Chapter 7 Discussion and Conclusion

7.1 Discussion

The lead author of this report was commissioned by Mott MacDonald Pettit (MMP) to undertake a detailed Environmental Impact Assessment of the likely relative improvement in water quality as a result of the proposed Lower Harbour Main Drainage Scheme. At present the towns of Cobh, Passage West, Monkstown, Glenbrook, Ringaskiddy, Crosshaven and Carrigaline all discharge untreated sewage into Cork Harbour. The proposed scheme will collect this waste and treat it to a secondary standard at a new wastewater treatment plant near Carrigaline. The treated effluent will be discharged through the existing Carrigaline/Crosshaven outfall near Dognose Bank. In spite of increasing population a marked improvement in quality is to be expected for two reasons: (a) the reduction in pollutant load due to the treatment plant, and (b) the increased dilution available downriver when the treated effluent is discharged just inside the mouth of the Outer Harbour. This study quantifies the improvement.

A computer model, called the 'OH_2' model covering an area from the Old Head of Kinsale to the Waterworks weir in Cork City was developed. The calibration of this model was based on that of a similar, but smaller, model of Cork Harbour (the 'RP_2' model) which covers an area from Roches Point to the Waterworks weir. The water level validation of the OH_2 model showed that it is capable of reproducing the tides in Cork Harbour with an acceptable error (<25cm).

The OH_2 model has been used to simulate the discharge, transport and decay of three separate micro-organisms present in sewage from the relevant outfalls:

1. **Faecal coliform bacteria -** The number of faecal coliforms per 100ml is a recognised standard in the relevant EU Directives. The I (mandatory) and G (guide) values for the Bathing Water Directive are, for faecal coliforms, 2000 counts per 100ml and 100 counts per 100ml respectively. The G (guideline) values for the Shellfish Waters

Directive are, for faecal coliforms, less than 300 counts per 100ml in the *shellfish flesh and intervalvular liquid.*

2. **Norovirus -** The *Norovirus* or "Winter Vomiting bug" is the primary pathogen in outbreaks of gastroenteritis following consumption of raw oysters. There is no standard for seawater at present due to the difficulty of measuring its concentration.

3. **Simple Nitrogen Cascade -** The forcing exerted on the Harbour ecosystem by organic nitrogen, nitrate and ammonia is examined using a simplified nitrogen cascade model.

In order to illustrate the overall benefit of the proposed scheme a detailed comparison was made between the case where untreated waste is being discharged from all of the relevant outfalls in 2010 (**CASE 2** in this report) and the case where treated waste is being discharged from the single Carrigaline/Crosshaven outfall near Dognose Bank in 2010 (**CASE 3** in this report).

The OH_2 model has a number of inherent assumptions:

- Bacteria, nitrogen, and *Norovirus* are neutrally buoyant.
- Adsorption onto sediment is not modelled.
- Density gradients and stratification due to variations in salinity are excluded.

In this study we have not considered the discharges of treated effluent from Carrigrennan, Midleton or Cloyne or the untreated discharges from the outfalls serving the towns on the eastern side of the harbour. Neither have we considered the intermittent discharge of storm overflows during heavy rainstorms and/or large infiltration of groundwater into sewers. Once secondary treatment has been introduced everywhere, these episodic discharges become important. Therefore, the results are not representative of the absolute water quality in the harbour and surrounding waters. They show the improvement to be expected from the proposed treatment plant.

We have examined the measurements of background concentrations of coliforms and nitrogen from the harbour. There are no measurements of

Norovirus in water anywhere in the world. The sampling error and the spatio-temporal variability of coliforms and nitrogen throughout the harbour make any estimate of the background concentrations very uncertain. Consequently, in our view, it is sufficient to model the improvement in concentrations due to the proposed treatment plant and outfall.

It is possible to model the background concentrations but this would require substantially more resources and time than were available for this comparative study.

The results of the three modelled micro-organisms are discussed in the following sections.

7.2 Faecal Coliform Results

The OH_2 model results showed that the proposed treatment plant will reduce the number of faecal coliforms in Cork Harbour and the waters outside Roches Point. This will lead to a considerable improvement in water quality.

The maximum number of faecal coliforms attained at each grid point of the model for Case 2 with repeating spring tides ranged from 2 to 1500 faecal coliforms per 100ml across the harbour. This range ignores the extremely high concentrations in the immediate vicinity of each individual outfall. The equivalent range with the proposed treatment plant in operation, Case 3, is from 2 to 400 faecal coliforms per 100ml. This represents a significant improvement in water quality. The results of the repeating neap tides were similar.

When the average number of faecal coliforms at each grid point were compared it was found that the range was reduced from 2 - 140 per 100ml for CASE 2 to 2 – 40 per 100ml for Case 3.

The reduction in the number of faecal coliforms was quantified by expressing the maximum concentrations attained at each grid point with the treatment plant in place as a percentage of the maximum concentrations attained at each grid point without any treatment in place. It was found that the percentage relative reduction varied across the harbour. For Lough Mahon, the Inner harbour, the East and West Passages as well as the area around Ringaskiddy the maximum concentrations with the treatment plant in place were less than 5% of the maximum concentrations with no treatment i.e. there is at least a 95% relative reduction in indicator organisms for these areas. For the rest of the harbour and the area outside Roches Point they were less than 20% i.e. there is at least an 80% relative reduction in indicator organisms for these areas.

When the averages in concentration were compared the same pattern emerged. There was a substantial relative improvement (at least 95% relative reduction) for Lough Mahon, the inner harbour and the East and West passages. For the outer harbour the relative improvement was less (at least 80% relative reduction).

This percentage relative reduction is one of the main findings of our report. The proposed treatment plant will significantly reduce the number of indicator organisms in the upper harbour area. It will also reduce the number of indicator organisms in the outer harbour area and outside the harbour mouth but to a lesser degree.

Time series of faecal coliform concentration were also presented for 15 points of special interest. The improvement in water quality was observed from these graphs by plotting the time series for Case 2 and Case 3 together. The concentrations for 2030 were not presented as they are simply equivalent to the plots for Case 3 multiplied by 1.431.

A sensitivity analysis was carried out on the release of treated waste from the proposed scheme with the 2010 population (**Case 3**). It was found that the maximum number of faecal coliforms may increase by as much as 30 – 40 per 100ml, in certain areas of the outer harbour, when they decay with a T90 of 24 hours and not 12 hours. It was also found that the maximum number of faecal coliforms may increase by as much as 40 – 60 per 100ml, in certain areas of the outer harbour, with adverse wind conditions.

We have assumed that there are $1.0*10^7$ faecal coliforms present in every 100ml of untreated sewage. We have also assumed that the proposed wastewater treatment plant will remove 90% of the organic matter such that there are $1.0*10^6$ faecal coliforms present in every 100ml of treated effluent. Both of these assumptions are conservative. In a similar study to this for a proposed wastewater treatment plant at Spiddle, Co. Galway[44] it was assumed that there were $2.2*10^5$ faecal coliforms per 100ml of treated effluent. Our assumption is 4.5 times greater than this. There was no comment in this report on the assumed removal efficiency of the wastewater treatment plant.

The 90% removal assumption of organic matter is also conservative. Over the course of the authors' previous *Norovirus* study data from the waste water treatment plant at Midleton was obtained from Cork County Council[45]. This data suggested that over 98% of indicator bacteria are removed in the secondary treatment plant at Midleton. Based on our assumption of $1.0*10^7$ faecal coliforms present in every 100ml of untreated sewage a 98% removal efficiency leads to $2.0*10^5$ faecal coliforms per 100ml of treated effluent (a figure similar to the Spiddle study). This figure is 5 times less than the value we used ($1.0*10^6$) in Chapter 4.

The principle of superposition allows us to rescale our results based on an assumed 98% removal rate of organic matter. The maximum concentrations for this rescaled case (i.e. Case 3 rescaled from 90% removal efficiency to 98% removal efficiency) may then be expressed as a percentage of the maximum concentrations of Case 2 (all the relevant towns discharging untreated waste). We can see from Fig. 7.1 that the maximum concentrations with the proposed treatment plant operating at 98% removal efficiency are less than 1% of the maximum concentrations with no treatment for the Inner harbour area. This is equivalent to a 99% removal of indicator bacteria. This exceeds the removal efficiency of the treatment plant because the number of outfalls will be reduced. All waste will be collected from these areas, treated and then discharged at a single point (the existing outfall from Carrigaline/Crosshaven near Dognose Bank)

For the outer harbour they are less than 4% i.e. there is a 96% removal of indicator bacteria.

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44 AQUA-FACT, Hydrographic Survey and Water Quality Model, Spiddle, Co. Galway, 2005

45 Personal communication with Cork County Council

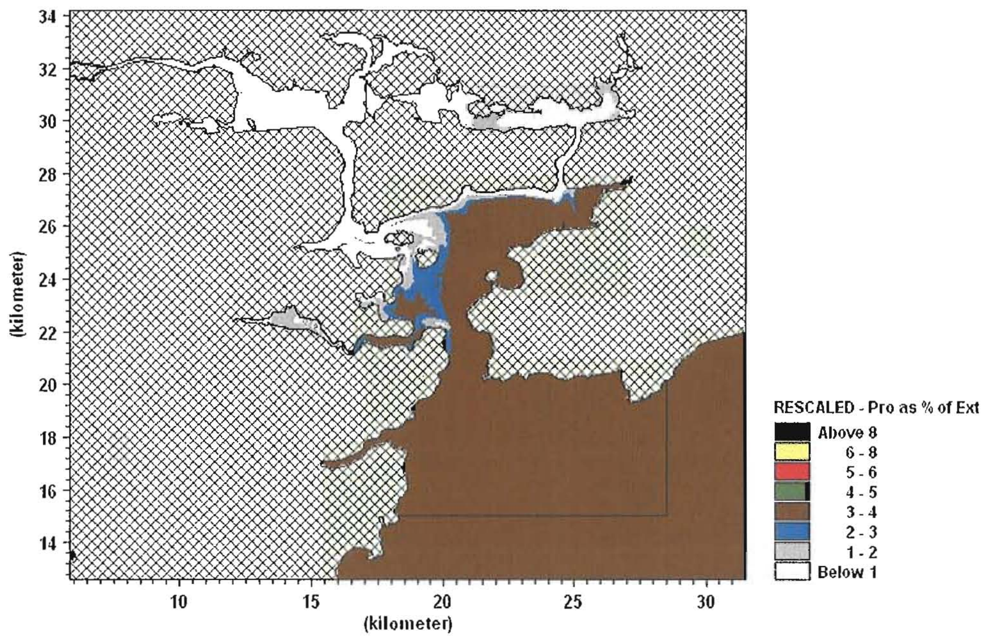


Fig. 7.1 The maximum concentrations from the proposed treatment (98% removal efficiency) as a percentage of the maximum concentrations with no treatment from the relevant towns.

The predicted concentrations of faecal coliforms are compared with the regulatory requirements in the 2 relevant EU Directives listed below.

The directives of interest are:

- Bathing Water Directive (76/160/EEC)
- Shellfish Waters Directive (79/923/EEC)

The I (mandatory) and G (guide) values for the Bathing Water Directive are, for faecal coliforms, 2000 counts per 100ml and 100 counts per 100ml respectively. From the results presented in Chapter 4 we may conclude that the contribution from the proposed treatment plant is several orders of magnitude less than these requirements far the bathing areas.

The G (guideline) values for the Shellfish Waters Directive are, for faecal coliforms, less than 300 counts per 100ml in the shellfish flesh and intervalvular liquid. We can see from the results presented in Chapter 4 that the contribution from the proposed treatment plant is several orders of magnitude less than these requirements.

7.3 Norovirus Results

The *Norovirus* was included as part of this study in order to determine the impact of the proposed treatment plant on the oyster farms and recreational areas present in the harbour. It was found that with the proposed scheme in place, the number of *Norovirus* in Cork Harbour and the surrounding waters will be reduced leading to a considerable improvement in water quality. The results of the model indicate a 90 – 95% relative reduction in the maximum number of *Norovirus* near the oyster farm with the introduction of the proposed treatment plant.

The maximum number of *Norovirus* reached at each grid point for the untreated waste simulation (Case 2) ranged from 2 to 18,000 *Norovirus* per cubic metre. This range ignores the extremely high concentrations in the immediate vicinity of each individual outfall. The equivalent range with the proposed treatment plant in operation (Case 3) is from 2 to 2,000 *Norovirus* per cubic metre indicating an improvement in water quality.

The reduction in the number of *Norovirus* was quantified by dividing the maximum values for the treated waste situation (Case 3) by the maximum values for the untreated waste situation (Case 2) and multiplying the answer by 100. This expressed the maximum concentrations with the treatment plant in place as a percentage of the maximum concentrations without any treatment. It was found that the percentage relative reduction varied across the harbour. For Lough Mahon, the Inner harbour, the East and West Passages as well as the area around Ringaskiddy the maximum concentrations with the treatment plant in place were less than 10% of the maximum concentrations with no treatment i.e. there was a 90% relative reduction in the maximum concentrations of *Norovirus* in this region.

For the rest of the harbour and the area outside Roches Point they were less than 20% i.e. there was an 80% relative reduction in the maximum concentrations of *Norovirus* in this area.

Time series of *Norovirus* concentration were also presented for 15 points of special interest. The improvement in water quality was observed from these graphs by plotting the time series for Case 2 and Case 3 together. The *Norovirus* plots for 2030 were not presented as they are simply equivalent to the plots for Case 3 multiplied by 1.431.

Regulatory requirements on concentrations of *Norovirus* are not included in any of the EU Directives on water quality.

7.4 Nitrogen Results

Nitrogen in different forms is an important nutrient in the coastal zone. Changes in the speciation and distribution of nitrogen can increase or decrease primary production by phytoplankton and macrophytes rooted to the bed of an estuary or harbour. We have chosen to examine the impact of the proposed scheme on such forcing by using a linear cascade model containing three species of nitrogen: organic nitrogen, ammonia and nitrate. The model quantifies the relative effect of the scheme on the concentration of these three species throughout the harbour and adjacent coast over a test period of ten days. The effect is with respect to an unaltered background concentration of each species of nitrogen.

The results reported were estimates of the change in forcing, expressed as changes in the concentrations of the three species of nitrogen, due to the proposed scheme. They are estimates of relative changes compared to the background concentrations of nitrogen. We have left the judgement of the wider consequences of these relative changes in nutrient forcing to the marine ecologists advising the project.

The time series presented in chapter 6 showed a marked reduction in concentrations of ammonia and nitrate in all of the fifteen points of special interest to the project compared to the unspecified background following the introduction of treatment. In other words the desired improvement has been demonstrated and quantified in the model under the specified conditions of tide, river flow and wind.

The spatially varying maps of concentration showed that the proposed scheme will reduce considerably the forcing on primary production in the inner harbour (Lough Mahon) and in the North Channel behind Great Island. There is also an improvement throughout the Outer Harbour with the possible exception of the immediate vicinity of the diffuser itself. The model does not resolve the near-field of the diffuser and results from our model very close to the diffuser may not be accurate.

7.5 Discussion of results inside and outside the mouth

A large area outside the mouth between Ballycotton and Oysterhaven gradually accumulates material discharged from the Outer Harbour on successive ebb tides. During all tides we have simulated, a large anticlockwise eddy forms immediately outside the mouth during the ebb. It is fed from the western side of the Outer Harbour. When the tide turns all the simulations show the tide running initially on the eastern side of the mouth and in many cases this feeds water of oceanic quality into the Outer Harbour improving its quality. This appears to be associated with a weak residual current along the coast to the southwest for the period we have chosen to simulate with the model (June 2004). Data from moored *in situ* devices would confirm this. This is extremely expensive and difficult to do. There are also several smaller eddies on the eastern side of the mouth during the flood tide as it enters the harbour.

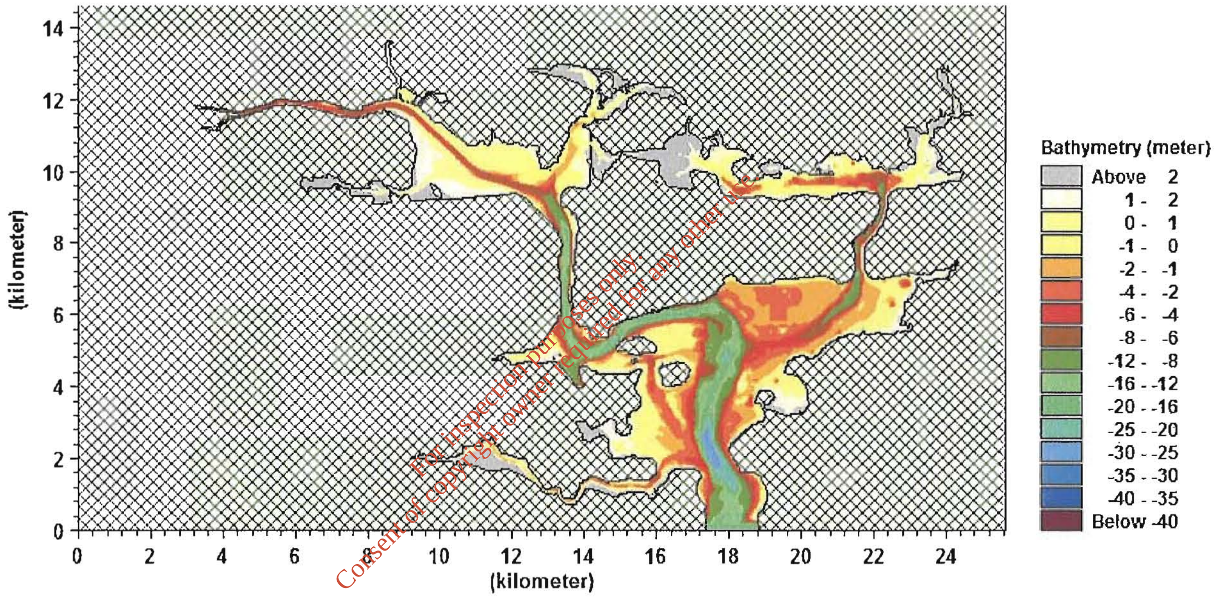
Consequently, we are unable to indicate with confidence and precision what effect the proposed scheme will have on the concentrations of coliforms and *Norovirus* in the coastal waters between Ballycotton and Oysterhaven. However the model shows a reduction in concentration.

Appendix A Calibration of the RP_2 model

The calibration and validation of the RP_2 model is described in this Appendix. The parameters from the calibrated RP_2 model (run with recorded data) have been exported and used in the OH_2 model (run with Proudman data).

A.1 Development of the RP_2 model

The Roches Point_2 (RP_2) model has two separate grids each of varying resolution (see below). The outer grid has a grid spacing of 30m and covers the outer harbour. The narrow Belvelly channel is resolved with a 10m resolution.

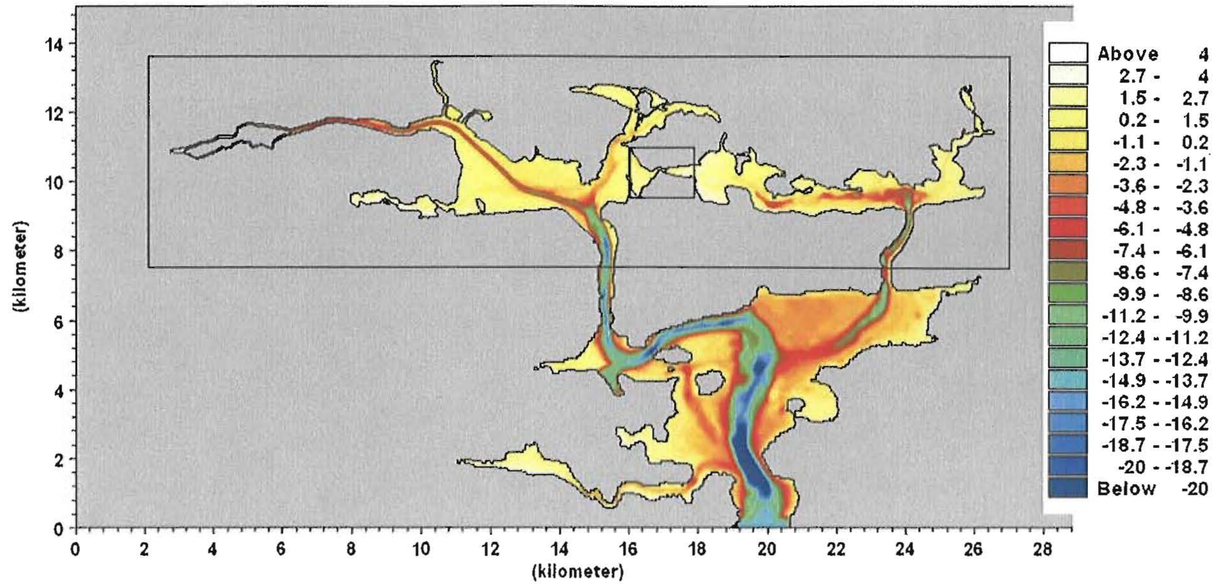


Layout of the RP_2 model. The resolution of the 2 nested grids are 30m and 10m

A.2 Calibration of the RP_2 model

Previous RP model

The calibration of the RP_2 model is based on the calibration of a similar model in the authors' previous work. This model, named the RP model, covers the same area as the RP_2 model but is resolved with 3 separate nested grids each with a different resolution (see next page).



RP model bathymetry plot from the previous study by the authors'. 3 nested grids of varying resolution (54m, 18m & 6m) are used in this model.

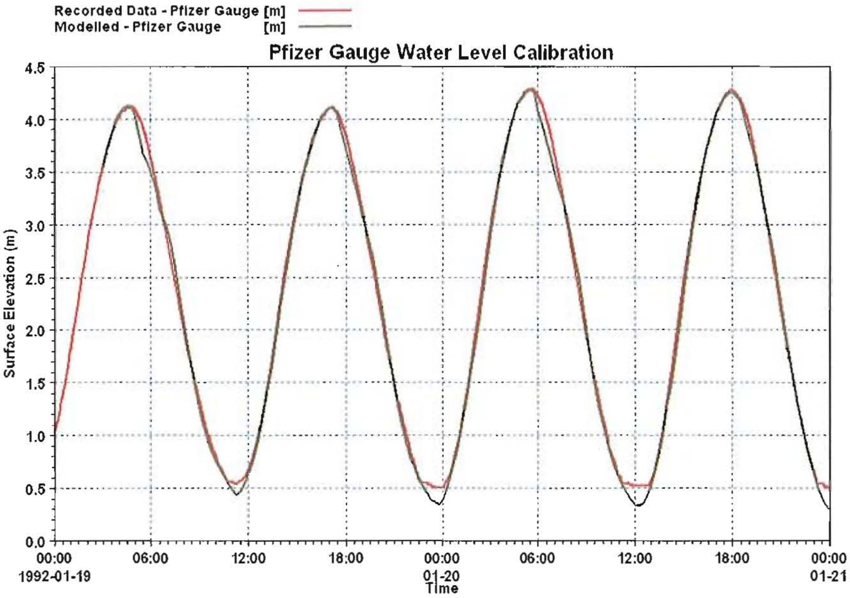
The calibration and validation of the RP_2 model is very similar to that of the RP model.

Calibration Period

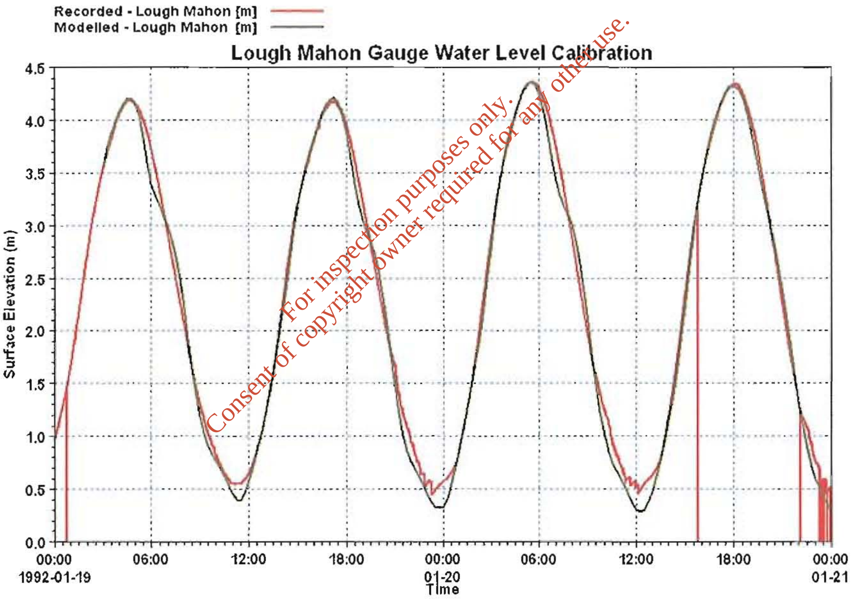
The model was calibrated and validated using the data from the 1992 survey by Irish Hydrodata. As discussed in chapter 2 six automatic water level recorders were deployed at sites in the Inner and Outer harbour on three separate occasions in December 1991 and January/February 1992, as well as two current speed and direction recorders. Data from the Fort Camden gauge was used to drive the hydrodynamics of the RP_2 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.

Water Level Calibration Plots

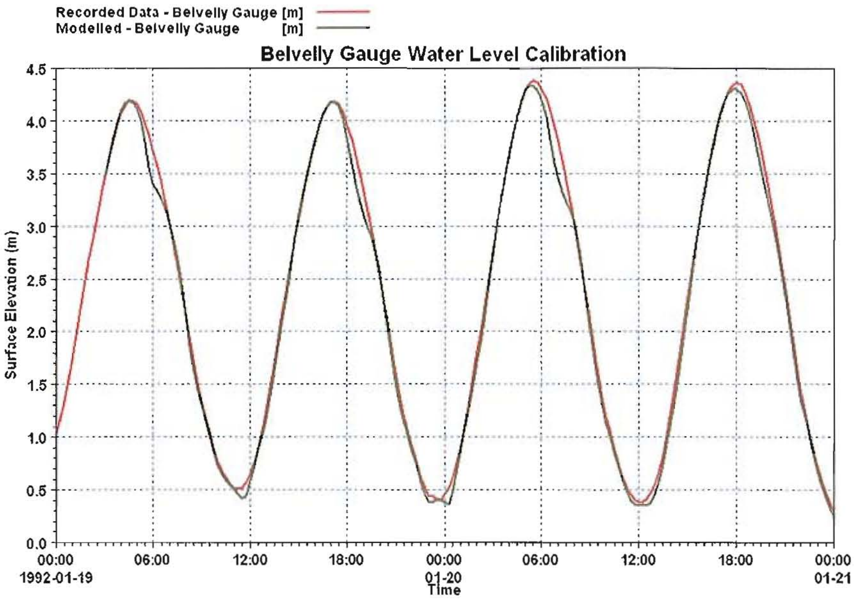
The water level calibration plots are shown below. The modelled data is plotted with a green line while the recorded is shown with a red line. We can see from the figures that there is a very good match between the recorded and modelled data for all three gauges.



Pfizer Gauge Calibration Plot



Lough Mahon Gauge Calibration Plot



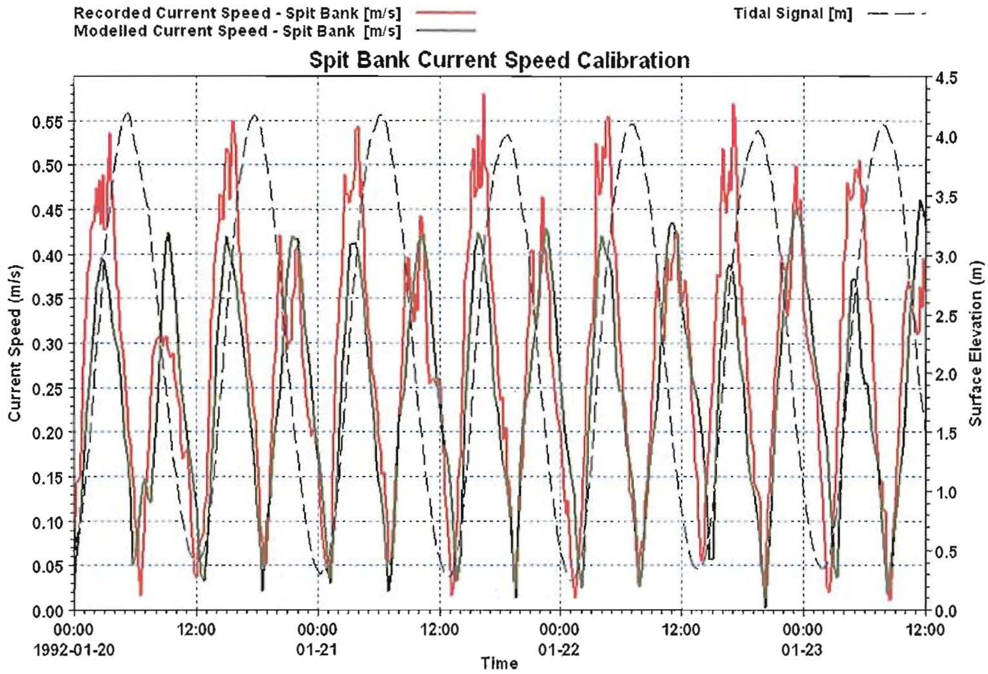
Belvelly Gauge Calibration Plot

From these figures we can conclude that the RP_2 model can reproduce the observed tides in Cork Harbour.

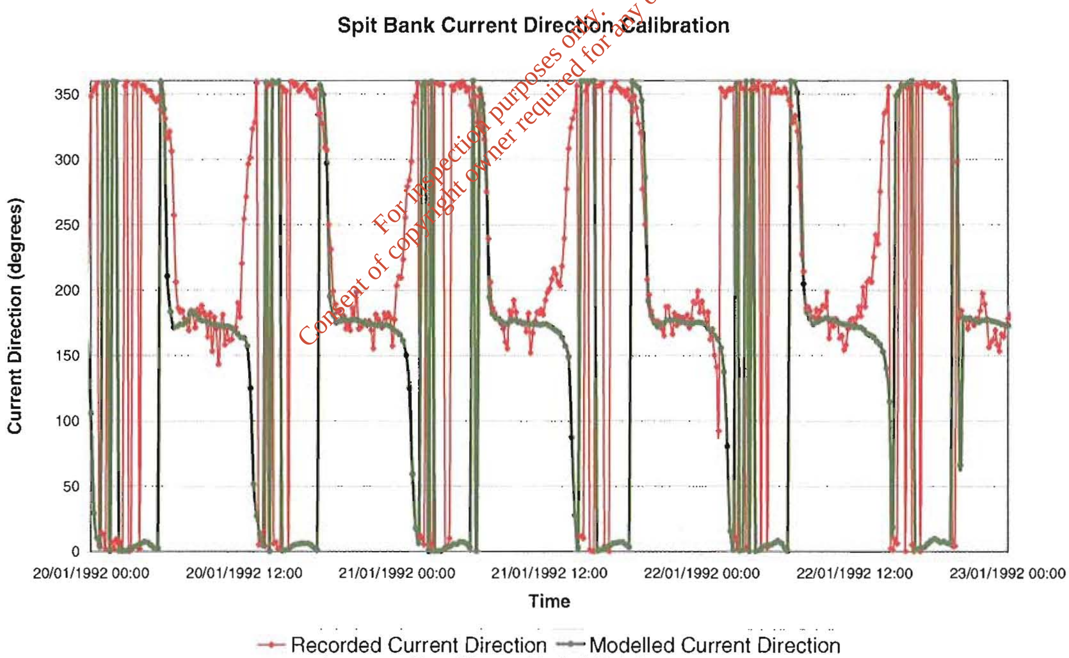
Current Speed and Direction Calibration Plots

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.

We can also see that there is a very good agreement between the measured and modelled current direction for this the Spit Bank as well.



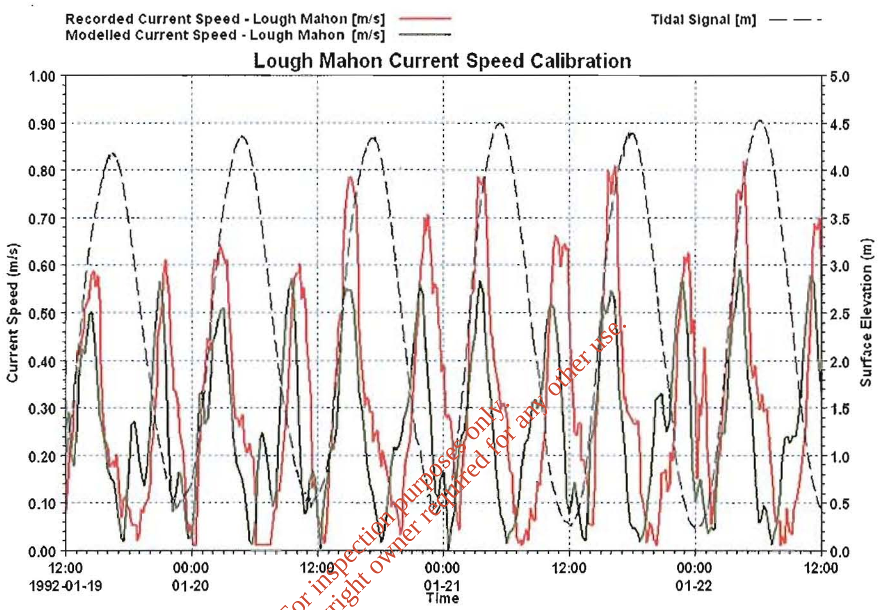
Spit Bank Current Speed Calibration



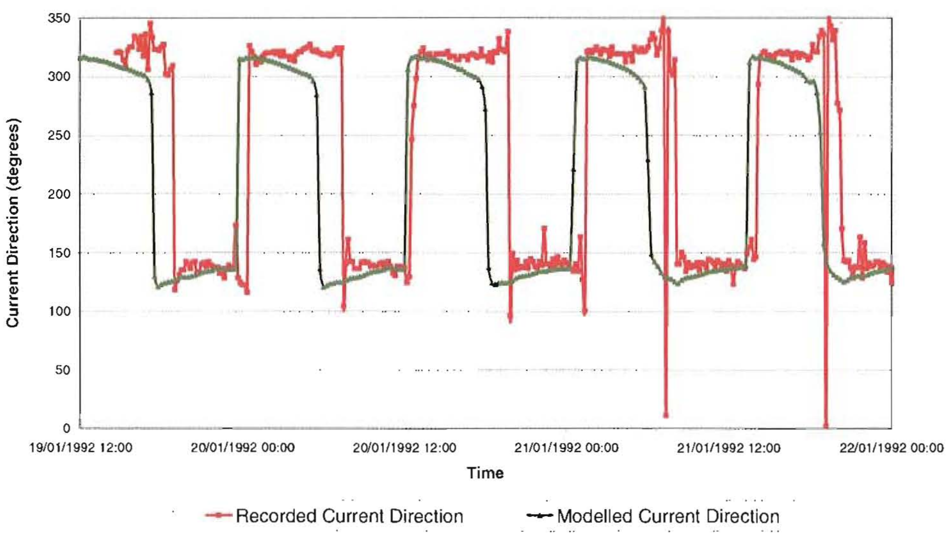
Spit Bank Current Direction Calibration

The current speed and direction calibration plots for the gauge in Lough Mahon are now presented. 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.

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 a 30m grid cell. The calibration is well within an acceptable limit of error.



Lough Mahon Current Speed Calibration



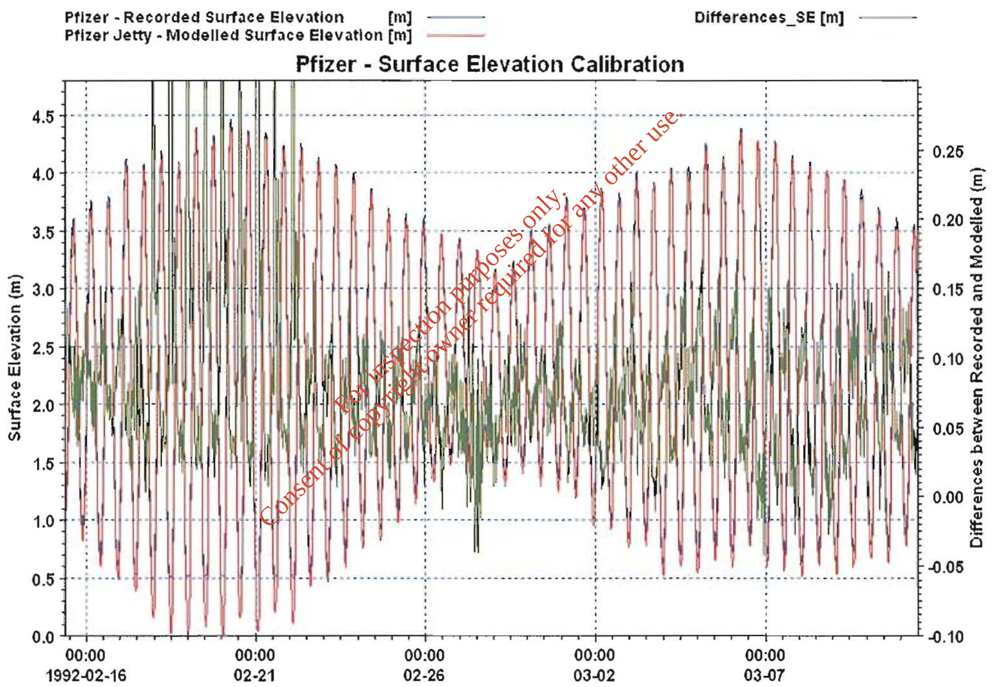
Lough Mahon Current Direction Calibration

A.3 Water Level Validation Plots

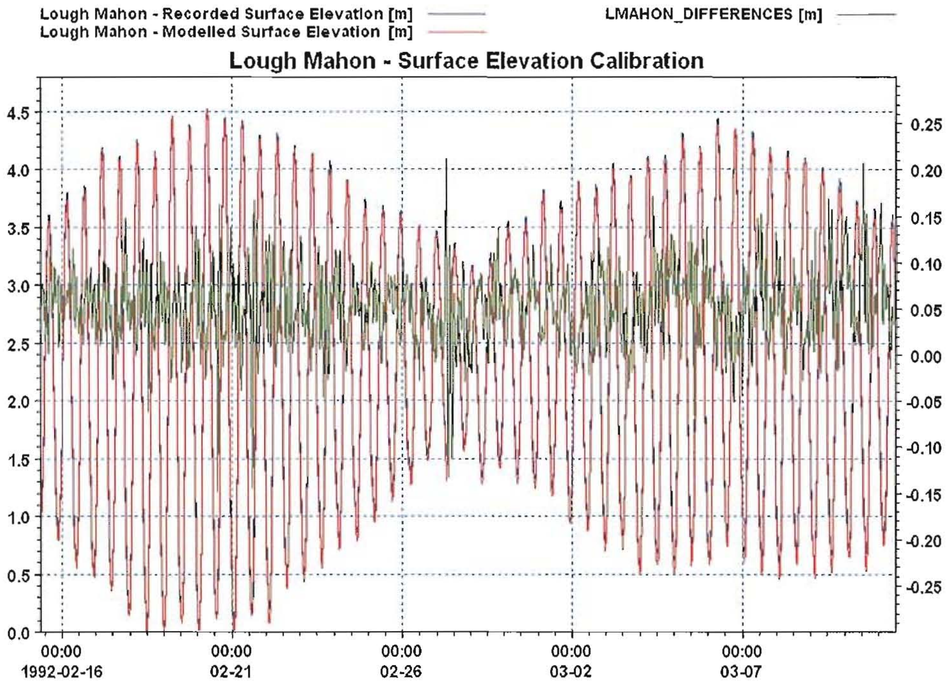
The water level validation plots are presented in this section. The recorded data is plotted with a blue line while the modelled data is shown with a red one. The difference between the modelled and the measured, the error, is plotted on the secondary axis on the left-hand-side with a green line. The scaling on this secondary axis varies slightly for each plot.

We can see from the figure below that there is a very close agreement for the Pfizer gauge. The error varies between 5 and 15cm.

The validation for the gauge in Lough Mahon is presented on the following page. Again we can see that the error is between 5 and 15 cm.

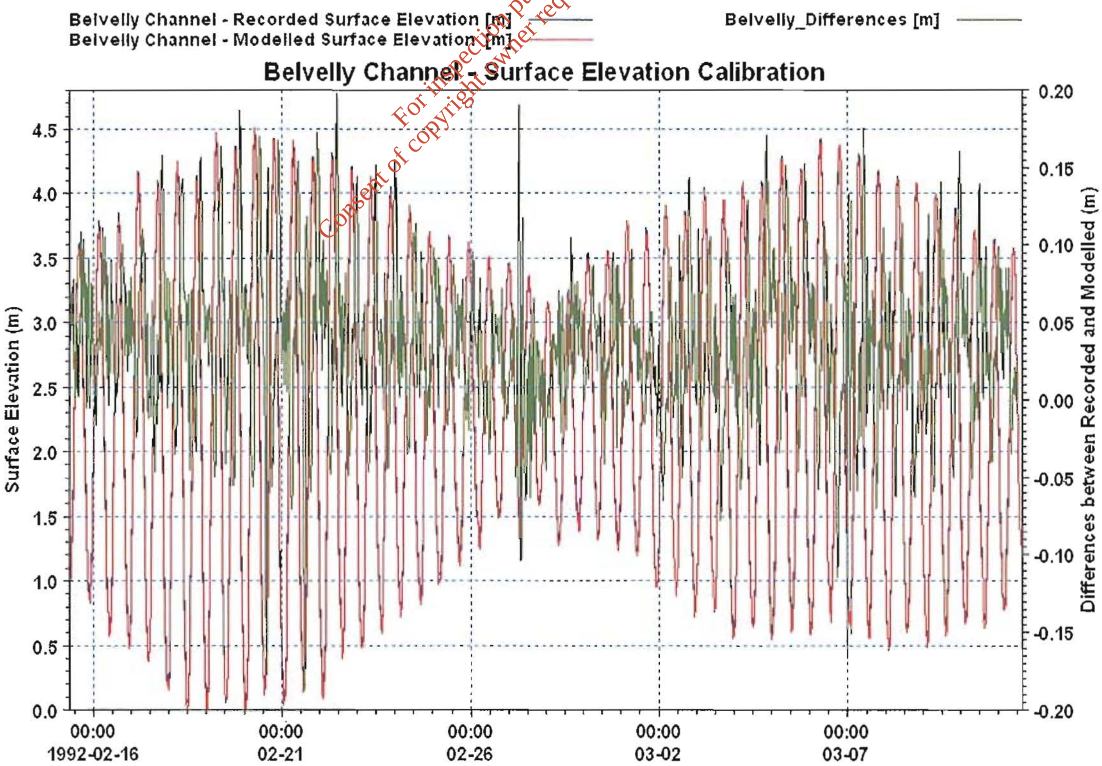


Pfizer Gauge Water Level Validation



Lough Mahon Gauge Validation

The validation for the Belvelly gauge is presented below. We can see that the error is between 5 and 18 cm.



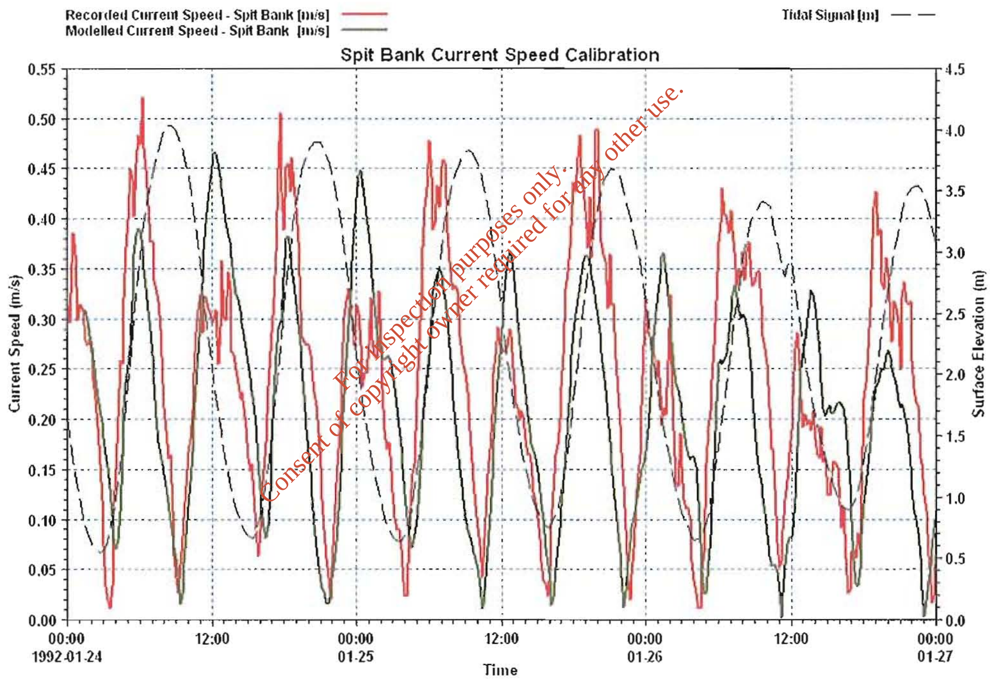
Belvelly Gauge Validation

A.4 Current Speed and Direction Validation

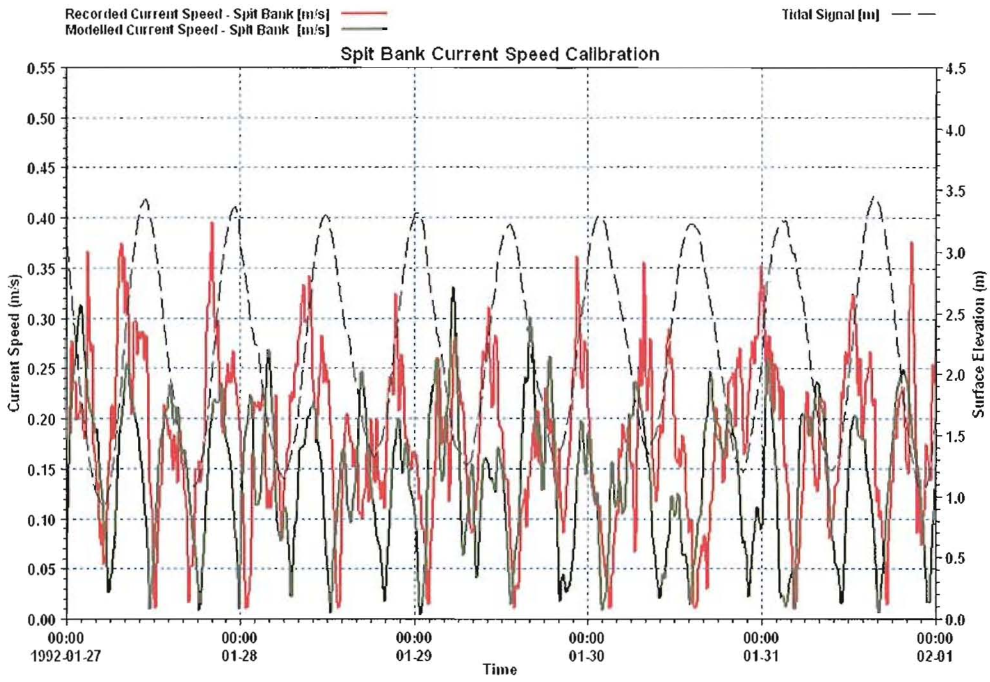
The current speed and direction validation for the Spit Bank are presented in the following 8 figures. The validation covers a 2-week period. We can see from the plots that overall a very good agreement between the datasets is achieved with the RP model. For the first 8 days, covering neap tide, the 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.

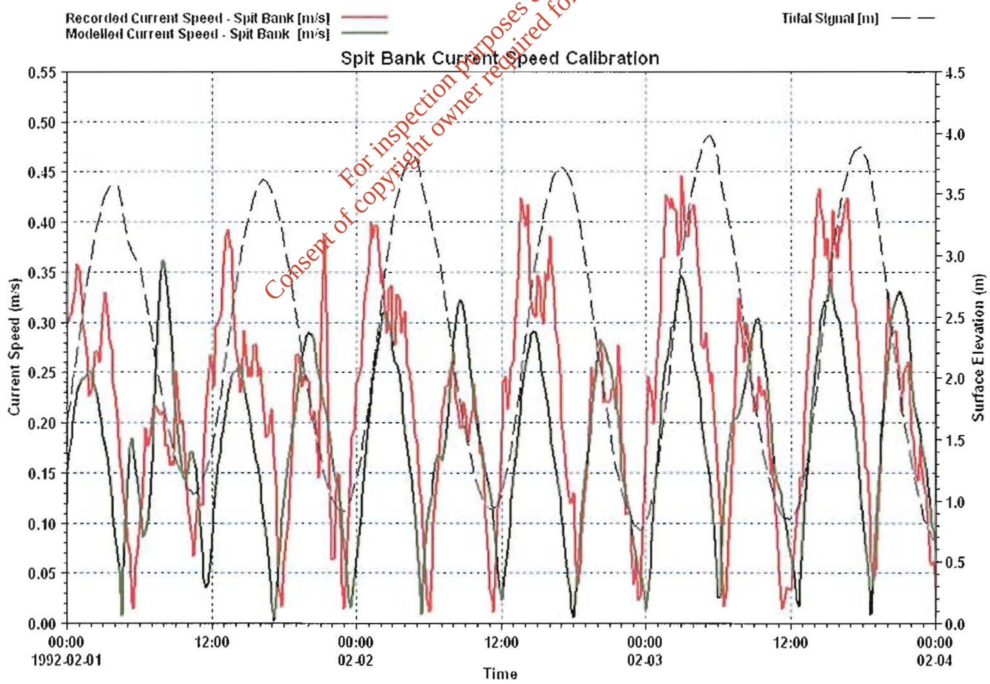
Spit Bank



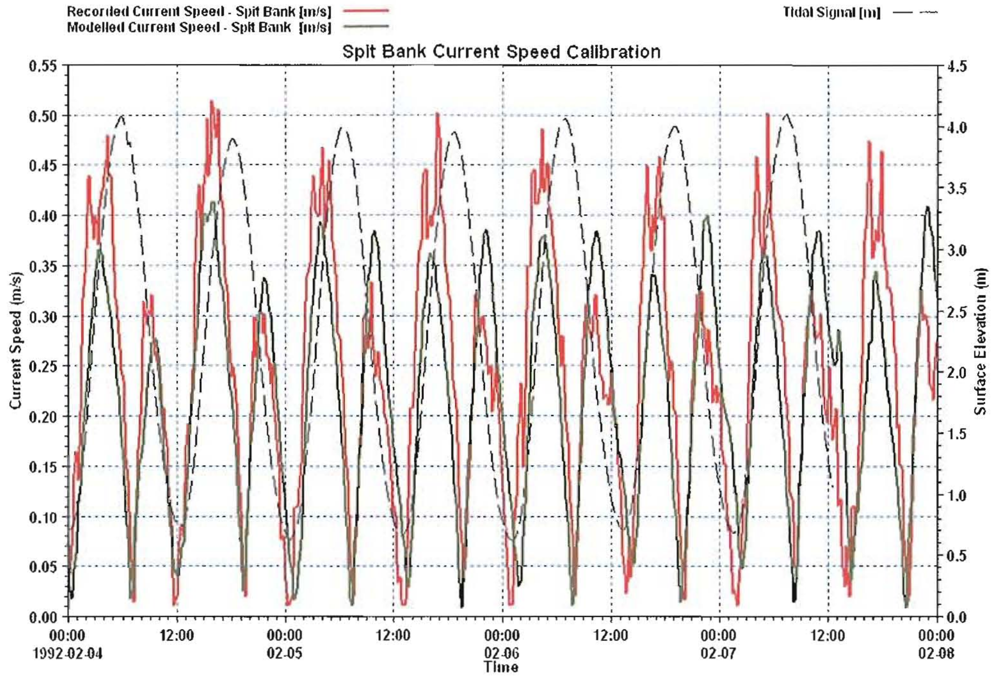
Spit Bank Current Speed Validation



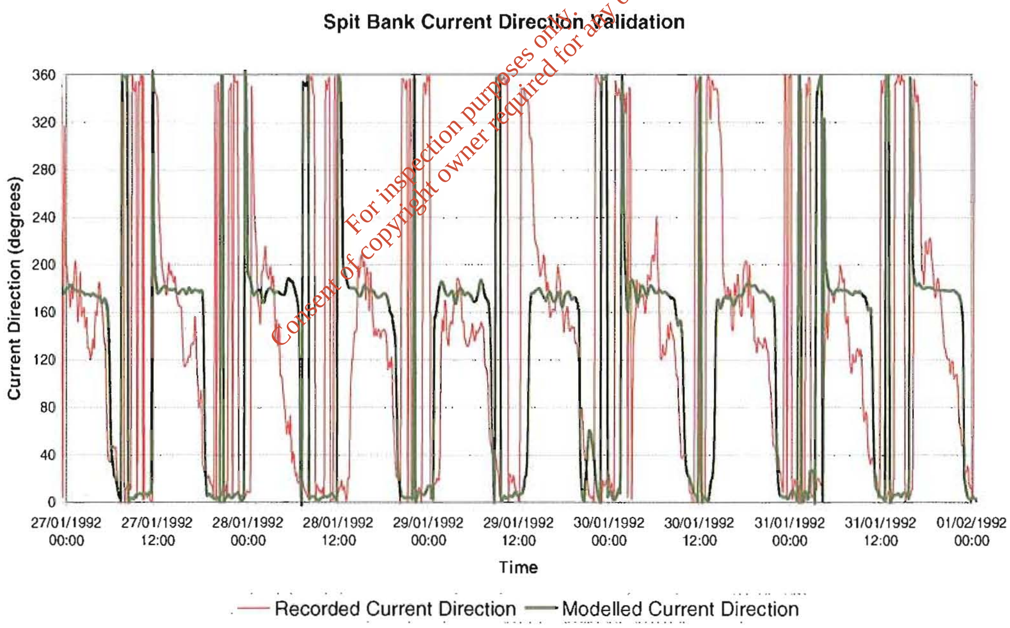
Spit Bank Current Speed Validation



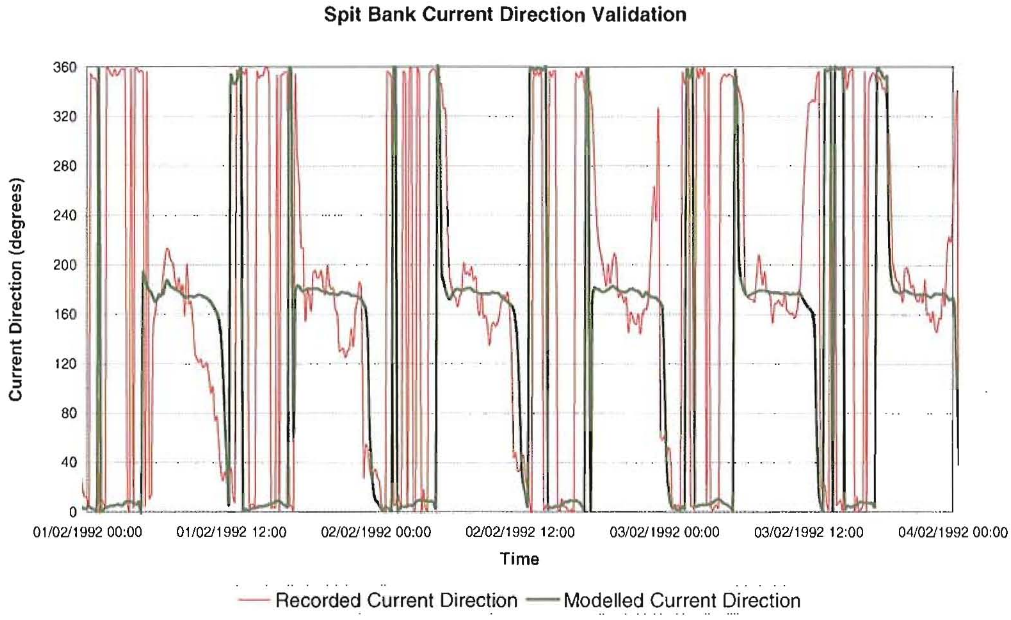
Spit Bank Current Speed Validation



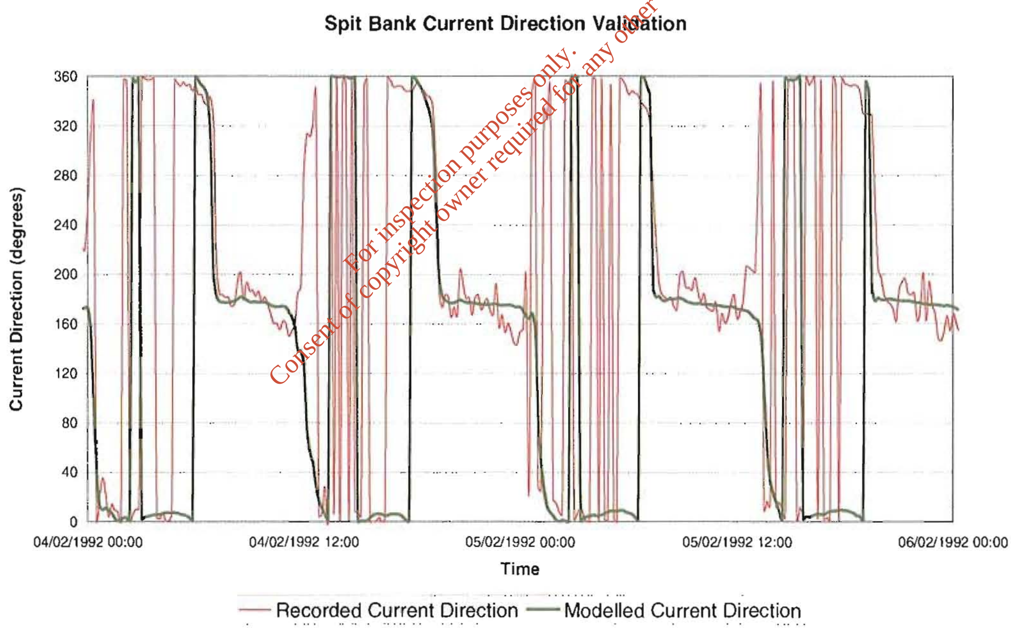
Spit Bank Current Speed Validation



Spit Bank Current Direction Calibration



Spit Bank Current Direction Calibration



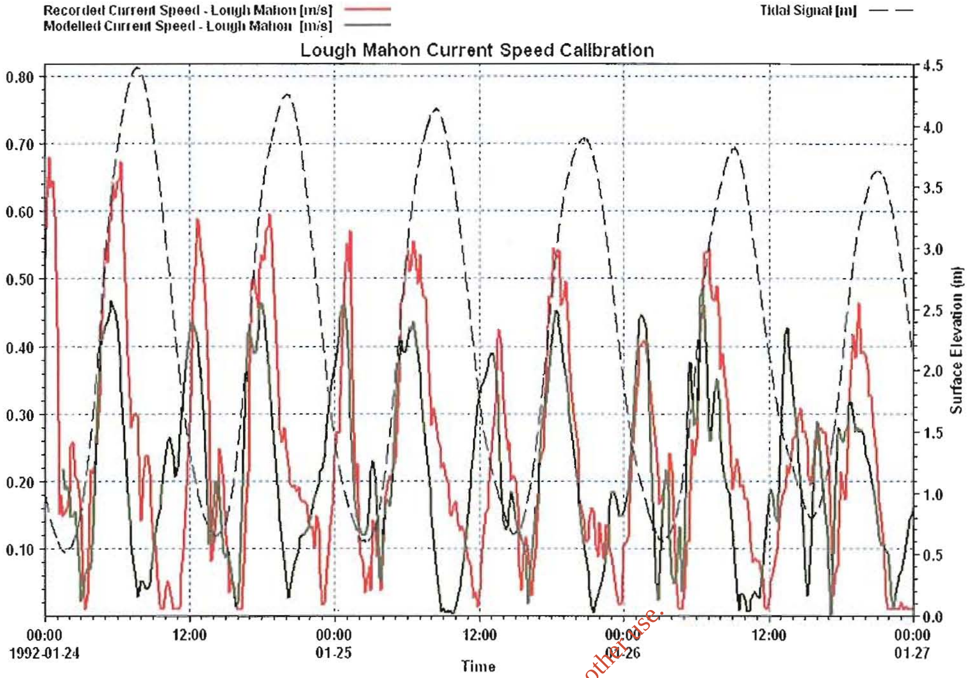
Spit Bank Current Direction Calibration

Lough Mahon Current Speed and Direction Validation

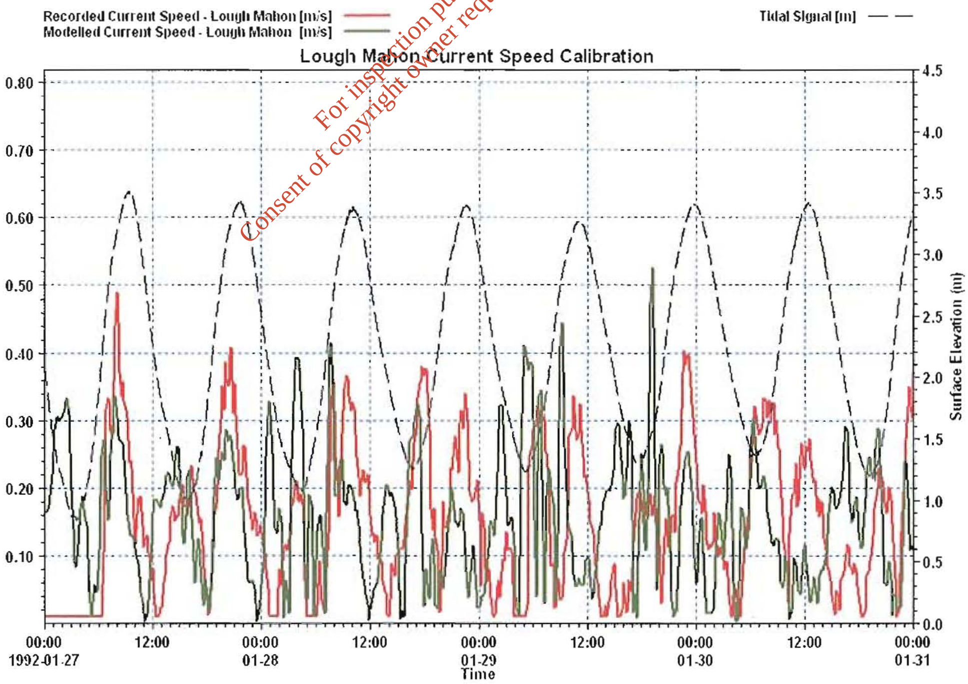
The current speed and direction validation for the Lough Mahon gauge are presented in the following 8 figures. The validation covers a 2-week period.

We can see that the difference between the modelled and measured current speeds is very good for some periods while less good for others

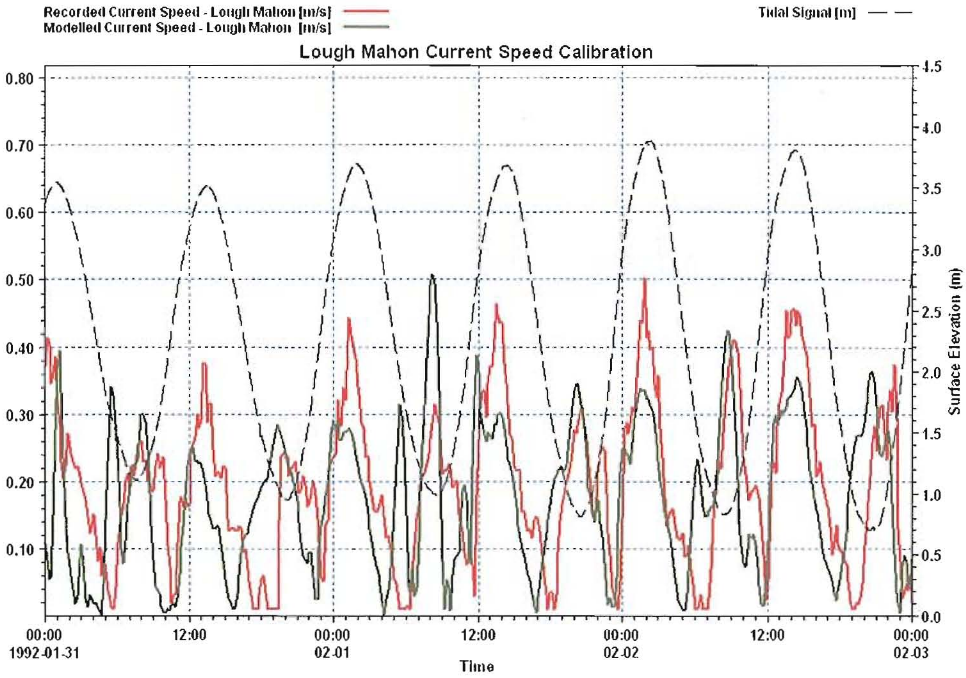
Overall however we can state that there is a very good agreement between the modelled and measured datasets for Lough Mahon.



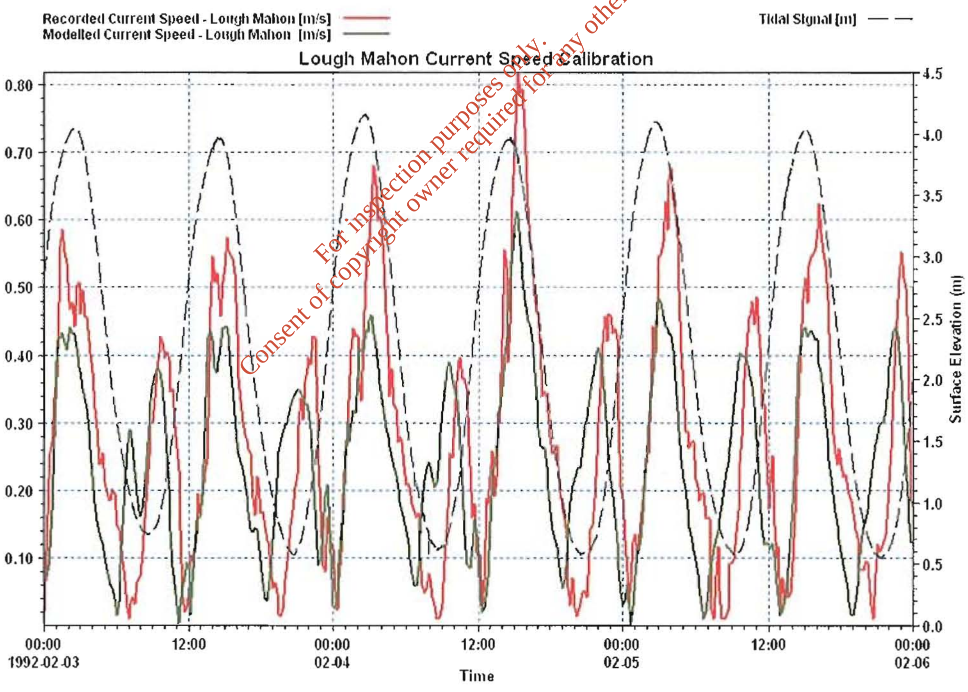
Lough Mahon Current Speed Validation



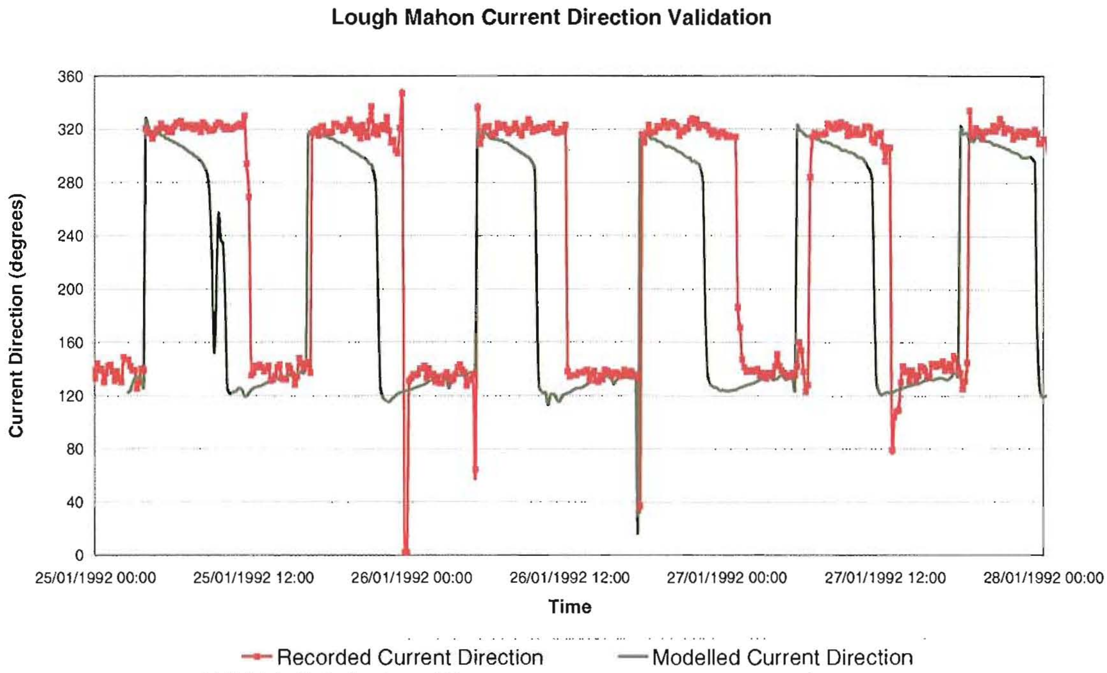
Lough Mahon Current Speed Validation



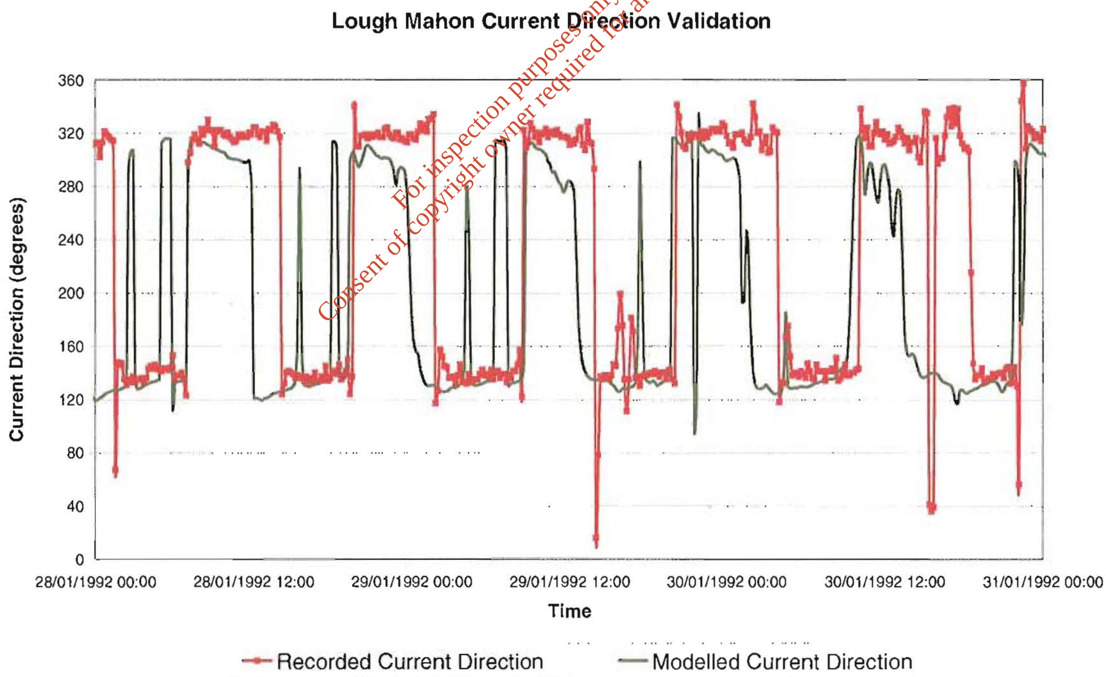
Lough Mahon Current Speed Validation



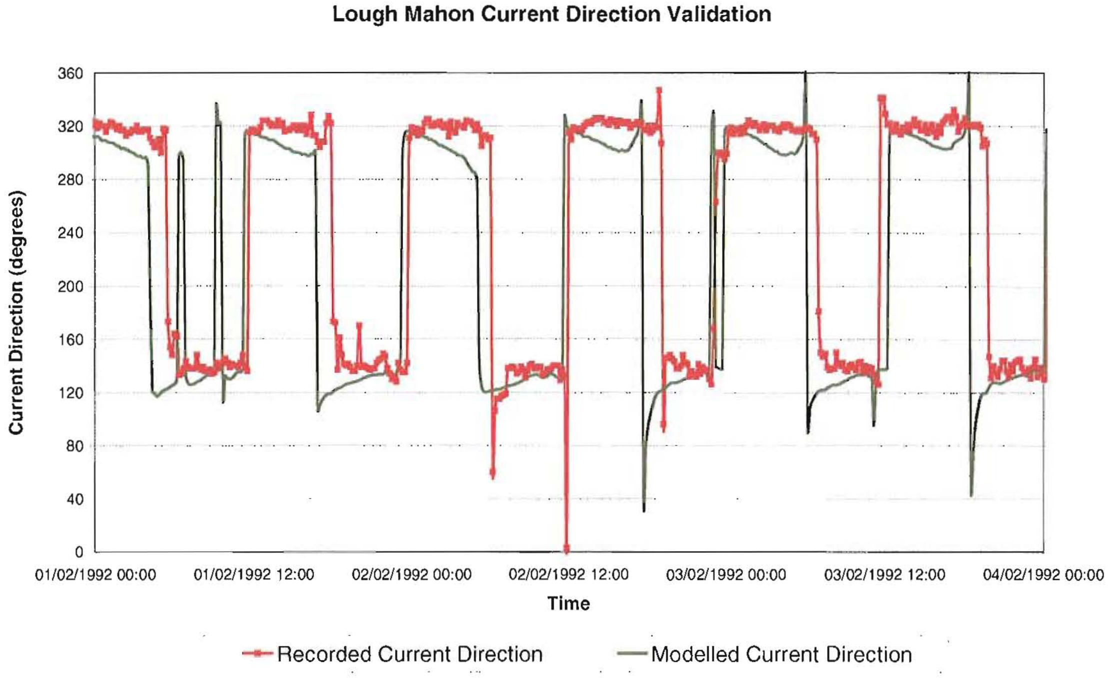
Lough Mahon Current Speed Validation



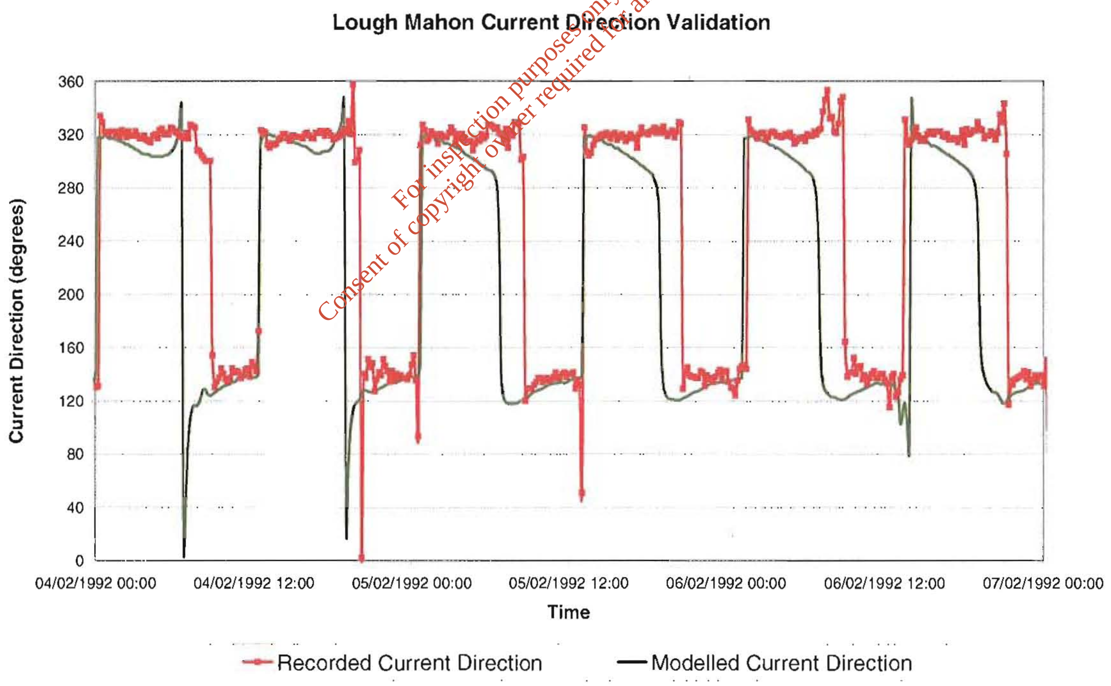
Lough Mahon Current Direction Validation



Lough Mahon Current Direction Validation



Lough Mahon Current Direction Validation



Lough Mahon Current Direction Validation

A.5 Conclusions

The RP_2 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.