KEEPING BRITAIN TRADING

IMMINGHAM EASTERN RO-RO TERMINAL

Summary of Simulated Flow Conditions

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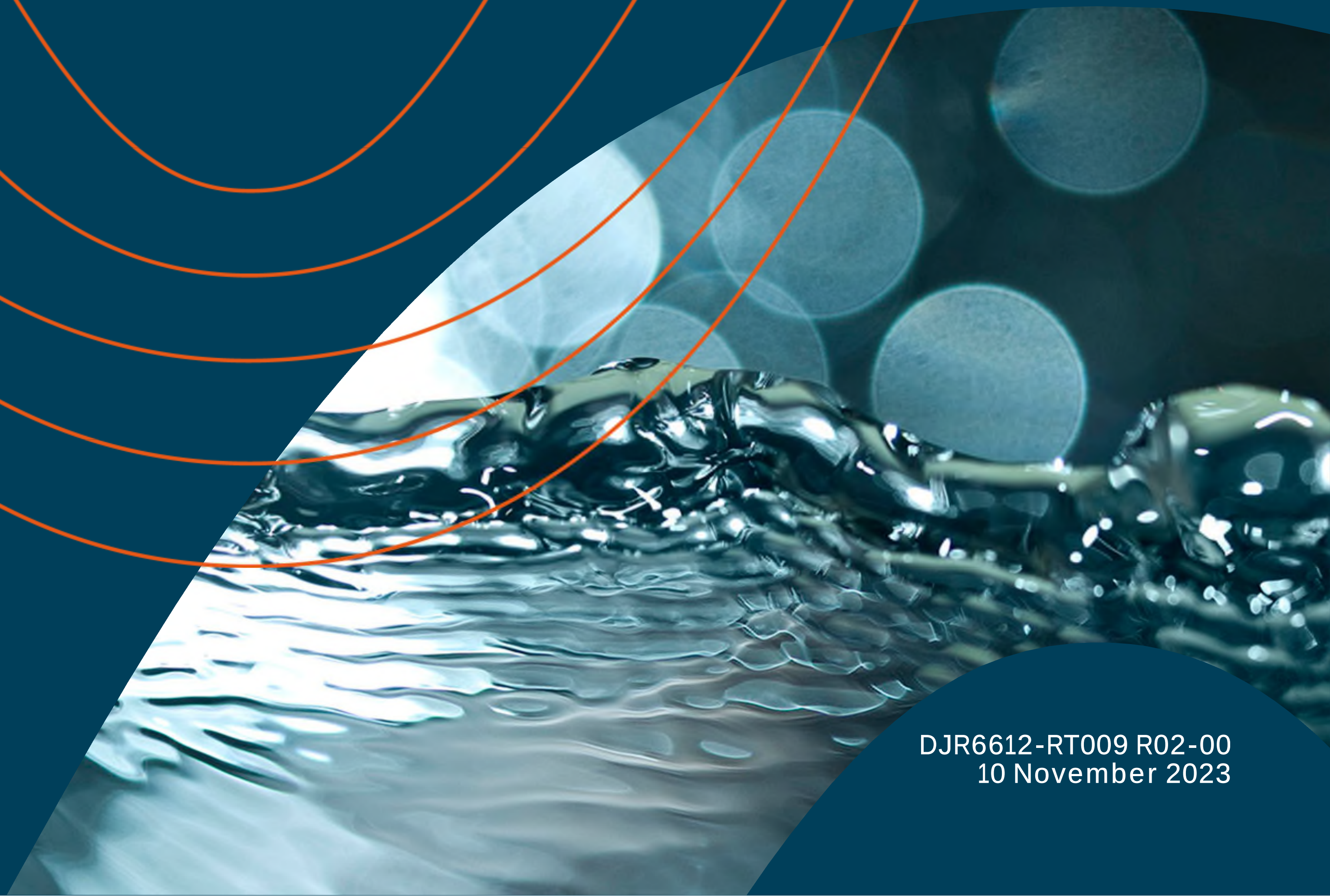
hr wallingford

Immingham East RoRo Terminal

Summary of simulated flow conditions



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1 Introduction

Associated British Ports (ABP) Humber are considering the development of additional RoRo berth capacity to the east of the Immingham dock, which will be known as the Immingham East RoRo Terminal (IERRT).

HR Wallingford have undertaken a series of studies for the project, including real time ship navigation simulation assessments of the feasibility of the design for the IERRT.

The purpose of this document is to summarise the various modelling tasks which have been undertaken by HR Wallingford to consider the flow conditions on the tidal River Humber in support of the navigation assessments. Specifically, HR Wallingford have been asked to comment on the area for which they have high confidence in the flow modelling work.

Observers may often have a simplified view of the flows at Immingham, however, historical evidence, recent data collection and computational flow modelling show that there is significant variation in flow speed and, notably, direction, associated with the tidal cycle. Fully understanding this variation is further complicated by the effects of the infrastructure in the river, fresh water flows and ongoing dredging works.

There has been considerable effort made to understand and model the flows at IERRT to ensure the design is safe and appropriate from a navigation perspective. This document summarises that effort and describes the level of confidence in the computational flow modelling.

2 Flow conditions

2.1 Flow data collection, modelling and analysis

HR Wallingford have undertaken 2 significant pieces of work to understand and verify the flows in the vicinity of IERRT:

- In Spring 2022 HR Wallingford undertook a detailed statistical analysis considering the nature and directions of flows in the vicinity of IERRT (Reference 1). This work was based on 6 months of fixed AWAC flow observations between Nov 2019 and Jun 2020, provided by ABPmer (Reference 4).
- In the autumn of 2022 HR Wallingford undertook an independent comparison of additional flow data collected by ABPmer, using a vessel mounted ADCP sensor in the vicinity of Immingham Harbour in Autumn 2022 (Reference 3), and the original data from the fixed AWAC buoy. The data was also used to verify HR Wallingford's TELEMAC-3D flow model (Reference 2).

References 1 to 4 should be consulted to obtain a full understanding of the detailed work which supports this summary document.

2.2 Flows in the vicinity of IOT and IERRT

Observers have suggested that the currents in the vicinity of the IOT flow in a single, particularly consistent direction. However, the flows at Immingham East Outer Harbour are highly complex, as shown in the AWAC data collected over 6 months between Nov 2019 to Jun 2020.

This complexity is similarly reflected in the TELEMAC-3D flow model produced by HR Wallingford and the guidance provided to Pilots and PECs in the Port of Humber Passage Plan (see Reference 5).

The flows have a significant variation in direction across the tidal cycle and they are not rectilinear on the ebb and the flood tides. As such, they cannot readily be analysed by casual observation and anecdotal evidence of the flows needs to be carefully considered.

The complexity of the flows can be seen in Figure 2.1, which shows the variation in flow direction and speed based on the 6 month AWAC flow observations (Reference 3). The data was collected at a single point between IOT and Immingham Eastern Jetty, a shown in Figure 2.2.

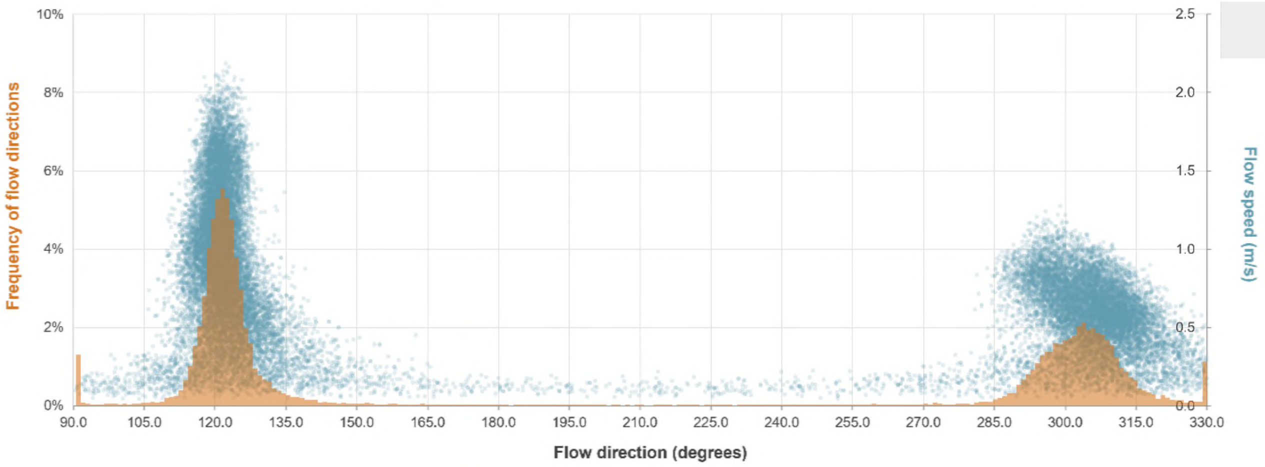


Figure 2.1: Comparison of frequency of depth averaged flow direction with flow speed

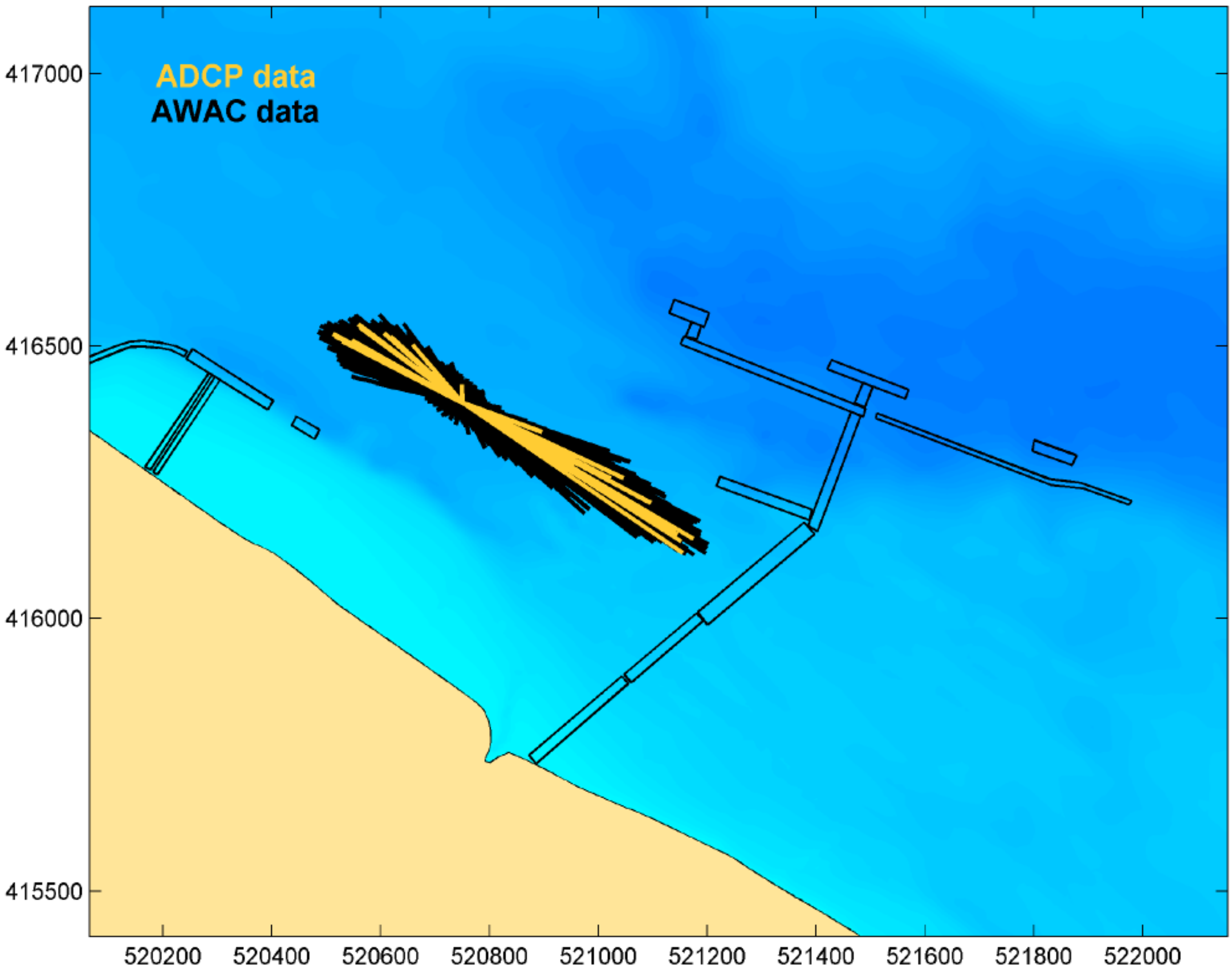


Figure 2.2: Comparison of envelope of observed currents for AWAC dataset and ADCP point

The nature of the flows is described in detail in Reference 1 and the key observations are:

- The mean flow direction varies depending on the tidal range;
- The nature of the flows is significantly different during neap tides compared to flood tides;
- Larger flow speeds occur during the ebb tide;
- Neap flows are less strong, but also less well aligned to the natural direction of the river;
- Stronger spring flows are better aligned with the river;
- The flow directions are not rectilinear, comparing the ebb and the flood, so the mean directions do not differ by exactly 180˚;
- The strongest flood tide flow speeds are not aligned with the mean direction.

For these reasons HR Wallingford developed and recommended a quasi-stationary analysis of the current forces likely to be experienced by vessels at the IERRT berths, based on different proposed berth orientations.

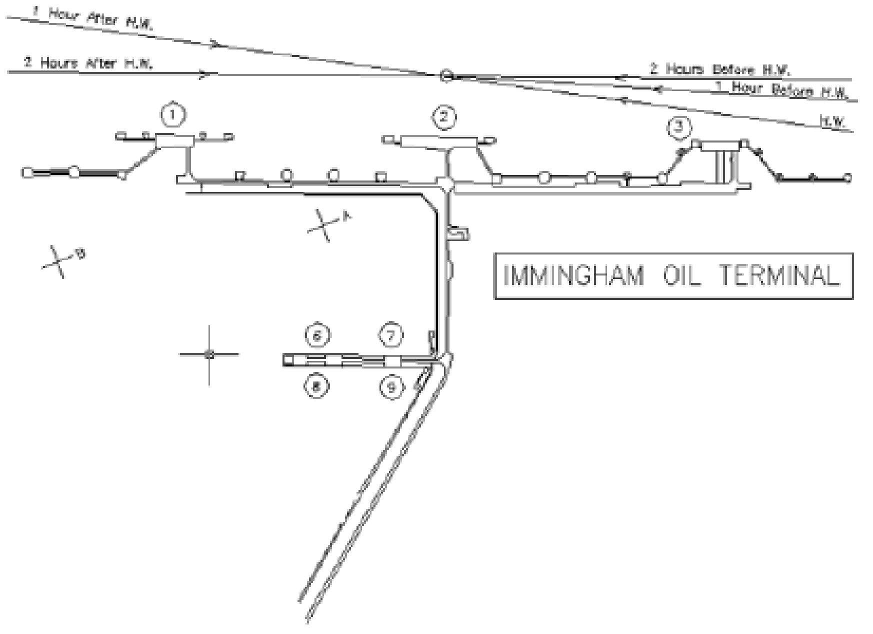
This analysis concluded that orientating the IERRT berths at 300°T/120°T (the directions of the greatest flow speeds) would create the optimum situation where, on average, the vessels approaching the berths would experience the minimum effect based on flows.

This does not mean that cross flows will not be experienced at IERRT, but, on average, the effect will be minimised. In particular it means that the berths are aligned to the strongest and most challenging flows, not necessarily the most frequent, where the effect may be less strong.

The complexity of the flows in the vicinity of IERRT are also described in detail in the Humber Port Passage Plan. The extract in Figure 2.3 shows page 33 and the predicted flow directions around high water inside of the main IOT terminal and towards the river. Although the data is from 1964, and anecdotally the flows have changed direction since then due to dredging, the data indicates that there has always been significant complexity in the directionality of flows in the vicinity of IOT.

Another way of considering the complexity of flows in the vicinity of the IERRT berths is to examine the vector plot in Figure 2.2. The centre of the yellow and black lines on the plot indicates the location of the AWAC buoy deployed between Nov 2019 and Jun 2020. The black vectors show the direction of all flow records, with their length relative to strength. The yellow vectors show flow data collected at the same position using vessel mounted ADCP in the autumn of 2022.

The figure clearly shows a significant variation in flow directions and strengths. In a single image it can also be seen that the verification flow data, shown in yellow, that was collected in autumn 2022, is contained within the envelope of the ADCP data set, and shows a similar variation, albeit for a much smaller sample.



TIDAL STREAM OBSERVATIONS TAKEN 5th NOV., 1964. POSITION 'A' BEARING 091° DISTANT 1375M TOWER 'A' IMMINGHAM DOCK

	Hours (GMT)	Direction	Rate knots	Spring Rate knots	Neap Rate knots
Before HW Immingham	6	104°	2.32	2.36	1.20
	5	106°	0.61	0.63	0.32
	4	283°	1.66	1.71	0.86
	3	294°	1.56	1.60	0.81
	2	299°	1.63	1.66	0.85
	1	304°	1.42	1.45	0.74
	HW	**312°**	**0.94**	**0.96**	**0.49**
After HW Immingham	1	130°	0.95	0.97	0.49
	2	114°	2.58	2.63	1.39
	3	114°	3.69	3.76	1.92
	4	112°	3.76	3.84	1.96
	5	110°	3.53	3.60	1.84
	6	105°	2.63	2.69	1.36

TIDAL STREAM OBSERVATIONS TAKEN 5th NOV., 1964. POSITION 'B' BEARING 089° DISTANT 1057M TOWER 'A' IMMINGHAM DOCK

	Hours (GMT)	Direction	Rate knots	Spring Rate knots	Neap Rate knots
Before HW Immingham	6	118°	1.95	2.00	1.02
	5	115°	0.30	0.37	0.16
	4	278°	1.89	1.94	0.98
	3	290°	1.72	1.77	0.89
	2	292°	1.84	1.89	0.96
	1	296°	1.46	1.50	0.76
	HW	**309°**	**0.72**	**0.74**	**0.37**
After HW Immingham	1	126°	1.81	1.21	0.61
	2	115°	2.69	2.76	1.40
	3	114°	3.84	3.95	2.00
	4	113°	3.54	3.64	1.84
	5	114°	3.25	3.34	1.69
	6	112°	2.42	2.49	1.26

Figure 2.3: Extract from Humber Passage Plan 2021 showing flow information at IOT

Source: Humber Estuary Services

2.3 Flow data comparison

HR Wallingford directly compared the flows recorded using the ADCP in autumn 2022 with flows for a comparable tidal range collected over a year earlier by the AWAC buoy. The details for the data collection are in References 3 and 4, and the comparison is fully described in Reference 2.

Figure 2.4 shows a comparison of the observed current speed between the AWAC and ADCP surveys and Figure 2.5 shows a comparison of observed flow directions.

These two figures show that the current speeds are close for the two surveyed periods. The current directions are also almost identical during the ebb tide when currents are highest. During the flood tide the two datasets compare well at the time of peak flood currents. Later in the flood tide, from about 5 hours after low water, the observed directions, as the tide strength reduces, vary slightly, with the ADCP data turning towards 310-320˚N whereas the AWAC remains at approximately 305˚N. This variation is during the period of slack water, when the flow strength is least and has the greatest variation due to other factors, such as changes to the longitudinal density gradient associated with seasonal changes to fresh water flow, which would be expected to be at their greatest.

The figures also show a high level of correlation between collected data for similar tidal ranges on separate occasions using independent means of survey.

From this comparison HR Wallingford concluded that the flow phenomena shown in the long term current measurements are representative of the conditions in the area.

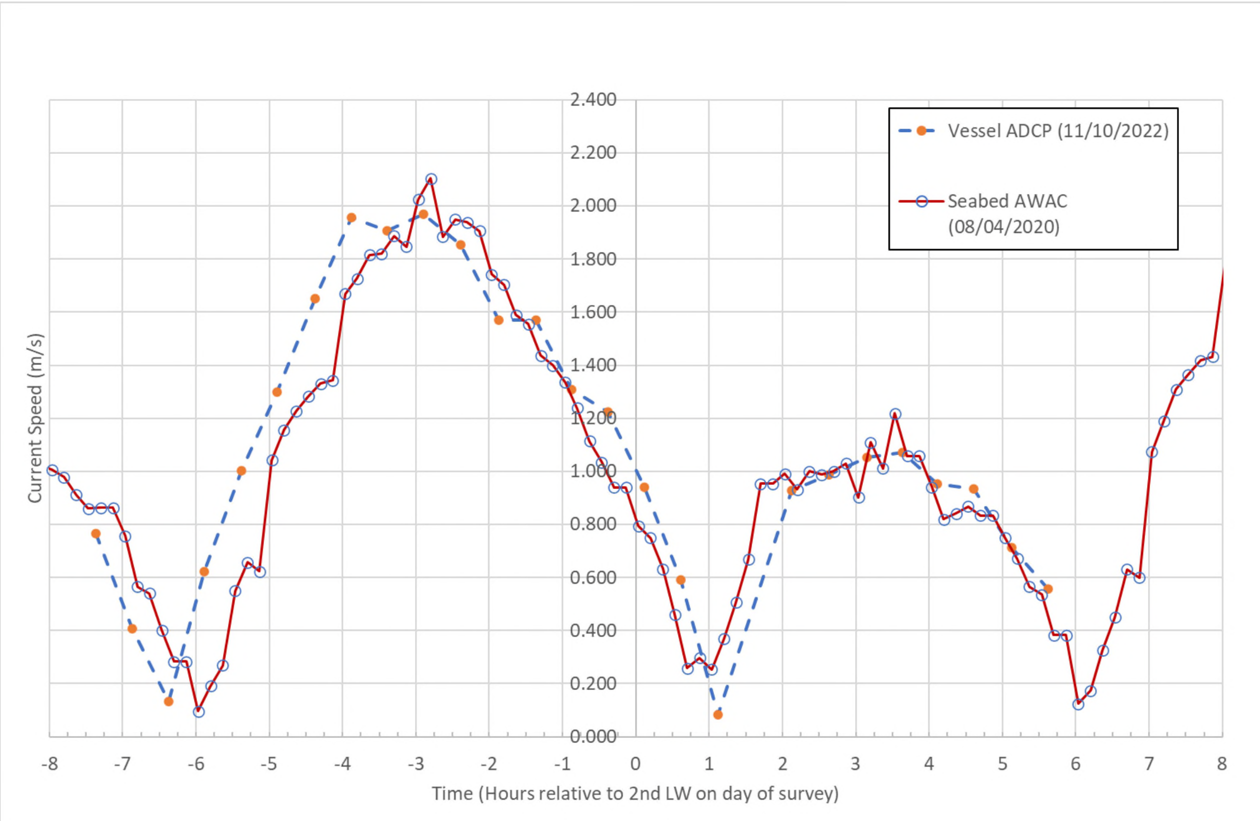


Figure 2.4: Comparison of observed current speed from AWAC 08/04/22 and ADCP 11/10/22

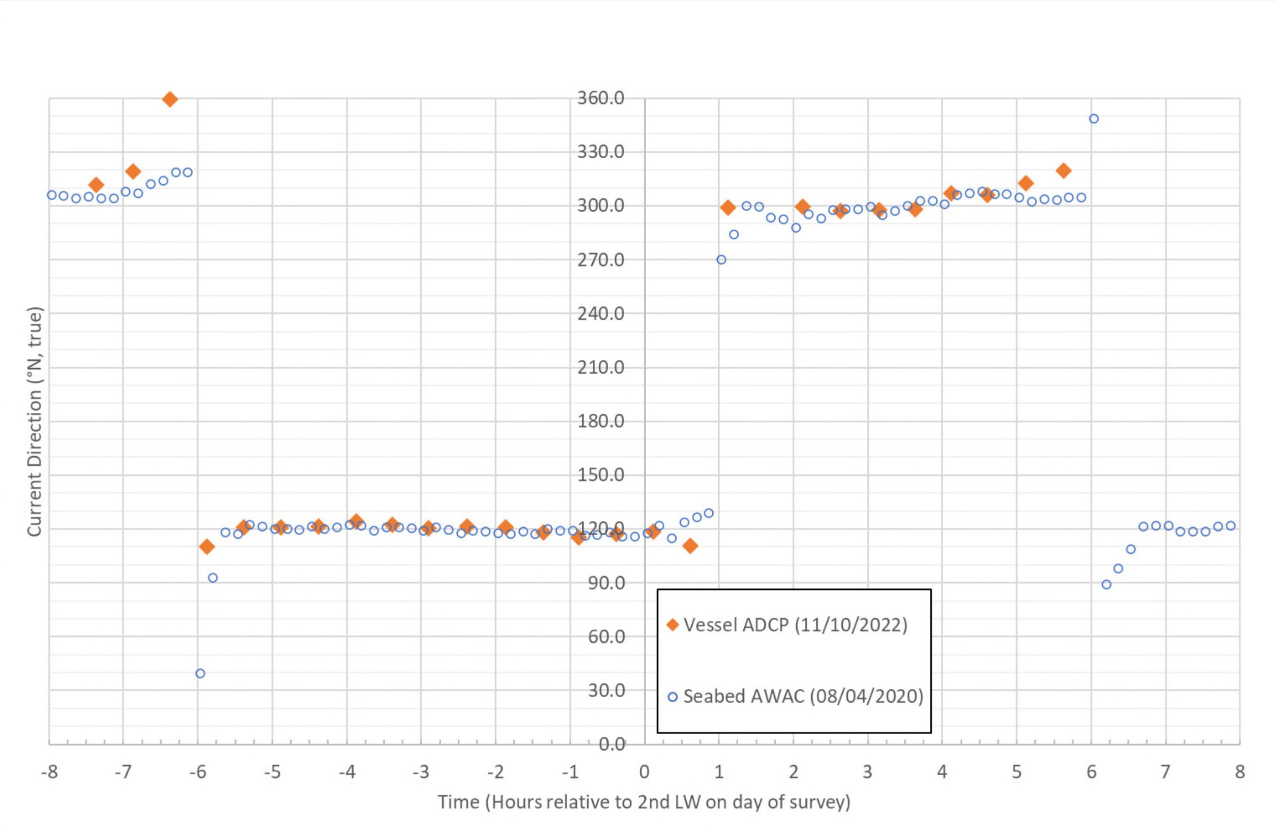


Figure 2.5: Comparison of observed current direction from AWAC 25/11/20 and ADCP 11/10/22

3 Flow model confidence

3.1 Validation against AWAC data

To understand the flows and provide data for the navigation simulation work, HR Wallingford produced a TELEMAC-3D flow model to represent the variation in current speed and direction throughout the water column. The measured data was used to validate this model.

In the case of the AWAC data, the current directions in the upper water column varied when compared to the through-depth average. This effect was considered to be associated with a longitudinal salinity gradient, which was also included in the 3D flow model.

The model was validated by comparison with the data from the AWAC buoy, which represented tides close to mean spring range. The key to aligning the model currents with the data was the addition of the longitudinal salinity gradient, which, in simple terms, represented the effect of fresh water in the river.

The key factor identified during the navigation simulation work, was the ability of the model to accurately represent the temporal variation in the directionality of the flows and where the model was adjusted was the focus of that effort.

A comparison of the modelled current speed and direction with those observed from the AWAC data is shown in Figure 3.1. It can be seen that the modelled flow directions correlate closely with the observed flow directions.

It was recognised that the model underpredicted the largest flow rates observed on the ebb tide, so, taking that into account, the flow speeds were manually scaled by between 15 and 20% during the simulation work. In each case the relevant Simulation Team were informed of this modification and this was also included in the study reports.

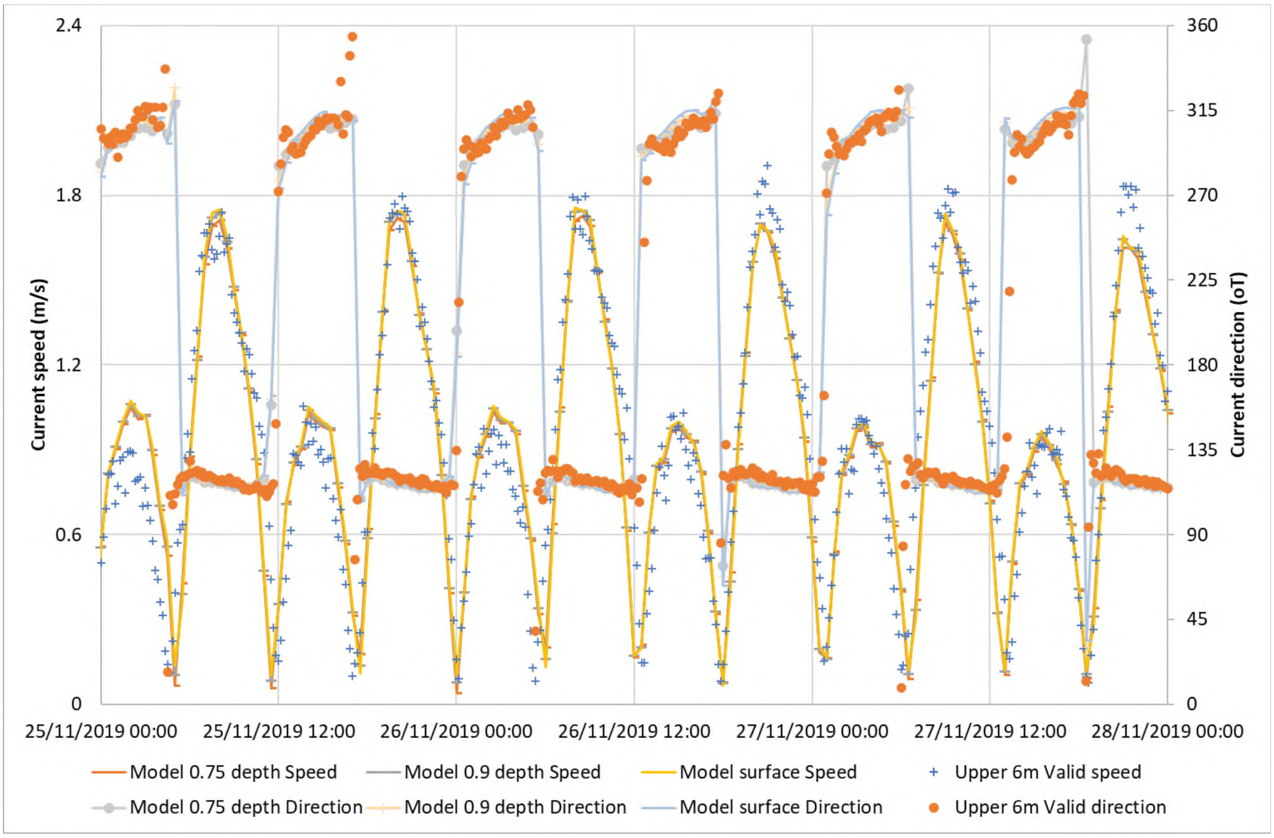


Figure 3.1: Comparison of model with data from AWAC 25-27 November 2019

Overall it was considered that the key phenomena shown by the AWAC data were well represented by the model, particularly with regard to the dominance of ebb tide currents and the variation in flood tide currents between 295˚N in on early flood to 315°N, as the tide level approaches high water. During the ebb tide the current directions in both the model and the observations were more consistent, being towards around 120˚N.

3.2 Verification against ADCP data

As previously mentioned, additional flow measurements were made in the autumn of 2022 (Reference 4).

As well as collecting flow data at the location of the original AWAC buoy deployment, ABPmer also collected flow information across the approaches to Immingham lock and in the vicinity of IERRT. Data at 20 locations from the ADCP transects were extracted to provide timeseries data for comparison with the model. The transects and data extraction locations used for data analysis are shown in Figure 3.2.

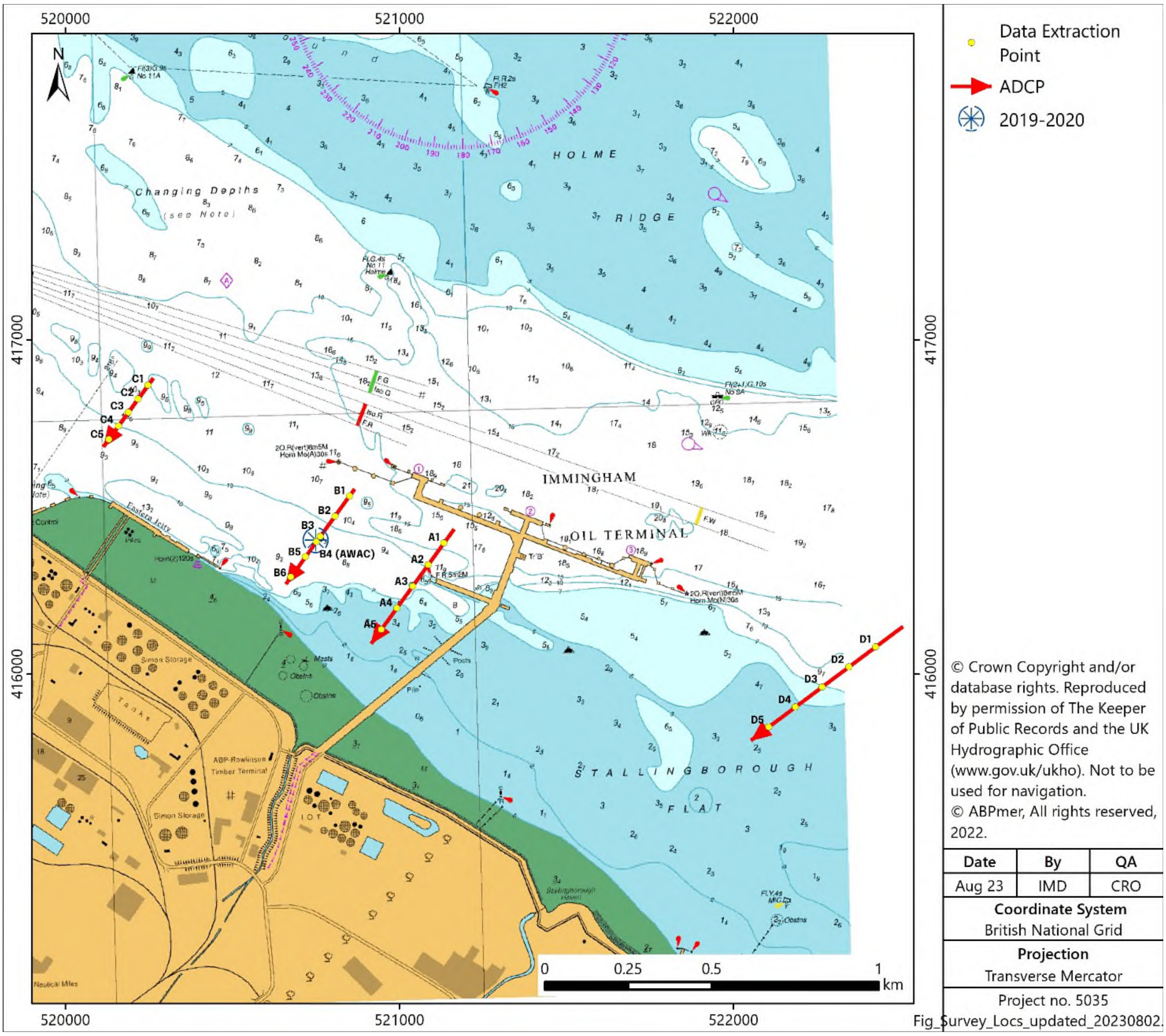


Figure 3.2: ADCP survey transects and extraction points

Source: ABPmer

The flow model data was compared directly with the survey data extracted at each of these locations. Full details of the process is described in Reference 2. The model setup and parameters were unchanged from the AWAC validation exercise.

The measured flow directions for 20 locations correlated well with the modelled data.

The flow rates, particularly during the peak ebb, correlated less well with modelled data. This reinforced the previous conclusion, from the validation against the AWAC data, which was taken into account in the navigation simulation by manual scaling of ebb flow speeds by 15 to 20%.

The results of the comparison underlined how well the HR Wallingford TELMAC flow model represented the direction of flow across the area of interest, not just at the single AWAC location.

A representative sample of comparative data for key locations are provided in Figure 3.3 to Figure 3.5.

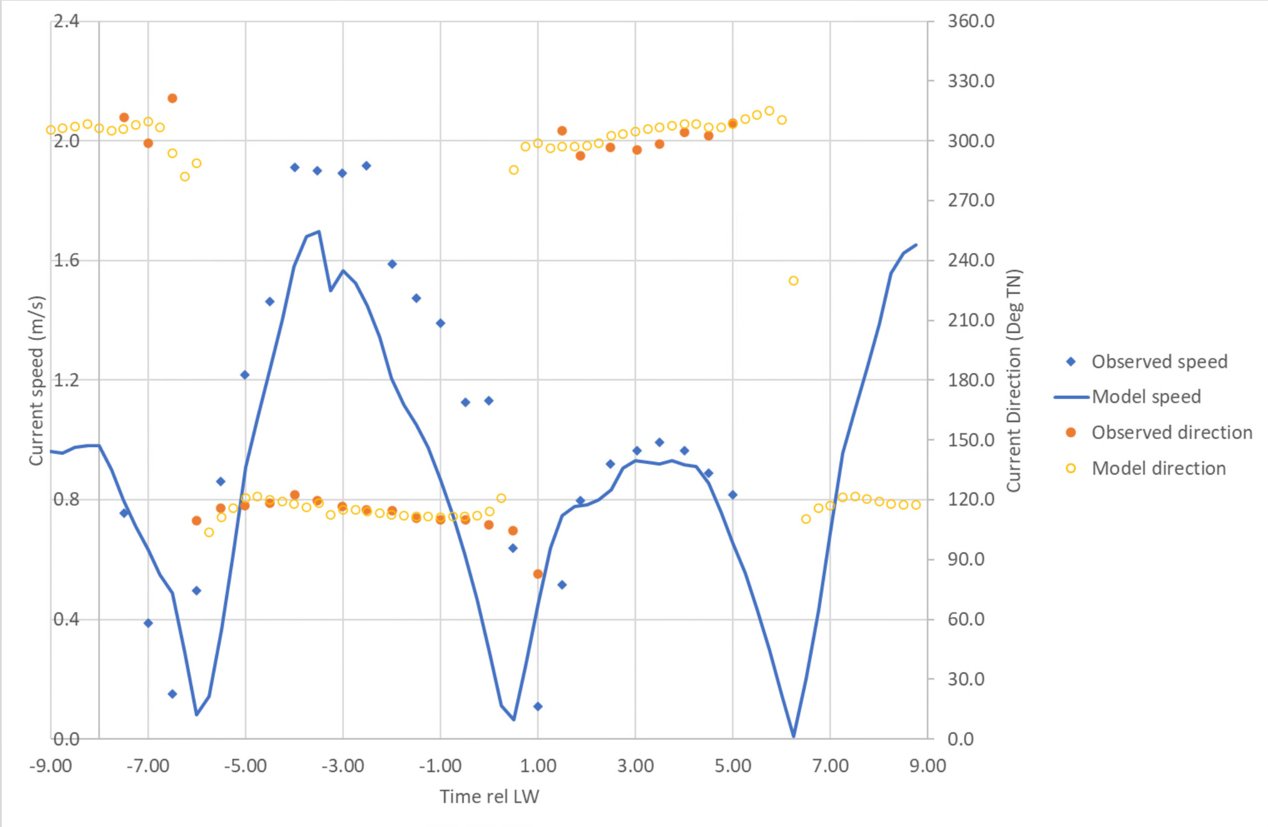


Figure 3.3: Comparison of model with data from ADCP point A3 11/10/22

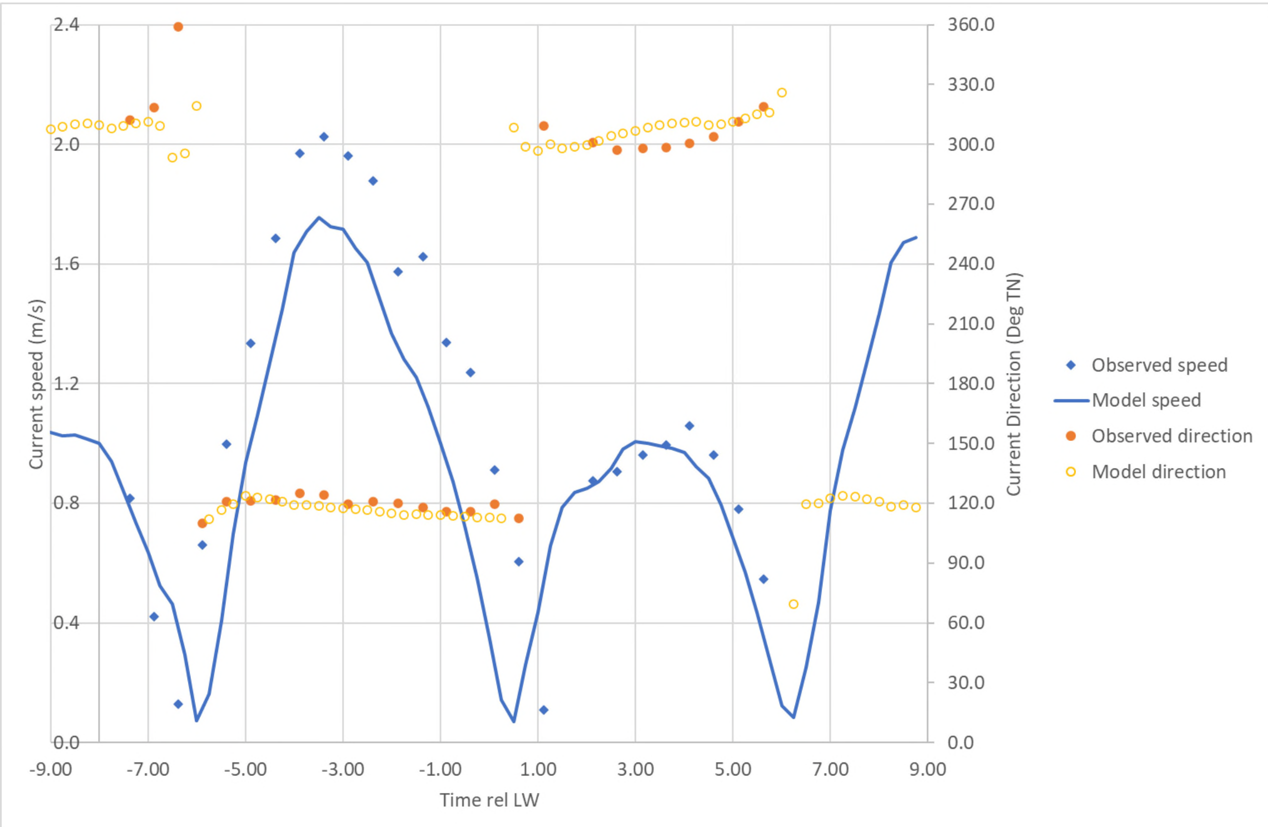


Figure 3.4: Comparison of model with data from ADCP point B3 11/10/22

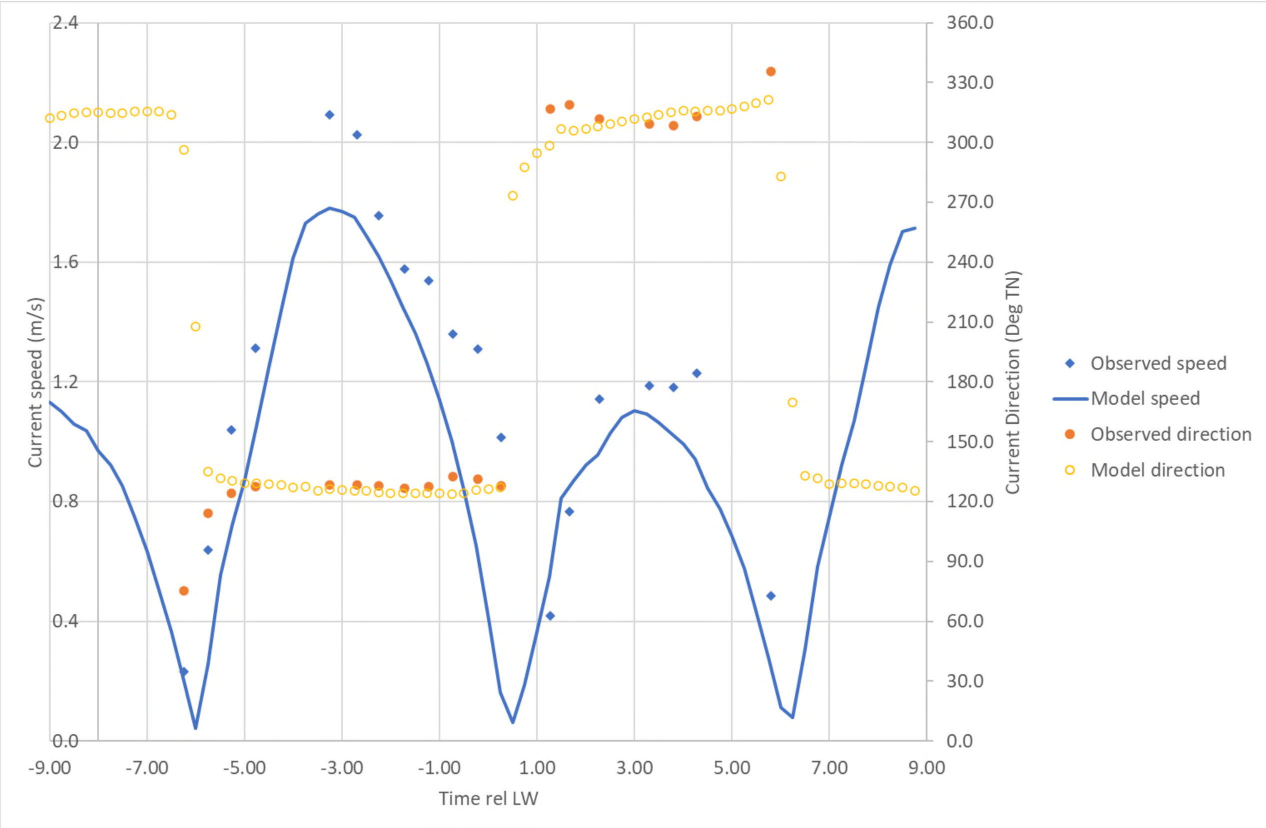


Figure 3.5: Comparison of model with data from ADCP point C3 11/10/22

At point A3 (Figure 3.3) which is in the vicinity of IERRT, and so was the focus for the study, the modelled directions correlated closely with the observed flows. Where there was a difference, the model was representing the anecdotal northerly flow tendency on the flood, so closer to 310°T than 300°T.

There was a similar pattern for locations further west at B3 (Figure 3.4) and C3 (Figure 3.5). Again these examples show there is more variation in the direction of on flood flow, however, the model tends to show a flow which is more closely aligned with the anecdotal 310°T to 315°T.

As previously mentioned, the modelled ebb flows under predicted the peak observed speeds, so were scaled by 15 to 20%.

Based on this analysis it was concluded that:

- The flow phenomena shown in the long term current measurements are representative of the conditions in the area and the model represented the spatial variation accordingly.
- It was confirmed that the long term AWAC data and flow model (verified using it), as applied to the project, were appropriate for the purposes of input to the navigation simulation and mooring analysis work.

3.3 Standards for modelling accuracy

Subsequently, the flow model was assessed according to the requirements of the Environmental Agency's 1998 guidance for estuarine modelling (technical report W113). In summary the standards require that:

- Modelled speeds should be within ±0.1 m/s or ±10-20% of observed speeds;
- Modelled directions should be within ± 20° of observed directions;
- These criteria should be satisfied for 90% of position/time combinations evaluated.

The statistical analysis of HR Wallingford's flow model, based on comparison with the AWAC data in the top 6m water depth, for a set of 5 spring tides shown in the model calibration report (Reference 2), gives the following results:

- The mean absolute error in modelled speed is 0.13 m/s or within 14% of the observed speeds, on average. This is 7.1% of the maximum observed current.
- Most of the errors are in the underprediction of peak ebb current speeds. Consequently, in the navigation simulation work, a 15% increase was applied to ensure they suitably conservative. Using this scaling in the model performance assessment reduced the mean absolute error to 0.12 m/s which is 6.2% of the maximum observed current.
- For directions, the mean absolute error was 15.5°, so the model is within 20° of the observations for 90% of the time.
- Current directions would be expected to be more variable for low current speeds, especially at the turn of the tide. So if the differences in direction are only considered when the currents are navigationally significant (when greater than 0.25 knots), the mean absolute error in the modelled direction reduces to 12.5ˆ and 92% of the modelled directions are within 20° of that observed.
- Further consideration showed that excluding the directional variability for current speeds of less than 0.5 knots reduces the mean absolute error in modelled direction to 6.5ˆ and the simulated current directions were within 20ˆ of those observed for 96% of the time.
- When considering the average ebb and flood tide directions, when currents are greater than 0.5 knots, the model directions were within 2° of those observed during the ebb tide and within 0.5ˆ during the flood tide.

Therefore, these all fall within or are close to the standards for modelling accuracy in the areas of importance and in the stronger flow conditions, which are of more relevance here.

4 Conclusions

The measurements made by ABPmer have shown that the flows on the River Humber are complex. There is significant temporal variation in flow direction in the vicinity of Immingham and the proposed IERRT infrastructure. Consequently, ABP expended significant resources in collecting flow data to support the modelling of the flow to support the project.

The model created provided vital input to the navigation simulation work, which met the EA guidance for estuarine modelling accuracy. Consequently, HR Wallingford are confident in the modelled flow outputs based on extensive analysis and verification of the flow model using observed data.

The model and the basis for the original measured data were further verified using additional data provided by a second independent flow survey.

Consequently, there is a high level of confidence in the spatial and temporal flow conditions represented in the model for the area verified using the ADCP data collected in autumn 2022, as shown by the red area in Figure 4.1.

There are anecdotal reports of flows which vary from the modelled direction north of the IOT in the main channel, but the following observations should be taken into account:

- The reports are based on evidence from mariners navigating within the main channel and approaching berthing areas elsewhere, but with a similar complexity to IERRT. However, determining the nature of flows in those areas was not part of HR Wallingford's study work.
- The nature of the flows in the Humber means that they should not be considered from a single orientation, but a range of directions that varies during the tidal cycle on a micro and macro basis. The most important aspect to consider was that the IERRT berths were suitably aligned to the flows, based on the potential for flow variation and the effect this may have on

navigation (and mooring). It was considered that the work undertaken in the quasi-stationary analysis (Reference 1) provided an appropriate assessment of this aspect.

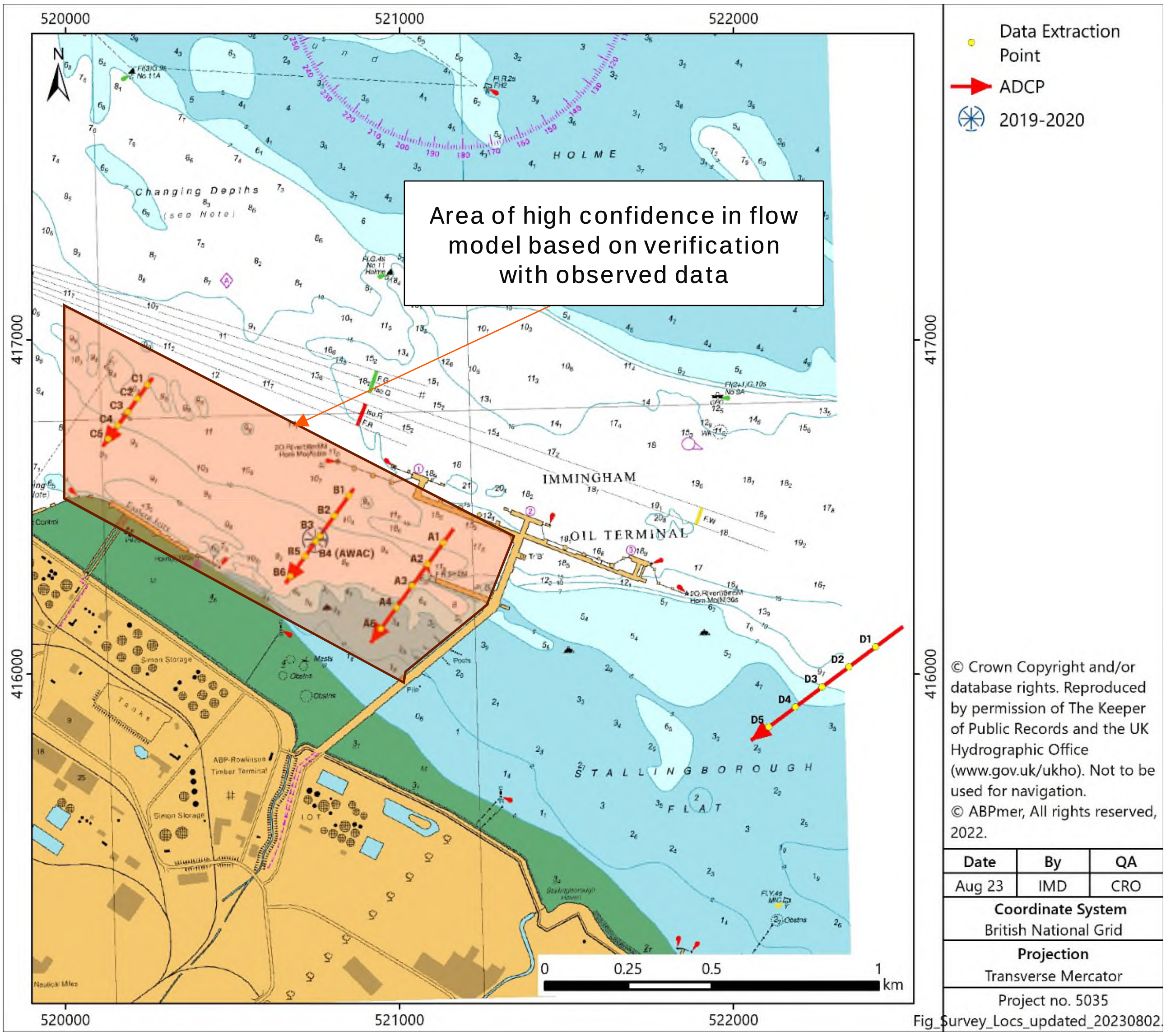


Figure 4.1: Area of flow model verification with observed data

5 References

1. HR Wallingford, “Project Sugar – ABP Humber – Immingham East Development – Quasi-static force assessment”, Report no. DJR6612-RT0004-01-00, 08 Jul 22.
2. HR Wallingford, “Project Sugar – ABP Humber – Immingham East Development – Flow model comparison with October 2022 ADCP survey – November 2022”, Report no. DJR6612-RT0007-01-00, 22 Nov 22.
3. ABPmer, “Nordic AWAC Deployment version 2, report ref. R3354,” 2022.
4. ABPmer, “Immingham Eastern RoRo Terminal – ADCP survey”, Report R.4059, 2022.
5. ABP HES, “Humber Port Passage Plan”, 2021.

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