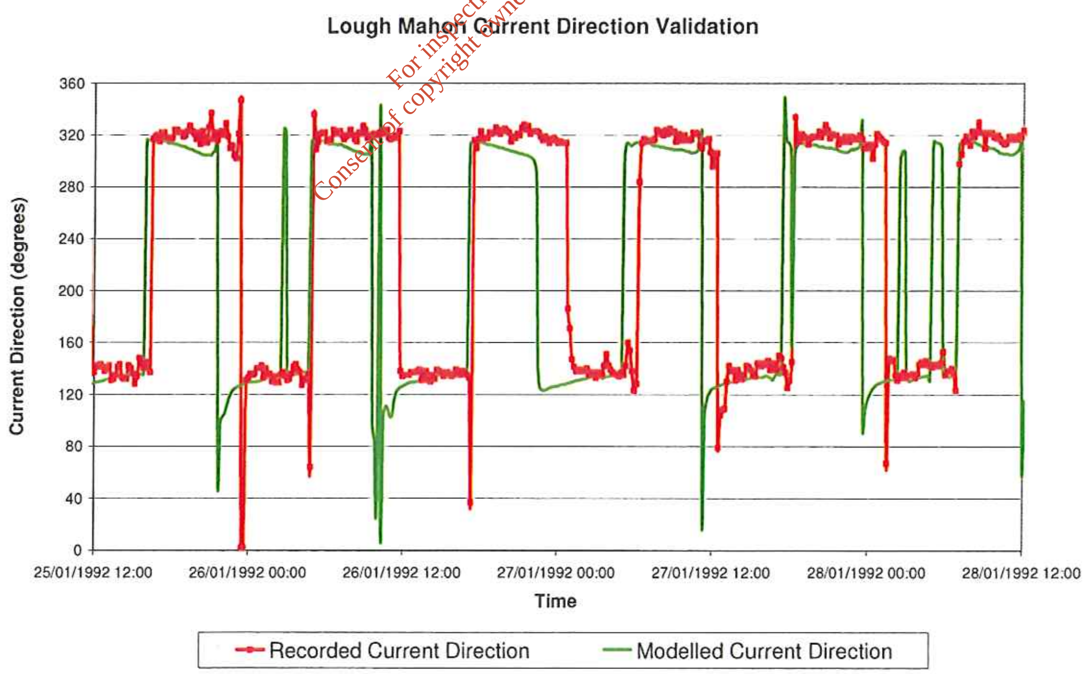

Fig. 3.42 Lough Mahon Current Direction Validation – 25th to 29th

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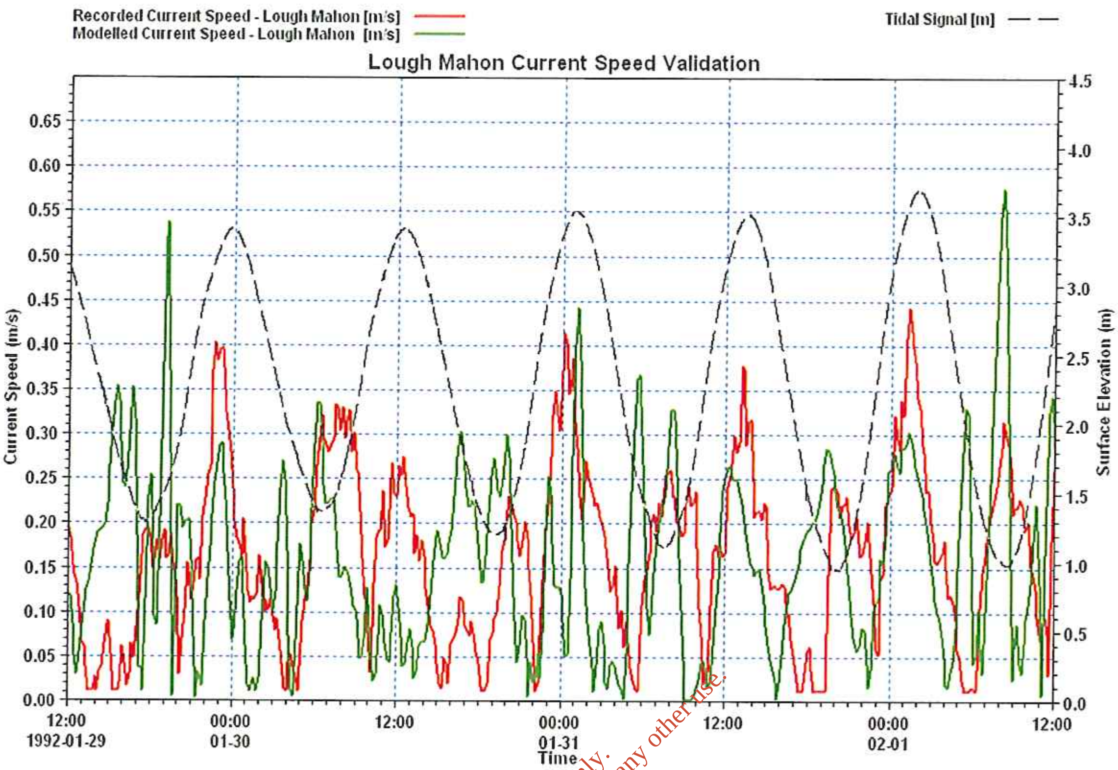

Fig. 3.43 Lough Mahon Current Speed Validation – 29th to 1st

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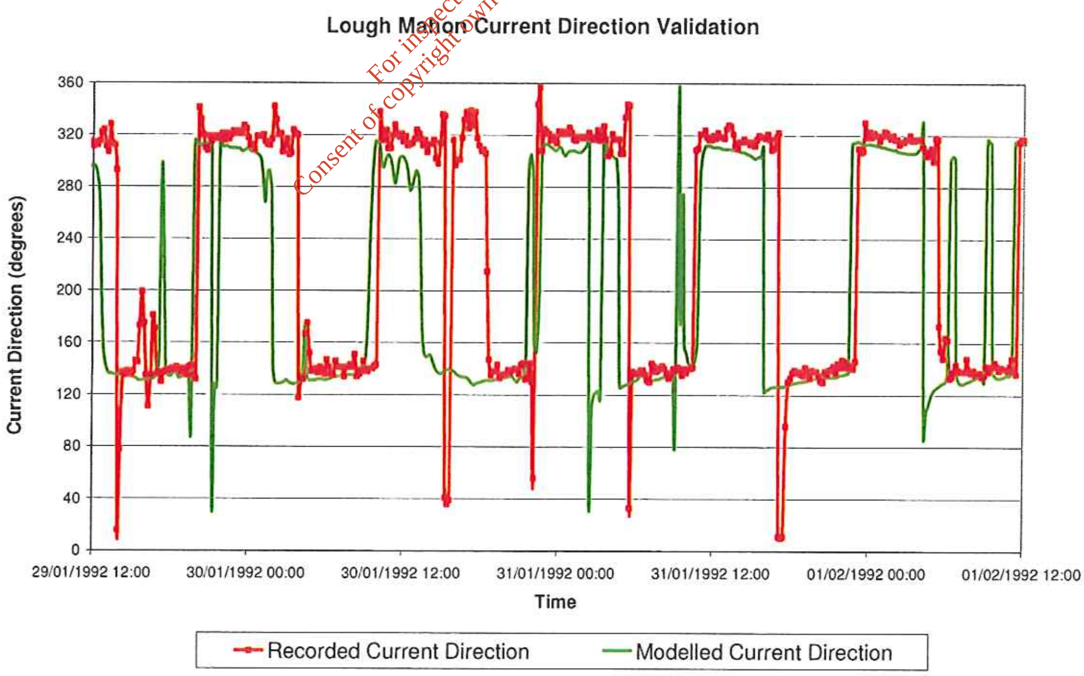

Fig. 3.44 Lough Mahon Current Direction Validation – 29th to 1st

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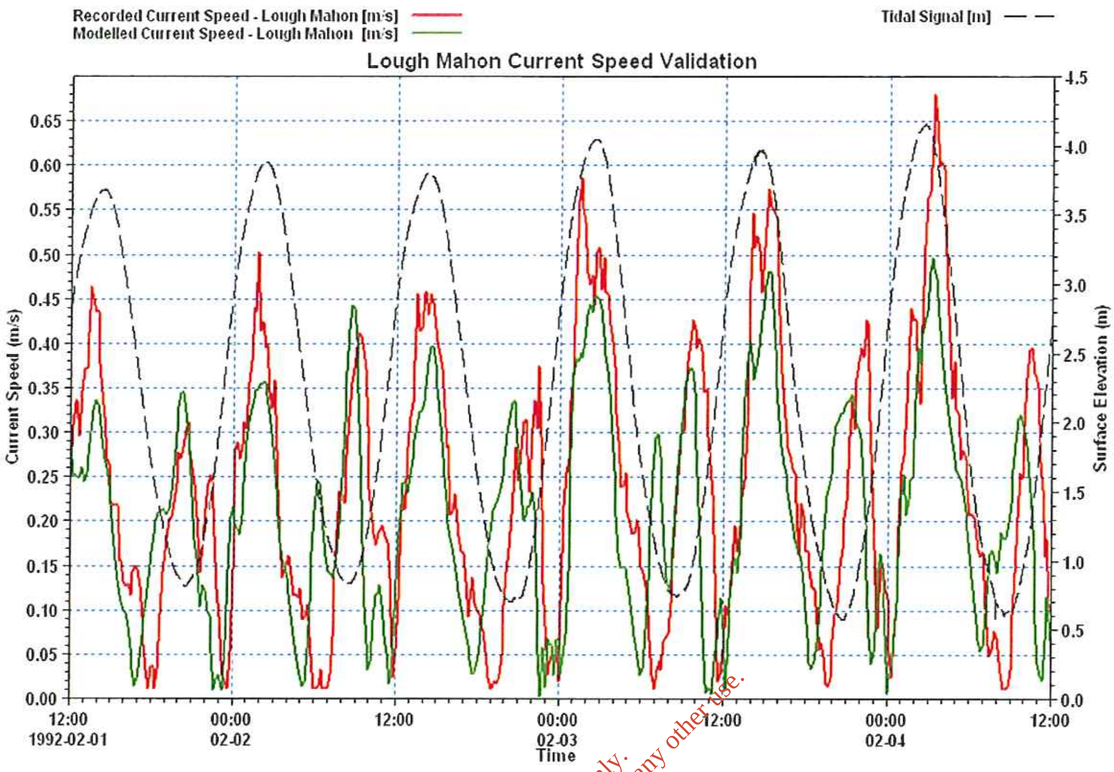

Fig. 3.45 Lough Mahon Current Speed Validation – 1st to 4th

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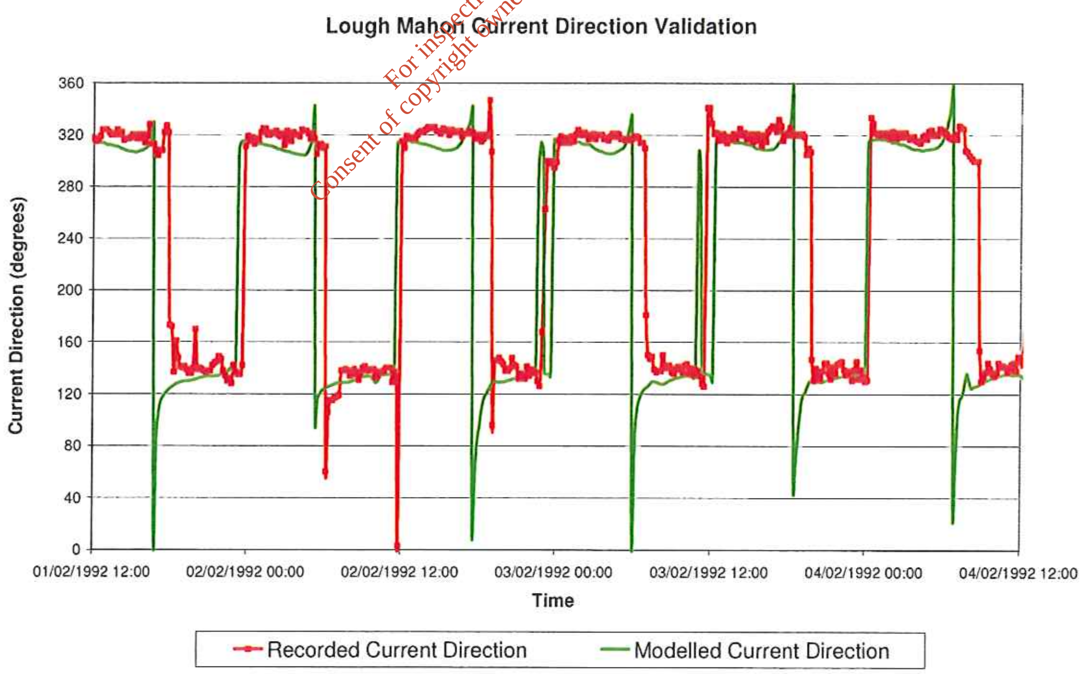

Fig. 3.46 Lough Mahon Current Direction Validation – 1st to 4th

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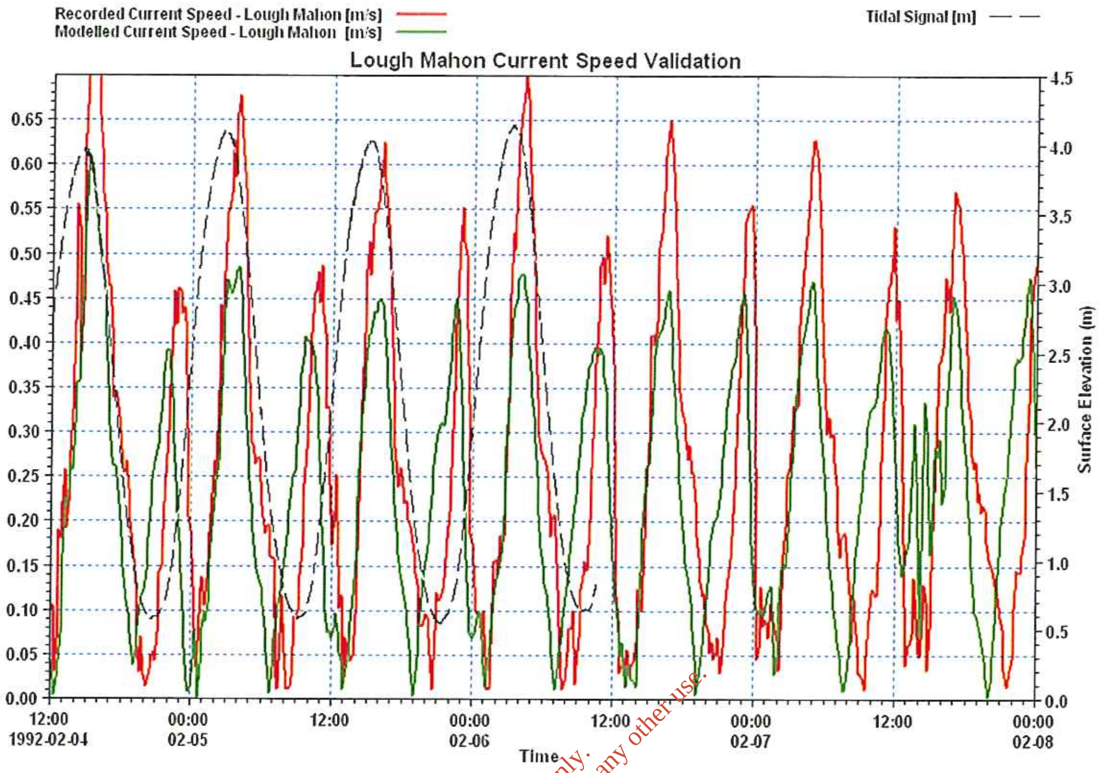

Fig. 3.47 Lough Mahon Current Speed Validation – 4th to 8th

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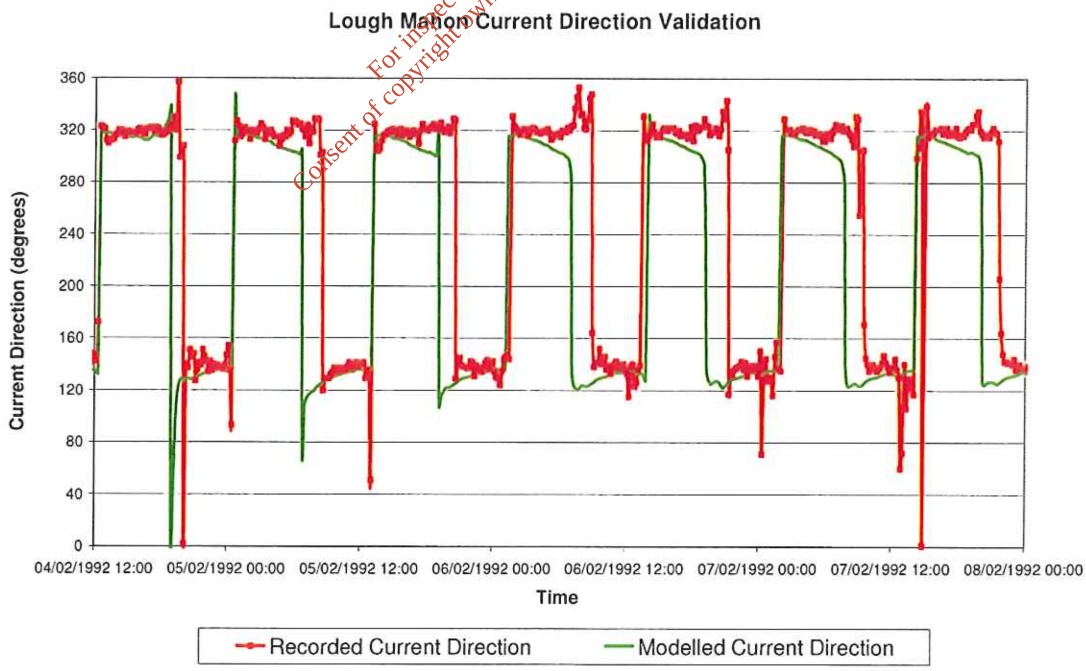

Fig. 3.48 Lough Mahon Current Direction Validation – 4th to 8th

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3.7 Conclusions

The RP model has been calibrated and validated against water levels for a number of locations in the harbour. Water levels recorded at the Pfizer gauge, Lough Mahon and the North Channel near the oyster farm are all in very good agreement with the model. There is a slight error at high and low water which varies between 10cm and 15cm. This is well within an acceptable limit of error.

The RP model has been calibrated and validated against current speed and directions for a number of locations in the harbour. Current readings from the Spit Bank in the outer harbour, Lough Mahon and the Belvelly Channel all compare very well with the output from the model. The calibration in Lough Mahon for neap tides is not as good as for Spring tides. The error is however well within an acceptable limit as velocities in a two-dimensional hydrodynamic model are averaged over the grid cell. For Lough Mahon this is 18m. Strong localised (i.e. less than 18m), subgrid scale hydrodynamics cannot be resolved.

Overall we can state that there is very good agreement between the RP model and the recorded datasets.

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