Isle of Man Government – Department of Infrastructure

Proposed Deep-Water Berth, Douglas Harbour - Sediment and Navigation Studies

Main study report

November 2019





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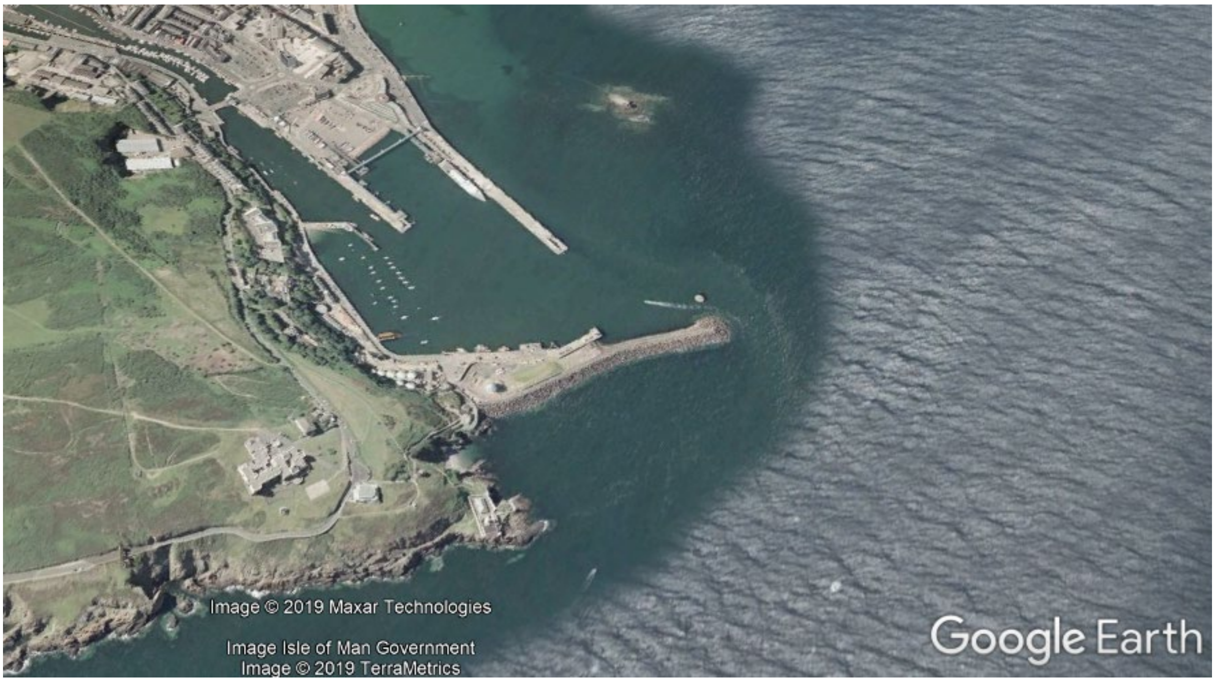

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Summary

Isle of Man Harbours, Department of Infrastructure – Ports Division is undertaking a Master Planning process for the port facilities at Douglas Harbour. The Master Planning has indicated the potential for deep-water berthing facilities outside the Douglas harbour entrance for vessels that cannot be accommodated within the existing harbour. Two proposals are being considered to potentially accommodate predominantly day-visit cruise vessels.

ABPmer has been commissioned by the Isle of Man Harbours Department of Infrastructure to provide input to this Master Planning process. The study includes an oceanographic survey campaign, baseline conceptual understanding and subsequent numerical modelling to inform sedimentation and navigation assessments for the two proposed berth development schemes.

To collect the required contemporary hydrodynamic information from the outer harbour area and surrounding coastal waters, a field survey campaign was conducted, which included:

- Static Recording Instruments including Acoustic Wave and Current (AWAC) devices, Conductivity/Temperature/Depth (CTD) sensors and Turbidity sensors;
- A Mobile (vessel-based) Survey using an Acoustic Doppler Current Profiler (ADCP), a CTD and Turbidity meter and a water sampling programme; and
- Seabed Sampling at pre-determined locations throughout the harbour entrance and surrounding coastline.

Applying the available survey data, and the subsequent conceptual understanding of the wider system, a numerical modelling study has been undertaken, to assess the impacts of the proposed schemes on the hydrodynamic, wave and sediment transport regime, across the study area.

Victoria Pier Berth dredge

The modelling of the Victoria Pier Berth scheme showed that dredging the berth to 9.5 m below CD has negligible effect on the existing flow regime at all states of tide. The change is almost entirely restricted to the berth itself, where existing flows are already low (peaking at <0.2 m/s on spring tides) and for most of the tide are orientated towards the east and aligned with the pier.

Given the small existing rate of accretion, the deepened berth will make negligible change to the volume of sedimentation occurring within the berth. As a result, the average thickness of annual sedimentation in the new berth is likely to be no greater than a few millimetres and unlikely to be noticeable when vessel disturbance is considered.

Deep-Water Berth

The hydrodynamic modelling of the Deep-Water Berth scheme showed that changes to the flow regime will be confined within an approximate radius of 1.2 km (centred on the head of Princess Alexandra Pier), with the greatest changes occurring around HW. The Deep-Water Berth scheme therefore has more potential to affect the accretion and erosion potential across wider parts of the study area than the Victoria Pier Berth scheme.

The results indicate construction of the Deep-Water Berth will have negligible sedimentary effects on Douglas Harbour and the immediate approaches with or without the proposed Victoria Pier Berth. The requirement for maintenance dredging will remain negligible unless there is a significant change to the

sediment supply in the immediate area. Existing and resulting flow regimes indicate there is little potential for significant sediment movement into the area.

In the area of the Deep-Water Berth itself, the pier interacts with both the flood and ebb flows in a complex manner, blocking, training and diverting the existing flow regime, particularly at the northern end. These changes, and the resultant flow patterns, will significantly influence vessel manoeuvring to and from the new berth.

The sediment transport modelling shows a reduction in erosionary areas and an increase in accretionary areas, compared to the existing baseline conditions, following construction of the Deep-Water Berth pier. The net effect in the berth area remains erosional, albeit predicted at an even smaller magnitude. These changes are, however, small and will be within the natural variability of the area. The Deep-Water Berth is therefore predicted to be self-maintaining, in net volume terms. However, isolated areas of small reductions in depth could occur immediately against the quay, particularly at the northern end of the berth. This, however, is unlikely to cause the need for a significant maintenance dredge requirement due to the wider lack of sediment supply.

Vessel Navigation

The vessel simulations undertaken indicate that manoeuvres conducted in conditions above Force 4 become increasingly difficult. The scenarios conducted in conditions above this were continued as far as possible in order to determine the possibility of the manoeuvre, however it was deemed that, in several cases, the operation would have been aborted due to the risks involved.

Victoria Pier

Manoeuvres conducted for the Victoria Pier Berth development showed difficulty in ship handling when operating in easterly wind conditions; these conditions lead to greater speeds over the ground, and swing rates that are difficult to control. Tug assistance of over a 50 t bollard pull was deemed necessary for all manoeuvres conducted, in order to improve safety margins and the effectiveness of ship handling. The standard cruise vessel was unable to depart the berth during easterly wind conditions above Force 4 without tug assistance, it is recommended that two tugs are used for departures during easterly wind conditions.

Deep-Water Berth

Ebb tides and following winds require greater speed over the ground to maintain steerageway on approach to the Deep-Water Berth. Greater speeds are required when passing the northern point of the berth for the mitigation of increased flow rate during HW -2 hours and HW +2 hours, reducing the time available to take way off when entering the new berth area. Tug assistance of over 60 t bollard pull is recommended for all manoeuvres conducted through both indirect towing during approach and direct force when taking off vessel way or preventing headway when departing.

Approaches

It has been identified that tug assistance is advisable for all manoeuvres conducted, especially in conditions above Force 4, for both proposed berth schemes. The conditions and limiting factors for tug operations and connecting lines should be considered in conjunction with the limiting factors of vessel operations. Vessel approaches from the vicinity of the Pilot boarding ground is considered to be effective, as this allows for determining the response of the vessel in relation to current conditions prior to approaching navigational hazards. When performing turns, winds contrary to the direction of stern swing increase the time taken to complete the manoeuvre and subject the vessel to a longer period of drift; it is therefore advised that turns are performed to the south of Douglas Bay.

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1 Introduction

ABPmer has been commissioned by the Isle of Man Harbours Department of Infrastructure to provide input to their Master Planning for Douglas Harbour. The study includes an oceanographic survey campaign informing a conceptual understanding and modelling assessment of two proposed berth development schemes at the Port.

1.1 Project appreciation

Isle of Man Harbours, Department of Infrastructure – Ports Division is undertaking a Master Planning process for the port facilities at Douglas Harbour. The Master Planning has indicated the potential for deep-water berthing facilities outside the Douglas Harbour entrance for vessels that cannot be accommodated within the existing harbour. Two proposals are being considered to potentially accommodate predominantly day-visit cruise vessels. Figure 1 shows a schematic representation of the two locations, whilst Figure 2 provides the wider context of the schemes, relative to the bathymetry of the existing harbour and its' approaches.

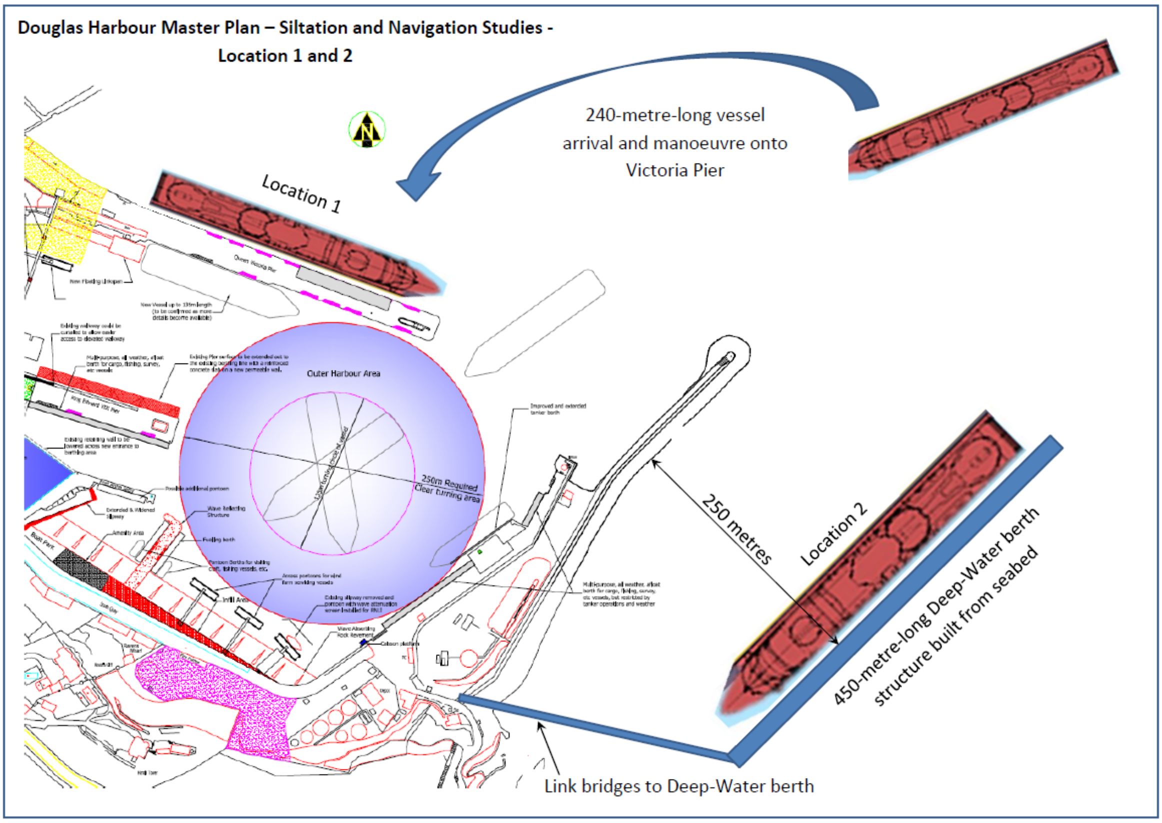


Figure 1. Schematic of proposal options for Douglas Harbour Master

- **Location 1**: Dredging of a deeper and longer berth pocket, to a depth of 9.5 m below Chart Datum (CD), against the existing breakwater that forms Victoria Pier. The berth is proposed to accommodate vessels up to 240 m long and 30 m beam; and
- **Location 2**: Construction of a Deep-Water berth outside the Harbour, about 250 m to the east of the outside of Princess Alexandra Pier, to accommodate day visits of vessels up to 'mega-cruise' size. The design vessel for the economic study (Delloites, 2018) was the MS 'Allure of

the Seas' with a length overall (LOA) of 362 m and beam of 47 m at the waterline. However small vessels such as the MS 'Queen Victoria' with LOA of 294 m and beam of 32.3 m are more likely to call. The berth is to be sheltered from waves by a long (*circa* 450 m), sea bed to water surface-piercing gravity structure, with a rock (or man-made unit) armour slope on the seaward side. The berth is located in an area of natural seabed depths of around 16 m below CD. The berthing pier structure is proposed to be connected to the harbour (and town) by South Quay Road via a pile supported link bridge.

In order to support the Master Plan, Isle of Man Harbours has commissioned ABPmer to undertake the following studies, with respect to the two potentially proposed berth locations:

- A **sedimentation study** to determine if siltation will occur at the proposed new berth locations and, if so, what the rate (depth) will be over a 12-month period, hence the requirement for maintenance dredging and its likely frequency and timing;
- A desktop **navigation study** incorporating ship simulation studies (Fast- and Real-time) for the design vessels for the respective berths. The studies investigate the manoeuvring of the vessels to and from the berths, under the range of wind, wave and tide conditions that would occur, predominantly during the cruise season. Consideration is needed with respect to the requirement for tugs and, if so, the maximum bollard pull requirements.

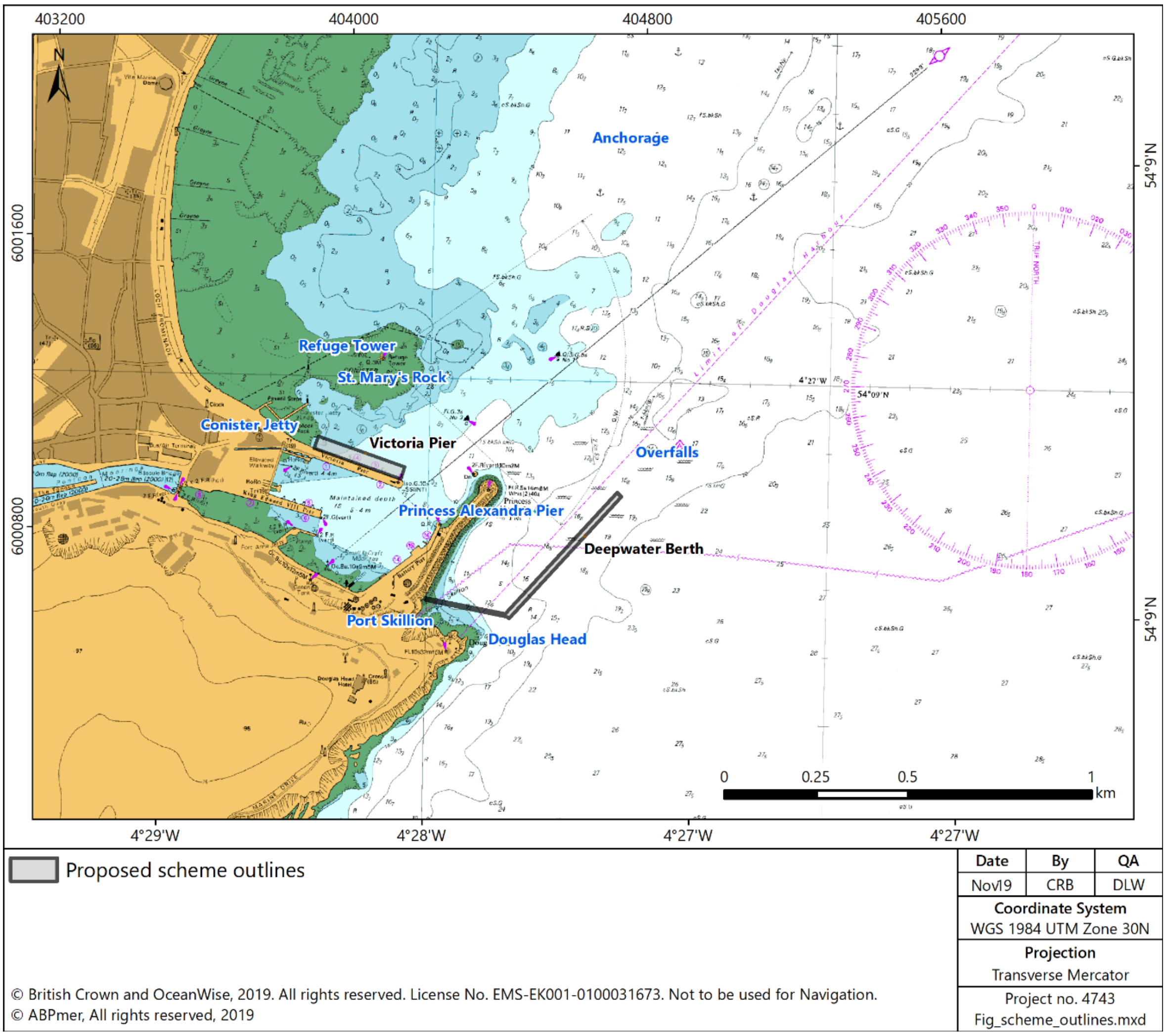


Figure 2. Location of proposed Victoria Pier dredge and Deep-Water Berth schemes

1.2 Method and report structure

To undertake the above studies there has been a need to collect, collate and analyse data to characterise the range in the 'forcing processes' (predominantly waves and tides) within the proximity of Douglas Harbour that occur throughout a 12-month cycle. This information has been collated from public domain searches, pre-existing studies and a bespoke field monitoring campaign.

These data have been combined to provide an understanding of the hydrodynamic and sedimentary environment, used to 'build' and calibrate numerical hydrodynamic and wave models. The results from these models with the cruise berth scenarios are used to determine the sedimentation rates (i.e. the sedimentation study) and provide the 'flow field' data input to the ship simulations as part of the navigation study. The modelled representation of the two schemes is provided in Section 3.4.

This report is structured as follows:

Section 2 Marine Physical Environment: This section provides the understanding of the hydrodynamic and sedimentary forcing processes and their temporal and spatial variability in proximity to the harbour. This incorporates summary results from the field monitoring. The full results are presented in Appendix A and supplied to Isle of Man Government as digital datasets;

Section 3 Modelling Approach: This section provides a brief overview of the modelling tools applied to the wider study. Full details of the model setup and calibration are provided in Appendix B;

Section 4 Modelling Results: This section provides a summary of the predicted effects on the hydrodynamic and sedimentary environment that result from the introduction of the two berthing scenarios.;

Section 5 Sedimentation Study: This section combines the understanding of the physical environment and the modelling results to determine the potential rates of sedimentation at each location, the potential for variation on different tides and time of year, along with an estimation of the possible rates of maintenance dredging that may be required at each location;

Section 6 Navigation study: The results of the navigation desk study, combined with the ship simulation results are summarised. Details of the modelling process and results are presented in Appendices G and H;

Section 7 Conclusion; provides an overview of the main findings from the study to allow input back to the Master Planning process.

2 Marine Physical Environment

2.1 Water depth and geomorphology

2.1.1 Offshore

Water depths around the IOM can reach over 100 m to the W and SW of the Island. To the E of the Island water depth is no greater than 50 m. The bathymetry of the Irish Sea has a significant impact on circulation and hydrography around the Isle of Man as flows from the north and south of Ireland meet and are further 'split' by the Isle of Man itself. This results in higher flow rates on the west coast compared to the east coast of the island.

Offshore from Douglas to the NE is a large shoal region of depths less than 20 m below CD (Chart Datum) and the Bahama Bank lies to the N/NNE of Ramsey with depths as low as 2.4 m below CD. The Bahama bank is at the Northern perimeter of the large eddy formed during peak flood tidal flow and is a region of high sediment deposition.

Within the Douglas Harbour vessel control limit, the maximum depth is considered to be a deep region in Liverpool Bay with maximum depths of 32 m below CD. The depth change is relatively steep moving inshore with depths of 25 m below CD in Douglas Bay reducing to 10 m below CD at the mouth of Douglas Harbour. These depths allow large draughted vessels to approach without 'hindrance' to within about 1 km of the Harbour Entrance.

2.1.2 Douglas Bay

Douglas Harbour is situated at the southern end of the crescent shaped Douglas Bay, which has a general south east aspect. The Bay is sheltered from the south by the cliffs at Douglas Head and from the north by the cliffs at the foot of Banks Howe. This coastal configuration and bathymetric depths, control the strength and orientation of the tidal currents that are experienced within the approaches to Douglas Harbour, hence will affect the sedimentation at, and the navigation to and from the Harbour and the proposed new berth at Location 1.

The Bay shape and bathymetry also allows large wave activity from directions predominantly in the arc NE – S, which will influence the potential for sediment movement around Douglas Bay, hence sedimentation in the vicinity of the Harbour and the berth at Victoria Pier in particular.

As seen from the Admiralty Chart (Figure 2) depths of at least 10 m below CD are present within about 900 m of the Central promenade over the northern part of the Bay. Depths the reduce quickly to 0 mCD about 375 m off the promenade at the edge of Black Rock. This rock infilled with sand and gravel is then exposed for about 200 m, before an area first of sand then gravel (shingle) forms the beach immediately in front of the Central promenade.

Image 1. Beach and intertidal rock area (Black Rock) north Douglas Bay

The steep bathymetry results in waves breaking on the shoreline (breakwater and promenade) at Douglas rather than offshore. This results in high wave energy interacting with coastal defences/sea walls and increases the potential for high wave energy within the harbour.

At the southern end of Douglas Bay, where the shoreline has a more easterly aspect, Black Rock is not present and the intertidal in front of Loch Promenade is deeper. The bed material in this area is sand with a few stony outcrops (see Image 2). Groynes were constructed here in the past, presumably to 'arrest' to movement of sediment around the Bay but are now ineffective as the sediment supply/ available for transport in the area is limited.

Image 2. Deeper area with sand in front of Loch Promenade

A the very southern end of the bay St Mary's Rock, a reef normally visible above sea level, is often submerged at high spring tides. This and the causeway to the Refuge Tower, Peveril Steps and the Conister Jetty Landing (see Figure 6 and Image 3) all combine to restrict circulation of tidal flow, wave effects and sediment movements for a significant part of lower tide.

St Mary's Rock also confines the deeper water area in the Harbour approaches on the north side with Princess Alexandra Pier confining the channel to the south, hence delineating the maximum area for vessel turning in the Harbour entrance. This bathymetric configuration indicates that any large vessel turning will be subject to varying, flow speeds and directions, and wave conditions along its length whilst manoeuvring as Princess Alexandra Pier is not long enough to provide a complete sheltering effect.

Image 3. Refuge Tower, St Mary's Rocks and Peveril Steps

2.1.3 Harbour approach

The navigation approach to the Harbour is from the north east with the predominant flows crossing at approximately 30° to the line of approach through outer Douglas Bay. Approaching the harbour depths shallow and then the channel passes between the low water drying area of St Mary's (Conister) Rock and the Princess Alexandra Pier. This area confines and varies the flow regime at different states of the tide. This is the area in which the proposed cruise vessels will need to turn and manoeuvre to access the proposed berth on the outside of Victoria Pier (Berth Location 1).

2.1.4 Harbour

Douglas is the main port and town of the Isle of Man with links to UK and Irish ports, international ferries and facilities for both commercial and private vessels. It is located on the E coast, at the Mouth of the River Douglas. To the south of Douglas Harbour is Douglas Head with Douglas Bay to the North. The River Douglas runs into the harbour through a marina, which is separated from the harbour by a system of tidal gates.

The outer harbour is protected by engineered sea defences; the Victoria Pier to the North and King Edward VIII Pier both located on the northern bank of the River Douglas and the large combination of Battery Pier and the rock (armour block) armoured Princess Alexandra Pier which protects the entrance to the harbour. The Fort Anne Jetty which projects from South Quay defines the west of the outer Harbour south of the River Douglas. This Jetty protects the Middle Harbour from wave activity. The mouth of the harbour faces N-NE and is offered natural protection from SW-E swell by Douglas Head.

A lifeboat slipway and boathouse are located near the 'root' of Battery Pier and the main RoRo facilities are situated between Victoria and King Edward VIII Piers. Currently the RoRo vessels turn within the confines of the piers. Limited dredging, mostly bed levelling is required to maintain harbour depths in this area.

Within the harbour depths range from 9.7 m below CD at the harbour mouth to -2.6 mCD at the SW wall.

2.2 Water levels

2.2.1 Tide levels

Tides in the Irish Sea are semi-diurnal, propagating from the Atlantic through St Georges Channel and the North Channel to the south and north of the island respectively. The tidal ranges in the Irish Sea vary from micro tidal ranges at the amphidromic points located between Mull of Kintyre and Islay in the North Channel to over 10 m in Liverpool Bay. The basic tidal period for the Irish Sea is 12.4 hours, the timings of maximum and minimum tidal heights show little variation either side of the Isle of Man.

Tidal levels for Douglas obtained from the United Kingdom Hydrographic Office (UKHO) tide tables (UKHO, 2018) are provided in Table 1. In proximity to the port, the mean spring and neap tidal ranges are 6.10 m and 3.00 m, respectively.

Table 1. Douglas tidal characteristics

Douglas Tidal Levels		Tidal Level (mCD)	Tidal Level (m) (OD local - D02)
Highest Astronomical Tide	(HAT)	7.90	4.10
Mean High Water Springs	(MHWS)	6.90	3.20
Mean High Water Neaps	(MHWN)	5.40	1.70
Mean Sea Level	(MSL)	3.79	0.09
Mean Low Water Neaps	(MLWN)	2.40	-1.30
Mean Low Water Spring	(MLWS)	0.80	-2.90
Mean Spring Range	(MHWS – MLWS)	6.10 m	
Mean Neap Range	(MHWN – MLWN)	3.00 m	
Note: Chart Datum (CD) is 3.7 m below Ordnance Datum (local D02)			

Source: UKHO, 2018

2.2.2 Extreme water levels

Over the lifetime of the development, mean and extreme coastal water levels may be influenced by both isostatic and eustatic effects. Sea levels are expected to increase considerably around the Isle of Man over the next century, in particular due to eustatic changes. For the UK, the most up to date estimates of future sea level are provided by the United Kingdom Climate Projections (UKCP18), which supersede the earlier projections set out in UKCP09. These projections are soon to be incorporated in Environment Agency Guidance to local planning authorities and developers (Environment Agency, 2019).

Climate change predictions are not exact but are based on a range of future Representative Concentration Pathways (RCPs) for greenhouse gases. These provide a best estimate upper and lower estimate of future sea level rise. For the area around Douglas, UKCP18 suggests that sea levels will rise between 0.24 m and 0.55 m above present levels by 2100, based on central (50%ile) estimates for various greenhouse gas concentration pathways. (Palmer *et al.* 2018) (Figure 3). A theoretical maximum rate of sea level rise (termed 'H++') of 1.9 m for the period to 2100 is provided in UKCP09 and remains valid in UKCP18. This is considered to be 'beyond the likely range but within physical plausibility.'

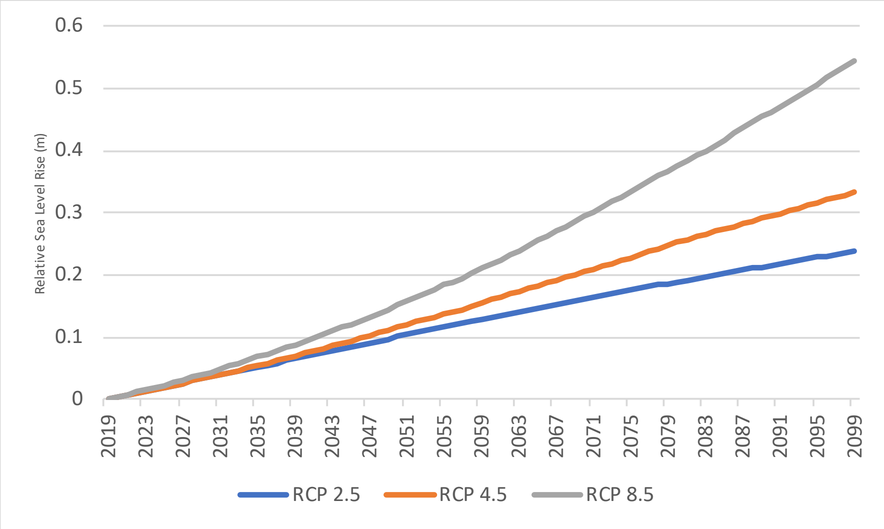


Figure 3. **Sea level rise at Douglas for the period 2019 to 2099, under future greenhouse gas Representative Concentration Pathways**

Based on storm surge modelling work, UKCP18 suggest a best estimate of no significant additional increase in the statistics of extreme water levels associated with atmospheric storminess change only. This means that the risk of coastal flood events will rise in accord with the projections of increase in time-mean sea level described above.

In 2014, JBA Consulting undertook a contract considering the IOM sea defence options for the Department of Infrastructure for the IOM Government (JBA, 2014). During this study the extreme water levels for Douglas Harbour were estimated for both present day conditions and for 2115 accounting for sea level rise. The extreme still water levels for return periods between annual and 1 in 10,000 years is presented in Table 2 relative to the Douglas 02 Datum (D02).

Table 2. **Estimated return extreme still water levels (m above D02) for Douglas**

Return Period T (years)	Douglas 2014	Douglas with Sea Level Rise to 2115
1	3.98	4.62
2	4.07	4.71
5	4.18	4.83
10	4.27	4.91
20	4.35	5.00
25	4.37	5.02
50	4.45	5.10
75	4.50	5.15
100	4.53	5.18
150	4.57	5.22
200	4.60	5.25
250	4.63	5.27
300	4.64	5.29
500	4.70	5.34
1,000	4.76	5.41
10,000	4.97	5.62

Source: JBA, 2014

These levels will have marginally changed due to the change in predicted sea level rise between UKCP09 and the updated UKCP18 projections.

2.3 Currents

2.3.1 Isle of Man

The Manx Marine Environmental Assessment (MMEA) (Hanley *et al*., 2013) states that there have not been any definitive studies of the currents and tides around the IOM. The following summary analysis of tidal flow/ current characteristics is based on observations from Reeds Almanac, UKHO tidal diamonds, the MMEA, and tidal flow models that include the IOM and leisure craft sources. An illustration of the complex tidal flow patterns around the Isle of Man at hourly intervals through the tide is presented in Appendix D. A short summary of the tidal change is provided below with examples of the tidal streams at approximately half flood and half ebb off Douglas in Figure 4.

Flood Tide – There is a general easterly flow direction in the Irish Sea through the Northern Channel and St Georges Channel which then funnels into estuaries in coastal areas. A study by Price *et. al.* (2010) found that the highest current speeds in the Irish Sea are seen to the north and south of the Isle of Man with speeds of 1.5 - 2.0 m/s. These flows interact for most of the flood tide on the west coast causing a divergence of flow to the north and south around Peel.

In the north the flows then turn eastwards around the Point of Ayre with rates of 1 -1.5 m/s. For the first *circa* two hours of the flood tide these flows pass southwards around the coast of Ramsey Bay, then a clockwise circulation forms to the north of Maughold Head in Ramsey Bay for much of the rest of the rising tide.

The southward flows on the west coast are strong at 1.5 - 2 m/s and turn to flow NE around the south of the Isle of Man. For the first 1 – 2 hours of the flood the tidal streams are relatively weak, moving north along the east coast, with a slight movement offshore around Douglas and Maughold Head. From about 4 hours before HW the flow speeds increase around the south of the island and move offshore (i.e. NE) at Langress Point. Anticlockwise flows are created inshore, coming towards the shore around Douglas Bay and Maughold Head (near Ramsey) (i.e. reversing the offshore movement to onshore movement in these areas. Inshore flows then pass southwards along the east coast and slacken towards HW. This general pattern is illustrated at about half flood in Figure 4.

It should be noted that these tidal streams do not entirely agree with the interpretation presented in Kennington *et al*, 2013, shown in Figure 5. This interpretation indicates that the flows passing around the north and south of the island interact to divert flows offshore around a location to either side of the area of Douglas Bay.

On the west coast the flows diverge around Peel; to the north and then eastwards across the north of the island and southwards along the west coast before turning to the east around the south of the island. The flow rounding the north of the island forms an eddy in Ramsey Bay about 2 hours before HW and a WSW flow is set up approximately parallel to the coast. This flow is then deflected offshore as the flow interacts with the NE flows from the St George's Channel. This divergence occurs in the vicinity of the northern part of Douglas Bay. Flows in the vicinity of Douglas Harbour will therefore be influenced by flows passing both north and south of the Island.

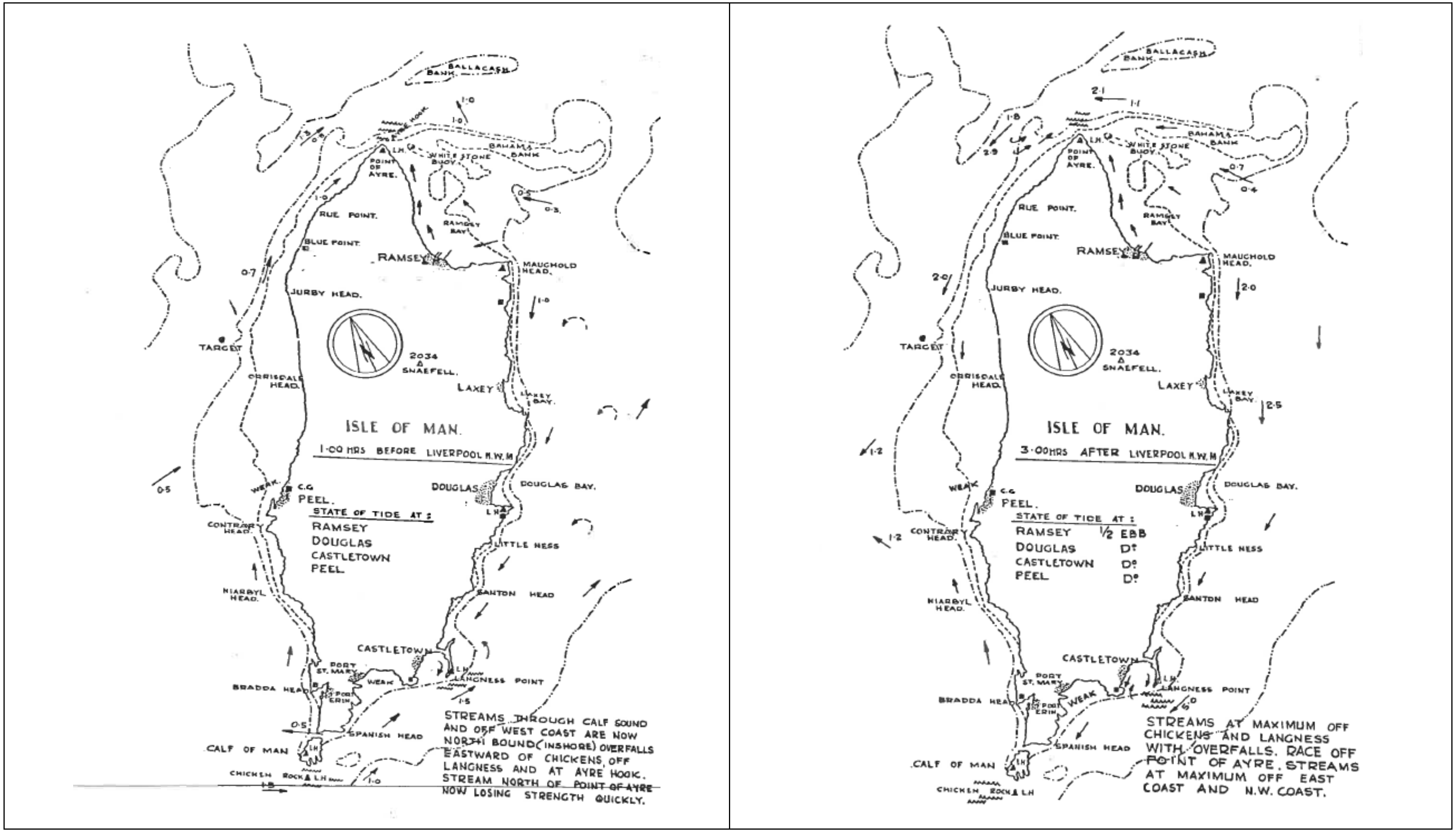


Figure 4. Example of peak flood (left) and ebb (right) tidal streams around the Isle of Man

Source: Kennington *et. al.* 2013

Figure 5. General tidal flow around the Isle of Man

Ebb Tide - The main ebb tidal flows on the east coast are predominantly in a general S - SW direction approximately parallel to the coast with moderately high flows for most of the ebb tide, particularly passing Douglas Bay. These flows slacken towards low water (LW) and then turn northwards.

These tidal flow characteristics mean the inshore tidal flow on the eastern coast of the Isle of Man is S - SW 'running' for approximately 9 hours and NE - N 'running for approximately 3 hours and the flow tends to change direction near to Douglas. The ebb flows at the time of maximum rate (about half ebb) are shown on the right side of Figure 4.

2.3.2 Douglas

In the region of Douglas Bay, tidal diamond 'A' (UKHO Chart 2096, 2014) shows maximum flow speeds of 1.5 knots (springs) and 0.9 knots (neaps) on the flood tide with an average flow speed of 0.8 knots (springs) and 0.5 knots (neaps), see Table 3 . The actual tidal streams in Douglas Bay show a continuous clockwise rotating character, swinging from N to S during the flood and S to N throughout the ebb tide. The change in direction is fastest during the last two hours of the flood and the first hour of the ebb, when the flow direction turns from approximately NE through S.

Table 3. Douglas Tidal Diamond A (time referred to HW Alfred Dock Liverpool)

Time	Direction (°N)	Spring Flow Speed (knots)	Spring Flow Speed (m/s)	Neap Flow Speed (knots)	Neap Flow Speed (m/s)
-6 h	007	0.2	0.10	0.1	0.05
-5 h	021	1.0	0.51	0.6	0.31
-4 h	023	1.6	0.82	0.9	0.46
-3 h	028	1.5	0.77	0.8	0.41
-2 h	051	0.5	0.26	0.3	0.15
-1 h	125	0.3	0.15	0.2	0.10
HW	176	0.7	0.36	0.4	0.21
+1 h	189	0.8	0.41	0.5	0.26
+2 h	194	1.1	0.57	0.6	0.31
+3 h	203	1.3	0.67	0.7	0.36
+4 h	209	0.9	0.46	0.5	0.26
+5 h	213	0.5	0.26	0.3	0.15
+6 h	270	0.1	0.05	0.0	0.00
Location: 54°08.91'N 4°27.38'W					

Source: UKHO Chart 2696

These flows were recorded some time ago and only reflect the flows passing the Harbour, therefore will only provide an indication of the flow regime around the proposed Berth Location 2. The data, however, will not characterise the flows in the navigation approach to the Harbour, as these will be influenced by the Harbour breakwaters (piers) and the bathymetry around St. Mary's Rock and therefore the area in which significant vessel manoeuvring is required in a confined space to access proposed Berth Location 1. Additionally, a good representation of the flow regime is also required to access the likely sedimentation patterns that could lead to a maintenance dredge requirement for the new berth and its approach.

Consequently, a programme of flow measurements has been undertaken for this study. The field survey programme was defined to:

- Measure the flow speeds and directions throughout the water column in the vicinity of the two proposed potential berth locations; and
- Provide data in order to locally calibrate and validate a numerical hydrodynamic model encompassing Douglas Harbour,its approaches and the wider Douglas Bay.

Measurements were undertaken at two fixed locations with an upward pointing AWAC (Acoustic Wave and Current) instrument from a bed mounted frame for a period of at least 30 days to measure the variations in the flows through a series of spring and neap tides. These data were supplemented by a set of mobile ADCP (Acoustic Doppler Current Profiler) transects at approximate hourly intervals through a spring tide. These transects were located to determine the spatial variation in flow speeds and directions particularly within the area where vessels would require to turn and manoeuvre to access the Harbour and the proposed potential cruise berth at Victoria Pier.

The locations of these measurements and locations of bed samples are shown in Figure 6. The full set of measurements is presented in Appendix A, the report of the field measurements programme.

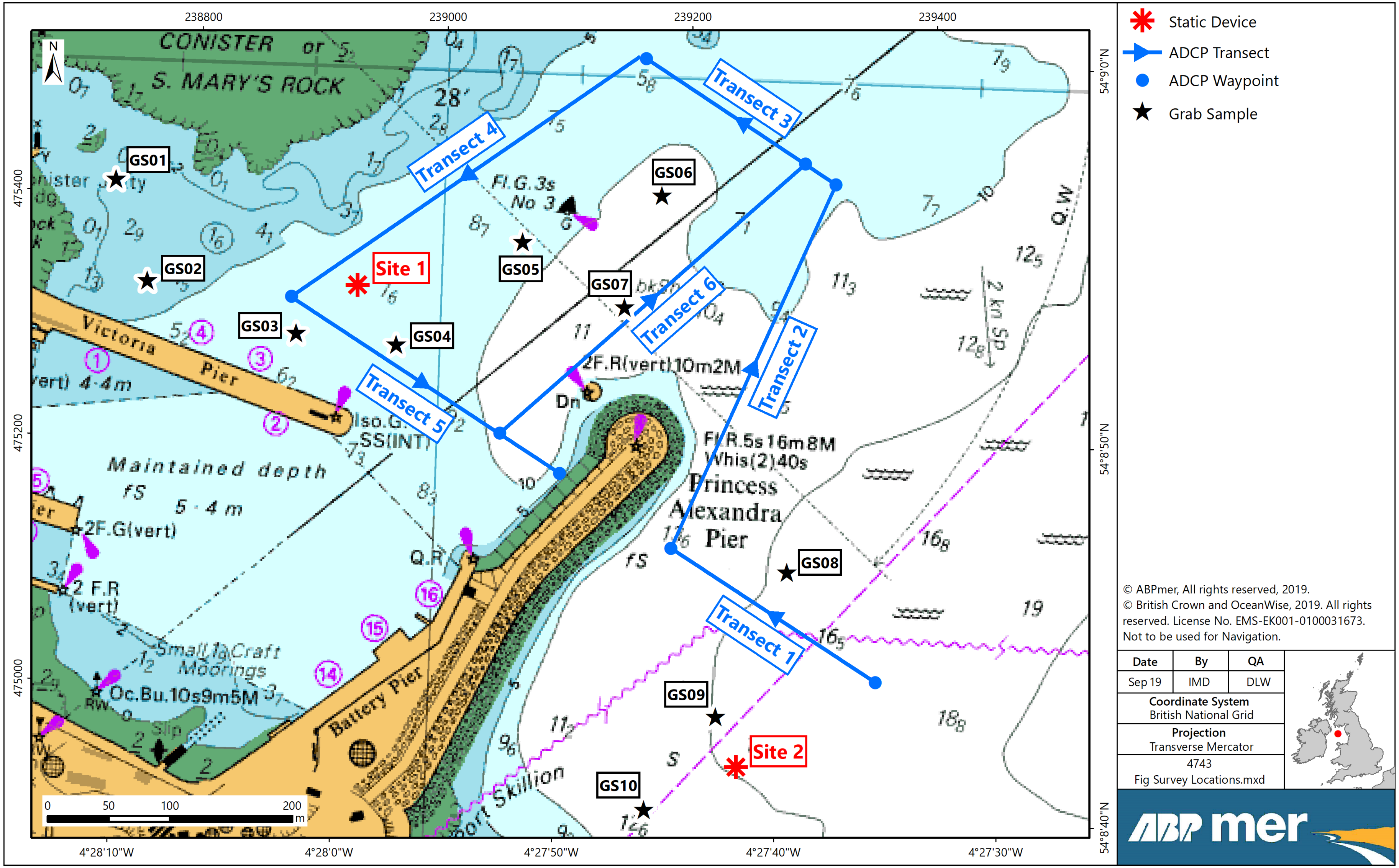


Figure 6. **Locations of static instrument packages, mobile survey transects and grab samples**

Figure 7 shows the flow speeds and directions through the water column for near mean spring and neap tides at the two AWAC locations. Also shown is the depth average data through the tide. These plots indicate the following characteristics of the flow regime:

- **AWAC 1 - Victoria Pier:**
  - On spring tides, depth average flows rarely exceed 0.3 m/s and on neap tides flows are low, rarely exceeding 0.1 m/s;
  - Peak flows occur from just before HW to about HW + 2 hours;
  - Except for the above period, flow speeds rarely exceed 0.15 m/s on both springs and neaps;
  - Maximum flows are generally recorded in the lower part of the water column with peaks generally less than 0.5 m/s and less than 0.2 m/s on neap tides;
  - With the slow flows on neap tides directions are variable from tide to tide and inconsistent. Ebb tidal streams tend to flow E – SE, whilst flood flows swing from predominantly S through to north as the tide rises;
  - Spring tide flows on the first half of the ebb generally flow just N of E. As the flow speeds reduce the directions first swing clockwise to N and then change back to a more easterly direction, albeit this is not consistent on consecutive tides. During the flood the flows remain weak and are shown to turn in an inconsistent manner.

This general pattern of flow is also illustrated in Figure 8, which shows the hourly flows along a transect along the east side of the Harbour Approach Navigation Channel on a spring tide.

- **AWAC 2 - Deep-Water Berth:**
  - Flow speeds are significantly greater than at AWAC 1;
  - Low water and flood tide flows are generally low being for the most part less than 0.3 m/s on both spring and neap tides. The peak flood flow occurs about 1 hour after LW with flows up to about 0.5 m/s for a short period of time;
  - Ebb flows are considerably faster than the flood, particularly from HW to HW + 4 hours. During this period spring tide flows exceed 1 m/s and depth average flows are consistently around 0.9 m/s. Neap flows follow a similar pattern with peaks around 0.7 m/s and depth average flows of 0.6 m/s;
  - From HW - 2 hours to HW and then during the peak ebb flows directions are consistently just W of S;
  - From HW + 4 to HW - 2 the neap flow direction is centred around NNE. However, on springs the flows steadily rotate clockwise from the southerly direction through N back to the general S direction.

Figure 9 shows the flow speeds and directors at hourly intervals for a transect moving inshore near the head of Princess Alexandra Pier. This plot again shows the highest flood flows occur just after LW, with low flows occurring for the rest of the flood. The plot also shows the spatial development of the flow pattern during the flood tide. As the tide rises the area of low flows moves away from the Pier, as an eddy increases in size with flows in a N - NE direction at the offshore end of the transect but turning to a general SW direction inshore.

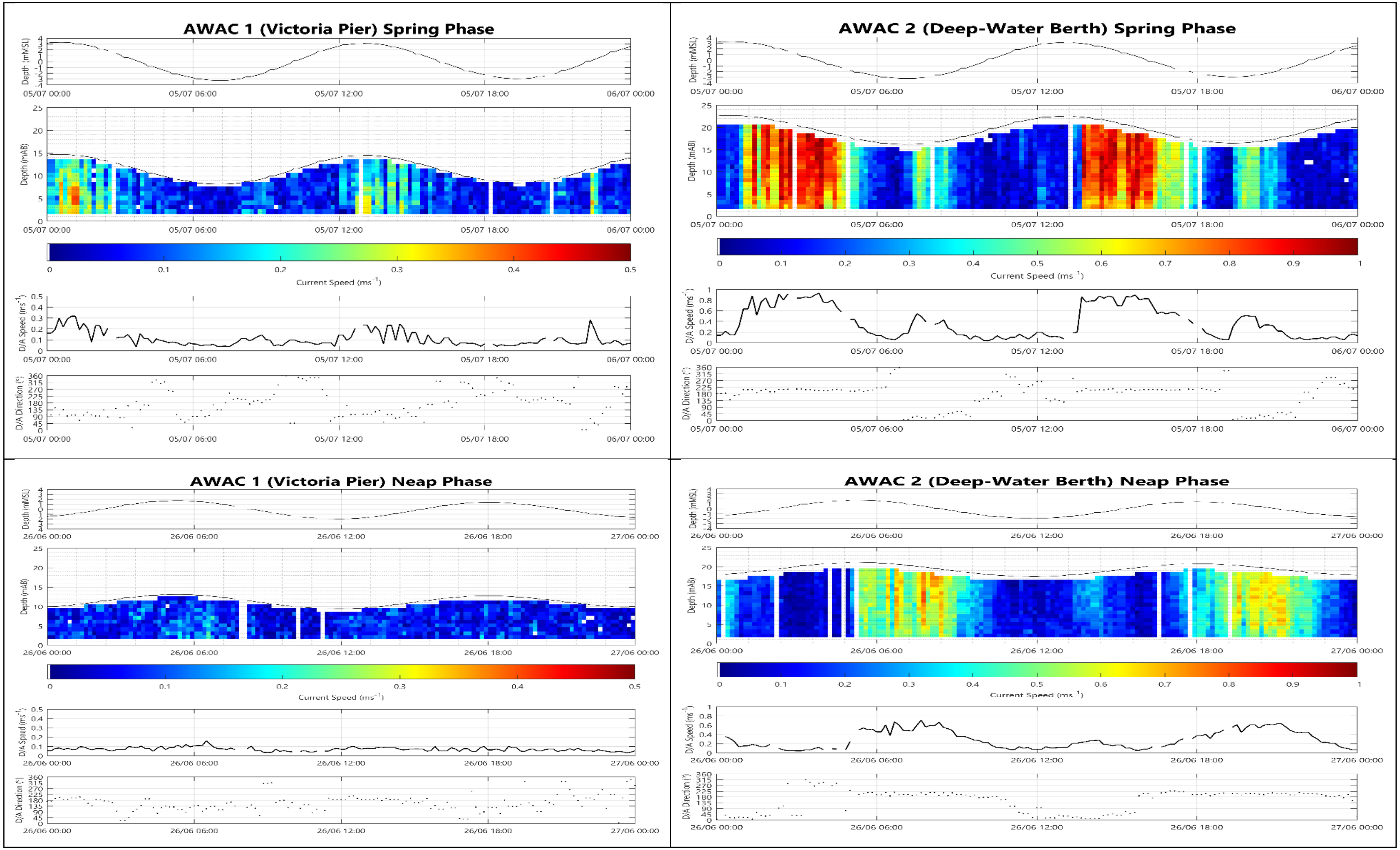


Figure 7. Flow speeds and directions for mean spring and neap tides at AWAC Locations 1 and 2

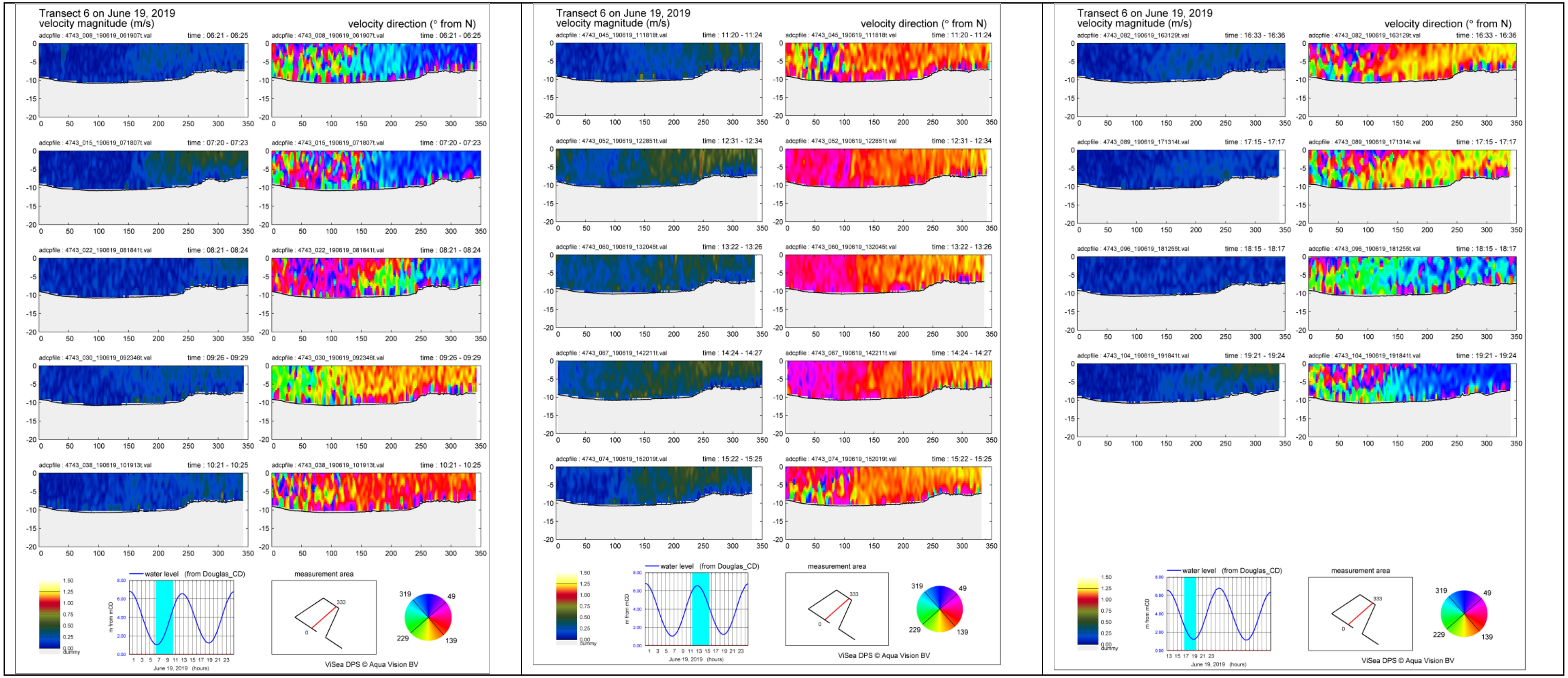


Figure 8. **Flow speeds and directions - Transect 6 - spring tide**

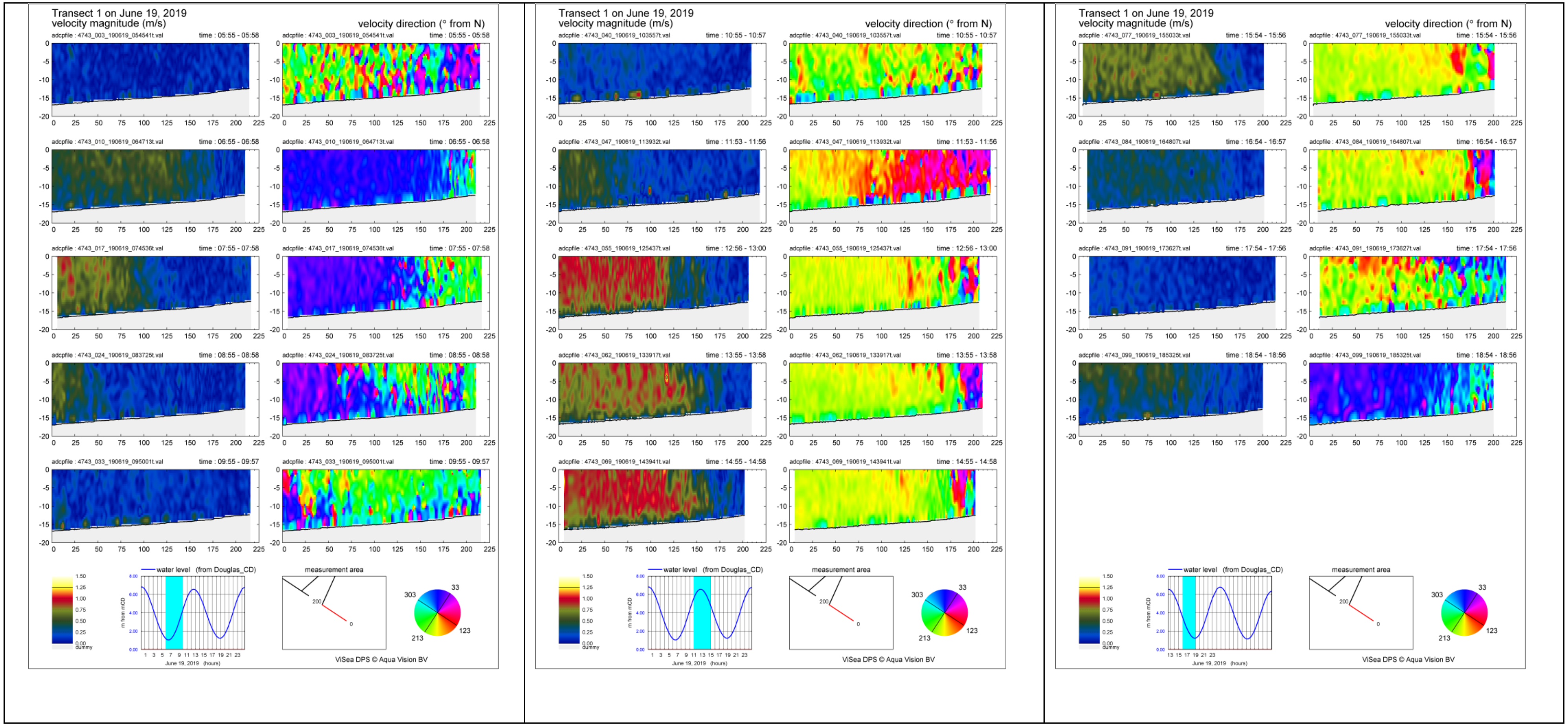


Figure 9. Flow speeds and directions - Transect 1 - spring tide

The high flows on the first four hours of ebb are evident over the outer three quarters of the transect before reducing quite suddenly inshore. The high flows are associated with directions just W of S, whist the slower inshore flows are moving in a general NE direction, again indicating a reversal in flow. Similar detailed plots are provided for the other transects in Appendix A.

Overall, these flow measurements show a complex flow regime in and around the entrance to Douglas Harbour. Areas of both high and low flows occur, with spatially varying size and location of eddies, at different states of the tide. These conditions will influence navigation practice at different tidal states. They also indicate that construction of the quay for the Deep-Water Berth may change the flow conditions within the approaches to the Harbour and the proposed potential Victoria Pier cruise berth.

2.4 Wind climate

Winds in the Irish Sea are generally from the W and SW for most of the year, though in spring there is an increased incidence of winds from all directions. In winter, there is a 20% chance of winds exceeding Beaufort scale 7 to the E of the Isle of Man, increasing to 25% around the rest of the island, whilst in the summer the frequency is reduced to 2%. This clearly indicates the wind is significantly more benign during the period of likely cruise ship calls at Douglas than for the Winter months.

The wind climate has been generated using the ABPmer SEASTATES metocean tools for the location outside Douglas Harbour (54.06°N, 4.40°W), as shown in Figure 10.

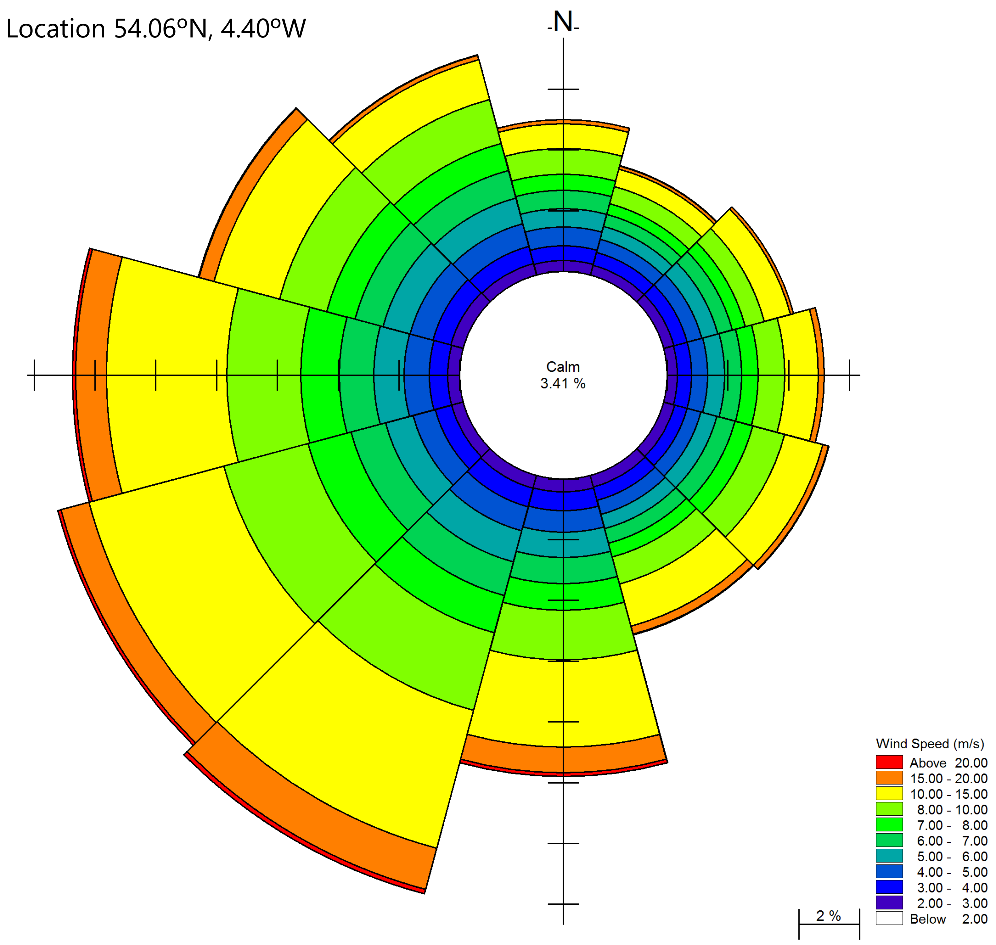


Figure 10. Wind rose for Douglas Harbour (SEASTATES)

The wind rose shows that the winds predominate from the W to SW directional sectors. Winds blowing over sea fetches that are likely to cause wind sea waves at Douglas are shown to occur for around 30% of the year, with peak wind speeds generally between 15 and 20 m/s. As noted above these winds are more likely to occur during the winter months.

It is interesting that the Douglas Harbour notes within the Reeds Nautical Almanac (Du Port and Buttress 2010) indicate that mooring (in Douglas Harbour) can be made very difficult in NE winds; i.e. it is advised that mooring on the inner end of Battery Pier is 'untenable' in NE/E winds.

2.5 Wave climate

Waves in the Irish Sea (wind and swell) are typically from the SW, propagating from the Atlantic Ocean, through St Georges Channel. However, during winter months the wind can swing to NE/E due to the seasonal trend for Polar Continental weather masses from Scandinavia. Dominant wave heights and directions (combined sea and swell waves) extracted from the SEASTATES analysis for the period 01/01/1979 to 31/12/2018 (40 years) at selected locations are shown in Figure 11.

The point locations selected indicate the variation in wave climate (wind wave and swell combined) in the following areas, relevant to the present study:

- Around Victoria Pier (Point 5) to determine the wave climate at the berth: Note reflections from the quay (or the vessel) are no included in the results. Point 1 is located to determine the potential wave effects that might affect sediment transport from Douglas Bay towards the new berth;
- In and around the Harbour entrance channel to determine the variation in likely wave climate in the area of vessel manoeuvring/turning to Victoria Pier and the Harbour, accounting for the sheltering effects of the existing piers and the bathymetry around St. Mary's Rock; and
- At locations in the vicinity of the potential Deep-Water Berth and its approach.

The following sections provide a summary of the long-term wave conditions for these areas.

2.5.1 Victoria Pier

The analysis indicates that at locations within the shelter of Princess Alexandra Pier, (i.e. Points 1, 5 and 6) the wave effect is reduced to a single 22.5° wind sector at each location. For the new Victoria Pier berth and its immediate approach all waves are minimal except from ENE, showing the Pier and local bathymetry in Douglas Bay provide significant wave protection except for this 'narrow' directional sector.

At Point 1, slightly further away from the shelter of the Pier the predominant wave energy is restricted to the directional sector centred on ESE. There is negligible wave energy to add to any tidal flows to enhance any tidal sediment movement towards the new berth.

Long term mean significant wave heights are shown to be generally in the range 0.22 – 0.28 m, with most wave conditions during the cruise season less than 0.3 m, with a likely annual wave up to around 1.95 m at the Victoria Pier Berth. The peak significant wave height from the 40-year hindcast record was about 3 m at the proposed new berth, based on the results of all directional information. Such large waves are more likely during the Winter (non-cruise months) and should such storms be predicted it is unlikely that cruise vessels would actually call at Douglas.

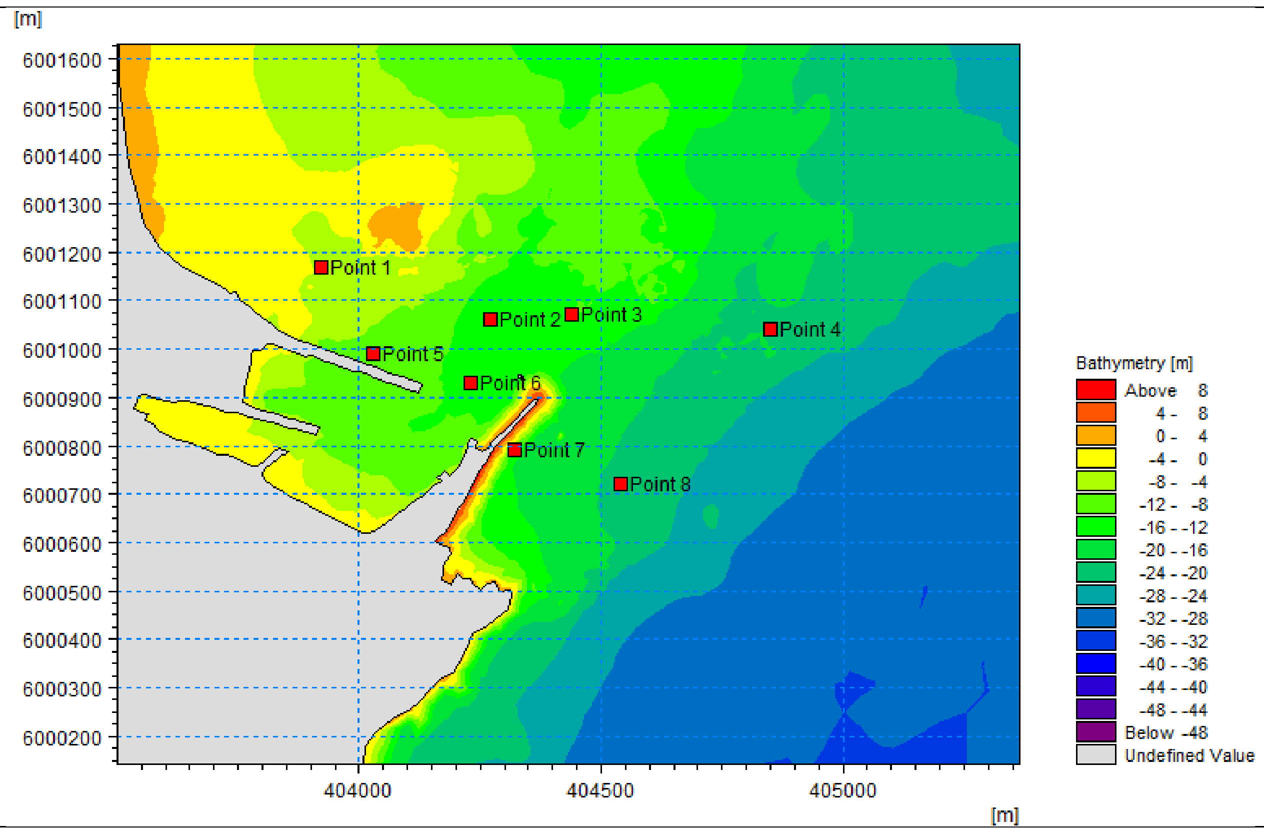
2.5.2 Harbour Entrance Channel

In the area of the approach (Point 4) and the outer end of the Entrance Channel (Point 3) the wave climate is dominate by waves from the ENE – SSW. Approaching Princess Alexandra Pier, the area is increasingly sheltered from the more southerly sector. The dominant wave direction therefore swings anticlockwise, through E beyond the end of the Pier to NE within the length of the Pier. Within this approach the mean significant wave height reduces relatively uniformly from around 0.72 m down to 0.25 m. The annual return period wave condition at the same locations reduces from 4 m to 1.5 m.

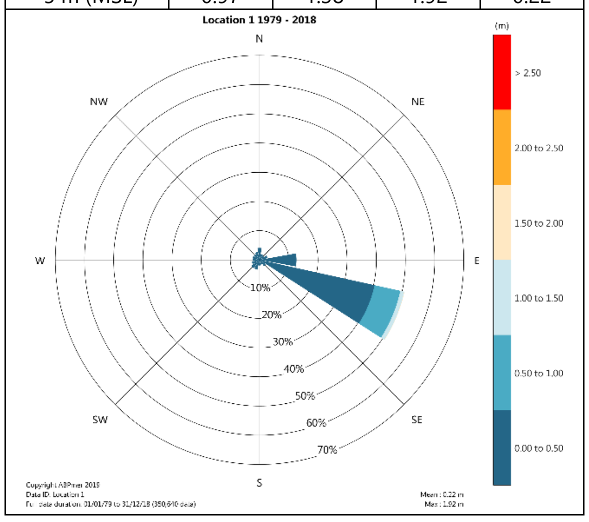
This pattern of waves suggests vessels entering and leaving the port will be subject to anticlockwise wave induced rotational forces on top of the flow and wind forces and these will vary as the vessel manoeuvres to and from the harbour and the proposed Victoria Pier Berth.

2.5.3 Deep-Water Berth

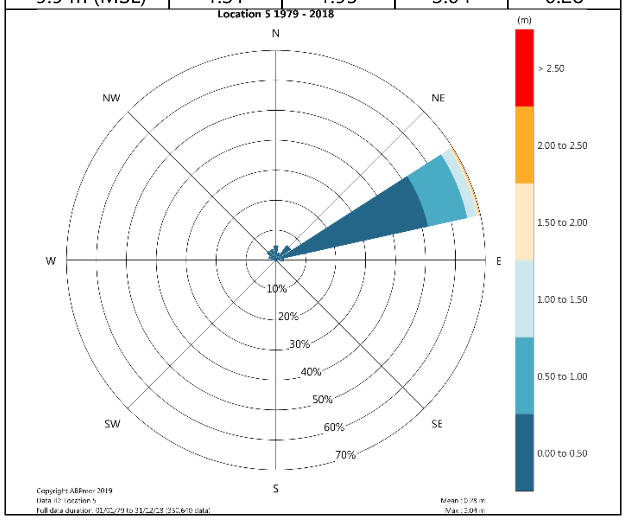
In the deep-water, Points 4 and 8, have almost identical wave climates, whereby the wave conditions are not influenced by the Harbour infrastructure. Here, mean significant wave heights are around 0.7 m, with annual significant wave heights of about 4 m. The peak significant wave heights in the long term hindcast are shown to be in excess of 6.5 m. These conditions will be characteristic of the wave climate that would 'impinge 'on the Deep-Water Berth structure. It is likely that the new structure, constructed at its maximum extent would also provide some additional shelter to the outer Harbour Entrance Channel, particularly for waves from the sector SE to E thus altering the navigation conditions attributable to wave effects in the Harbour approach navigation channel.



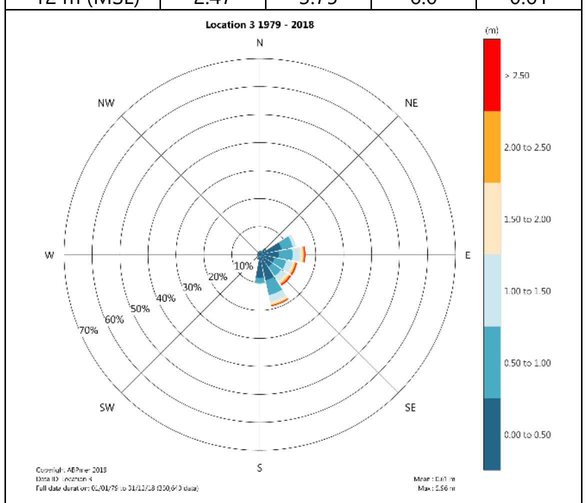
Location 1	Hs (m)			
Depth	10:1	1:1	Max	Mean
-5 m (MSL)	0.97	1.38	1.92	0.22



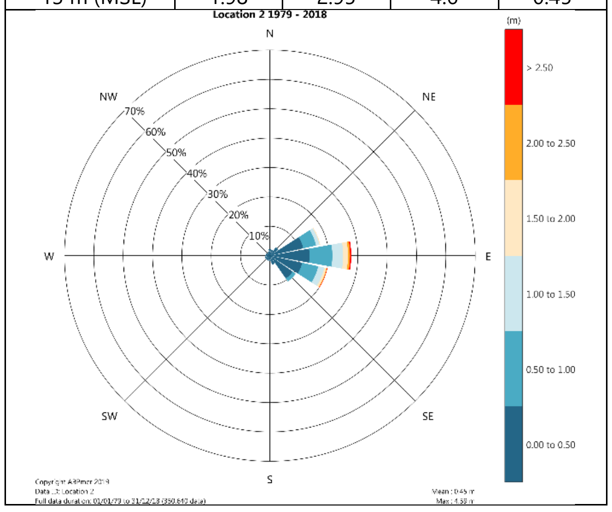
Location 5	Hs (m)			
Depth	10:1	1:1	Max	Mean
-9.9 m (MSL)	1.31	1.95	3.04	0.28



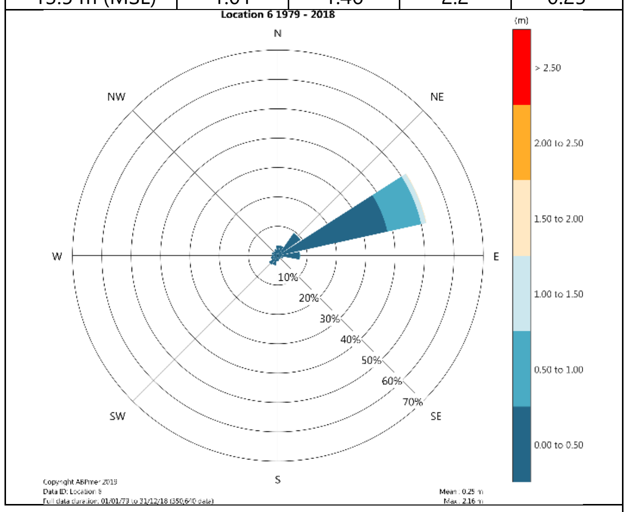
Location 3	Hs (m)			
Depth	10:1	1:1	Max	Mean
-12 m (MSL)	2.47	3.75	6.0	0.61



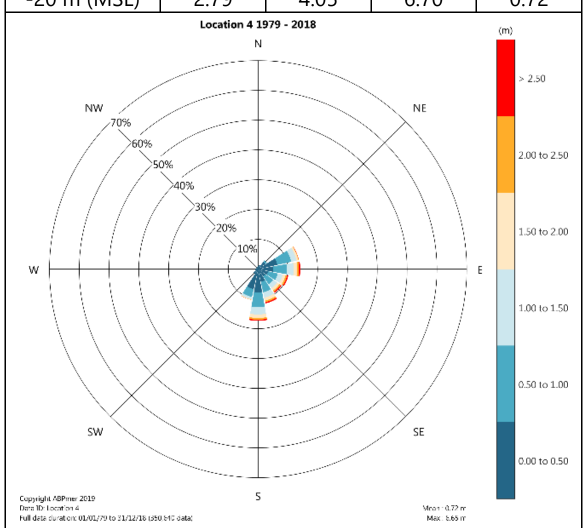
Location 2	Hs (m)			
Depth	10:1	1:1	Max	Mean
-13 m (MSL)	1.98	2.95	4.6	0.45



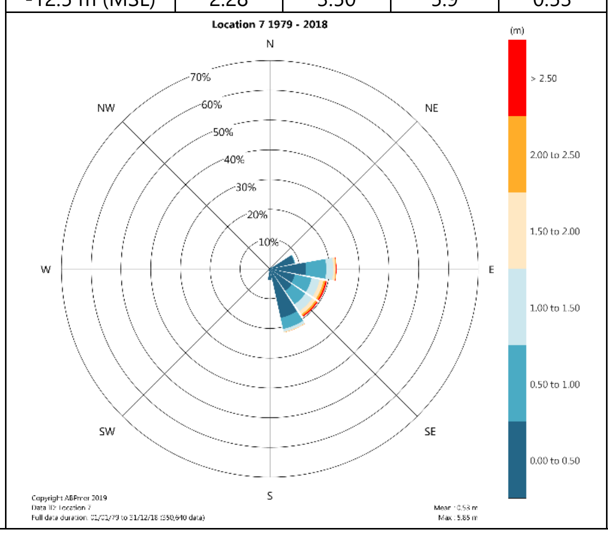
Location 6	Hs (m)			
Depth	10:1	1:1	Max	Mean
-13.5 m (MSL)	1.01	1.46	2.2	0.25



Location 4	Hs (m)			
Depth	10:1	1:1	Max	Mean
-20 m (MSL)	2.79	4.05	6.70	0.72



Location 7	Hs (m)			
Depth	10:1	1:1	Max	Mean
-12.5 m (MSL)	2.28	3.50	5.9	0.53



Location 8	Hs (m)			
Depth	10:1	1:1	Max	Mean
-21 m (MSL)	2.70	3.95	6.50	0.70

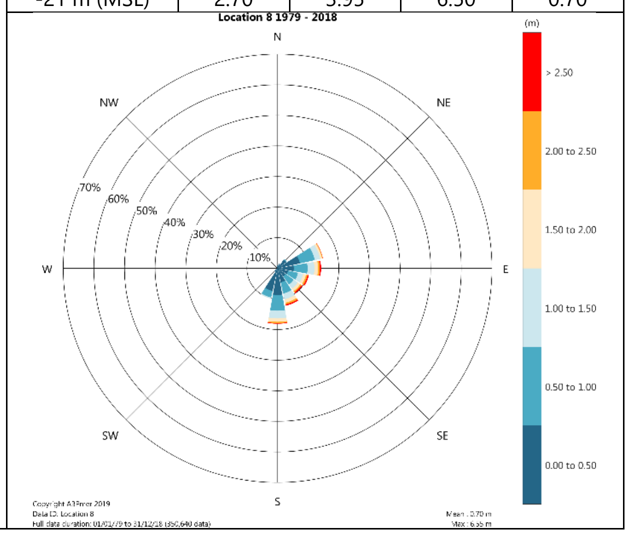


Figure 11. Wave Roses at selected locations (40 year SEASTATES hindcast)

2.6 Douglas wave measurements

To provide local calibration of the transformation of the hindcast wave climate to the locality of Douglas a time series of significant wave heights, maximum wave heights, wave period and direction were recorded for the same 30-day period as the flow speed and directions at the same locations. The calibration of the wave model against this data is provided in Appendix B.

The time series of the recorded data is shown in Figure 12 and Figure 13-for the AWAC 1 and AWAC 2 monitoring locations, respectively.

The plots show a period of wave activity from about 22 June to the end of June 2019 at both locations. This activity was associated with a period of consistent easterly wave directions at AWAC 1 and SE directions at AWAC2. Both wave directions were associated with local winds from the sector NE - SE with speeds of 10 – 20 knots (around 5 – 10 m/s) at the Douglas Breakwater. This period also coincided with neap range tides. During the period a maximum wave height of 2.5 m was recorded at AWAC 2, east of Princess Alexandra Pier with a significant wave height of 1.5 m. The same event resulted in a maximum height of 1.1 m (significant wave height 0.7 m) at AWAC 1 in shallower water directly exposed to a NE direction but sheltered from the east.

The peak wave period (Tp) generally varied between 3 and 5 seconds with a Tz (Zero Crossing Period) consistently around 3 seconds at both locations. These periods indicate the waves were generated by the local winds and were not created offshore by swell conditions.

The outer location (AWAC 2) also recorded two other periods of wave activity at the very end of June and around 18 July that were no recorded at AWAC 1. These events were associated with winds from the SW and West respectively creating waves from the south which were sheltered AWAC 1 by Princess Alexandra Pier.

The maximum peak wave periods (Tp) recorded were generally between 9 and 12 seconds at both locations. All were associated with significant wave height of less than 0.5 m at AWAC 2 and less than 0.2 m at AWAC 1 in the entrance to the Harbour.

During the period of measurement, the maximum wind speed at Douglas Breakwater reached 30 knots (e.g. 15 m/s) on two occasions, both building up from a consistent period of winds from the NW, hence blowing offshore across the shallower areas of Douglas Bay. Wave heights were small, due to the limited fetch length and sheltering of the measurement sites from this direction by St. Mary’s Rock and Princes Alexandra Pier respectively.

These measurements clearly show that the local wave climate in and around the harbour is significantly influenced by the Harbour structures and the shallow area around St. Mary's Rock.

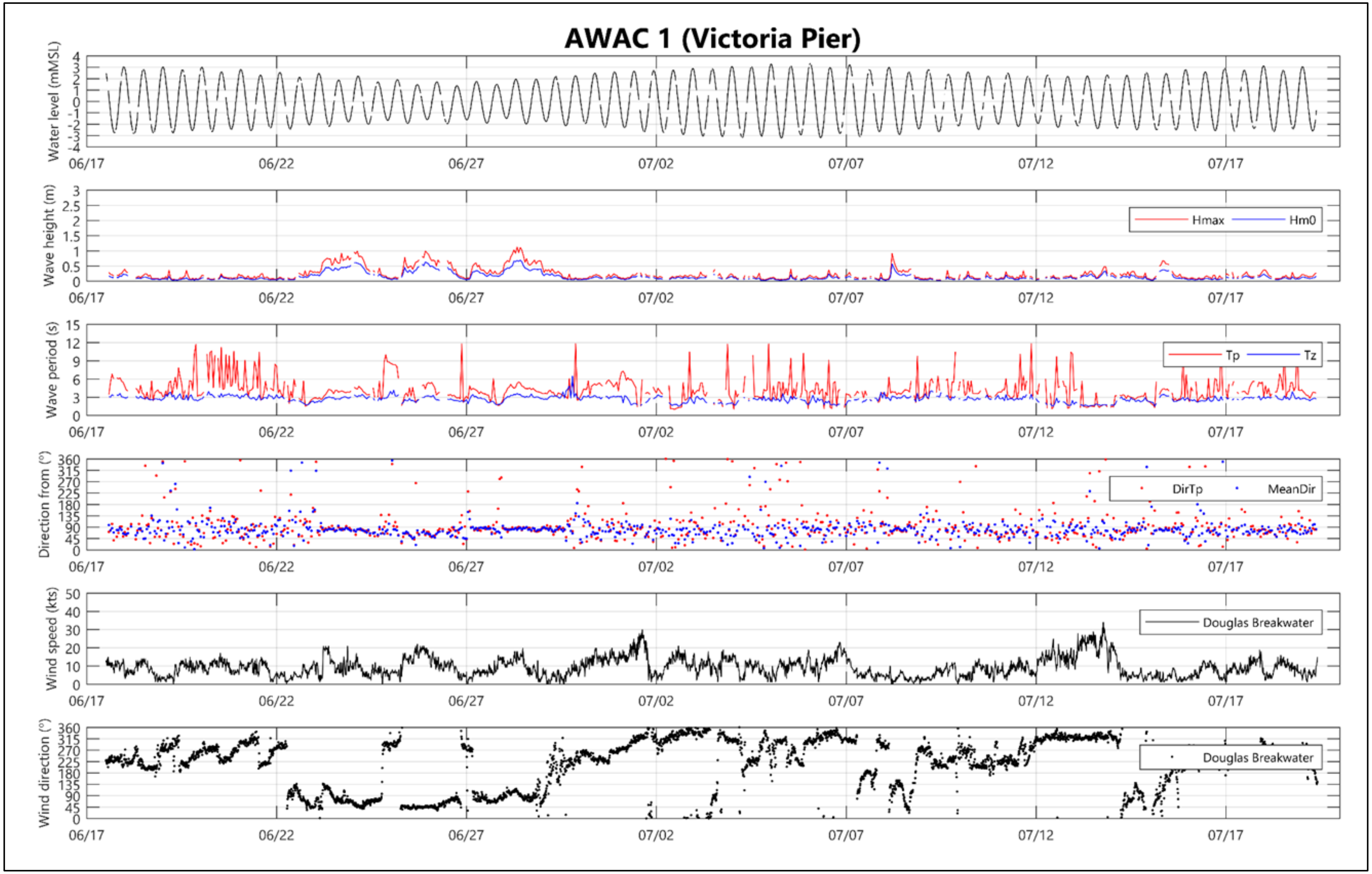


Figure 12. **AWAC 1 (Victoria Pier) wave parameters**

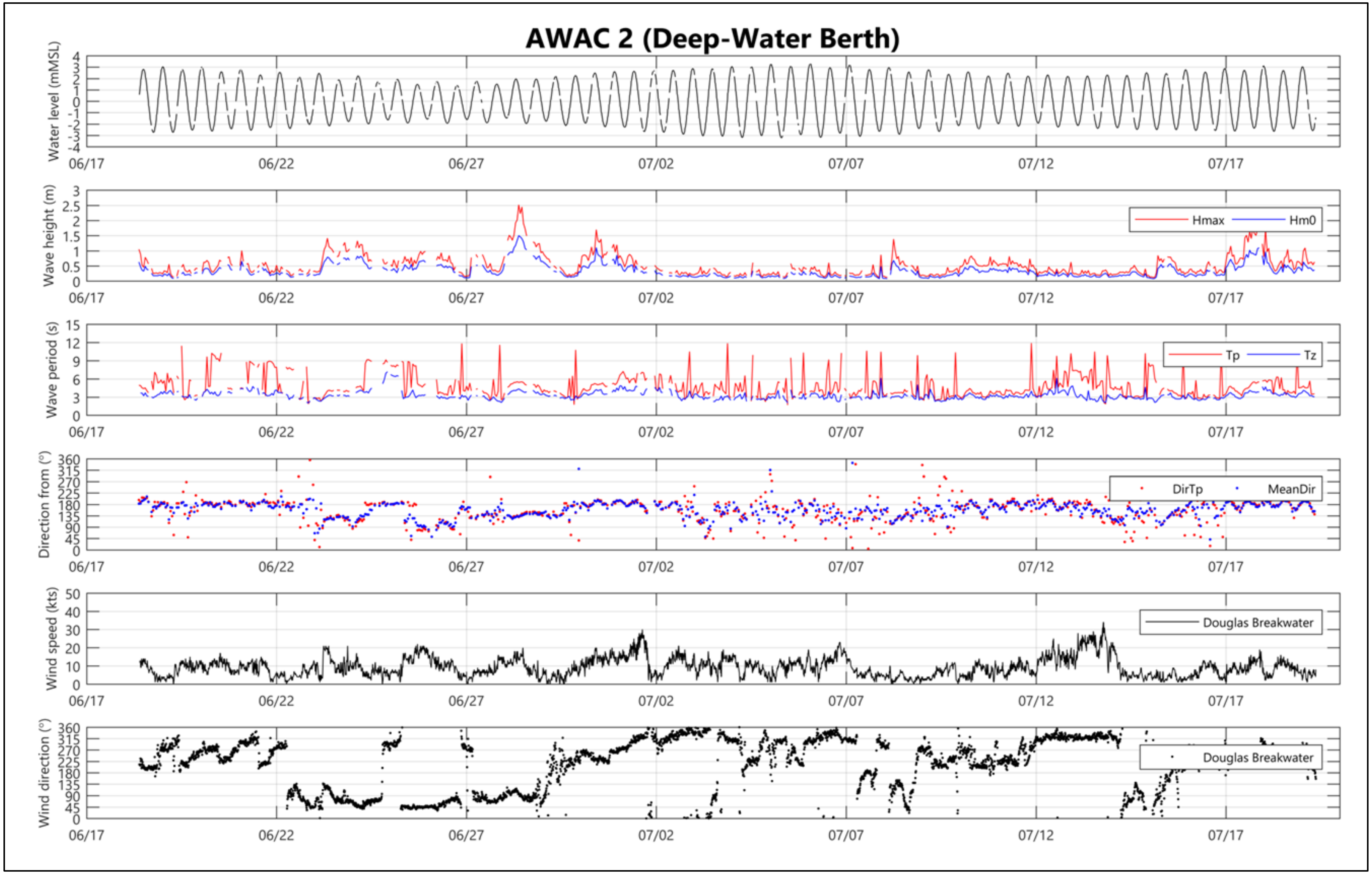


Figure 13. **AWAC 2 (Deep-Water Berth) wave parameters**

2.7 Sediments and sediment transport processes

Offshore from Douglas, the sediment pathways are in a predominantly NE direction. Offshore sediment transport near Douglas Bay was found to be 50-100 m^3/m/year by Price *et. al.* 2013.

Sandstone is the main terrestrial substrate near Douglas. In Douglas Bay the coastal sediment types, as documented in regional mapping by the British Geological Survey (BGS) vary between gravelly Sand (gS) and slightly gravelly muddy Sand ((g)mS) (Hawkins *et. al.* 2013). These predominantly large sediment sizes are indicative of high wave-energy and/or high levels of tidal flow as there is a strong correlation between maximum spring tidal currents and mean sea bed stress.

The mud seen at times within the harbour is most likely the result of fluvial sediment deposition from the River Douglas that settles in the more quiescent areas of the harbour. These conditions mainly occur within the marina and inner harbour. Some sedimentation in the outer harbour around the extremities can occur at the time of high freshwater flows and low wave activity. However, much of this material is considered to be dispersed during high wave energy conditions and/or displaced from the centre of the harbour by an '*ad hoc*' dredging programme (mainly by bed levelling). Sedimentation is therefore generally low and likely to be 'sporadic' and temporary throughout the outer harbour. No dredging of any significance currently occurs within the Harbour Approach Channel.

To define the bed sediment type in the areas of the proposed new berths and the turning area in the Harbour approach for the current study, and to provide information for the sediment transport and sedimentation study, bed samples have been collected and analysed for their Particle Size Distribution (PSD). The locations of these samples relative to the bathymetry is shown in Figure 6. The PSD of the bed material at each site is summarised in Table 4. The full PSD curves for each sample are provided in the field survey report (Appendix A to this report).

Table 4. Summary of particle size distribution analysis of bed samples

Sample	Median Grain Size d_{50} (µm)	D_{90} (µm)	D_{10} (µm)	Fraction (%)		
				Gravel	Sand	Mud
Victoria Pier Area						
GS01	201	294	134	0.0	100.0	0.0
GS02	196	291	128	0.0	100.0	0.0
GS03	208	22384	125	14.5	85.5	0.0
Harbour Approach Area						
GS04	197	413	112	7.7	89.3	3.0
GS05	190	326	112	1.9	97.6	0.5
GS06	18725	26233	3740	95.8	4.0	0.2
GS07	9655	21402	185	68.1	31.9	0
Deep-Water Berth Area						
GS08	10511	21473	3472	99.6	0.4	0.0
GS09	Hard bed – No sample recovered					
GS10	333	568	192	0.0	100.0	0.0

Table 4 shows that in the vicinity of the potential Victoria Pier berth (Sample GS01 - GS03) the bed sediment is almost entirely well sorted sand with a median grain size (d50) of *circa* 200 µm (0.2 mm). The potentially mobile sand does marginally fine W to E as the water depths deepen. Towards the east end of Victoria Pier there is evidence, both of a small proportion of mud (less than 3%) and gravel (up to 14. 5%) towards the deeper water areas. The finer muds will have settled from the water column and are likely to be transient, whilst the gravel is likely to be non-mobile and part of the underlying geological strata.

Within the deeper water of the Harbour Approach the bed sediment (samples as GS04 – GS07) varies from predominantly sand on the western side of the channel where depths are of the order of 8 m below CD to predominantly gravel in the deeper areas below 10 m below CD. In the gravel area the median grain size of 9 – 27 with a sand size proportion of 32% and 4% for the two samples respectively. The sand samples GS04 and GS05 had a median grain size like those from the Victoria Pier area, but also included some gravel and a small proportion of mud.

East of Princess Alexandra Pier in the vicinity of the proposed potential Deep-Water Berth the sea bed was generally 'hard' compacted gravel below depths of around 15 m below CD, which was difficult to sample and comprised very little fine sediment. The PSD was similar to the gravel within the Harbour Approach Channel. At the most southern sample location where depths shallow (sample GS10) the material recovered was 100% sand, however, much coarser than the Victoria Pier area, with a median grain size of 333 µm (0.33 mm).

Image 4 shows a comparison of the sea bed at AWAC sites 1 and 2, respectively, in the predominantly sandy area and that adjacent to the gravelly area where a sea bed sample could not be obtained.

Image 4. Seabed character at location AWAC1 (left) and AWAC2 (right)

Both images generally show clear water above the bed and little evidence of mobile material at the surface or signs of sedimentation. This analysis of the spatial distribution of the character of the sea bed suggests there is little mobile sediment in the area to be moved around by the tidal hydrodynamics and waves to form a supply for sedimentation in the new berths and approach area. The largest source of sediment is restricted to *circa* 200 µm (d50) sand from the shallow areas immediately adjacent to St. Mary's Rock.

The locations of the gravel indicate non-mobile bed material that is highly compacted forming an 'armour' layer to the bed, with most fine material, either trapped below or removed over time. This material appears to be the underlying geological strata and not mobile material. It is also possible the sand at sample sites GS04 and GS05 is a geological layer above the gravel.

As noted above the water column is clear both near the Harbour and the Deep-Water Berth area to the east. This is confirmed by the water column sampling undertaken at the time of the field survey instrument deployment and during the mobile ADCP survey, see Appendix A. For the most part, the concentration of total suspended solids was less than 10 mg/l at all states of the tide (and often considerably less) particularly at location AWAC2. A single sample with a total suspended solid concentration of about 37 mg/l was, however, collected from near the bed. It was noted from diver video that impact on the bed caused by the instrument package did create a 'thin' near bed plume which quickly resettled and/or dispersed.

In the Harbour Approach Channel (around the location of AWAC1), samples collected at LW showed concentrations up to 27 mg/l, but these were only evident for a short period of time.

These trends for very low suspended sediment concentrations with a few high readings occurred at both sampling locations, although they were slightly more variable at AWAC1 compared to AWAC2. Similar trends were indicated by the time series of turbidity readings recorded at the instrument frames on the sea bed, see Appendix A. No calibration to suspended solids was obtainable for these instruments which showed such low turbidity readings.

These observations of the characteristics of the sea bed sediments and low suspended matter transported in the water column indicate that any sedimentation that could occur in the proposed deepened berth pocket at Victoria Pier is likely to be low as a result of the tidal dynamics.

3 Modelling

3.1 Models

The Danish Hydraulic Institute (DHI) software package MIKE21FM (Flexible Mesh) has been used for this project. This package was specifically, developed for applications within open ocean, coastal and estuarine environments. The MIKE21 Hydrodynamic (HD) model is used to simulate the variations in water level and two-dimensional depth averaged flow within the study area. These data provide the input forcing conditions to the MIKE21 Sand Transport (ST) module to calculate the resultant transport of sand bed sediment. The MIKE21 Spectral Wave (SW) package has also been used to simulate the transformation of wind-generated waves and swell waves from offshore regions into coastal environments.

The specific setup, calibration and validation of these models is presented in detail in Appendix B. Figure 14 shows the general extent of the models and the variation in mesh resolution allowing finer, local detail to be represented around Douglas Harbour.

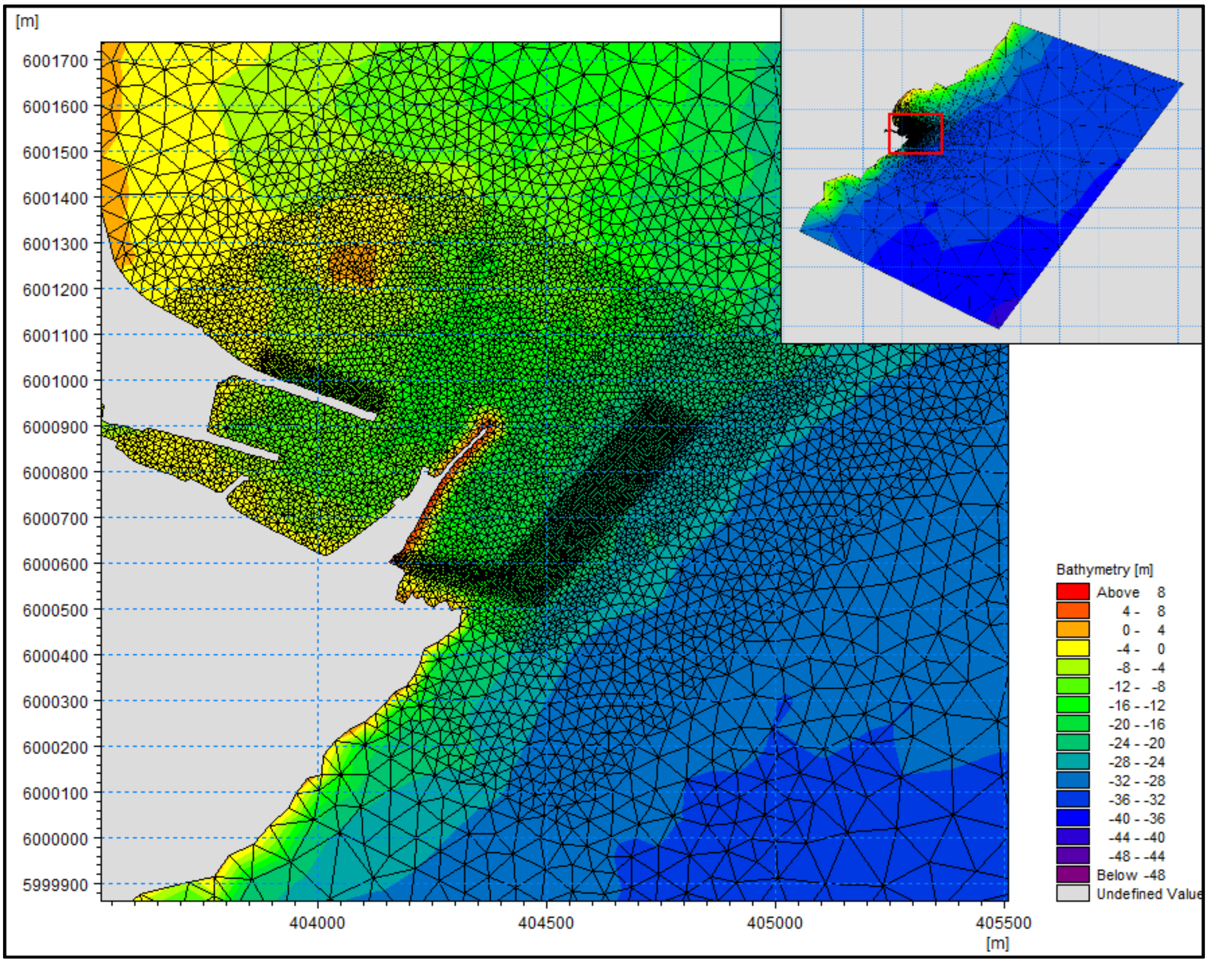


Figure 14. Extent of model and the local resolution of the model grid

Utilising these modules provides a representation of how the proposed berth developments will affect the hydrodynamic, wave and sediment regimes in the approaches to Douglas Harbour and provide the environmental forcing data to inform the separate navigation ship simulation studies.

3.2 Model calibration and validation

These models have been calibrated and validated against a set of field measurements from the locations shown on Figure 6. The data consists of:

- Two static instrument package locations, recording for *circa* 30 days;
- Flow speeds and directions through the water column;
- Near bed temperature, salinity and turbidity;
- Wave parameters: Significant wave height (Hs), maximum wave height (Hmax), peak and zero-crossing wave period (Tp and Tz); and
- Six mobile ADCP transects, measuring the flow speed and direction through the water column on a typical spring tide.

These measurements are presented in full in Appendix A, with summary information provided in Section 2.

3.2.1 Flow regime

The full calibration of the models is reported in Appendix B. Figure 15 and Figure 16 provide examples of the calibration of water levels and flows for spring tides in the vicinity of the proposed Deep-Water Berth (AWAC 2) and for neap tides in the approach to the Harbour and the proposed Victoria Pier Berth (AWAC 1), respectively.

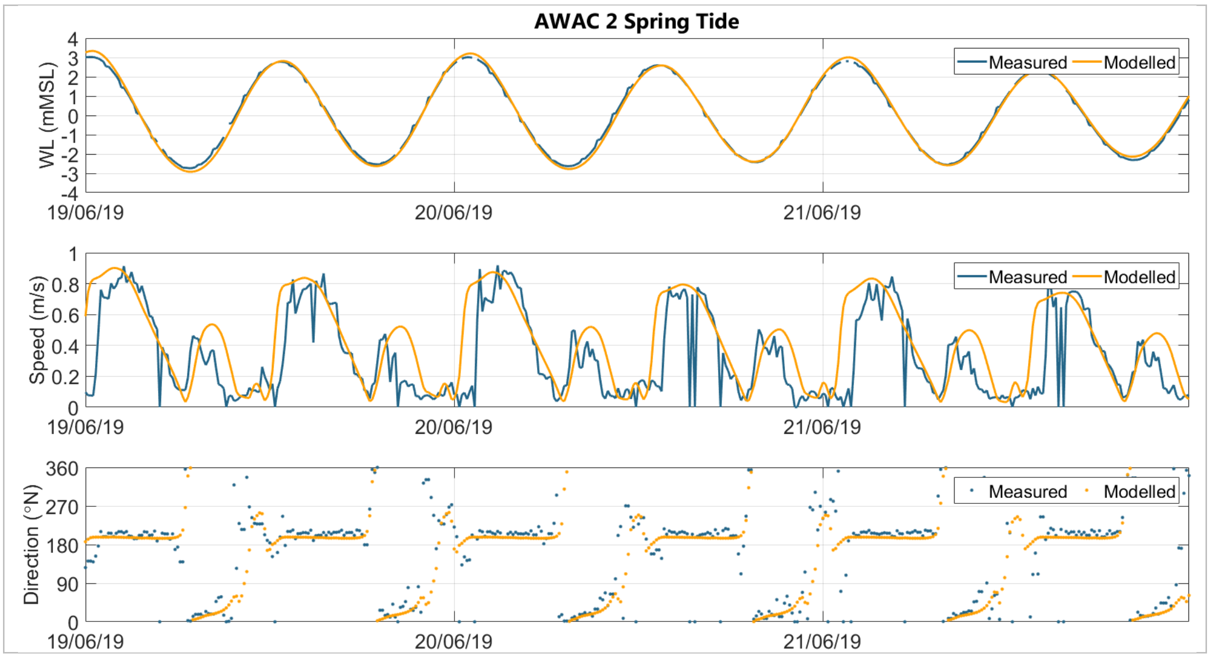


Figure 15. Spring tide calibration - Deep-Water Berth area (AWAC 2)

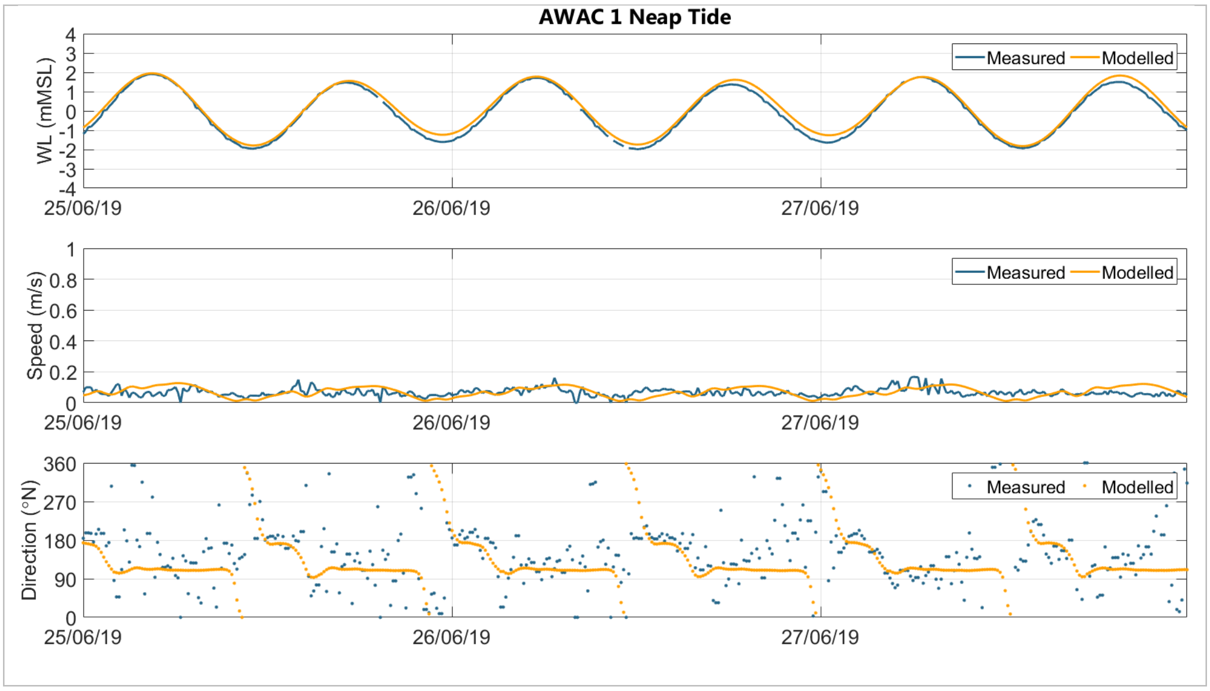


Figure 16 Neap tide calibration - Approach to proposed Victoria Pier Berth (AWAC 1)

These diagrams show the propagation of water levels is for the most part accurately represented in both phase (timing) and elevation. The greatest difference is an under representation of the neap tide LW elevations.

The model represents the 'sheltering' effects of the harbour breakwaters with respect to flow speeds and the directional characteristics even at low flows, albeit with less short-term directional 'scatter'. At the location of the Deep-Water Berth the pattern and magnitude of the tidal timeseries of both flows and directions are well represented.

Statistical analysis of the model calibration results shows that the overall mean difference in high and low water levels is within 3% of measured values. Mean flow speed differences were within ±0.04 m/s and directions within ±15° (with most within 10°); see Appendix B for the full analysis.

Validation of the model flow regime is provided in a spatial context by comparing the depth averaged mobile ADCP transect data with the equivalent from the model. Example transect comparisons are shown for the times of near peak flood (HW -1 hour) and ebb (HW +2 hours) for the spring tide in Figure 17 and Figure 18, respectively. The full comparison set at hourly intervals, relative to HW, is shown in Appendix B.

Figure 17 on the flood, for the most part, shows good agreement of the trends along each transect (see Figure 6 for locations and direction of travel along the transect). It is noted that the field measurements recorded in close proximity to the end of Princess Alexandra Pier show directional instability, particularly at low flows, whereas the model directions are more consistent. This is a feature of the comparisons throughout most of the tide.

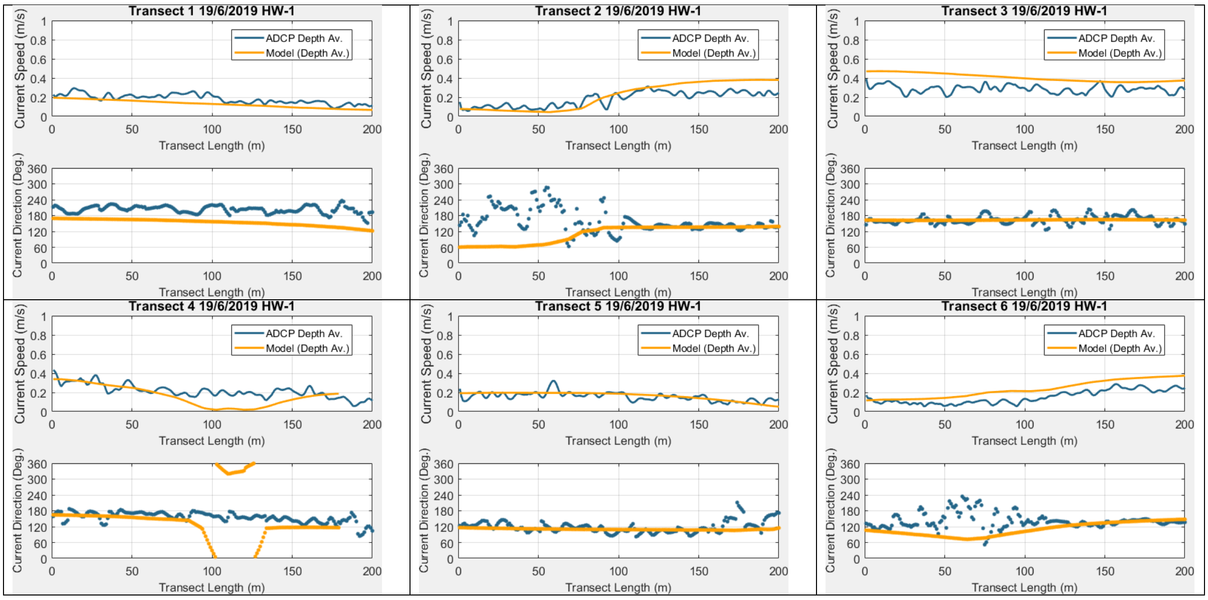


Figure 17. Model and ADCP measured transect flow comparison - FLOOD - Spring Tide – HW -1 Hour

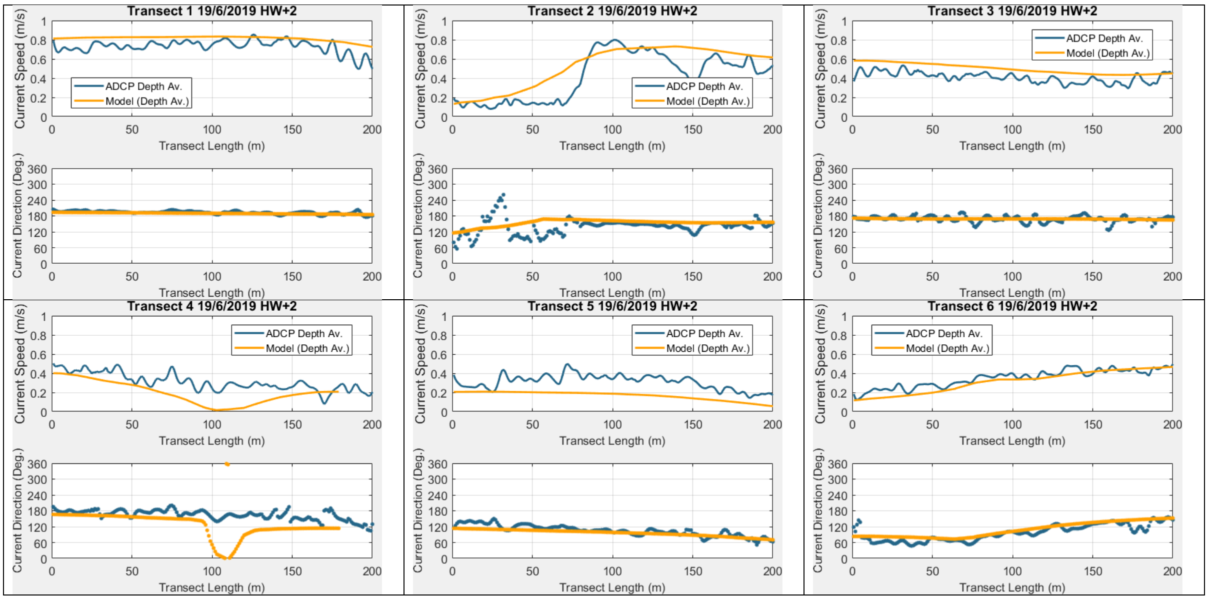


Figure 18. Model and ADCP measured transect flow comparison - EBB - Spring Tide HW +2 Hours

On the ebb, the model transect comparison with the field data is improved compared to the flood as illustrated by the example at the time of peak ebb flows (HW + 2 hours), Figure 18. This plot indicates three areas where the model does not completely replicate the field data:

- On Transect 2 the model shows a 'smoother' transition in flow speeds compared to the field data as the transect passes north of the Princess Alexandra Pier. The plot also shows the instability in the field directional data noted on the flood tide. This is a feature in the calibration on all tides.;
- On Transect 4, which passes close to the shallow edge of St. Mary's Rock, the model shows reduced flows and variance in directions centred around chainage 110 m. This is apparent throughout the tide. This discrepancy is an artefact of the model depth grid resolution not being able to correctly define the local bathymetry at the edge of St. Mary's Rock;

- Flow speeds are under-represented in the model at Transect 5 but generally follow the pattern for a reduction in flow approaching Princess Alexandra Pier. This discrepancy, however, only occurs for a short time as it is not apparent for the rest of the ebb tide.

Considering all data together the calibration and validation is very good and illustrates that the model will produce reliable evidence of the effects of the proposed new berth scenarios. Care will be required in interpreting the development effects with respect to directions around the end of Princess Alexandra Pier as the model does not fully capture the instability in the flows in this area. Also, the greatest discrepancies in the calibration occur at the times of very slow flows (generally well less than 0.2 m/s), i.e. flows that have the least effect on manoeuvring vessels.

3.2.2 Waves

The model was calibrated and validated for waves at the two static instrument locations over a spring neap cycle that contained the greatest wave activity recorded at the sites. The order of calibration is shown in Figure 19 for the significant wave height (Hs), Mean Wave Period (Tm) and the Mean Wave Direction (DirM). The plots (see Appendix B for full detail) show very good agreement at both locations. The timing of the 'set-up' and decay of the wave activity is well reproduced as is the change in direction through the period of wave activity, reflecting the change in wind direction.

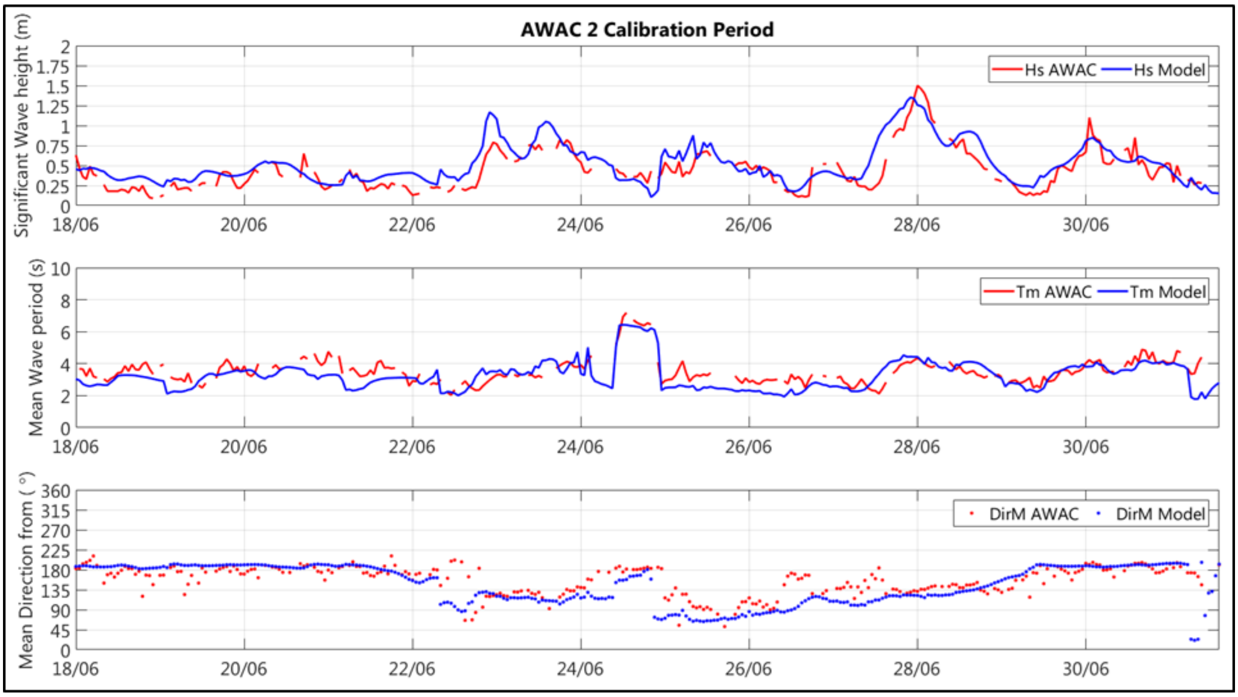


Figure 19. Modelled and AWAC2 measured wave height (Hs), period (Tm) and direction (DirM)

3.2.3 Sediments

The combined hydrodynamic and wave model has been used to drive a sand transport (ST) model, assessing the sediment transport potential across the study area. The full setup and verification of the ST model is detailed in Appendix B, with a general summary of the approach provided below.

The description of the sediment across the wider study area is informed by the regional mapping available from the British Geological Survey, with site-specific data provided by the analysis of grab samples collected during the oceanographic survey campaign (see Section 2.7 for further detail). Sensitivity tests on the ST model setup have been undertaken to consider the influence of changes to mean grain size and sediment coverage. In order to inform the wider siltation study, and to assess the potential effects arising from the two proposed berth development schemes, a mean grain diameter of 200 µm (fine/medium sand), has been applied. A variable coverage has also been used as input to the model, with a deeper sediment depth in the shallow inshore regions (approximately inside the -10 mCD contour), and a thin veneer of sediment across the wider, deeper parts of the study area. The rationale for this model setup is provided in further detail in Appendix B)

The generally limited (in both magnitude and extent) sand transport potential, as described in the conceptual understanding (Section 2.7), is well replicated by the model (see example output in Figure 20, where areas of erosion are shown in blue, and accretion in orange). Further detail of the sediment model performance is provided in the Calibration Report (Appendix 0). In summary, the modelling showed suspended sediment concentrations (when assumed to be constrained to within 0.5 m of the bed) of up to 16 mg/l, and averaging less than 2 mg/l, in the vicinity of the field measurements (i.e. of a similar magnitude to the available measured values (see Section 2.7)).

The influence of different wave events has been assessed and is described further in Section 3.3. The model shows little or no potential for sand movement under existing conditions at the proposed development locations and nearby approaches to the harbour. Flows are higher in the outer approaches and a small general potential for offshore movement of sand is indicated, should a sand supply exist at these locations.

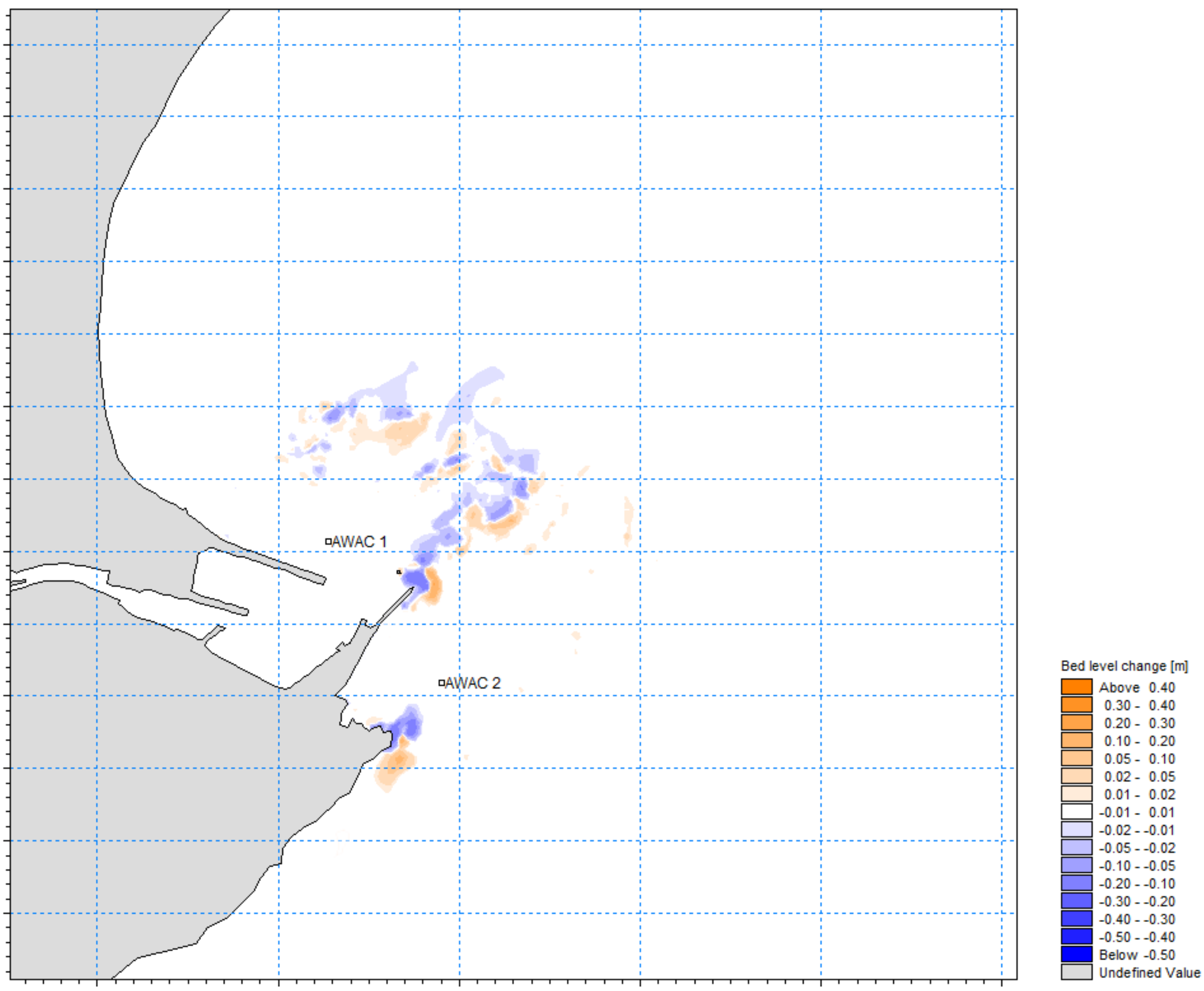


Figure 20. Predicted bed level change over a mean spring-neap tidal cycle, assuming an initial bed thickness of 0.2 m across the shallow embayment and 0.01 m across the remainder of the study area (see Appendix B)

3.3 Sand transport model sensitivity to waves

The ST model has been verified using a 'typical' cruise season wave event, as observed during the oceanographic survey campaign (June/July 2019). The sensitivity of the modelled sediment transport to a more extreme wave event (more typical of an annual winter storm) has also been considered and applied to inform the subsequent siltation study.

In order to assess this, the 40-year SEASTATES wave hindcast data has been analysed and a range of extreme wave events have been defined for the harbour region. From this, an annual (1 in 1-year) wave event has been extracted and used as input to the ST model. The predicted bed level change over a spring/neap tidal period, including the defined wave events, has been modelled.

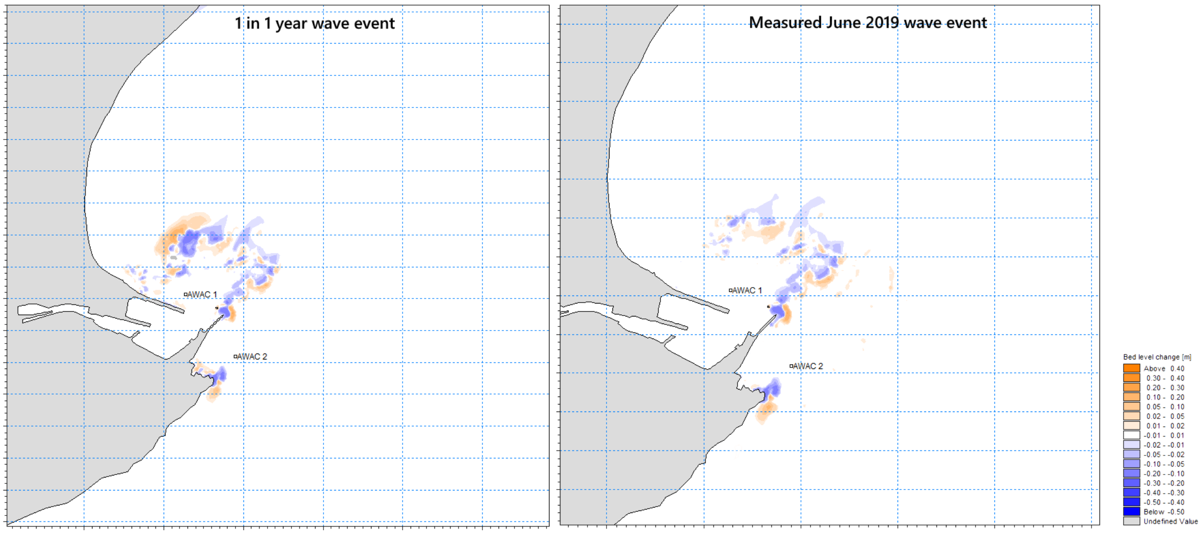


Figure 21. Sensitivity of modelled sand transport to extreme wave events

The comparison of model output provided in Figure 21 shows some small changes in sand transport under the two different wave conditions. For the smaller (summer) measured wave event – shown in the right-hand image – predicted areas of erosion, and associated accretion are shown in and around Douglas Head, along the entrance to the harbour (coincident with the boundary between sediment thickness boundaries) and around the outcrop at St. Mary's Rock.

When comparing against the equivalent result for the larger, extreme (1 in 1-year) wave condition, the locations of predicted change remain relatively consistent. The predicted magnitude of change around St. Mary's Rock is slightly increased, and the extent of predicted change extends closer inshore, towards the existing Victoria Pier and the shallow outcrop adjacent to Conister Jetty.

These differences are small, but it does suggest under annual wave conditions there is a marginally increased potential to move some sediment eastwards towards the area of the Victoria Pier, should the material be available inshore of St Mary's Rock.

3.4 Model representation of berth scenarios

Following the model calibration and sensitivity analysis the proposed berth scenarios defined in Section 1.1 were implemented in the model grid, suitably modified to represent the various structures and dredging. Figure 22 shows the deepened berth pocket in the bathymetry for the Victoria Pier Berth. No further modification to the bathymetry has been made.

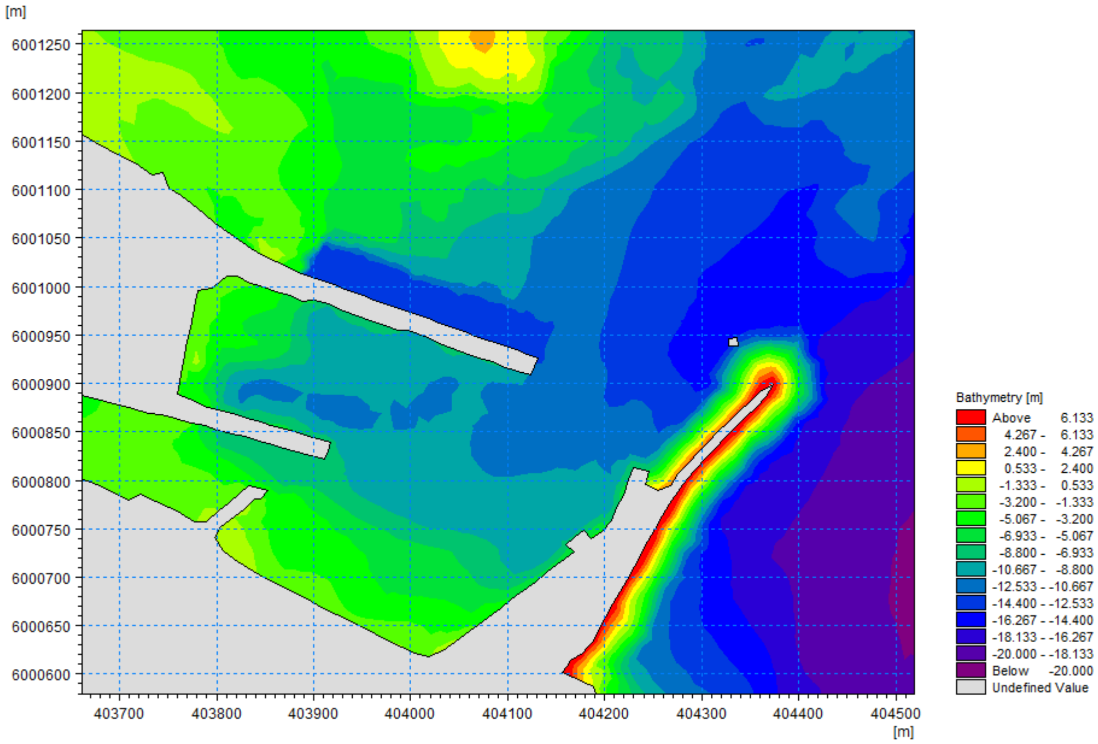


Figure 22 Bathymetric representation in model (relative to MSL) for the Victoria Pier Berth scenario

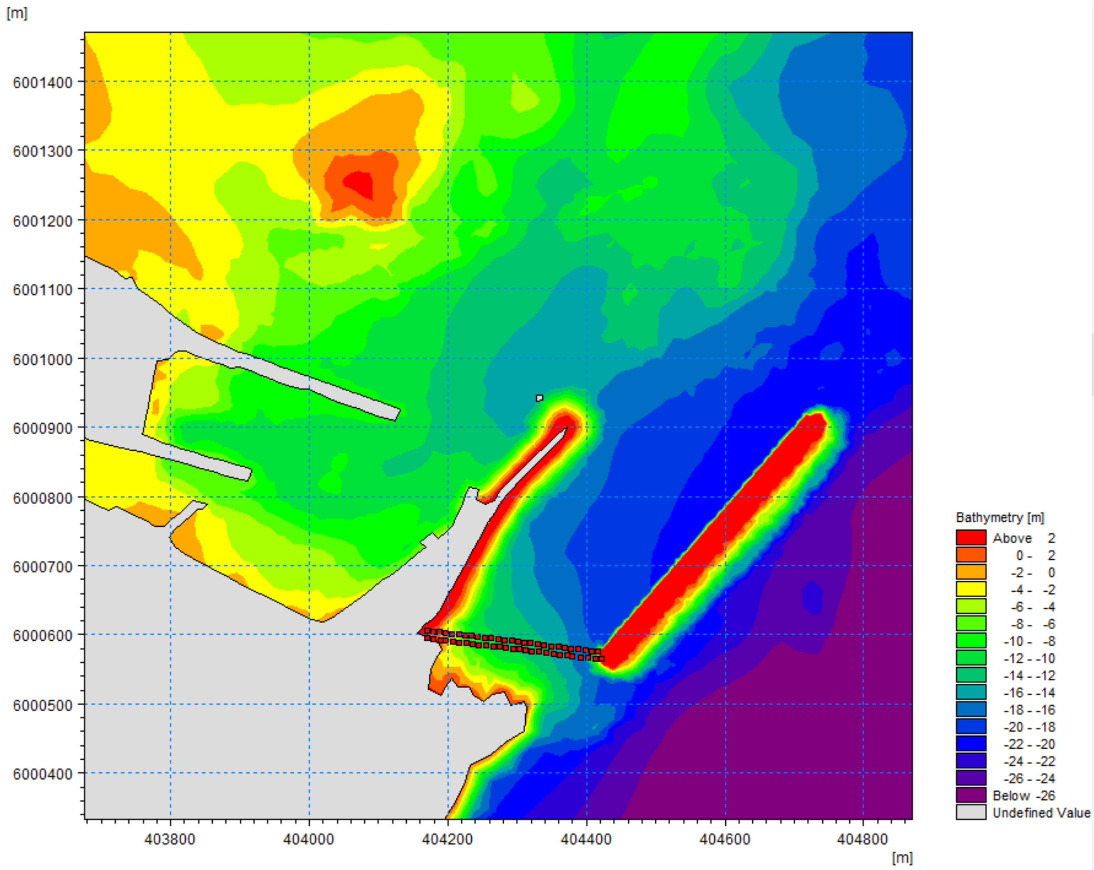


Figure 23. Bathymetric representation in model (relative to MSL) for the Deep-Water Berth scenario. (Pile locations shown schematically)

Figure 23 shows the equivalent representation of the Deep-Water Berth scenario. Here the pier is represented as a solid structure extending from the seabed to above the highest water levels. The rock/ man-made armour units on the outside of the pier are represented as a slope in the bathymetry at 1:1.5 (v:h) from the top of pier to intersect with the existing bathymetry. A bed roughness of 12.5 (Manning's 'M') has been incorporated in this area to reflect the relatively rough surface of the armour affecting the flow. The connection to the land (piled approach) is represented by 'pile bents' consisting of two 1 m diameter piles perpendicular to the axis of the approach at 10 m spacing along its length. Each pile is represented as an individual structure allowing their blockage effects to be modelled. The locations are shown schematically as red dots on Figure 23. No dredging is incorporated in this scenario.

The results of the modelling of these scenarios and the differences from the existing baseline are summarised in Section 4.

3.5 Model output presentation

For each proposed berth scenario, the absolute effects to the flows and initial bed level change are presented, as well as comparisons with the equivalent existing baseline conditions.

The most significant changes for the berth scenarios have occurred during spring tides. Neap tide changes, for the most part, are much smaller in both extent and magnitude but follow a similar overall pattern of change to the flows. For this reason, the modelling results for flows (magnitude and direction) and bed shear stresses have concentrated on the changes occurring on at least two consecutive spring tides, at the time of an approximate mean spring range, within the complete 15-day spring/neap cycle model run. Effects on erosion and accretion patterns have been assessed over the full spring/neap cycle (15 days), in order to take into account, the complete range of effects (relative to sediment accretion and deposition thresholds) from the variation in tidal ranges.

Two forms of output, described in the following sub-sections, are provided to illustrate the modelled hydrodynamic and sedimentary effects of the two proposed berth scenarios. These are:

- Plan (map) plots; and
- Timeseries plots.

Together, these forms of output present the spatial (plan) and temporal changes resulting from the two development proposals, on the different process parameters. This allows discussion of the berth scenario effects on port operations (e.g. effects on vessel manoeuvring) and potential for future sedimentation (hence any dredging requirements).

Figure 6 provides a plan for reference to the locations identified in the report, and the specific locations of timeseries model data, extracted for the purpose of assessing the temporal effect of the two proposed berth scenarios.

3.5.1 Plan (map) plots

These plots show the magnitude and vector form of the flows, accretion and erosion patterns, resulting from each berth scenario and how these are likely to change spatially, from the existing baseline conditions. The flow plots present the depth averaged flow speeds and directions, at the time of peak flows on the flood and ebb and around HW, to illustrate the most significant tidal effects.

Data for analysis have been extracted at hourly intervals from the model referenced relative to High Water (HW) at Douglas. However, only examples that illustrate the maximum changes from the baseline conditions or those that could affect vessel operations are presented in the following sections.

Full plan plot datasets for the existing baseline and Deep-Water Berth spring tide flow regimes are presented in Appendix E and Appendix F respectively. The effects of the Victoria Pier Berth scenario were for the most part negligible compared to the baseline; as a result, the full set of flow vectors have not been reproduced as an appendix. All changes of relevance are presented within the following sections.

Sediment erosion and accretion patterns for the sand substrate are shown as the cumulative resultant change at the end of the full 15-day spring/neap cycle, with the model outputs presented at the time of LW on a mid-tide, in each case.

These plots provide information on the extent of development induced change, as well as indicating the maximum magnitudes of change within the overall spatial extent. For the sand sediment modelling, the results indicate the distribution of indicative initial sedimentary effects (erosion and accretion), with the two proposed berth scenarios over a 15-day typical spring neap cycle, and how this differs from the existing situation. The results provide information on the proportional volumetric differences, in order to determine potential sedimentation rates, hence the potential for maintenance dredging. The results are directly comparable with those obtained for the existing baseline conditions, hence the individual effects of the berth scenarios can be assessed/discussed, both in relation to each other, and to the existing baseline conditions.

3.5.2 Timeseries plots

The hydrodynamic timeseries plots show the changes to the flow speed and direction, water levels and bed shear stress for a series of spring tides. On each diagram:

- Baseline results are shown using a solid **black** line;
- Scheme results are shown using a solid **red** line; and
- On the plots of bed shear stress, the thresholds for motion (**blue** dashed line) and suspension (**pink** dashed line) of 200 µm sand are indicated to allow interpretation of the likely movement of the typical bed sediment at the site.

The sediment modelling plots show the change in the bed thickness, as a result of the two berth scenarios, over spring tides and throughout the spring/neap cycle (for sedimentary effects).

The timeseries show the absolute magnitude of each parameter, and how these change through the tide (with varying water levels), whilst providing a comparison with the baseline conditions for specific locations. The locations are selected to highlight the specific scheme effects and to determine effects at a number of strategic locations; for example, the berth locations and the vessel manoeuvring areas.

4 Model Results

4.1 Baseline

Following analysis of the model baseline flows at hourly intervals through the tide (and including consideration of the conceptual understanding and a review of the field data), a preliminary comparison of the effects of the two berth scenarios has been undertaken.

Four states of the tide have been selected that provide a summary of the maximum flood and ebb effects of the proposed developments. These tidal states are HW -4 hours and HW -1 hour on the flood, HW at the start of the ebb and at HW +2 hours. These states of tide also reflect the flow conditions when the larger vessels are likely to transit to and from the Harbour and Victoria Pier and to manoeuvre off the harbour entrance.

Figure 24 provides the existing baseline spring tide flow vectors, showing a spatial representation of the flow speeds and directions at the four identified tidal states. These plots provide the basis for the subsequent comparison in determining the maximum predicted effects of the proposed developments. Should further detail (at other states of tide) be required, the full set of vector plots is provided as Appendix E.

The vector plots in Figure 24 clearly show the general NW directed flow past Douglas Head with a reduction in flow speed as the flow is drawn into Douglas Bay, north of Princess Alexandra Pier. This flow separation initially sets up as an elongated anticlockwise eddy. This circulation, which becomes 'rounder', larger in form and characterised by the centroid moving offshore as the tide rises, can be seen at HW -1 hour in Figure 24

The ebb flows have already started before HW and flow starts to drain from Douglas Bay, splitting around St. Mary's Rock. This causes a concentration of flow on the end of Princess Alexandra Pier, approximately perpendicular to the Harbour approach Channel. This flow joins that which 'bypasses' Douglas Bay, creating an area of maximum flow immediately off Douglas Head. A slow eddy (<0.2 m/s) is set up in the 'recess' between the Head and the end of the Pier. This general pattern continues throughout the ebb, at increasingly slower flows. Negligible flow occurs for about ±1 hour around LW, particularly inshore of a 'line' running approximately north from Princess Alexandra Pier.

The baseline tidal flows around Douglas are, therefore, controlled by the interaction between the outcrop at Douglas Head and the end of Princess Alexandra Pier.

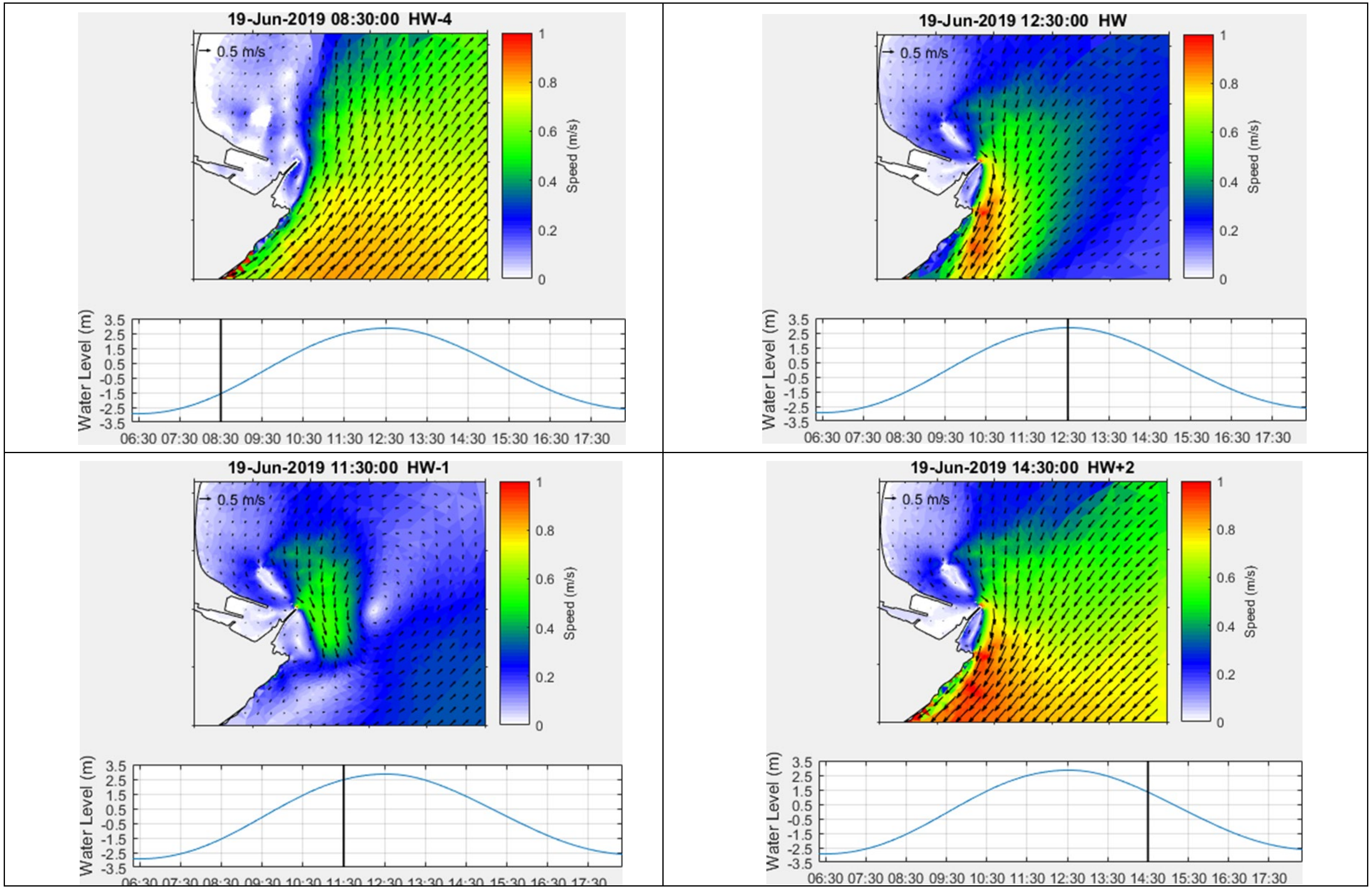


Figure 24. **Baseline Flow Vectors - Flood (left: HW - 4 hours and HW - 1 hours) - Ebb (right: HW and HW + 2 hours)**

4.2 Victoria Pier Berth

4.2.1 Effects on hydrodynamics

Hydrodynamic modelling of the proposed Victoria Pier Berth has been undertaken for a 15-day spring-neap cycle. Comparison with the baseline conditions shows that dredging the berth to 9.5 m below CD has negligible effect on the existing flow regime at all states of tide. The change is almost entirely restricted to the berth itself, where existing flows are already low (peaking at <0.2 m/s on spring tides). Figure 25 shows the timeseries of flow speeds over a spring tide, compared to the equivalent baseline flows, at three locations within the berth pocket, the approach channel and at a location to measure any effects on the distribution of flow around St. Mary's Rock. Figure 26 shows the local flow vectors and the difference (from the baseline) plots at HW -1 hour and HW +2 hours (representative times of the peak flood and ebb flows within the vicinity of the Victoria Pier Berth).

These diagrams, summarising the results, indicate the following:

- The berth has a small effect on flow speeds ±4 hours around HW;
- The maximum change is an approximate 40% reduction in flow speed, which - due to the slow existing flows - represents a change of less than 0.07 m/s. This change is confined to a small area at the west end of the berth where the dredging is greatest, see location QVD3 on Figure 25 and the vector difference plot on Figure 26;
- Flow directions with the dredged berth are predominantly towards the east, and aligned with Victoria Pier, except towards LW when they turn westwards in the middle and northwards at the west end;
- Change to the predominant flow directions from the baseline is negligible at all locations. The greatest difference is at the west end of the berth where flows start to turn marginally later at HW and slightly earlier at LW;
- Outside the berth area, the only change is a very small (<0.1 m/s) reduction in flow at the lower states of tide, as indicated at Site 'SMr' on Figure 25 and in the shallower areas around St. Marys Rock, see Figure 26. This same magnitude of effect is noticeable in the results from other locations in the approaches. This is likely due to the small retardation of flow over the pocket, slowing the momentum as the tide falls at the outer locations. This change, however, will not be measurable in reality;
- Of relevance to sedimentation, the bed shear stress plots show that within the berth, flows in the baseline case are low enough to prevent initiation of motion of 200 μm sand for ±2 hours around low water, but slow bedload movement can occur for the rest of the tide. Flow speeds, except for tides greater than the mean spring range, are unlikely to cause suspension of the local bed sediments. With the deepened pocket, the bed shear stress is reduced to almost zero, therefore the berth will accumulate any sediment that can move into the pocket. In the baseline condition this material can move through the area, hence the negligible sedimentation that is currently experienced;
- The flow vectors (at the times of greatest flood and ebb flow) in the vicinity of the berth (Figure 26), show negligible change in the hydrodynamics that could subsequently affect the supply of sediment within the Harbour approach and berth area. The total volume of sediment available for sedimentation is therefore unlikely to increase, but (when it is available) more will be retained within the berth pocket.

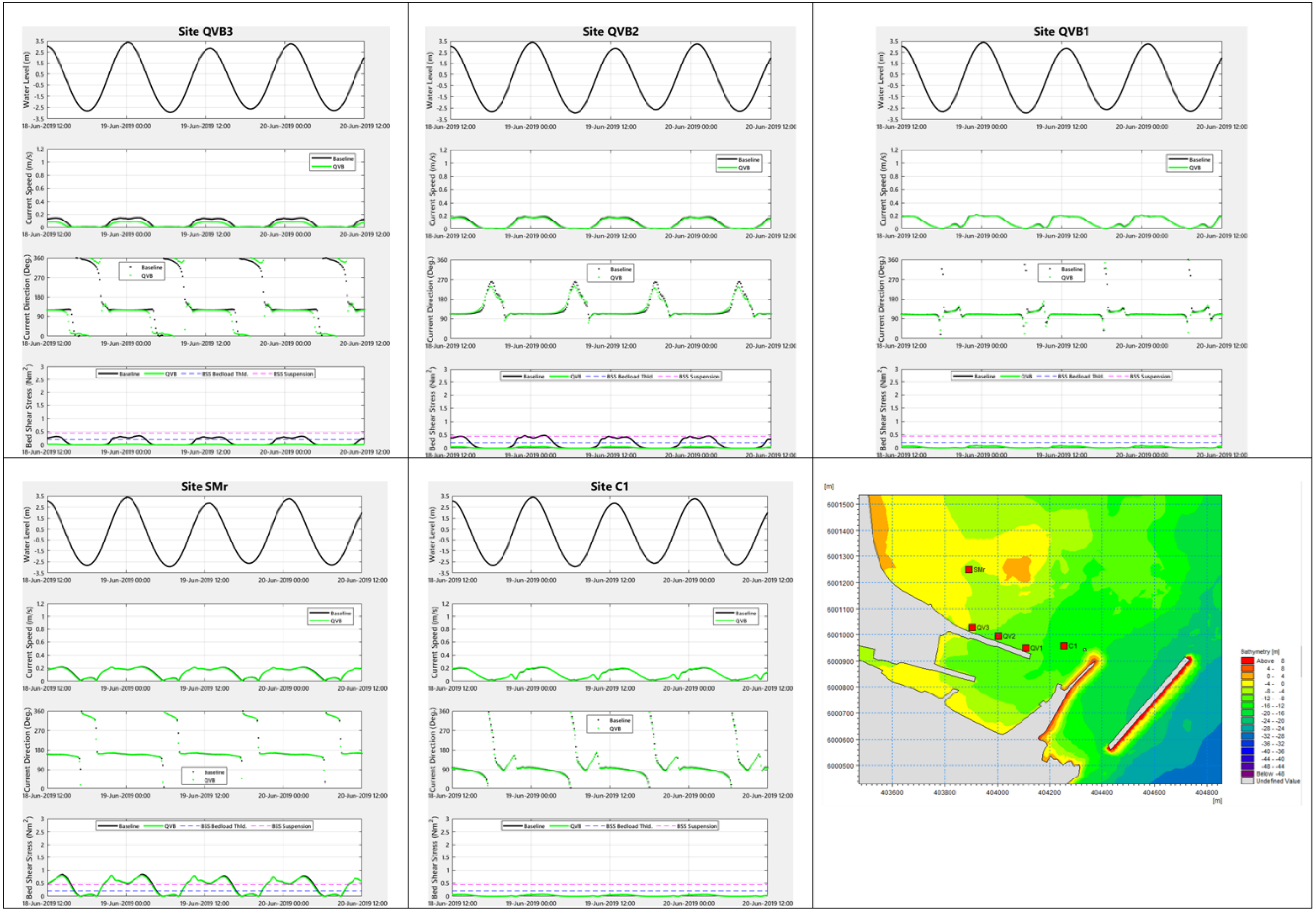


Figure 25. **Timeseries of Victoria Pier Berth v Baseline scenario comparison : Victoria Pier Berth area - Spring Tide.**

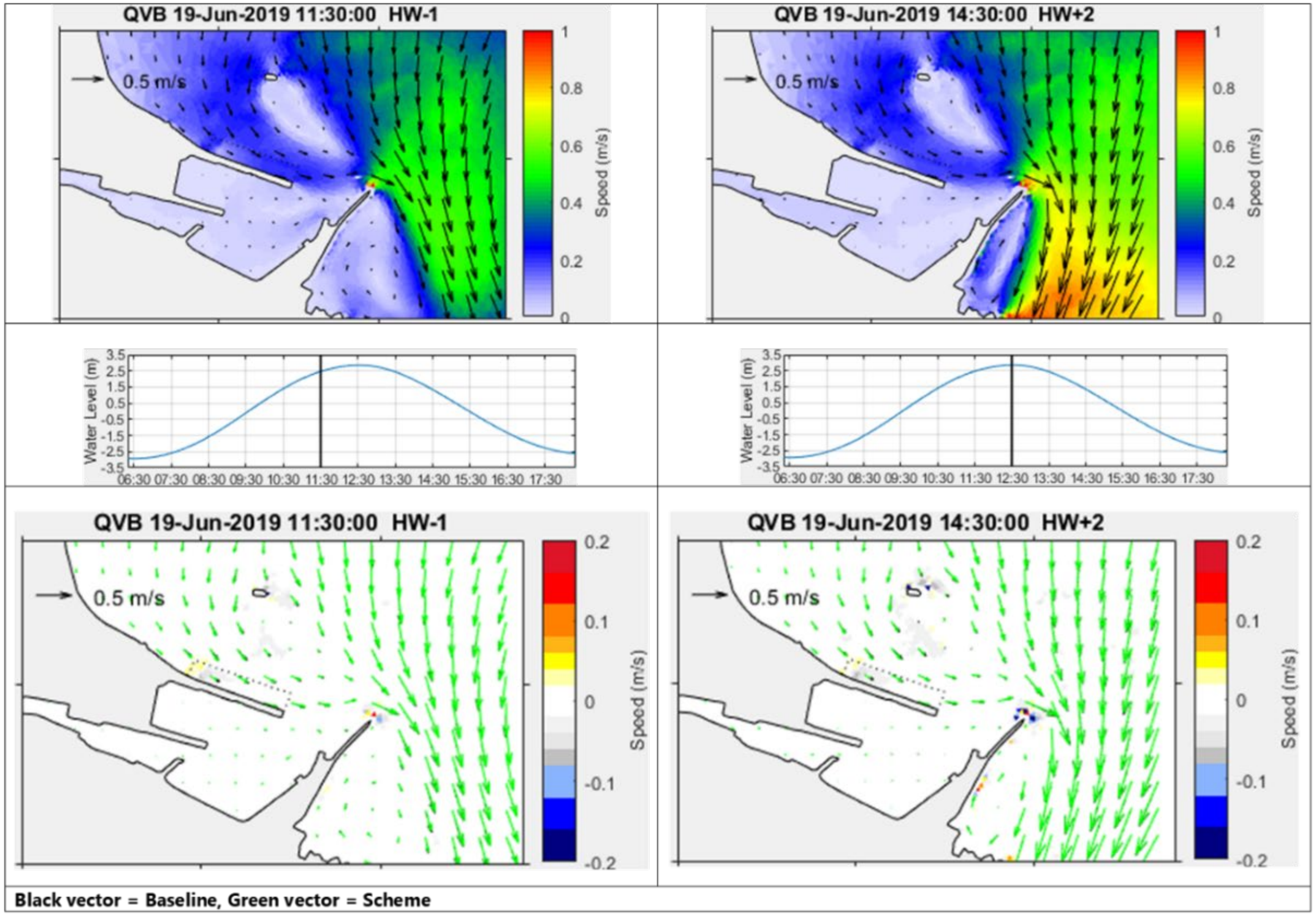


Figure 26. **Flood and ebb tide flows vectors with the Victoria Pier Berth and difference from the Baseline for times of maximum development change: Spring tide HW - 1 hours and HW + 2 hours.**

4.2.2 Effects on sediment transport

The small effects on the hydrodynamics as a result of the deepened Victoria Pier Berth (described above) are unlikely to have enough effect on the existing flow regime to further affect the existing navigation to the berth or the Harbour. Flows are slowed, from the overall baseline low levels. The deepening further lowers the bed shear stresses, creating a permanent siltation pocket for any sediment able to be transported to the berth. However, this supply is currently low.

As described in Section 3.2.3, assessment of the potential impacts of the Queen Victoria Pier dredge, under a measured summer storm condition (approximately a 10 in 1-year event), and a more extreme winter storm (equivalent to a 1 in 1-year event) has been conducted.

Under the less severe summer wave event, there is no predicted change in the sediment transport regime as a result of the Victoria Pier dredge.

When considering the larger winter storm event, predicted changes in sediment transport are generally small, and limited to the area immediately within, and adjacent to, the dredge pocket. Figure 27 shows the predicted change in sediment thickness, following a mean spring/neap tidal cycle, as a result of the proposed Victoria Pier dredge. In this figure, areas where material on the bed is thicker following the dredge are shown in orange; areas where bed material is thinner following the dredge are shown in blue (noting also that the dredge itself is not included). These results, therefore only show the response of the system to a deepening of the Victoria Pier berth. It should be noted that, since the plot shows a thickness change, areas of orange may be caused by either more accretion or less erosion (the resultant change effectively being the same). Similarly, blue areas may be caused by less accretion or more erosion. In this way, the output provides an indication of areas that are predicted to be affected by the dredge, and the general direction of predicted change in sediment transport.

As can be seen from the model output, the influence of the dredge on the extreme 1 in 1-year storm event is constrained to two areas – one towards the eastern end of the dredge pocket, the other to the western end of the pier, between the pocket and the Conister Jetty (Figure 27) Figure 28 provides a set of extracted timeseries of bed thickness change, at selected locations to investigate the predicted change in more detail (see Figure 27 for extraction locations VP1 to VP7).

To the eastern end of the dredge pocket, the sand transport model predicts a small reduction in accretion in the centre of the pocket (VP2), as a result of changes to the sediment transport regime following the proposed dredge. Associated with this is a switch from general erosionary conditions (baseline) to slight accretion (following the dredge), along the offshore face of the quay wall (as illustrated at VP1). The predicted difference is a change of approximately 0.03 to 0.05 m over a mean spring/neap tidal cycle, when coincident with a 1 in 1-year storm event.

Towards the middle of the Victoria Pier berth, a similar pattern of bed thickness change is observed. In the middle of the berth pocket (VP4) accretion is predicted under baseline conditions, but effectively no change is observed following the dredge. A smaller effect is predicted along the quay wall, at the same location (VP5), where a slight reduction in erosion is shown in Figure 28. It is likely that the deeper water depths here (following the dredge) reduce the effect of the wave on the seabed, reducing the local bed mobility, and leading to a smaller overall change (either erosion or accretion) as a result.

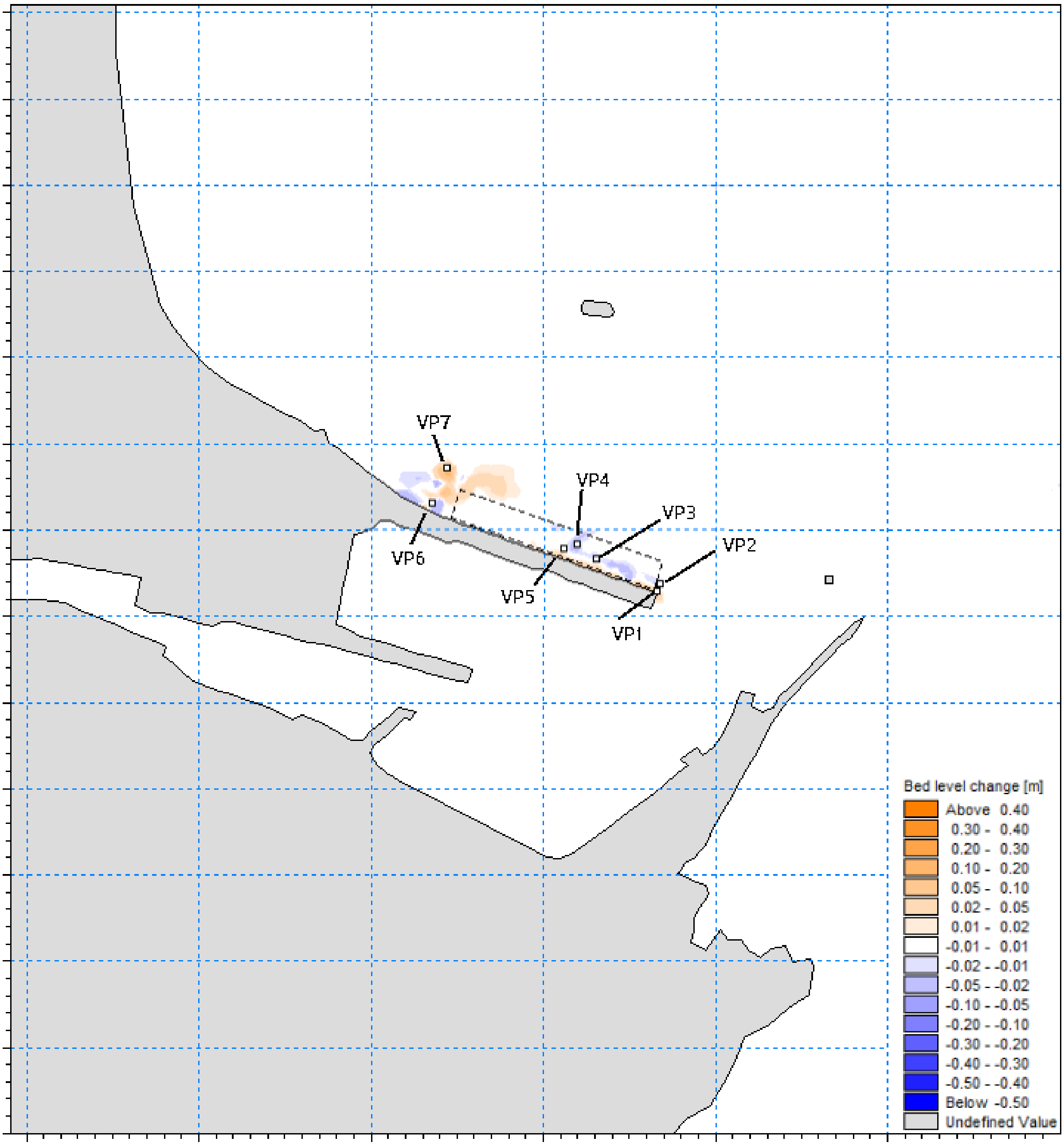


Figure 27. Predicted change in bed thickness following Victoria Pier dredge – 1 in 1-year wave event

To the west of the dredge pocket, in between Victoria Pier and Conister Jetty (Figure 27), the proposed dredge is predicted to result in further slight changes to sediment transport under extreme (1 in 1-year) storm conditions. Along the coastal frontage (VP6), Figure 27 (and the timeseries in Figure 28) shows a reduction in accretion, following the proposed dredge. Associated with this, offshore within the shallow subtidal (VP7), and similar to the eastern end of the berth pocket at VP1, the dredge results in a switch from generally erosional conditions (baseline) to slight accretion (following the dredge). This is likely to be a result of the material that is shown (in Figure 28) to build up at VP6 now being maintained in motion, and available to subsequently accrete, when bed shear stresses drop low enough as the water depth increases away from the Quay..

For the Victoria Pier dredged berth, the calmer wave conditions (such as the event measured during the oceanographic survey campaign), do not result in any notable predicted change to sediment transport over the study area.; This is the same as the predicted changes resulting from the changes to the hydrodynamics alone (tidal currents without consideration of additive wave interaction).

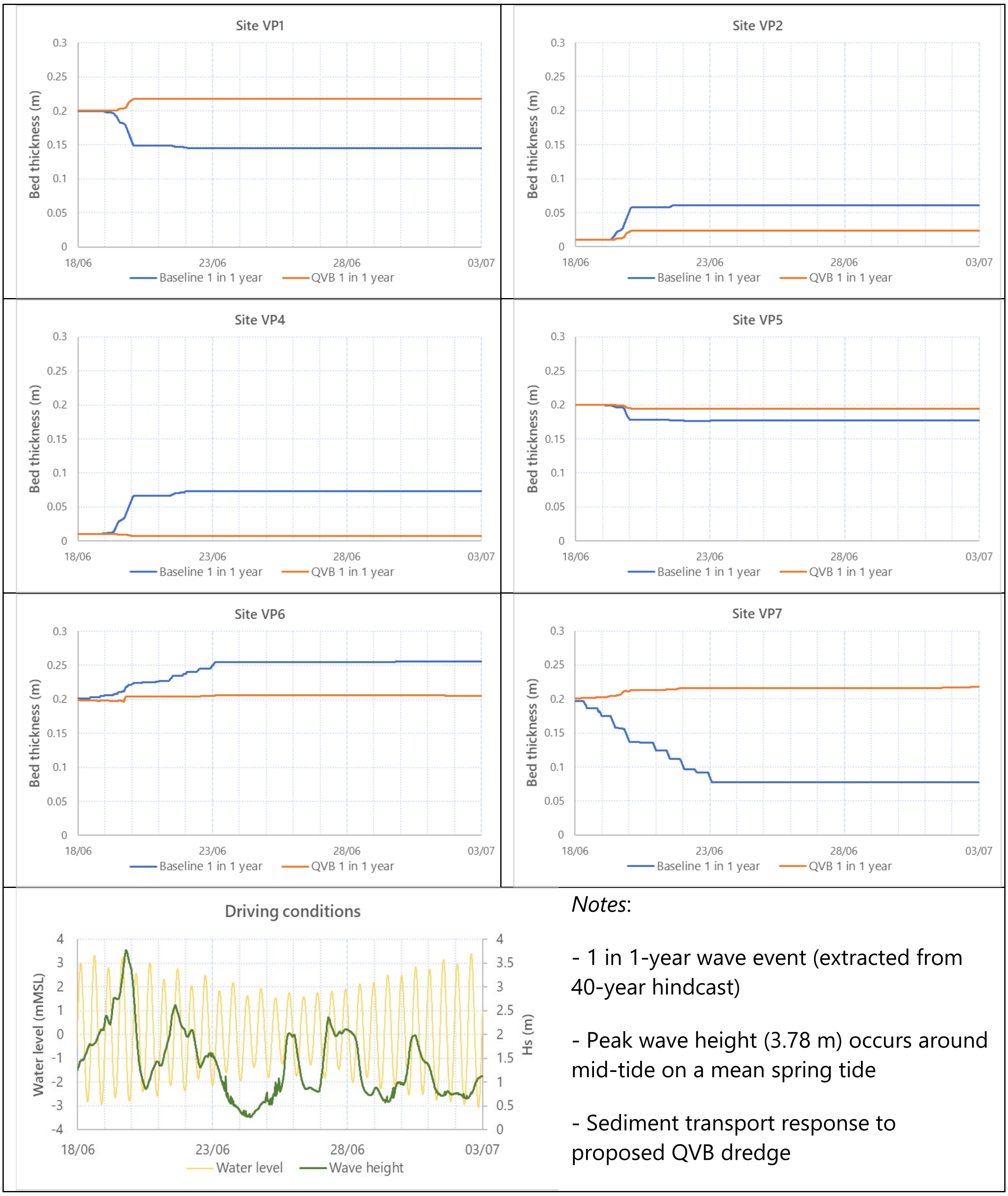


Figure 28. Timeseries of predicted bed level change, following QVB dredge, at selected location in and around Victoria Pier – 1 in 1-year wave event

4.3 Deep-Water Berth

4.3.1 Effects on hydrodynamics

When assessing the potential influence of the proposed Deep-Water Berth, the modelling of the hydrodynamics indicates effects on the baseline flow regime will be confined within an approximate radius of 1.2 km (centred on the head of Princess Alexandra Pier), with the greatest changes occurring around HW. Examples of flow vectors for the Deep-Water Berth scenario (and the resultant difference in flow speed and direction against baseline conditions) are provided for the times of peak flows and the times of maximum effect on both the flood (HW -4 hr and HW -1 hr) and ebb tide (HW and HW +2 hr) in Figure 29 and Figure 30, respectively. The full set of plots, at hourly intervals throughout the tide, are provided in Appendix F.

Based on the difference plots throughout the tide, sets of timeseries sites have been extracted from the model to show the temporal distribution of the predicted effects as a result of the Deep-Water Berth development.

These data have been grouped to show the effects in four general areas (Figure 31 to Figure 34) that could have potential effects on sedimentation and navigation to the Harbour and the Victoria Pier Berth area. These areas are defined as:

- Victoria Berth Area and inner approach to the Harbour (Figure 31);
- Outer approach to the Harbour (Figure 32);
- Deep-Water Berth area (Figure 33); and
- Offshore of Deep-Water Berth pier (Figure 34).

The following sections summarise the hydrodynamic effects of implementation of the Deep-Water Berth within these areas.

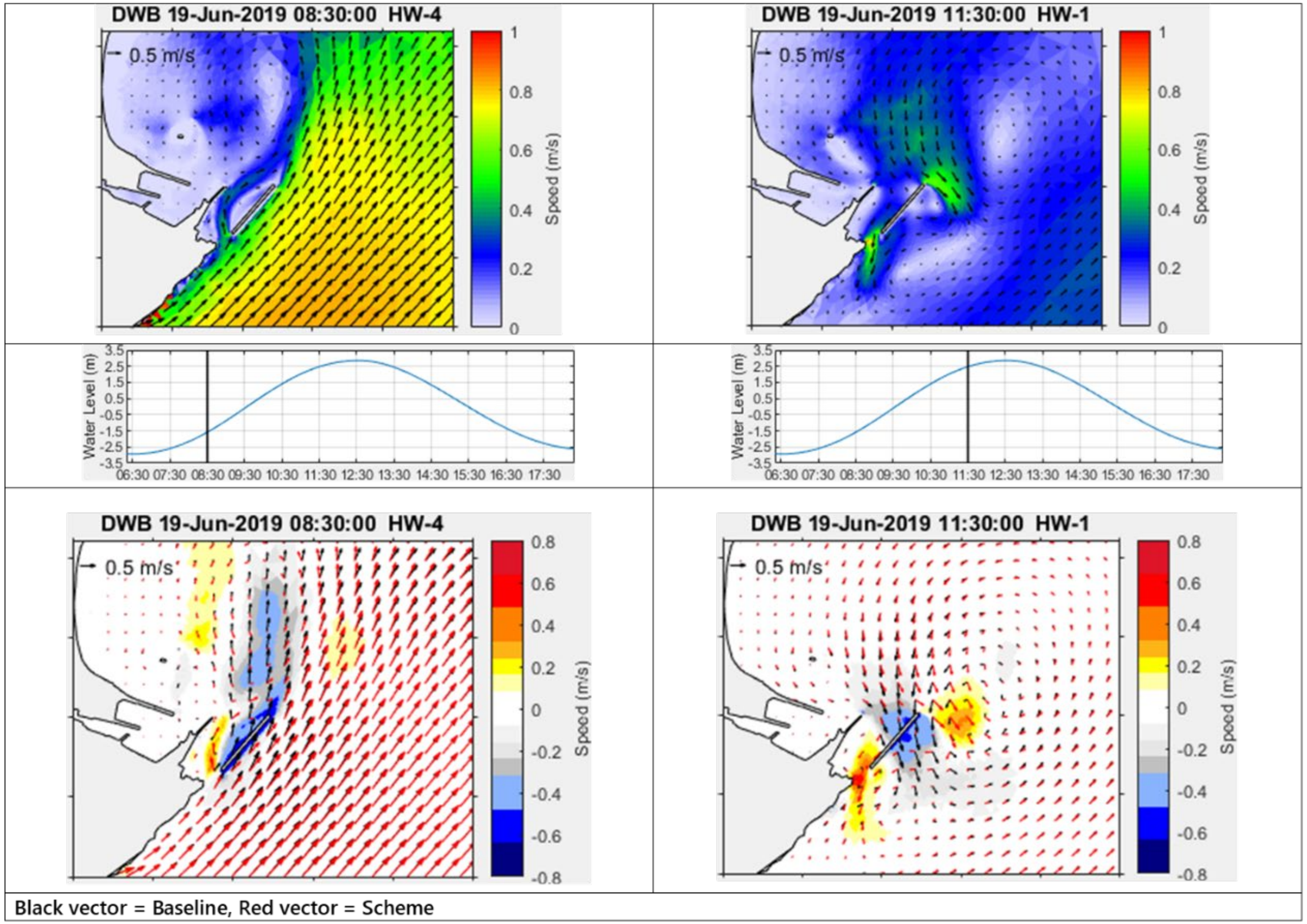
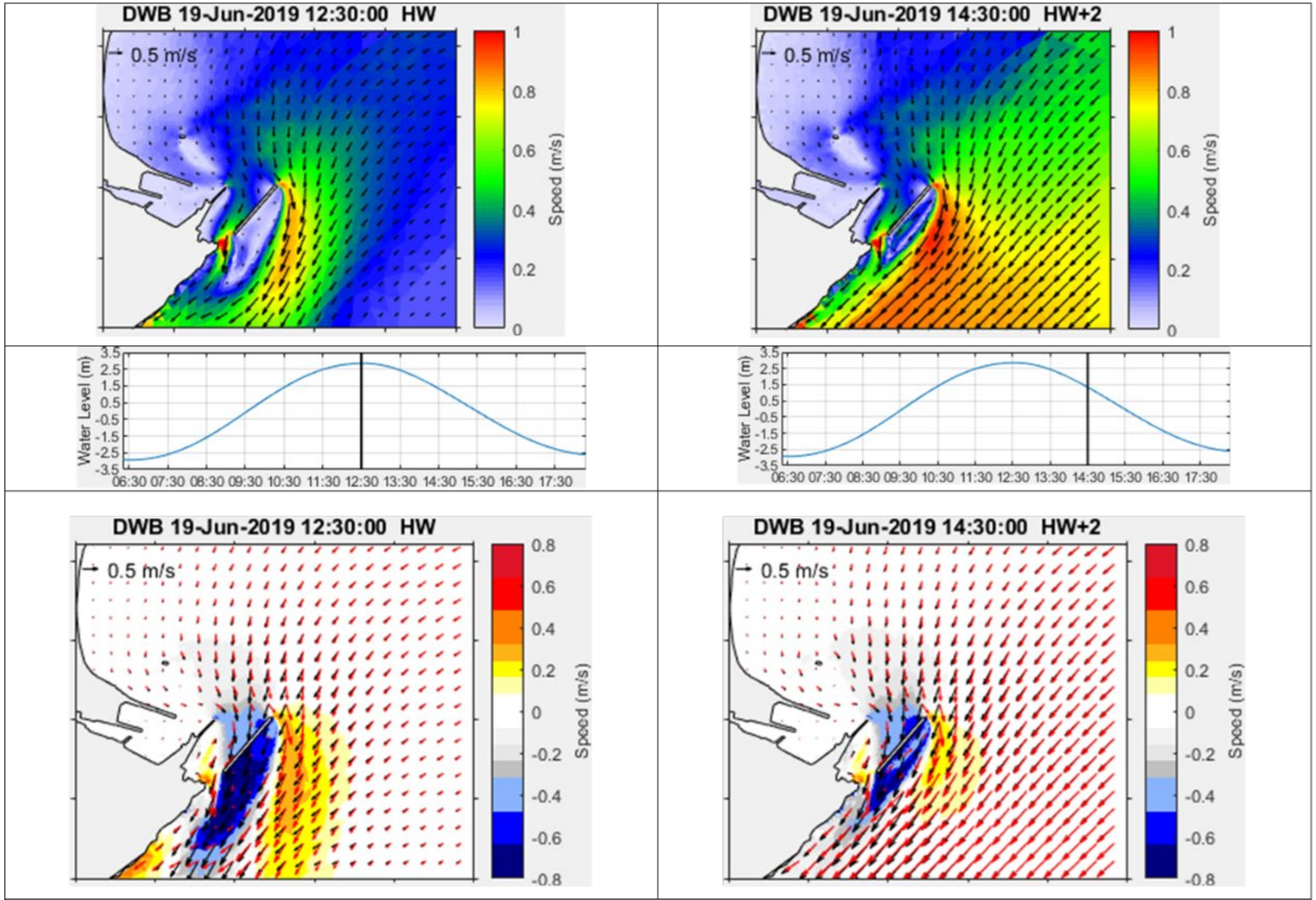


Figure 29. Example of flood tide flow vectors with the Deep-Water Berth and difference from the Baseline : Spring tide HW -4 hr and HW -1 hr



Black vector = Baseline, Red vector = Scheme

Figure 30. Example of ebb tide flow vectors with the Deep-Water Berth and difference from the Baseline : Spring tide HW and HW +2 hr

Victoria Pier Berth area

The flow vectors show that the Deep-Water Berth scenario has little effect on the overall directional flow patterns within this area. Flow speeds are, however, reduced at all locations throughout the tide (see Figure 31). The plots show that existing flows within the area are generally slow (peaking around 0.2 m/s) and relatively consistent between ±4 hours, relative to HW; flows generally become slack for the rest of the tide, around LW.

With the Deep-Water Berth development, the flow speeds are reduced consistently by about 0.06 m/s (*circa* 30%) at all locations. For most sites, the flow directions are unaffected, with the exception of Site C1, in the Harbour approach channel, just outside the entrance, over the period of *circa* 2 hours after LW. During this period, the directions swing clockwise, from a general easterly direction to westerly and then back easterly again, albeit flow speeds are negligible at the time. As noted for the calibration (Section 3.2), these are the conditions where the model calibration was least accurate, therefore such predicted changes should be treated with caution (particularly when considering the validity of assigning a direction to negligible flow speeds).

Possibly of greatest significance, is the reduction in bed shear stress in this area. The existing flows, for the most part, are strong enough to mobilise the *circa* 200 μm sand which characterises the bed material in this area. Some suspension of the sand could be possible on the largest tides. Photographic evidence from the field survey suggests a supply of sand does exist in this area. The reduction in flow speed with the Deep-Water Berth scenario has a greater proportional effect on the bed shear stresses compared to that for the flows. This reduction in bed shear stress indicates any suspension of the sand is unlikely following the development. Any movement will occur as bedload. The timeseries indicate that little movement of the sand will occur within the entrance or against Victoria Pier, due to tidal hydrodynamics alone. However, given the predicted reduction in bed shear stress, increased sedimentation could occur in this area, but only if a greater supply of sediment has the potential to be first moved into the berth.

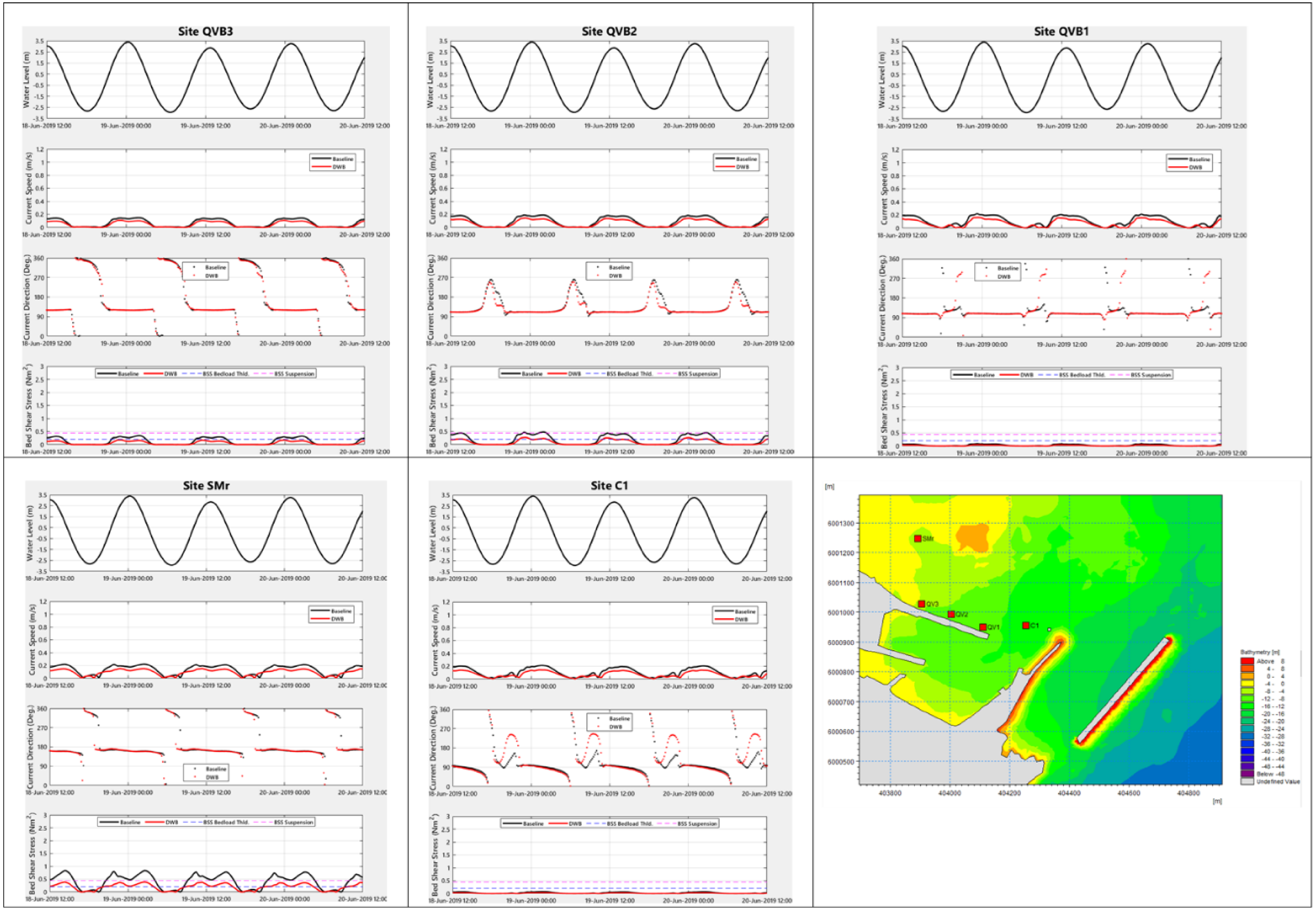


Figure 31. Timeseries of Deep-Water Berth v Baseline scenario comparison : Victoria Pier Berth area - Spring Tide

Outer Approach to Harbour

The changes in flow regime, caused by the Deep-Water Berth scenario, in the outer approach area to the Harbour are summarised by the timeseries sites N2 to N6, and shown on Figure 32. This is an important area that vessels will need to navigate through, in order to reach either of the two proposed berths or Douglas Harbour itself.

The maximum change in flood tide flow speeds through this area occurs around HW -4 hr, coinciding with the time of peak flows. The greatest change in flood directions (from the baseline) occurs around HW -1 hr, as shown in Figure 29.

At HW -4 hours, which characterises the flow regime for most of the flood, the Deep-Water Berth pier acts as a training wall and is situated almost on the 'line' where existing flow speeds begin to reduce and turn northwards around Douglas Head. The proposed pier structure blocks this flow, realigning it more to the NW, and also reduces speeds by 0.3 - 0.4 m/s in the outer approach area, to almost slack at the 'centroid' of a slow-moving anticlockwise eddy. This eddy becomes more dominant as the tide rises, albeit with flows slower than those which presently exist. At the extremities of the eddy, particularly in the shallow areas of Douglas Bay and offshore, flow speeds are increased by about 0.2 m/s from slack, and by around 0.4 – 0.5 m/s, respectively, as seen in Figure 29. This magnitude of change in flow speeds reduces as the tide rise. At the same time, the eddy becomes larger, 'rounder' in shape and with the centroid moving offshore - as illustrated at HW -1 hr on Figure 29.

The flows of most significance, with respect to sedimentation and navigation in the outer approach area, are predominantly reduced on the flood tide. This is illustrated, along with the flow realignment effects of the proposed Deep-Water Berth pier, by comparing Figure 24 (baseline) with Figure 29 (Deep-Water Berth scheme) for the time of HW -4 hr.

The timeseries sites shown on Figure 32 are located within the eddy pattern described above, and for the most part show the reductions in flow speed throughout the tide, with a similar pattern of change at all sites.

The greatest changes are at sites N5 and N6, on the vessel access route to the Harbour, see Figure 32. Here, flows are reduced, compared to the baseline, by up to 0.4 m/s (67%) on the early flood. The flow directions during this period swing from south, quickly to north and then back to south slightly earlier in the tide than occurs at present.

During the ebb, the maximum reduction in flow speed is less than on the flood (up to 0.15 m/s, *circa* 30%) between HW +2 hours and HW +3 hours. Ebb flow directions are almost everywhere in a near due S direction, having been rotated *circa* 15° anticlockwise from the existing flows, hence diverted more across the alignment of the approach channel to the Harbour, see Figure 30.

Figure 32 also indicates that, with the exception of the shallowest site (N3), existing bed shear stresses would only suspend the sand on the bed on the largest range tides and then only for less than an hour just after HW and LW. With the Deep-Water Berth scenario, all bed shear stresses are reduced so that bed mobility will be reduced, and only occurring for the highest tidal ranges.

Site N3, within the shallower subtidal area to the NE of St. Mary's Rock, indicates that 200 µm sand can presently be suspended and moved in this local area. With the Deep-Water Berth scenario this will still be the case, however the magnitude of suspension would be reduced. This would indicate a lowering of potential supply and movement of sediment, which is already low.

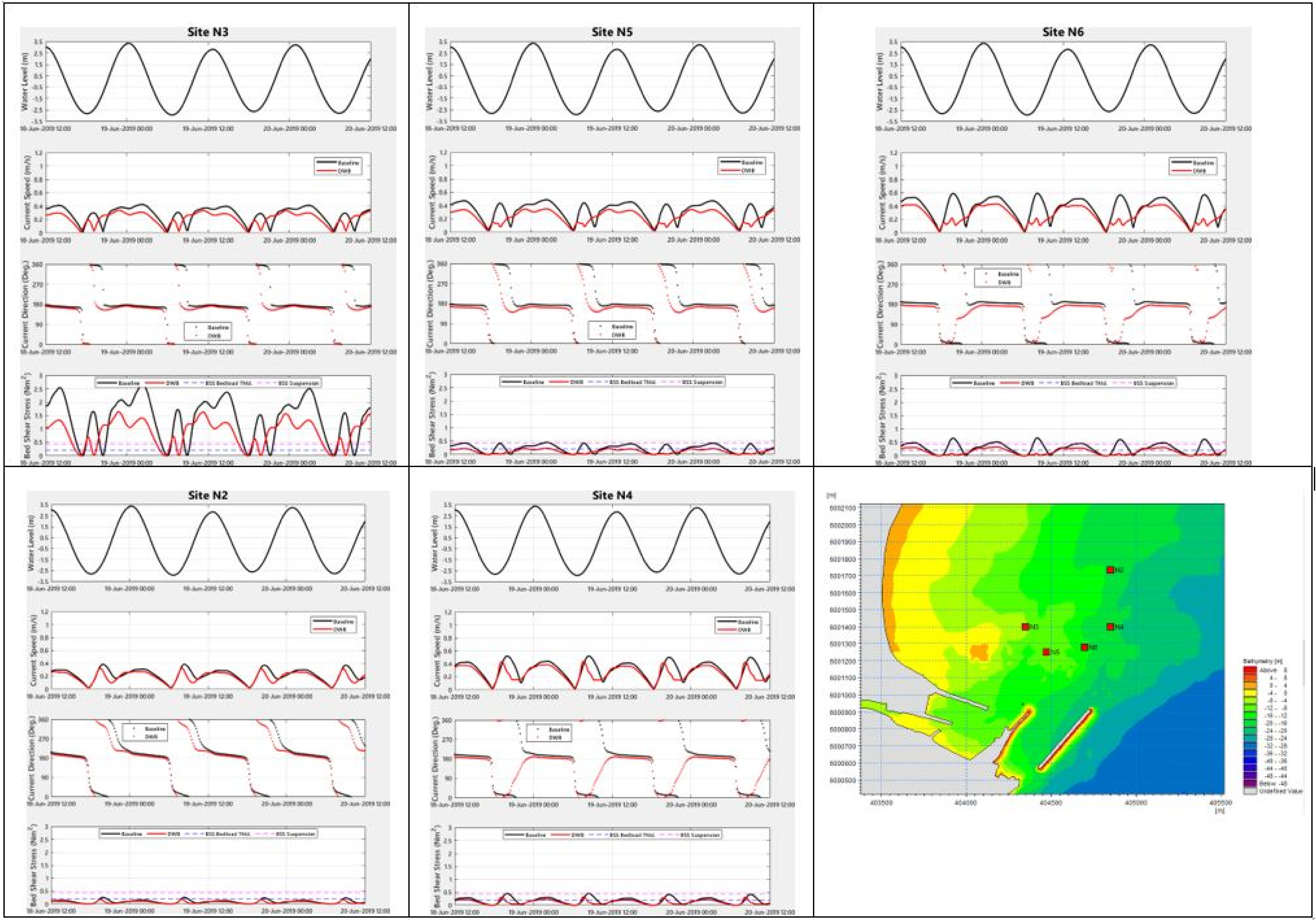


Figure 32. **Timeseries of Deep-Water Berth v Baseline scenario comparison: Outer Approach to Harbour - Spring Tide**

Deep-Water Berth area

Within the new berthing area, between the new pier and Princess Alexandra Pier, the tidal flows are notably changed by the development, most notably throughout the flood and for the first half of the ebb tide. The proposed new pier is approximately located where the baseline (existing) coastal flows begin to reduce inshore, to and from Douglas Bay.

On the flood tide, the pier blocks the northward passage of flows and 'trains' the vectors toward the NE during the rising tide. This creates a significant reduction in flow (up to *circa* 0.5 m/s) at the location of the vessel berth, as can be seen in Figure 29 at HW -4 hours. As the tide rises, an anticlockwise eddy develops across the Harbour Approach channel, to the north of Princess Alexandra Pier. This eddy moves closer to the Harbour as the tide rises and the northern end of the new pier blocks the offshore flow from the southern part of the eddy. This creates enhanced southward flow in the berth area and accelerated flows, exceeding 1 m/s, through the area of the link bridge. This complex flow pattern can be seen at HW -1 hr in Figure 29.

This flow-blockage effect also occurs throughout the ebb tide, although more flow is diverted around the northern end of the pier. This reduces flows along most of the berth area, by up to 0.5 m/s from the existing flows at this location, particularly at the northern end. Towards the southern end of the berth/pier the constriction between the pier and Douglas Head accelerates flows to around 1 m/s under the link bridge. This pattern of flow with the Deep-Water Berth scheme, and the change from existing conditions, is illustrated for the peak ebb flows in Figure 30. This diagram also shows there will be a significant flow speed gradient - from about 0.2 m/s to around 1 m/s - north to south along, the length of the berth.

The change in flow pattern between Princess Alexandra Pier and the new pier is further illustrated, throughout the tide, in the timeseries plots shown in Figure 33. Locations B1 and B2, within the berth, show that flow directions are trained near parallel with the pier for most of the tide, but also show the significant reduction in flow speeds, as well as the 'north to south' gradient along the berth. At Location B4, the effect on the flows is less, with the main change over LW where flows are increased from 0.2 m/s to 0.4 m/s. The directions, however. are realigned by the pier for most of the tide. At Location B8, in the gap between the new pier and Douglas Head, flows are marginally increased through the tide.

Analysis of the bed shear stress plots indicates that, should a large supply of 200 μm sand be available on the bed, then there would be increased potential for sedimentation to occur, particularly in the northern half of the berth and the immediate approach area. These bed shear stress levels, however, are not lower than exists presently at Location B4. Presently, there is little evidence that accretion is occurring in this area and the field measurements, and associated photographs, suggest that the overall supply of sediment to the area is low. This would further suggest that although the Deep-Water Berth flow conditions would be conducive to accretion, this is unlikely to cause the need for a significant maintenance dredge requirement due to the wider lack of sediment supply.

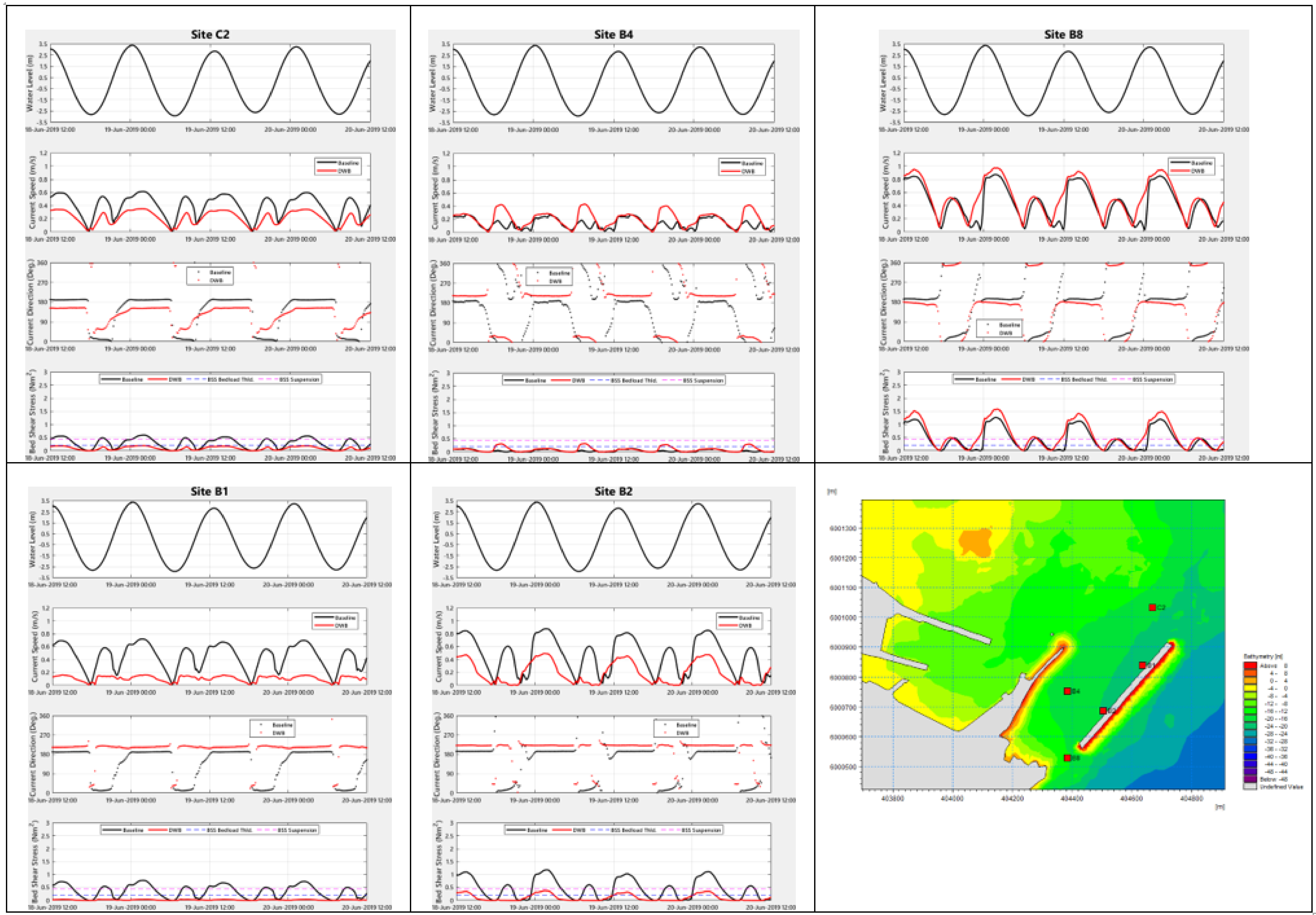


Figure 33. Timeseries of Deep-Water Berth v Baseline scenario comparison : Deep-Water Berth area - Spring Tide

Offshore of Deep-Water Berth pier

The main effect of the new pier and rock revetment on the flood tide is to realign the flow anticlockwise, by up to about 30° towards the NE. Flow speeds are reduced as they pass over the revetment, but the diversion of the flow causes increases in flow speeds of up to 0.2 m/s off the northern end of the pier, particularly at the lower states of tide. At HW -1 hr, the flow pattern immediately offshore of the pier becomes complex as flow from the eddy is obstructed and diverted, albeit at predominantly low flow speeds of the order of 0.2 m/s. These flood tide characteristics in this offshore area are shown in Figure 29.

During the ebb tide, the new pier significantly blocks the southward moving flows, concentrating them and then ‘pushing’ them offshore at the northern end of the pier, see Figure 30. This concentration of the flow induces a slow (almost slack) clockwise circulation, up to about 200 m wide, from the pier with faster flows further offshore. In this area, flow speeds are reduced by around 0.6 m/s and flow directions are reversed, when compared to the existing conditions. This is illustrated by reference to timeseries Location B5 (Figure 34).

The diagram also shows that, offshore of the eddy, the 'coastal’ flow directions are unaffected. At Location B7, about 250 m from the pier, the effect of the development is restricted to a 0.2 m/s increase in flow speed for the first 2 hours of the ebb tide.

The changes to bed shear stress (Figure 34) indicate a potential for sedimentation in the area of reduced flows, extending along the length of the pier and up to *circa* 200 m offshore. Location S1 also shows a reduction in bed shear stress, which is sufficient to create the potential for sedimentation in this area. Whether sedimentation will occur will depend on the wider supply of sediment to these areas. The conceptual analysis suggests that, under existing conditions, this supply is not available and, consequently, the changes predicted as a result of the development are unlikely to change this pattern.

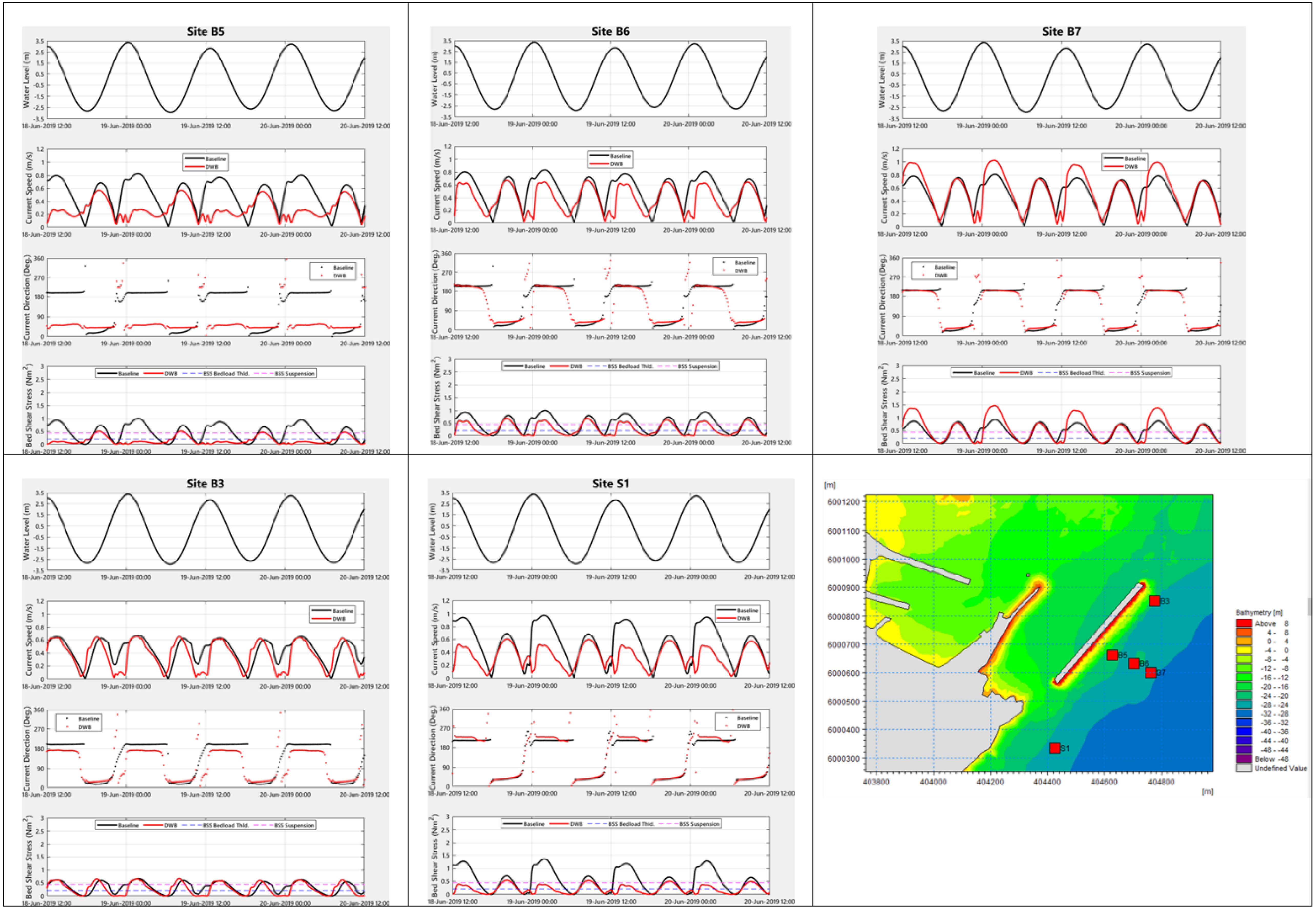


Figure 34. **Timeseries of Deep-Water Berth v Baseline scenario comparison : Offshore of Deep-Water Berth pier - Spring Tide**

4.3.2 Effects on sediment transport

In contrast to the proposed Victoria Pier Berth dredge, where resultant hydrodynamic effects were typically small, and associated changes to sediment transport were low, the changes arising from the Deep-Water Berth scheme have the potential to affect the accretion and erosion potential across wider parts of the study area.

In a similar approach to that described for the Victoria Pier scheme, assessment of the potential impacts of the Deep-Water Berth, under a measured summer storm wave event (approximately a 10 in 1-year event), and a more extreme storm (equivalent to a 1 in 1-year (annual) event) which is more likely to occur during the winter, has been modelled.

Figure 35 shows the predicted difference in bed thickness, as a result of the Deep-Water Berth scheme, under the less severe summer wave event. The equivalent model output for the more extreme 1 in 1-year (annual) winter storm event is provided in Figure 36 . Additionally, Figure 37 gives a set of timeseries plots, showing how the bed thickness is predicted to change compared to the baseline (existing) during the 1 in 1-year (annual) event and typical summer conditions over a spring-neap cycle following construction of the Deep-Water Berth scheme. The locations selected for extraction from the model are shown in Figure 36.

The predicted impacts on the sediment regime are described in the following Sections, focussing on the existing Victoria Pier Berth, and the proposed Deep-Water Berth scheme.

Victoria Pier Berth area and approaches

As shown in Figure 35 and Figure 36 neither wave condition causes a substantial change to bed sediment thickness in and around the Victoria Pier Berth and its approaches, when compared to the baseline (existing) conditions and with the Deep-Water Berth scheme.

The slight changes to sheltering and exposure, as a result of the Deep-Water Berth scheme extending out past the existing Princess Alexandra Pier, result in some changes to sediment transport, in and around the existing Victoria Pier Berth, under more extreme annual storm wave conditions (Figure 36). Alternating areas of thicker and thinner bed material are predicted within and to the northwest of the Victoria Pier, extending to the intertidal area in the lee of St. Mary's Rock.

The predicted changes are illustrated in the timeseries plots provided in Figure 37. For example, in the middle of the berth pocket (Site DW7) accretion is predicted under baseline conditions, but with the Deep- Water Berth scheme a slight erosional effect is observed To the north west of the Victoria Pier Berth pocket, in the shallow subtidal (Site DW8), the Deep-Water Berth scheme results in a switch from generally erosionary conditions (baseline) to slight accretion (following the dredge).

No change to sand transport in and around the approaches to the existing Victoria Pier is predicted under either typical summer or the annual storm conditions (as shown in Figure 35 and Figure 36).

Deep-Water Berth area and approaches

Very little change to the bed thickness is predicted around the proposed Deep-Water Berth pier structure with either wave forcing condition and there is no difference in sedimentary effect as a result of the change in wave events. The pier creates benign tidal and wave conditions immediately in the lee of the pier structure which results in a very slight predicted increase in bed thickness at isolated locations immediately adjacent to the pier. This is likely to be associated with the region of predicted increased erosion seen in Figure 35 and Figure 36 between the southern end of the offshore structure and the coastline at Douglas Head.

At this location, the restriction to flow imposed by the offshore structure, results in increased flow speeds (see Section 4.3.1), increasing BSS and, as a result, leading to an increase in predicted sand transport (assuming bed coverage of 200 μm sand material in this region). The predicted change is also shown in Figure 37 (Site DW2). From this timeseries of bed level change, it can be seen that, under baseline (existing) condition, the bed thickness is predicted to increase (under a 1 in 1-year wave event) by about 0.06 m - predominantly on the spring tides. As a result of the Deep-Water Berth construction, this predicted accretion switches to erosion. The 1 in 1-yr wave event therefore effectively strips the bed material at this location and could create a scour hole depending on the underlying composition of the bed.

Further to the south of Douglas Head, a reversed situation is predicted. The timeseries of bed level change at Site DW1 (Figure 37) shows that the 1 in 1-year wave event, under baseline (existing) conditions, strips out material from the bed. However, slight changes to exposure and sheltering once the offshore DWB structure is implemented result in a gradual build-up of material at this location, up to around 0.05 m following a mean spring/neap tidal cycle, under typical summer or extreme annual winter wave conditions.

Offshore of the Deep-Water Berth scheme (to the east of the northern end of the offshore structure), an area of net erosion is predicted over a spring-neap cycle. The shape of this area is essentially the same under both wave conditions, see Figure 35 and Figure 36. This change is shown in the timeseries of bed level change at Site DW3 (Figure 37). Approximate equilibrium conditions are shown to occur under the baseline (existing) scenario with little change in bed thickness over the spring-neap tidal cycle. With the Deep-Water Berth scheme wave effects outside the pier are unlikely to be affected and the large water depths (>20 mCD) would limit the wave effects at the bed hence there is little influence from the 1 in 1-year wave event. Figure 29 and Figure 30, for example, however, show the construction of the pier increases the flow speeds and associated BSS in this area. As can be seen in Figure 37 (Site DW3), erosion is evident as the sand is eroded (although the rate of removal is insufficient to completely starve the area of the initially-placed bed material, approximately 10% of which is maintained above the 'harder' underlying bed). Figure 36 and Figure 37 suggest that the sediment eroded from this area will deposit off Douglas Head, as indicated at Site DW1.

The above analysis indicates the sedimentary behaviour around the Deep-Water Berth is primarily a function of the changes to the hydrodynamic flow regime, with little overall effect from the change in wave conditions through a year.

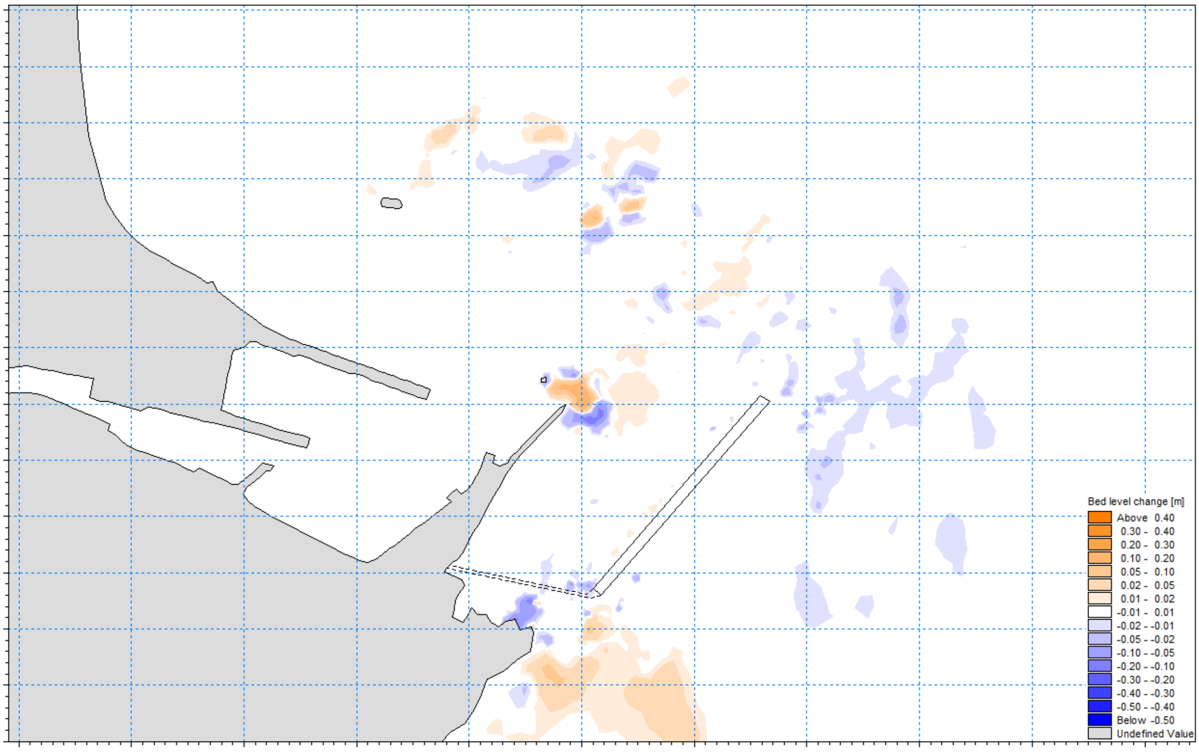


Figure 35. Predicted difference (against baseline) in bed thickness change following Deep-Water Berth – 10 in 1-year wave event

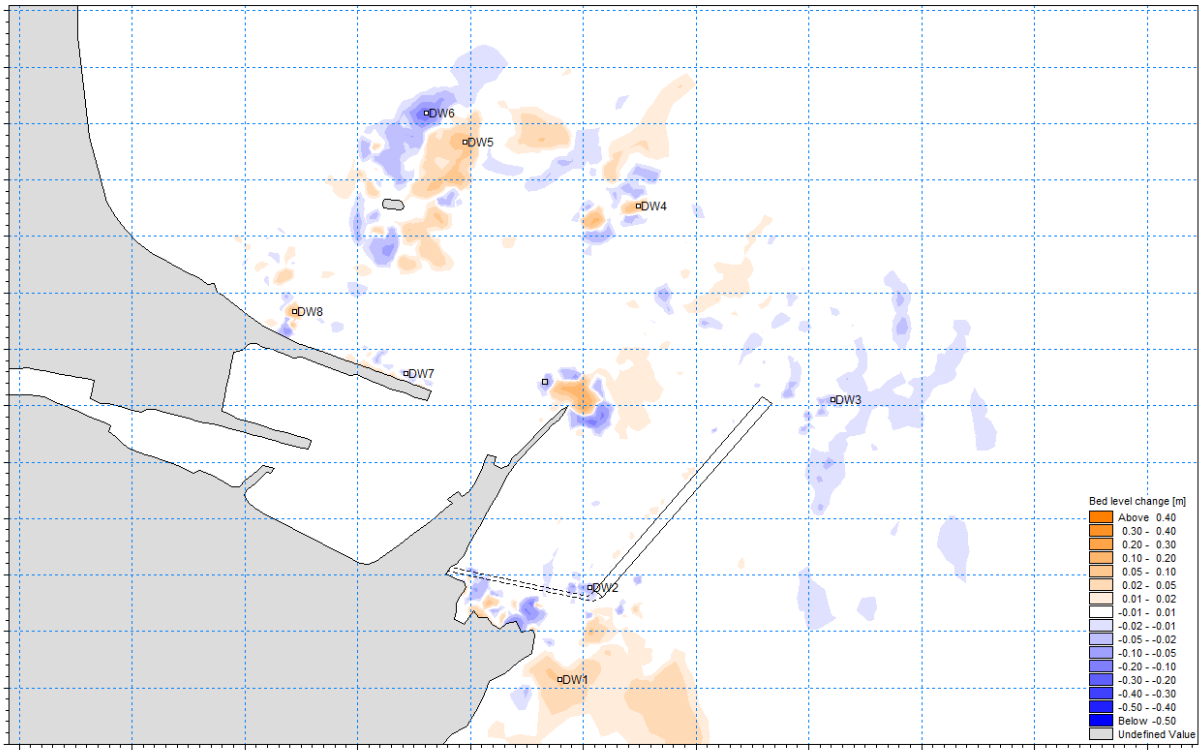
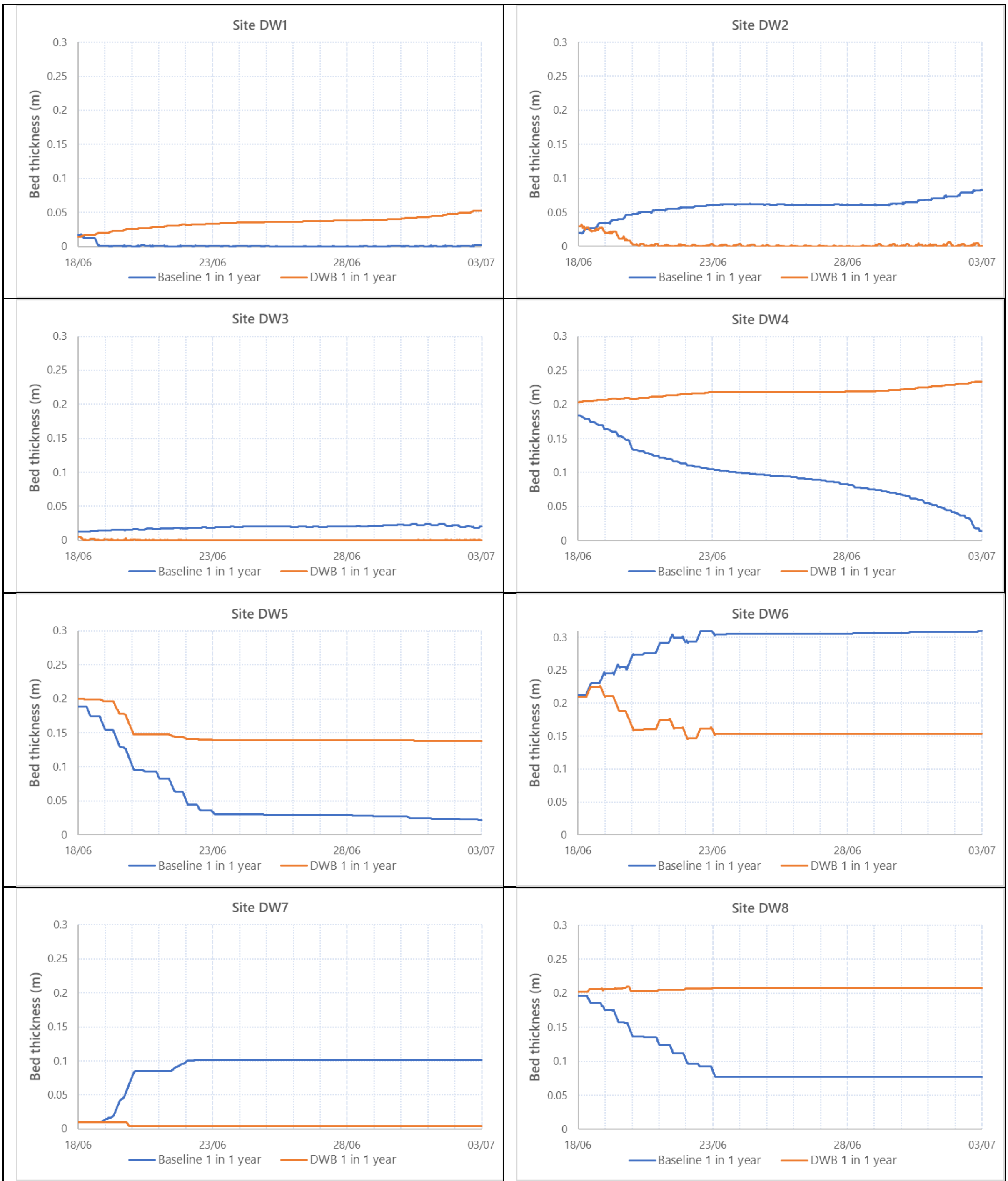
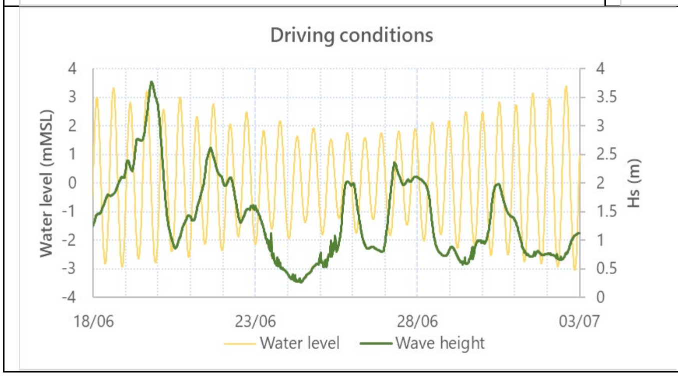


Figure 36. Predicted difference (against baseline) in bed thickness change following Deep-Water Berth – 1 in 1-year wave event





Notes:

- 1 in 1-year wave event (extracted from 40-year hindcast)

- Peak wave height (3.78 m) occurs around mid-tide on a mean spring tide

- Sediment transport response to proposed DWB scheme

Figure 37. Predicted bed level change - Deep-Water Berth scheme; 1 in 1-yr event

5 Sedimentation Study

As described above, the assessments of the potential impacts arising from the proposed developments at Douglas Harbour have provided a range of information, including field survey, desk study and conceptual understanding (Section 2) and numerical modelling of flows, waves and sediment transport (Sections 3 and 4). When considered together, these various inputs allow subsequent consideration of the relative potential impacts, of the proposed berth schemes, on the sedimentation processes in and around the existing (and proposed) berth pockets. The following sections collate the supporting information and summarise the predicted siltation effects arising from each scheme at each berth location.

5.1 Victoria Pier Berth pocket area

Table 5 summarises the predicted modelled effects, over a spring neap cycle for typical summer wave conditions and for a period including the annual storm event, with regard to changes to sedimentation and erosion, within the location of the Victoria Pier Berth, and as a result of each of the proposed schemes.

Table 5. Predicted volume change (per 15-day spring/neap cycle) within Victoria Pier berth following implementation of proposed schemes

Scheme	Scenario	Volume Change Associated with Predicted Bed Level Change			Net Relative Change to Baseline
		Positive Change (accretion) (m^3)	Negative Change (erosion) (m^3)	Net Change (±) (m^3)	
Baseline	10 in 1-yr	-	-	-	-
	1 in 1-yr	69.8	-54.1	15.7	-
Victoria Pier Berth	10 in 1-yr	1.2	-0.9	0.3	Negligible
	1 in 1-yr	32.7	-16.7	16.0	+2%
Deep-Water Berth	10 in 1-yr	no change	no change	no change	no change
	1 in 1-yr	26.8	-24.8	2.0	-87%

When considering the lower intensity typical 'summer' wave condition, Table 5 shows no accretion or erosion of the bed within the berth pocket is predicted from the modelling with the baseline conditions.,

Under baseline (existing) conditions and following an extreme 1 in 1-year storm (annual) event, Table 5 shows that some areas of the location of the proposed Victoria Pier Berth pocket erode by around 54 m^3, whilst other areas exhibit an accretion of approx. 70 m^3. This gives a net accretion of around 16 m^3. This indicates that there is a small influx of material to the berth pocket area from the wider Douglas Bay, under larger storm events, assuming an updrift supply of material (sand) is available. Given that this small net accretion is only evident for the annual storm, this also indicates the order of sedimentation and supply of sediment to the area on an annual basis, hence currently the Port have no need to dredge.

5.1.1 Predicted effects of Victoria Pier Berth dredge scheme

Following the proposed dredging of the Victoria Pier Berth pocket, the associated changes to flow speed and bed shear stress (as described in Section 4.2.1), result in a small change in the overall sedimentary behaviour in the berth.. The proposed dredge increases the water depth within the berth (particularly towards the western end, where baseline depths are considerably shallower. The deepening reduces the influence of the wave energy at the bed and a negligible amount of sedimentation is predicted over a spring/neap cycle for typical summer conditions. With the annual storm event there is a predicted overall reduction in the 'erosionary' areas within the berth. The change in volume, however, is small at only approximately 17 m^3 (compared to 54 m^3 under baseline conditions). This *circa* 200 μm material is unlikely to travel large distances once the bed motion is initiated. The previous BSS analysis indicated that most sediment movement would be near bed (should it occur) and therefore any sediment was unlikely to 'escape' the dredge pocket unless disturbed by the vessel propulsion. The material would therefore be expected to re-deposit in other parts of the Victoria Pier Berth pocket. The reduced eroded volume accounts for an almost equivalent reduction in the accretionary volume following the dredge (33 m^3, down from 70 m^3 under baseline conditions).

As a result, the net effect of the proposed Victoria Pier Berth dredge is for negligible change under more frequent summer storm conditions, with a slight increase in net accretion (by 2%) following the assessed 1 in 1-year storm event. This supports the previous conclusion from the BSS analysis that the berth pocket becomes marginally more accretionary (as a result of the reduced flows associated with deeper dredged depths). Such effects, however, will be limited by the availability of material, which requires the influence of storm waves to mobilise material and enter the area of the berth pocket with these slow tidal flows.

As a result, the average thickness of annual sedimentation in the new berth is likely to be no greater than a few millimetres and unlikely to be noticeable when vessel disturbance is considered.

5.1.2 Predicted effects of Deep-Water Berth scheme

The end of the proposed Deep-Water Berth pier extends out to the east, past the existing Princess Alexandra Pier. Waves approaching from the south and southeast will, hence, be pushed further out into the approaches to Douglas Bay by the new structure. This will subsequently result in a change in the wave transformation into the inner parts of Douglas Bay, effectively refocussing the wave energy (that otherwise approaches the Victoria Pier region) and reducing the potential influence of waves on the bed material; the result is a limited supply of material. Instead, the wave energy appears to be focussed onto the shallow areas around St. Mary's Rock (particularly to the north and east), as indicated by the greater predicted changes to bed level in these areas, depicted in Figure 36.

As a result, should the proposed Deep-Water Berth scheme be constructed in addition to the Victoria Pier Berth Scheme, there will be wider changes to sheltering and exposure from larger (1 in 1-yr) storm events and a slight reduction in the magnitudes of hydrodynamic flows in the area of the Victoria Pier Berth and its approaches. As described above (Section 5.1.1), under existing conditions, there is a (small) net accretion of material within the berth pocket following the assessed extreme storm event. This indicates a very small supply of material (under these specific conditions) from the wider Douglas Bay region.

The sediment modelling of the effects of the Deep-Water Berth scheme on the sedimentary behaviour within the Victoria Pier Berth pocket is also indicated in Table 5. The modelling indicates that the increased sheltering effect and reduction in hydrodynamic flows reduces the potential bed mobility in the berth and the local vicinity under the annual storm wave condition. Under the typical summer wave condition there is no change in the sediment regime.

Following implementation of the Deep-Water Berth scheme, erosionary areas of the Victoria Pier Berth pocket amount to around 25 m^3 following the assessed extreme storm event (compared with 54 m^3 for the baseline). Associated areas of accretion amount to approximately 27 m^3 with the Deep-Water Berth scheme (compared to approx. 70 m^3 under baseline (existing) conditions). The resultant net effect is a very slight accretion of 2 m^3 (a reduction of around 90% of the baseline accretion volume).

The results indicate construction of the Deep-Water Berth will have negligible sedimentary effects on Douglas Harbour and the immediate approaches with or without the proposed Victoria Pier Berth. The requirement for maintenance dredging will remain negligible unless there is a significant change to the sediment supply in the immediate area. Existing flows indicate there is little potential for significant sediment movement into the area.

5.2 Deep-Water Berth area

Assessment of the sediment modelling results has been undertaken in the area of the proposed Deep-Water Berth for typical summer wave conditions and the 1 in 1-year return period (annual) storm event. The volumetric results for the 15-day spring-neap cycle are summarised in Table 6, providing predicted effects, with regard to changes to sedimentation and erosion within the location of the proposed new Deep-Water Berth (located inside the new pier structure), and as resulting from each scheme.

Table 6. Predicted volume change within Deep-Water Berth over a 15 day spring-neap cycle following implementation of proposed schemes

Scheme	Wave Scenario	Volume Change Associated with Predicted Bed Level Change			Net Relative Change to Baseline
		Positive Change (accretion) (m^3)	Negative Change (erosion) (m^3)	Net Change (±) (m^3)	
Baseline	10 in 1-yr	12.8	-88.1	-75.2	-
	1 in 1-yr	12.2	-89.2	-77.0	-
Victoria Pier Berth	10 in 1-yr	no change	no change	no change	no change
	1 in 1-yr	no change	no change	no change	no change
Deep-Water Berth	10 in 1-yr	23.5	-44.5	-21.0	-72%
	1 in 1-yr	24.3	-44.6	-20.3	-74%

Table 6 shows little variation in predicted sedimentary effects when considering either the low intensity ‘summer’ storm conditions, or the more extreme 1 in 1-year wave event. This indicates that the movement of bed material at this location is driven by the overriding hydrodynamic (flow) conditions, with water depths being sufficient to limit the influence of these waves on the bed.

Under baseline (existing) conditions, Table 6 shows that, over a mean spring-neap tidal cycle, some areas of the Deep-Water Berth erode by a total of around 90 m^3, whilst other areas exhibit accretion to a total of approximately 13 m^3. This gives a net erosion of around 77 m^3 and indicates that there is a net very small movement of material out of the assessment area to the wider Douglas Bay region, under spring tidal conditions.

5.2.1 Predicted effects of Victoria Pier Berth dredge scheme

The conceptual analysis and hydrodynamic modelling showed that construction of the Victoria Pier Berth would have no effect in the area of the Deep-Water Berth. The interpretation of the sediment modelling results confirms the hydrodynamic and BSS assessments as there is no change in the sedimentation patterns, within the proposed Deep-Water Berth area, as a result of the proposed deepening of the Victoria Pier berth pocket. We note here that that the assessment scenarios considered each scheme in isolation. The results therefore do not include any potential for in-combination effects, however, no potential for significant interaction is indicated from the various modelling results.

5.2.2 Predicted effects of the Deep-Water Berth scheme

Following construction of the proposed Deep-Water Berth scheme, there remains no notable variation in predicted sediment movement between either of the assessed wave events. This indicates that it is the hydrodynamic (flow) conditions that dictate the movement of bed material in the Deep-Water Berth.

As a result of the construction of the proposed pier, general changes to the hydrodynamic conditions (as described in Section 4.3.1), are shown to influence the sediment movement within the Deep-Water Berth. The proposed Deep-Water Berth scheme provides a generally sheltered environment within the berth (particularly during the flood tide, where the pier structure diverts the flow towards the east) and, by association, reduces the flow speeds and bed shear stress applied to the bed material. This, subsequently, results in an overall reduction in the 'erosionary' areas by around half, which amount to only approximately 45 m^3 (compared to 90 m^3 under baseline conditions). The erosionary areas are predominantly at the southern end, where fast flows through the constricted passage under the link bridge near Douglas Head remain sufficient to mobilise the bed material (see areas of bed change in Figure 36 and Site DW2 in Figure 37).

Associated with the predicted reduction in erosionary areas, is a predicted increase in the accretionary areas, following construction of the Deep-Water Berth pier, which amount to around 24 m^3 (compared to 13 m^3 under baseline (Existing) conditions). As a result, the net effect of the proposed Deep-Water Berth scheme is for a general reduction in net erosion over the mean spring-neap tidal cycle, from around 77 m^3 to approximately 21 m^3 (equating to a reduction of around 74%). This supports the previous conclusion that the area behind the pier becomes less erosionary, as a result of the reduced flows associated with the more sheltered conditions offered by the structure. These changes are, however, small and will be within the natural variability of the area. The Deep-Water Berth is therefore predicted to be self-maintaining.

5.3 Sedimentation assumptions

The predicted changes to sedimentation described in Section 5.1 and 5.2 provide a relative scale of effect, in each of the assessment areas, and as a result of implementation of each of the proposed schemes. As noted above, these predicted effects are based on the following assumptions:

- The bed material is characterised by a layer of 200 µm (fine) sand of varying thickness. In the area of the Deep-Water Berth (and offshore) larger bed material, or a more armoured bed occurs. Also, a proportion of finer sediment is evident on the sea bed in the approaches to the Victoria Pier Berth. This evidenced from the underwater survey described in Section 2.7 and will marginally vary the magnitude of predicted bed movement;
- The predicted changes are a result of the forcing conditions assessed (covering a mean spring-neap tidal cycle; additive inclusion of two different wave events extracted from the 40-year hindcast database, chosen to provide an indicative range of wave events that might be expected in any given year. Different wave conditions, different wave approach directions and peak wave events coinciding with different tidal states could result in a different predicted effect, however, analysis over a spring-neap cycle will tend to average out some of these effects;
- The initial bed thickness (as described in Appendix B) provides a general description of the baseline bed conditions and allows for predicted changes without limitation to availability of material. Areas where bed material might already be stripped by the forcing conditions (e.g. rocky outcrops around St. Mary's Rock and scour around the end of Princess Alexandra Pier) would limit the predicted bed level changes (erosion) in the vicinity of these areas and reduce the transport potential relative to that modelled.

6 Navigation Study

6.1 Introduction

Navigation studies have been undertaken to provide feasibility analysis for the two berth proposals set out in Section 1. The main aims of the studies were to ascertain:

- If the proposed standard design (240 m) cruise vessel can safely manoeuvre onto and off the proposed berth at Victoria Pier, including associated manoeuvres for berthing starboard-side-to;
- If the proposed large cruise vessel (362 m) can safely manoeuvre onto and off the proposed Deep-Water Berth, including associated manoeuvres for berthing port-side-to;
- The possible environmental effects on the vessels of wind, wave and tidal conditions that can be expected during the cruise season;
- If the vessels are likely to be able to safely leave each berth; and
- The requirements for tug assistance and associated bollard pull.

The studies to meet these aims have been undertaken in the following three stage methodology:

- Stage 1: Navigational assessment (Section 6.3);
- Stage 2: Vessel simulation (Fast- and Real time) assessment (Section 0); and
- Stage 3: Summary analysis (Section 6.5).

The assessment conducted in Stage 1 informed the selection of scenarios and vessel simulations conducted in Stage 2. The results of both stages were then combined and analysed to provide the summary findings presented in Stage 3.

6.2 Method

6.2.1 Stage 1: Navigational assessment

The navigational assessment covers the area surrounding each of the proposed berth developments and their approaches, and includes:

- A chart assessment, identifying the navigational environment, hazards and aids to navigation;
- Weather conditions for the year and cruise season, identifying predominant wind directions and forces;
- Tides and currents resulting from the proposed developments;
- Identification of port services, including:
  - Pilotage requirements;
  - Tug availability;
  - Local Port Services; and
- Traffic assessment.

The results from this assessment informed the ship simulation scenarios conducted in Stage 2 and the final summary analysis (Stage 3).

6.2.2 Stage 2: Vessel simulation assessment

The second stage used outcomes from the navigational assessment and fast-time runs to inform scenarios assessed under real-time conditions.

Vessel simulations are used to assess the limitations on ship handling from external factors, with continuous changes to manoeuvring orders and subsequent response of set model parameters providing a realistic output on which to make an assessment. As the parameters of a simulator model can be adjusted to provide a range of variables, the level set can be used in assessing the limiting factors, manoeuvres required and their water-space, vessel limitations and practicability of the proposed schemes.

The vessel simulations were conducted in two parts to ascertain the navigational issues and limitations arising from the proposed developments:

- Fast -time simulations; and
- Real-time simulations.

The first part was Fast-time simulation runs to identify the broad scale effects of the environmental conditions (weather and tide) on ship handling within the approaches to Douglas Harbour. These Fast-time simulations are computer controlled and show the influence of external forces on the ability of a vessel to maintain a track using standard ship handling, without the intuitive direction of real time effects that would be provided by an experienced mariner. The outcomes of Fast-time simulations helped identify:

- The effects on ship handling during different tidal and weather conditions;
- Difficulties of ship handling that are likely to require assessment from an experience mariner;
- Difficulties of ship handling that may require auxiliary propulsion or assistance.

The second part of the vessel simulation assessment explores scenarios in Real-time, informed by the Fast-time runs. Real-time simulations are designed to mimic ship handling operations as close to real life as possible in order to provide realistic human response and subsequent actions of the vessel. The Real-time simulations therefore test the ability to manoeuvre a vessel as required within set variables by an experienced mariner. The use of a realistic environment and vessel behaviour provides robust outcomes for use in the assessment of the proposed developments.

The scenarios were run on the Real-time simulator at the Fleetwood Nautical College assessed by marine professionals Captain Martin Phipps former Southampton Pilot and Harbour Master and Captain David Eccles Senior Master for Stena Line and Instructor at Fleetwood Nautical College. The scenarios assessed identified key points including, navigational constraints, limiting factors, the water-space required, and a realistic appraisal of the risk factors involved. The outcomes from Real-time simulations include:

- The requirements for auxiliary propulsion or assistance;
- The bollard pull of any tugs required;
- Limiting levels of the various forcing environmental variables;
- Points of approach and water-space required for manoeuvring; and
- Potential influence of navigational hazards;

The results from these vessel simulation assessments are used alongside the navigational assessment conducted in Stage 1 for the final summary analysis in Stage 3.

6.2.3 Stage 3: Summary analysis

The outcomes from Stages 1 and 2 have been analysed to identify the navigational issues of the proposed developments. The summary analysis provides the results of the studies with respect to the study aims set out in Section 1, above

The findings from the navigational study are presented (in summary format) in the following sections, with the full set of Fast-time and Real-time simulation assessments provided in Appendix G and Appendix H, respectively.

6.3 Navigational assessment

The navigational assessment covers the area surrounding each of the proposed developments and their approaches. This assessment determines the constraints or limitations currently in place which are likely to affect the feasibility of the developments and informs the scenarios to be assessed by vessel simulation.

6.3.1 Chart assessment

Douglas Harbour is located on the east coast of the Isle of Man situated at the southern headland of Douglas Bay. The chart assessment is conducted using admiralty chart number 2696 and identifies the navigational environment, hazards and aids to navigation within the area of the proposed developments. Figure 2 shows the location of Victoria Pier and the Deep-Water Berth developments.

6.3.2 Navigational environment

The coastline within the area consists of abrupt rocky cliffs and a sand beach located within Douglas Bay. Shallow water of less than 5 m extends from the beach into the bay as far as Victoria Pier. The nature of the sea bed near and on the approaches to Victoria Pier and the Deep-Water Berth comprise of course sand, broken shell, gravel and rock outcrops that can affect the navigational environment. An anchorage area is denoted in the Bay lying on the outer approach to Douglas Harbour.

6.3.3 Navigational hazards

The charted navigational hazards on the approach and in the vicinity of the proposed developments of Victoria Pier and the Deep-Water Berth include:

- Refuge tower located 280 m N of Victoria Pier, visible to surface shipping and fitted with a navigational light;
- St Mary's Rock situated beneath Refuge tower and above chart datum (CD). The rock extends to 130 m N of Victoria Pier;
- Spot heights of less than 5 m below CD exist to the NW of the current navigational channel;
- A 10 m contour line is present within the approaches to the Harbour entrance and Victoria Pier;
- A 5 m contour line extends from the western end of Victoria Pier surrounding St Mary's Rock;
- An underwater cable runs from Port Skillion to the UK mainland crossing the proposed Deep-Water Berth development; and
- Overfalls exist at certain states of tide to the NE of Princess Alexandra Pier.

The charted navigational hazards identified require consideration for operations such as anchoring, berthing, manoeuvring and navigating on approach and departure from the proposed developments.

6.3.4 Aids to navigation

Current aids to navigation for Douglas Harbour include:

- A sector light for Refuge tower;
- Headland marker light for Douglas Head;
- Marked dolphin denoting the extent of Princess Alexandra Pier;
- Lead lights and marks for Douglas Harbour;
- Starboard lateral markers denoting edge of approach channel;
- Breakwater lights;
- Conister Jetty miscellaneous marker; and
- Other beacons denoting berths within the Harbour.

The current layout of navigational aids provides indication of fixed features, used to highlight navigational hazards, determine vessel positions and guide approach or departure transits. Floating lateral marker buoys denote the western limit of the approaches to the harbour with shallow water behind.

The current use and layout of navigational aids has been arranged to best assist the present layout and use of the harbour. In accordance with recommendations from national bodies a review of aids to navigation should be conducted after a change to the ports baseline condition or every five years. It is therefore understood that the feasibility of the proposals, although informed by, is not dependant on the present use of navigational aids.

6.3.5 Weather conditions

The weather conditions comprise the effects of both winds and waves. The prevailing weather conditions are from the W and SW accounting for over 40 % of the time. These conditions have wind speeds more frequently above 16 kts than from any other direction. Douglas Harbour is afforded a natural shelter from these prevailing conditions due to its location at the S of Douglas Bay. The Harbour area is most susceptible from NE to SE wind directions, although not at a high frequency, accounting for 20 % of the time. The Bay and Port infrastructure provide no shelter from wind, fetch or waves from these directions.

Wind conditions from the S account for around 15 % of wind directions and have a proportionally higher frequency of strong winds. The outer approaches to Douglas Harbour are not sheltered from southerly conditions, therefore they may cause significant vessel drift towards the navigational hazards.

A wind rose displaying the conditions outside of Douglas Bay is shown in Figure 10; these data have been collected and modelled through the SEASTATES service (ABPmer, 2018).

Wave conditions most affecting the approaches to Douglas Bay are from the S, accounting for almost half of the conditions encountered, waves from this direction have a greater frequency of heights above 2 m. Wave states within the Douglas Bay are affected by the local geography, with no shelter or interruption of fetch from the SE to NE directional sector. Waves from within these directions are generally highest and will cause vessel drift towards the navigational hazards. Figure 38 shows the direction of waves by percentage and their heights which affect the approaches to Douglas Bay. These data have been collected and modelled through the SEASTATES service (ABPmer, 2018).

Variations in the local wave data from points surrounding the proposed developments were modelled during the flow modelling study; the wave roses produced are shown in Figure 11. These wave roses show direction by percentage of time and corresponding wave heights experienced. As determined by analysis of the waves affecting the approaches to Douglas Bay, Douglas Harbour is least sheltered from NE to SE sector with greatest wave heights primarily from a south-easterly direction.

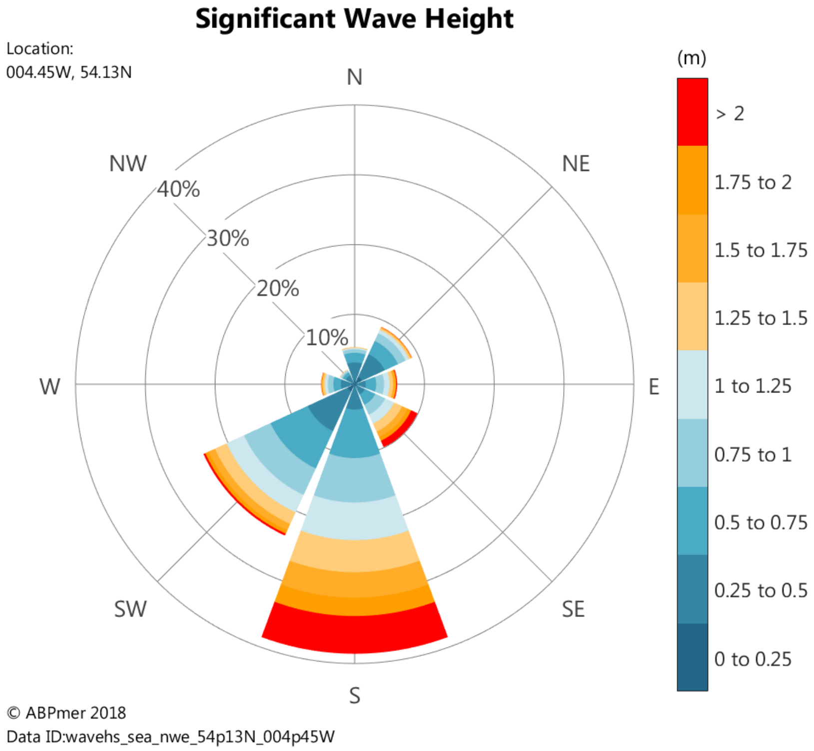


Figure 38. Douglas approaches wave rose

Weather conditions experienced on the beam of a vessel when transiting in the approaches is likely to cause a significant degree of set on the vessel, increasing the swept-path and reducing clearing distances or closest point of approach (CPA) to navigational hazards. The most prevalent and strongest wind and wave conditions experienced around the environs of Douglas Harbour have winds centred from around the SW direction t and waves from the S. The Harbour is least sheltered from the arc from NE to S wave direction. The most prevalent and strongest conditions from these directions are expected to have a greatest relevance to the point of approach and set of a vessel within the approaches to Douglas Harbour.

6.3.6 Tides and currents

The tides and currents modelled during the flow analysis have been used to determine the potential effects on ship handling, some figures in this section are repeated in order to highlight points made. The flows modelled for each proposed development show expected currents throughout a tidal cycle in the environs of Douglas Harbour. The vector flow fields in the diagrams are for spring tides as these are of greater force and will therefore illustrate larger effects on ship handling.

Deep-Water Berth

The creation of a Deep-Water Berth to the east of Princess Alexandra Pier will alter the currents within the surrounding area, notably, near Douglas Head, the Deep-Water Berth and across the Harbour entrance. The effect of these currents at different states of tide will impact upon ship handling, including the point of approach required, drift experienced and increase in swept-path leading to a reduction in distances off navigational hazards.

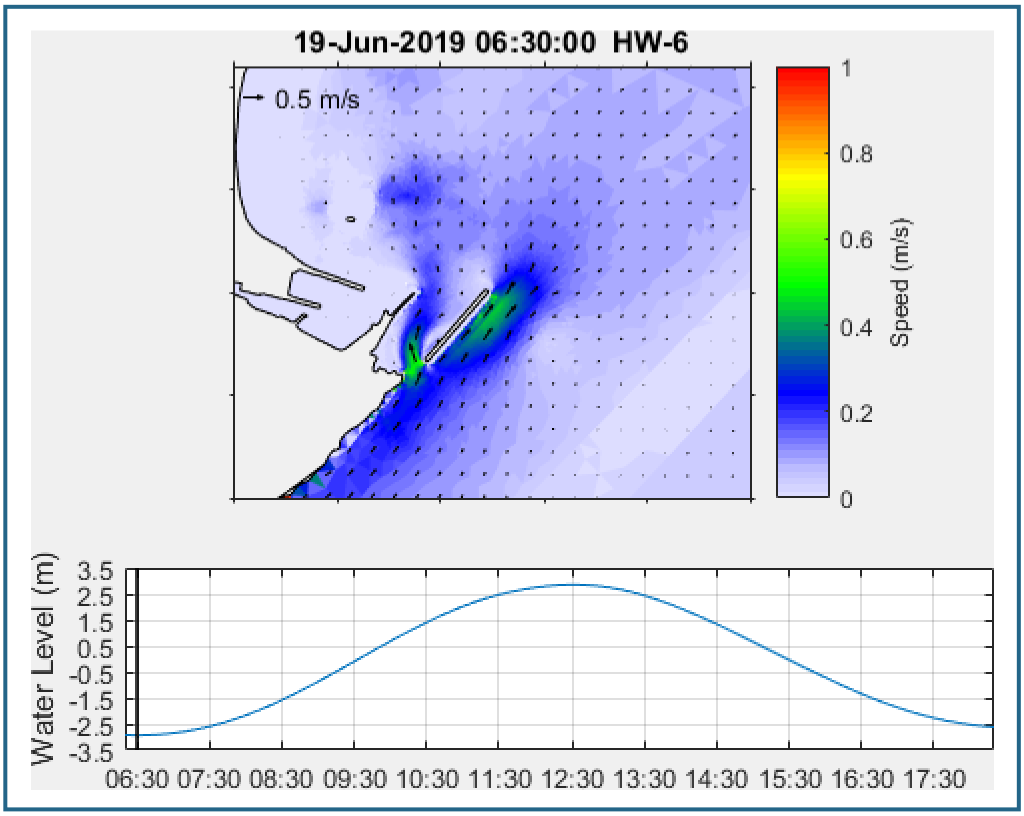


Figure 39. Deep-Water Berth currents at HW -6 hours.

Currents have their least effect during the period HW +6 to HW –6 hours (Figure 39). During this period a northerly flow through the Deep-Water Berth area with speeds up 0.5 m/s (1 kts) between Douglas Head and the southern point of the new pier. A current of similar speed is also present along the outer face of the new pier, increasing in speed towards the northern point.

The currents shown during these periods are generally weak with only minor effects on vessels expected during approach and departure to the Deep-Water Berth. In order to minimise the effects of these currents an approach from the NE towards the centre of the new berth would minimise the effect from the outer face of the pier and allow adequate space for stern-drift of the vessel. Due to the northerly current within the new berth area a vessel may experience bow-drift and be required to approach the berth at a steeper angle[1] or rely on bow thrusters to check this swing. Depending on wind conditions this northerly current may assist manoeuvring alongside when ferry gliding[2].

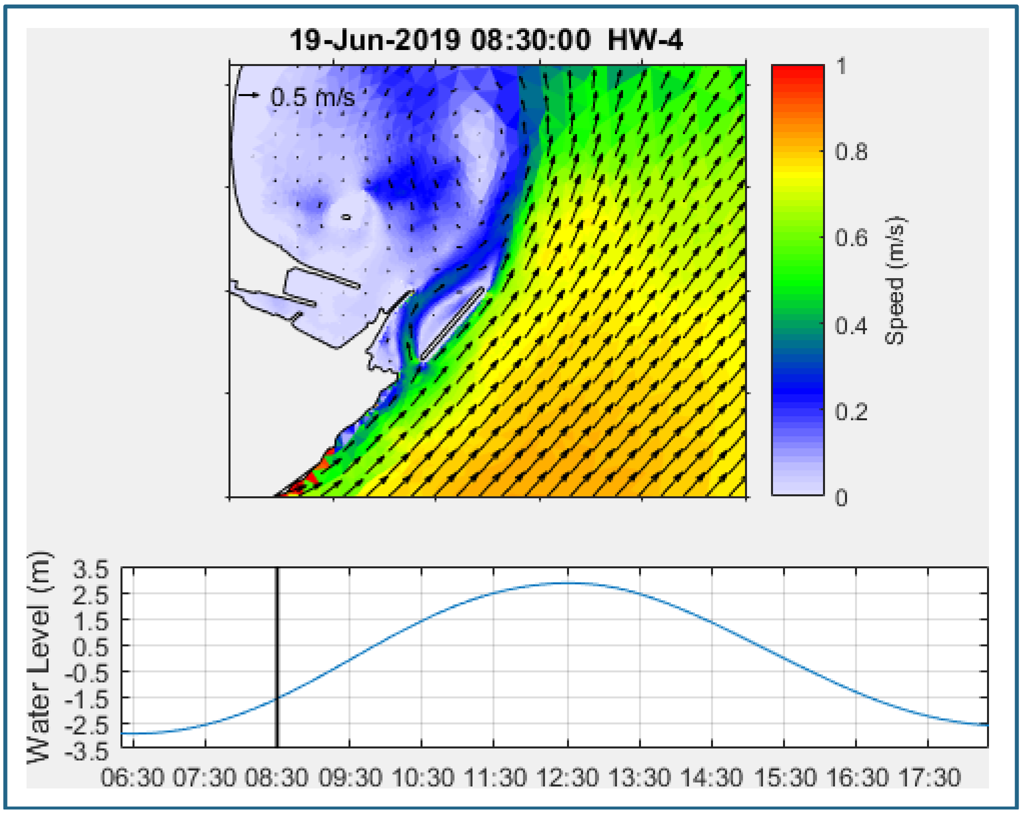


Figure 40. Deep-Water Berth currents at HW -4 hours

During the flood tide, current strength increases in a general flow direction from SW to NE, as indicated in Figure 40 at HW -4 hours, this flow runs along the outer edge of the deep-water berth and into Douglas Bay. On passing the northern point of the berth the current becomes more northerly and forms a weaker anti-clockwise flow around the bay to the west of the main current. A northerly tidal stream between Douglas Head and the southern point of the deep-water berth flows through the new dock and along the outer face of Princess Alexandra Pier before joining the anti-clockwise flow around Douglas Bay.

At HW -4 hours the main tidal stream exceeds 1.5 kts off the coast reducing to around 1 kts along the face of the Deep-Water Berth pier. The tidal stream within the new berth strengthens to between 0.5 and 1 kts, before joining the anti-clockwise flow within the Bay at speeds below 0.5 kts.

Vessels within the approaches to the Deep-Water Berth will be subject to northerly drift. Conventional vessels on arrival may benefit from increased flow over rubbers and more manoeuvrability, however, vessels on departure will experience less steerage and be more subject to the effects of the drift. Vessels departing from Port Side To (PST) may experience difficulty when leaving the new dock area due to the sudden increase in tidal flow off the pier head, this effect may be further pronounced when turning the vessel as the current will tend to increase stern movement (way) to starboard. Vessels on arrival are also subject to this phenomenon and may experience a swing to port when entering the new berth area for a PST berthing. In these conditions a Starboard Side To (SST) berthing would offer easier ship handling

1 A steeper angle is one closer to the perpendicular when approaching a specified point.
2 See glossary in Appendix I.

on arrival, as the vessels pivot point would be aft and the turn may be made further out, and on departure as greater steerage way can be made.

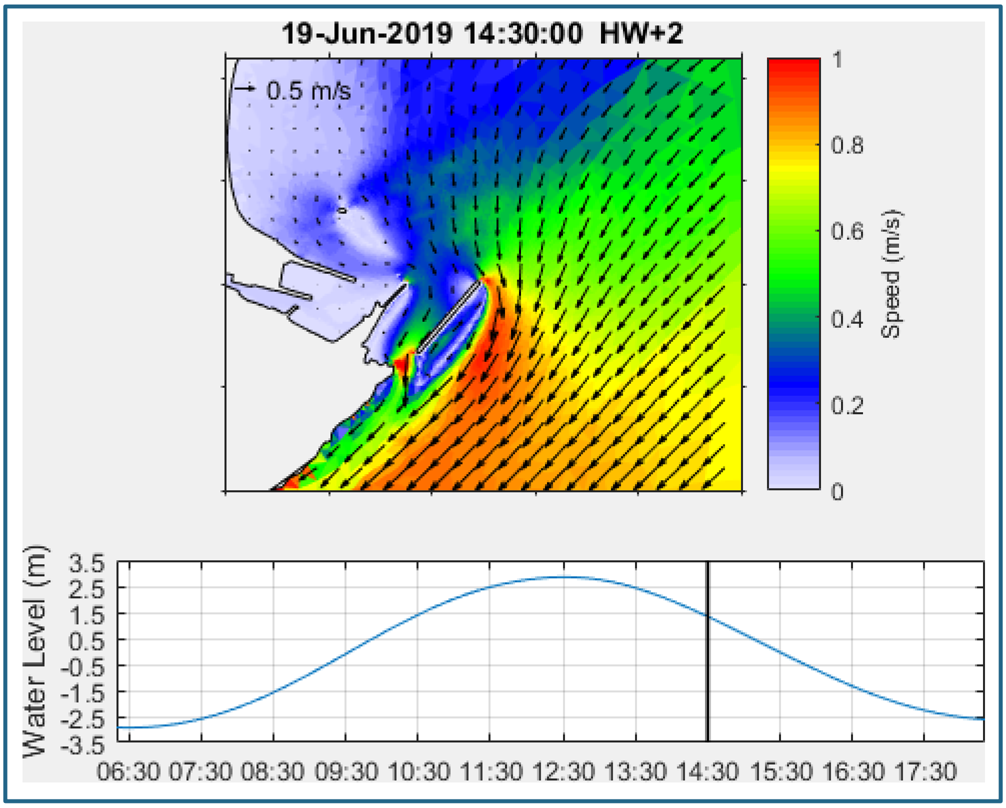


Figure 41. Deep-Water Berth currents at HW +2 hours

Currents during the ebb tide are strongest at HW +2 hours (Figure 41); the general flow is from the NE to the SW with flows as high as 2 kts. Currents of about 0.5 kts t in Douglas Bay flow S joining the main SW current in the vicinity of the Deep-Water Berth.

Within the area of the new berth entrance the southerly current from Douglas Bay increases in speed and diverts either SE around the northern point of the Deep-Water Berth or SW through the new berth area, joining the main currents between Douglas Head and the southern point of the Deep-Water Berth. Current passing around the northern point of the Deep-Water Berth flows faster, reaching up to 2 kts around the pier. Current flowing through the new berth area increases in speed on passing the head of Princess Alexandra Pier and within the approach to the area between Douglas Head and the southern point of the Deep-Water Berth. This flow increases to 2 kts when passing this area. With the deflection of this current an area of relatively still water is created on the western face of the Deep-Water Berth's northern point. This difference in flow rate around the northern point is likely to affect ship handling in the area.

Vessels approaching the Deep-Water Berth from the north are likely to experience reduced manoeuvrability due to the SW current, leading to the requirement for a faster vessel approach speed. The currents on approach to the Deep-Water Berth change from the SW to south, which is likely to cause vessels to approach with a more northerly track compensating for the expected southerly drift.

Within the new berth area water flows to the SW; vessels manoeuvring in this area are likely to experience drift in this direction and difficulty in either slowing on approach or checking headway on departure from PST.

The difference in flow rates around the northern point of the Deep-Water Berth will affect the handling of vessels in this area especially when at slow speeds. A northerly approach or departure would avoid manoeuvring in this area, however, a departure from PST would require adequate clearance from this area before turning due to the southerly drift. In these conditions a Starboard Side To (SST) berthing would offer easier ship handling on arrival, as the vessels pivot point would be aft, the turn may be made further out and drift to the south-west inside the dock can be check more effectively by the vessel's main propulsion. On departure the south-westerly drift may also be more effectively checked by the vessels main propulsion and steerage way improved when leaving the new dock area.

Victoria Pier berth

The creation of a dredge pocket alongside the outer face of Victoria Pier may influence the flow of currents in the area. Changes to currents, however, are not expected to be significant but the change in berth use to larger vessels requires analysis into the effects of the predicted current on ship handling.

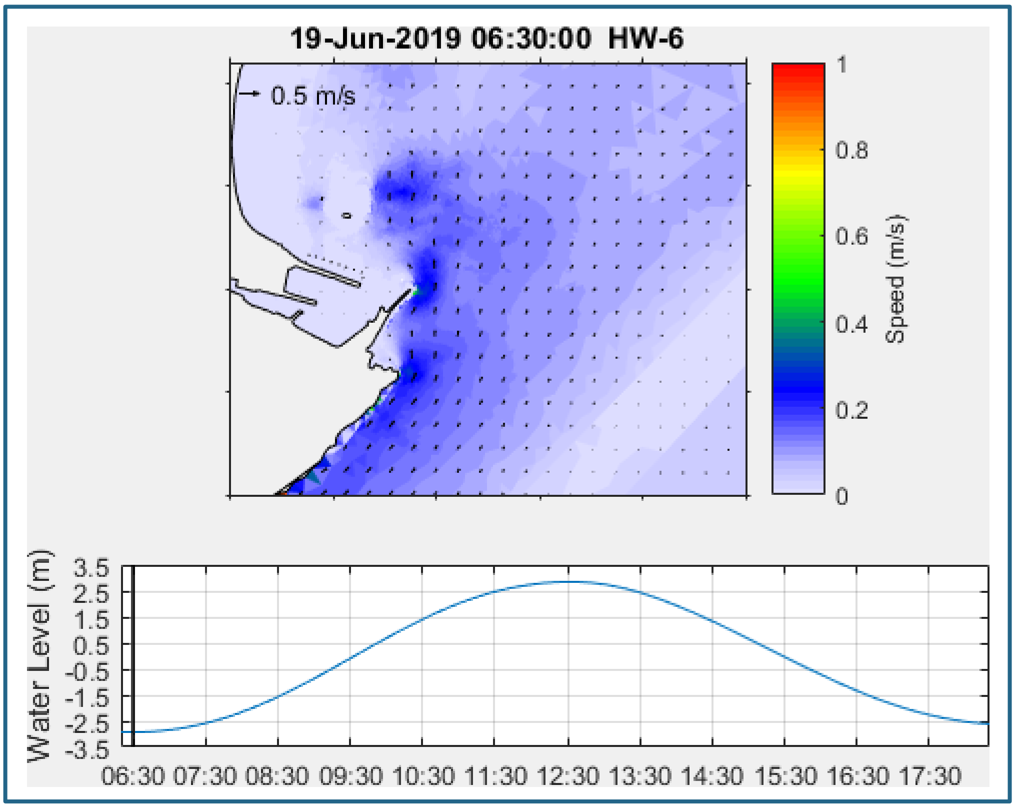


Figure 42. Victoria Pier berth currents at HW -6 hours

The general tidal flow at HW -6 hours (Figure 42) is from SW to NE with speeds up to 0.5 kts along the coastline. On passing Douglas Head the current moves northerly until deflected by Princess Alexandra Pier, once past the pier head the current again moves northerly into Douglas Bay.

Vessels manoeuvring to or from the Victoria Pier berth may experience a minor drift to the north when passing the head of Princess Alexandra Pier where the current flows north at less than 0.5 kts. Currents affecting the immediate vicinity of Victoria Pier are minor and are not considered to have an impact on ship handling.

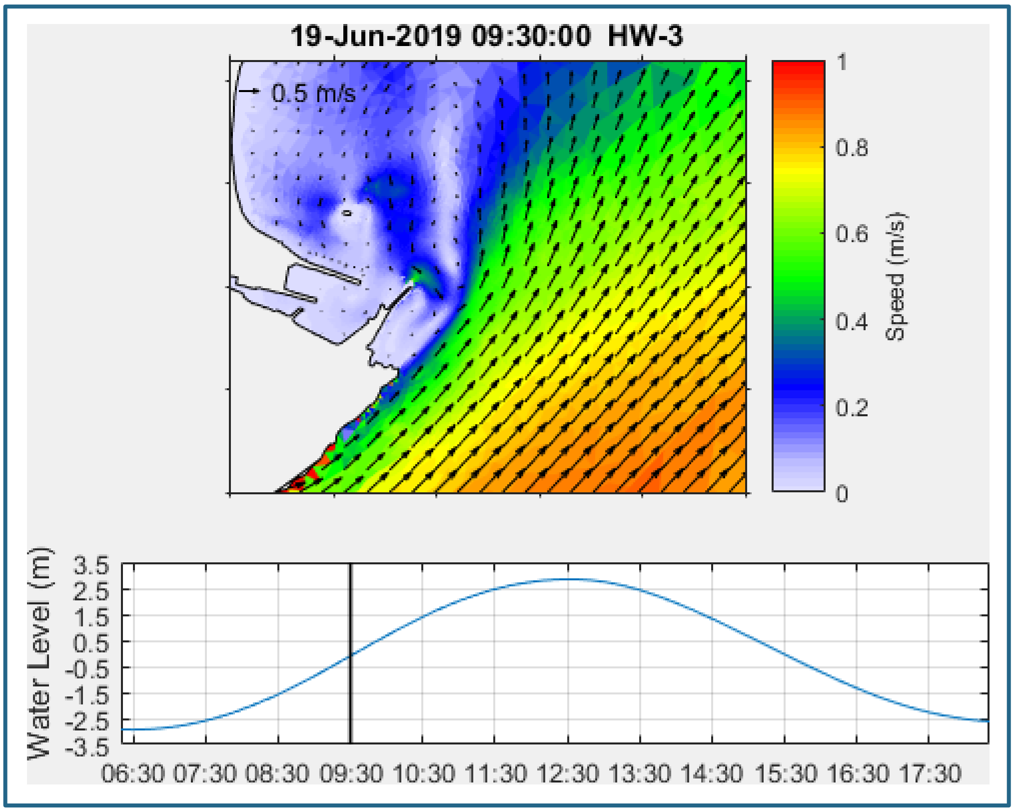


Figure 43. Victoria Pier berth currents at HW -3 hours

At HW -3 hours (Figure 43) the SW to NE flow increase in speed to between 1.5 kts and 2 kts off the coast. The main current follows the coast, passing Douglas Head and opening out into Douglas Bay. On entering the Bay, a weaker current flows anti-clockwise to the west of the main flow, this flow varies in speed between 0.5 kts and 1 kts.

The anti-clockwise current become most pronounced when passing the head of Princess Alexandra Pier and the Refuge tower, where the current splits and flows either side of St Mary's Rock. This flow creates a southerly current across the approaches to Victoria Pier and a SE flow across the dredge pocket of up to 0.5 kts.

Vessels passing between the Refuge tower and Princess Alexandra Pier are likely to keep towards the N due to southerly drift. The effects of current for manoeuvres onto and off the berth are not considered to have a significant impact on ship handling.

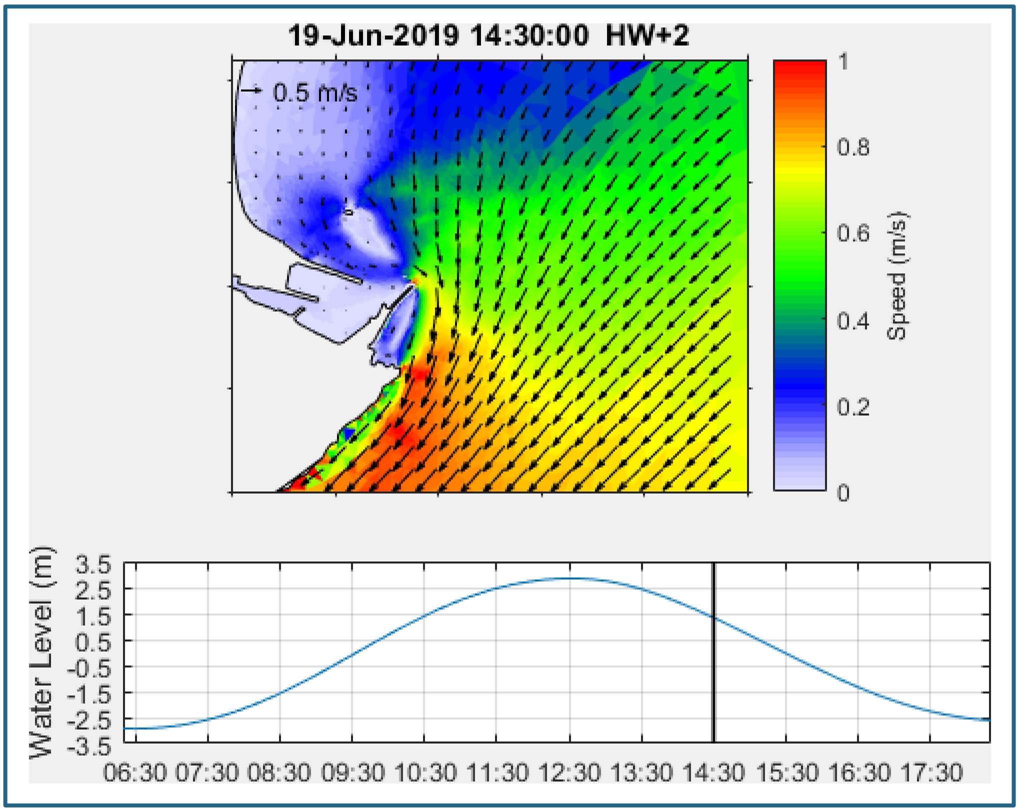


Figure 44. Victoria Pier berth currents at HW +2 hours

On the ebb, from high water onwards the general tidal flow is from the NE to SW with a southerly current joining the main flow from Douglas Bay (e.g. Figure 44). The split of the current around Refuge tower increases to exceed 0.5 kts and combines with the southerly flow off Princess Alexandra Pier where flow is further increased to over 1 kts.

The southerly current across the approaches to Queen Victoria pier becomes stronger, doubling in speed to over a knot, flow over the dredge pocket in a south-easterly flow also increases.

Vessels approaching Victoria Pier from the N are likely to experience reduced manoeuvrability due to the SW current, leading to a requirement for a faster approach speed. Vessels passing between the Refuge tower and Princess Alexandra Pier are likely to keep towards the N due to southerly drift. Manoeuvres from and to the berth are affected by a south easterly current, pushing vessels onto the berth.

6.3.7 Port Services

Douglas Harbour is operated by the Isle of Man Department for Infrastructure Ports Division. The harbour provides services for commercial and recreational craft, including:

- Local Port Services (LPS);
- Pilotage services;
- Tug and towage services;
- Tendering services;
- Dredging facilities; and
- Cranage facilities.

Local Port Services are controlled through the harbour office and provides port information for mariners, including the scheduling of available berths and ship traffic, dissemination of weather information and publishing of notice to mariners.

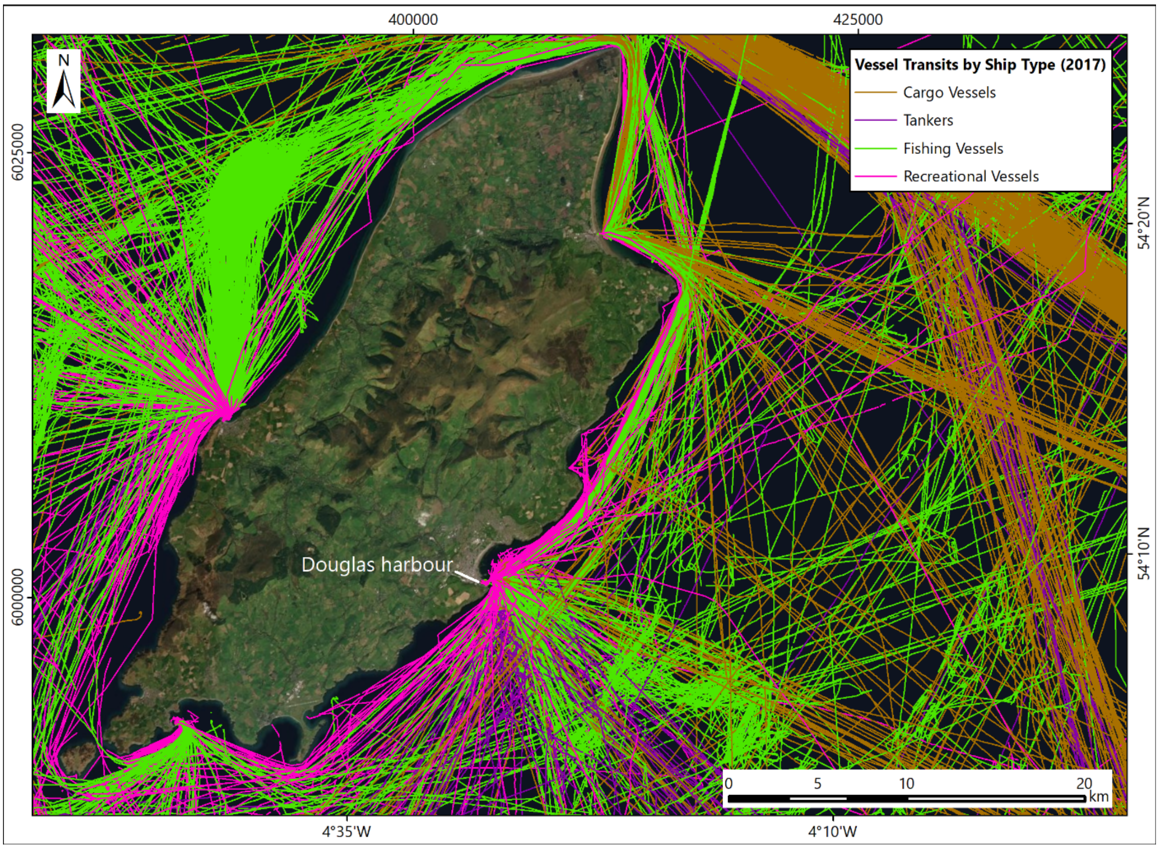
Pilotage services are available for commercial vessels, with requirement determined on a case by case basis. The Douglas Harbour pilot launch and boarding ground may be utilised by other Ports within the region during inclement weather for the embarking and disembarking of pilots.

Tug, towage and tendering services are provided by Laxey Towing Co. Ltd., this independent company is based in Douglas Harbour and provides services to the whole island. Douglas Harbour does not have a dedicated tug service on demand, vessel requiring tug assistance are required to arrange this in advance. As Laxey Towing Co. have a single tug available further tug assistance may be provided by other ports in the region.

Conservancy for Douglas Harbour is provided by a mixture of port operated and chartered vessels, these include a dredger, survey vessels and miscellaneous workboats.

6.3.8 Traffic assessment

The Isle of Man holds a strategic position within the Irish Sea having major shipping routes passing through its waters. Douglas Harbour forms an integral link with the mainland of the United Kingdom (UK) operating as the island's passenger service link and energy hub for the east of the island. Vessel movements within and surrounding Douglas Harbour have been assessed to determine traffic trends and vessel types. The figures used in this section are a result of the analysis of Automatic Identification System (AIS) data for 2017 (reproduced here with permission of the MCA and MMO)



Basemap: Esri *et al*. AIS data published under Open Government License Reproduced with permission of the MCA and MMO.

Figure 45. AIS transits for cargo, tanker, recreational and fishing vessels

The AIS vessel tracks, for 2017, are provided in Figure 45 for Cargo vessels, tankers, fishing vessels and recreational vessels.

Cargo vessels operate on an established route between Douglas Harbour and the UK mainland. Other cargo traffic using the harbour is evident from vessels crossing the Irish Sea and on coastal routes between Douglas and Ramsey

Douglas Harbour is used as an energy hub for the island, accepting tankers on routes from the UK mainland and Wales. AIS transits of tankers indicate these vessels occasionally drift or circle outside of the harbour before entering.

Recreational vessels associated with the marina within Douglas Harbour are present throughout the year, however this vessel type is seasonally affected with an increase in movements during summer months. The majority of this traffic is engaged on coastal routes with a concentration of vessels around the major ports, most notably Douglas Harbour.

Fishing vessel operate between Douglas Harbour and fishing grounds in the Irish Sea. AIS tracks indicate these vessels primarily follow direct routes between the harbour and their intended area.

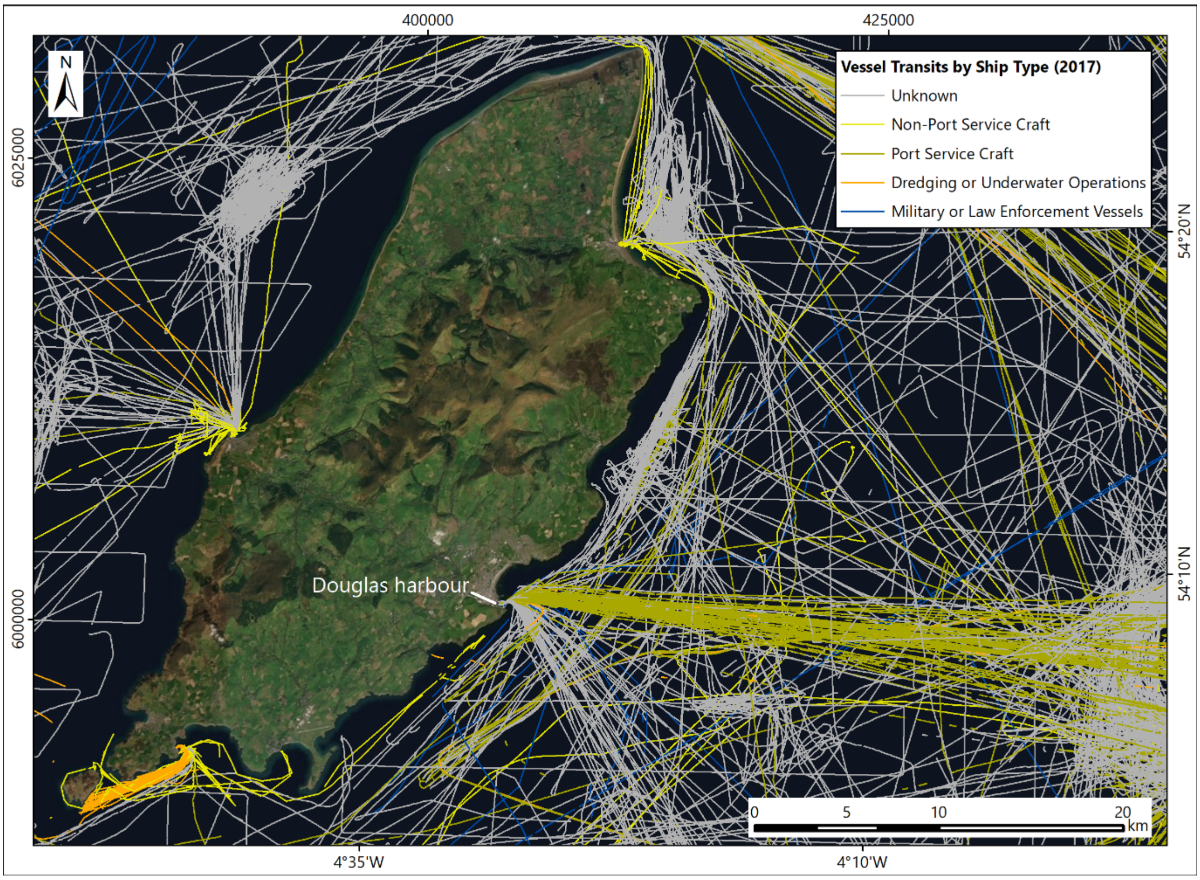


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Figure 46. AIS transits for Port Service craft, Non-port Service craft, Dredgers, Military or Law Enforcement and Unknown vessels

The AIS vessel tracks, for 2017, are provided in Figure 46 for non-port service craft, port service craft, dredging/underwater operations, military/law enforcement and 'unknown' vessels.

AIS transits indicate minimal use of Douglas Harbour by Port Service craft, however, Non-Port Service craft activity is shown between the harbour and ports to the north and west of the Island. This traffic may be associated with the services provided by Laxey Towing Co. Ltd.

Dredging and Military or Law Enforcement vessel show few and sporadic tracks in the area, it is indicated however that these vessel types operate out of Douglas Harbour.

Unknown vessel tracks are from AIS signals without identification markers, these tracks cannot be positively identified although they are often associated with recreational, fishing and Non-Port Service craft. Unknown vessel tracks show transits between Douglas Harbour and areas of activity in the Irish Sea, indicating Douglas as a hub of operation.

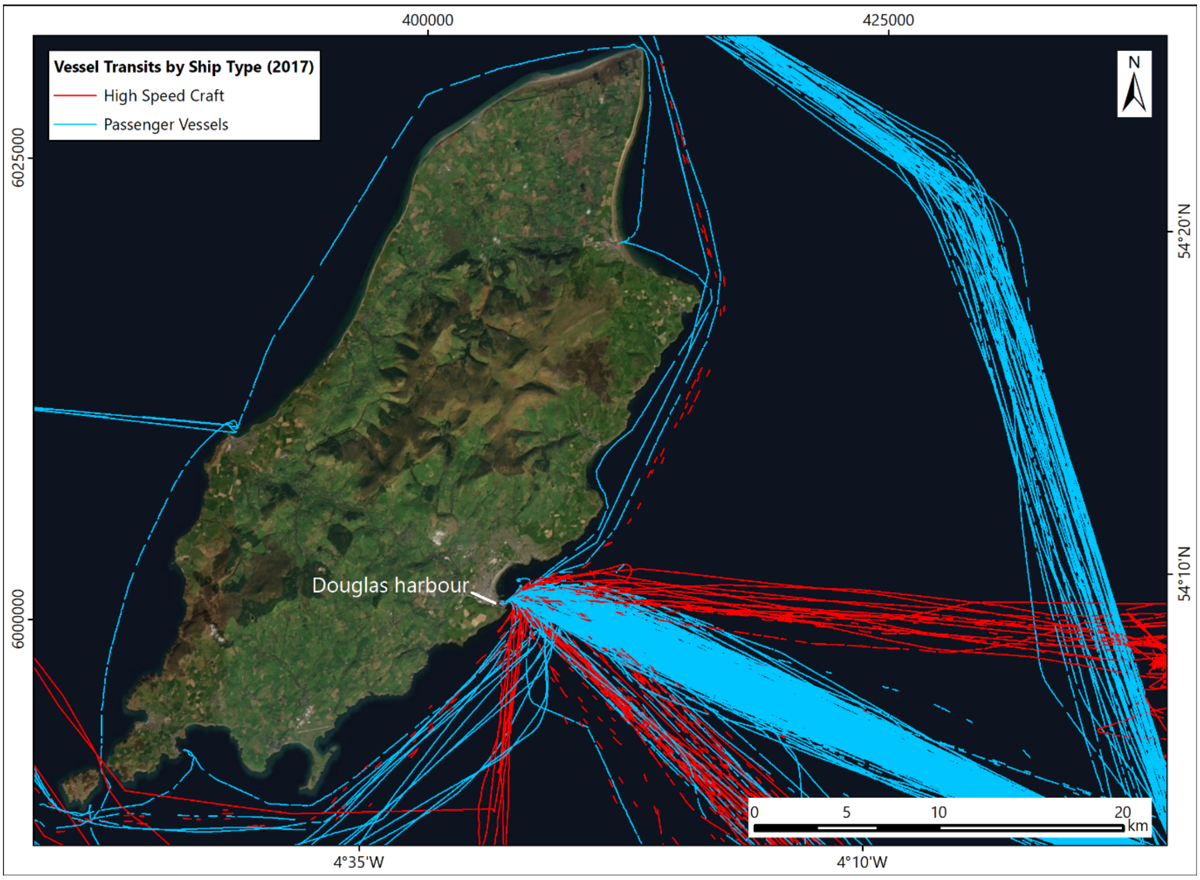

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Figure 47. AIS transits for high speed craft and passenger vessels

The AIS vessel tracks, for 2017, are provided in Figure 47 for high-speed crat and passenger vessels.

High speed craft and passenger vessels operate on established routes between Douglas Harbour the UK mainland and Ireland. The AIS transits in Figure 47 show regular use of the harbour by these vessel types, indicating their predominance in commercial traffic for the harbour.

6.4 Vessel simulation assessment

6.4.1 Fast-time simulations

Method

The Fast-time simulations were conducted using the same simulator model (developed by Transas), and as adapted by Fleetwood Nautical College. These simulations incorporate the current field during different states of tide, as developed from the flow-modelling of the two berth developments undertaken by ABPmer (and summarised in Section 4). The secondary instructor station was used to run the simulations, assisted by a technician and observed by maritime professionals (Captain Martin Phipps and Captain David Eccles) along with the Harbour Master and Deputy Harbour Master for Douglas Harbour. All results were recorded *in situ* with further assessment made on completion of all runs.

The model vessel used was given six degrees of freedom (see Appendix G) allowing for realistic impact from the effects of current, wind and other influences. For each run, environmental data was loaded into the simulation model and a track to follow provided with speeds to maintain. Throughout each of these runs the behaviour of the vessel and actions taken to meet set courses and speeds were monitored and assessed to establish the impact of conditions on ship handling.

In total, 25 simulation runs were conducted for five different states of tide and five different weather conditions for each tidal state for the approach to the Deep-Water Berth in order to provide an indication to the effects of the flow regime around the new pier. As the assessment was concerned with identifying the effects of this flow regime, additional runs for departure were not considered necessary. Due to the negligible change in flow regime from the creation of a dredge pocket on the north face of Victoria Pier, fast-time runs were not required to identify the effects of the new current regime within the approaches to the berth.

The states of tide chosen for Fast-time simulations were at 2-hour intervals for spring tides, from HW -4 hours to HW +4 hours. Spring tides have been chosen as they present the greatest flow rate and subsequent effect on ship handling. As determined in the navigational assessment, flows at HW +6 hours and HW -6 hours are minimal with negligible resultant effects on ship handling.

Simulation runs

The fast-time simulation runs were conducted for five different weather conditions for each of the tidal states, a summary of the runs conducted is shown in Table 7. Runs conducted in calm conditions show the ability of the vessel to approach the Deep-Water Berth with only the effect of the tidal state on ship handling. Other weather conditions test the combined effect of tidal state and wind direction using a 20 kts wind speed as the most extreme. Vessel approaches in wind speeds above this would not be permissible without special exception from the Harbour Authority.

Table 7. Environmental conditions for Fast-time simulation runs to the Deep-Water Berth development

Simulation ID	Tide	Runs Wind Conditions				
1.1.	HW -4	1.1.1 Calm	1.1.2 S'ly 20 kts	1.1.3 N'ly 20 kts	1.1.4 SW 20 kts	1.1.5 E'ly 20 kts
1.2	HW -2	1.2.1 Calm	1.2.2 S'ly 20 kts	1.2.3 N'ly 20 kts	1.2.4 SW 20 kts	1.2.5 E'ly 20 kts
1.3	HW	1.3.1 Calm	1.3.2 S'ly 20 kts	1.3.3 N'ly 20 kts	1.3.4 SW 20 kts	1.3.5 E'ly 20 kts
1.4	HW +2	1.4.1 Calm	1.4.2 S'ly 20 kts	1.4.3 N'ly 20 kts	1.4.4 SW 20 kts	1.4.5 E'ly 20 kts
1.5	HW +4	1.5.1 Calm	1.5.2 S'ly 20 kts	1.5.3 N'ly 20 kts	1.5.4 SW 20 kts	1.5.5 E'ly 20 kts

The following sub-sections provide a summary of observations on the effects of the environmental conditions on the passage of a vessel to the Deep-Water Berth with an overall assessment of the findings. Full details of the individual runs in graphical form for each simulation run are shown in Appendix G.

Simulation 1.1

Fast-time simulator Run 1.1 tests the feasibility of approaching the Deep-Water Berth at HW -4 hours with different wind conditions. The observations made are listed in Table 8, below:

Table 8. Fast-time simulation Run 1.1 - observations (HW -4 hours)

Run	Observations
1.1.1	Vessel achieved approach without deviation
1.1.2	20° of set to Port experienced Northerly drift created a steeper point of approach to the berth
1.1.3	When reducing speed, the wind brought the vessel to Starboard
1.1.4	Approach made at a slower speed, further reduction in speed when turning Stern swing checked by wind during turn Higher speed to be maintained until inside the berth area
1.1.5	Excessive speed required with 3.3 kts required to maintain the track Excessive swing encountered when turning

The state of tide assessed during Simulation 1.1 flows from the SW to the NE causing a northerly drift across the area with greatest affect around the northern end of the Deep-Water Berth. The effects from weather conditions reduced the ability of the vessel to maintain course and speed in greater measure than the influence of current.

Simulation 1.2

Fast-time simulator Run 1.2 tests the feasibility of approaching the Deep-Water Berth at HW -2 with different wind conditions. The observations made are listed in Table 9, below:

Table 9. Fast-time simulation Run 1.2 - observations (HW -2 hours)

Run	Observations
1.2.1	Vessel achieved approach without deviation
1.2.2	Vessel unable to regain track after drifting north, 20° of set experienced Difficulty in regaining track compounded by reduction in speed.
1.2.3	Vessel drift to south when turning, loss of control of swing Set to Starboard increases stern swing, exaggerated with reduction in speed
1.2.4	Slower approach with good steerage Vessel ferry glided to final position
1.2.5	Increase speed on approach Loss of control on swing to Port

The state of tide assessed during Simulation 1.2 flows from the SW to the NE causing a northerly drift across the area with greatest affect around the northern end of the Deep-Water Berth. Current during this state of tide has a greater effect than during HW – 4 hours, with northerly drift more pronounced when reducing speed on approach to the berth during northerly and southerly weather conditions. South westerly and easterly winds have a greater effect on ship handling than current during this state of tide.

Simulation 1.3

Fast-time simulator Run 1.3 tests the feasibility of approaching the Deep-Water Berth at HW with different wind conditions. The observations made are listed in Table 10 below:

Table 10. Fast-time simulation Run 1.3 - observations (HW)

Run	Observations
1.3.1	Approach to the berth area from north of track would counter increased drift near pier head
1.3.2	Northerly drift creating 15° of set Vessel drift increased when reducing way below 4 kts
1.3.3	Excessive speed on approach Southerly drift increasing on approach to the berth area
1.3.4	Track maintained on approach Increased southerly drift and reduction in speed preventing final approach
1.3.5	Difficulty in reducing speed throughout Bow drifting south combining with stern swing to Starboard on turn

The state of tide assessed during Simulation 1.3 is at HW with the ebb flow present off the northern point of the Deep-Water Berth. Southerly drift affects the vessel on the approach with an increase in effect when nearing the new berth. Vessel tracks made further to the north avoid the area of strongest effect with a steeper angled point of approach into the berth area being preferable for this state of tide, unless wind conditions are from the east.

Simulation 1.4

Fast-time simulator Run 1.4 tests the feasibility of approaching the Deep-Water Berth at HW +2 with different wind conditions. The observations made are listed in Table 11, below:

Table 11. Fast-time simulation Run 1.4 observations (HW +2 hours)

Run	Observations
1.4.1	Approach to the new berth area from N of track would counter increased drift near pier head
1.4.2	Vessel achieved approach without deviation Vessel manoeuvred well throughout
1.4.3	Southerly drift increasing on approach to the berth area Vessel unable to recover track
1.4.4	Effective steerage above 5 kts More northerly point of approach required due to increase southerly drift near pier head
1.4.5	Difficulty in reducing speed throughout Bow swing to Port due to increase southerly drift near pier head

The state of tide assessed during Simulation 1.4 has the fastest flow rate and subsequent effect on ship handling. Southerly winds assisted with the ability of the vessel to maintain course and speed, with all other weather conditions increasing difficulty of the manoeuvre.

Simulation 1.5

Fast-time simulator Run 1.5 tests the feasibility of approaching the Deep-Water Berth at HW +4 with different wind conditions. The observations made are listed in Table 12, below:

Table 12. Fast-time simulation Run 1.5 - observations (HW +4 hours)

Run	Observations
1.5.1	Vessel achieved approach without deviation Difficulty in reducing speed on final approach
1.5.2	Increased stern swing when reducing speed Vessel should line-up with centre of the berthing area earlier
1.5.3	Southerly drift increasing on approach to the new berthing area Vessel unable to recover track
1.5.4	Vessel achieved approach without deviation
1.5.5	Difficulty in reducing speed throughout Vessel speed too high in the new berthing area

The state of tide assessed during Simulation 1.5 flows from the NE to the SW causing a southerly drift across the area with greatest affect around the northern end of the Deep-Water Berth. This tidal state produced similar effects to those experienced in Simulation 1.4 to a lesser degree.

Observation assessment

The observations for vessel access to the Deep-Water Berth made during the fast-time simulation runs have been assessed and the findings given below:

- A northerly track and larger angled point of approach is required from HW to HW +4 hours, except during southerly winds;
- A faster approach speed is required until inside the new berthing area;
- All runs would benefit from the use of auxiliary propulsion or tug assistance;
- Reduction in speed when entering the berthing area increases the effect of current and wind on set and drift;
- Northerly and southerly winds cause a high degree of set when the vessel speed is below 4 kts over the ground;
- A high speed over the ground is required to maintain steerageway during following winds and ebb tides;
- SW winds are the most favourable weather conditions;
- During the Fast-time simulations ebb tide approaches were more favourable than on the flood tide for ship handling to the Deep-Water Berth.

The key findings from fast-time simulation identifies that high speeds (>4 kts) are required on approach, in order to maintain steerageway, this is exacerbated by easterly winds. Reduction in speed when entering the berth area causes increased drift poorer ship handling. Although requiring higher speeds on approach, the faster flow rates of the ebb tides provide more favourable conditions for ship handling.

6.4.2 Real-time simulations

Method

Real-time simulations were undertaken using the full mission simulator facilities at Fleetwood Nautical College. Each scenario was conducted by a master mariner and observed by a simulator instructor, other maritime professionals and representatives from the Isle of Man Ports division.

Simulator facilities included the use of three bridges providing the immediate re-run of a scenario should an alteration be required such as the use of a tug. Each bridge was provided with a standard vessel interface, instrumentation and multi-function displays, these were arranged to provide two ECDIS outputs to assist with analysis of the scenario. The use of a third eye view was also provided and displayed within each bridge for the assessment of clearing distances and improving situational awareness. On completion of each scenario the observations made were discussed using a de-briefing facility fitted with a smart board projector capable of displaying a simulator replay.

Scenarios were created from the selection of variables affecting ship handling for the proposed developments. Ten variables were identified as displayed in Table 13.

Table 13. Variables affecting ship handling for Real-time vessel simulation of the proposed developments

Variable	Parameter					Notes
Vessel	Standard cruise vessel	Large cruise vessel				As per model vessels used
Berth	Victoria Pier Berth	Deep-Water Berth				
Direction	Arrival	Departure				
Approach	Northerly	Southerly				
Alongside	Port-side-to	Starboard-side-to				
Visibility	Day clear	Night clear	Restricted			Specific conditions included as required
State of tide	HW - 4	HW - 2	HW	HW + 2	HW + 4	Parameter informed from navigational assessment
Wind direction	Variable	North	South	South-West	North-East	Variable to be informed throughout
Wind strength	Light	20 kts (worst case)	12 kts (most probable)			As prescribed by Port Authority
Wave state	Calm	Force 4	Force 6			Parameter informed from navigational assessment Wave direction follows wind direction

Requirements of the real-time simulations were to identify the navigational constraints for manoeuvring to and from the new proposed berths, as detailed in Section 6.3. The scenarios developed with the variables selected were identified for the purpose of ascertaining three states:

- The conditions where all manoeuvres would most likely be possible;
- If the manoeuvres would be possible in the least favourable conditions; and
- The requirements of these manoeuvres in the most commonly expected conditions.

Throughout the real-time simulations, observations were made identifying issues to be tested during further Real-time assessment. These issues, where possible were incorporated into later scenarios or noted for comment should a further series of simulations be required after adoption, or further working of the proposed developments.

Thirteen scenarios were conducted in order to assess different variables and establish the limiting factors for the proposed developments. These scenarios are listed in Table 14. Scenarios 1.1.1 to 1.3.2 are for large cruise vessel manoeuvres around the Deep-Water Berth with scenarios 2.1.1 to 2.2.4 conducted for manoeuvres associated with the standard cruise vessel to the proposed Victoria Pier Berth.

Table 14. Real-time simulation scenarios

Scenario	Vessel	Berth	Direction	Approach	Alongside	Visibility	Tidal State	Wind Direction	Wind Strength	Sea State
1.1.1	Large	DWB	Arrival	Northerly	PST	Day clear	HW +4	Variable	Light	Calm
1.1.2	Large	DWB	Departure	Northerly	PST	Day clear	HW +4	Variable	Light	Calm
1.2.1	Large	DWB	Arrival	Northerly	PST	Day clear	HW +2	N	20 kts	Force 6
1.2.2	Large	DWB	Arrival	Northerly	PST	Day clear	HW +2	N	20 kts	Force 6
1.3.1	Large	DWB	Arrival	Southerly	PST	Day clear	HW +2	SW	20 kts	Force 6
1.3.2	Large	DWB	Departure	Northerly	PST	Day clear	HW +2	SW	20 kts	Force 6
2.1.1	Standard	VPB	Arrival	Northerly	PST	Day clear	HW -4	Variable	Light	Calm
2.1.2	Standard	VPB	Departure	Northerly	PST	Day clear	HW -4	Variable	Light	Calm
2.1.3	Standard	VPB	Arrival	Northerly	SST	Day clear	HW -4	Variable	Light	Calm
2.2.1	Standard	VPB	Arrival	Northerly	PST	Day clear	HW +2	NE	20 kts	Force 6
2.2.2	Standard	VPB	Departure	Northerly	PST	Day clear	HW +2	NE	20 kts	Force 6
2.2.3	Standard	VPB	Arrival	Northerly	SST	Day clear	HW +4	SW	12 kts	Force 4
2.2.4	Standard	VPB	Departure	Northerly	SST	Day clear	HW +4	SW	12 kts	Force 4

DWB Deep Water Berth
VPB Victoria Pier Berth
PST Port side to
SST Starboard side to
Most challenging tidal state – H +2 hours
Most challenging weather conditions – 20 kts winds, Force 6 sea state
Most probable conditions – 12 kts winds from SW, Force 4 sea state

Deep-Water Berth scenarios

The following scenarios relate to vessel operations associated with access to and from the proposed Deep-Water Berth.

Scenario 1.1.1

This scenario was conducted to identify the ability to manoeuvre the large cruise vessel PST the Deep-Water Berth in light wind conditions. The state of tide was approximately mid ebb (HW +4 hours) as this is the most general pattern of currents for most of the ebb tide.

Observations:

- Vessel achieved the desired manoeuvre;
- High speeds over the ground (>4 kts) were required to maintain steerage;
- Difficultly in taking vessel way off when entering the berthing area;
- The most successful approach is to enter the middle of the berthing area as soon as possible;
- A tug would assist in taking way off and countering stern swing; and
- Required bollard pull of Azimuth Stern Drive (ASD) tug above 60 t.

The vessel was able to manoeuvre alongside the berth PST, the approach speed required was above that considered safe due the need to maintain steerageway. The use a tug in assisting steerage and slowing the vessel would improve ease and safety of the manoeuvre.

Scenario 1.1.2

This scenario was conducted to identify the ability to manoeuvre the large cruise vessel off (depart) the Deep-Water Berth from PST in light wind conditions. The state of tide chosen was approximately mid ebb (HW +4 hours) as this is the general pattern of currents for most of the ebb tide.

Observations:

- Vessel achieved the desired manoeuvre;
- Immediate headway made on letting go lines;
- The location of the swing is made away from stronger southerly currents around the pier head;
- Swinging the vessel further out allows for a more predictable manoeuvre that is less subject to drift towards navigational hazards; Tug assistance on the Starboard quarter checks initial headway, brings the stern off and pushes during the swing; and
- Required bollard pull of tug above 60 t (ASD).

The vessel was able to manoeuvre off the berth and perform a turn outside of the berthing area and pier. On letting go of lines the current within the berth area caused immediate headway, this required astern propulsion that cannot operate whilst lines are in the water. It is therefore recommended that a tug is used to check headway until the main propulsion can be used, assistance from a tug would also assist in moving off the berth and performing the swing.

Scenario 1.2.1

This scenario was conducted to identify the ability to manoeuvre an arriving large cruise vessel PST the Deep-Water Berth without tug assistance in the most challenging conditions identified; 20 kts winds from the N at HW +2 hours with a Force 6 sea state.

Observations:

- Vessel unable to achieve the manoeuvre;
- Lead markers for the centre of the berthing area are essential;
- Increased speed through the water would improve steerage but could not be reduced in time once inside the berthing area;
- Significant stern swing when entering berth area;
- Unable to counter southerly drift;
- Tug assistance considered essential; and
- Required bollard pull of tug above 60 t (ASD).

The vessel was unable to achieve the manoeuvre without assistance; weather conditions combined with the tidal state caused an unrecoverable drift to the south. It was determined that this approach would have been aborted from the outset due to difficulty experienced in handling the vessel.

Scenario 1.2.2

This scenario was conducted to identify the ability to manoeuvre the large cruise vessel PST the Deep-Water Berth in the most challenging conditions identified with tug assistance on the Starboard quarter. This scenario was included following on from the results of Scenario 1.2.1.

Observations:

- Vessel able to berth with assistance;
- Conditions would make it challenging to board a Pilot;
- Difficult conditions for the tug boat to manoeuvre and attach, would have aborted the operation;
- Indirect towage effective at 6 kts;
- Tug weight increased to 50 t on the beam as vessel slows;
- Would have aborted run due to minimal margin of error;
- Required bollard pull of tug above 60 t (ASD).

Although the vessel was able to berth with the assistance from a tug, attempts at attaching the tug with the simulator indicated that this would not have been possible, and the approach aborted. The effects of indirect towage greatly assisted the ability to maintain the track and check stern swing when reducing speed. Full use of propulsion and auxiliary systems to manoeuvre the vessel preventing any margin for error would also have prompted abortion of the approach.

Scenario 1.3.1

This scenario was conducted to identify the ability to manoeuvre the large cruise vessel PST the Deep-Water Berth from a southerly approach with the most challenging tidal state and winds from a south-westerly direction. This scenario was included following assessment of the observations for Scenarios 1.2.1 and 1.2.2.

Observations:

- Vessel able to achieve the manoeuvre;
- Required 3.5 kts on entry into the berthing area to maintain steerageway;
- Difficulty experienced in taking way off;
- Large list and rolling experienced during turn;
- Recommended use of a tug to assist in reducing headway;
- Would have aborted run due to minimal margin of error; and
- Required bollard pull of tug above 60 t (ASD).

The vessel was able to complete a turn outside of the berthing area and manoeuvre alongside the berth PST. The turn was conducted outside of the large tidal effects north of the Deep-Water Berth pier and assisted by the south-westerly weather conditions. During the turn a large degree of list and roll was experienced. Additionally, a short turn from the south was considered more dangerous and avoids the pilot boarding area. From this assessment it was decided that all subsequent scenarios would be conducted with the approach direction from the north.

Scenario 1.3.2

This scenario was conducted to identify the ability to manoeuvre the large cruise vessel off (departure) the Deep-Water Berth from PST and turn for a northern departure with the most challenging tidal state and winds from a south-westerly direction.

Observations:

- Vessel able to achieve the manoeuvre;
- Turn became difficult with wind on the beam;
- Favourable conditions when manoeuvring from the berth;
- Bow thruster or tug required to complete the turn; and
- Required bollard pull of tug above 60 t (ASD).

The vessel was able to manoeuvre off the berth and perform a turn outside of the berthing area. South-westerly weather conditions assisted the manoeuvre when coming off the berth, however, these conditions checked the vessel swing during the turn. Full use of propulsion was required in order to perform the turn leaving no margin of error for manoeuvre.

Victoria Pier Berth scenarios

The following scenarios relate to vessel operations associated with access to and from the Victoria Pier berth.

Scenario 2.1.1

This scenario was conducted to identify the ability to manoeuvre the standard cruise vessel PST the Victoria Pier Berth in light wind conditions. The state of tide chosen was HW -4 hours, as this represents the general pattern of flood tide currents of greatest magnitude. A PST approach was used as the mariners felt this was the most realistic way to accomplish the manoeuvre.

Observations:

- Vessel able to achieve the manoeuvre;
- High angled point of approach made difficult by the location of No 1 buoy and the shallows around St Mary's Rock (Conister Rock);
- Difficult to bring the ship forward when coming alongside due to rocks at the western end.
- Tug assistance considered advisable due to close passing distances with navigational hazards; and
- Required bollard pull of tug above 50 t (ASD).

A high angled point of approach was required for the manoeuvre alongside the pier, however, this was made difficult due the location of No. 1 buoy and westerly shallows, limiting the available space. When turning towards the pier the stern passed within 20 m of the dolphin at the end of Princess Alexandra Pier with little margin for error in the swing.

Scenario 2.1.2

This scenario was conducted to identify the ability to manoeuvre the standard cruise vessel off the Victoria Pier Berth from PST in light wind conditions. The manoeuvre was undertaken at the time of near fastest flood flows (HW -4 hours);

Observations:

- Vessel able to achieve the manoeuvre;
- Stern propulsion used on departure to open up distance from the rocks to the west;
- Southerly track made close to the dolphin to counter northerly drift past the head of Princess Alexandra Pier;
- A tug advised on the Starboard quarter to check stern swing and assist with the turn; and
- Required bollard pull of tug above 50 t (ASD).

The vessel was able to manoeuvre off the berth and perform a turn. Due to the proximity of an area with shallow rocks, immediate astern propulsion was required on letting go which cannot be operated whilst lines are in the water. It is therefore recommended that a tug is used to prevent headway.

Scenario 2.1.3

This scenario was conducted to identify the ability to manoeuvre the standard cruise vessel SST the Victoria Pier Berth in light wind conditions at the time of peak flood tidal flows (HW -4 hours).

Observations:

- Vessel able to achieve the manoeuvre;
- Northerly drift during the turn made approach more difficult;
- Northerly drift towards the shallow water areas experienced during approach;
- Vessel manoeuvred to the east of the pier then brought in line due to the proximity of the shallow rocks to the west;
- A tug available to check stern swing would assist in maintaining a southerly approach;
- Required bollard pull of tug above 50 t (ASD).

The vessel was able to complete a turn and manoeuvre astern on approach to the pier. Northerly drift experienced during the turn caused a much higher angled point of approach than expected, leading to a closer approach to the No. 1 buoy and shallow water to the west. Use of a tug would assist in turning and preventing northerly drift of the stern on approach.

Scenario 2.2.1

This scenario was conducted to identify the ability to manoeuvre the standard cruise vessel PST the Victoria Pier Berth in the most challenging conditions identified. A PST approach was used as the mariners felt this was the most likely way to accomplish the manoeuvre.

Observations:

- Vessel unable to achieve the manoeuvre;
- Speed had to be maintained above 6 kts to maintain steerageway;
- PST considered the most likely approach in these conditions;
- Drift experienced near the breakwater which was difficult to counter in the limited navigational space;
- Tug assistance required to counter drift and manoeuvre to berth; and
- Required bollard pull of tug above 50 t (ASD).

The vessel was unable to achieve the manoeuvre due to high approach speed required to maintain steerageway. On turning towards the pier, wind affects created an increased stern swing that could not be arrested. Due to wind direction the manoeuvre to the pier was required north of the dredge pocket in an area of shallows.

Scenario 2.2.2

This scenario was conducted to identify the ability to manoeuvre the standard cruise vessel off (depart) the Victoria Pier Berth from PST in the most challenging conditions identified.

Observations:

- Vessel unable to achieve the manoeuvre;
- Tug assistance would have to maintain constant weight on the stern;
- Required bollard pull of tug above 50 t (ASD).

Weather conditions prevented the vessel from manoeuvring off the berth. Full propulsion and auxiliary thrust required to move the stern with immediate counter swing observed on attempting to develop sternway.

Scenario 2.2.3

This scenario was conducted to identify the ability to manoeuvre the standard cruise vessel SST the Victoria Pier in the most probable conditions. A turn was made in Douglas Bay and approach to the pier made stern first.

Observations:

- Vessel able to achieve the manoeuvre with limitations.
- Conducting turn further to the south would counter northerly drift.
- Low approach angle is favourable on approach.
- Considerable stern thrust required, would be difficult in a less capable vessel.
- Manoeuvre to the berth made north of the pier in shallow area, where vessel ran aground.
- Tug assistance would reduce need for stern thruster and reduce the effects of drift.
- Bollard pull of tug above 50 t (ASD).

The vessel was able to approach the berth however; the vessel would have run aground when manoeuvring north of the pier. Drift to the north was experienced during the turn requiring the vessel to regain the track to the south, providing a shallow point of approach to the pier. Northerly drift experienced on the approach required manoeuvring to the berth be conducted north of the dredge pocket.

Scenario 2.2.4

This scenario was conducted to identify the ability to manoeuvre the standard cruise vessel off the Victoria Pier Berth from SST in the most probable conditions.

Observations:

- Vessel able to achieve the manoeuvre;
- Headway required when letting go due to proximity of shallow rocks astern;
- Vessel approached close to shallows north of the berth when manoeuvring off;
- Tug assistance advised to prevent sternway on letting go; and
- Required bollard pull of tug above 50 t (ASD).

The vessel was able to manoeuvre as required, prevention of sternway when letting go is necessary due the proximity of rocks. Main propulsion cannot be operated whilst lines are in the water, it is therefore recommended that a tug is used.

Observation assessment

Observations were made throughout each scenario with a feedback session provided on conclusion of the simulation. The observations made and feedback given was collated and assessed to provide the findings given below:

Victoria Pier Berth

- Turns made for SST approaches are most effected by tide and weather between HW – 4 hours and HW + 4 with southerly winds;
- Low angled points of approach to the Victoria Pier Berth are preferable in all weather conditions, although they require manoeuvres to be made north of the dredge pocket;
- High angled points of approach to the Victoria Pier Berth allow manoeuvres within the dredge pocket, although they reduce clearing distances to navigational hazards;
- The standard cruise vessel requires a tug of over 50 t bollard pull with an azimuth stern drive design recommended;
- In more severe weather conditions, a PST approach is recommended for the Victoria Pier Berth;

Deep-Water Berth

- Lead markers indicating the centreline of the new Deep-Water Berth is essential when making an approach;
- The large cruise vessel requires a tug of over 60 t bollard pull with an azimuth stern drive design recommended;
- Approaches to the Deep-Water Berth should enter the berthing area quickly with subsequent reduction in way and manoeuvre to the berth made inside;

Generic points

Generic points have been listed below and are considered to affect both of the proposed developments.

- Approaches made between HW and HW + 4 hours require high approach speeds in order to maintain steerageway;
- Scenarios that required full use of main and auxiliary propulsion leave no margin for error and are considered to have a higher risk.
- Northerly approaches from the vicinity of the Pilot boarding station are preferable in all conditions for both schemes;
- Winds from the east cause high approach speeds and increase swing rates of the stern when manoeuvring;
- South-westerly winds improve ship handling during approaches, however, hamper manoeuvres when turning;
- All simulations conducted are either required or advised to have a tug;
- The effects of the sea state within Douglas Bay for attaching tug lines should be considered. In some sea state conditions this may not be possible;

The key findings observed for the operation of both schemes found that manoeuvres conducted in conditions above a Force 4 escalated difficulties in ship handling and associated risk to a level above that deemed acceptable without additional mitigations. Tug assistance is prudent for all manoeuvres providing either direct or indirect towing. High speeds over the ground on approach are required to counter the effects of current and weather on ship handling. Manoeuvres to and from Victoria Pier Berth require space N of the dredge pocket, hence the potential need for additional dredging (in an area where rock could be near the surface).

6.5 Summary analysis

The summary analysis studies the findings from the Fast-time and Real-time simulations to determine the key issues set out in Section 2.3. These outcomes are examined with the findings made to establish the key points and their impact. Each key point is listed with its effect on the outcome including any requirements, limitations or considerations.

6.5.1 Victoria Pier Berth

Can the proposed standard design cruise vessel safely manoeuvre onto and off the proposed berth at Victoria Pier, including associated manoeuvres for berthing starboard-side-to?

The standard cruise vessel was able to perform the required arrival, departure and associated manoeuvres during favourable environmental conditions. It was noted, however, that tug assistance would be required for all scenarios conducted with less capable ships experiencing limiting factors based on type of propulsion and auxiliary systems. All scenarios conducted above a Force 4 in spring tidal states between HW -4 hours and HW +4 hours required the use of full thrust, reducing any margin of error and failing to achieve the manoeuvre safely. It was determined that the most effective method for approach and departure from the pier required the manoeuvre to be conducted north of the dredge pocket, as shown in Figure 48.

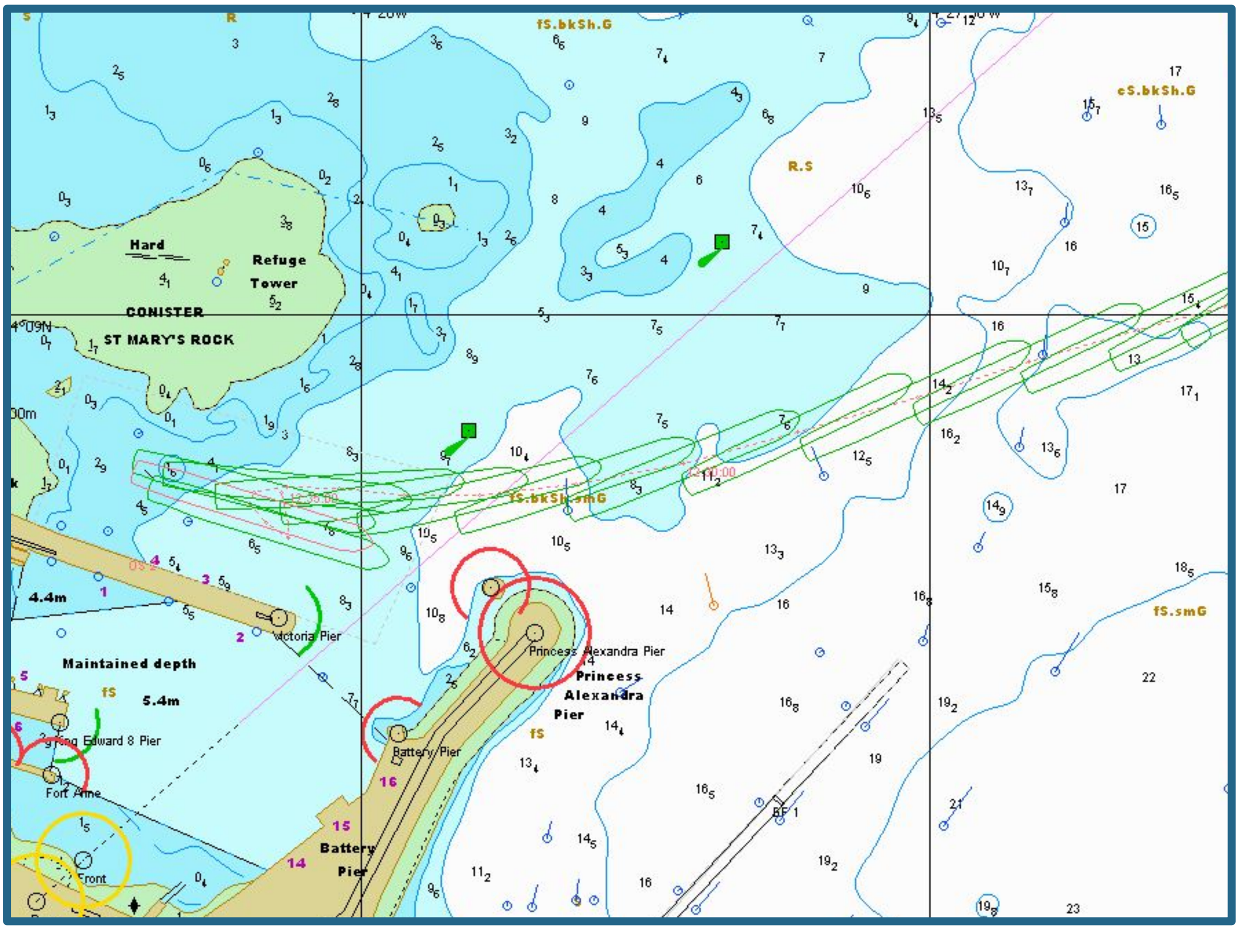

Figure 48. Starboard arrival to the Victoria Pier Berth- spring tide

The key points identified are tabulated below (Table 15), along with their effects and impact on the outcome.

Table 15. Victoria Pier Berth- spring tide: Key points

Key point	Note	Impact
Shallow point of approach is preferable.	Provides more clearance from navigational hazards	Consideration
Approach cannot be made without auxiliary propulsion or tug assistance.	Effective bow thrust is required to maintain heading or check swing.	Requirement
PST berthing preferable.	PST approaches and departures were found easier during more severe environmental conditions.	Consideration
Turns should be made to the south.	Turns made in all conditions drifted towards navigational hazards. Turns made further to the south would increase the safety margin.	Consideration
Manoeuvres best achieved N of the pier.	Manoeuvres conducted north of the pier allow the vessel to pass the area of greatest tidal effect with a larger passing distance from navigational hazards before approaching the pier as required. Approaching to N of the pier also allows the vessel more space to check swing when approaching at high speed or during north and east winds.	Limitation
South westerly winds assist steerage.	Winds from the SW assist vessel handling on approach and departure by improving steerage and assisting vessel swing.	Consideration
North-easterly and easterly winds are detrimental to ship handling.	Following winds require increased vessel speed on approach to maintain steerageway, increase vessel swing and increase the difficulty in departing the berth.	Limitations
Tidal flow across the head of Princess Alexandra Pier and St Mary's rock is much greater than surrounding water space.	Crossing this flow at slow speed causes a detrimental drift, maintaining speed rescues the effect. Higher approach speeds are therefore required during times of the greatest flow-rate.	Consideration
High north-easterly and easterly winds prevented departure.	The standard cruise vessel was unable to depart the Victoria Pier Berth.	Limitation

6.5.2 Deep-Water Berth

Can the proposed large cruise vessels safely manoeuvre onto and off the proposed Deep-Water Berth, including associated manoeuvres for berthing port-side-to?

The large cruise vessel was able to perform the required arrival, departure and associated manoeuvres during favourable environmental conditions (below Force 4 sea state). It was noted, however, that tug assistance would be required for all scenarios conducted with less capable ships experiencing limiting factors based on type of propulsion and auxiliary systems and recommended for the large cruise ship.

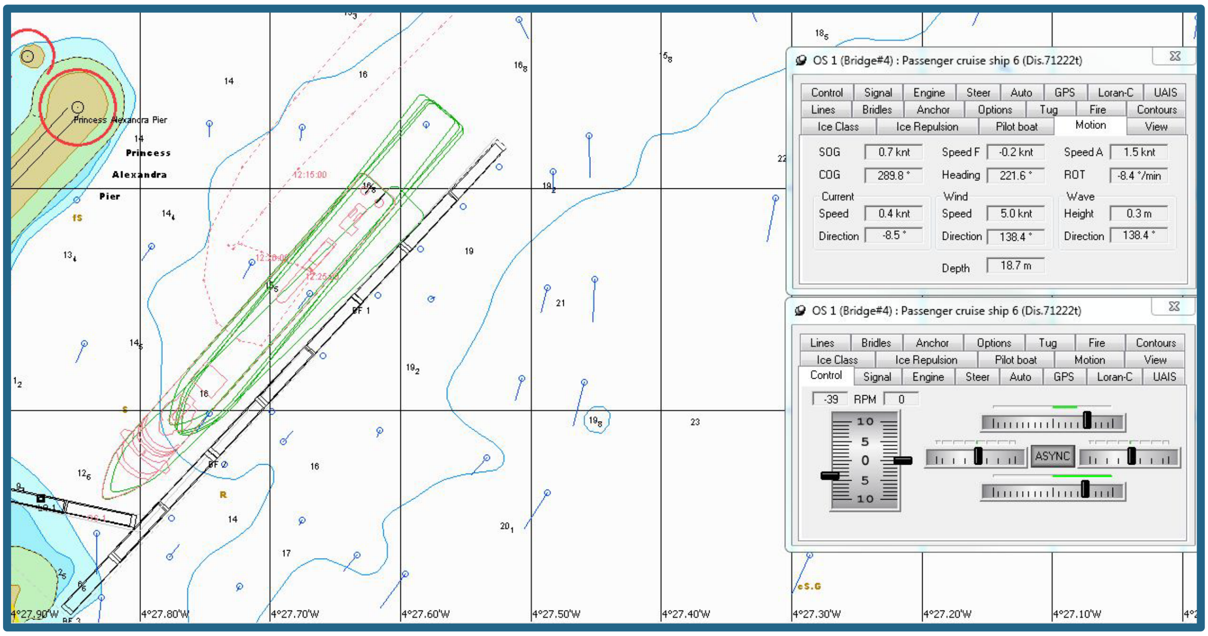

Figure 49. Large cruise vessel- need for headway on departure

All scenarios conducted above Force 4 tidal states between HW -4 hours and HW +4 hours required the use of full thrust, reducing any margin of error and the required manoeuvres were not achieved safely. Tidal flow around the northern point of the berth caused an increase in drift when passing and therefore required a more northerly approach or faster speeds when entering the berthing area. Tidal flow inside the berthing area on an ebb tide increased the difficulty in reducing way, compounding the effects of a fast approach. The same tidal flow causes headway during departure, requiring the use of immediate astern propulsion or tug assistance. The vessel controls in Figure 49 show the need for 0.7 kts of headway during departure.

The key points identified are tabulated below (Table 16), along with their effects and impact on the outcome.

Table 16. Large cruise vessel – Deep-Water Berth: Key points

Key point	Note	Impact
Approach cannot be made without auxiliary propulsion or tug assistance.	Additional propulsion is required to reduce way, counter drift and check vessel swing.	Requirement
Northerly approaches during ebb tides.	Approaches from N of the berthing area centreline provide easier ship handling during ebb tides except during southerly wind conditions.	Consideration
Turns should be made to the S.	Turns made in all conditions drifted towards navigational hazards. Turns made further to the S would increase the safety margin.	Consideration
High approach speed should be made until inside the berthing area.	Higher speed when entering the berthing area reduces the effect of the tidal flow around the northern point of the Deep-Water Berth.	Consideration
Difficulty in taking way off	Difficulty experienced in taking way off when entering the berthing area during ebb tides and following winds.	Limitation
South westerly winds assist steerage.	Winds from the SW assist vessel handling on approach and departure by improving steerage and assisting vessel swing.	Consideration
Easterly winds and ebb tides are detrimental to ship handling.	Following winds require increased vessel speed on approach to maintain steerageway and increase sternway when turning.	Limitations
Tidal flow around the northern point of the Deep-Water Berth is greater than the surrounding water space.	Crossing this flow at slow speed causes a detrimental drift, maintaining speed rescues the effect. Higher approach speeds are therefore required during times of the greatest flow rate.	Consideration
Turns should be made to the S.	Turns made in all conditions drifted towards navigational hazards. Turns made further to the S would increase the safety margin.	Consideration
Flow during ebb tides create vessel headway when departing.	The ebb flow inside the dock causes vessel headway on letting go of lines, requiring immediate astern propulsion or tug assistance.	Consideration

6.5.3 Both Berths

The environmental effects of wind, waves and tides that can be expected during the cruise season. The effects from tidal state and weather conditions were assessed to determine their effect on ship handling. The tidal states used represented spring tides due to these having a greater effect and clear impact on the vessel simulations. Weather conditions analysed covered calm conditions for determining the possibility of achieving the manoeuvres required and winds of up to 20 kts as the greatest wind speed that could be acceptable for vessel operations. The most frequently experienced weather conditions for a cruise season were determined to be from the SW at up to Force 4. Figure 50 shows an example of the simulation runs for the departure of the standard vessel from the Victoria Pier Berth.

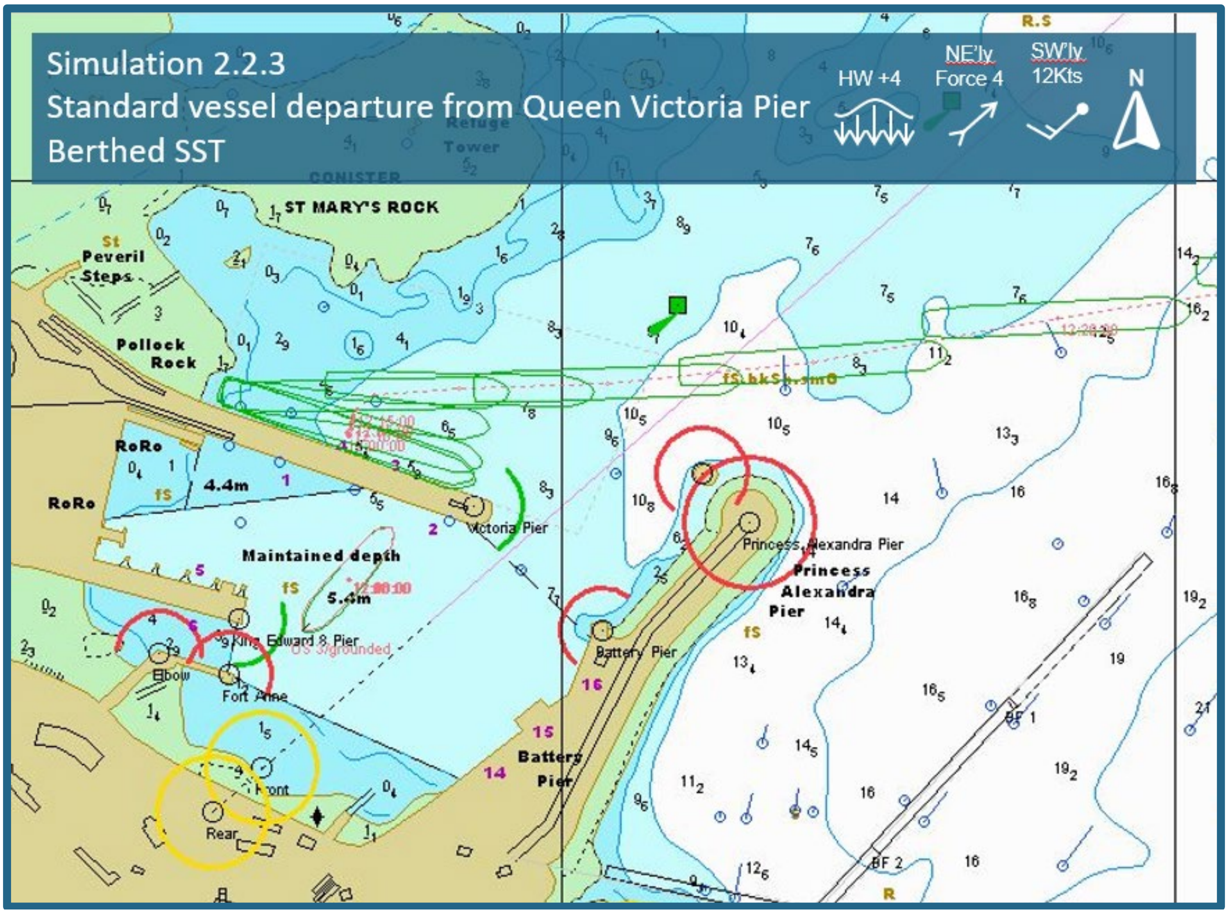

Figure 50. Departure scenario conducted with SW Force 4 weather conditions at HW +4 hours from the Victoria Pier Berth

The key points arising from the range of environmental conditions for manoeuvres to and from both proposed berth developments are tabulated in Table 17, below.

Table 17. Manoeuvring effects of environmental conditions – both berths: Key points

Key point	Note	Impact
South westerly winds assist steerage.	Winds from the SW assist vessel handling on approach and departure by improving steerage and assisting vessel swing.	Consideration
Easterly winds and ebb tides are detrimental to ship handling.	Following winds require increased vessel speed on approach to maintain steerageway and increase sternway when turning.	Limitations
Tidal flow across the head of Princess Alexandra Pier and St Mary's Rock has a higher flow rate than the surrounding water space.	Crossing this flow at slow speed causes a detrimental drift, maintaining speed recues the effect. Higher approach speeds are therefore required during times of the greatest flow-rate.	Consideration
Tidal flow around the northern point of the Deep-Water Berth is greater than the surrounding water space.	Crossing this flow at slow speed causes a detrimental drift, maintaining speed recues the effect. Higher approach speeds are therefore required during times of the greatest flow-rate.	Consideration
Turns should be made to the south.	Turns made in all conditions drifted towards navigational hazards. Turns made further to the south would increase the safety margin.	Consideration
North-easterly and easterly winds prevented departure.	The standard cruise vessel was unable to depart Victoria Pier Berth during easterly winds due to the	Limitation

Can the model vessels safely leave each berth?

Both model vessels were able to depart their respective berths during favourable environmental conditions. It was noted, however, that tug assistance would be required for all scenarios conducted with less capable ships experiencing limiting factors based on type of propulsion and auxiliary systems. All scenarios conducted above a Force 4 in tidal states between HW -4 hours and HW +4 hours required the use of full thrust, reducing any margin of error and failed to achieve the outcome safely. High easterly and north-easterly winds proved the most difficult weather conditions for departure from the Victoria Pier Berth where the standard cruise vessel was unable to depart.

This is illustrated by the Real-time scenario shown in Figure 51, where the vessel is 'pinned' to the pier at the stern.

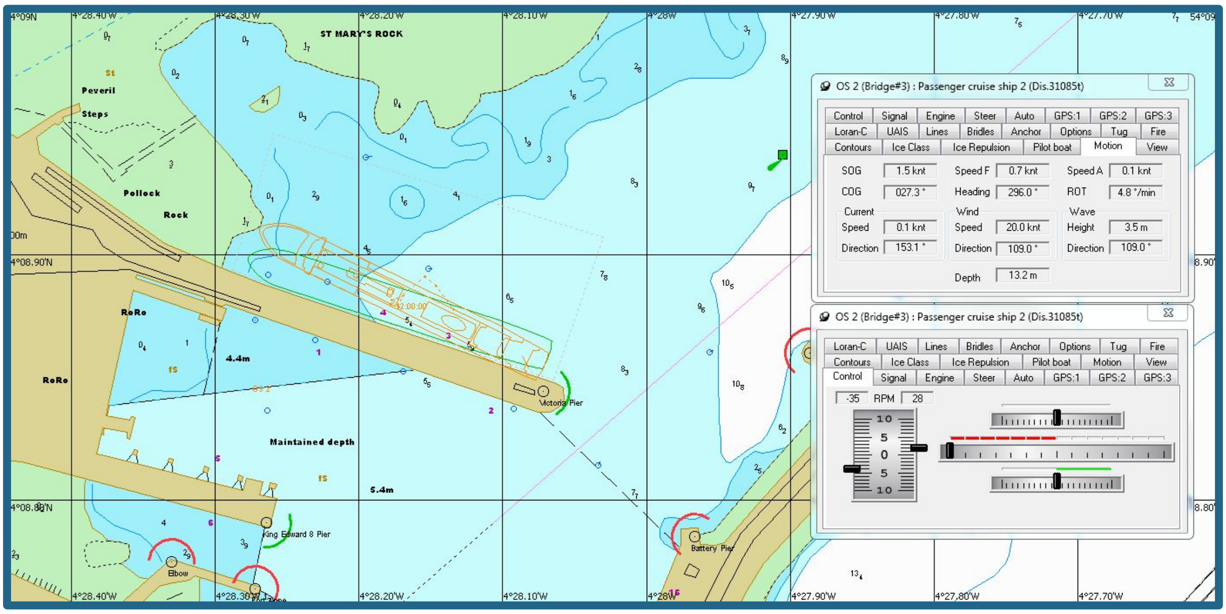

Figure 51. **Standard cruise vessel unable to depart the Victoria Pier Berth due to high easterly winds**

The key points arising from the assessment of vessel departure from both proposed berth developments are tabulated in Table 18, below.

Table 18. **Vessel departure from each berth: Key points**

Key point	Note	Impact
North-easterly and easterly winds prevented departure.	The standard cruise vessel was unable to depart Victoria Pier during easterly winds.	Limitation
Flow during ebb tides creates vessel headway when departing.	The ebb flow inside the Deep-Water Berth area causes vessel headway on letting go of lines, requiring immediate astern propulsion or tug assistance.	Consideration

The requirements for tug assistance and associated bollard pull.

Tug assistance is either required or recommended for all manoeuvres conducted for both berth developments. Tug assistance provides a margin of error in situations where full use of propulsion is required, or where drift is expected to reduce the distance from navigational hazards. The availability of tug assistance reduces the requirements for auxiliary vessel propulsion such as the requirement of bow thrusters. Figure 52 shows a Real-time simulation example where tug assistance would be required to offset the effects of vessel drift whilst accessing the Deep-Water Berth.

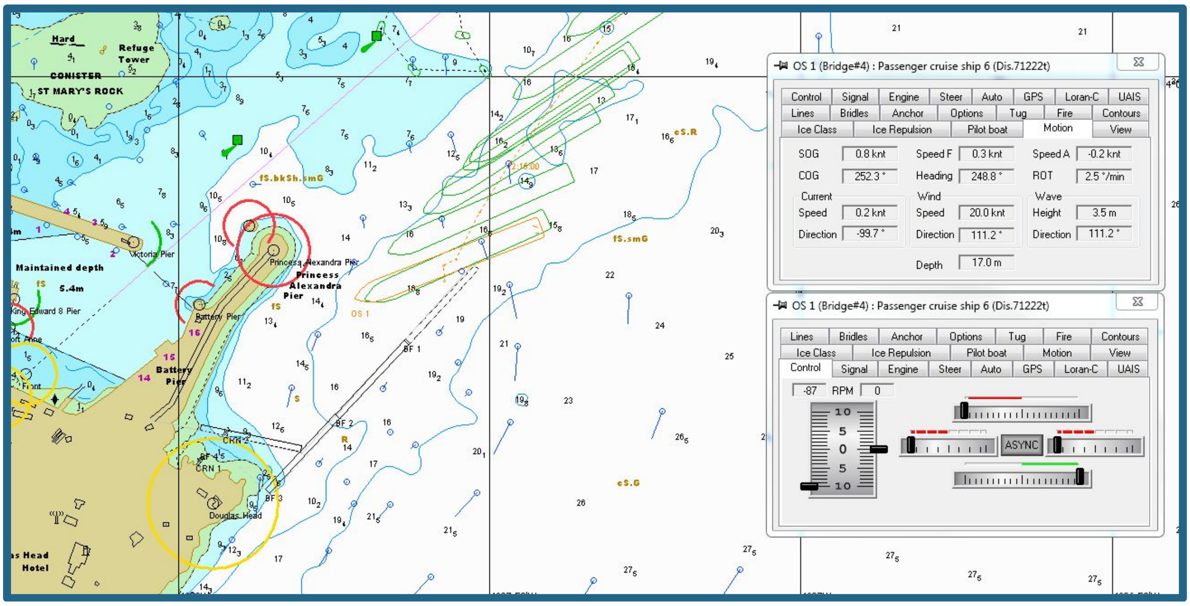

Figure 52. **Large cruise vessel requiring tug assistance when experiencing drift**

The key points associated with the use of tugs arising, from the vessel simulations for both proposed berths, are tabulated in Table 19, below.

Table 19. **Use of tugs for each berth scenario: Key points**

Key point	Note	Impact
Difficulty in connecting tugs during high weather conditions.	A high sea state can make tug operations difficult or impracticable for tugs either standing by or connecting.	Limitation
Approaches cannot be made without auxiliary propulsion or tug assistance.	Tug assistance increases the margin for error and safety of vessel manoeuvres.	Requirement
Large cruise vessel tug assistance requires bollard pull of 60+ t.	The large cruise vessel requires a tug with a bollard bull of over 60 t, recommended to be of Azimuth Stern Drive configuration.	Requirement
Standard cruise vessel tug assistance requires bollard pull of 50+ t.	The standard cruise vessel requires a tug with a bollard bull of over 50 T, recommended to be of Azimuth Stern Drive configuration.	Requirement

Further key points identified

Further key points relating to the operation of the proposed developments are listed in Table 20, below.

Table 20. Additional Key points identified from the ship simulations

Key point	Note	Impact
Lead marks are required indicating the centreline of the new Deep-Water Berth area.	For assistance in determining approach angle and position.	Consideration
Approaches should be made from the north.	Approaches made from the south created large degrees of list and roll with less margin for error. Northerly approaches provide a better point of approach and commence near the pilot boarding area.	Consideration

7 Conclusions

The main conclusions from the various elements of the studies, concentrating on the sedimentary and navigation effects arising from the proposed Victoria Pier and Deep-Water Berth schemes, are provided below.

7.1 Conceptual understanding

The bathymetry of the Irish Sea has a significant impact on circulation and hydrography around the Isle of Man. The available depths allow large-draughted vessels to approach without 'hindrance' to within about 1 km of the Harbour Entrance and the location of the proposed new berths.

The coastal configuration, rock outcrops, harbour piers and bathymetry, control the strength and orientation of the tidal currents and waves that are experienced within the approaches to Douglas Harbour, consequently they also affect the sediment regime and navigation requirements.

The flow measurements collected by the field survey show a complex flow regime in and around the entrance to Douglas Harbour, within which the proposed cruise vessels will need to turn and manoeuvre. Areas of both high and low flows occur, with a spatially varying size and location of eddies, at different states of the tide. Flow speeds were measured up to about 2 kts (1 m/s) in the area of the Deep-Water Berth and 1.5 kts (0.75 m/s) in the Harbour approaches. These conditions will influence navigation practice at different tidal states. They also indicate that construction of the quay for the Deep-Water Berth will change the flow conditions within the approaches to the Harbour and the proposed potential Victoria Pier cruise berth.

Waves within the Victoria Pier area are likely to be less than 0.3 m (significant wave height) during the cruise season. However, vessels could pass through areas of waves of the order of 0.7 m along the approaches, impinging on the beam of the vessel, with the wave height reducing uniformly to the berth. The same conditions would occur for vessels approaching the Deep-Water Berth.

Sediment transport pathways are in a predominantly NE direction offshore of Douglas, although the rate of transport is generally low (*circa* 0.1 m^3/m/tide). In the Victoria Pier Berth area, the bed sediment is almost entirely well-sorted sand with a median grain size of *circa* 200 μm. This changes to gravel in the deeper areas of the approaches and in the vicinity of the Deep-Water Berth. The gravel areas are indicated to be highly compacted, forming on 'armour' layer to the bed. This spatial distribution of the sea bed character suggests there is little mobile sediment in the area to be moved around by the tidal hydrodynamics and waves, which would subsequently form a supply for sedimentation in the new berths and approach area. This is confirmed by the low water column suspended sediment concentrations collected during the field survey. The largest source of sediment is restricted to sand from the shallow areas immediately adjacent to St. Mary's Rock.

7.2 Modelling and sedimentation analysis

7.2.1 Victoria Berth Pier scheme

The modelling of the Victoria Pier Berth scheme showed that dredging the berth to 9.5 m below CD has negligible effect on the existing flow regime at all states of tide. The change is almost entirely restricted to the berth itself, where existing flows are already low (peaking at <0.2 m/s on spring tides) and for most of the tide are orientated towards the east and aligned with the pier.

Under existing conditions, the flows can be just sufficient to move 200 µm sand as bed load on spring tides, from around HW -4 hours to HW +4 hours, but the material is not suspended. With the deepened pocket, the bed shear stress is reduced to almost zero, therefore the berth will accumulate any sediment that can move into the pocket. In the baseline condition, this material can move through the area, hence the negligible sedimentation that is currently experienced. Within the vicinity of the berth there is negligible change in the hydrodynamics that could subsequently affect the supply of sediment within the Harbour approach and berth area. The total volume of bed material available for sedimentation is, therefore, unlikely to increase; however, (when it is available) more will be retained within the berth pocket.

The sediment transport modelling was undertaken to test the sensitivity of the results for different wave conditions; those most likely during the summer cruise season and for the 1 in 1-year storm condition, most likely to occur during the winter months. With the summer wave condition, the berth deepening had no effect on the sediment regime. With the annual wave condition, a small redistribution of sediment within the berth area occurred with a marginal increase for overall accretion. Given the small existing rate of accretion, the deepened berth will make negligible change to the volume of sedimentation occurring within the berth. As a result, the average thickness of annual sedimentation in the new berth is likely to be no greater than a few millimetres and unlikely to be noticeable when vessel disturbance is considered.

7.2.2 Deep-Water Berth scheme

The hydrodynamic modelling of the Deep-Water Berth scheme showed that changes to the flow regime will be confined within an approximate radius of 1.2 km (centred on the head of Princess Alexandra Pier), with the greatest changes occurring around HW. The Deep-Water Berth scheme therefore has more potential to affect the accretion and erosion potential across wider parts of the study area than the Victoria Pier Berth scheme.

In the area of the Victoria Pier Berth and the Harbour entrance, the construction of the Deep-Water Berth has little effect on flow directions, however flows are reduced throughout the tide by about 30% (0.06 m/s) on spring tides with an associated reduction in the bed shear stress. Under existing flow conditions, the modelling results indicated that 200 µm sand is mobile at the bed. Following construction of the new Deep-Water Berth pier the modelling indicates that the increased sheltering effect, and reduction in hydrodynamic flows, reduces the potential bed mobility in the berth and the local vicinity under the annual storm wave condition, creating a slightly more sedimentary regime. Increased sedimentation could, however, only occur in this area with a greater supply of sediment. The modelling does not indicate that this will occur as there is no change predicted to sand transport in and around the approaches to the existing Victoria Pier under either typical summer or annual storm conditions

The results indicate construction of the Deep-Water Berth will have negligible sedimentary effects on Douglas Harbour and the immediate approaches with or without the proposed Victoria Pier Berth. The requirement for maintenance dredging will remain negligible unless there is a significant change to the sediment supply in the immediate area. Existing and resulting flow regimes indicate there is little potential for significant sediment movement into the area.

In the area of the outer approaches, the Deep-Water Berth pier acts as a training wall and is situated almost on the 'line' where existing flow speeds begin to reduce and turn northwards around Douglas Head. The proposed pier structure blocks both flood and ebb flows, reducing speeds by 0.3 - 0.4 m/s on the flood within a slow-moving anticlockwise eddy, which becomes more dominant over a larger area as the tide rises. On the ebb, flows are reduced by up to 0.15 m/s. These changes are important, as the vessels will need to navigate through this area in order to reach either of the two proposed berths or Douglas Harbour itself.

With the existing flows, the bed shear stresses are sufficient to move sand at the bed and would suspend material on the largest range tides, but for less than an hour just after HW and LW. With the Deep-Water Berth scenario, all bed shear stresses are reduced so that bed mobility will be reduced, and only occur for the highest tidal ranges. Sediment movement in the approaches is therefore likely to reduce from the existing small rate following construction of the Deep-Water Berth.

In the area of the Deep-Water Berth itself, the pier interacts with both the flood and ebb flows in a complex manner, blocking, training and diverting the existing flow regime, particularly at the northern end. These changes, and the resultant flow patterns, will significantly influence vessel manoeuvring to and from the new berth.

The new pier provides a generally sheltered environment within the berth itself and, consequently, reduces the flow speeds and bed shear stress applied to the bed material. Flow speeds within the berth area will generally be reduced by up to 0.5 m/s, compared to the baseline flows at this location. However, of more relevance for navigation purposes, at peak ebb flows there will be a significant flow speed gradient, from about 0.2 m/s to around 1 m/s, north to south, along the length of the berth as flows move towards the constriction under the proposed link bridge.

Analysis of the bed shear stress plots indicates an increased potential for sedimentation within the berth area, particularly in the northern half of the berth and the immediate approach area. Presently, there is little evidence that accretion is occurring in this area and the field measurements, and associated photographs, suggest that the overall supply of sediment to the area is low and therefore little sedimentation will result.

The sediment transport modelling over a spring-neap cycle under the different wave conditions shows very little change to the bed thickness around the proposed Deep-Water Berth pier structure, compared to the baseline. This indicates that there will likely be no difference in sedimentary effect under the influence of either of the assessed wave events. As a result, it is considered that the sedimentary behaviour around the Deep-Water Berth is primarily a function of the changes to the hydrodynamic flow regime, with little overall effect from the change in wave conditions through a year.

The sediment transport modelling shows a reduction in erosionary areas and an increase in accretionary areas, compared to the existing baseline conditions, following construction of the Deep-Water Berth pier. The net effect in the berth area remains erosional, albeit predicted at an even smaller magnitude. These changes are, however, small and will be within the natural variability of the area. The Deep-Water Berth is therefore predicted to be self-maintaining, in net volume terms. However, isolated areas of small reductions in depth could occur immediately against the quay, particularly at the northern end of the berth. This, however, is unlikely to cause the need for a significant maintenance dredge requirement due to the wider lack of sediment supply, and the potential for sediment redistribution as a result of vessels manoeuvring to and from the berths.

7.3 Navigation Study

The vessel simulations undertaken indicate that manoeuvres conducted in conditions above Force 4 become increasingly difficult. The scenarios conducted in conditions above this were continued as far as possible in order to determine the possibility of the manoeuvre, however it was deemed that, in several cases, the operation would have been aborted due to the risks involved. The simulation results for the proposed developments are summarised below.

7.3.1 Victoria Pier Berth

Manoeuvres conducted for the Victoria Pier Berth development showed difficulty in ship handling when operating in easterly wind conditions; these conditions lead to greater speeds over the ground, and swing rates that are difficult to control. Manoeuvres to and from the berth were best accomplished north of the dredge pocket as this was away from shallow rocks to the west of the pier and allowed for a greater margin of error when turning and positioning. A PST approach was considered best in conditions above Force 4 and between HW -4 hours and HW +4 hours, as this enabled greater speeds to be maintained, improving steerageway and reducing risks from turning. Tug assistance of over a 50 t bollard pull was deemed necessary for all manoeuvres conducted, in order to improve safety margins and the effectiveness of ship handling. The standard cruise vessel was unable to depart the berth during easterly wind conditions above Force 4 without tug assistance, it is recommended that two tugs are used for departures during easterly wind conditions.

7.3.2 Deep-Water Berth

Ebb tides and following winds require greater speed over the ground to maintain steerageway on approach to the Deep-Water Berth. This impacts on the control of the vessel when making turns and reduces the margin of error when taking way off. Greater speeds are required when passing the northern point of the berth for the mitigation of increased flow rate during HW -2 hours and HW +2 hours, reducing the time available to take way off when entering the new berth area. Tug assistance of over 60 t bollard pull is recommended for all manoeuvres conducted through both indirect towing during approach and direct force when taking off vessel way or preventing headway when departing. Currents present within the new berth area affect manoeuvring and require the use of navigational marks, such as lead lights, to create a visual reference of heading, speed and swing rate.

7.3.3 Approaches

It has been identified that tug assistance is advisable for all manoeuvres conducted, especially in conditions above Force 4, for both proposed berth schemes. The conditions and limiting factors for tug operations and connecting lines should be considered in conjunction with the limiting factors of vessel operations. Vessel approaches from the vicinity of the Pilot boarding ground is considered to be effective, as this allows for determining the response of the vessel in relation to current conditions prior to approaching navigational hazards. When performing turns, winds contrary to the direction of stern swing increase the time taken to complete the manoeuvre and subject the vessel to a longer period of drift; it is therefore advised that turns are performed to the south of Douglas Bay.

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9 Abbreviations/Acronyms

ADCP	Acoustic Doppler Current Profiler
AIS	Automatic Identification System
ASD	Azimuth Stern Drive
AWAC	Acoustic Wave And Current
BGS	British Geological Survey
BSS	Bed Shear Stress
CD	Chart Datum
CPA	Closest Point of Approach
CPP	Controlled Pitch Propeller
DirM	Mean wave direction
DHI	Danish Hydraulics Institute
DWB	Deep-Water Berth
ECDIS	Electronic Chart Display and Information System
HAT	Highest Astronomical Tide
HD	Hydrodynamic
HW	High Water
Hs	Significant wave height
IOM	Isle of Man
LPS	Local Port Services
LW	Low Water
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
MMEA	Manx Marine Environmental Assessment
MSL	Mean Sea Level
OD	Ordnance Datum
PSD	Particle Size Distribution
PST	Port-Side-To
QVB	Queen Victoria Berth
QVP	Queen Victoria Pier
RCP	Representative Concentration Pathways
RoRo	Roll-on, Roll-off
SSC	Suspended Sediment Concentration
SST	Starboard Side To
ST	Sand transport
STW	Speed Through the Water
SW	Spectral wave
Tp	Peak wave period
Tz	Mean zero-crossing wave period
UK	United Kingdom
UKCP09	UK Climate Projections (2009)
UKCP18	UK Climate Projections (2018)
UKHO	United Kingdom Hydrographic Office

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Appendices





Innovative Thinking - Sustainable Solutions

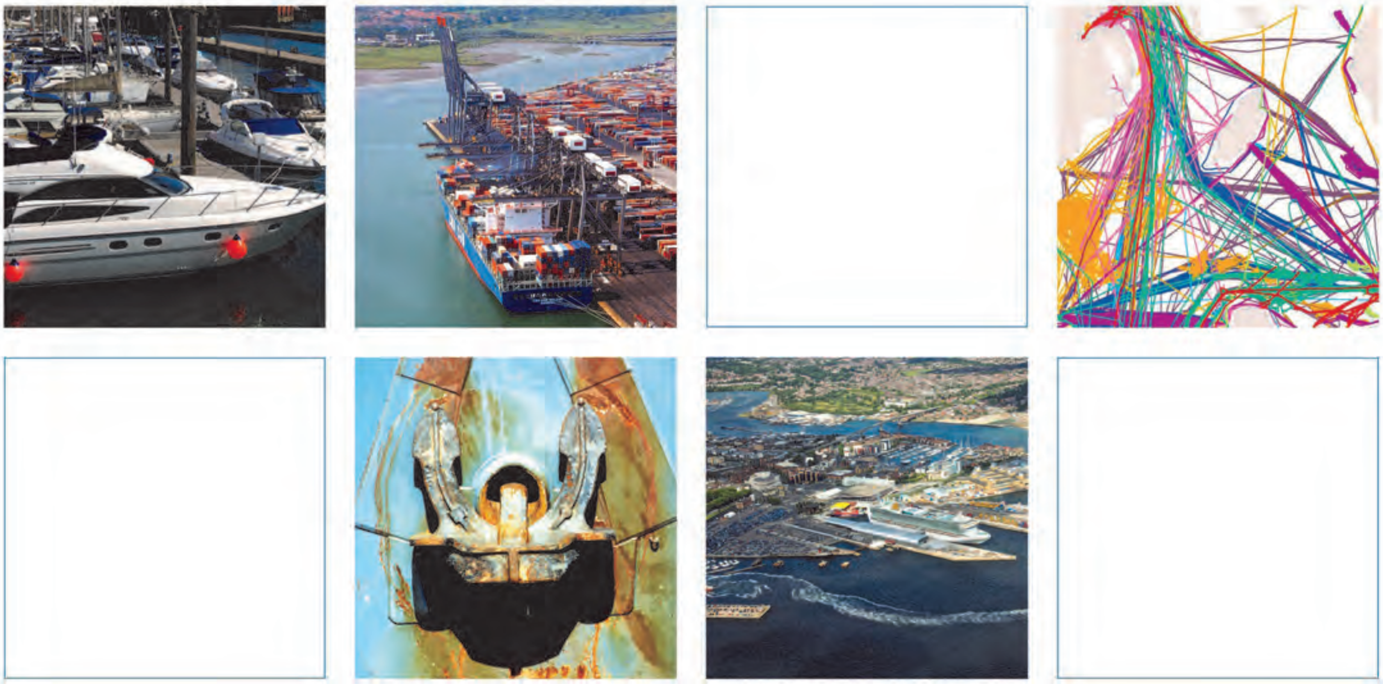
A Field Survey Report

Isle of Man Government - Department of Infrastructure

Proposed Deep-Water Berth, Douglas Harbour - Sediment and Navigation Studies

Hydrodynamic survey and seabed sediment sampling

November 2019



Innovative Thinking - Sustainable Solutions

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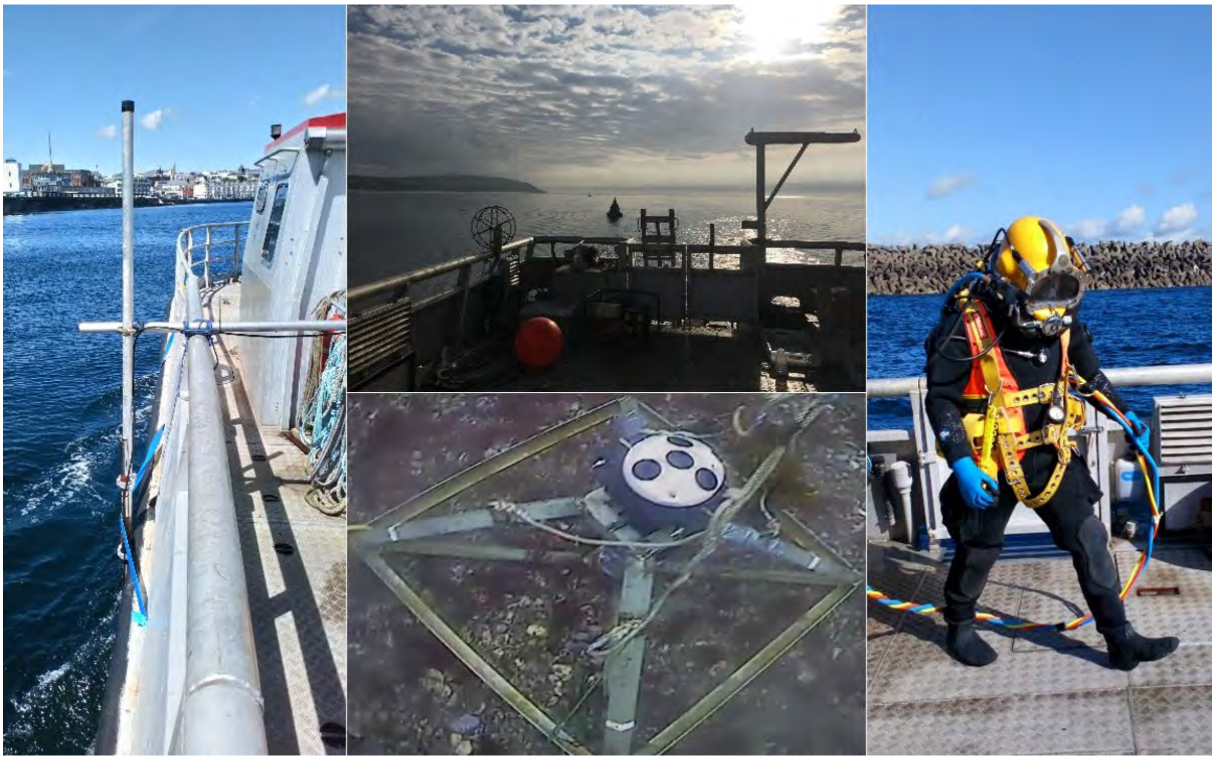

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Summary

Isle of Man (IoM) Harbours, Department of Infrastructure - Ports Division is undertaking a Master Planning process for the port facilities at Douglas Harbour. The Master Planning has indicated the potential for berthing facilities outside the Douglas Harbour entrance for vessels that cannot be accommodated within the existing harbour. To support the initial feasibility studies a local wave and sediment model of the harbour and surrounding coastal waters has been constructed (see ABPmer; 2019b) with a supporting hydrodynamic and sediment characterisation field survey conducted.

Instruments observing current flow, wave activity, salinity and turbidity were deployed at two locations within Douglas harbour for a full 30-day spring/neap tidal period. A mobile, vessel-based survey was conducted on a spring tide to acquire current information over a wider expanse of Douglas harbour. Grab samples and water samples were acquired to characterise the seabed and to assess any likely sediment movement within the harbour.

This report summarises the equipment used, deployment parameters and resulting data acquired as part of this field survey, conducted in June/July 2019.

Contents

Appendices

Tables

Figures

1 Introduction

1.1 Project context

Isle of Man (IoM) Harbours, Department of Infrastructure - Ports Division is undertaking a Master Planning process for the port facilities at Douglas Harbour. The Master Planning has indicated the potential for berthing facilities outside the Douglas Harbour entrance for vessels that cannot be accommodated within the existing harbour. Two proposals are being considered to potentially accommodate predominantly day-visit cruise vessels: dredging of a deeper and longer berth pocket than currently present; and construction of a Deep-Water berth outside the Harbour. Greater details of the proposals can be found in the supporting conceptual understanding of Douglas Harbour (see ABPmer; 2019a).

To support the initial feasibility studies a local wave and sediment model of the harbour and surrounding coastal waters has been constructed (see ABPmer; 2019b). During initial data reviews (i.e. prior to model construction), a lack of recent observations of patterns of hydrodynamics and sediments in the local area was apparent. It was therefore agreed that a field survey should also be conducted to a) provide contemporary information for a conceptual understanding to be made; and b) to calibrate/validate the numerical model.

1.2 Key survey tasks

To collect the required contemporary hydrodynamic information from the outer harbour area and surrounding coastal waters, the following three survey tasks were undertaken.

- **Static Recording Instruments** including Acoustic Wave and Current (AWAC) devices, Conductivity/Temperature/Depth (CTD) sensors and Turbidity sensors were deployed over a full spring/neap tidal phase. These instruments enabled the description of waves, tides, water levels, salinity and suspended sediment (via Optical Backscatter (OBS)) content;
- **A Mobile (vessel-based) Survey** using an Acoustic Doppler Current Profiler (ADCP), a CTD and Turbidity meter and a water sampling programme to describe the flow, salinity and suspended solid regimes in greater detail in selected areas outside of Douglas Harbour entrance and surrounding coastal waters; and
- **Seabed Sampling** was conducted at pre-determined locations throughout the harbour entrance and surrounding coastline using a hand-deployed Van-Veen grab sampler. Laboratory-based Particle Size Analysis (PSA) was then undertaken on each sample.

Survey operations were conducted in June/July 2019.

2 Survey Methods

2.1 Static recording instruments

The static recording instruments were deployed at two fixed locations as detailed in Table 1 and illustrated in Figure 1. Site 1 is located offshore of Victoria Pier and Site 2 is located in the area of the proposed Deep-Water berth. The specific locations were selected for a comparatively level seabed and ensuring no adverse effects to navigation. Locations were agreed with the Port of Douglas Harbour Master prior to equipment deployment.

The instrument deployments were for a minimum duration of 30 days to ensure that required parameters were recorded over at least two full spring/neap cycles, whilst simultaneously considering any short-term variations in fluvial input. The specific equipment deployed at each site and the acquisition parameters are described below (see Appendix A for full instrument specifications and Appendix B for calibration certificates):

- **Nortek 1 MHz Acoustic Wave and Current (AWAC)** instruments were deployed at Sites 1 and 2 to acquire water level, tidal flow and wave data. Average current flow data over a 60 second burst was acquired at 10-minute intervals at 0.5 m depth bins through the water column. 1024 wave activity observations were acquired at 1 Hz at 60-minute intervals;
- **YSI 6600 CTD/Turbidity** sensors were deployed on the same seabed frame at each site to acquire near-bed salinity and suspended sediment data. Sampling was set to acquire at 10-minute intervals.

In advance of the deployment, all instruments had new batteries installed, and the internal compass and pressure sensors were calibrated, and quality checked in the laboratory. Further checks were conducted onboard the vessel immediately prior to deployment. The internal clocks of the AWAC and CTD/Turbidity sensors were all synchronised to Greenwich Mean Time (GMT).

The Nortek AWAC (SN: WPR2877) instrument and YSI6600 CTD/Turbidity (SN:09M100310) sensor was secured to a seabed frame and deployed at Site 1 on 17 June 2019. The Nortek AWAC (SN: P28262) instrument and YSI6600 CTD/Turbidity (SN:06L1043AA) sensor was secured to a seabed frame and deployed at Site 2 on 18 June 2019. The deployment coordinates and deployment/recovery times for each site are provided in Table 1.

Table 1. Coordinates and timings of deployed AWAC and CTD/turbidity instruments

Site ID	WGS84		OSGB36 (OSTN15)		Deployment Date/Time (GMT)	Recovery Date/Time (GMT)
	Latitude	Longitude	Easting	Northing		
Site 1 (Victoria Pier)	54˚08.904' N	04˚28.063' W	238926	475321	17/06/2019 12:04	19/07/2019 09:50
Site 2 (Deep-Water Berth)	54˚08.697' N	04˚27.767' W	239235	474927	18/06/2019 09:00	19/07/2019 08:50

The instruments were mounted on seabed frames and were deployed and retrieved using qualified commercial divers provided by the IoM Government using the dive support vessel, *Kesh Varrey*. Lift bags appropriate for the weight of the instrument package were used to aid deployment/recovery. At Site 2 (Deep-Water Berth) a ground line was run from the frame out to a sinker weight secured to a marker buoy for navigational safety. A schematic of this deployment configuration is shown in Figure 2. A marker buoy was not required at Site 1 (Victoria Pier) in order to minimise risk to navigational safety (this was pre-agreed in discussions with the Harbour Master).

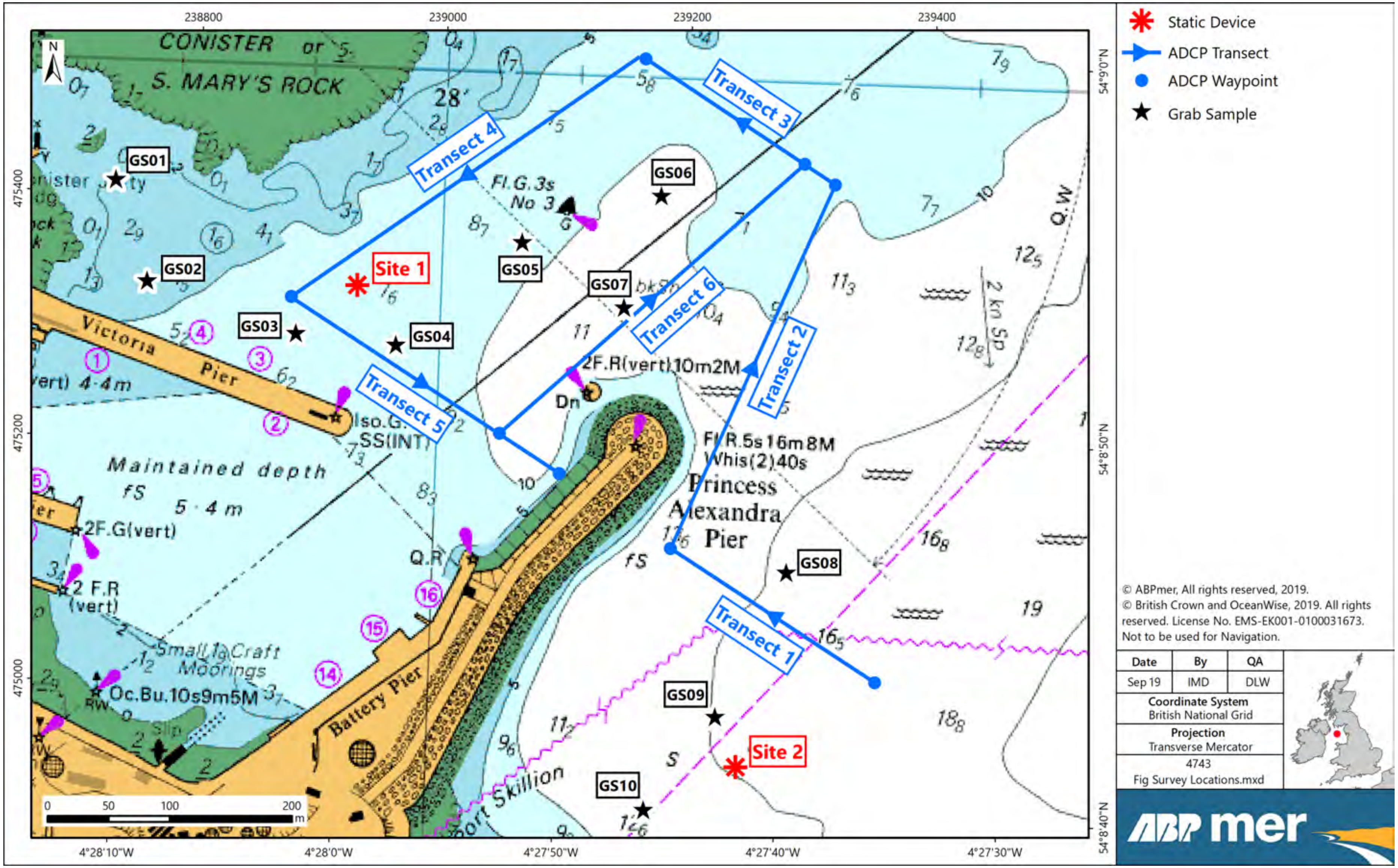
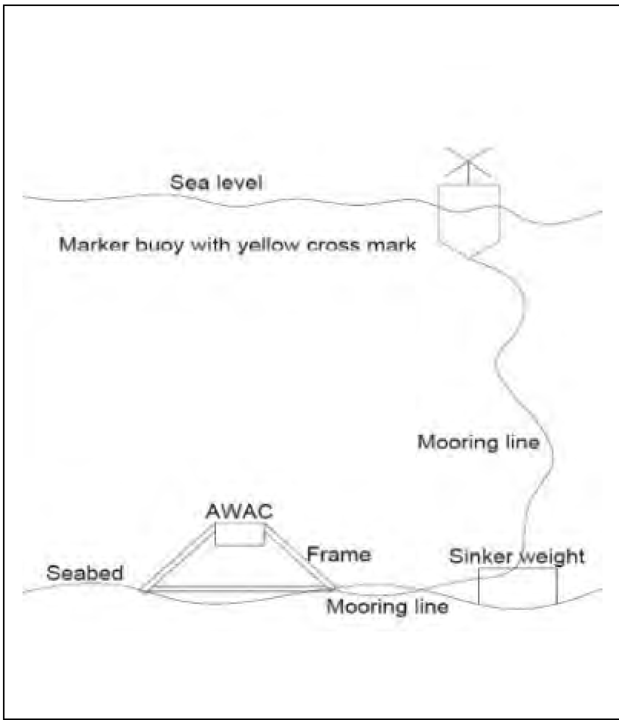


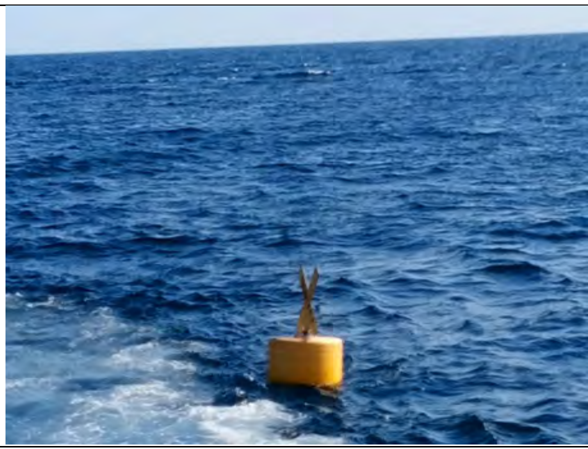
Figure 1. **Locations of static instrument packages, mobile survey and grab samples**



Deployment Configuration

Deployment using divers and lift-bags

Deployment at Site 2 (diver camera)



Deployment at Site 2 (marker buoy)

Figure 2. Seabed frame deployment schematic and photographs

The seabed frames were recovered on 20 July 2019 and all data successfully downloaded. Thus, the deployments covered the required minimum 30-day period (32 days at Site 1 and 31 days at Site 2). Following recovery, each dataset was quality checked and processed according to the following procedure:

- The raw data from both AWAC and CTD/Turbidity instruments was initially examined visually in a time-series format to determine any unusual trends, data offsets or data drift, e.g. as a result of biofouling around the sensor. Based on this data inspection, a decision was made about whether the data could be used. All collected datasets passed this initial procedure. There was no evidence of gradual or long-term biofouling affecting the instrument throughout the deployment, however, some short term temporary periods of potential effect (less than 24 hr in duration) were noted;

- Raw OBS readings acquired by the YSI 6600 instruments were increased by the absolute value of the lowest negative OBS reading for each device recorded throughout the length of the deployment. Following examination of the whole time series, individual readings deemed to be erroneous (in this case readings >100 NTU) were removed.
- The raw data from each AWAC instrument was interrogated through the manufacturers' quality/integrity tests to determine whether any parameters (pitch/roll/heading) were outside the specified tolerances for best quality. Any data outside these tolerances was marked and not included within any statistical analysis;
- A calibration of the AWAC pressure readings was applied in order to consider the instrument height above the seabed, the blanking distance of the AWAC's vertical sensor and variations in atmospheric pressure at the time of deployment;
- East and North components of current speed at each depth interval (0.5 m) were converted into an absolute current speed and direction for each AWAC. Data recorded close to (within 10% of the total water depth from) the water surface in each time step was discarded. A depth-averaged time series was created using the remaining data. At this point the vertical component of each sample was also analysed in time series format for any anomalies or unusual trends.

The results of the quality review indicate that a high percentage of the data time series is valid and can be used for later analysis and model calibration. A total of 267 time step records were removed from the final datasets due to exceedance of the minimum/maximum Heading, Pitch and Roll tolerance levels (±0.5° at Site 1 (Victoria Pier) and ±1° at Site 2 (Deep-Water Berth)). This is equivalent to 3.1 % of the total data record, providing an overall data return for the survey period of 96.9 %.

2.2 Mobile (vessel-based) survey

To analyse the three-dimensional (3D) patterns in the flow, salinity and suspended sediment regimes at the mouth of Douglas Harbour and coastline surrounding the proposed Deep-Water Berth, mobile ADCP (Acoustic Doppler Current Profiler) profile measurements were acquired, at 0.5 m depth intervals from near-surface to near-seabed, along six pre-determined transects. The locations of the transects are illustrated in Figure 1.

A Teledyne RD Instruments Workhorse Sentinel 600 kHz ADCP (see Appendix A for full specification) was pole-mounted securely to the port side of the dive support vessel, *Kesh Varrey* (see Figure 3). Although suitable for making measurements throughout the majority of the water column, it should be noted that this instrument does not always provide an accurate measure of flows within 1 m of the seabed, depending on the suspended sediment regime.

The mobile survey was carried out on 19 June 2019. The timings of the surveys in relation to the UKHO predicted tidal frame at Douglas Harbour are provided in Table 2. Data was repeatedly collected along each transect at approximate hourly intervals over a minimum of one full (LW-HW-LW) tidal cycle.

Table 2. Timetable of mobile surveys in relation to UKHO predicted tide times

Transect ID	Transect Start OSGB36 (OSTN15)		Transect End OSGB36(OSTN15)		Start Time	End Time	Predicted High/Low Water Time	Predicted Tidal Height (m CD)
	Easting	Northing	Easting	Northing				
1	239349	474996	239182	475106	05:55	18:56	00:13 06:40 12:35 18:54	6.7 1.0 6.4 1.2
2	239182	475106	239317	475403	06:00	19:01		
3	239317	475403	239162	475506	06:05	19:08		
4	239162	475506	238872	475312	06:09	19:13		
5	238872	475312	239091	475167	06:15	19:18		
6	239042	475200	239292	475420	06:21	19:24		
All times stated in GMT								

Figure 3. ADCP mounted to port side of vessel (left) and water sampling (right)

Salinity and turbidity profiles throughout the water column were taken at *circa* hourly intervals at Site 1 (Victoria Pier) and *circa* two-hourly intervals at Site 2 (Deep-Water Berth) during the mobile survey to observe potential vertical and temporal change in the structure of the water column over a tidal cycle. This was undertaken with another YSI 6600 CTD/Turbidity (SN:11G101176) sensor (see Appendix A for specification and Appendix B for calibration certificate). The device was held just below the surface, at mid-depth and just above the seabed.

The ADCP measurements and individual CTD/Turbidity casts were processed according to the following procedure:

- Raw ADCP measurements from each Transect were processed in ViSea DAS/DPS software. A mounting offset of -4.9˚ was applied to the heading sensor to take into account the installation angle of the instrument relative to the vessel. Each raw file was examined for data affected by shipwash and vessel-induced turbulence; affected measurements were removed. Individual 0.5 m depth cells that contained erroneous velocities (>2 m/s) were also removed.
- Calibration of the raw depth and OBS data provided by the CTD/Turbidity instrument was conducted. The depth measured during each CTD cast was increased by the absolute value of the (initially negative) depth indicated by the instrument on the vessel deck prior to the first cast. Raw OBS readings were increased by the absolute value of the lowest negative OBS reading observed throughout all casts.

Water samples were also obtained near the surface (<1 m), at mid-depth and near the bed (<1 m from seafloor) using a 2L horizontal Niskin bottle sampler. Samples were collected at *circa* hourly intervals at Site 1 (Victoria Pier) and *circa* two-hourly intervals at Site 2 (Deep-Water Berth) during the mobile survey. Laboratory analysis was undertaken on these samples to obtain the Total Suspended Solid (TSS) within the 'stability period' (14 days). TSS values from these water samples were then plotted against OBS readings from both the CTD/Turbidity instruments deployed as part of the static deployment packages, and that used during the mobile survey, to calibrate the raw OBS values into suspended sediment concentration (SSC). This calibration process is presented within Section 3.2.3.

2.3 Seabed sediment sampling

A total of 10 seabed sediment sample locations were chosen throughout the harbour entrance and offshore of the Princess Alexandra Pier prior to the survey commencing. Seabed sediment samples were collected on 18 June 2019 from the *Kesh Varrey* using a hand-deployed Van-Veen grab sampler. The locations of the acquired samples are provided in Table 3. A maximum of three attempts were made at each location.

Table 3. Location of obtained grab samples

Sample ID	OSGB36 (OSTN15)		No. Grab Attempts	Water Depth (m CD)
	Easting	Northing		
GS01	238728.83	475407.90	1	2.2
GS02	238754.20	475324.89	1	4.5
GS03	238875.74	475281.93	1	6.3
GS04	238957.43	475272.17	2	7.8
GS05	239060.90	475356.10	1	9.0
GS06	239174.81	475393.94	3	10.2
GS07	239144.20	475302.62	2	10.9
GS08	239276.73	475086.00	1	15.6
GS09	239218.35	474967.99	3	15.1
GS10	239159.74	474892.20	1	12.8

Each sample was subject to Particle Size Analysis (PSA) at ABPmer's accredited laboratory, according to the following procedure:

- The samples were dried at 105 °C for a minimum period of 12 hr;
- The samples were sieved into six grades between 20 mm and 1 mm to establish the mass distribution of coarse sand and gravel fractions;
- Material <1 mm was then analysed using a laser particle size analyser to establish the mass distribution of medium/fine sand and mud fractions;
- The cumulative distributions of coarse and fine material were combined to produce an overall grain size distribution curve for each sample.

The full results of the sediment sample PSA can be found in Appendix C.

3 Survey Results

This section provides a brief overview and summarises key findings from both the static instrument packages and the mobile survey operations. More detailed analysis and interpretation of the findings can be found within the supporting conceptual understanding of Douglas Harbour and surrounding coastal waters (see ABPmer; 2019a).

3.1 Static recording instruments

3.1.1 Site 1 (Victoria Pier)

Full presentation of the results from the static recording instruments at Site 1 is provided in Figure 8 to Figure 11. Meteorological conditions recorded on Princess Alexandra Pier (Douglas Breakwater) are provided for visual comparison.

AWAC current speed and direction

Depth-averaged current speeds throughout the area immediately north of Victoria Pier and the entrance to Douglas Harbour are generally low, with a maximum of 0.4 m/s during spring tides and 0.2 m/s during neap tides. Current direction throughout the flood tide typically rotates clockwise from an easterly direction around LW to north-northwest around two hours before HW. On the ebb tide, direction generally remains south-easterly for a period of *circa* 4 hours after HW, then briefly rotating anti-clockwise to a north-westerly direction for *circa* 1 hour before rotating back to an easterly direction around LW.

AWAC wave climate

Significant wave height (H_{m0}) was typically less than 0.5 m during the static deployment period, with associated peak wave periods (T_p) of less than 6 s. However, longer period waves with T_p up to 12 s are observed erratically when swell enters the harbour entrance relatively unaffected from northeast and north-northeast directions. The associated maximum height of individual waves (H_{max}) will be larger than the value of H_{m0} at any given time.

A total of three sustained events can be identified from the wave record. These are:

- **23 to 24 June 2019** - elevated wave heights for a period of *circa* 24 hours, with H_{max} and H_{m0} peaking at 1.0 m and 0.5 m respectively. T_p was around 4 s. Wave direction was concentrated between north-easterly and easterly directions;
- **26 June 2019** - elevated wave heights for a period of *circa* 20 hours, with H_{max} and H_{m0} peaking at 1.0 m and 0.5 m respectively. T_p ranged between 4 and 6 s. Wave direction fluctuated between north-easterly and easterly directions;
- **28 June 2019** - elevated wave heights for a period of *circa* 24 hours, with H_{max} and H_{m0} peaking at 1.1 m and 0.6 m respectively. T_p ranged between 3 and 6 s. Wave direction was concentrated from an easterly direction.

Two smaller events (duration < 8 hr) occurred on 08 and 15 July 2019. H_{max} peaked up to 1.0 m, although H_{m0} remained under 0.5 m. T_p for both events was less than 6 s. Wave direction was easterly for both events.

Salinity and turbidity

Salinity near to the seabed at Site 1 (Victoria Pier) remained between 33 and 34.5 PSU throughout the duration of the static deployment. Small variations of up to 0.5 PSU are likely a result of short-term fouling of the instrument and/or reaction to individual storm events.

Turbidity was low at this site, with typical values less than 5 NTU. Three steady peaks up to 10 NTU occur between 24-29 June 2019 and are likely to represent reactions to storm events identified in the wave record.

3.1.2 Site 2 (Deep-Water Berth)

Full presentation of the results from the static recording instruments at Site 2 is provided in Figure 12 to Figure 15. Meteorological conditions recorded on Princess Alexandra Pier (Douglas Breakwater) are provided for visual comparison.

AWAC current speed and direction

Depth-averaged current speeds immediately west of the harbour wall and north of Douglas Head are higher than within the harbour entrance, with peak spring currents exceeding 0.8 m/s and occasionally reaching 1.0 m/s. During neap tides they remain higher than Site 1 and typically reach up to 0.6 m/s. Peak current speeds are consistently higher on the ebb tide than the flood tide, particularly during spring tides. Flow direction is consistently south-westerly (225°N) during the ebb before rotating clockwise to around due north around LW. On the flood, flows continue to rotate clockwise through to a westerly direction 3 hours before HW and reverting anti-clockwise to a southeast direction for the 3 hours leading up to HW.

AWAC wave climate

The area immediately east of Princess Alexandra Pier is exposed to high-energy wave action from easterly directions, and typically experienced larger H_{m0} (0.5 to 1.0 m) throughout the record from these sectors. Typical associated T_p values are also larger and more varied, ranging between 3 and 9 s. Similarly, to Site 1 (Victoria Pier), larger period swell waves (T_p up to 12 s) can also be seen at various points throughout the record. Site 2 also shows greater exposure to southerly and south-south-westerly waves between 180 °N and 225 °N.

A total of five sustained events can be identified from the wave record. These are:

- **24 to 27 June 2019** - H_{m0} consistently above 0.5 m for a period of *circa* 72 hours, with H_{max} peaking at 1.5 m on 24 June 2019. T_p ranged between 3 s and 9 s during this period. Wave direction veered to the south for *circa* 24 hours before backing to a south-easterly direction;
- **28 June 2019** - Wave heights at Site 2 (Deep-Water Berth) during the event on 28 June 2019 were the largest seen throughout either record for the duration of the static deployments. H_{max} peaked at 2.5 m, whilst H_{m0} peaked at 1.5 m. T_p ranged between 3 and 6 s, with wave direction focused around the southeast sector (135 °N);
- **30 June 2019** - H_{max} and H_{m0} peaked at 1.7 m and 1.1 m respectively during this event. T_p steadily increased throughout the duration of the event from *circa* 3 s to *circa* 7 s (T_z remained consistent at *circa* 3 s). Wave direction fluctuated between southerly and south-westerly sectors;
- **08 July 2019** - This was a relatively short (< 12 hr) event in which H_{max} peaked at 1.4 m and H_{m0} peaked at 0.6 m. Wave period remained consistent at around 3 s. Wave direction was initially easterly, veering south-easterly throughout the duration of the event;
- **17 to 18 July 2019** - H_{max} steadily climbed from 0.5 m on 16 July 2019 to peak at over 1.5 m on 18 July 2019. H_{m0} followed a similar trend, peaking at over 1.0 m. T_p also climbed from 3 s to *circa* 6 s during this event. Wave direction fluctuated between southerly and south-south-westerly sectors.

Salinity and turbidity

Salinity at the bed remained consistent between 33.5 and 34 PSU throughout the duration of the deployment at Site 2 (Deep-Water Berth), except for fluctuations of ±1 PSU between 26-30 June and 10-17 July 2019. These fluctuations are likely a result of short-term fouling of the instrument during the respective periods.

Despite greater exposure to higher energy wave conditions throughout the length of the deployment, Turbidity at Site 2 (Deep-Water Berth) was generally lower than that seen at Site 1 (Victoria Pier) with values generally between 0 NTU and 0.5 NTU and rarely exceeding 5 NTU for subsequent readings. The exceptions to this are on 03, 06 and 17 July 2019; all of which are likely to represent either short-term reaction to storm events, or temporary fouling of the instrument.

3.2 Mobile (vessel based) survey

3.2.1 ADCP current speed and direction

Full presentation of the ADCP results acquired during the mobile transect survey is provided in Figure 16 to Figure 21.

Transect 1

Throughout a spring flood tide, flows are generally highest around HW -3 hr with turbulent patches of the upper water column (to a depth of *circa* 10 m) mainly around 0.7 m/s and occasionally reaching speeds around 1.0 m/s. The Transect shows a clear divide in flow direction during this period, with predominantly northerly flow in the outer section of the Transect (i.e. seaward of Douglas Head) and south-westerly in the inner section (i.e. shoreward towards the Princess Alexandra Pier). This divide in flow progresses seaward by *circa* 100 m during the duration of the flood tide until around HW -1 hr, where speeds consistently reduce to near stationary and flow direction becomes variable in small patches with depth.

Flow speeds throughout Transect 1 are considerably higher on a spring ebb tide than the flood. Peak flow speeds consistently reach and exceed 1.0 m/s throughout the entire water column to the bed between HW and HW +2 hr. Speeds then reduce throughout the depth of the water column from *circa* 0.7 m/s at HW -3 hr to near stationary between HW +4 hr and LW. Similarly, to the flood tide, a clear divide in flow direction occurs throughout periods of peak ebb flow; with southerly and south-westerly flows in the seaward end of the Transect and north-easterly, northerly and north-westerly flows in the landward end. Like the flood tide, this divide progresses *circa* 100 m landward during periods of peak flow. The ebb tide also shows greater variation at the bed, with the bottom 2 m of the water column often experiencing a local reversal of flow direction.

Transect 2

Peak flows over a spring flood tide are generally low throughout Transect 2, with maximum speeds of around 0.6 m/s. These high flows are mainly within the top 5 m of the water column and concentrated in the northern half of the Transect. On the first half of the ebb, flows are generally low (<0.5 m/s) within the southernmost 100 m of the Transect. A strong front develops at the northern end of the Princess Alexandra Pier between HW -3 hr and HW -1 hr, with flow speeds rising rapidly to around 1.0 m/s throughout the depth of the water column. A clear divide in flow direction (up to 180°) develops along this front from LW and throughout the flood, particularly between HW -4 hr and HW -1 hr. This is maintained throughout HW and the majority of the ebb to around HW +5 hr when the front then dissipates to a more uniform current speed and direction around LW.

Transect 3

This Transect has relatively low flow speeds throughout the duration of the tidal cycle, with maximum values around 0.7 m/s in the top 5 m of the water at HW -5 hr (flood tide) and between HW and HW +3 hr (ebb tide). At depths >5 m flows generally remain generally lower at around 0.3 m/s.

Flow direction on the flood tide is generally uniform throughout the length of the Transect, rotating clockwise from a northerly and north-westerly direction between LW and HW -3 hr to south-easterly, southerly and south-westerly directions between HW - 3 hr and HW. On the ebb, they are generally south-easterly and southerly between HW and HW +4 hr, before backing north and north-westerly between HW +4 hr and LW. Flow directions near to the bed (i.e. bottom 2 m) are consistently of a south-westerly direction throughout both the flood and ebb tides.

Transect 4

The general flow speed throughout this Transect remains less than 0.3 m/s for the duration of the tidal cycle. Peak flow speeds throughout Transect 4 are around 0.5 m/s but are isolated to small patches throughout the water column within the first 50 m of the Transect (i.e. in shallow water surrounding St. Mary's Rock). These peak flow speeds generally occur on the ebb tide between HW and HW +3 hr.

Flow direction throughout the flood tide is variable, indicating circulation around St. Mary's Rock. The northernmost 100 m of the Transect indicates a northerly flow between LW and HW -4 hr, with contrasting south-westerly and southerly flows within the southern 250 m of the Transect. As water depths increase from HW -3 hr to HW, a reversal in direction is seen; with southerly and south-easterly flows in the northern 150 m and northwest/northerly flows in the southern 100 m.

Throughout HW and for the majority of the ebb tide, flow direction in the northernmost 200 m of the Transect is variable with depth; with predominantly south-easterly flow in the top 5 m of the water column and south-westerly flow at the near bed. However, a *circa* 100 m section of the southern end of the Transect suggests a reversal of flow in westerly and north westerly direction. Direction then becomes general uniform and northerly throughout the Transect when approaching LW (i.e. between HW +4 hr and HW +5 hr).

Transect 5

General flow speeds throughout the tidal cycle within Transect 5 are low, less than 0.3 m/s. Although the maximum flow speeds are around 0.7 m/s, this tends to occur only in localised areas immediately north of Victoria Pier (i.e. not in the immediate harbour mouth) and there only on ebb tides between HW and HW +3 hr. The peak flow speeds also appear to move progressively to the western side of the Transect during this period. On the flood, flow speeds are generally more consistent.

Direction is variable throughout the Transect around LW and on the first hour of the flood tide, before a directional split occurs between HW -3 hr and HW; with north-easterly and easterly flows within the 150 m section of the Transect seaward of Victoria Pier and southerly and south-westerly flows throughout the remaining length of the Transect across the Harbour entrance. On the ebb tide the area of easterly flow progresses through the length of the Transect, with a small (*circa* 50 m) section of southerly and south-easterly flow compressed against the Princess Alexandra Pier.

Transect 6

Flow patterns throughout Transect 6 are similar to those in Transect 2. Peak speeds up to 1.0 m/s are concentrated on the flood tide at HW -5 hr and on the ebb tide between HW and HW +3 hr. The peak flows are located in the northern half of the Transect and are generally concentrated within the top 5 m of the water column with lower speeds of *circa* 0.2 m/s near to the bed.

Directions are influenced by the presence of Princess Alexandra Pier throughout the tidal cycle. From LW to HW -4 hr northerly flows entering the harbour entrance are deflected clockwise to more easterly directions. Brief reversal of flow close to the Harbour entrance occurs at HW -3 hr, before reverting to a more uniform easterly and south-easterly direction approaching HW and throughout the first half of the ebb tide (up to HW +2 hr). On the second half of the ebb flushing of the Harbour is visible, with south-westerly flows in the southernmost 100 m of the Transect. In the northern half of the Transect, flows then rotate anti-clockwise and return to northerly directions around LW.

3.2.2 Salinity and turbidity

Vertical profiles taken during the mobile ADCP suggest the water column at Victoria Pier remains well mixed at around 34.5 PSU throughout the duration of the tidal cycle, with a small increase (*circa* 0.2 PSU) occurring at LW (Figure 4). Apparently small fluctuations of ±0.01 PSU (visible in the data but not at the scale of the plots in Figure 4) reflect only the measurement accuracy of the instrument (See Appendix A). Turbidity remains less than 2 NTU throughout the water column over most of a typical spring tide cycle, with small increases at near bed depths to *circa* 6 NTU during the beginning of the ebb (HW +1 hr).

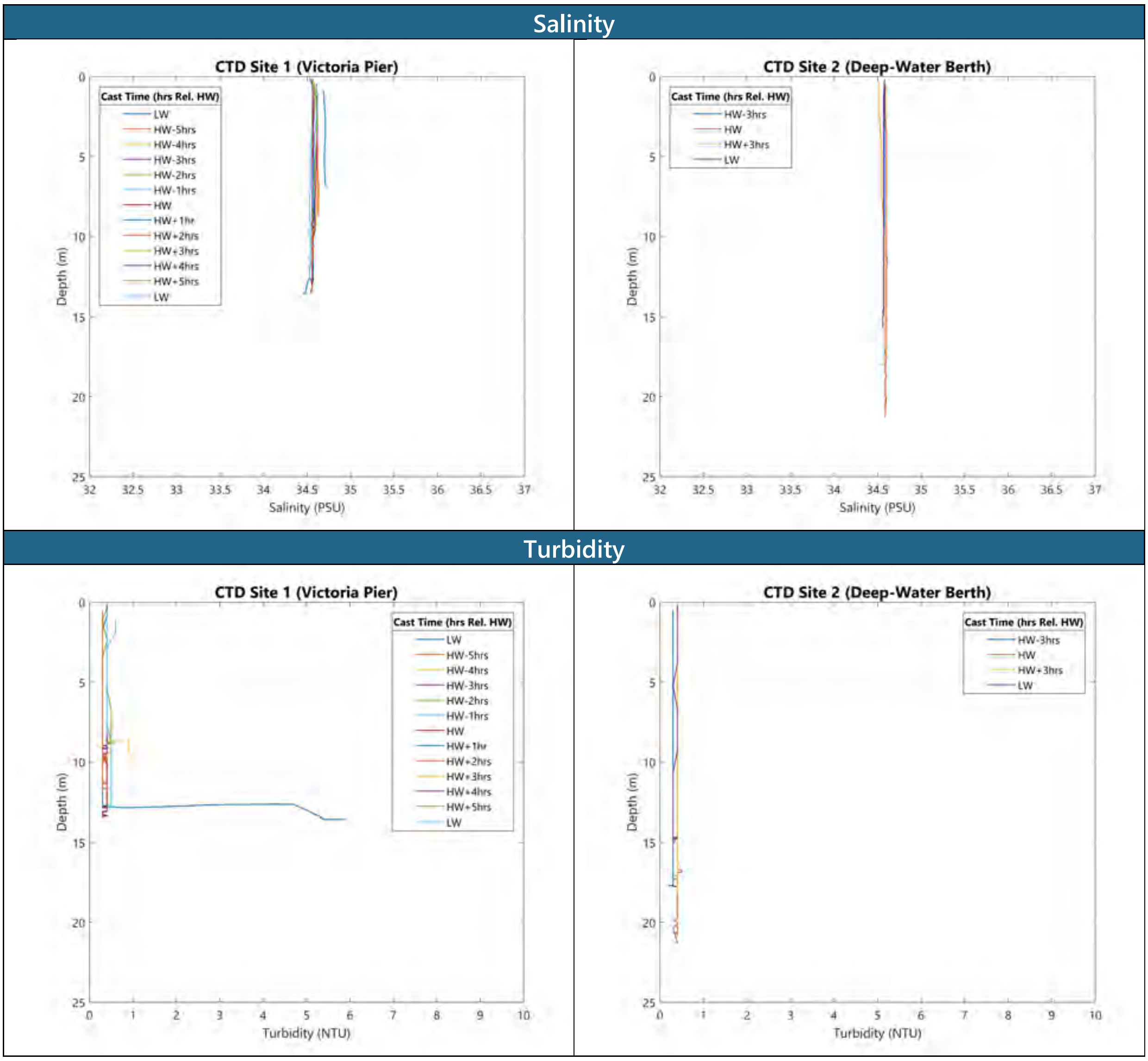


Figure 4. Vertical salinity (top) and turbidity (bottom) profiles collected during mobile ADCP

Offshore of Princess Alexandra Pier, the water column also remains well mixed at 34.5 PSU for the duration of the tidal cycle. Unlike at Victoria Pier, no variation in Salinity occurs around LW. Turbidity is uniform with depth and values remain below 1 NTU (Figure 4).

3.2.3 Water sampling and turbidity calibration

Total suspended solids (TSS) are measured by the filtration of water samples. TSS may therefore represent a range of conditions, from fine material in suspension to a small number of larger organic and inorganic solid particles (e.g. seaweed, algae, other small debris) in otherwise clear water.

Turbidity is measured by an optical backscatter sensor (OBS) device that makes indirect measurements of the opacity of the water via the backscatter intensity of particular colours (wavelengths) of light. Turbidity is therefore more sensitive to the concentration of finer material (e.g. clays, silts) in suspension.

TSS and turbidity are therefore potentially related. However, corresponding values for the same sample/location/time may deviate if the material in suspension is not predominantly fine in nature.

For both TSS and turbidity, values in the range 0-30 mg/l are relatively low in an absolute sense for the marine environment. Relative fluctuations within the range are close to the sensitivity of the sampling methodologies and the expected range of localised short-term natural variability.

TSS from water samples obtained at the locations of the static instrument packages are shown in Table 4. TSS at the near-seabed was higher than the mid-depth and near-surface, with the lowest concentrations seen at mid-depths.

Table 4. Water samples acquired during static instrument package deployments

Sample	Sample Date and Time (GMT)	Relative to HW (hr)	Depth (m)	Total Suspended Solids (mg/l)
Site 1 (Near-surface)	17/06/2019 11:38	HW	1	16.0
Site 1 (Mid-depth)	17/06/2019 11:42	HW	4	3.0
Site 1 (Near-seabed)	17/06/2019 11:50	HW	12	31.0
Site 2 (Near-surface)	18/06/2019 09:55	HW -2 hr	1	5.0
Site 2 (Mid-depth)	18/06/2019 10:00	HW -2 hr	10	2.1
Site 2 (Near-seabed)	18/06/2019 10:05	HW -2 hr	18	37.2

TSS from water samples collected at Site 1 during the mobile survey are shown in Table 5, with those collected at Site 2 shown in Table 6. TSS was generally higher and more variable at Site 1 when compared to Site 2.

Values at near-surface and mid-depths were also similar over the duration of a spring tidal cycle to that during the static deployments, but were slightly lower at near-bed depths with a maximum of *circa* 27.0 mg/l. The highest values were seen at near-seabed and mid-depth both at LW (26.2 mg/l and 26.7 mg/l) and HW (23.7 mg/l), respectively. No clear pattern can be established at any depth throughout the duration of the spring tidal cycle.

Table 5. Water samples collected at Site 1 (Victoria Pier) during mobile ADCP

Sample	Sample Date and Time (GMT)	Relative to HW (hr)	Depth (m)	Total Suspended Solids (mg/l)
WS1/1 (Near-surface)	19/06/2019 06:30	LW	1	26.2
WS1/1 (Mid-depth)	19/06/2019 06:33	LW	4	4.4
WS1/1 (Near-seabed)	19/06/2019 06:35	LW	8	4.8
WS1/2 (Near-surface)	19/06/2019 07:30	HW -5 hr	1	6.8
WS1/2 (Mid-depth)	19/06/2019 07:40	HW -5 hr	5	3.9
WS1/2 (Near-seabed)	19/06/2019 07:42	HW -5 hr	9	6.2
WS1/3 (Near-surface)	19/06/2019 08:30	HW -4 hr	1	3.1
WS1/3 (Mid-depth)	19/06/2019 08:32	HW -4 hr	5	5.6
WS1/3 (Near-seabed)	19/06/2019 08:36	HW -4 hr	9	3.8
WS1/4 (Near-surface)	19/06/2019 09:34	HW -3 hr	1	9.3
WS1/4 (Mid-depth)	19/06/2019 09:35	HW -3 hr	6	3.8
WS1/4 (Near-seabed)	19/06/2019 09:37	HW -3 hr	10	7.9
WS1/5 (Near-surface)	19/06/2019 10:30	HW -2 hr	1	5.5
WS1/5 (Mid-depth)	19/06/2019 10:32	HW -2 hr	6	3.1
WS1/5 (Near-seabed)	19/06/2019 10:34	HW -2 hr	12	0.8
WS1/6 (Near-surface)	19/06/2019 11:30	HW -1 hr	1	3.4
WS1/6 (Mid-depth)	19/06/2019 11:32	HW -1 hr	7	6.0
WS1/6 (Near-seabed)	19/06/2019 11:37	HW -1 hr	13	7.3
WS1/7 (Near-surface)	19/06/2019 12:39	HW	1	23.7
WS1/7 (Mid-depth)	19/06/2019 12:41	HW	7	7.4
WS1/7 (Near-seabed)	19/06/2019 12:43	HW	14	3.3
WS1/8 (Near-surface)	19/06/2019 13:31	HW +1 hr	1	5.5
WS1/8 (Mid-depth)	19/06/2019 13:34	HW +1 hr	7	7.2
WS1/8 (Near-seabed)	19/06/2019 13:37	HW +1 hr	13	0.4
WS1/9 (Near-surface)	19/06/2019 14:32	HW +2 hr	1	7.5
WS1/9 (Mid-depth)	19/06/2019 14:34	HW +2 hr	7	5.1
WS1/9 (Near-seabed)	19/06/2019 14:36	HW +2 hr	13	2.9
WS1/10 (Near-surface)	19/06/2019 15:31	HW +3 hr	1	4.5
WS1/10 (Mid-depth)	19/06/2019 15:33	HW +3 hr	5	7.9
WS1/10 (Near-seabed)	19/06/2019 15:35	HW +3 hr	10	9.6
WS1/11 (Near-surface)	19/06/2019 16:41	HW +4 hr	1	5.9
WS1/11 (Mid-depth)	19/06/2019 16:43	HW +4 hr	5	5.2
WS1/11 (Near-seabed)	19/06/2019 16:44	HW +4 hr	9	5.7
WS1/12 (Near-surface)	19/06/2019 17:30	HW +5 hr	1	5.1
WS1/12 (Mid-depth)	19/06/2019 17:32	HW +5 hr	5	4.5
WS1/12 (Near-seabed)	19/06/2019 17:34	HW +5 hr	9	7.6
WS1/13 (Near-surface)	19/06/2019 18:24	LW	1	14.8
WS1/13 (Mid-depth)	19/06/2019 18:26	LW	4	10.9
WS1/13 (Near-seabed)	19/06/2019 18:28	LW	8	26.7

Table 6. Water samples collected at Site 2 (Deep-Water Berth) during mobile ADCP

Sample	Sample Date and Time (GMT)	Relative to HW (hr)	Depth (m)	Total Suspended Solids (mg/l)
WS2/1 (Near-surface)	19/06/2019 09:43	HW -3 hr	1	7.2
WS2/1 (Mid-depth)	19/06/2019 09:46	HW -3 hr	9	6.1
WS2/1 (Near-seabed)	19/06/2019 09:48	HW -3 hr	18	4.4
WS2/2 (Near-surface)	19/06/2019 12:49	HW	1	2.2
WS2/2 (Mid-depth)	19/06/2019 12:50	HW	11	7.2
WS2/2 (Near-seabed)	19/06/2019 12:53	HW	22	7.1
WS2/3 (Near-surface)	19/06/2019 15:41	HW +3 hr	1	2.3
WS2/3 (Mid-depth)	19/06/2019 15:43	HW +3 hr	10	3.4
WS2/3 (Near-seabed)	19/06/2019 15:48	HW +3 hr	19	4.5
WS2/4 (Near-surface)	19/06/2019 18:34	LW	1	1.7
WS2/4 (Mid-depth)	19/06/2019 18:36	LW	8	5.0
WS2/4 (Near-seabed)	19/06/2019 18:38	LW	15	4.1

TSS values from the collected water samples have been plotted against observed Turbidity readings at both static instrument package locations for the corresponding time periods. These are shown in Figure 5 (top). Furthermore, TSS values are plotted against corresponding Turbidity readings for near-surface, mid-depth and near-seabed depths obtained from the vertical Turbidity profiles (summarised in Section 3.2.2) collected at both Site 1 and Site 2 during the mobile survey. These are shown in Figure 5 (bottom).

No clear increases in TSS can be seen relative to increases in Turbidity readings over the corresponding periods of water sampling conducted for either static instrument package deployments and individual vertical profiles collected during mobile ADCP. Values of Turbidity are very low (> 5 NTU), with all values less than 15 NTU.

In conclusion, no clear relationship is shown between the (usually higher) TSS from collected water samples and corresponding turbidity values. This suggests that:

- The measured TSS within the water samples reflects mainly the presence of larger organic material, sediment grains and/or other debris in otherwise clearer water;
- Any sediment being transported in suspension is likely to be coarser (i.e. sand or larger).

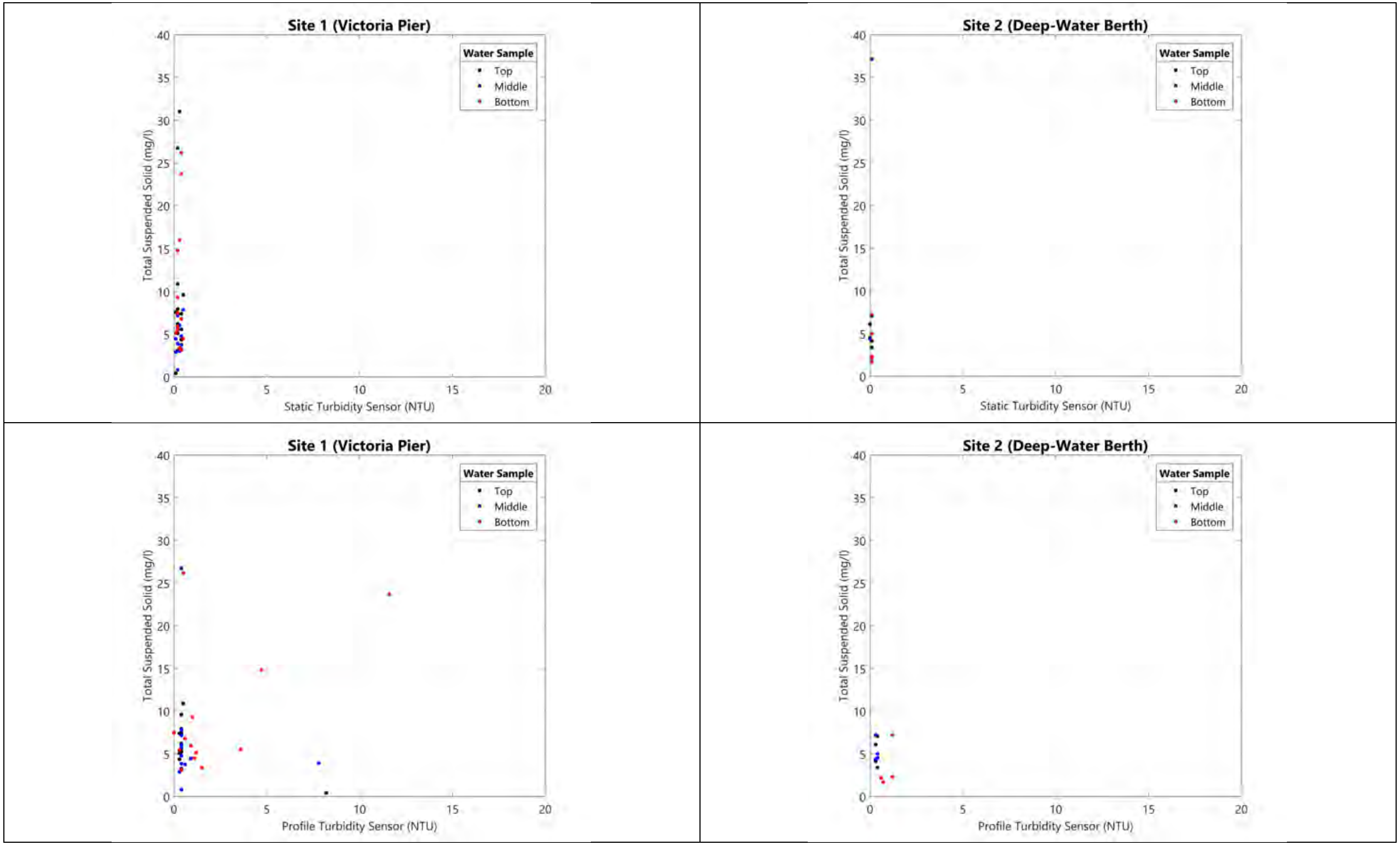


Figure 5. Static (top) and profile (bottom) turbidity observations plotted against water sample TSS

3.3 Seabed sampling

Statistics computed from PSA are shown in Table 7. The Median Grain Size (D_{50}) values of collected samples suggest that bed material consists of a mixture of sand (samples GS01, GS02, GS05 and GS10), mixed sand/gravel (GS03 and GS04) and gravel (samples GS06, GS07 and GS08). After three attempts, no sample was recovered at location GS09. Little (<5 %) or no mud fraction was seen at any site, suggesting a general lack of fine (silt and clay) material throughout the study area.

Table 7. Sediment description and computed statistics from laboratory PSA

Sample	Description*	D_{90} (µm)	Median Grain Size D_{50} (µm)	D_{10} (µm)	Fraction (%)		
					Gravel	Sand	Mud
GS01	Slightly Gravelly Sand	294	201	134	0.0	100.0	0.0
GS02	Sand	291	196	128	0.0	100.0	0.0
GS03	Gravelly Sand	22384	208	125	14.5	85.5	0.0
GS04	Gravelly Sand	413	197	112	7.7	89.3	3.0
GS05	Slightly Gravelly Sand	327	190	112	1.9	97.6	0.5
GS06	Gravel	26233	18725	3740	95.8	4.0	0.2
GS07	Sandy Gravel	21402	9655	185	68.1	31.9	0.0
GS08	Gravel	21473	10511	3472	99.6	0.4	0.0
GS09	-	-	-	-	-	-	-
GS10	Slightly Gravelly Sand	568	333	192	0.0	100.0	0.0

* Description based on Wentworth (1922)

Screenshots from video footage collected by the IoM divers during recovery of the static instruments (shown in Figure 6) also provide further information on the properties of the bed material in these areas.

Figure 6. Screenshots from IoM diver cameras during static instrument recovery at Site 1 (Left) and Site 2 (Right)

In general, the material at Site 1 appears to be sandy material to that at Site 2 which appears to consist of a consolidated mixed gravel and shell bed. This concurs with the properties of collected grab samples (Table 7) in relation to their respective locations (Figure 1).

3.4 Additional notes

3.4.1 Weather conditions

It was initially intended to deploy both static instrument packages on 17 June 2019. Wind speeds and wave heights on the day were deemed unsuitable to safely deploy at Site 2 following discussions with the dive deployment team onboard *Kesh Varrey*; estimated between Force 3-4 (Beaufort Scale) and wave conditions around 1 m. Deployment at Site 2 was therefore delayed until 18 June 2019 when conditions had improved. However, Site 1 was sheltered and generally unaffected and therefore deployment was conducted as planned.

During the mobile survey on 19 June 2019 wind speeds were Force 1-2. Visibility was good and sea state was calm, building to smooth throughout the day.

Throughout the record of the deployed static instrument packages, wind speeds were generally between Force 1 and Force 5, with peaks on 01 July (Force 6) and 13 July (Force 7). See Figure 9 and Figure 13. Wind direction during these two events were either westerly or north westerly. During three identified peak wave events between 24 June and 27 June, wind speeds were around Force 5 and of easterly and north-easterly directions.

Wind speeds upon recovery of the static instrument packages on 19 July were Force 1-2, visibility moderate and sea state slight.

3.4.2 Vessel traffic during the mobile surveys

Douglas Harbour Control apply a ten-minute curfew on all vessel movements entering and exiting the Harbour whilst passenger vessels *Manannan* and *Ben-my-Chree* (Figure 7) are manoeuvring in the Harbour approaches and berthing within the Harbour itself.

Figure 7. Passenger vessels Manannan (left) and Ben-my-Chree (right) entering Douglas Harbour

This resulted in the delay of some ADCP Transect legs during the mobile survey, whilst the curfew was in force and until subsequent turbulence throughout the water column had dissipated sufficiently. These periods were observed on 19 June 2019 at:

- 05:44 GMT - *Manannan* exiting Douglas Harbour;
- 09:16 GMT - *Ben-my-Chree* exiting Douglas Harbour;
- 12:15 GMT - *Manannan* entering Douglas Harbour;
- 13:55 GMT - *Manannan* exiting Douglas Harbour; and
- 16:15 GMT - *Ben-my-Chree* entering Douglas Harbour.

Traffic of smaller commercial vessels (fishing boats, military patrol boats and Douglas Lifeboat) were also observed throughout the mobile survey, resulting in small (<5 minute) delays. These were not deemed to significantly affect results of collected data.

3.4.3 Seabed sampling

A seabed sample could not be obtained at Site 9 following a total of three unsuccessful grab attempts. I It is considered that the seabed type is not likely to be significantly different at this site compared to others in the Harbour area that were collected successfully.

4 References

ABPmer (2019a). Proposed Deep-Water Berth, Douglas Harbour - Sediment and Navigation Studies: Main Study Report, ABPmer Report No. R.3270 A report for Isle of Man Government – Department of Infrastructure, 2019.

ABPmer (2019b). Proposed Deep-Water Berth, Douglas Harbour - Sediment and Navigation Studies: Numerical Model Calibration, ABPmer Report No. R.3272. A report for Isle of Man Government – Department of Infrastructure, 2019.

Wentworth, C.K. (1922). A scale of grade and class terms for clastic sediments. Journal of Geology. 30. 377-392.

5 Abbreviations/Acronyms

3D	Three-Dimension(al)
ADCP	Acoustic Doppler Current Profiling
AWAC	Acoustic Wave and Current
CD	Chart Datum
CTD	Conductivity/Temperature/Depth
D/A	Depth-Averaged
D_{50}	Median Grain Size
DAS	Data Acquisition Software
DirTp	Peak Wave Direction
DPS	Data Processing Software
GIS	Geographic Information System
GMT	Greenwich Mean Time
Hm0	Significant Wave Height
Hmax	Maximum Wave Height
HW	High Water
Hz	Hertz
ID	Identity
IoM	Isle of Man
LW	Low Water
mAB	metres Above Bed
mCD	metres relative to Chart Datum
mDir	Mean Wave Direction
meanDir	Mean Direction
mMSL	metres relative to Mean Sea Level
ms	metres per Second
MHz	Megahertz
MSL	Mean Sea Level
NTU	Nephelometric Turbidity Units
OBS	Optical Backscatter
OSGB36	Ordnance Survey Great Britain (1936)
OSTN15	Ordnance Survey Definitive Transformation (2015)
PSA	Particle Size Analysis
PSU	Practical Salinity Units
QA	Quality Assurance
SN	Serial Number
SSC	Suspended Sediment Concentration
Tp	Peak Wave Period
TSS	Total Suspended Solid
TU	Turbidity
Tz	Mean Wave Period
UKHO	UK Hydrographic Office
WGS84	World Geodetic System (1984)

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Figures





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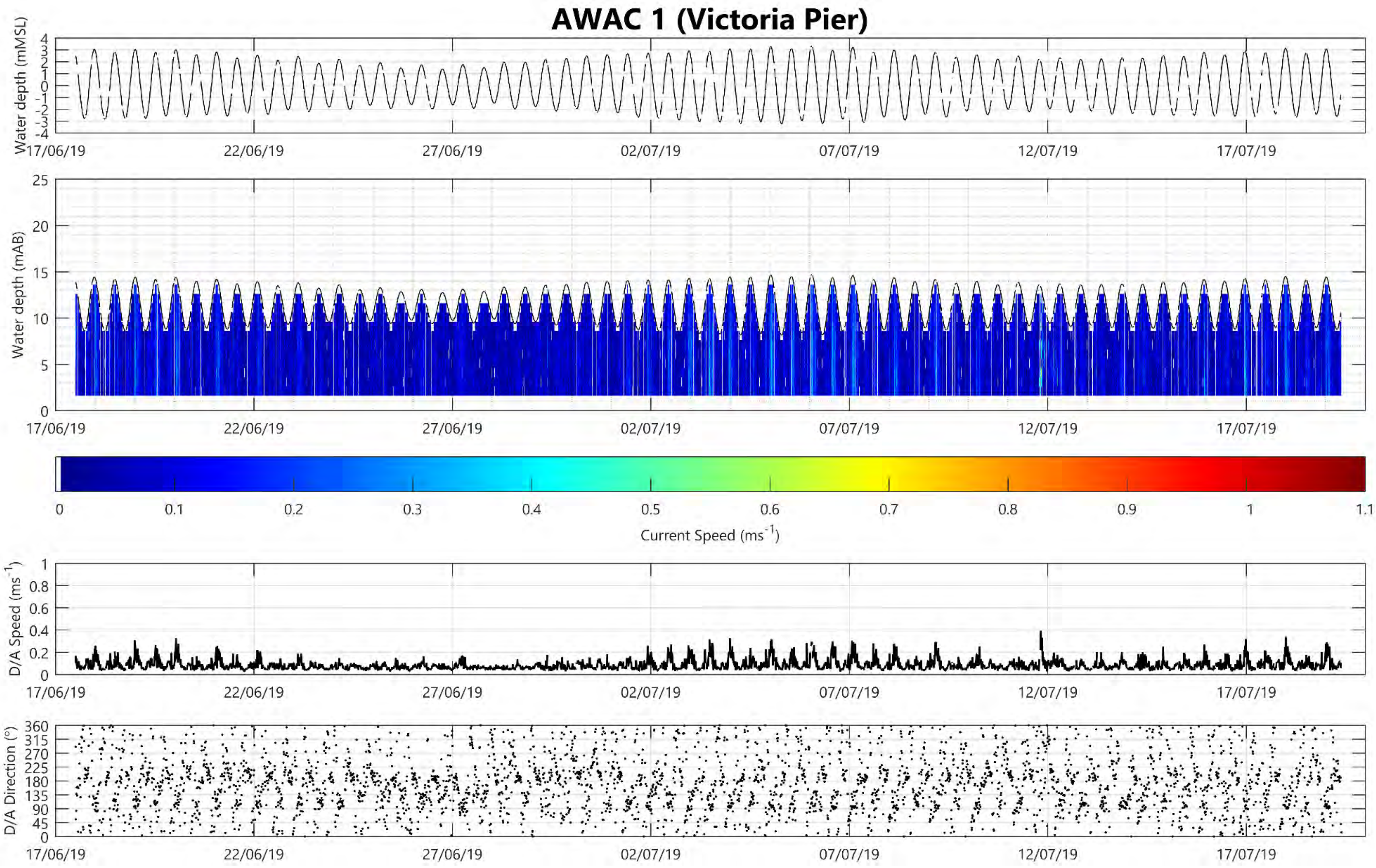


Figure 8. **AWAC 1 (Victoria Pier) depth average (D/A) current speed and direction**

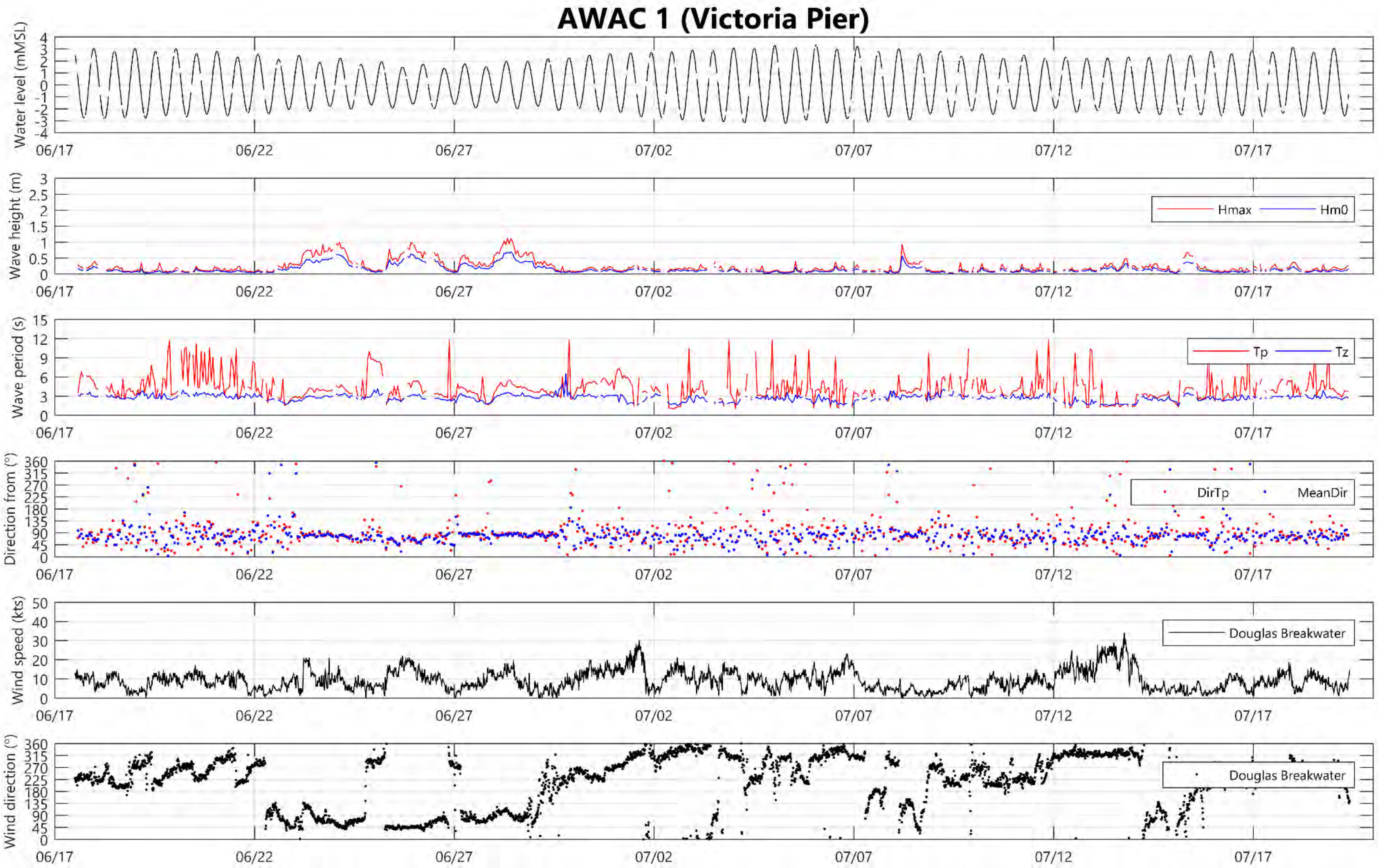


Figure 9. AWAC 1 (Victoria Pier) coincident water level, wave and wind parameters

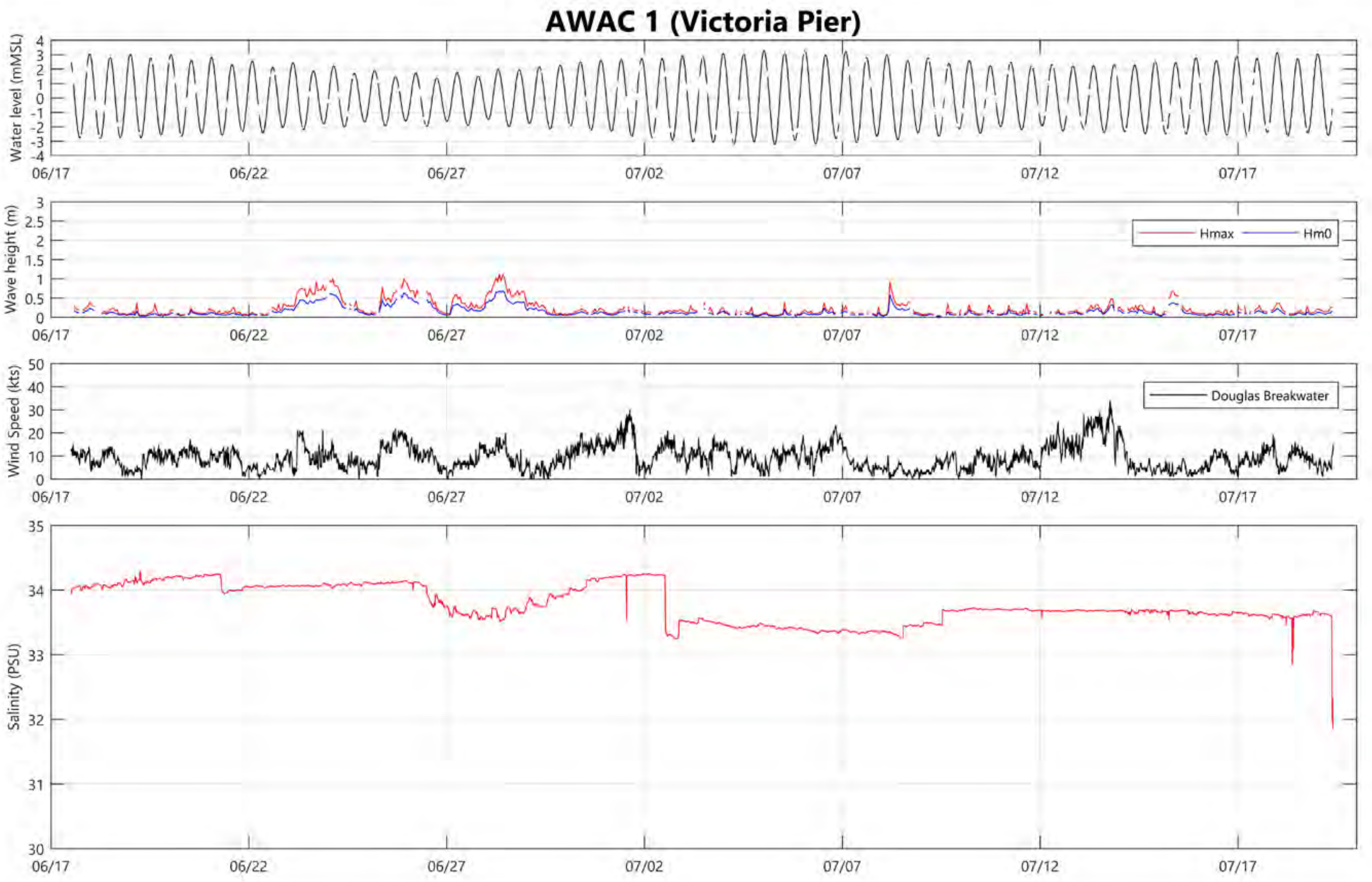


Figure 10. AWAC 1 (Victoria Pier) coincident water level, wave height, wind speed and salinity

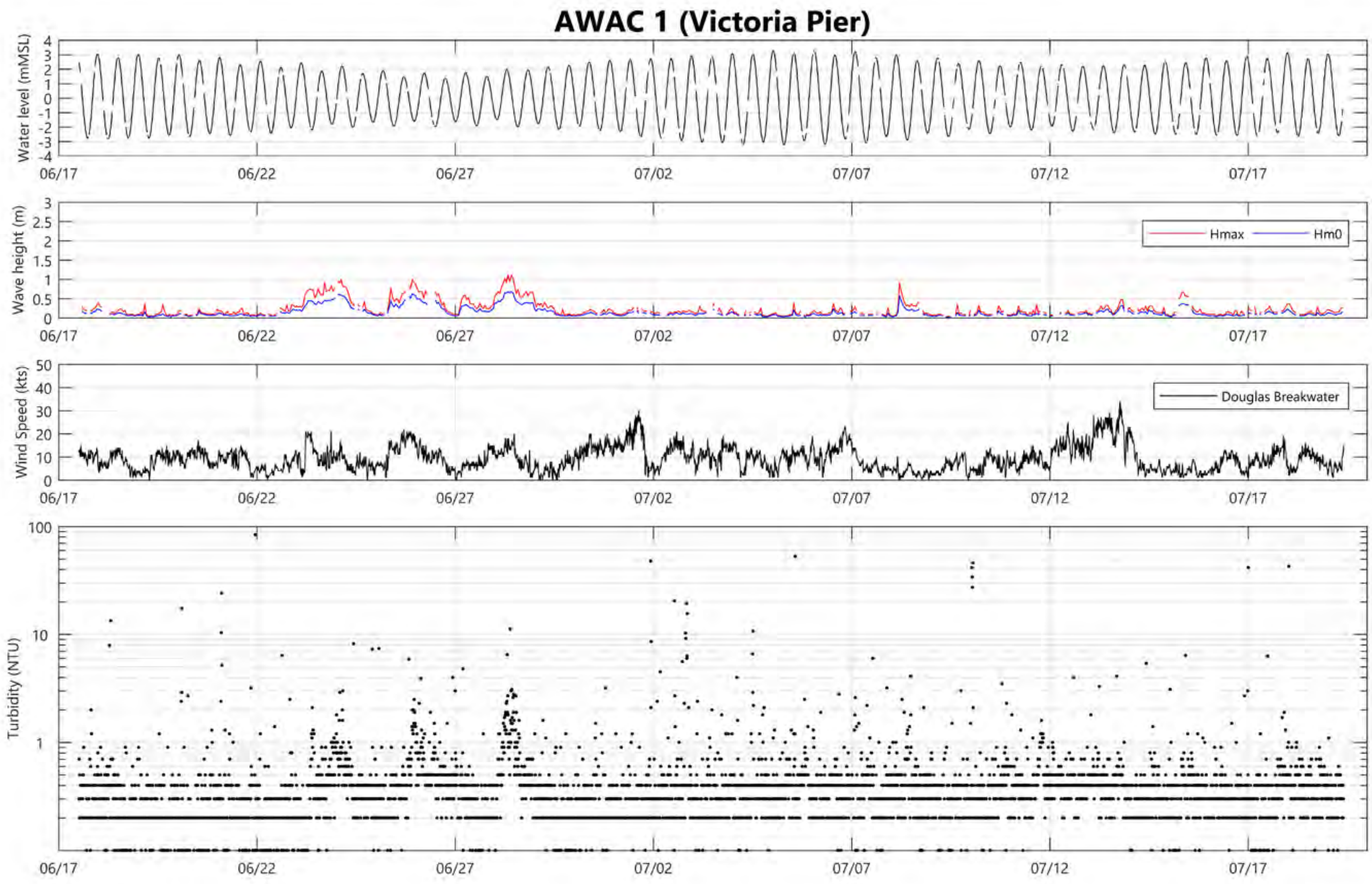


Figure 11. **AWAC 1 (Victoria Pier) coincident water level, wave height, wind speed and turbidity**

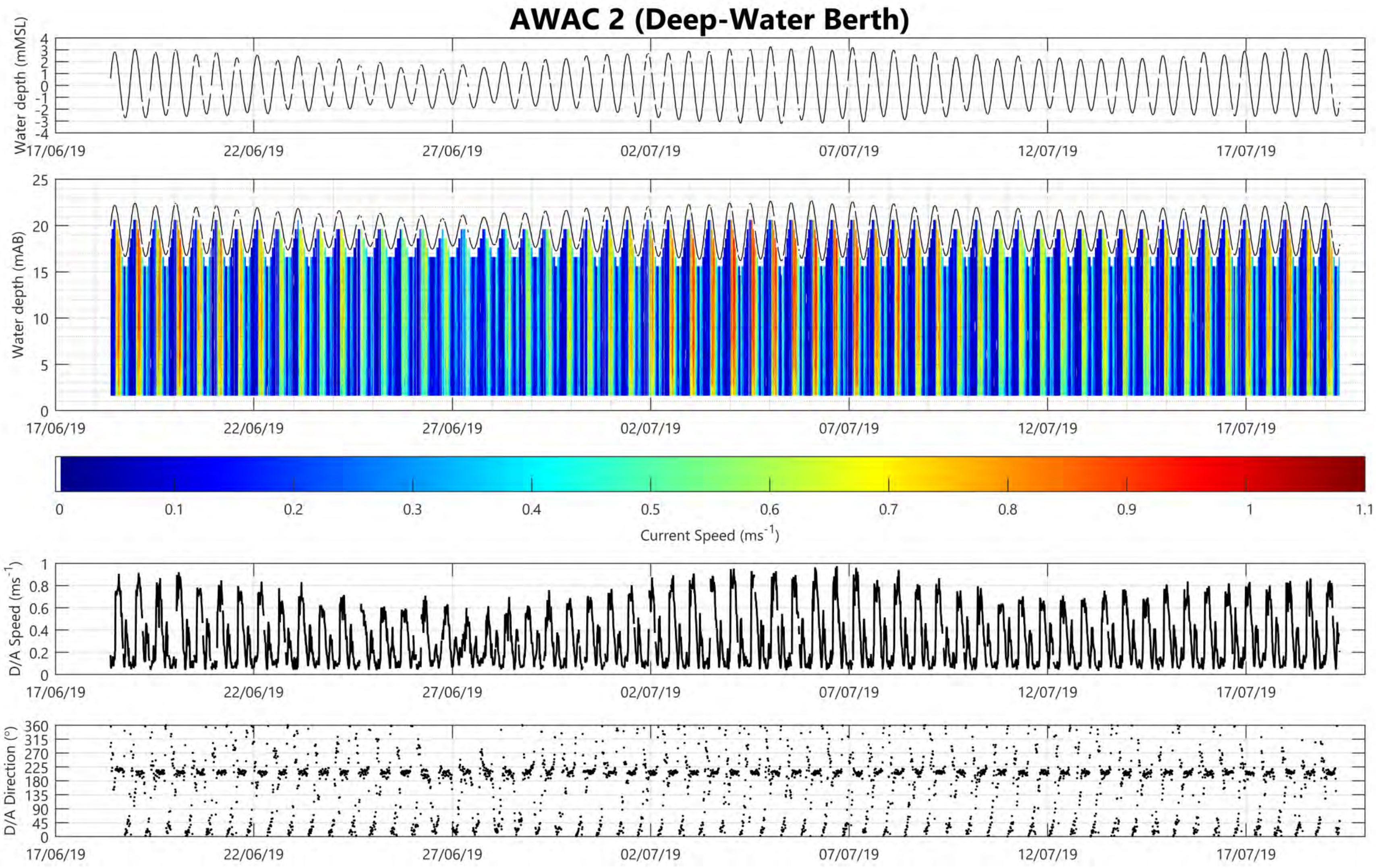


Figure 12. **AWAC 2 (Deep-Water Berth) depth average (D/A) current speed and direction**

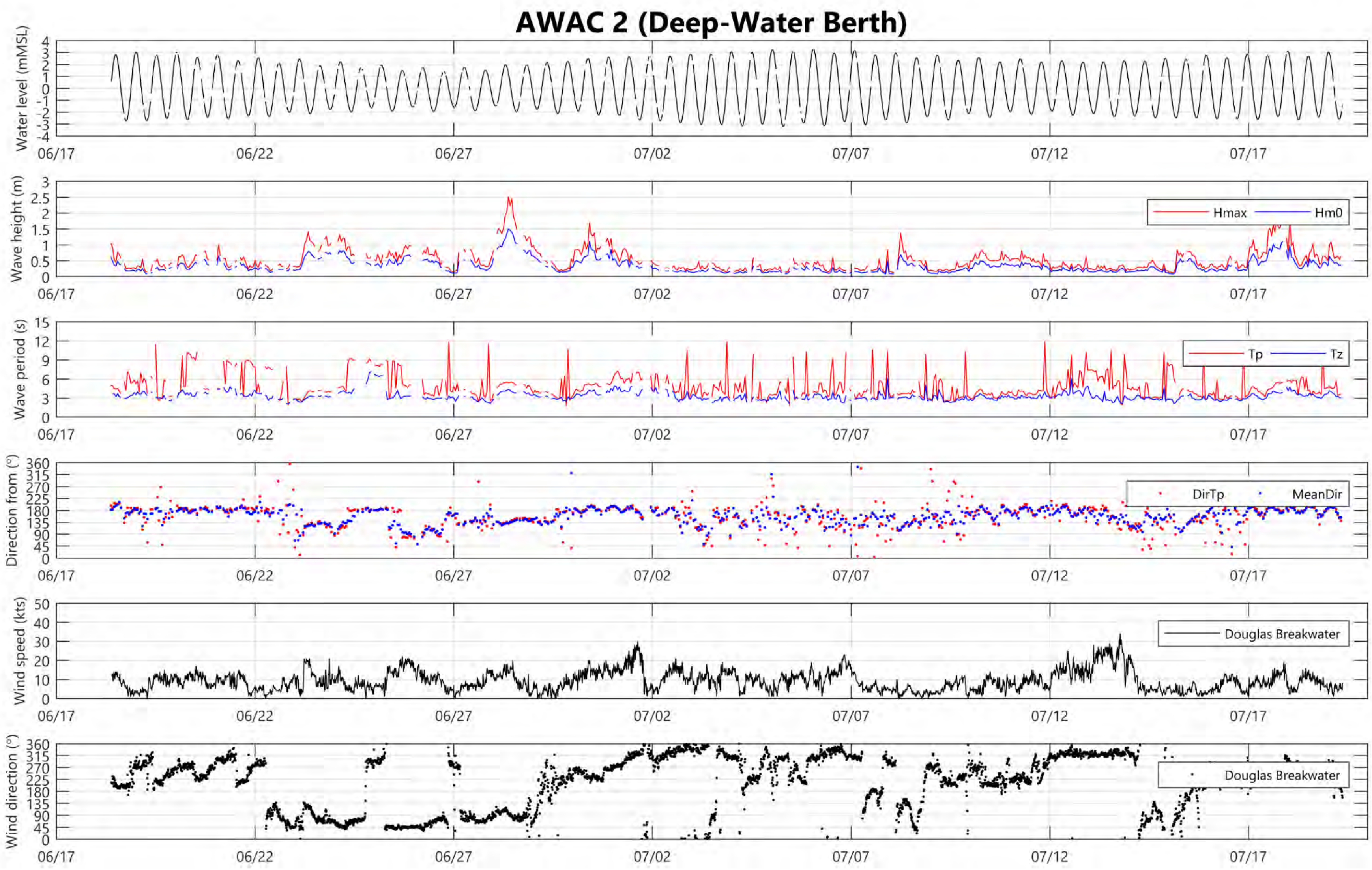


Figure 13. **AWAC 2 (Deep-Water Berth) coincident water level, wave and wind parameters**

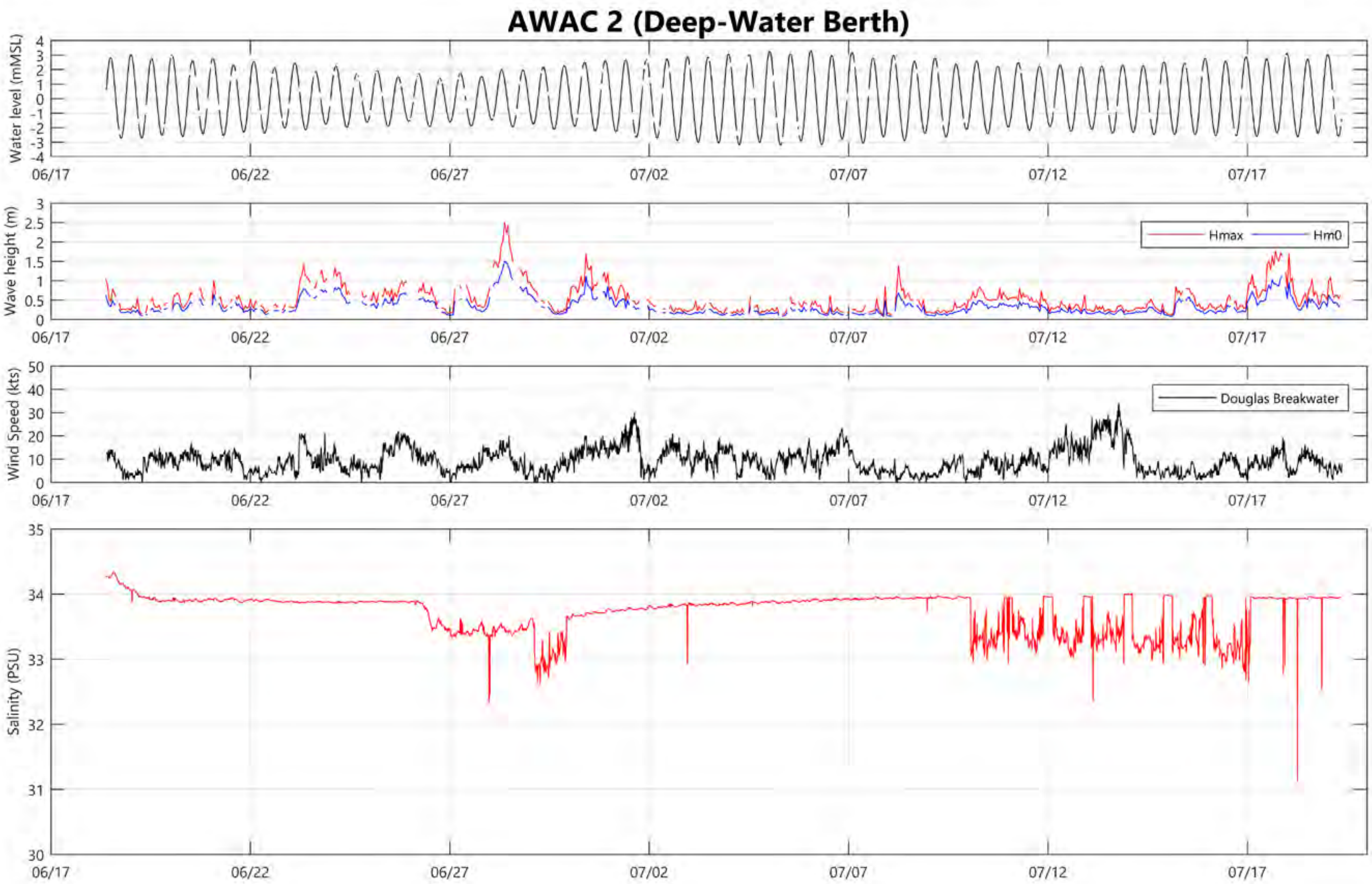


Figure 14. AWAC 2 (Deep-Water Berth) coincident water level, wave height, wind speed and salinity

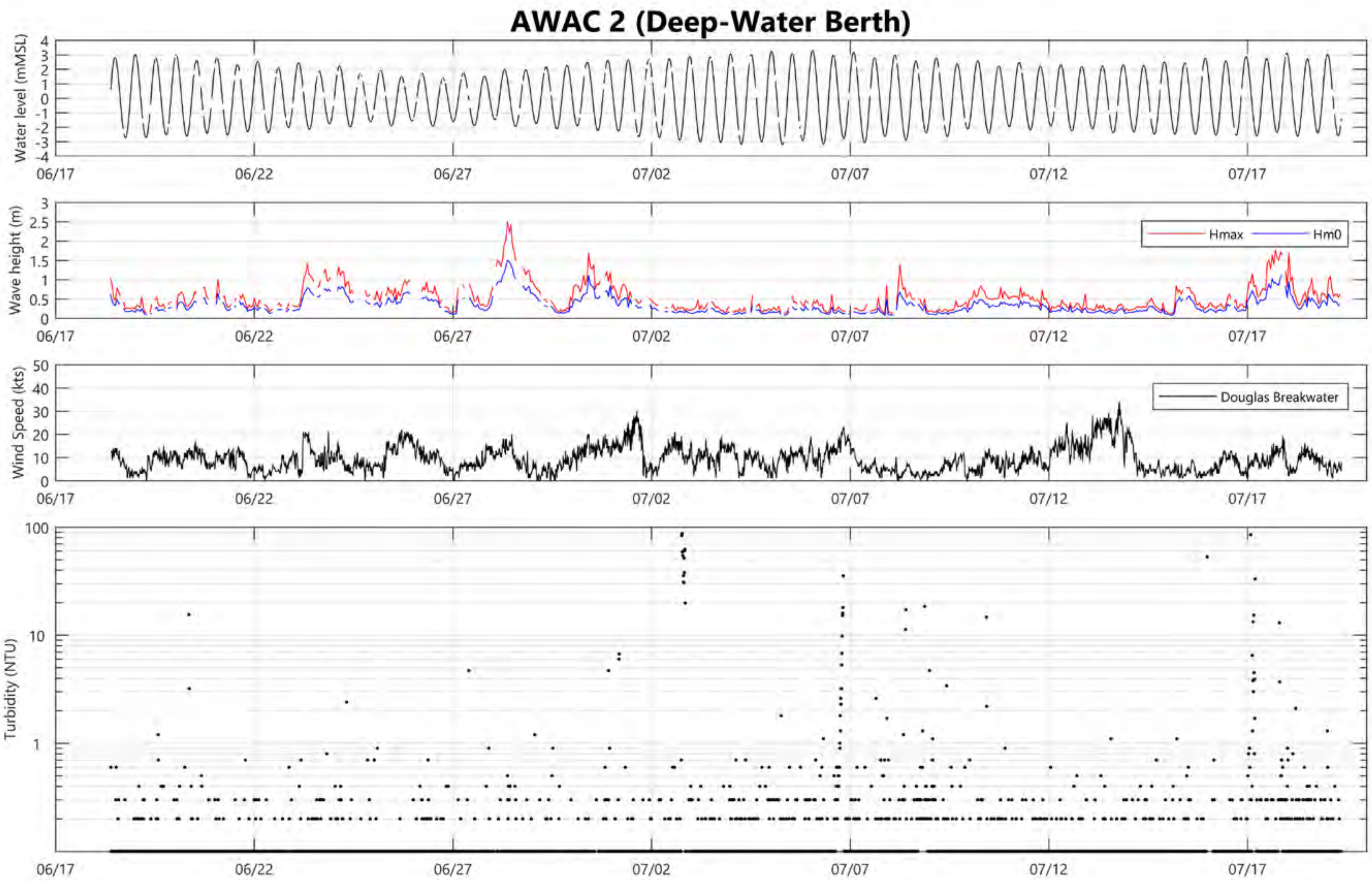


Figure 15. **AWAC 2 (Deep-Water Berth) coincident water level, wave height, wind speed and turbidity**

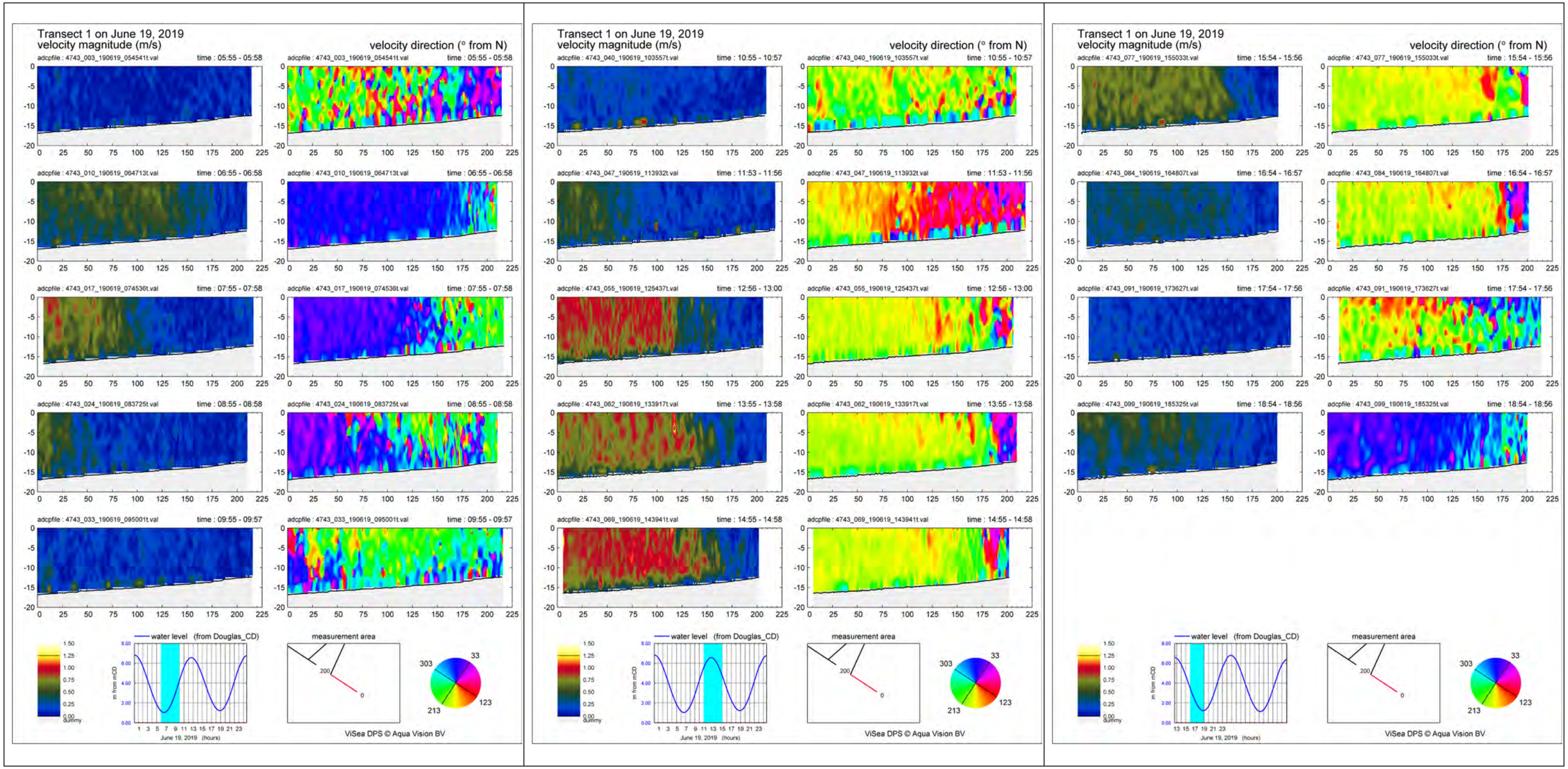


Figure 16. ADCP Transect 1 current speed and direction

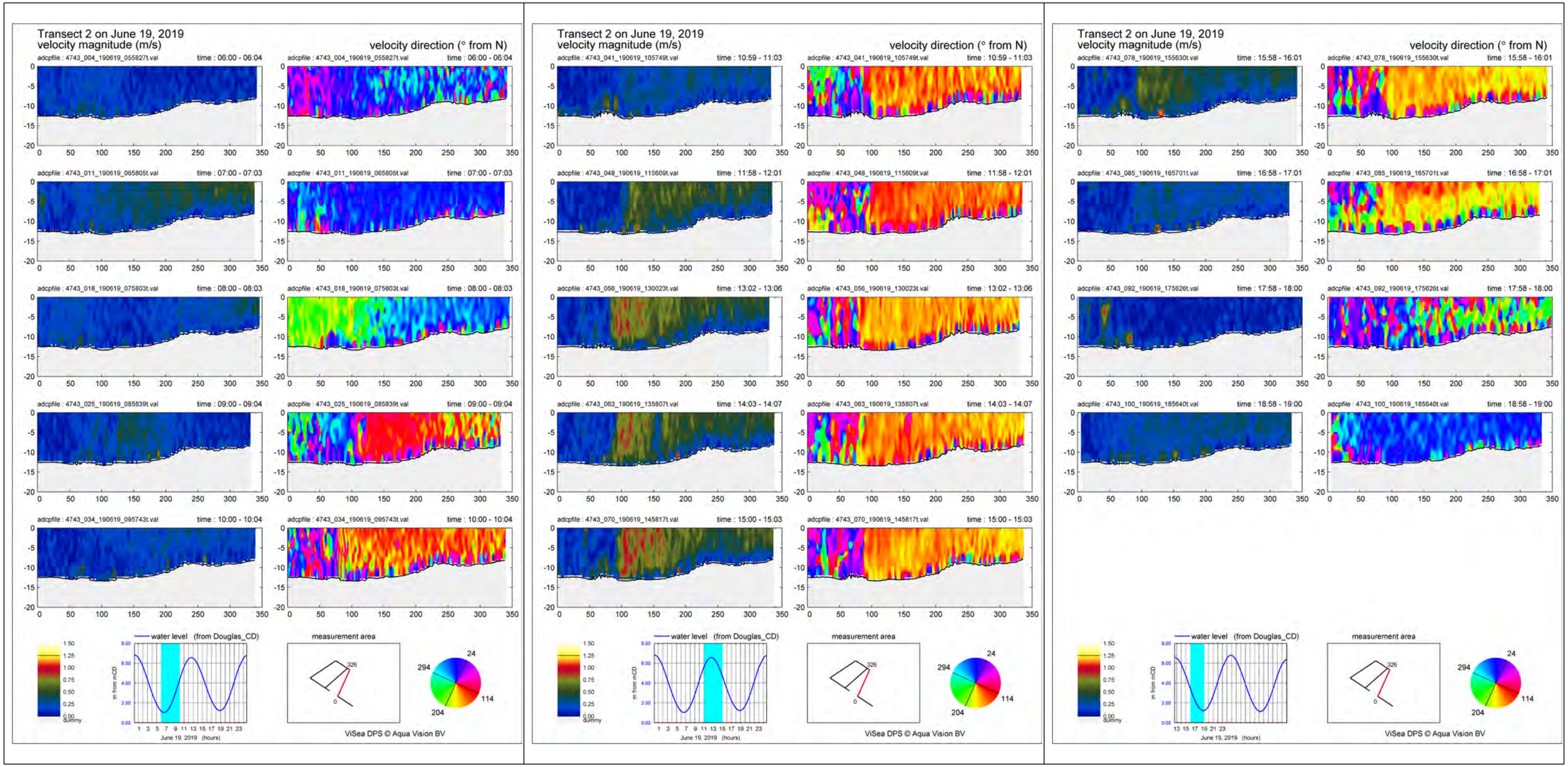


Figure 17. ADCP Transect 2 current speed and direction

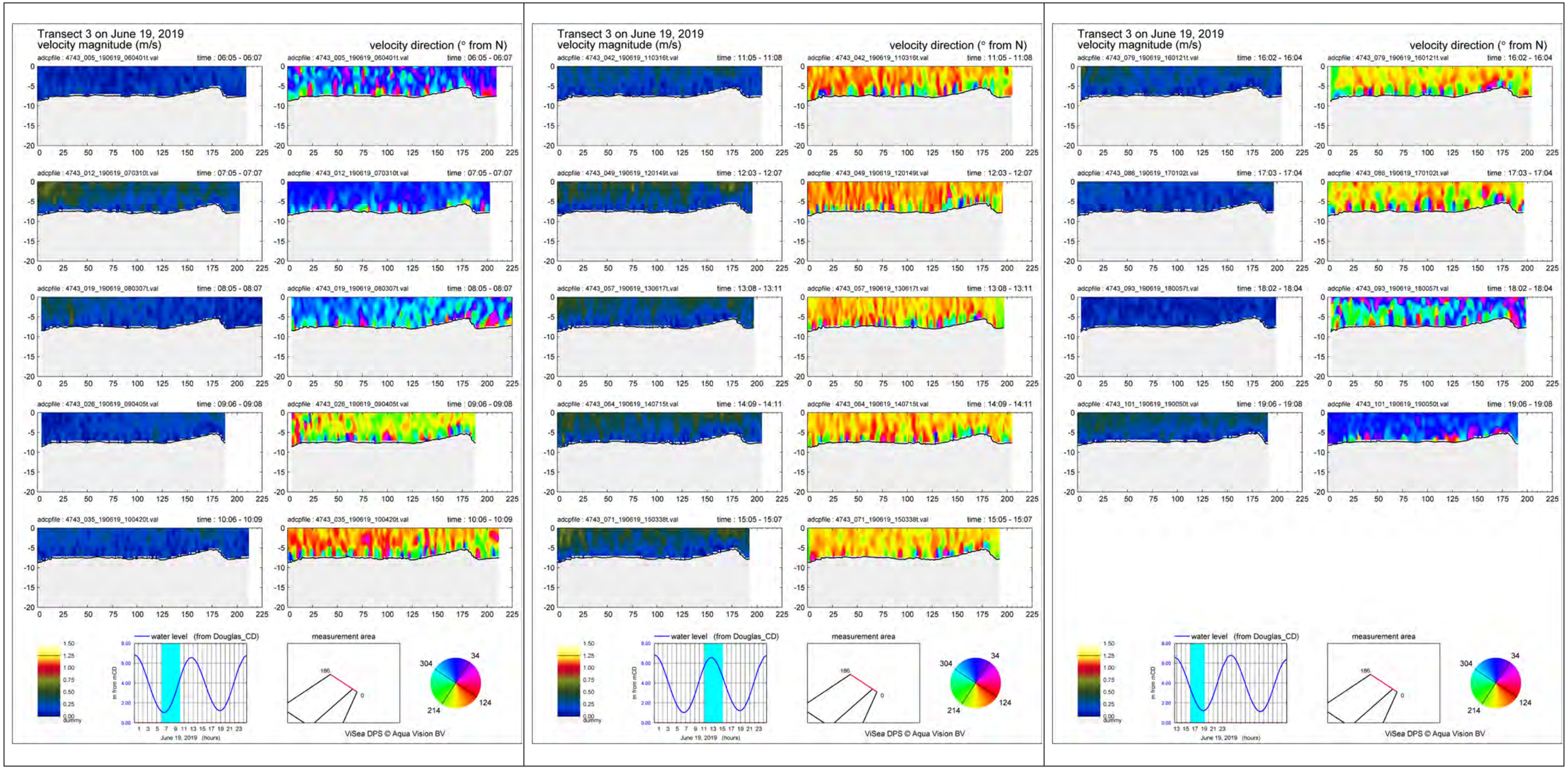


Figure 18. ADCP Transect 3 current speed and direction

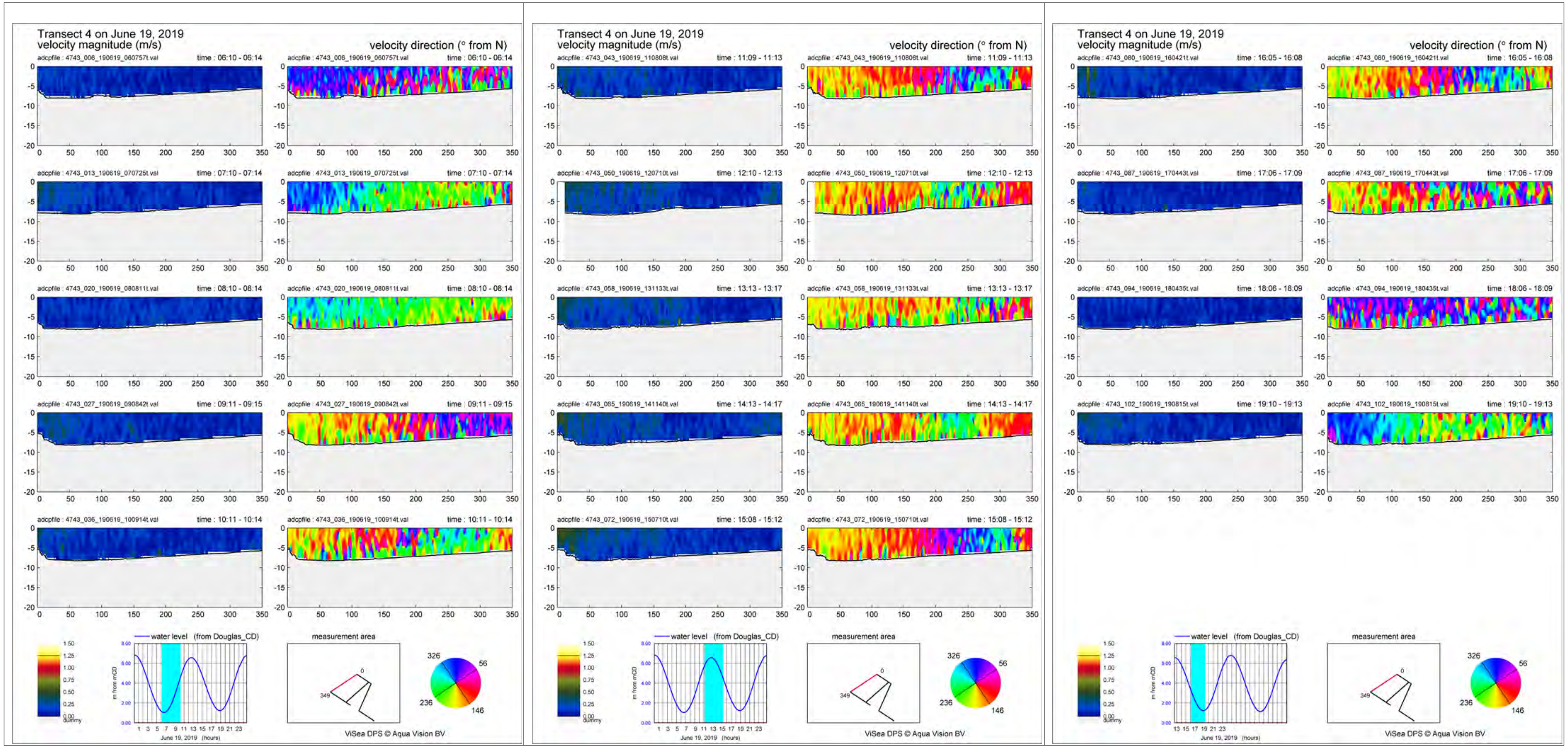


Figure 19. **ADCP Transect 4 current speed and direction**

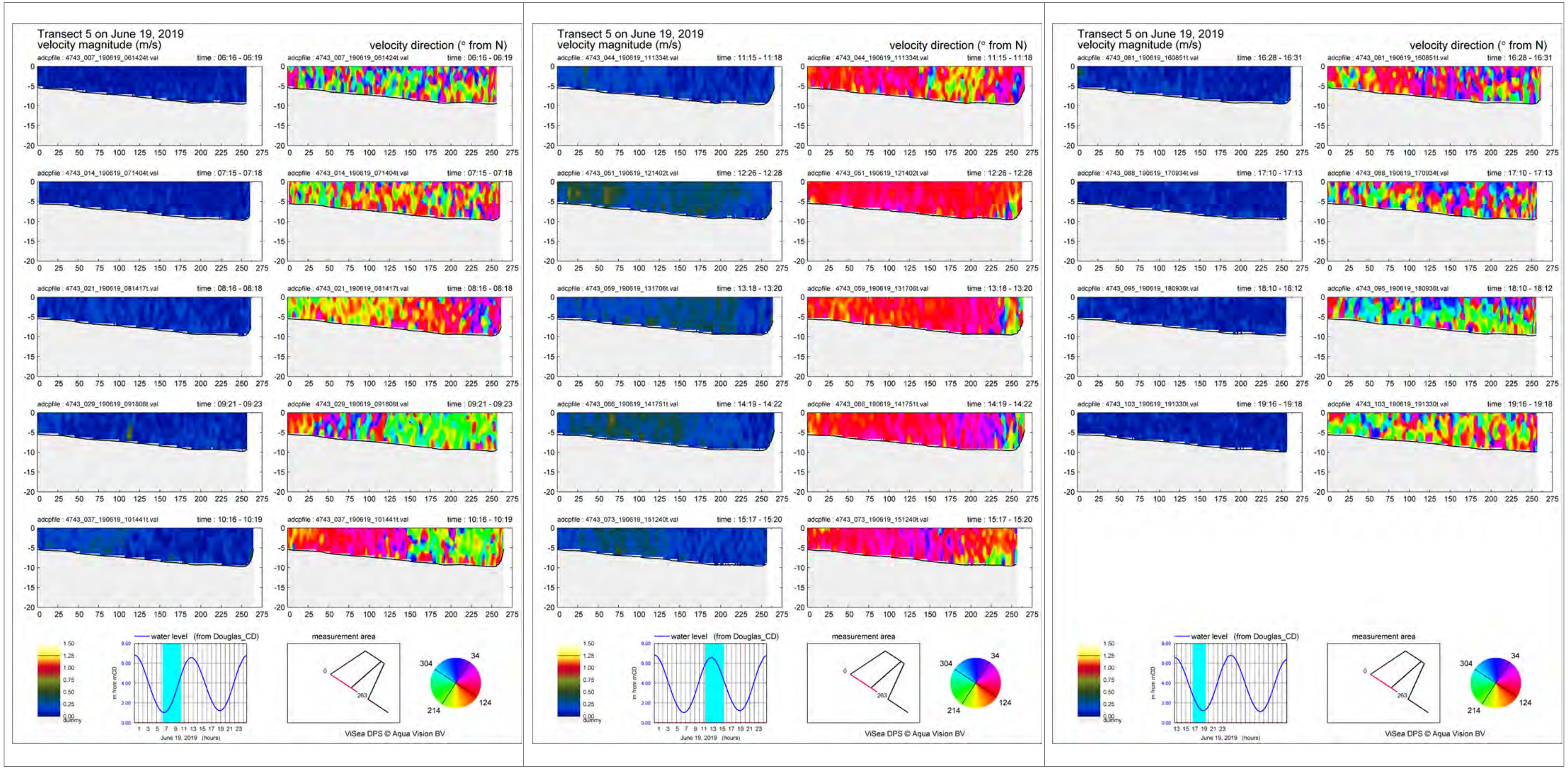


Figure 20. ADCP Transect 5 current speed and direction

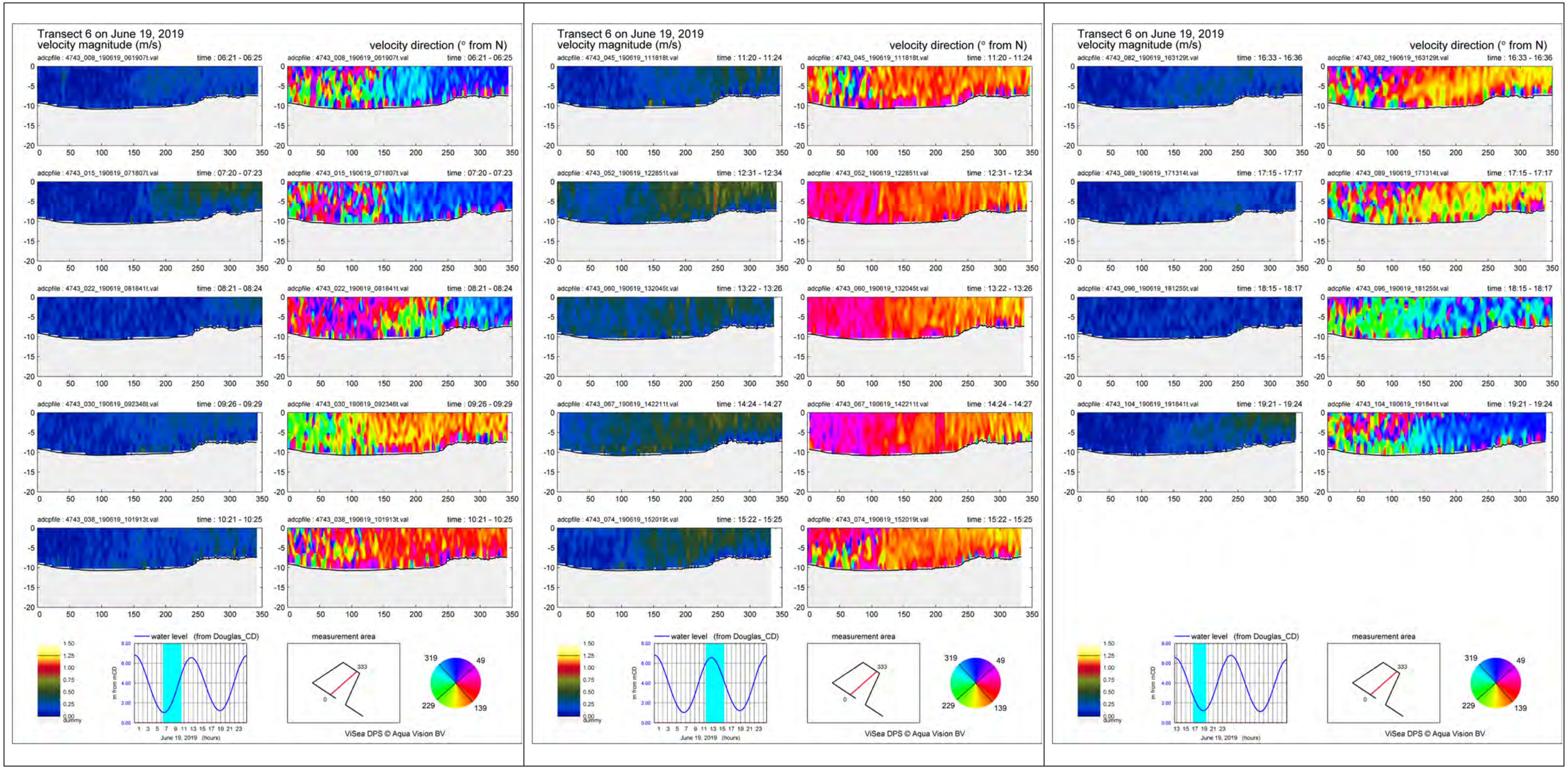


Figure 21. ADCP Transect 6 current speed and direction

Appendices





Innovative Thinking - Sustainable Solutions

ABP mer

A Instrument Specifications

- Nortec - AWAC - 1 MHz
- Teledyne RD Instruments - Workhorse Sentinel
- YSI Environmental - YSI 6600 V2 Sonde

ACOUSTIC WAVE AND CURRENT PROFILER

AWAC - 1 MHz

Real-time current profiles and directional waves for shallow water

The AWAC 1 MHz ADCP has become the standard reference technology in submerged wave-measurement applications. Thousands of these ADCPs have been deployed to capture the full wave spectrum in combination with current profiles. With a 35 m maximum range for wave measurements and 4 Hz sampling of the surface elevation, the AWAC 1 MHz is the optimal tool for shallow current and wave measurements.

ACOUSTIC WAVE AND CURRENT PROFILER

AWAC - 1 MHz

NORTEK

Highlights

- Real-time current profiles to 30 m range
- Real-time directional waves to 35 m range
- Acoustic surface tracking (AST) with vertical beam
- Can be used both with fixed frames and subsurface buoys

Applications

- Online measurements of currents and waves
- Design data for planning of new coastal structures
- Site studies for offshore wind platforms
- Coastal erosion studies
- Measurement campaigns where the full wave spectrum is needed
- Monitoring of transient waves for channel wall protection
- Studies of tidal currents

ACOUSTIC WAVE AND CURRENT PROFILER

AWAC - 1 MHz

NORTEK

Technical specifications

→ Water velocity measurements	
Maximum profiling range	30 m
Cell size	0.25-4.0 m
Number of cells	Typical 20-40, max. 128
Velocity range	±10 m/s horizontal, ±5 m/s along beam
Accuracy	±1% of measured value ±0.5 cm/s
Velocity precision	Consult instrument software
Maximum output rate	1 Hz
Internal sampling rate	7 Hz
→ Echo intensity (along slanted beams)	
Sampling	Same as velocity
Resolution	0.45 dB
Dynamic range	90 dB
Transducer acoustic frequency	1 MHz
Number of beams	3 beams 120° apart, one vertical beam (90° apart, one at 5° for platform mount)
Beam width	1.7°
Beam width vertical beam	1.7°
→ Wave measurement option (AST)	
Maximum depth	35 m
Data types	Pressure, one velocity along each beam, AST
Sampling rate velocity (output)	2 Hz
Sampling rate AST (output)	4 Hz
No. of samples per burst	512, 1024 or 2048

Teledyne RD Instruments

Workhorse Sentinel

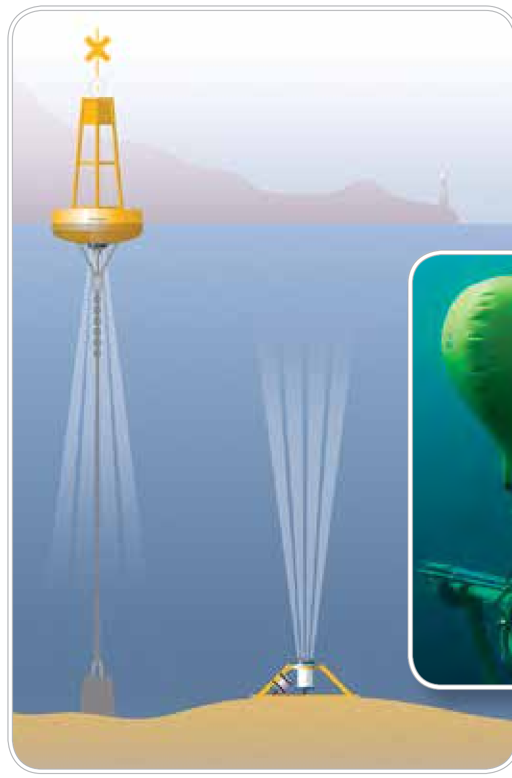
Self-Contained 1200, 600, 300kHz ADCP

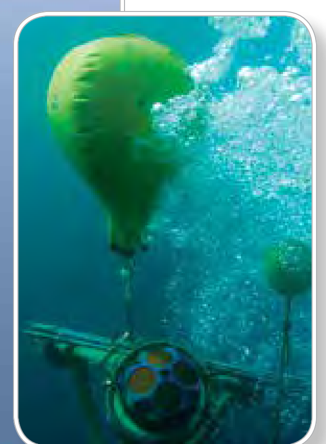
The Industry Standard for High Accuracy Data Collection

The self-contained SENTINEL is Teledyne RD Instruments' most popular and versatile Acoustic Doppler Current Profiler (ADCP) configuration, boasting thousands of units in operation in over 50 countries around the world.

By providing profiling ranges from 1 to 154m, the high-frequency Sentinel ADCP is ideally suited for a wide variety of applications. Thanks to Teledyne RDI's Broadband signal processing, the Sentinel also offers unbeatable precision, with unmatched low power consumption, allowing you to collect more data over an extended period.

The lightweight and adaptable Sentinel is easily deployed on buoys, boats, or mounted on the seafloor. Real-time data can be transmitted to shore via a cable link or acoustic modem, or data can be stored internally for short or long-term deployments. The Sentinel is easily upgraded to include pressure, bottom tracking, and/or directional wave measurement—for the ultimate data collection solution.





PRODUCT FEATURES

- **Versatility:** Direct reading or self contained, moored or moving, the Sentinel provides precision current profiling data when and where you need it most.
- **A solid upgrade path:** The Sentinel has been designed to grow with your needs. Easy upgrades include pressure, bottom tracking, and directional wave measurement.
- **Precision data:** Teledyne RDI's BroadBand signal processing delivers very low-noise data, resulting in unparalleled data resolution and minimal power consumption.
- **A four-beam solution:** Teledyne RDI's 4-beam design improves data reliability by providing a redundant data source in the case of a blocked or damaged beam; improves data quality by delivering an independent measure known as error velocity; and improves data accuracy by reducing variance in your data.

Workhorse Sentinel

Self-Contained 1200, 600, 300 kHz ADCP

TECHNICAL SPECIFICATIONS

Water Profiling	Depth Cell Size[1]	Typical Range[2] 12m **1200kHz**		Typical Range[2] 50m **600kHz**		Typical Range[2] 110m **300kHz**	
	Vertical Resolution	Range[3]	Std. Dev.[4]	Range[3]	Std. Dev.[4]	Range[3]	Std. Dev.[4]
	0.25m	11m	14.0cm/s				
	0.5m	12m	7.0cm/s	38m	14.0cm/s	see note 1	
	1m	13m	3.6cm/s	42m	7.0cm/s	83m	14.0cm/s
	2m	15m[2]	1.8cm/s	46m	3.6cm/s	93m	7.0cm/s
	4m	see note [1]		51m[2]	1.8cm/s	103m	3.6cm/s
	8m					116m[2]	1.8cm/s
Long Range Mode	2m	19m	3.4m/s				
	4m			66m	3.6cm/s		
	8m					154m	3.7cm/s

		1200kHz	600kHz	300kHz
Profile Parameters	Velocity accuracy	0.3% of the water velocity relative to ADCP ±0.3cm/s	0.3% of the water velocity relative to ADCP ±0.3cm/s	0.5% of the water velocity relative to ADCP ±0.5cm/s
	Velocity resolution	0.1cm/s	0.1cm/s	0.1cm/s
	Velocity range:	±5m/s (default) ±20m/s (max)	±5m/s (default) ±20m/s (max)	±5m/s (default) ±20m/s (max)
	Number of depth cells	1–255	1–255	1–255
	Ping rate	Up to 10Hz	Up to 10Hz	Up to 10Hz

Echo Intensity Profile	Vertical resolution	Depth cell size, user configurable
	Dynamic range	80dB
	Precision	±1.5dB
Transducer and Hardware	Beam angle	20°
	Configuration	4-beam, convex
	Internal memory	Two PCMCIA card slots; one memory card included
	Communications	RS-232 or RS-422; ASCII or binary output at 1200-115,200 baud
Power	DC input	20–50VDC.
	Number of batteries	1 internal battery pack
	Internal battery voltage	42VDC (new) 28VDC (depleted)
	Battery capacity @ 0°C	450 watt hrs
Standard Sensors	Temperature (mounted on transducer)	Range -5° to 45°C, Precision ±0.4°C, Resolution 0.01°
	Tilt	Range ±15°, Accuracy ±0.5°, Precision ±0.5°, Resolution 0.01°
	Compass (fluxgate type, includes built-in field calibration feature)	Accuracy ±2°[5], Precision ±0.5°[5], Resolution 0.01°, Maximum tilt ±15°
Environmental	Standard depth rating	200m; optional to 500m, 1000m, 6000m
	Operating temperature	-5° to 45°C
	Storage temperature (without batteries)	-30° to 60°C
	Weight in air	13.0kg
	Weight in water	4.5kg
Software	TRDI's Windows™-based software included: **WinSC**—Data Acquisition System; **WinADCP**—Data Display and Export	
Available Options	• Memory: 2 PCMCIA slots, total 4GB • Pressure sensor • External battery case • High-resolution water-profiling modes • Bottom tracking or surface referencing track • AC/DC power converter, 48VDC output • Pressure cases for depths up to 6000m • Directional Wave Array • Acoustic Modem • Inductive Modem • **Velocity** for advanced post processing	
Dimensions	228.0mm wide x 405.5mm long *(line drawings available upon request)*	

1 User's choice of depth cell size is not limited to the typical values specified.
2 Longer ranges available.
3 Profiling range based on temperature values at 5°C and 20°C, salinity = 35ppt.
4 BroadBand mode single-ping standard deviation (Std. Dev.).
5 <±1.0° is commonly achieved after calibration.

Specifications subject to change without notice.

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With 2 or 4 optical ports and new sensor options

Make the most of your environmental monitoring efforts: The 6600 V2 sonde offers the most comprehensive water quality monitoring package available with simultaneous measurement of conductivity (salinity), temperature, depth or level, pH/ORP. The 6600 V2-4 also measures these parameters: dissolved oxygen, turbidity, chlorophyll, and blue-green algae; the V2-2 measures two of the four parameters simultaneously. Additional calculated parameters include total dissolved solids, resistivity, and specific conductance.

Take advantage of YSI's new optical sensor design and anti-fouling wiper control for improved reliability during extended deployments.

- **Self-cleaning optical sensors with integrated wipers remove biofouling and maintain high data accuracy**
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Take Advantage of YSI's New Optical Sensors

In addition to turbidity, chlorophyll, and rhodamine, YSI now offers these optical sensors:

ROX Reliable Optical Dissolved Oxygen

The ROX sensor uses lifetime luminescence detection technology to offer the most reliable oxygen sensor with the lowest possible maintenance effort. The sensor is insensitive to hydrogen sulfide interference and does not require regular membrane changes.

Blue-Green Algae (BGA)

YSI's fluorescence-based blue-green algae sensors will allow you to monitor blue-green algae populations where their presence is a concern. Whether providing an early warning to an algal bloom, tracking taste and odor-causing species in drinking water supplies, or conducting ecosystem research, YSI BGA sensors will provide sensitive and reliable *in situ* data.

Complete Data Record

The YSI 6600 V2-4 Sonde, with 4 optical sensor ports, is the only instrument available to simultaneously measure dissolved oxygen, turbidity, chlorophyll, and blue-green algae!

*Sensor performance verified**

The 6600 V2 sonde uses sensor technology that was verified through the US EPA's Environmental Technology Verification Program (ETV). For information on which sensors were performance-verified, turn this sheet over and look for the ETV logo.

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6600 Upgrades Available

YSI is committed to offering our customers reliable and cost-effective water monitoring solutions. To this end, we are offering V2 Upgrades for existing 6600s. Upgrades will be available from YSI Authorized Service Centers and will include the new 6600 V2 bulkhead, a ROX Optical Dissolved Oxygen Sensor, and firmware/software upgrades. In addition, the sonde will be fully tested and calibrated by an experienced YSI service technician.

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*Sensors with listed with ETV logo were submitted to the ETV program on the YSI 6600EDS. Information on performance characteristics of YSI water quality sensors can be found at www.epa.gov/etv, or call YSI at 800.897.4151 for the ETV verification report. Use of ETV name or logo does not imply approval or certification of this product nor does it make any explicit or implied warranties or guarantees as to product performance.

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Who's Minding the Planet?®

YSI 6600 V2 Sensor Specifications

	Range	Resolution	Accuracy
ROX™ Optical Dissolved Oxygen• % Saturation	0 to 500%	0.1%	0 to 200%: ±1% of reading or 1% air saturation, whichever is greater; 200 to 500%: ±15% of reading
ROX™ Optical Dissolved Oxygen• mg/L	0 to 50 mg/L	0.01 mg/L	0 to 20 mg/L: ± 0.1 mg/L or 1% of reading, whichever is greater; 20 to 50 mg/L: ±15% of reading
Dissolved Oxygen•• % Saturation, 6562 Rapid Pulse™ Sensor* (ETV)	0 to 500%	0.1%	0 to 200%: ±2% of reading or 2% air saturation, whichever is greater; 200 to 500%: ±6% of reading
Dissolved Oxygen•• mg/L, 6562 Rapid Pulse™ Sensor* (ETV)	0 to 50 mg/L	0.01 mg/L	0 to 20 mg/L: ± 0.2 mg/L or 2% of reading, whichever is greater; 20 to 50 mg/L: ±6% of reading
Conductivity••• 6560 Sensor* (ETV)	0 to 100 mS/cm	0.001 to 0.1 mS/cm (range dependent)	±0.5% of reading + 0.001 mS/cm
Salinity	0 to 70 ppt	0.01 ppt	±1% of reading or 0.1 ppt, whichever is greater
Temperature 6560 Sensor* (ETV)	-5 to +50°C	0.01°C	±0.15°C
pH 6561 Sensor* (ETV)	0 to 14 units	0.01 unit	±0.2 unit
ORP	-999 to +999 mV	0.1 mV	±20 mV
Depth — Deep	0 to 656 ft, 200 m	0.001 ft, 0.001 m	±1 ft, ±0.3 m
Depth — Medium	0 to 200 ft, 61 m	0.001 ft, 0.001 m	±0.4 ft, ±0.12 m
Depth — Shallow	0 to 30 ft, 9.1 m	0.001 ft, 0.001 m	±0.06 ft, ±0.02 m
Depth — Vented Level	0 to 30 ft, 9.1 m	0.001 ft, 0.001 m	±0.01 ft, 0.003 m
Turbidity• 6136 Sensor* (ETV)	0 to 1,000 NTU	0.1 NTU	±2% of reading or 0.3 NTU, whichever is greater**
Nitrate/nitrogen••••	0 to 200 mg/L-N	0.001 to 1 mg/L-N (range dependent)	±10% of reading or 2 mg/L, whichever is greater
Ammonium/ammonia/ nitrogen••••	0 to 200 mg/L-N	0.001 to 1 mg/L-N (range dependent)	±10% of reading or 2 mg/L, whichever is greater
Chloride••••	0 to 1000 mg/L	0.001 to 1 mg/L (range dependent)	±15% of reading or 5 mg/L, whichever is greater
Rhodamine•	0-200 µg/L	0.1 µg/L	±5% reading or 1 µg/L, whichever is greater

• Maximum depth rating for all optical probes is 200 feet, 61 m. Turbidity and Rhodamine are also available in a Deep Depth option (0 to 200 m).
•• Rapid Pulse is only available on 6600 V2-2 (two optical ports version).
••• Report outputs of specific conductance (conductivity corrected to 25° C), resistivity, and total dissolved solids are also provided. These values are automatically calculated from conductivity according to algorithms found in *Standard Methods for the Examination of Water and Wastewater* (ed 1989).
•••• Freshwater only. Maximum depth rating of 50 feet, 15.2 m. 6600 V2-2 has 3 ISE ports; not available on the 6600V2-4.

**In YSI AMCO-AEPA Polymer Standards.

	Range	Detection Limit	Resolution	Linearity
Blue-Green Algae Phycocyanin•	~0 to 280,000 cells/mL† 0 to 100 RFU	~220 cells/mL§	1 cell/mL 0.1 RFU	$R^2 > 0.9999$**
Blue-Green Algae Phycoerythrin•	~0 to 200,000 cells/mL† 0 to 100 RFU	~450 cells/mL§§	1 cell/mL 0.1 RFU	$R^2 > 0.9999$***
Chlorophyll• 6025 Sensor* (ETV)	~0 to 400 µg/L 0 to 100 RFU	~0.1 µg/L§§§	0.1 µg/L Chl 0.1% RFU	$R^2 > 0.9999$****

• Maximum depth rating for all optical probes is 200 feet, 61 m. Also available in a Deep Depth option (0 to 200 m).
RFU = Relative Fluorescence Units

† Explanation of Ranges can be found in the 'Principles of Operation' section of the 6-Series Manual, Rev D.

§ Estimated from cultures of *Microcystis aeruginosa*.
§§ Estimated from cultures *Synechococcus sp.*
§§§ Determined from cultures of *Isochrysis sp.* and chlorophyll *a* concentration determined via extractions.

**For serial dilution of Rhodamine WT (0-400 ug/L).
***For serial dilution of Rhodamine WT (0-8 µg/L).
****For serial dilution of Rhodamine WT (0-500 ug/L).

YSI 6600 V2 Sonde Specifications

Medium	Fresh, sea or polluted water	Software	EcoWatch®
Temperature — Operating	-5 to +50°C	Dimensions — Diameter	3.5 in, 8.9 cm
Temperature — Storage	-10 to +60°C	Length, no depth	19.6 in, 49.8 cm
		Length, with depth	21.6 in, 54.9 cm
		Weight	7 lbs, 3.18 kg (batteries installed, with depth)
Communications	RS-232, SDI-12	Power — External	12 V DC
		Power — Internal	8 C-size alkaline batteries

B Calibration Certificates

- YSI6600_CalCert_09M100310
- YSI6600_CalCert_06L1043AA
- YSI6600_CalCert_11G101176

Sonde Calibration

COMPANY	OSIL Hire Sonde on behalf of ABPMer
CONTACT	Paul Clement
INSTRUMENT	YSI 6600V2 S/N 09M100310
REASON	Pre-Hire Calibration

Sensors Fitted

Sensor	Model	Serial No	Notes
Temp/Cond	6560	10H100160	
Dissolved Oxygen	n/a	n/a	
pH	n/a	n/a	
Turbidity	6136	11M100981	
Chlorophyll	n/a	n/a	
Depth	M	n/a	Integral to Sonde

Calibration Figures

Calibration	Standard	Pre-Cal	Post Cal
Conductivity	36 Sal	36.44	36.00
D/O 100%	xxx.xx mmHg	n/a	n/a
Pressure Offset	1006.05 mBars	10.128	0.000 m
pH 7	7.00	n/a	n/a
pH 4	4.00	n/a	n/a
pH 10	10.00	n/a	n/a
Turbidity 1	0 NTU	3.4	0.0
Turbidity 2	126 NTU	122.5	126.0
Turbidity 3	1000 NTU	998.0	1000.1
Chlorophyll	n/a	n/a	n/a
Temperature	14.9975°C		14.98

Calibration Details

Cal Constants	Pre-Cal	Post Cal
Conductivity	5.0	4.94815
Pressure Offset	0.0	-14.3964
pH Offset	n/a	n/a
pH Gain	n/a	n/a
Turbidity Offset	0.0	3.50523
Turbidity A1	500	125.335
Turbidity M1	500	121.9440
Turbidity A2	1000	902.689
Turbidity M2	1000	876.772
Chlorophyll Offset	n/a	n/a
Chlorophyll A1	n/a	n/a
Chlorophyll M1	n/a	n/a
Chlorophyll A2	n/a	n/a
Chlorophyll M2	n/a	n/a
Fluoro Offset	n/a	n/a
D/O Gain	n/a	n/a
T0	n/a	n/a
K1	n/a	n/a
K2	n/a	n/a
K3	n/a	n/a
K4	n/a	n/a

Calibrated In Accordance With YSI Procedures

Date 13 June 2019

Steve Greenaway
Service & Calibration Manager
steve.greenaway@osil.com

Sonde Calibration

COMPANY	OSIL Hire Sonde on behalf of ABPMer
CONTACT	Paul Clement
INSTRUMENT	YSI 6600V2 S/N 06L1043 AA
REASON	Pre-Hire Calibration

Sensors Fitted

Sensor	Model	Serial No	Notes
Temp/Cond	6560	13C100822	
Dissolved Oxygen	n/a	n/a	
pH	n/a	n/a	
Turbidity	6136	08J100199	
Chlorophyll	n/a	n/a	
Depth	M	n/a	Integral to Sonde

Calibration Figures

Calibration	Standard	Pre-Cal	Post Cal
Conductivity	36 Sal	36.75	36.00
D/O 100%	xxx.xx mmHg	n/a	n/a
Pressure Offset	1005.9 mBars	10.314	0.000 m
pH 7	7.00	n/a	n/a
pH 4	4.00	n/a	n/a
pH 10	10.00	n/a	n/a
Turbidity 1	0 NTU	3.3	0.0
Turbidity 2	126 NTU	126.3	126.0
Turbidity 3	1000 NTU	985.4	1000.1
Chlorophyll	n/a	n/a	n/a
Temperature	14.9975°C		14.97

Calibration Details

Cal Constants	Pre-Cal	Post Cal
Conductivity	5.0	4.90592
Pressure Offset	0.0	-14.6598
pH Offset	n/a	n/a
pH Gain	n/a	n/a
Turbidity Offset	0.0	3.39246
Turbidity A1	500	125.335
Turbidity M1	500	125.677
Turbidity A2	1000	902.689
Turbidity M2	1000	893.674
Chlorophyll Offset	n/a	n/a
Chlorophyll A1	n/a	n/a
Chlorophyll M1	n/a	n/a
Chlorophyll A2	n/a	n/a
Chlorophyll M2	n/a	n/a
Fluoro Offset	n/a	n/a
D/O Gain	n/a	n/a
T0	n/a	n/a
K1	n/a	n/a
K2	n/a	n/a
K3	n/a	n/a
K4	n/a	n/a

Calibrated In Accordance With YSI Procedures

Date 13 June 2019

Steve Greenaway
Service & Calibration Manager
steve.greenaway@osil.com

Sonde Calibration

COMPANY	Unique Systems UK Ltd
CONTACT	Nick Love
INSTRUMENT	YSI 6600V2 S/N 11G101176
REASON	Service & Calibration

Sensors Fitted

Sensor	Model	Serial No	Notes
Temp/Cond	6560	11F100763	
Dissolved Oxygen	6150 ROX	13M102084	
pH	6589	16J	
Turbidity	6136	13K102523	
Chlorophyll	n/a	n/a	
Depth	M	n/a	Integral to Sonde

Calibration Figures

Calibration	Standard	Pre-Cal	Post Cal
Conductivity	34.993 Sal	34.93	34.99
D/O 100%	765.85 mmHg	95.5	100.8
Pressure Offset (m)	1021.05 mBars	10.358	0.000
pH 7	7.00	7.85	7.00
pH 4	4.00	4.07	4.00
pH 10	10.00	9.97	9.99
Turbidity 1	0 NTU	3.0	0.0
Turbidity 2	126 NTU	89.1	126.0
Turbidity 3	1000 NTU	1016.0	1000.0
Chlorophyll	n/a	n/a	n/a
Temperature	14.9975°C		14.98

Calibration Details

Cal Constants	Pre-Cal	Post Cal
Conductivity	5.0	5.00768
Pressure Offset	0.0	-14.7026
pH Offset	0.0	-252.5980
pH Gain	-5.05833	-5.20457
Turbidity Offset	0.0	3.06262
Turbidity A1	500	125.335
Turbidity M1	500	88.8685
Turbidity A2	1000	902.689
Turbidity M2	1000	648.915
Chlorophyll Offset	n/a	n/a
Chlorophyll A1	n/a	n/a
Chlorophyll M1	n/a	n/a
Chlorophyll A2	n/a	n/a
Chlorophyll M2	n/a	n/a
Fluoro Offset	n/a	n/a
D/O Gain	1.0	1.00518
T0	2.51358	2.51358
K1	2.51358	2.51358
K2	0.15717	0.15717
K3	3.35187	3.35187
K4	22.8596	22.8596

Calibrated In Accordance With YSI Procedures

Date 13 November 2018

Steve Greenaway
Service & Calibration Manager
steve.greenaway@osil.com

C Particle Size Analysis

- PSA Site 1
- PSA Site 2
- PSA Site 3
- PSA Site 4
- PSA Site 5
- PSA Site 6
- PSA Site 7
- PSA Site 8
- PSA Site 10

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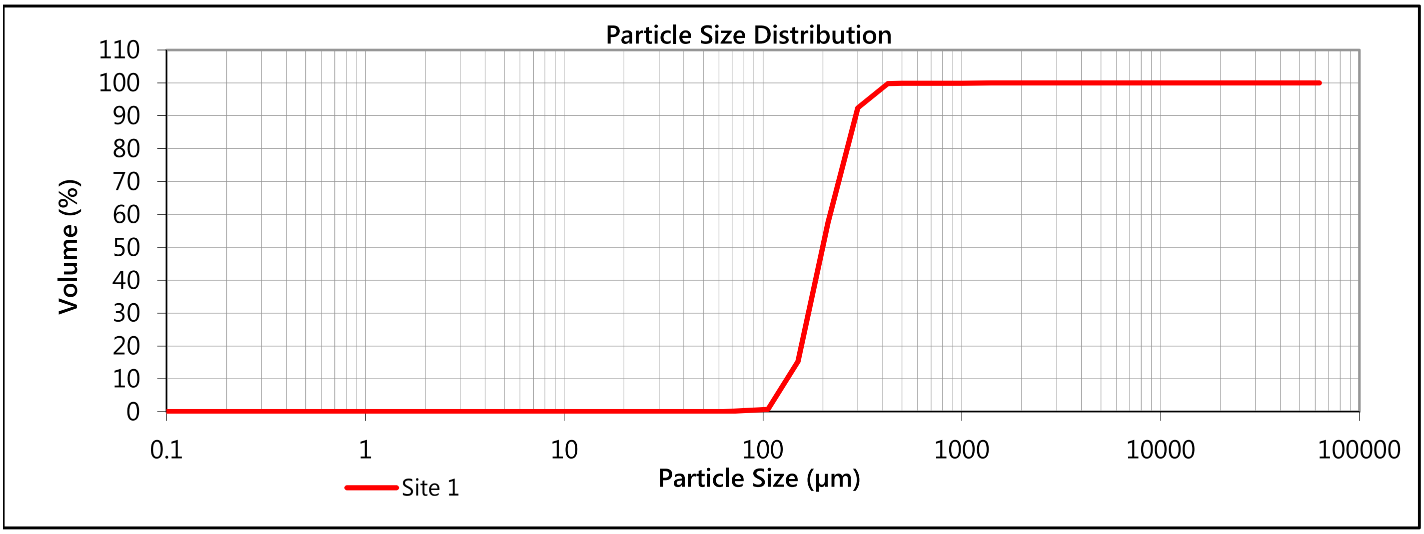
Particle Size Analysis Report

Sample Name:	Site 1	**Measured by:**	IDavidson
Sample Source:	Douglas		
Sample Collected:	June 2019		4743

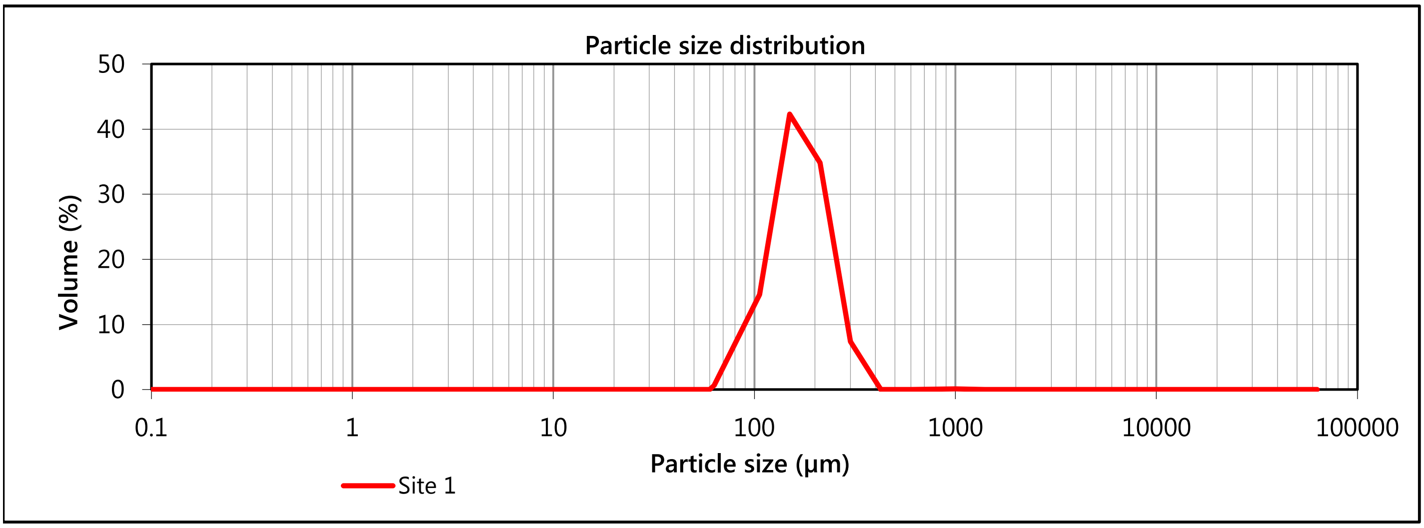
d(0.1):	134.1	µm	**d(0.5):**	**200.9**	**µm**	d(0.9):	293.9	µm

Cumulative Frequency Plot



Clay (%)	Silt (%)			Sand (%)			Gravel (%)			Cobble (%)
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
0.0	0.0	0.0	0.0	57.6	42.3	0.1	0.0	0.0	0.0	0.0

Frequency Curve



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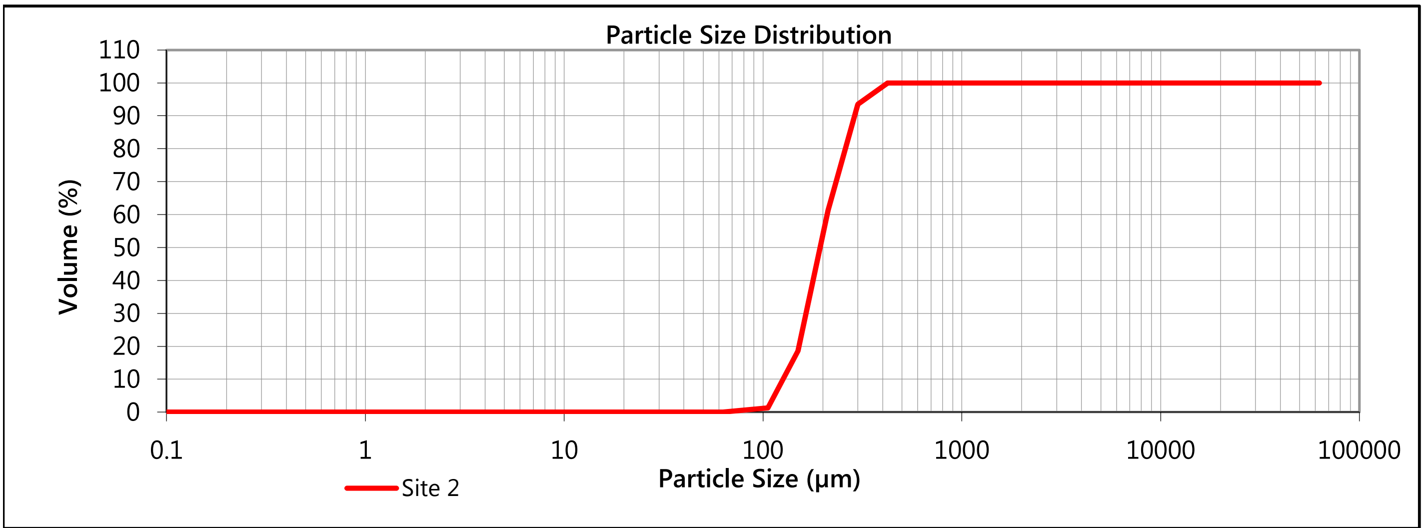
Particle Size Analysis Report

Sample Name:	Site 2	**Measured by:**	IDavidson
Sample Source:	Douglas		
Sample Collected:	June 2019		4743

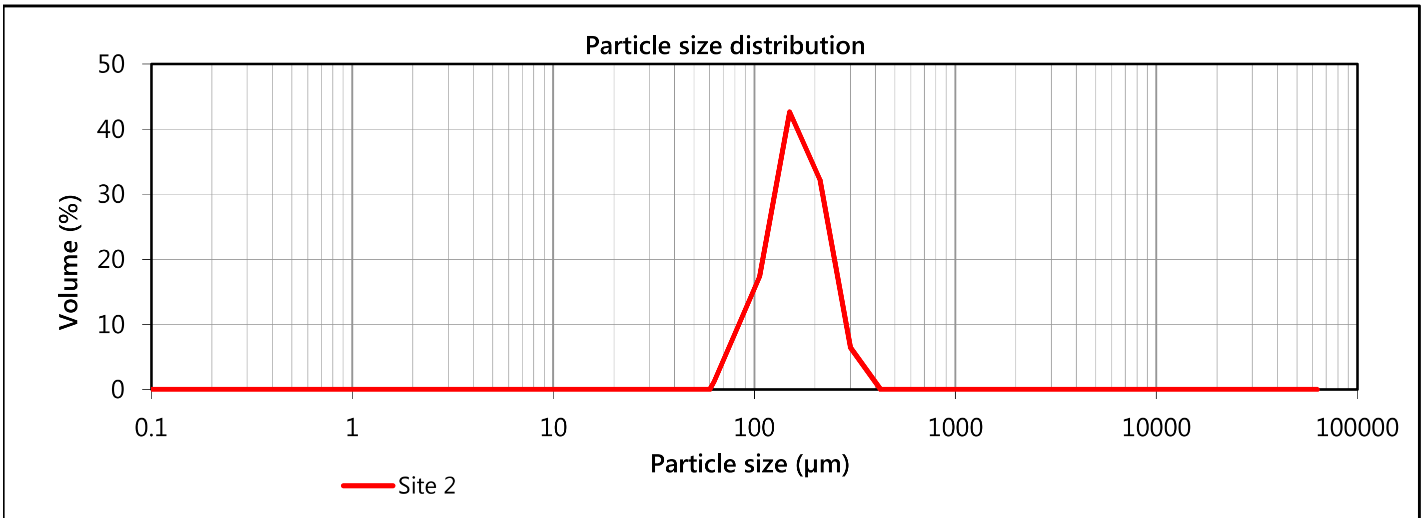
d(0.1):	128.1	µm	**d(0.5):**	**195.6**	**µm**	d(0.9):	290.6	µm

Cumulative Frequency Plot



Clay (%)	Silt (%)			Sand (%)			Gravel (%)			Cobble (%)
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
0.0	0.0	0.0	0.0	61.3	38.7	0.1	0.0	0.0	0.0	0.0

Frequency Curve



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Particle Size Analysis Report

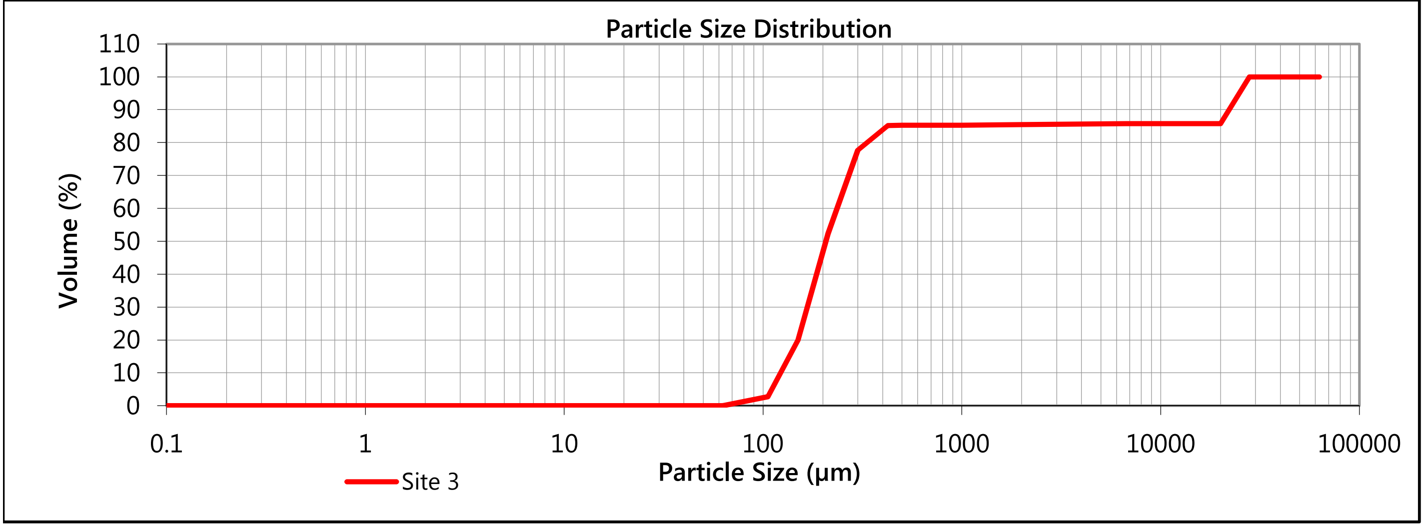
Sample Name: Site 3 **Measured by:** IDavidson

Sample Source: Douglas

Sample Collected: June 2019 4743

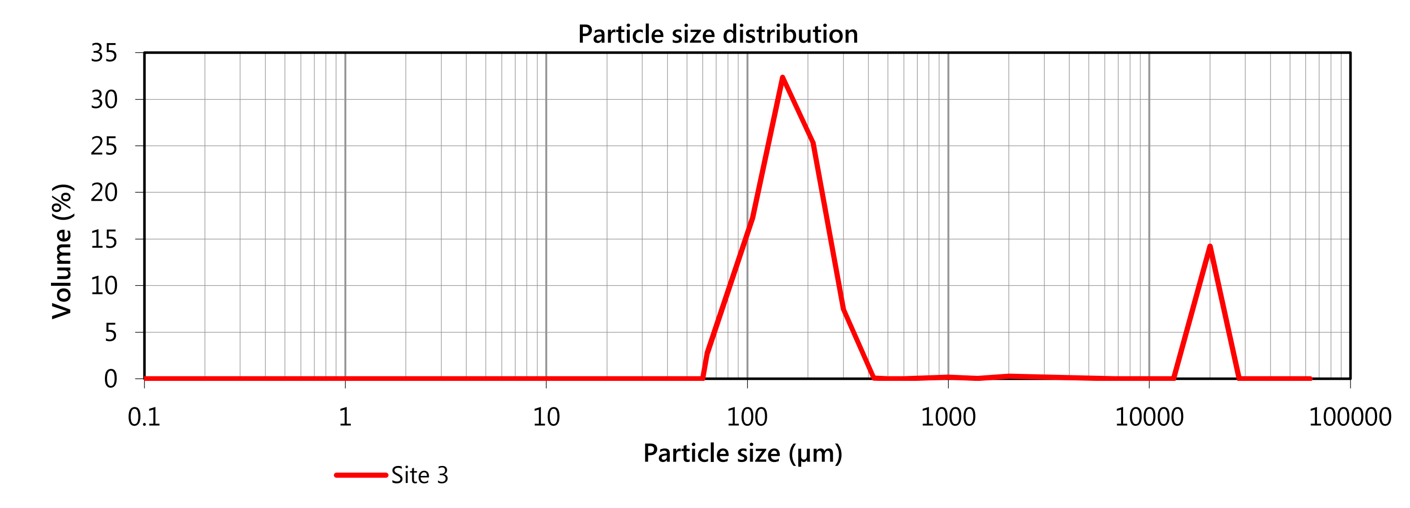
d(0.1): 124.5 µm **d(0.5): 207.5 µm** d(0.9): 22383.5 µm

Cumulative Frequency Plot



Clay (%)	Silt (%)			Sand (%)			Gravel (%)			Cobble (%)
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
0.0	0.0	0.0	0.0	52.3	32.9	0.2	0.3	0.0	14.2	0.0

Frequency Curve



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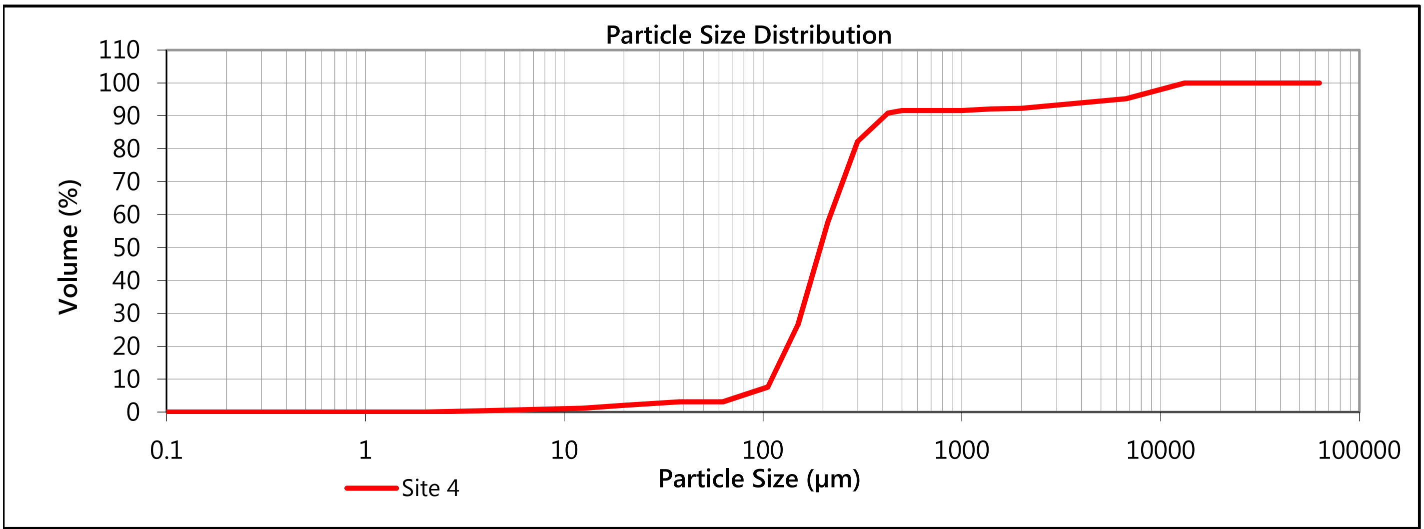
Particle Size Analysis Report

Sample Name:	Site 4	**Measured by:**	IDavidson
Sample Source:	Douglas		
Sample Collected:	June 2019		4743

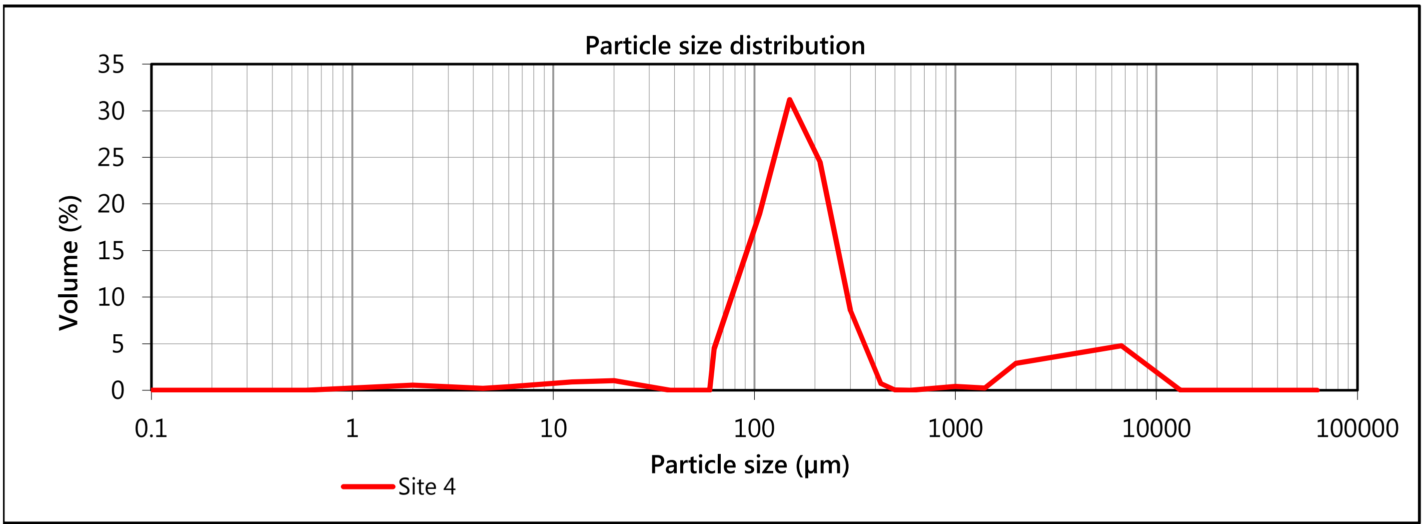
d(0.1):	111.5	µm	**d(0.5):**	**196.6**	**µm**	d(0.9):	412.7	µm

Cumulative Frequency Plot



Clay (%)	Silt (%)			Sand (%)			Gravel (%)			Cobble (%)
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
0.0	0.8	1.3	1.0	54.7	33.9	0.7	2.9	4.8	0.0	0.0

Frequency Curve



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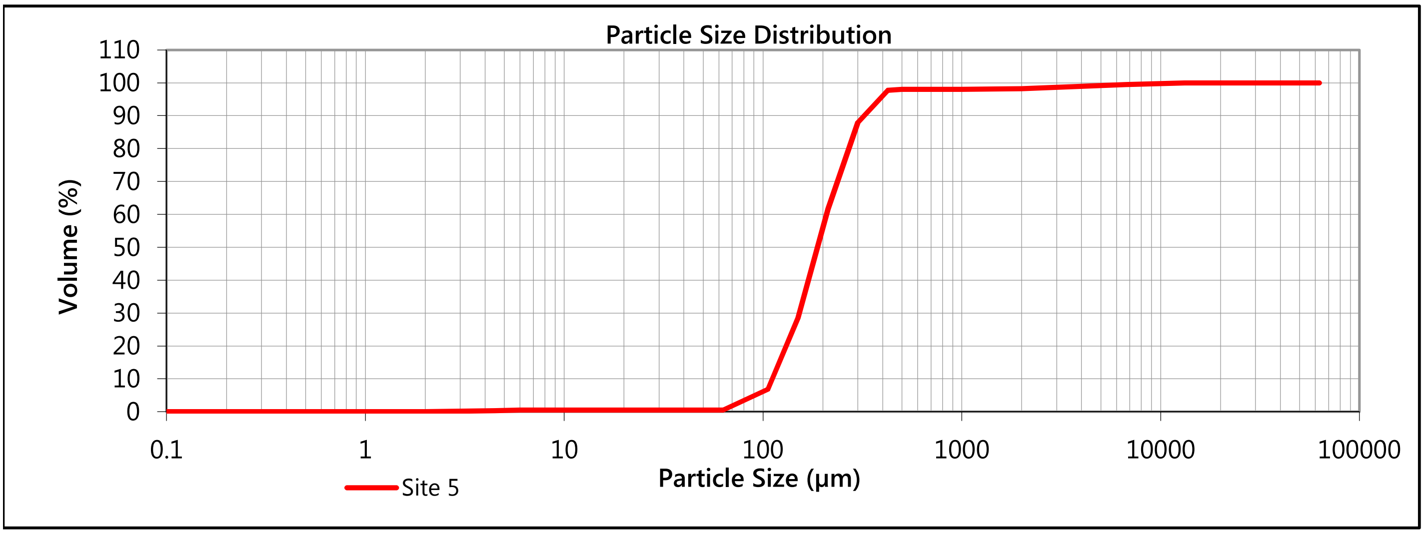
Particle Size Analysis Report

Sample Name:	Site 5	**Measured by:**	IDavidson
Sample Source:	Douglas		
Sample Collected:	June 2019		4743

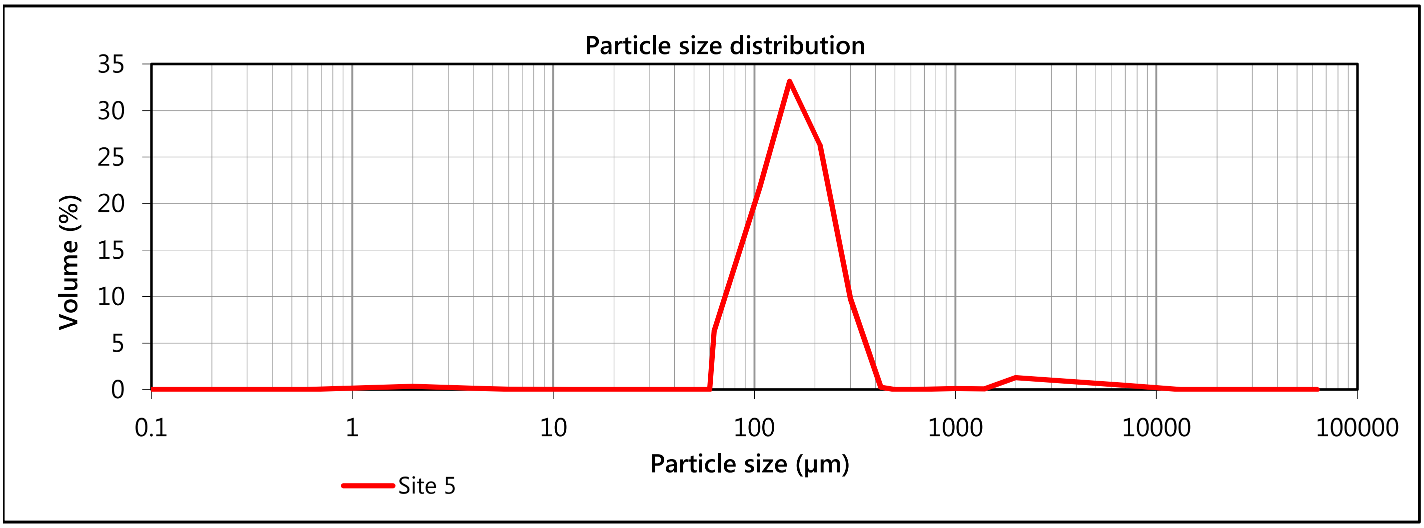
d(0.1):	112.4	µm	**d(0.5):**	**190.2**	**µm**	d(0.9):	326.3	µm

Cumulative Frequency Plot



Clay (%)	Silt (%)			Sand (%)			Gravel (%)			Cobble (%)
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
0.0	0.5	0.0	0.0	61.1	36.3	0.2	1.3	0.5	0.0	0.0

Frequency Curve



Malvern Instruments Ltd.
Malvern, UK

Mastersizer 2000 Ver. 5.22
Serial Number: 34403-66

File Name: xxxxx
Record Number: xx

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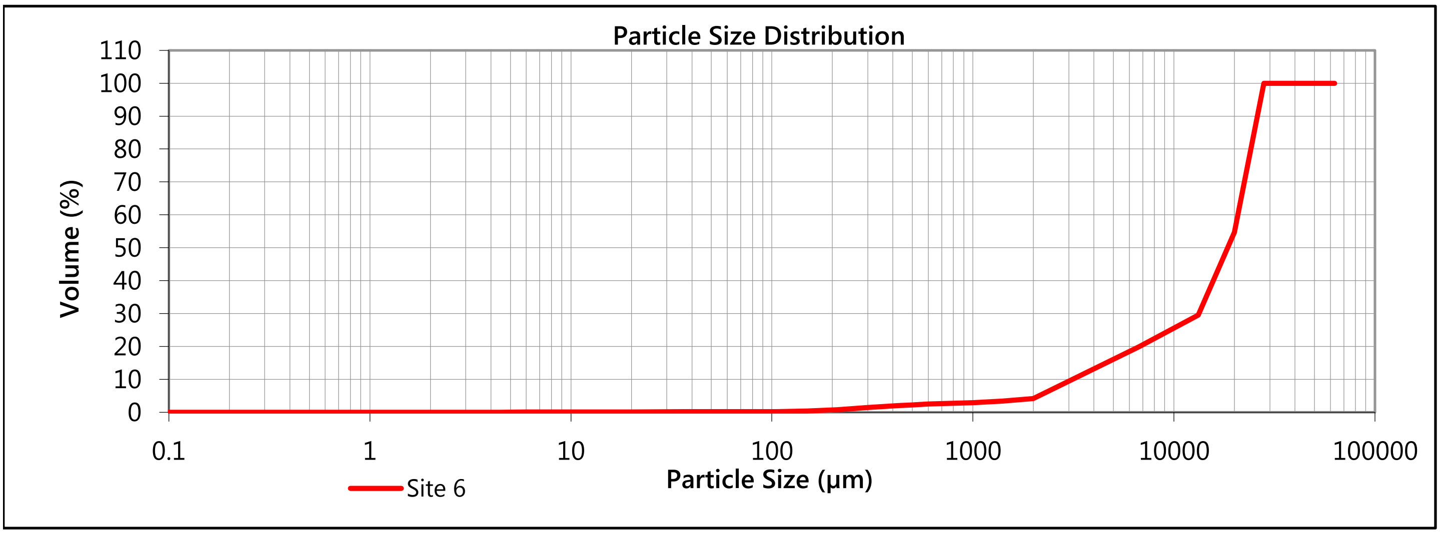
Particle Size Analysis Report

Sample Name:	Site 6	**Measured by:**	IDavidson
Sample Source:	Douglas		
Sample Collected:	June 2019		4743

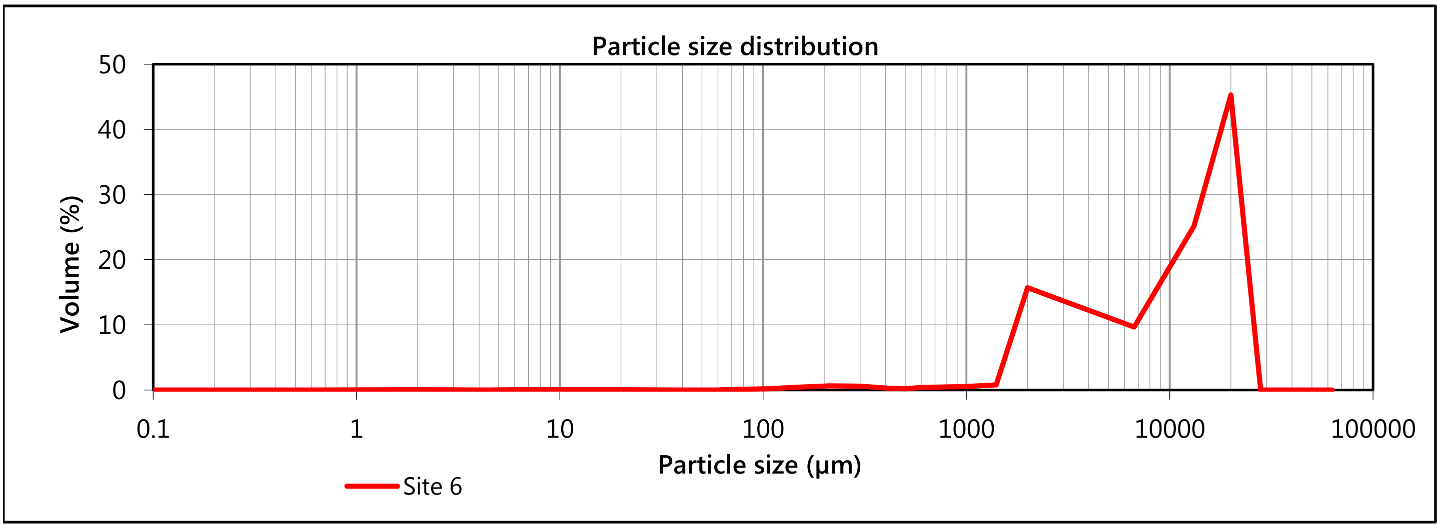
d(0.1):	3740.4	µm	**d(0.5):**	**18725.3**	**µm**	d(0.9):	26233.2	µm

Cumulative Frequency Plot



Clay (%)	Silt (%)			Sand (%)			Gravel (%)			Cobble (%)
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
0.0	0.0	0.1	0.1	0.6	1.7	1.7	15.7	34.8	45.3	0.0

Frequency Curve



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Particle Size Analysis Report

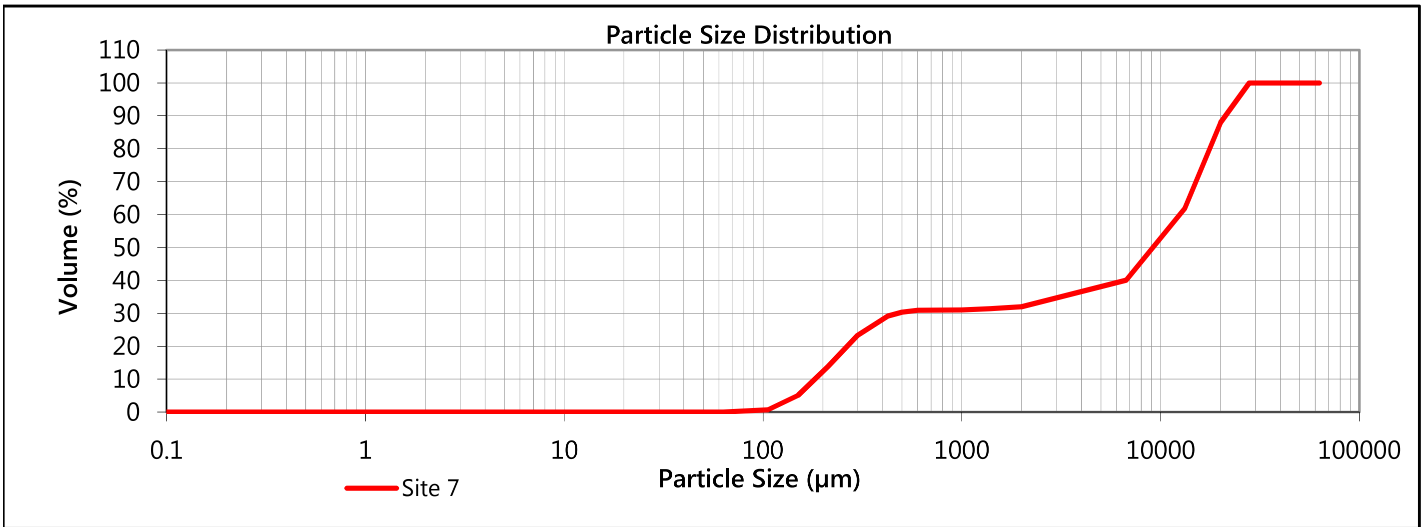
Sample Name: Site 7 **Measured by:** IDavidson

Sample Source: Douglas

Sample Collected: June 2019 4743

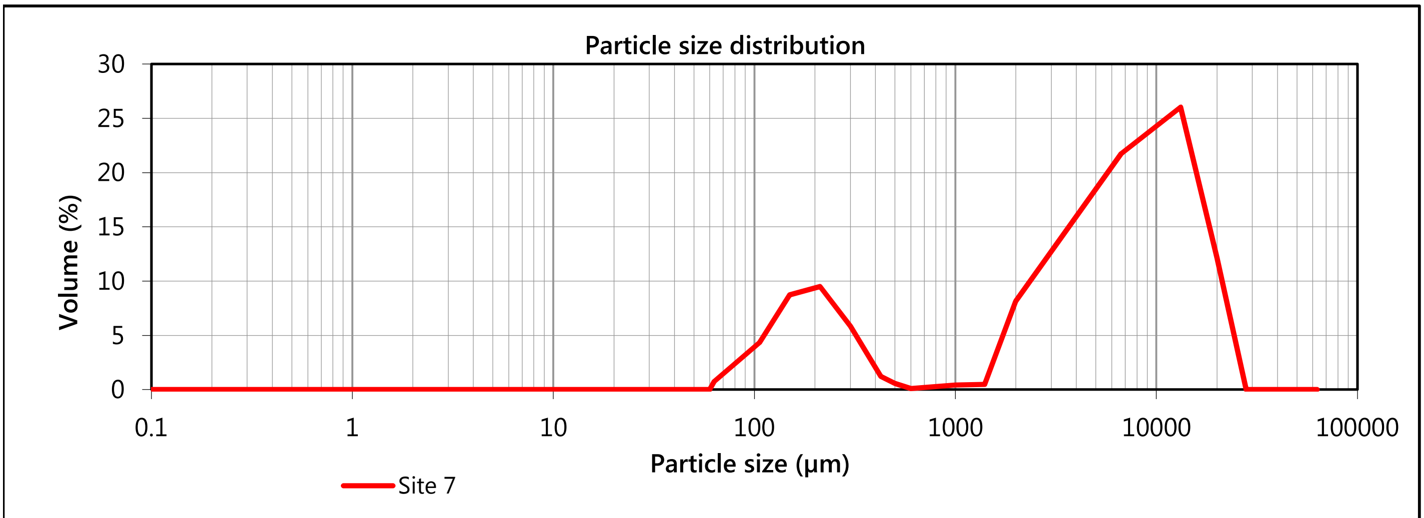
d(0.1): 184.8 µm **d(0.5): 9654.7 µm** d(0.9): 21401.5 µm

Cumulative Frequency Plot



Clay (%)	Silt (%)			Sand (%)			Gravel (%)			Cobble (%)
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
0.0	0.0	0.0	0.0	13.8	17.1	1.0	8.2	47.8	12.1	0.0

Frequency Curve



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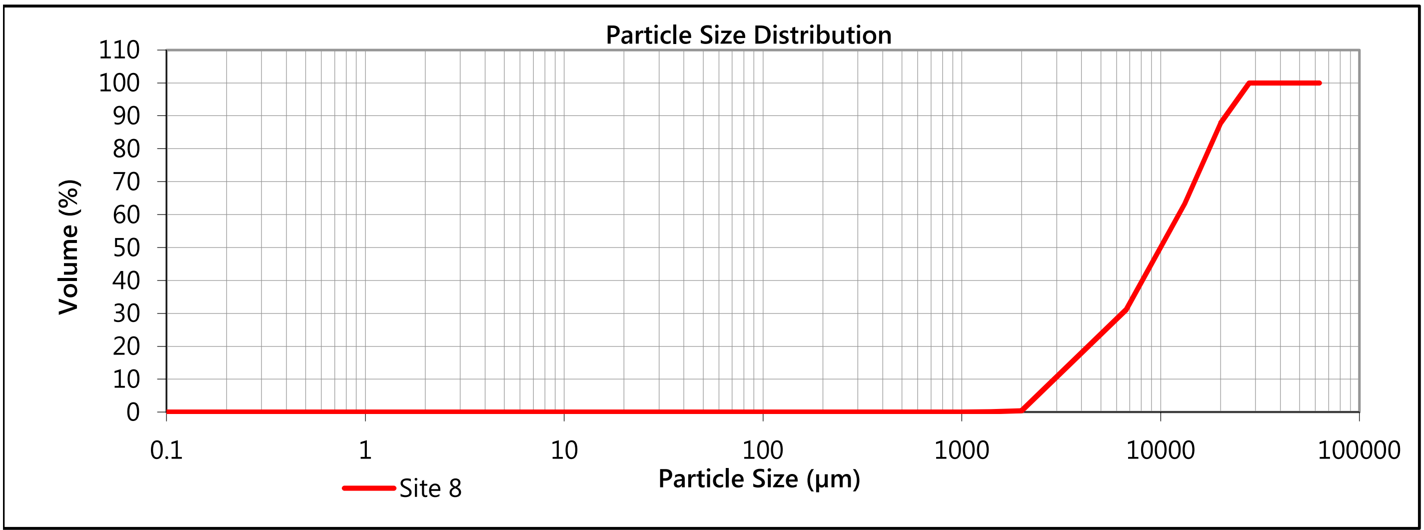
Particle Size Analysis Report

Sample Name:	Site 8	**Measured by:**	IDavidson
Sample Source:	Douglas		
Sample Collected:	June 2019		4743

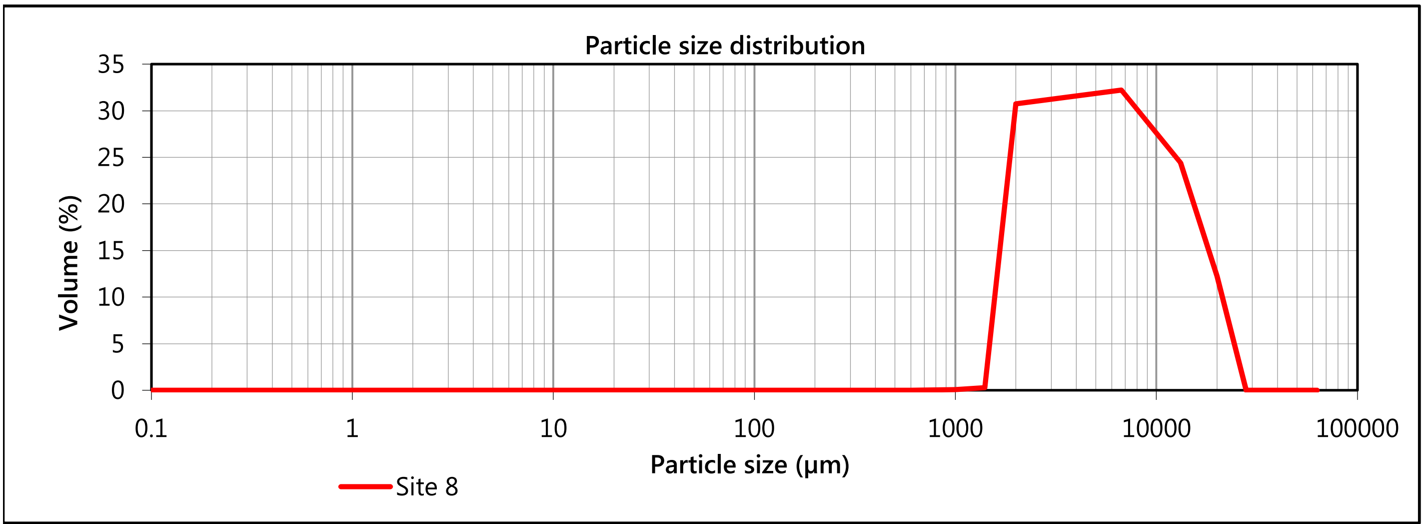
d(0.1):	3471.7	µm	**d(0.5):**	**10510.5**	**µm**	d(0.9):	21473.0	µm

Cumulative Frequency Plot



Clay (%)	Silt (%)			Sand (%)			Gravel (%)			Cobble (%)
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
0.0	0.0	0.0	0.0	0.0	0.0	0.4	30.7	56.6	12.3	0.0

Frequency Curve



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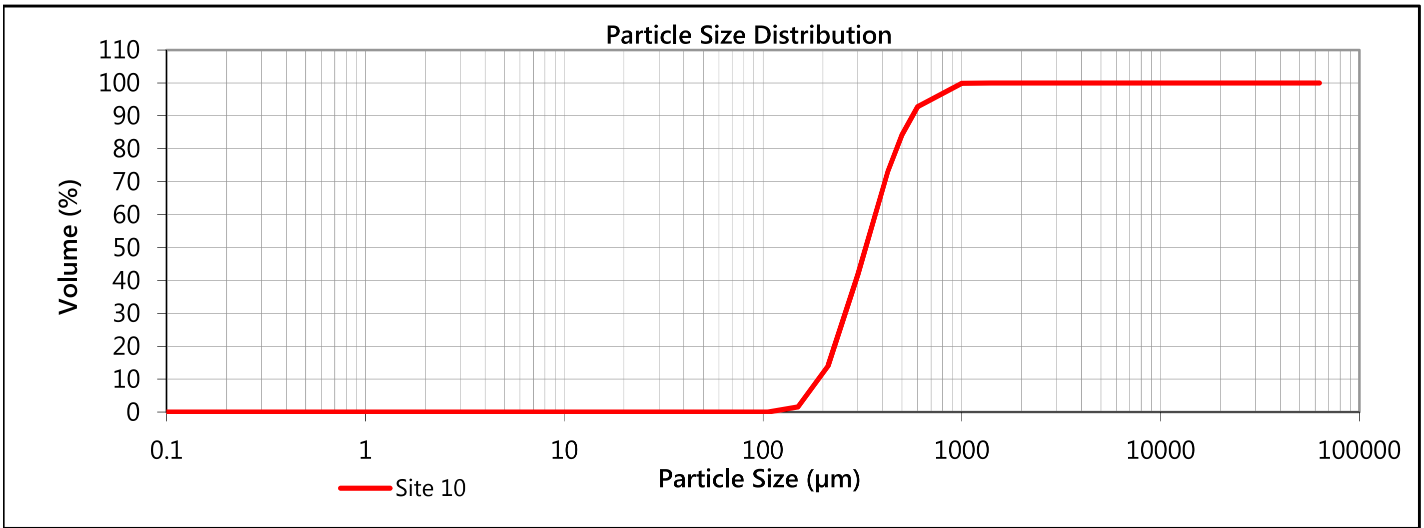
Particle Size Analysis Report

Sample Name:	Site 10	**Measured by:**	IDavidson
Sample Source:	Douglas		
Sample Collected:	June 2019		4743

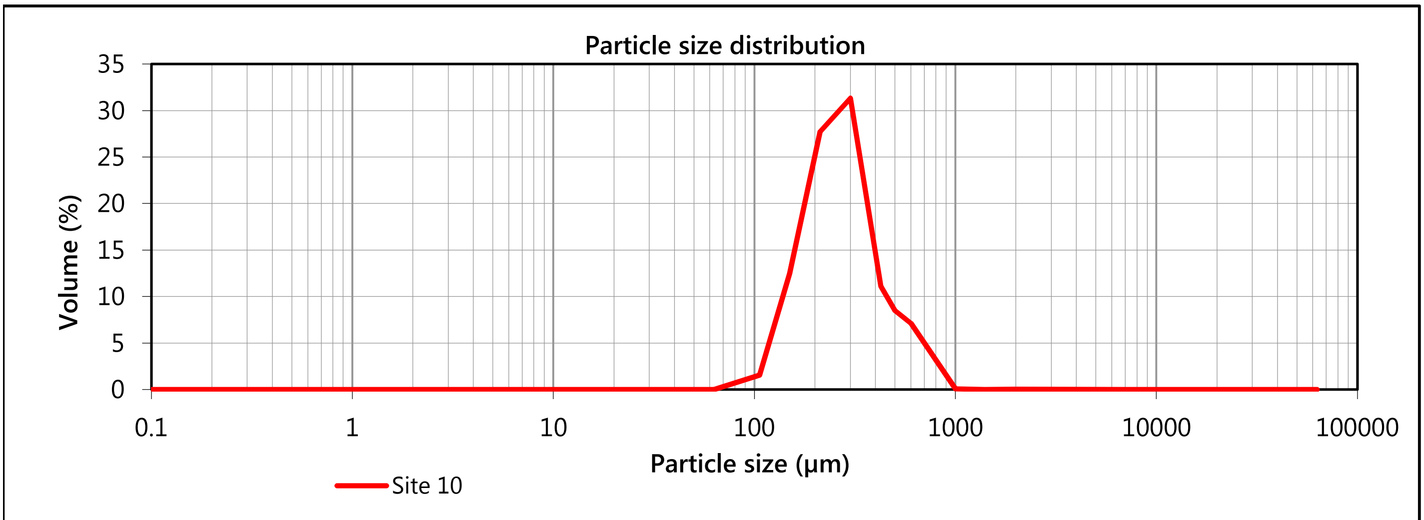
d(0.1):	191.8	µm	**d(0.5):**	**332.9**	**µm**	d(0.9):	568.1	µm

Cumulative Frequency Plot



Clay (%)	Silt (%)			Sand (%)			Gravel (%)			Cobble (%)
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
0.0	0.0	0.0	0.0	14.1	78.7	7.2	0.0	0.0	0.0	0.0

Frequency Curve



End of Main Report Appendix A

Appendices B to I continue on next page

Contact Us

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B Model Set-up, Calibration and Validation

Isle of Man Government – Department of Infrastructure

Proposed Deep-Water Berth, Douglas Harbour - Sediment and Navigation Studies

Numerical model calibration

November 2019





Innovative Thinking - Sustainable Solutions

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Proposed Deep-Water Berth, Douglas Harbour - Sediment and Navigation Studies

Numerical model calibration

November 2019

Document Information

Document History and Authorisation	
Title	Proposed Deep-Water Berth, Douglas Harbour - Sediment and Navigation Studies
	Numerical model calibration
Commissioned by	Isle of Man Government – Department of Infrastructure
Issue date	November 2019
Document ref	R.3272
Project no	R/4743/5

Date	Version	Revision Details
16/10/2019	1	Issued for Client Review
20/11/2019	2	Issued for Client Use

Prepared (PM)	Approved (QM)	Authorised (PD)
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Notice

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1 Introduction

Isle of Man Harbours, Department of Infrastructure – Ports Division is undertaking a Master Planning process for the port facilities at Douglas Harbour. The Master Planning has indicated the potential for two new berthing facilities outside the Douglas harbour entrance for vessels that cannot be accommodated within the existing harbour. Siltation and navigation studies are required to provide further information on the feasibility from an operational perspective.

To assist these studies a series of numerical models have been set up and calibrated. This report provides a description of the hydrodynamic, wave and sediment models applied in this assessment and details the setup, calibration and validation process undertaken. This approach demonstrates that the flow and wave models produce a representative simulation of the existing processes and provide the underlying conditions for driving the sediment transport model. The model outputs will be used to address the following aims:

- To investigate the effects of the proposed new berthing facilities on the tidal regime and the conditions in the navigation approach to Douglas Harbour;
- Determine the wave climate in the area of the berths, and how waves may influence the tidal flows;
- Determine any likely siltation in the harbour areas, hence inform the potential for future maintenance dredging; and
- To provide environmental 'forcing' data for navigation ship simulation studies.

In describing these modelling studies, the remainder of this calibration report is structured as follows:

Section 2: Describes the setup of the modelling components for assessing hydrodynamics (water levels and flows), wave climate and sediment transport potential;

Section 3: Details the approach to calibration of the wave model, and compares the modelled wave climate to the measured survey data from Douglas Harbour;

Section 4: Provides detail on the calibration of the hydrodynamic model, assessing the ability of the model to replicate the measured water levels and flows across the study area; and

Section 5: Explains the rationale for the approach to sediment transport modelling and compares the model results against available suspended sediment concentration data.

2 Model Setup

The modelling work during this study has been completed using the state-of-the-art Danish Hydraulic Institute (DHI) software package MIKE21FM (Flexible Mesh), which has been developed specifically for applications within oceanographic, coastal and estuarine environments.

This project utilises the MIKE21 Hydrodynamic (HD) model to simulate the variations in water level and two-dimensional depth averaged flow within the study area. These data provide the input forcing conditions to the MIKE21 Sand Transport (ST) module to calculate the resultant transport of sand bed sediment. The MIKE21 Spectral Wave (SW) package has also been used to simulate the transformation of wind-generated waves and swell waves from offshore regions into coastal environment.

Utilising all of these packages provides a representation of how the proposed developments will affect the hydrodynamics and sediment regime in the approaches to Douglas Harbour and provide the environmental 'forcing' data to the separate navigation ship simulation studies.

The following sections provide information on the setup, and the calibration and validation results for each model.

2.1 Spectral wave model

This Spectral Wave (SW) model is a local model with the primary purpose to transform offshore wave conditions into the coastal region at a higher resolution. For this study, 'annual' and 'average' wave characteristics have been derived from ABPmer's 40-year SEASTATES hindcast dataset to act as 'normal' conditions to demonstrate:

- How the berth developments are influenced by the local wave climate under the range of wave conditions that could occur in operation; and
- Any effects the wave climate has on the tidal flow characteristics.

2.1.1 Model grid

The SW model extent has been taken from a study previously completed by ABPmer at Douglas Harbour (ABPmer, 2015), extending into the Irish Sea offshore of Douglas (see Figure 1).

The model grid utilises the flexible mesh feature of the MIKE 21 software allowing the grid resolution to vary, with areas of interest typically covered with a higher resolution to increase the accuracy and level of detail, with offshore areas given a coarse resolution to aid computational efficiency. Within this model grid, at the outer extents the model resolution is at 1,500 m, with a gradual change to the harbour to a finer resolution of 20 m.

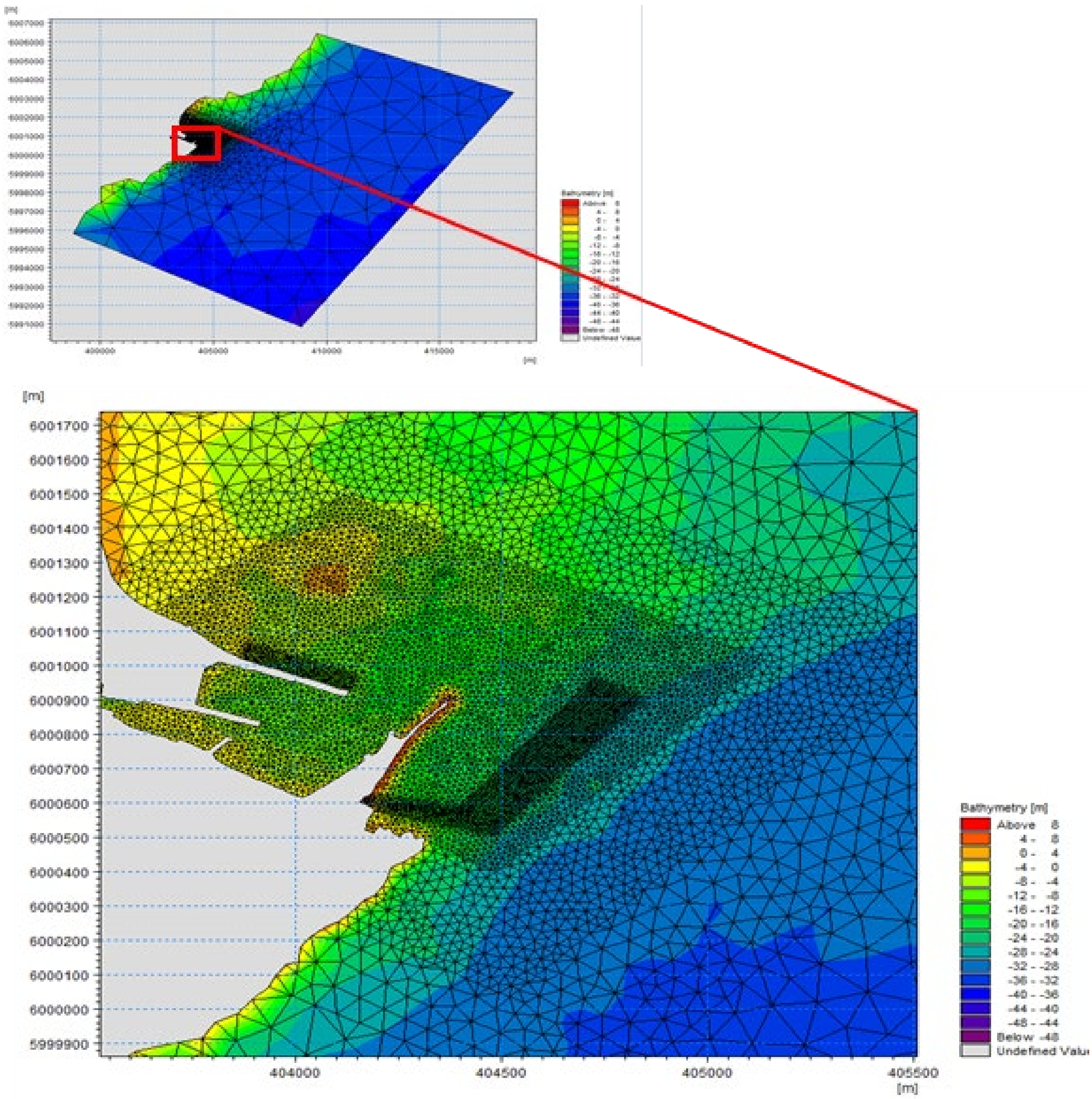

Figure 1. Extent of model and the local resolution of the SW model grid

2.1.2 Model bathymetry

The bathymetry data sets interpolated to form the model mesh are all referenced to Mean Sea Level (MSL). Table 1 lists each dataset, its source and resolution.

Table 1. Model bathymetry data sources

Coverage	Source	Resolution (m)
Douglas Harbour, 1 May 2019.	Client supplied multibeam survey data - Aspect Land & Hydrographic Surveys Ltd (ALHS)	0.5
LiDAR coverage of Douglas Harbour and Bay	Client supplied tiles of LiDAR	0.5
North and eastern waters of the Isle of Man	EMap Site	20
Coarse, outer model extent	ABPmer SEASTATES regional hindcast model	7,500

2.1.3 Model boundary conditions

Offshore boundaries

Waves were forced along three open boundaries (South, East and North - see Figure 2), consisting of the following key wave parameters; Significant Wave Height (Hs), Peak Wave Period (Tp), Mean Wave Direction (DirM) and Directional Standard Deviation (DirSD). The wave boundaries describe the temporally and spatially varying wave climate, along each boundary, with data derived from ABPmer's SEASTATES hindcast. This 40-year wave hindcast includes the deployment period for the survey equipment (as described in Section 3.1), between 17 June and 19 July 2019; thus allowing a direct comparison of the model output with the measured wave climate within the Douglas study area.

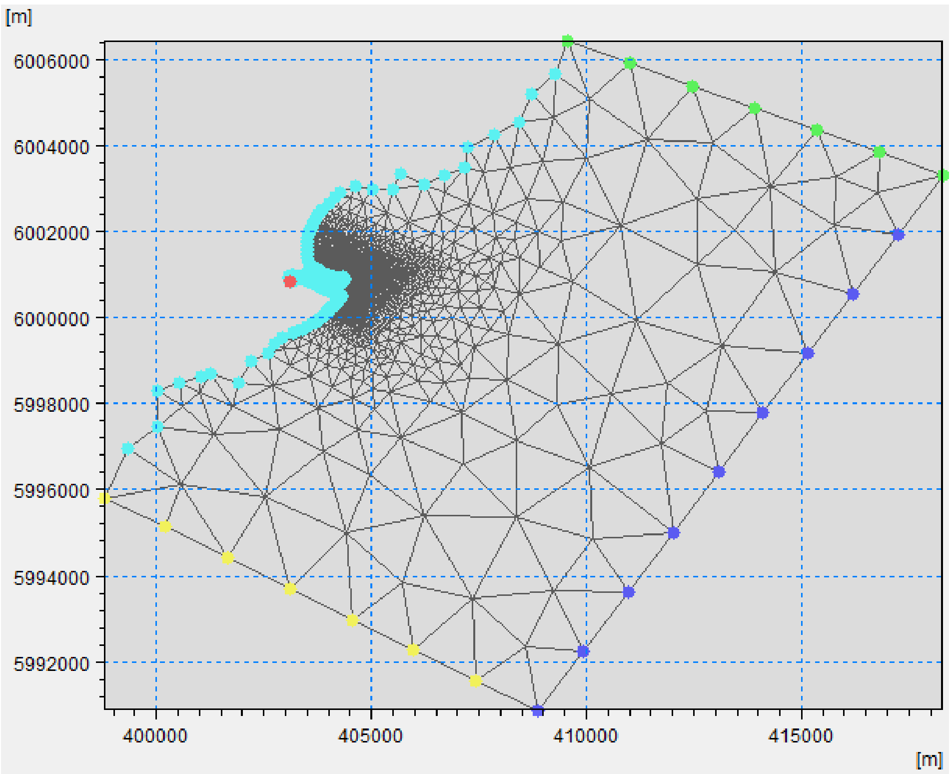

Figure 2. SW model boundaries

Meteorological forcing

The wind field across the model domain was forced by wind data provided by the client which is at one-minute intervals of both wind speed and direction from the measurement device located on the Douglas breakwater and Princess Alexandra Pier. This local wind data ensures the nearshore wave transformation provides a good, local representation.

Water levels

Astronomic tidal levels were generated for the model run period using harmonic constituents derived from the UK Hydrographic Office Tide Tables.

2.2 Hydrodynamic model

2.2.1 Model grid

The hydrodynamic (HD) model has the same outer extent and resolution as the SW model, with the only exception being slight increases in mesh resolution in and around Douglas Harbour. Within the approach to the harbour, the resolution is finer (*circa* 15 m) along with the inclusion of both the flap-gate and upper marina (Figure 3). This provides a full, operational representation of the harbour, to ensure the correct volumetric exchange is replicated through the harbour and approach channel during the flood and ebb phases of the tide, aiding the representation of the magnitude and phasing of the tidal signal generated by the model.

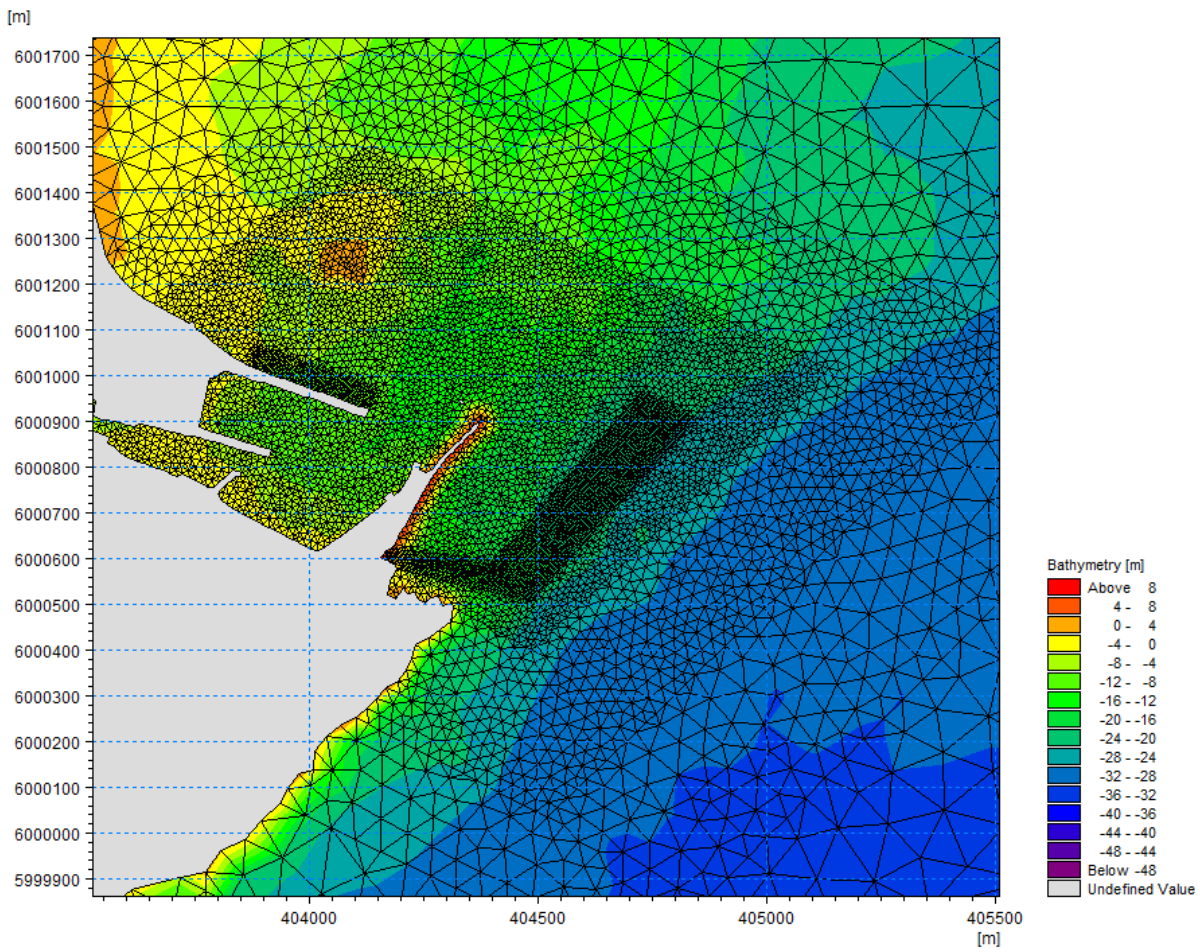

Figure 3. Local resolution of the HD grid

2.2.2 Model bathymetry

The HD model utilises the same bathymetry data as in the SW model (Table 1) due to the domains covering the same extents. As mentioned, the HD model extends further up the harbour and includes the flap-gate and the upper marina which required an additional bathymetry data set to cover these upper regions of the harbour. This data set was client supplied and is of a resolution of approximately 5 m.

2.2.3 Model boundary conditions

Tidal boundaries

The driving boundaries for the HD model match the orientation and locations of those applied to the wave model (see Figure 2). The boundary definitions for the HD model are derived from the ABPmer UK Tide and Surge regional hindcast model (ABPmer, (2017). This regional model, which covers the northwest European continental shelf, has been extensively calibrated against available tide gauge and current meter datasets and has been successfully applied to provide boundary conditions for local, high-resolution models on a number of studies.

For the Douglas project, the driving HD boundary data applies temporally and spatially varying flow conditions (eastward and northward current vectors to provide both magnitude and directionality) along the north and south boundaries, driving flow across the entrance to Douglas Harbour. The offshore (eastern) boundary applies a water level condition to drive tidal elevations across the study area.

2.2.4 Bed roughness

Bed roughness in the model describes the friction from the seabed 'felt' by moving water. Changing the magnitude of bed roughness locally affects the rate at which water moves in that area and so can affect both tidal range and phasing, and (mainly the speed of) tidal currents. As such, bed roughness is a key variable in the model that can be varied to optimise the model performance in comparison to coincident measured data.

Following a series of sensitivity tests with this parameter, a spatially varying bed roughness map was applied within the study area, with values based on seabed type and water depth. The choices were informed by and consistent with the conceptual understanding of the regional coastal processes (as provided in the main report for this Douglas study).

2.3 Sand transport (ST) model

The Sand Transport (ST) module simulates the movement of non-cohesive sediments (e.g. sands) within the model domain, using the combined flows from the HD and SW modules as forcing conditions. The ST module accounts for the settling, deposition and erosion of sediment within the model domain, and allows for sediment motion as bedload or in suspension.

2.3.1 Model grid

The ST model is driven by the combined flow field from the coupled HD and SW modules. As a result, it is based on the HD model grid, as described in Section 2.2.1.

2.3.2 Model bathymetry

Using the coupled approach to ST modelling, driving the transport potential with forcing conditions from HD and SW inputs, the ST module applies the same bathymetry data as the HD module, described in Section 2.2.2.

Where predicted, resultant changes to bed levels (through erosion and deposition within the ST module) are fed-back into the coupled model, influencing the subsequent associated HD and SW predictions.

2.3.3 Model inputs

Table 2 provides a summary of the inputs to the ST module, along with the rationale for their selection. In general, a range of sensitivity tests have been carried out to assess the effects of changing these inputs, and to subsequently inform the optimum setup.

Table 2. Sand transport (ST) model inputs

Parameter	Input	Rationale
Sediment grain size	200 µm	Median grain diameter from particle size analysis of inshore grab samples (ABPmer, 2019b)
Initial bed layer thickness	Varying bed thickness map, ranging from 0.2 m in inshore areas to 0.01 m offshore (see Figure 4)	Conceptual understanding of processes and baseline environment across study area (ABPmer, 2019a))

The application of a varying bed thickness to the model domain (Figure 4) allows the potential for sediment mobility across the wider study area, should the forcing conditions dictate. This subsequently allows the model to assess the fate of any mobile sediment, which will help to inform the siltation assessment of the proposed schemes.

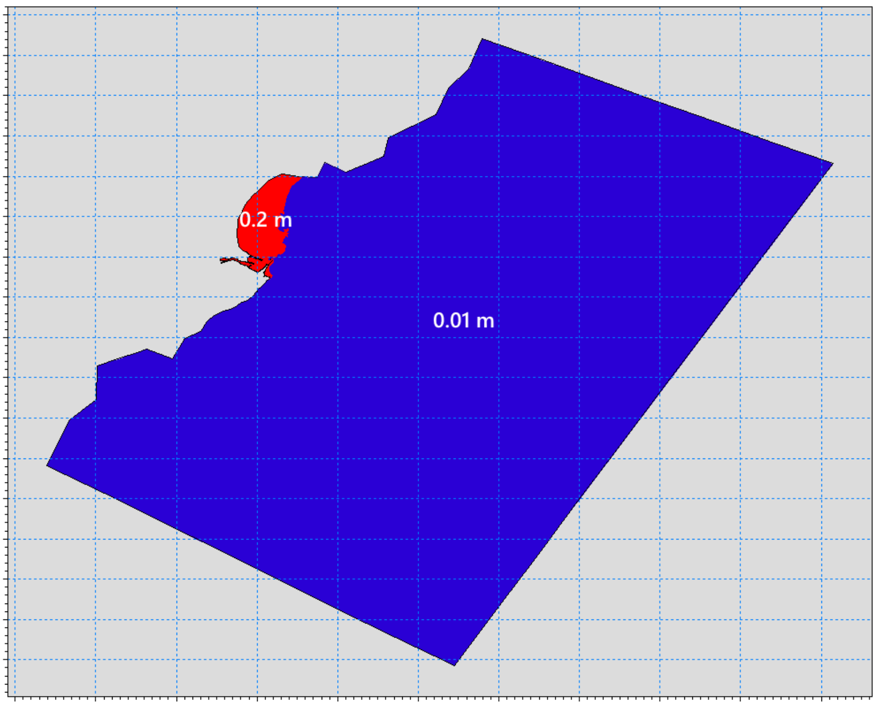

Figure 4. Initial bed thickness for ST module

3 Spectral Wave Model Calibration

3.1 Calibration data

To calibrate the Spectral Wave (SW) model, data was obtained from two static AWAC (Automatic Wave and Current) instruments which were strategically positioned off the Victoria Pier (AWAC 1), adjacent to the navigation approach channel and outside the breakwater, that forms Princess Alexandra Pier, for the proposed Deep-Water Berth (AWAC 2). These instruments were placed *in situ* for a month, recording measurements of key wave characteristics (Hs, Tm and DirM) at hourly intervals. The positions of the instruments are shown, in respect to the harbour, in Figure 5. The full data set and information on the deployment is provided in ABPmer (2019b).

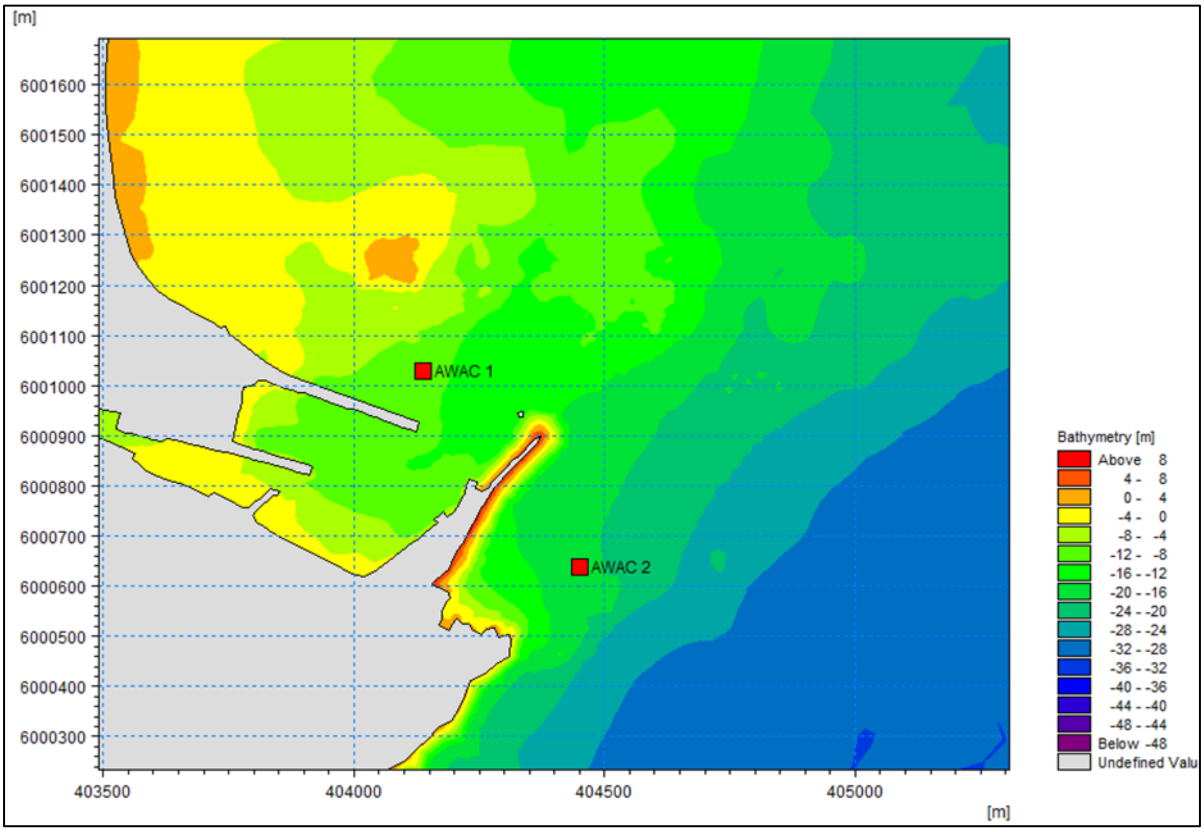

Figure 5. Location of deployed AWAC devices

3.2 Model performance metrics and guidelines

The SW model is assessed to ensure that the model is accurately transforming the wave characteristics forced at the boundaries into the coastal region. The model's performance is quantitatively assessed against the metrics defined in an internal calibration guidance document, maintained by ABPmer (ABPmer, 2014).

3.2.1 Wave metrics and targets

- **Significant Wave Height**. The significant wave height, Hs, is the mean of the highest third of the waves in a time-series of waves representing a certain sea state. This corresponds well with the average height of the highest waves in a wave group. Hs is computed using spectral analysis and is referred to as Hm0;
- **Mean Wave Period**. The mean wave period, Tm, is the mean of all wave periods in a time-series representing a certain sea state; and
- **Mean Wave Direction**. The mean wave direction, DirM, is defined as the mean of all the individual wave directions in a time-series representing a certain sea state.

For waves, guidelines for required model performance at the calibration and validation stage must be specific to a given project due to a varying site providing varied degrees of complexity. There is also a need for a quality review of the data source. The calibration targets for waves are nominally:

- Wave heights within ±10% of observed values;
- Wave periods to within ±20% of observed values; and
- Wave directions to within ±30° of observed values.

Meeting these criteria for at least 90% of position/time combinations is realistically acceptable for most applications.

3.3 Model calibration

To provide a direct comparison to the model output, wave parameters were extracted from the model at the location of each AWAC site. The model's performance is presented against AWAC 1 and AWAC 2 in Figure 6 and Figure 7, respectively.

As shown in Figure 6 during the first five days of the calibration period, the model agreement reduces when the seastate is relatively calm, for example DirM at AWAC 1 where the measured wave direction is variable. This is also apparent towards the end of the calibration period during another calm period. At this later time, both the period and the DirM parameters are not well simulated.

There are three notable (more energetic) wave events that occur during the calibration period. The wave events are replicated well by the model in respect to the magnitude and timing of variation in Hs, T_m and DirM.

The model also reproduces the relatively more sheltered aspect of the AWAC 1 site (in comparison to the nearby but more exposed AWAC 2 site), with very low wave heights at the start and end of the calibration period. Periods of very low measured wave height are often associated with more variable measured Tm and DirM. Apparent differences between modelled and measured Tm and DirM in association with very low wave height are ignored with respect to model calibration.

The calibrated SW model is shown to meet the guidelines set out in Section 3.2.1.

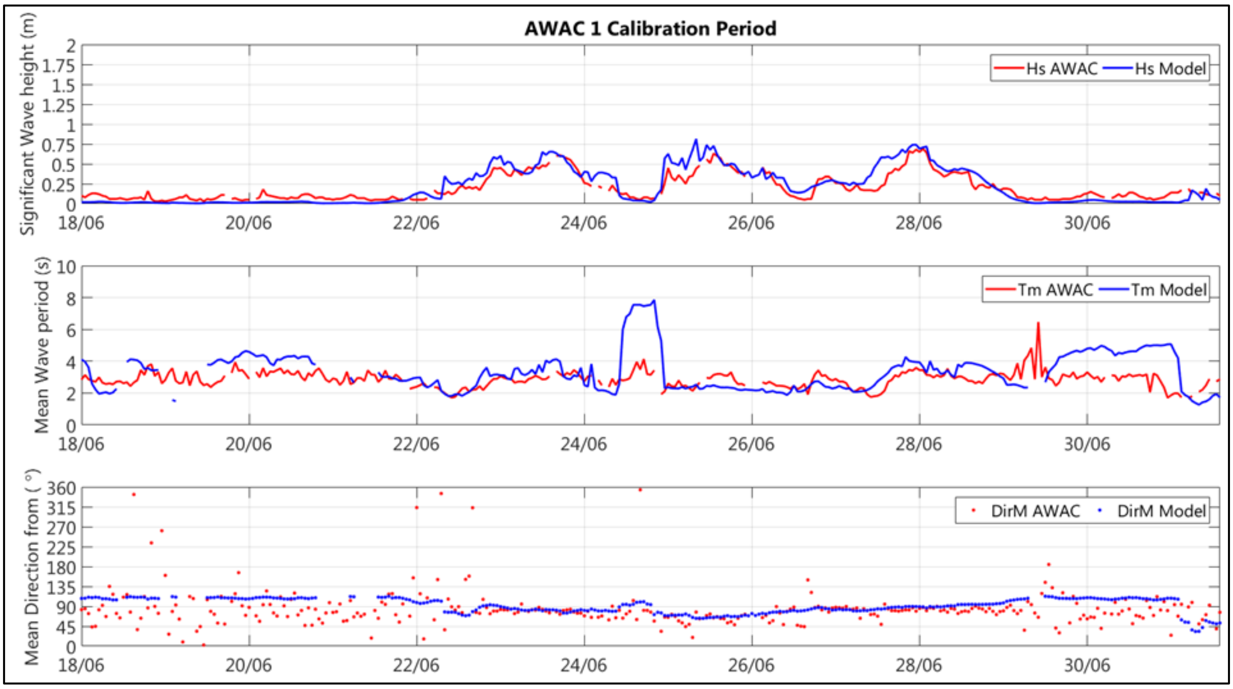

Figure 6. **SW Calibration at AWAC 1**

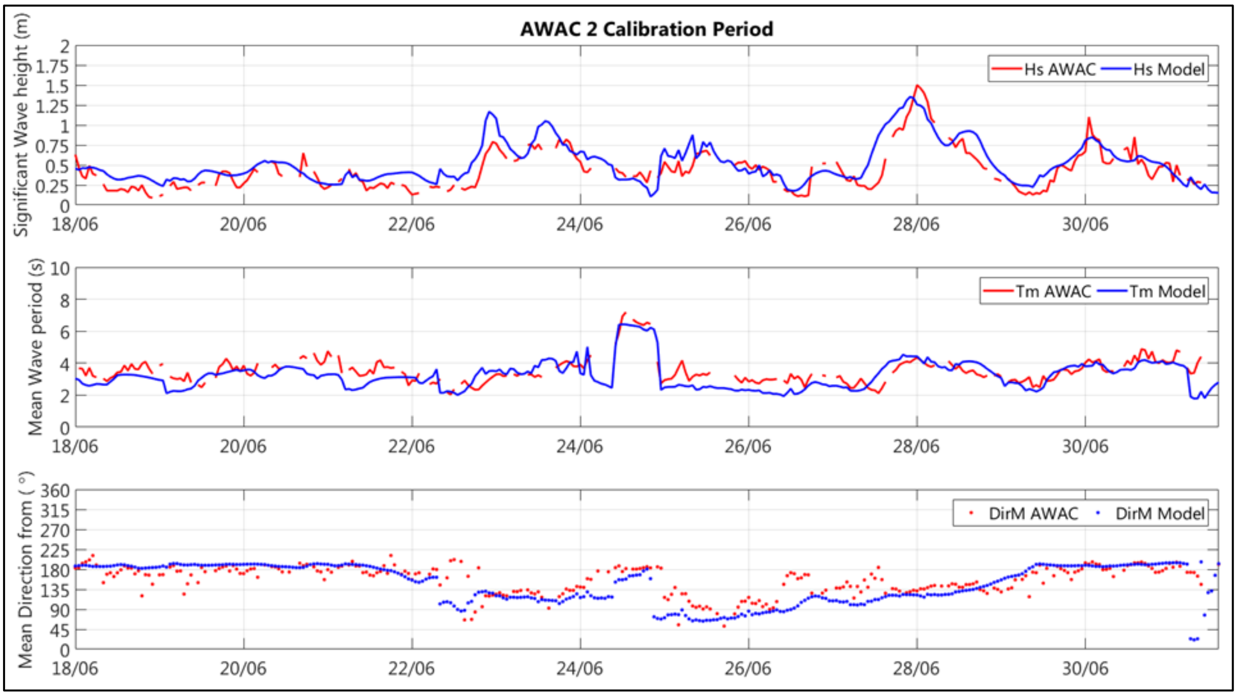

Figure 7. **SW Calibration at AWAC 2**

4 Hydrodynamic Model Calibration

4.1 Calibration data

The calibration of the hydrodynamic (HD) model has been carried out with respect to both water levels and current speed and direction. This was achieved by using time series data collected from the two static AWAC locations as in the SW calibration. In addition, six mobile ADCP (Acoustic Doppler Current Profiler) transects were collected at hourly intervals relative to HW for the spring tide of 19 June 2019. To provide further spatial validation the depth average data from the length of these transects was compared with the corresponding model representation. The locations of the six transects, in relation to the harbour, are shown in Figure 8, which also uses arrows to indicate the vessel direction of movement along each transect.

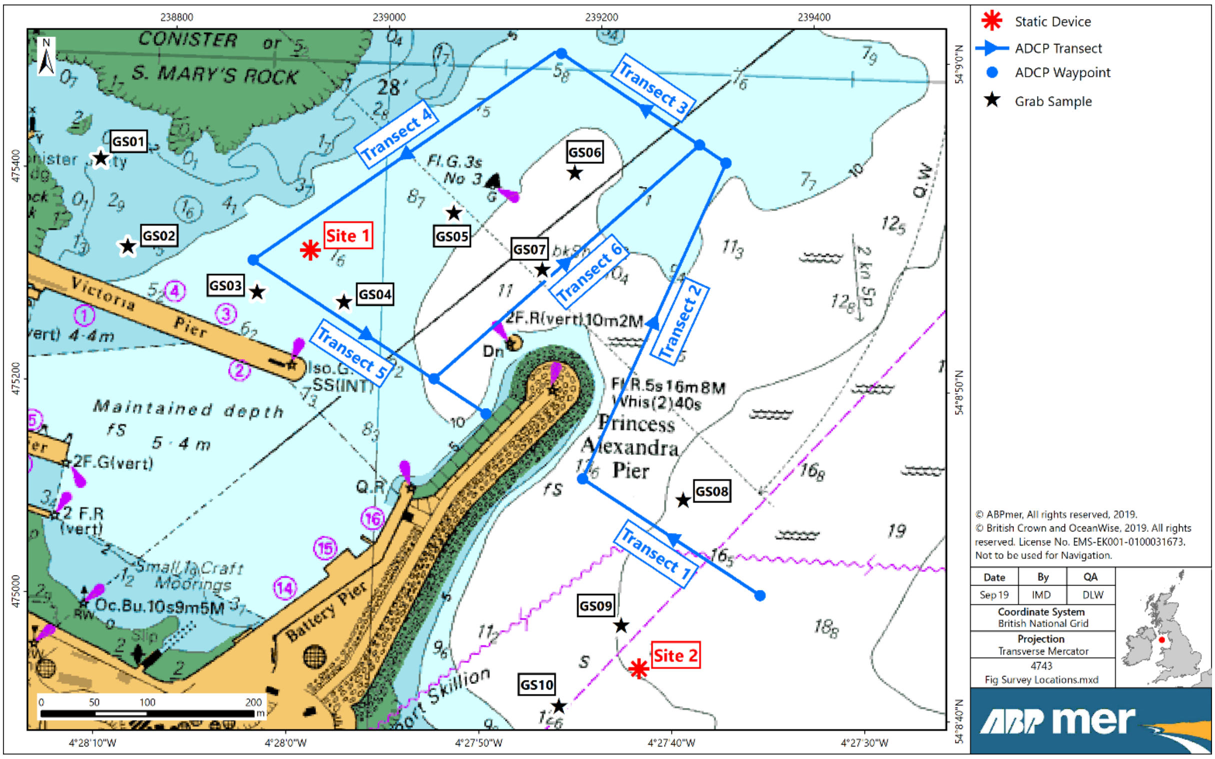

Figure 8. Location of the ADCP transects

4.2 Model performance metrics and guidelines

The target metrics provide a comparative measure for the goodness-of-fit for both temporal and peak features of the calibration data, and results are presented as a range of magnitude difference, percentage difference and Root Mean Square (RMS) difference values. The model's performance is first compared visually against the measured values. This is an objective assessment to ensure that the model is performing suitably, replicating the specific features of the tide at Douglas Harbour. In addition to ensuring that the model replicates the features of the local tide, the model's performance is quantitatively assessed against the metrics defined in an internal calibration guidance document (ABPmer, 2014) This document brings together all relevant literature and guidance on model calibration, including the current Environment Agency standards for hydrodynamic model calibration and validation (Bartlett, 1998). Some discrepancy between the observations and model will always occur due to how the measured data is captured (discrete observations in space and time) compared to the model result (depth and time averaged grid cell values). It is therefore not considered necessary to further justify small discrepancies between modelled and measured values that are within the defined metric targets. The guideline values should be treated as targets and not as pass/fail metrics; Bartlett (1998) stipulates that guideline standards should be achieved for 90% of space-time combinations. Where calibration guidelines are not met, this is acceptable if this can be explained and factored into the interpretation of the model results.

The performance metrics used to assess the hydrodynamic model performance are set out below, along with the recommended guideline values. The target metrics given are generic in nature and have been, where necessary, tailored to apply specifically to meet the needs of the present study.

4.2.1 Water level metrics and targets

- **Mean surface elevation difference (at high and low water).** Calculated as the mean difference (bias) in water level at High Water (HW) and Low Water (LW) (model minus observed value) for a defined period. The mean difference is expressed in both absolute and relative terms as a percentage of the mean tidal range. For reference the tidal range at Douglas Harbour is 6.1 m and 3.0 m on mean spring and mean neap tides, respectively;
- **Mean phase difference at HW**. Calculated as the mean difference in the time of modelled and observed HW over a defined period;
- **Time adjusted fit.** This is the phase correction required to yield the minimum RMS difference between the modelled and observed water levels at all time-steps over a defined period; and
- **RMS surface elevation difference**. Calculated as the RMS difference between modelled and measured water levels at all time-steps over a defined period, after the application of the time adjusted fit.

Recommendations in Bartlett (1998) suggest that for coastal areas mean level differences at HW and LW should be within ±0.1 m, while the percentage differences should be within 10% of spring tidal ranges and 15% of neap tidal ranges and for 90% of the time, explaining any reasons for deviations.

4.2.2 Flow metrics and targets

- **Mean flow speed difference (at peak flood and ebb**). Calculated as the mean difference (bias) in peak flood and ebb current speeds over a defined period. The mean difference is expressed in both absolute and relative terms as a percentage of the maximum measured current speed.
- **Mean flow direction difference (at peak flood and ebb).** Calculated as the mean difference in flow direction recorded at the times of peak flood and peak ebb current speed over a defined period;
- **Time adjusted fit.** This is the phase correction required to yield the minimum RMS difference between the modelled and observed flow speeds at all time-steps over a defined period; and
- **Flow RMS difference**. This value is the RMS of flow speed difference and gives an indication of the agreement between modelled and measured flows throughout the tide and not just at the time of peak flow. This is calculated following the application of the time adjusted fit. Values are calculated over a defined period.

Bartlett (1998) recommends that, for coastal areas, peak modelled speeds (i.e. maximum flood and ebb flows) should be within ±0.1 m/s or ±10-20% of peak observed speeds and for 90% of the time.

The modelled directions should be within ±10° of observed directions in coastal (Bartlett, 1998). Phasing of flows should be within ±15 minutes. RMS scores for flows should be within ±0.2 m/s.

4.3 Model calibration

Calibration of the hydrodynamics has been carried out at both AWAC locations with the calibration period covering a 15-day, neap-spring tidal cycle. Both locations have been analysed visually and statistically following the metrics and guidelines set out in Section 4.2. The full 15-day period is presented for each location, accompanied by a subset of both spring and neap conditions during this period. Figure 9 to Figure 11 are provided for the AWAC 1 location (Victoria Pier Berth) and Figure 12 to Figure 14 for the AWAC 2 location (Deep-Water Berth). A quantitative statistical analysis of both the water-level and flow speed and direction at each location is presented in Table 3 and Table 4, which link directly to the metrics and guidelines for water-levels and flows as stated above in 4.2.1 and 4.2.2.

Table 3. Calibration water level statistics

Location	Mean Surface Elevation Difference at HW		Mean Surface Elevation Difference at LW		RMS Elevation Difference (m)	Time Adjusted Fit (minutes)
	Absolute (m)	Relative* (%)	Absolute (m)	Relative* (%)		
AWAC 1 (QVB)	0.14	3	0.06	2	0.17	3
AWAC 2 (DWB)	0.11	2	0.06	2	0.17	3

* Relative difference as percentage of the mean spring tidal range (6.1 m).

Table 4. Calibration flow statistics.

Location	Mean Flow Speed Difference (m/s)		Mean Flow Direction Difference (°)		Time Adjusted Fit (minutes)	RMS Difference (m/s)
	Flood	Ebb	Flood	Ebb		
AWAC 1	-0.02	-0.04	-8	7	-4	0.06
AWAC 2	0.03	-0.02	**15**	-5	8	0.06

Values in **bold** exceed the guideline range.

The time-series plots in Figure 9 to Figure 14 show that the calibrated model closely replicates the magnitude and timing of variations in water levels, current speed and current direction at locations AWAC 1 and AWAC 2 throughout the calibration period.

The measured current speeds and directions (against which the model is being compared) exhibit short term variability due to naturally occurring flow shear and turbulent processes. Measured current direction can also become highly variable in association with very low current speeds, when the actual direction of the water motion is not well defined and is at the limit of the sensitivity of the measurement device. The model is not expected to directly reproduce the detail of these apparent measured fluctuations and will rather return a more consistent value based on the expected longer term average water motion.

At AWAC 1, the model correctly reproduces the observed pattern of relatively low current speeds (<0.2 m/s) and extended late flood/HW/early ebb flow dominance. At AWAC 2, the model also correctly reproduces the observed pattern of relatively higher current speeds and extended ebb flow period, and relatively lower current speeds and shorter flood flow period. Minor differences in the detail of current speed and direction within these general patterns, especially in association with very low current speeds, are not considered to be a limitation of the model. Despite the level of noise in the measured data, the statistical analysis in Table 3 and Table 4, of the model calibration results shows that the mean difference (bias) between the modelled and measured high and low water levels is less than 3%. Mean flow speed differences are less than ±0.04 m/s and directions are generally within the metrics guideline of ±10°.

The calibrated HD model is shown to meet the guidelines set out in Sections 4.2.1 and 4.2.2.

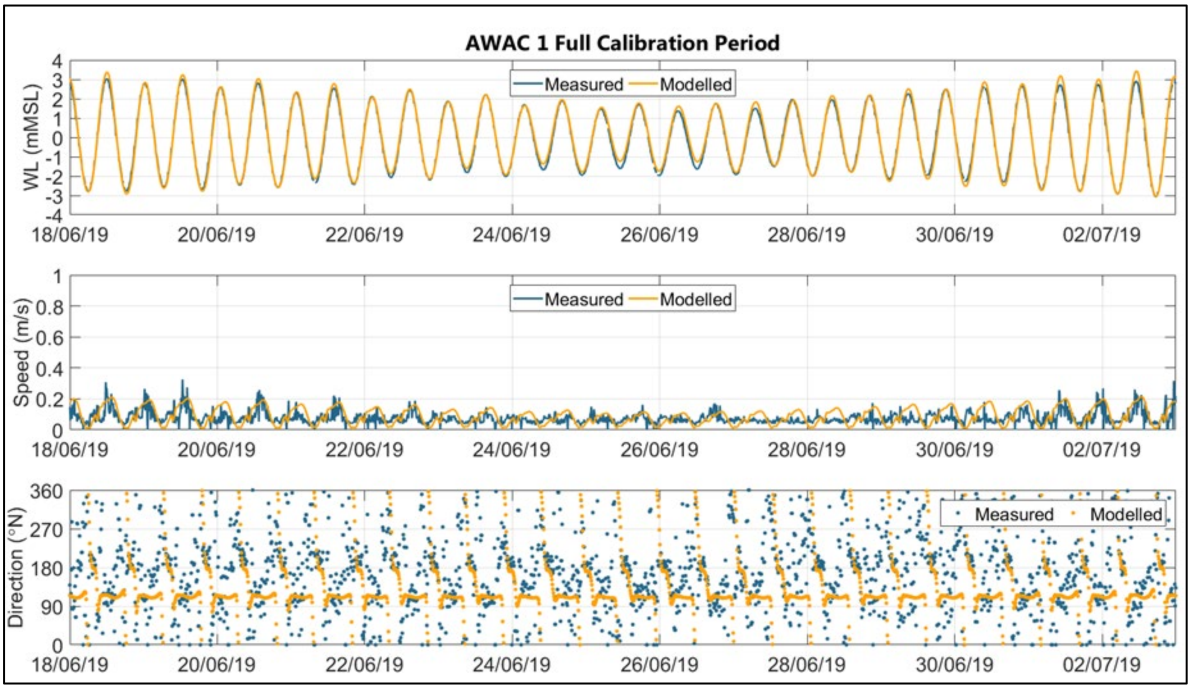

Figure 9. **AWAC 1 across the full 15-day calibration period**

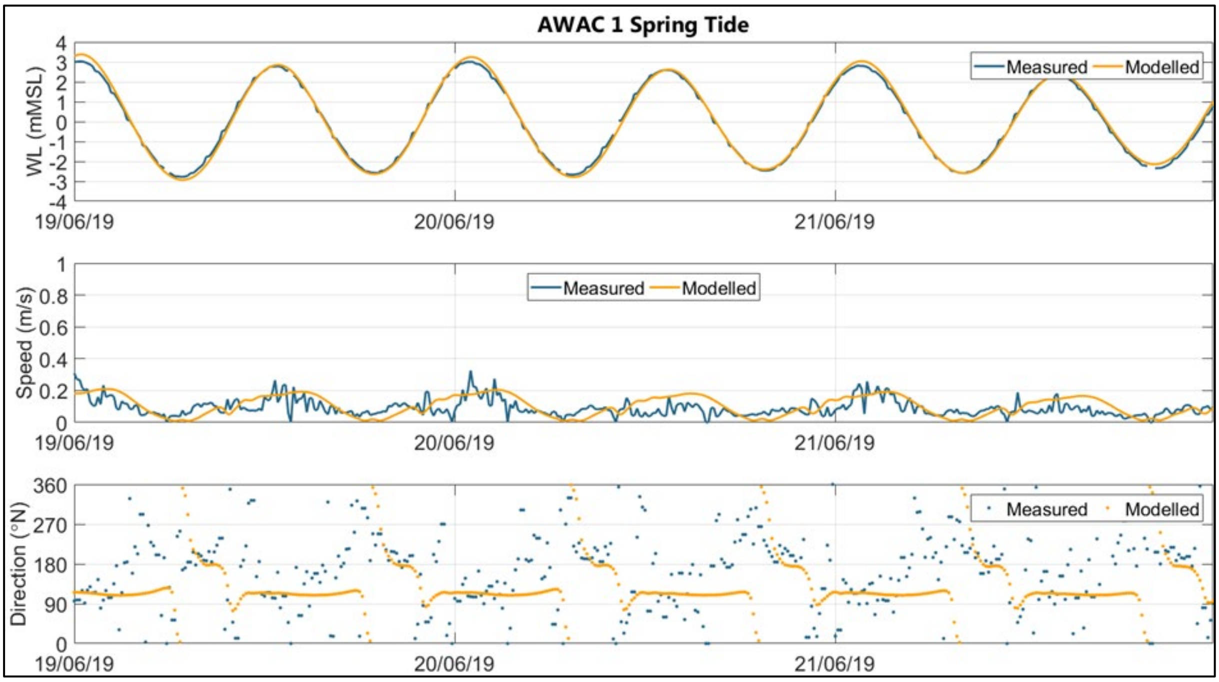

Figure 10. **AWAC 1 calibration during spring tides**

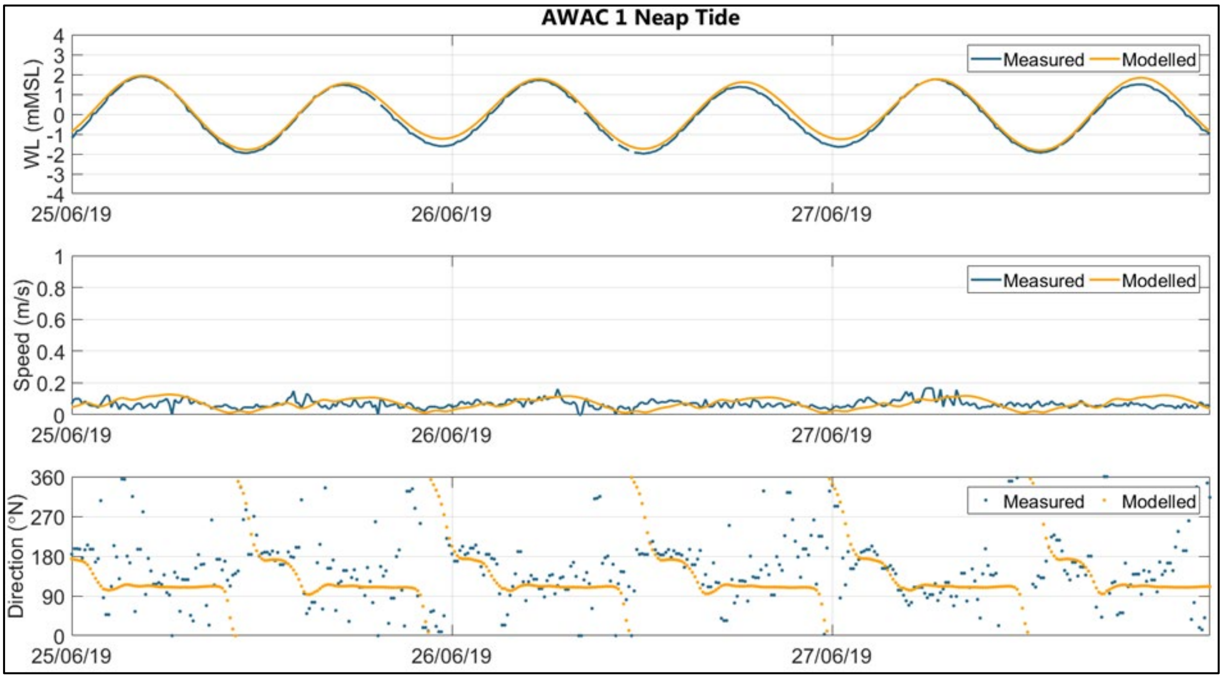

Figure 11. AWAC 1 calibration during neap tides

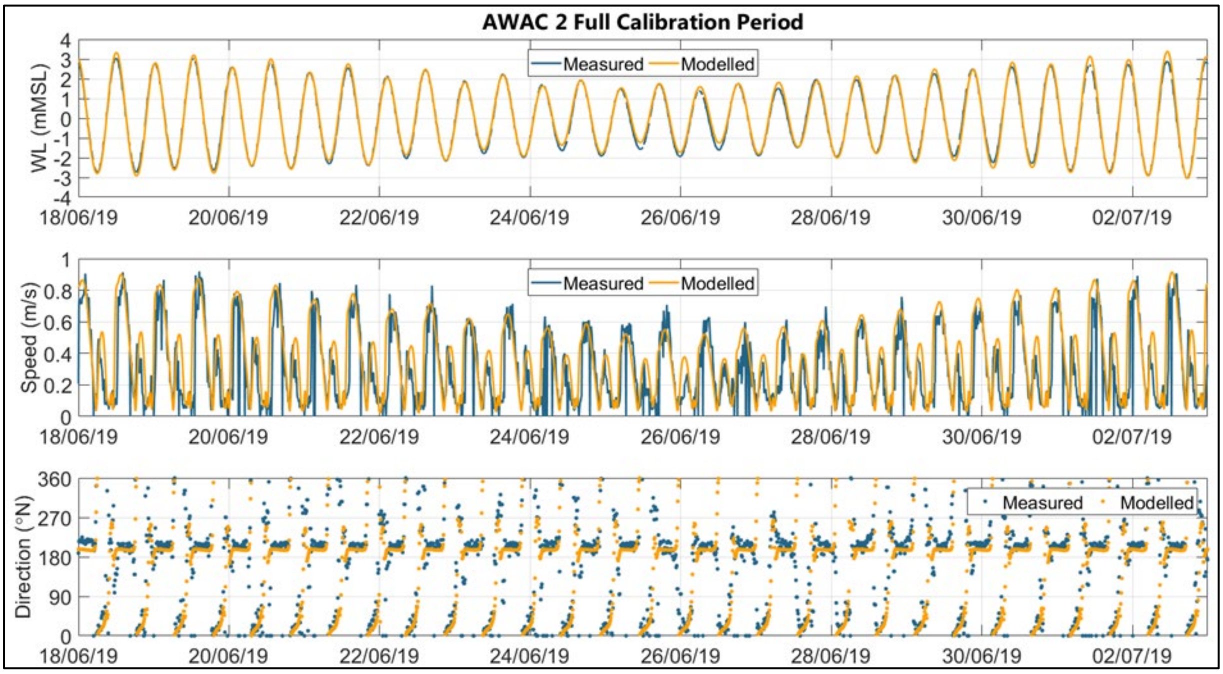

Figure 12. AWAC 2 across the full 15-day calibration period

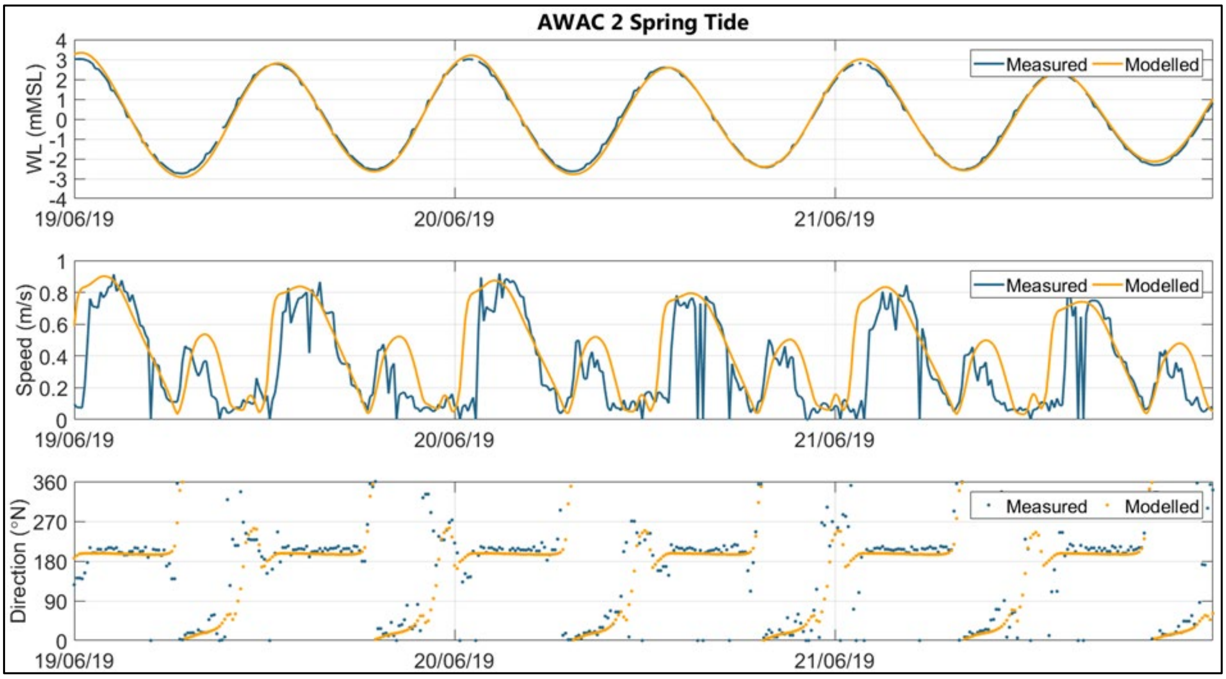

Figure 13. **AWAC 2 calibration during spring tides**

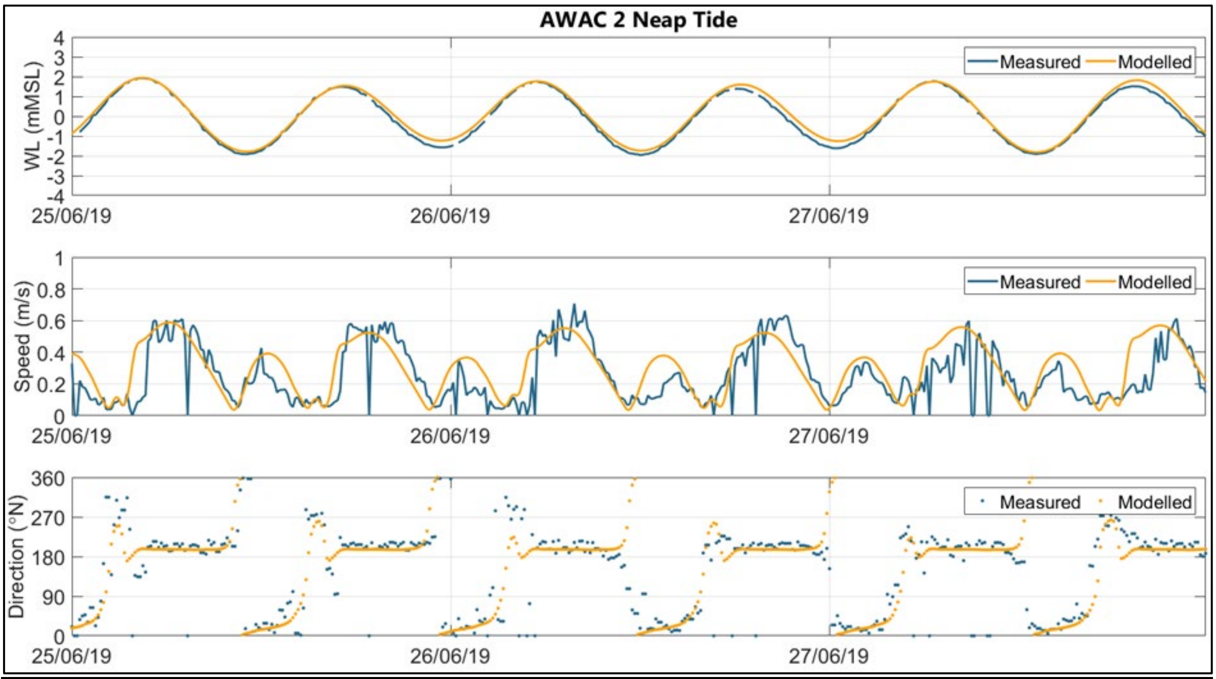

Figure 14. **AWAC 2 calibration during neap tides**

4.4 Model validation

The validation of the HD model has been completed by comparing depth averaged, mobile ADCP transects to the equivalent extractions from the HD model. Example transect comparisons are shown for the times on the flood (HW–1 hour) and ebb (HW +2 hr) for the spring tide in Figure 15 and Figure 16, respectively. The full comparison set at hourly intervals relative to HW is shown in Appendix A.

Figure 15 on the flood, for the most part, shows good agreement of the trends along each transect (see Figure 8 for locations and direction of travel along each transect). It is noted that the field measurements recorded in close proximity to the end of Princess Alexandra Pier show natural random directional instability during periods of very slow flows, whereas the model directions are more consistent.

Figure 16 on the ebb shows the model transect comparison with the field data is improved compared to the flood. This plot indicates three areas where the model does not completely replicate the field data:

- On Transect 2 the model shows a 'smoother' transition in flow speeds compared to the field data as the transect passes north of the Princess Alexandra Pier. The plot also shows the instability in the field directional data noted on the flood tide. This is a feature in the calibration on all tides.;
- On Transect 4, which passes close to the shallow edge of St. Mary's Rock, the model shows reduced flow speed and variance or reversal in directions centred around chainage 110 m. This is apparent throughout the tide. This discrepancy is where the model predicts a stronger effect of shallow local bathymetry at the edge of St. Mary's Rock, causing a wake area with weak flow recirculation which is not so strongly apparent in the measured data;
- Flow speeds are under-represented in the model at Transect 5 but generally follow the pattern for a reduction in flow approaching Princess Alexandra Pier. This discrepancy, however, only occurs for a short time as it is not apparent for the rest of the ebb tide.

Overall, the calibration and validation is of good quality and illustrates that the model will produce reliable evidence regarding the effects of the proposed new berth scenarios. Care will be required in interpreting the development effects with respect to directions around the end of Princess Alexandra Pier as the model cannot be expected to accurately reproduce the natural random instability of slow flow directionality in this area. The model correctly reproduces the relatively low current speeds (<0.2 m/s) experienced in many parts of the study area. Differences in modelled and measured patterns of current direction in association with such low current speeds are not considered to be a limitation of the model.

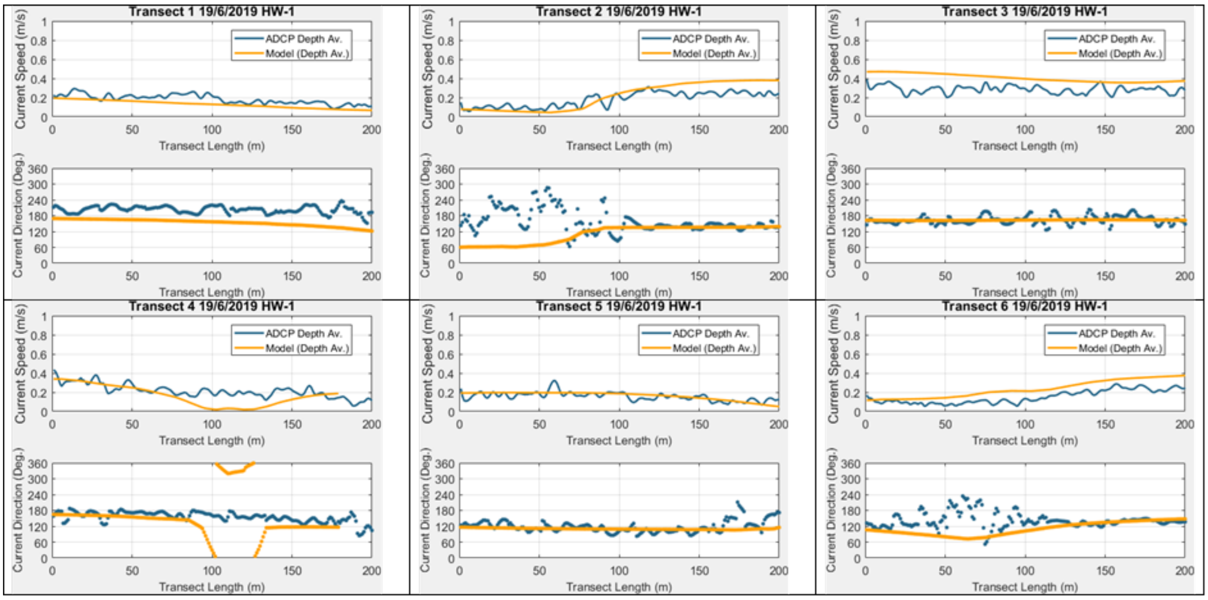

Figure 15. Modelled and ADCP measured transect flow comparison – peak flood, spring tide (HW -1 hr)

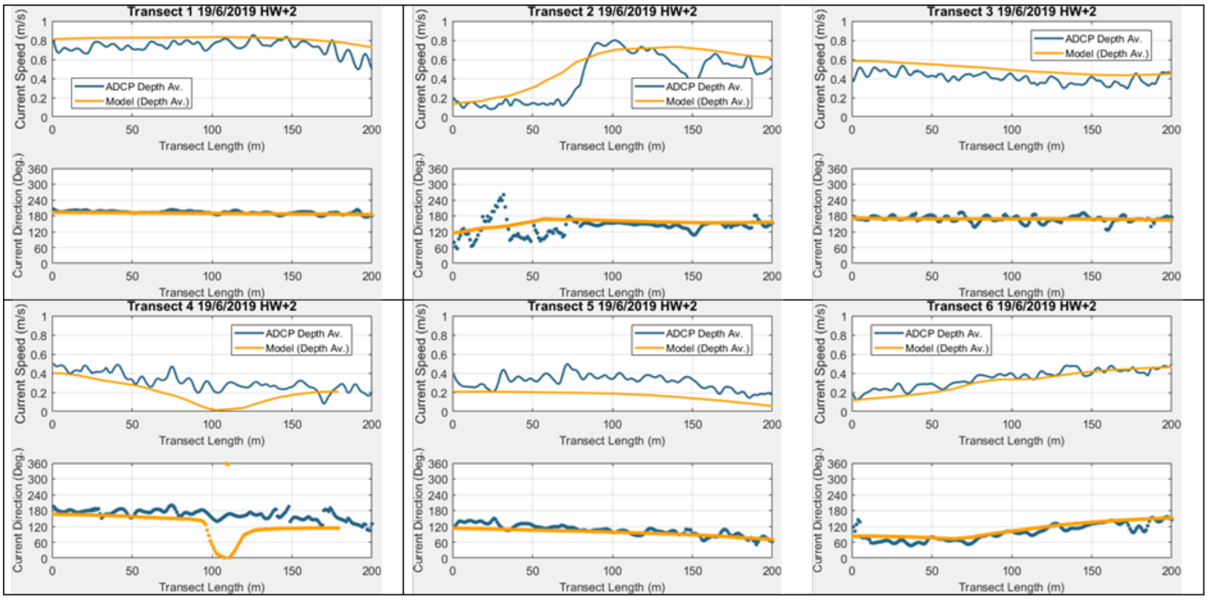

Figure 16. Modelled and ADCP measured transect flow comparison - peak ebb, spring tide (HW +2 hr)

5 Sand Transport (ST) Model Verification

The following sections describe the approach taken to verify the Sand Transport (ST) module, using available measured data from the study area.

5.1 Verification data

A verification of the predicted sand transport has been undertaken to assess the ability of the model to replicate the understanding of the sediment regime across the Douglas Harbour study area.

The time and spatially varying current speeds and directions from the calibrated HD model are used in conjunction with standard empirical relationships to drive sediment transport within the ST model. The performance of the HD model used to drive the ST model is validated in Section 4.

Measured suspended sediment concentration data was collected during the project oceanographic survey (and reported in ABPmer 2019b). The survey also collected water samples for laboratory analysis of total suspended solids. In general, very little fine sediment was observed in suspension, with concentrations generally less than 10 mg/l observed across the sample locations.

5.2 Model performance

Given the low concentrations observed throughout the survey and water sampling campaign, along with a lack of a distinct temporal trend in material suspension (e.g. in response to flood-ebb or spring-neap tidal cycles), a ‘standard’ calibration of the ST model output against a measured timeseries of varying SSC values is not valid for this study. Instead, a comparison of the model performance has been made against the conceptual understanding of the local sediment regime in and around Douglas Harbour.

As reported in ABPmer 2019a, in the vicinity of Victoria Pier the bed sediment is almost entirely well sorted sand with a median grain size (d50) of *circa* 200 µm. Towards the east end of Victoria Pier there is evidence of a small proportion of mud (less than 3%) and gravel (up to 14.5%) present towards the deeper water areas. The finer muds are likely fluvial in origin and are likely to be a temporary or transient deposit. The gravel is likely to be sourced from local coastal erosion processes and is likely to be normally largely immobile.

In the deeper water of the Harbour Approach Channel, seabed sediments vary from predominantly sand on the western side of the channel to predominantly gravel in the deeper areas (below 10 mCD). In the gravel area the median grain size ranges from 9 to 27 mm, with a finer sand component of up to around 30%. The sand in this location is generally similar in character to that found in the shallower regions.

East of Princess Alexandra Pier in depths greater than approximately 15 mCD, the sea bed is generally 'hard', compacted gravel, which was difficult to sample and contained very little fine sediment. The particle size distribution was similar to the gravelly sediments found within the Harbour Approach Channel. Towards the southern approaches, where depths start to again shallow the bed material comprises exclusively of sand, however with a much coarser grain size than the Victoria Pier area, with a d50 of 330 µm.

This analysis of the spatial distribution of the character of the sea bed suggests there is little mobile sediment in the area to be mobilised by tidal currents and/or waves to form a supply for wider sediment movement. The offshore location in particular, where gravel dominates the bed, indicate non-mobile material that is compacted, forming an 'armour' layer to the bed. In these regions, most fine material is either trapped below the immobile armour layer or removed (winnowed) from surficial sediments over time.

As a result, we would expect a sand transport model to show only very limited material in suspension, with any areas of sediment movement limited to bedload motion in and around the shallow inshore areas.

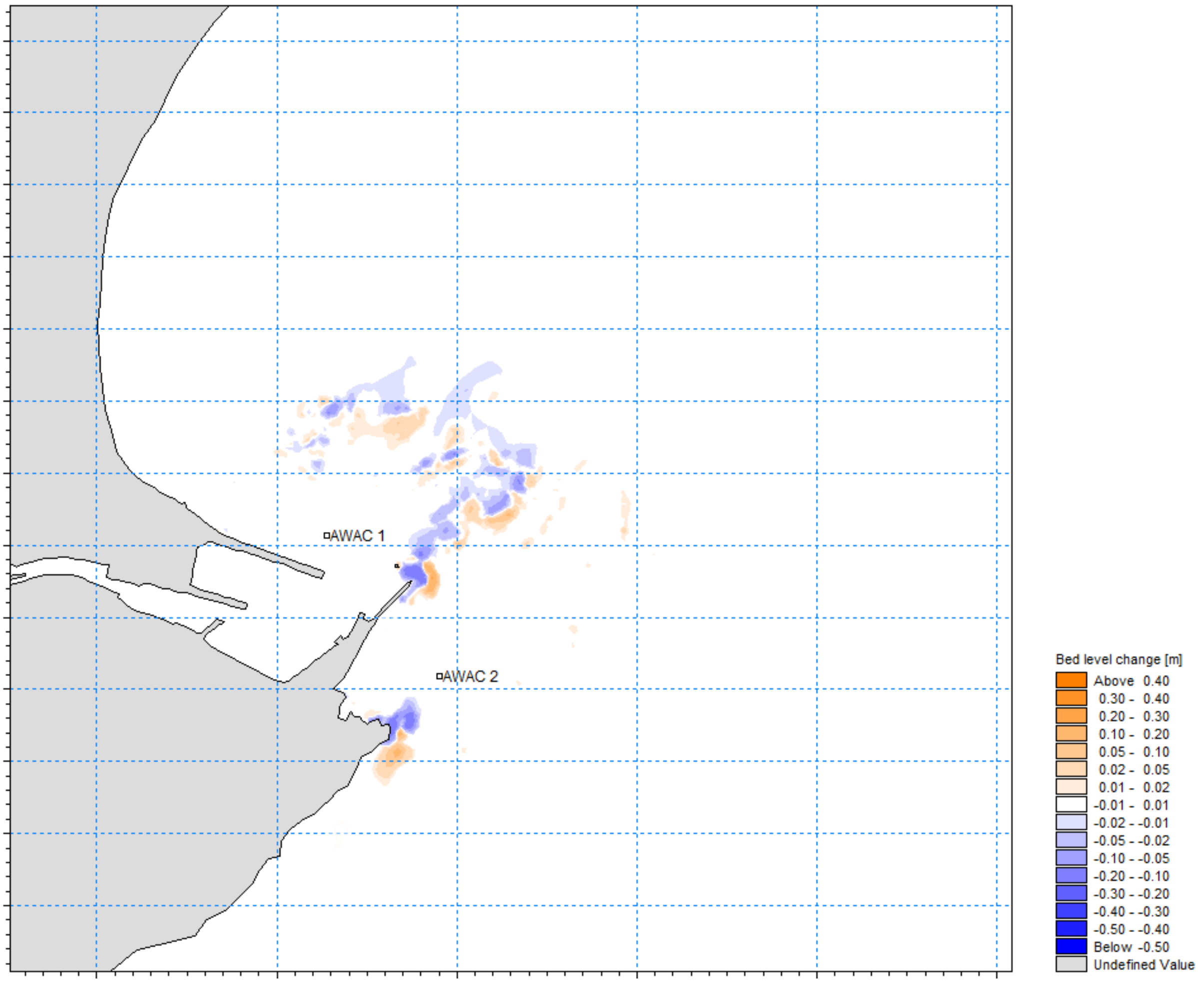

Figure 17. Predicted bed level change over a mean spring-neap tidal cycle, assuming the initial bed thickness across the study area, shown in Figure 4

The ST model also provides predictions of suspended sediment concentration (SSC). At AWAC 1, no transport in suspension is predicted throughout the tidal cycle. As shown in Figure 18, at AWAC 2, relatively low levels of SSC (up to 5-10 m mg/l) are predicted in association with the time of, and in proportion to the magnitude of, peak current speeds on each ebb tide. At AWAC 2 levels of SSC are consistently negligible (<2 mg/l) throughout flood tides, and generally lower at times other than peak flow on ebb tides.

The predicted SSC timeseries shown in Figure 18 assumes the predicted depth-averaged SSC value (as output from the model) is maintained within 0.5 m of the bed. The modelled values show peak SSC's of around 16 mg/l on the larger spring tides, dropping to less than 1 mg/l on neaps. This is similar in both absolute and relative terms to the low concentrations of suspended sediments observed during the oceanographic survey campaign.

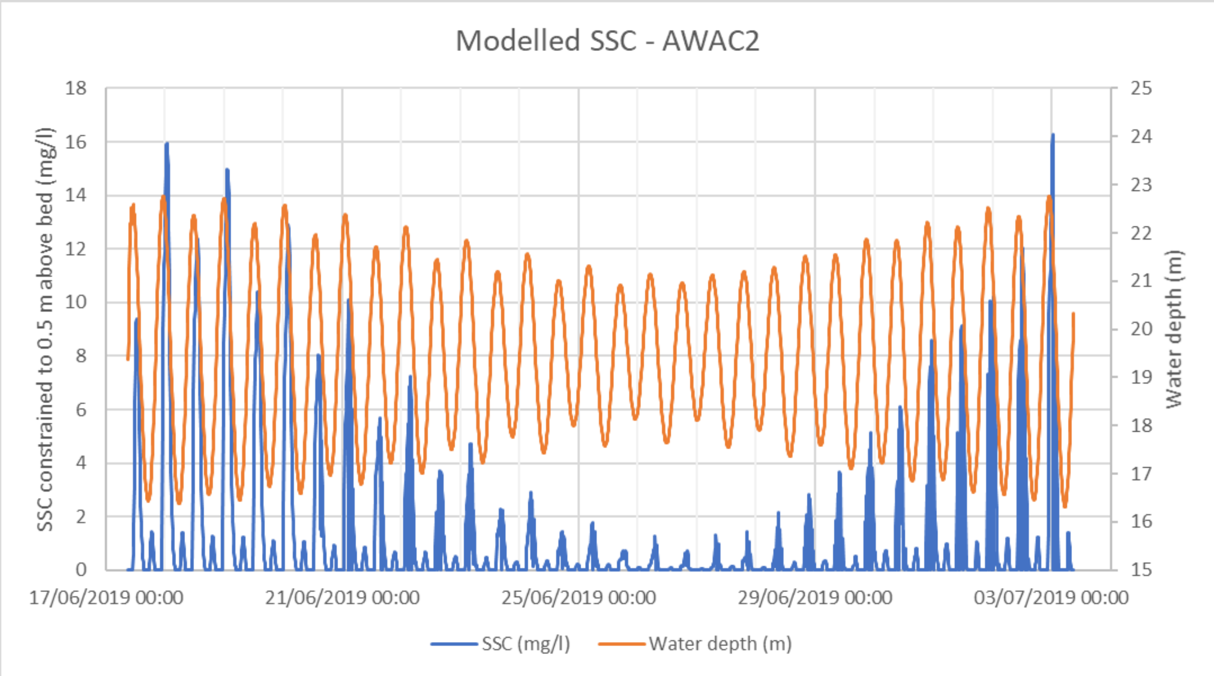

Figure 18. Modelled SSC at AWAC 2, over a spring-neap tidal cycle

Overall, based on the available sediment data, and the accompanying conceptual understanding of the sediment regime across the study area, the ST model is considered to be performing well in describing the sediment transport regime within the study area and will provide a realistic basis to assess the potential effects of the proposed schemes on sediment transport processes.

6 References

ABPmer (2014). Numerical Model Calibration and Validation Guidance. ABP Marine Environmental Research Ltd, Report No. QA.0020 v1.0, September 2014.

ABPmer (2015). Wave Modelling of Proposed Lifeboat Berth, Douglas Harbour – Isle of Man. Report ABP Marine Environmental Research Ltd, Report No. No. R.2507, September 2015.

ABPmer, (2017). SEASTATES North West European Continental Shelf Tide and Surge Hindcast Database, Model validation report, ABPmer Report No. R.2784. A White Paper, March 2017. Available from https://www.seastates.net/downloads/.

ABPmer (2019a). Proposed Deep-Water Berth, Douglas Harbour – Sediment and Navigation Studies – Main Study Report. ABPmer Report No. R3270.

ABPmer (2019b). Proposed Deep-Water Berth, Douglas Harbour – Sediment and Navigation Studies – Hydrodynamic survey and seabed sediment sampling. ABPmer Report No. R3277.

ABPmer SEASTATES: www.seastates.net

Bartlett, J. M. (1998). Quality control manual for computational estuarine modelling, R&D Technical Report W113. Environment Agency.

7 Abbreviations/Acronyms

ADCP	Acoustic Doppler Current Profiler
ALHS	Aspect Land & Hydrographic Surveys Ltd
Av	Average
AWAC	Acoustic Wave and Current
CD	Chart Datum
DHI	Danish Hydraulic Institute
DirM	Mean wave coming direction
DirSD	Standard deviation of wave coming direction
FM	Flexible Mesh
HD	Hydrodynamic
Hs	Significant wave height
HW	High Water
LiDAR	Light Detection and Ranging
LW	Low Water
MSL	Mean Sea Level
RMS	Root Mean Square
SSC	Suspended Sediment Concentration
ST	Sand Transport
SW	Spectral Wave
Tm	Spectral mean wave period
Tp	Spectral peak wave period
UK	United Kingdom

Cardinal points/directions are used unless otherwise stated.

Oceanographic conventions are used for direction (currents TOWARDS, waves and wind FROM).

SI units are used unless otherwise stated.

Appendix





Innovative Thinking - Sustainable Solutions

A Comparison of Modelled and ADCP Transect Flows

This appendix consists of comparative plots showing modelled against measured flow speeds (m/s) and direction (ºN) from six mobile ADCP transects. These transects were conducted at hourly intervals across a spring tide (see Figure A1). These figures accompany the HD validation as described in Section 4.4.

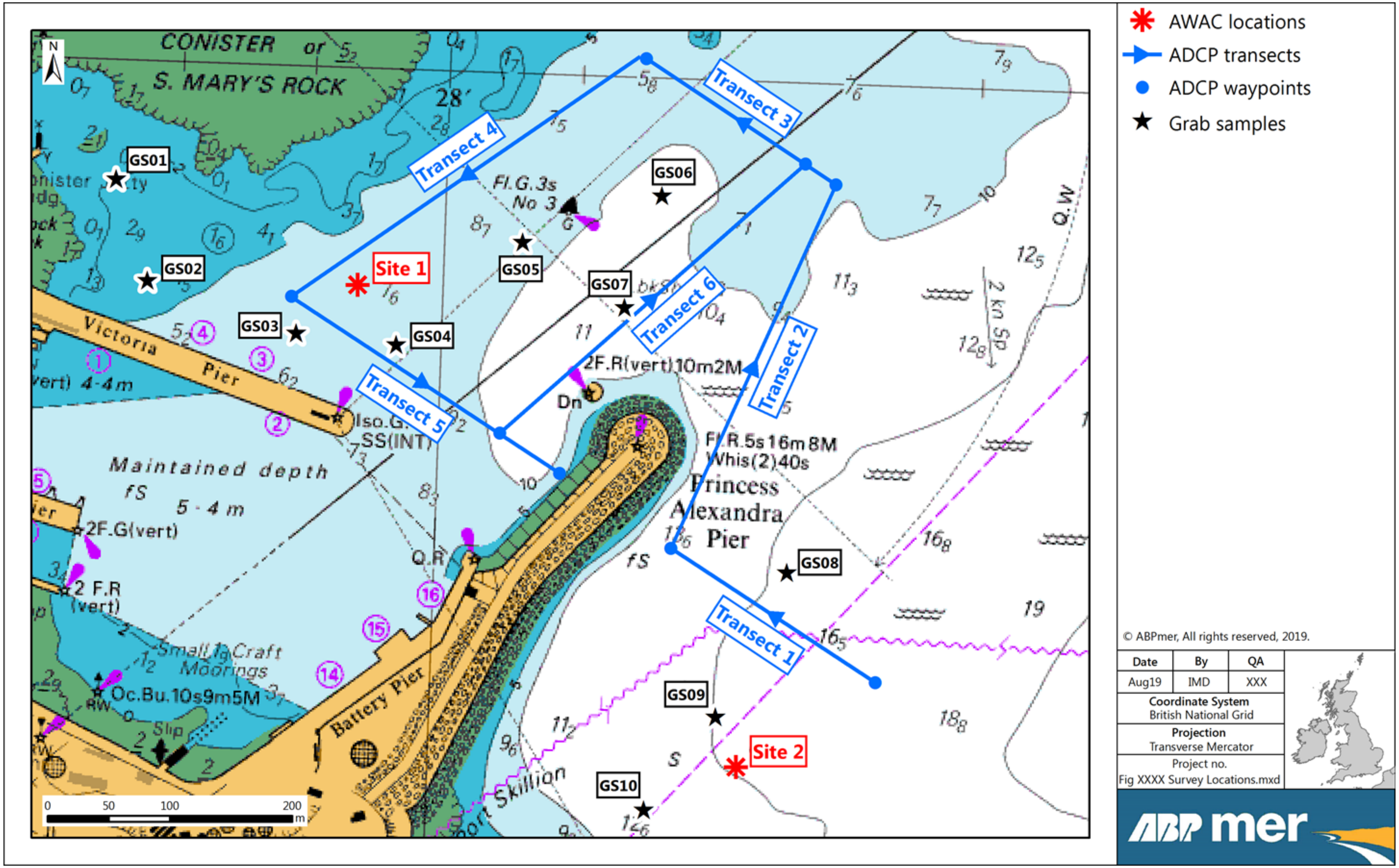

Figure A1. **Location and direction of the mobile ADCP transects**

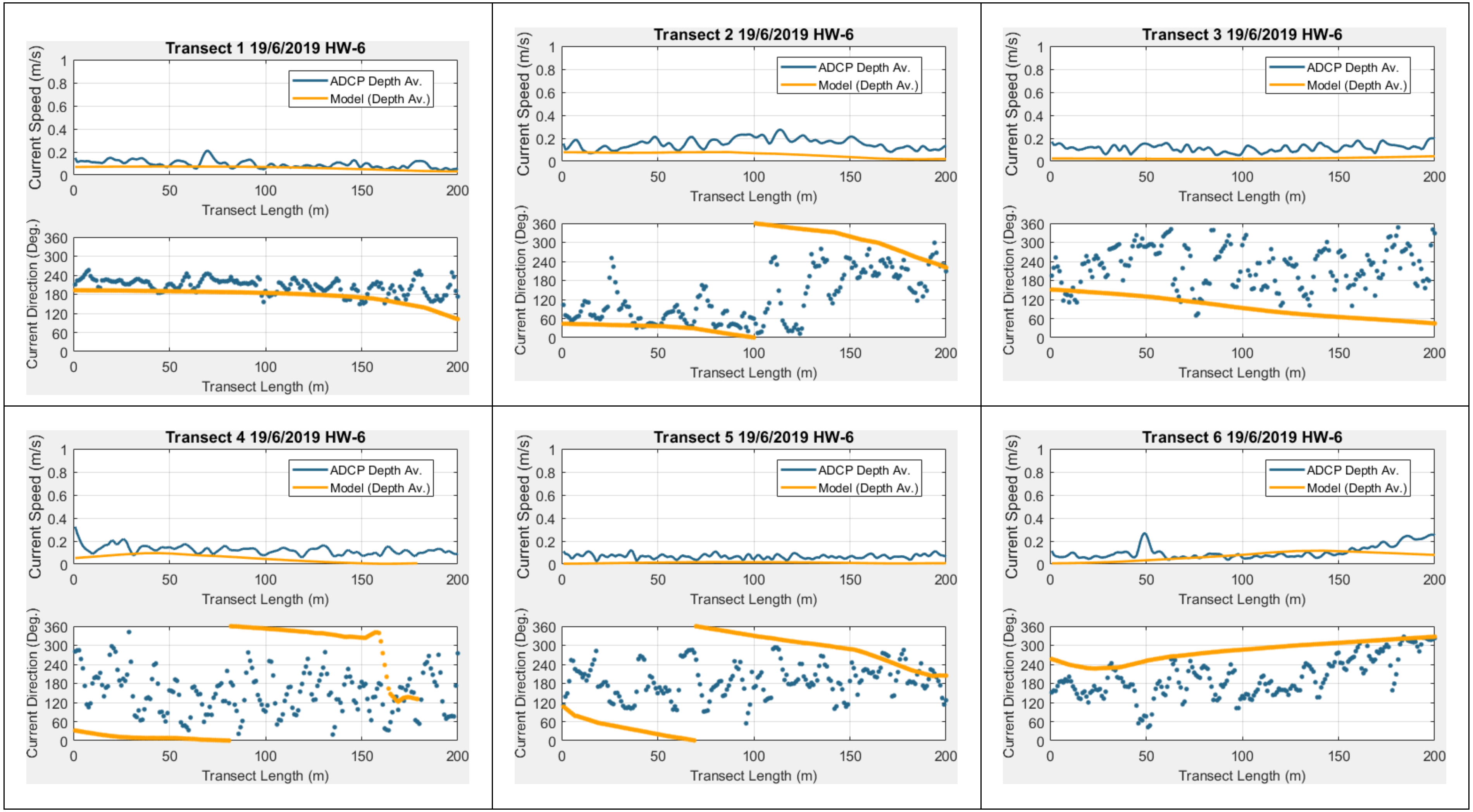

Figure A2. Model and ADCP measured flow comparison - FLOOD - Spring tide: 19/06/2019 HW -6 hr

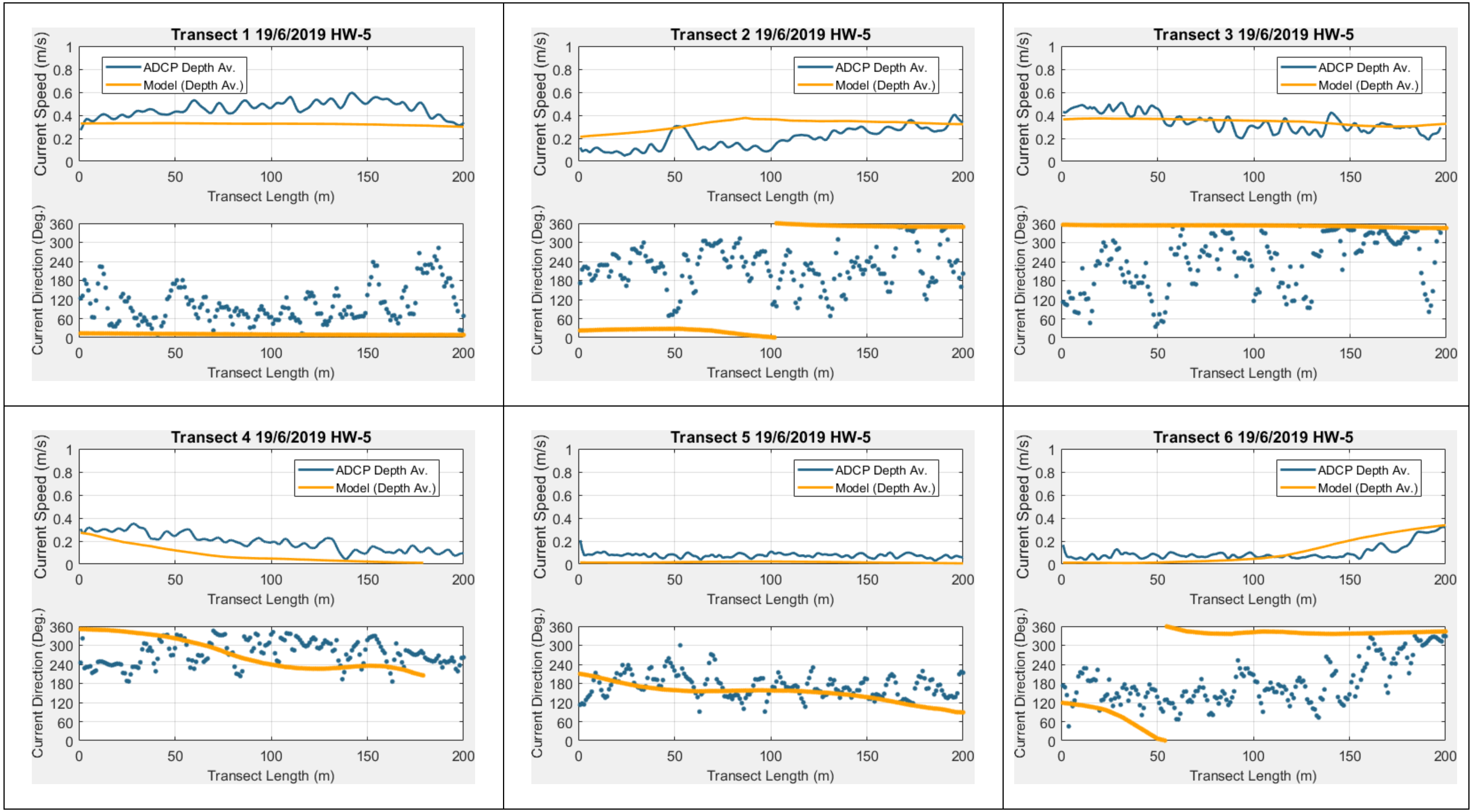

Figure A3. Model and ADCP measured flow comparison - FLOOD - Spring tide: 19/06/2019 HW -5 hr

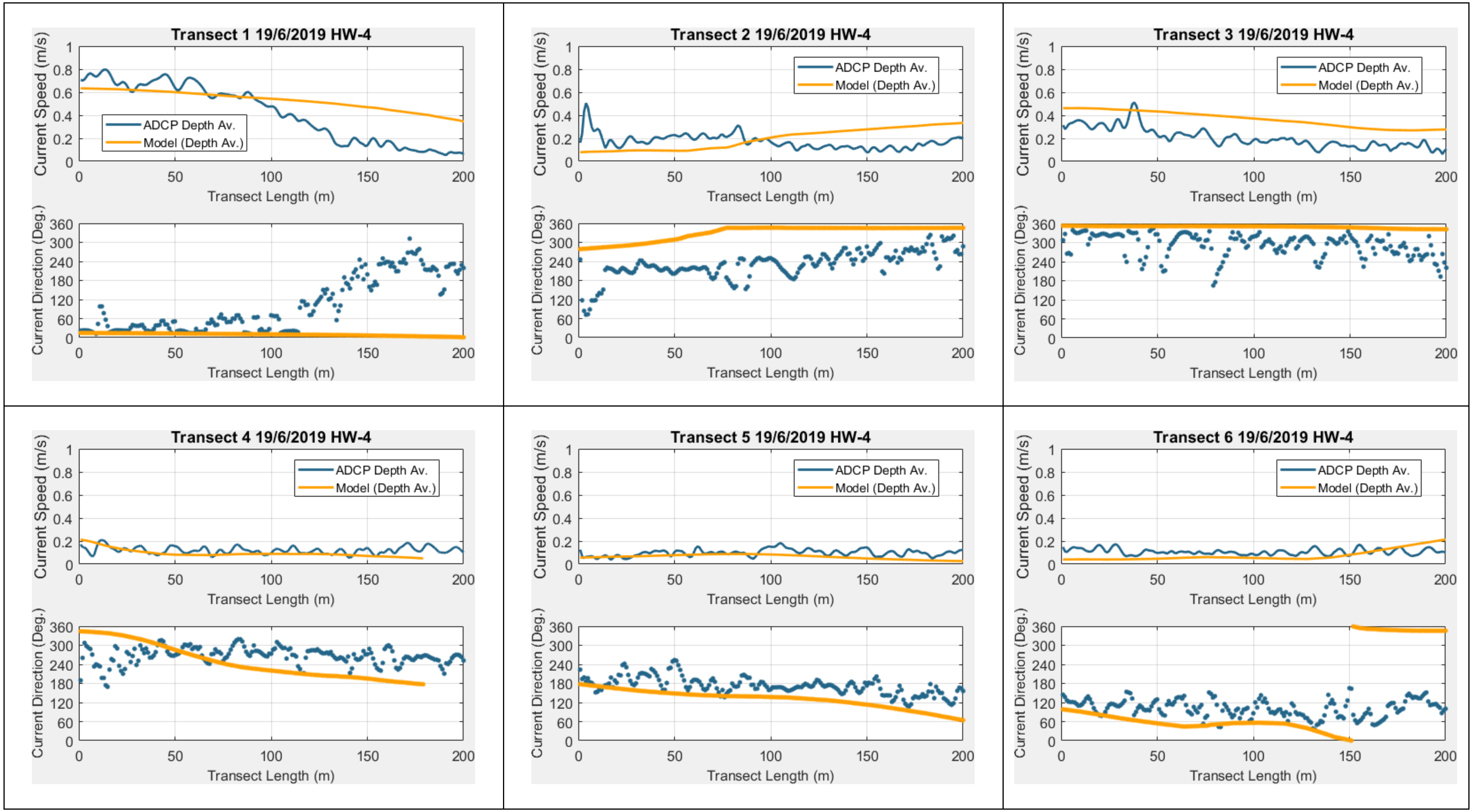

Figure A4. Model and ADCP measured flow comparison - FLOOD - Spring tide: 19/06/2019 HW -4 hr

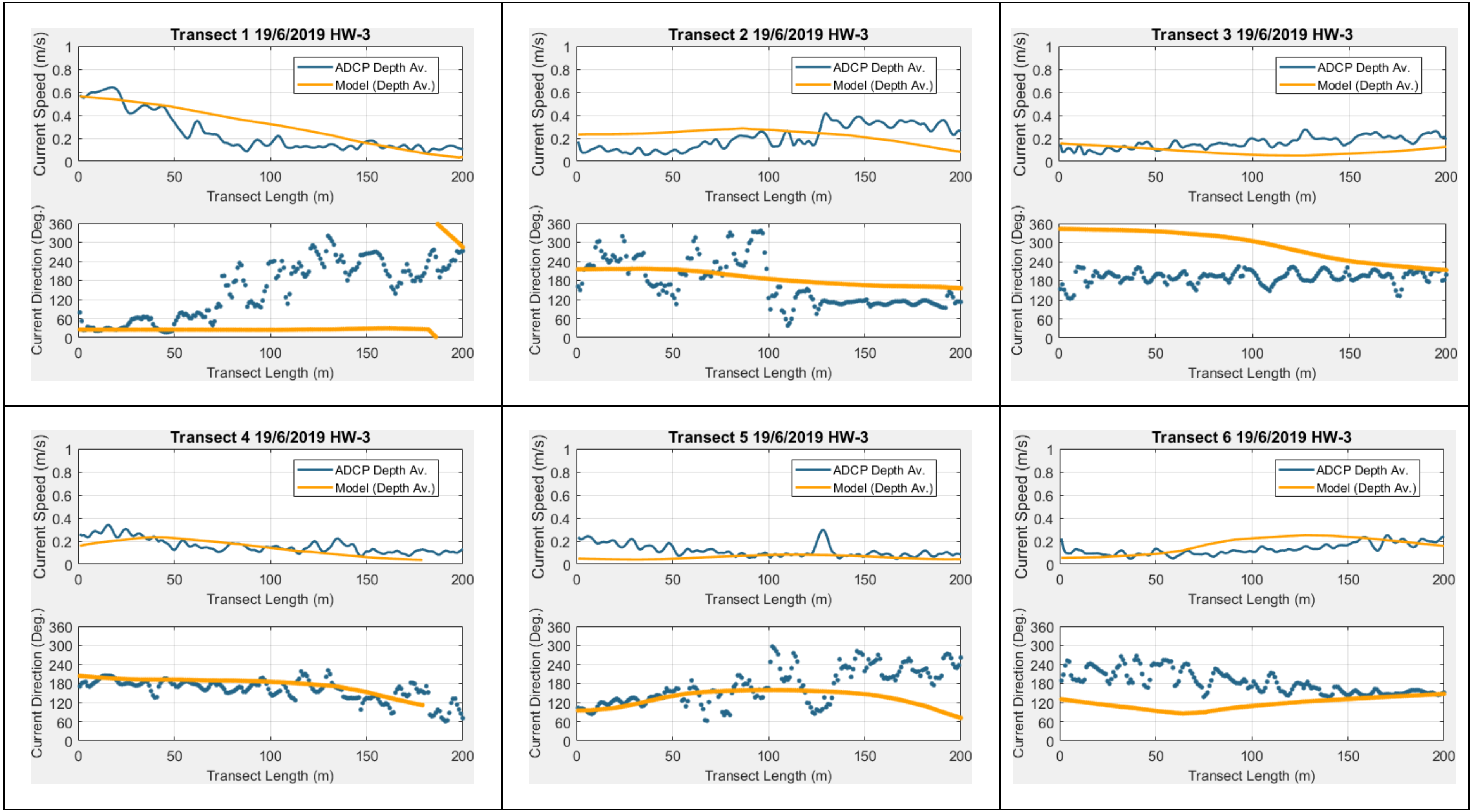

Figure A5. Model and ADCP measured flow comparison - FLOOD - Spring tide: 19/06/2019 HW -3 hr

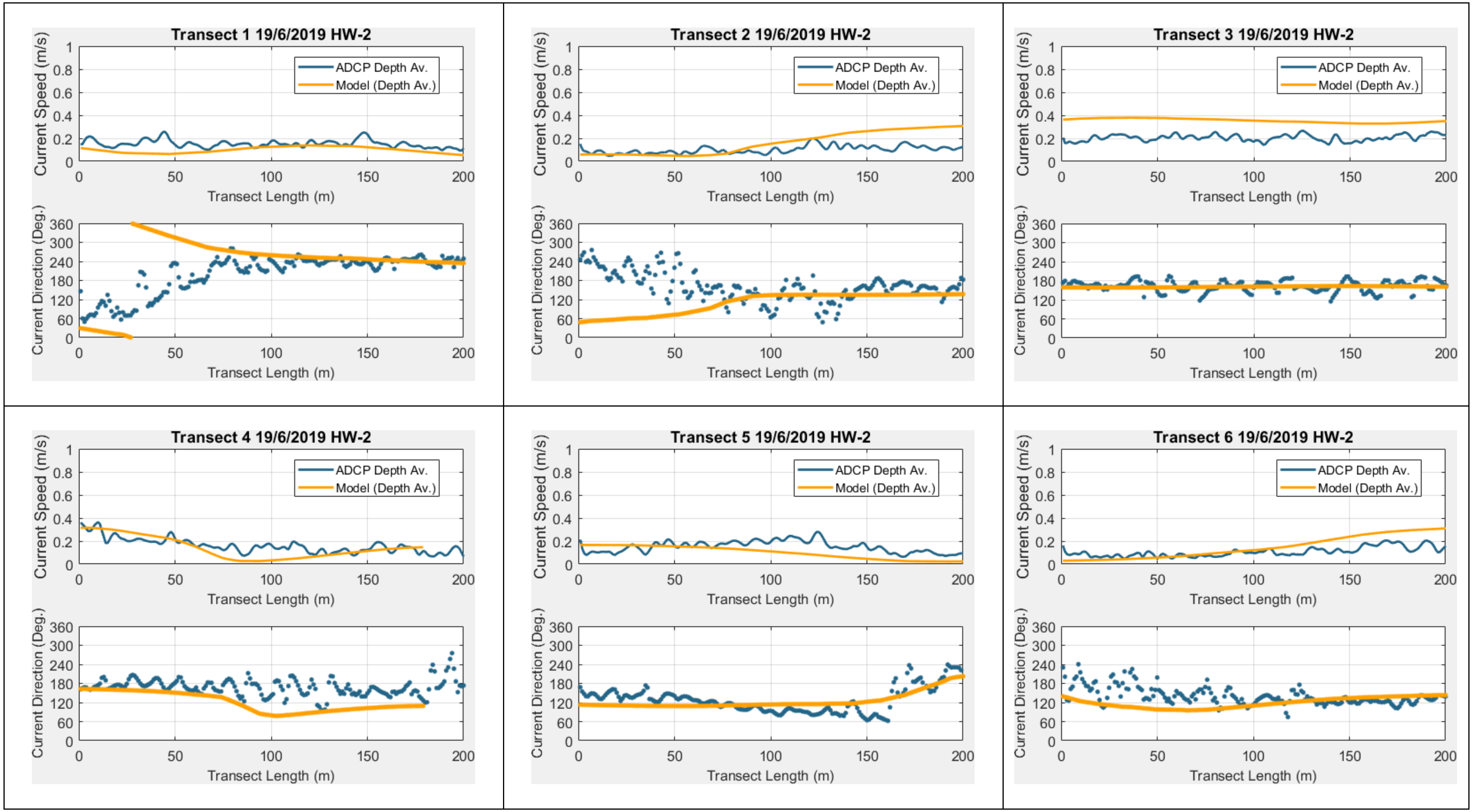

Figure A6. Model and ADCP measured flow comparison - FLOOD - Spring tide: 19/06/2019 HW -2 hr

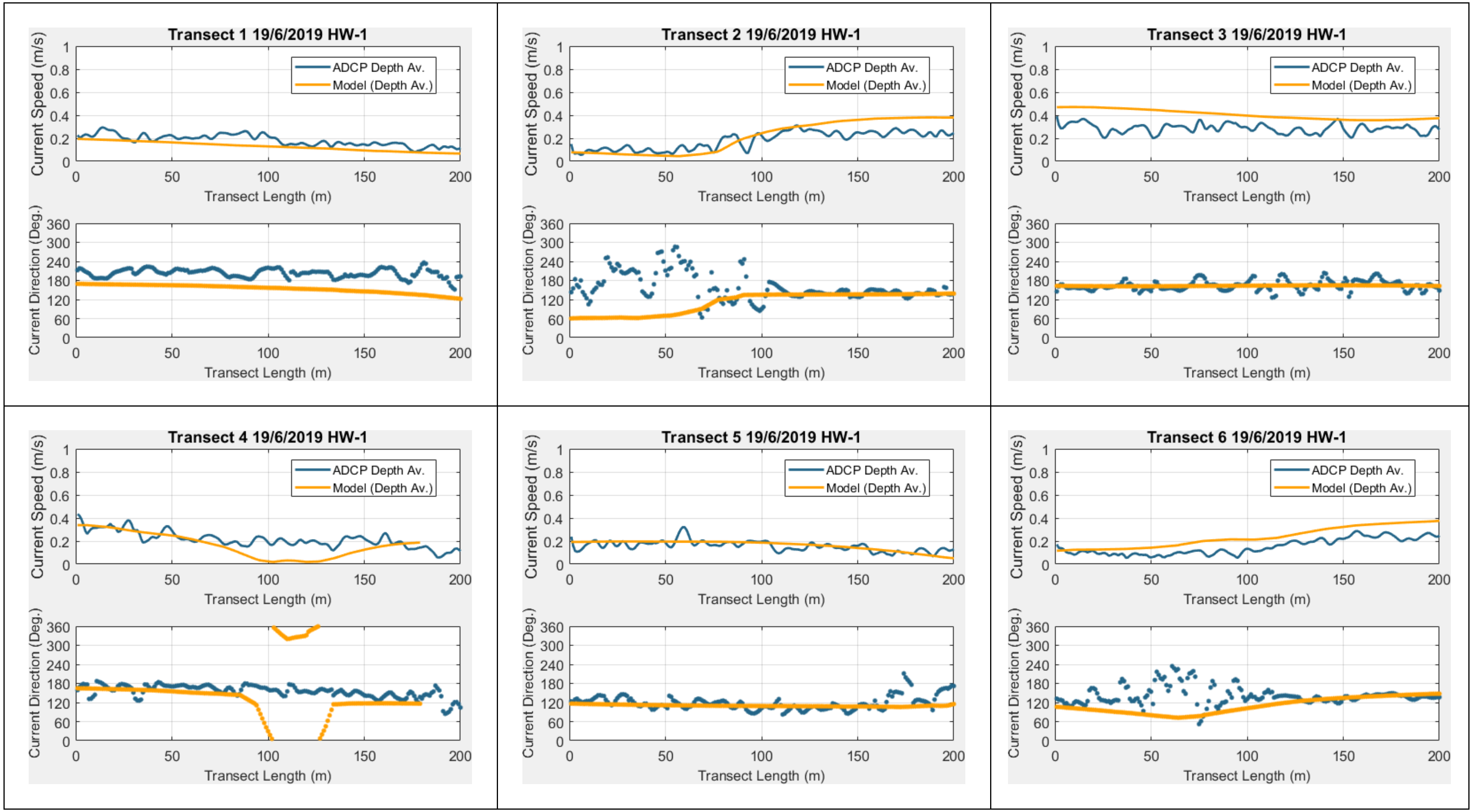

Figure A7. Model and ADCP measured flow comparison - FLOOD - Spring tide: 19/06/2019 HW -1 hr

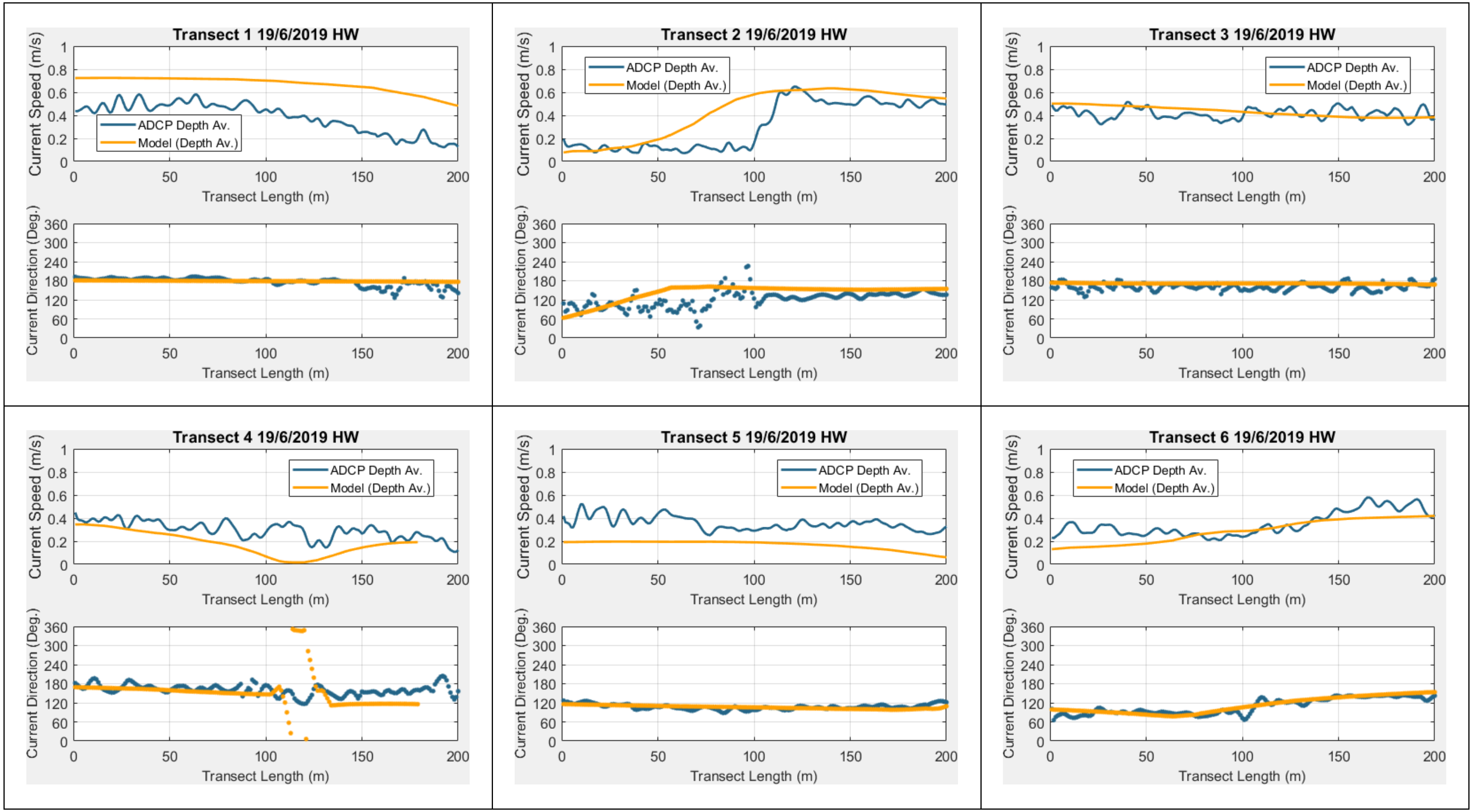

Figure A8. **Model and ADCP measured flow comparison - Spring tide: 19/06/2019 HW**

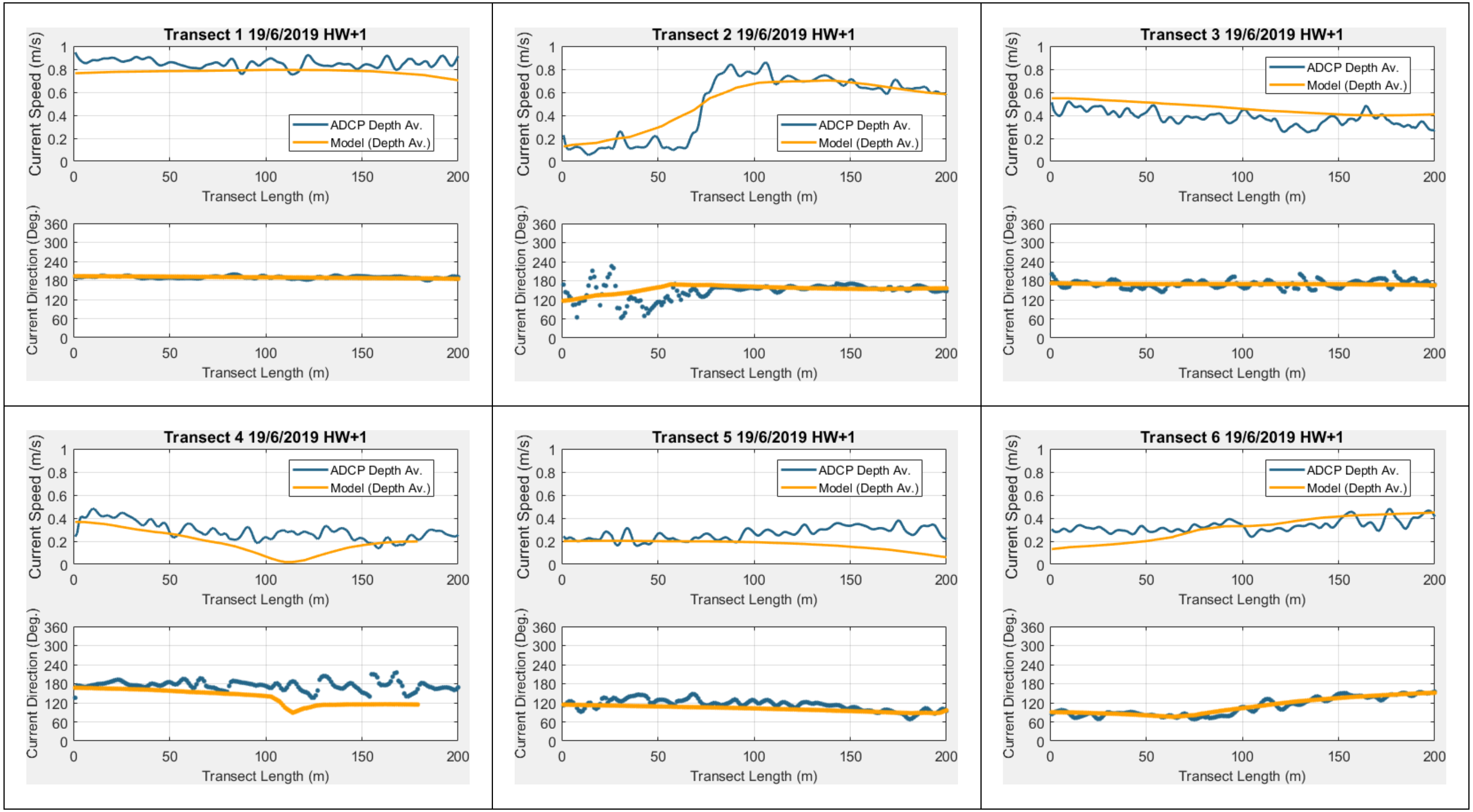

Figure A9. Model and ADCP measured flow comparison - EBB - Spring tide: 19/06/2019 HW +1 hr

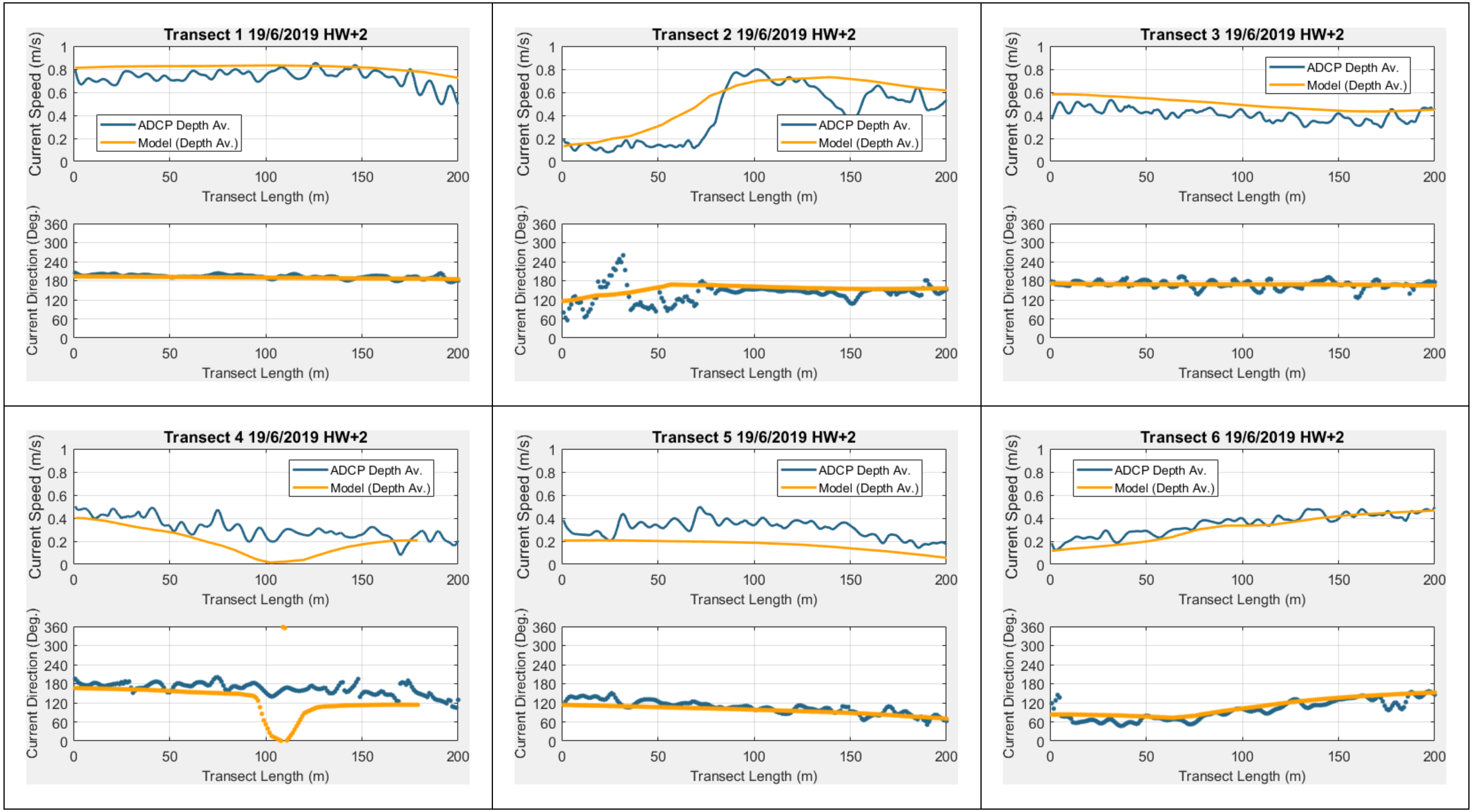

Figure A10. Model and ADCP measured flow comparison - EBB - Spring tide: 19/06/2019 HW +2 hr

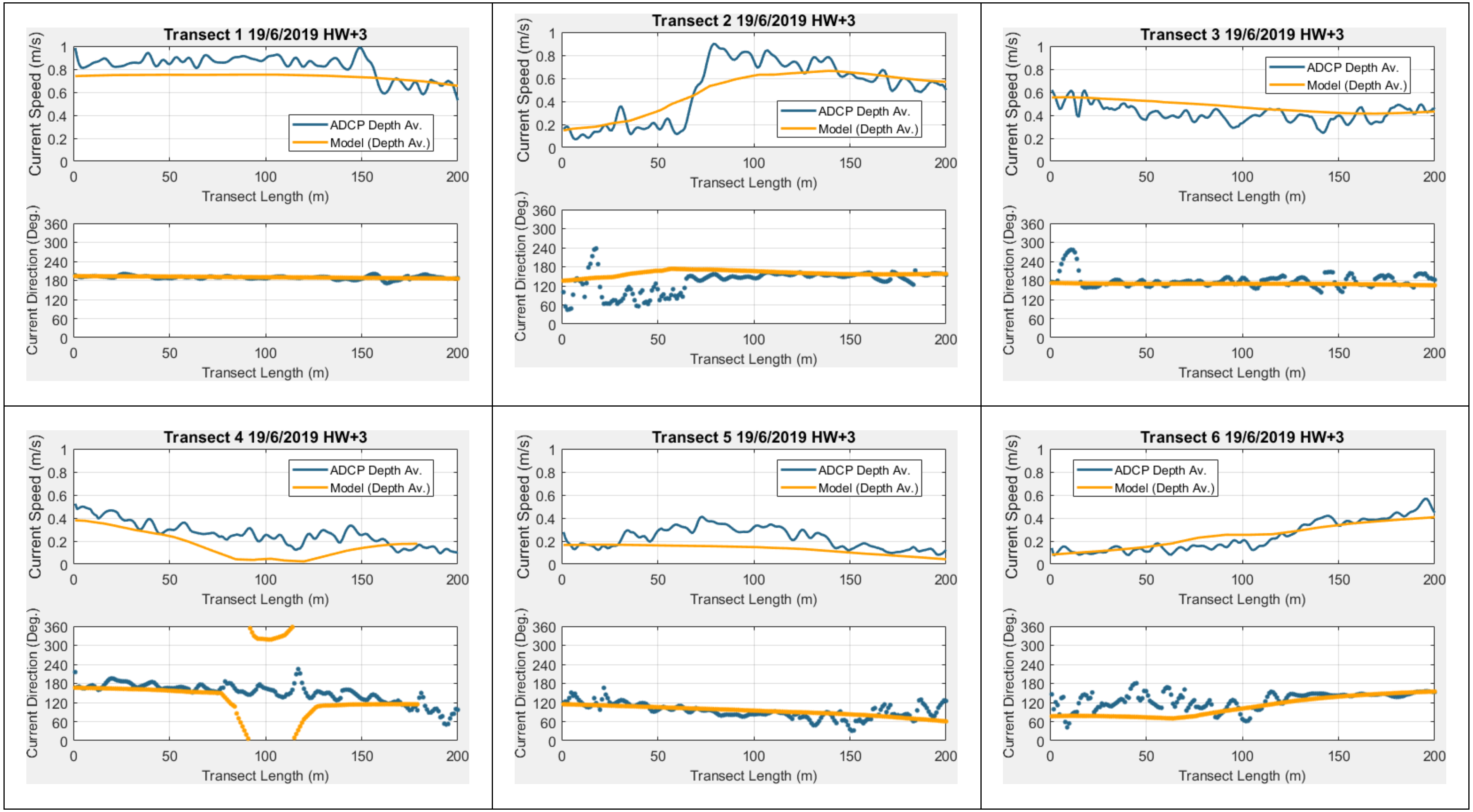

Figure A11. Model and ADCP measured flow comparison - EBB - Spring tide: 19/06/2019 HW +3 hr

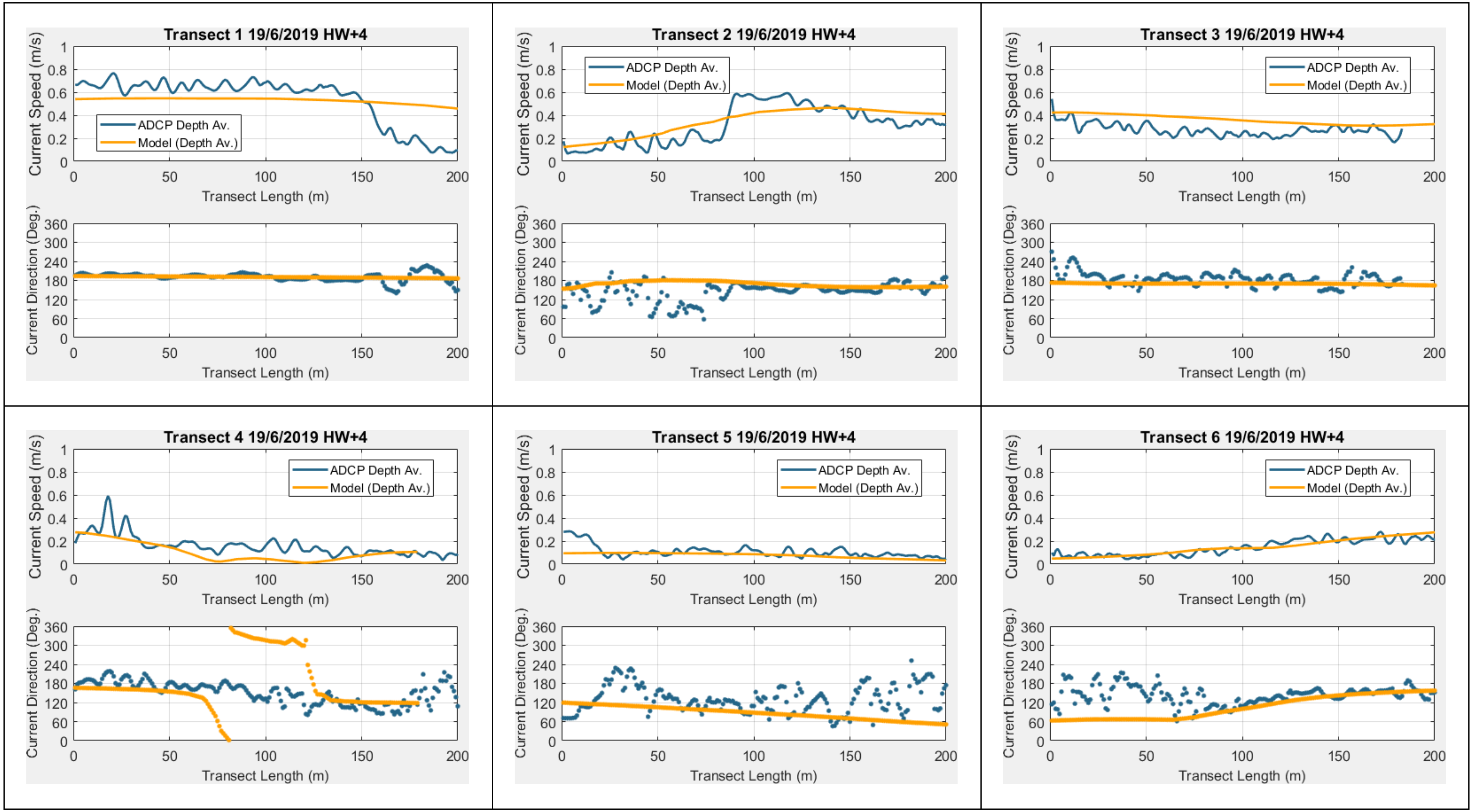

Figure A12. Model and ADCP measured flow comparison - EBB - Spring tide: 19/06/2019 HW +4 hr

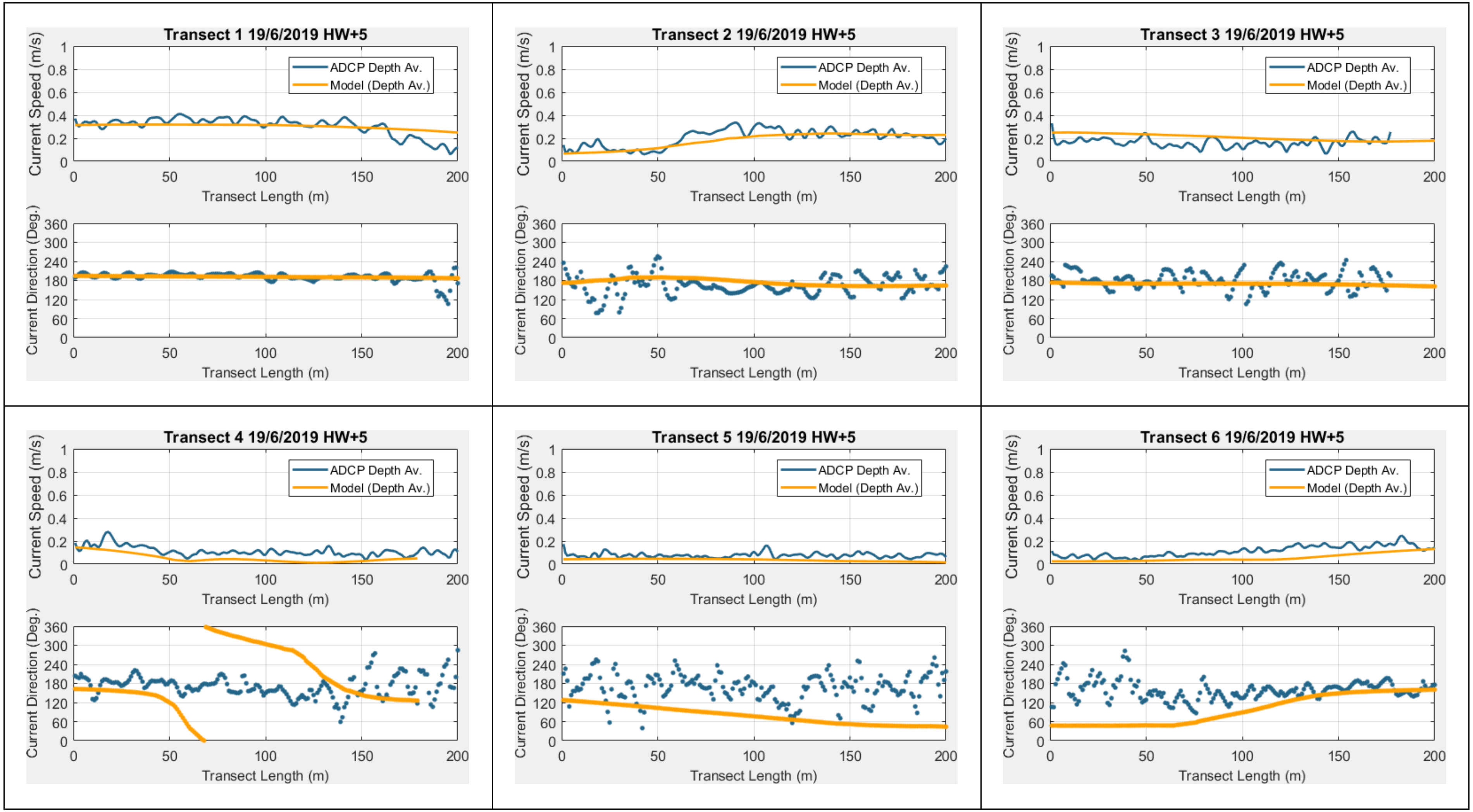

Figure A13. Model and ADCP measured flow comparison - EBB - Spring tide: 19/06/2019 HW +5 hr

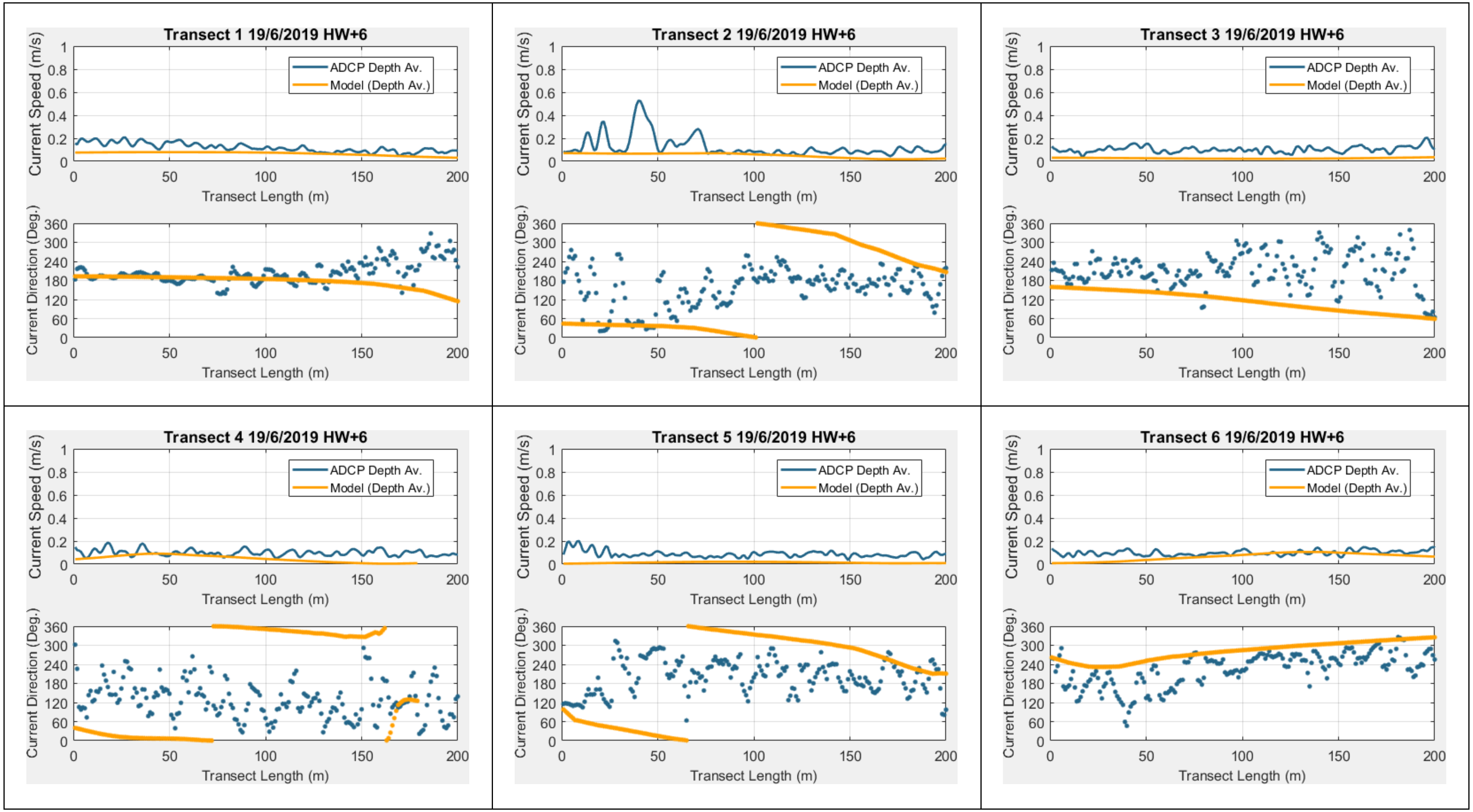

Figure A14. Model and ADCP measured flow comparison - EBB - Spring tide: 19/06/2019 HW +6 hr

End of Main Report Appendix B

Appendices C to I continue on next page

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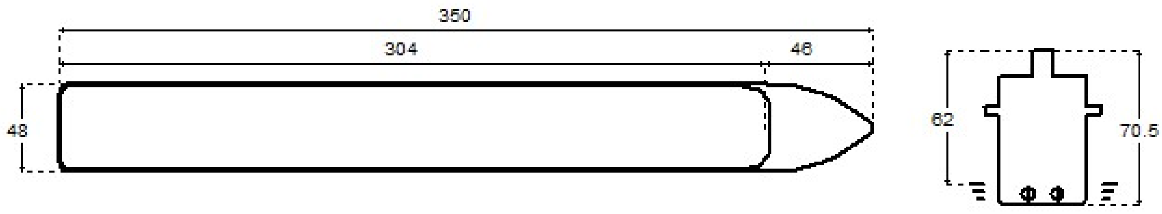
C Ship Simulation – Model Vessel Manoeuvring Data

PILOT CARD

Ship name	Passenger cruise ship 6 (Dis.71222t) TRANSAS 2.31.1.0 *			Date	06.02.2016
IMO Number	N/A	Call Sign	N/A	Year built	N/A
Load Condition	Full load				
Displacement	71222 tons		Draft forward	8.5 m / 27 ft 11 in	
Deadweight	11020 tons		Draft forward extreme	8.5 m / 27 ft 11 in	
Capacity			Draft after	8.5 m / 27 ft 11 in	
Air draft	62 m / 203 ft 11 in		Draft after extreme	8.5 m / 27 ft 11 in	

Ship's Particulars

Length overall	350 m	Type of bow	Bulbous
Breadth	48 m	Type of stern	Transom
Anchor(s) (No./types)	2 (PortBow / StbdBow)		
No. of shackles	14 / 13	(1 shackle =25 m / 13.7 fathoms)	
Max. rate of heaving, m/min	15 / 15		



Steering characteristics

Steering device(s) (type/No.)	Normal balance rudder / 2	Number of bow thrusters	3
Maximum angle	35	Power	3000 kW / 3000 kW / 3000 kW
Rudder angle for neutral effect	0 degrees	Number of stern thrusters	2
Hard over to over(2 pumps)	26 seconds	Power	3000 kW / 3000 kW
Flanking Rudder(s)	0	Auxiliary Steering Device(s)	N/A

Stopping			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAH to FAS	391.6 s	7.37 cbls	Advance	4.34 cbls
HAH to HAS	557.6 s	6.84 cbls	Transfer	1.55 cbls
SAH to SAS	827.6 s	6.66 cbls	Tactical diameter	3.73 cbls

Main Engine(s)

Type of Main Engine	Low speed diesel	Number of propellers	2
Number of Main Engine(s)	2	Propeller rotation	Inward
Maximum power per shaft	2 x 26200 kW	Propeller type	FPP
Astern power	50 % ahead	Min. RPM	10
Time limit astern	N/A	Emergency FAH to FAS	1.1 seconds

Engine Telegraph Table

Engine Order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	23.7	48700	140	1.07
"FAH"	15.2	13225	90	1.07
"HAH"	10.2	4076	60	1.07
"SAH"	6.8	1308	40.1	1.07
"DSAH"	3.3	221	20	1.07
"DSAS"	-1.6	366	-20.3	1.07
"SAS"	-3.2	2373	-40.3	1.07
"HAS"	-4.8	7749	-60.5	1.07
"FAS"	-7.2	25472	-90.6	1.07

WHEELHOUSE POSTER

Ship's name Passenger cruise ship 6 (Dis.71222t) TRANSAS 2.31.1.0 , Call sign N/A ,
Gross tonnage N/A , Net tonnage N/A , Load Condition Full load , Displacement 71222 tons , Deadweight 11020 tons

DRAFTS IN PRESENT CONDITION	
Forward	8.5 m
Forward extreme	8.5 m
After	8.5 m
After extreme	8.5 m

STEERING PARTICULARS	
Type of rudder	Normal balance rudder
Maximum rudder angle	35 degrees
Hard-over to hard-over(1/2 pumps)	52 sec/26 sec
Neutral effect angle	0 degrees
Flanking Rudders	0

ANCHORS INFO	
Anchor(s) (No./types)	2 (PortBow / StbdBow)
No. of shackles	14 / 13
Max. rate of heaving, m/min	15 / 15
(1 shackle =25 m / 13.7 fathoms)	

PROPULSION PARTICULARS			
Type of Main Engine	Low speed diesel	Number of propellers	2
No. of Main Engines	2	Propeller rotation	Inward
Max. power per shaft	2 x 26200 kW	Propeller type	FPP
Astern power	50 % ahead	Min. RPM	10
Time limit astern	N/A	Emergency FAH to FAS	1.1 seconds

Engine Telegraph Table

Engine Order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	23.7	48700	140	1.07
"FAH"	15.2	13225	90	1.07
"HAH"	10.2	4076	60	1.07
"SAH"	6.8	1308	40.1	1.07
"DSAH"	3.3	221	20	1.07
"DSAS"	-1.6	366	-20.3	1.07
"SAS"	-3.2	2373	-40.3	1.07
"HAS"	-4.8	7749	-60.5	1.07
"FAS"	-7.2	25472	-90.6	1.07

THRUSTER EFFECT

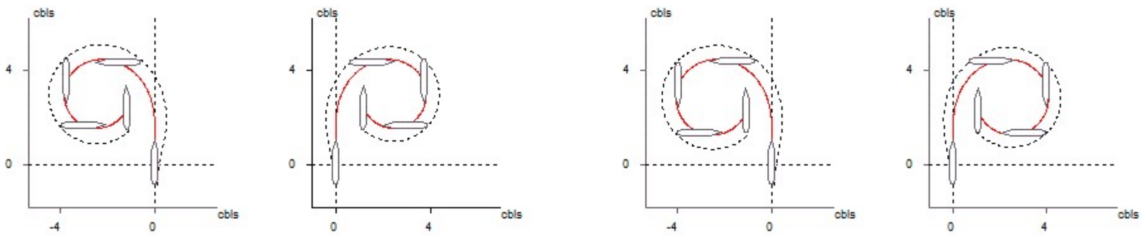
Thruster (s)	No. of units	Power (kW)	Time delay for full thrust(s)	Turning rate at zero speed(degrees/min)	Time delay to reverse full thrust(s)	Not effective above speed (knots)
Bow	3	9000	9.5	6.93	19	6
Stern	2	6000	9.5	-14.3	19	6
Combined	5	15000	9.5	-15.17	19	6

Auxiliary Steering Device(s): N/A

DRAFT INCREASE IN PRESENT CONDITION

Squat effect				Heel effect	
Under keel clearance	Ship's speed	Bow squat	Stern squat	Heel angle	Draft increase
3m	17.26 knots	-0.22 m	1.25 m	2 deg	0.51 m
	14.13 knots	0.26 m	0.6 m	4 deg	1 m
	9.92 knots	0.11 m	0.26 m	8 deg	1.91 m
2 m	16.86 knots	-0.36 m	1.44 m	12 deg	2.74 m
	13.87 knots	0.25 m	0.7 m	16 deg	3.49 m

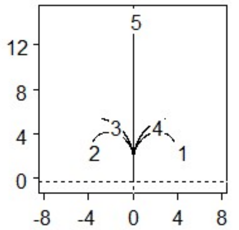
Deep Water TURNING CIRCLES Shallow Water*



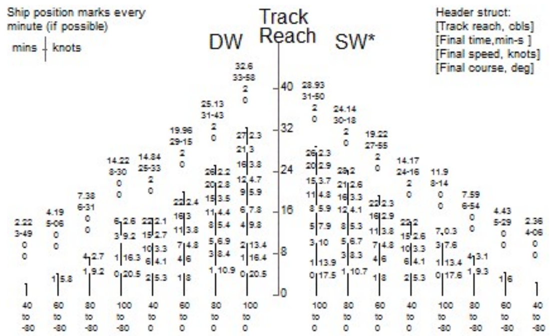
Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	4.34 cbls	1.55 cbls	3.73 cbls	59 deg/min	8 knots	374.6 s
100	-35	4.34 cbls	-1.55 cbls	-3.73 cbls	-59 deg/min	8 knots	374.6 s

Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	4.36 cbls	1.67 cbls	3.97 cbls	54 deg/min	9 knots	415.6 s
100	-35	4.36 cbls	-1.67 cbls	-3.97 cbls	-54 deg/min	9 knots	415.6 s

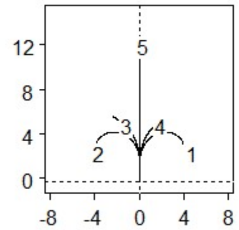
Emergency Manoeuvers(DW)



STOPPING CHARACTERISTICS

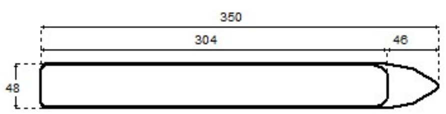


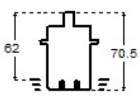
Emergency Manoeuvers(SW*)



No.	Rudd.	Eng.	Full time	Head reach	Side reach
1	35	100	191.8 s	3.5 cbls	3.73 cbls
2	-35	100	191.8 s	3.5 cbls	-3.73 cbls
3	35	-80	302.6 s	5.79 cbls	-2.87 cbls
4	-35	-80	302.6 s	5.79 cbls	2.87 cbls
5	0	-80	510.6 s	14.21 cbls	0 cbls

No.	Rudd.	Eng.	Full time	Head reach	Side reach
1	35	100	214.9 s	3.36 cbls	3.97 cbls
2	-35	100	214.9 s	3.36 cbls	-3.97 cbls
3	35	-80	321.6 s	5.94 cbls	-2.45 cbls
4	-35	-80	321.6 s	5.94 cbls	2.45 cbls
5	0	-80	494.6 s	11.89 cbls	0 cbls





MAN OVERBOARD
RESCUE MANOEUVRE

SEQUENCE OF ACTION TO BE TAKEN:

- TO CAST A BUOY
- TO GIVE THE HELM ORDER
- TO SOUND THE ALARM
- TO KEEP THE LOOK OUT

Approximate Maneuver Program

Time	Action
0 s	Set rudder 35 STBD. Wait till ship course altered to 30.5 degrees from initial.
42 s	Set rudder 35 PORT. Wait till course altered to -170 degrees from initial.
296 s	Turn AP on. The difference between AP course and initial course must be 180 degrees.

Bridge To Stern(A)	304 m	Length of Midbody(D)	262.5 m	Air Draft(G)	62 m / 203 ft 11 in
Bridge To Bow(B)	46 m	Length Overall(E)	350 m	Forward Blind Zone(I)	27 m
Breadth(C)	38 m	Height(F)	70.5 m	Backward Blind Zone(J)	182 m

* Shallow Water: depth is equal 2 Draft ** Model: 2.166.1432.129; VSY02: 2.91.3084.0;

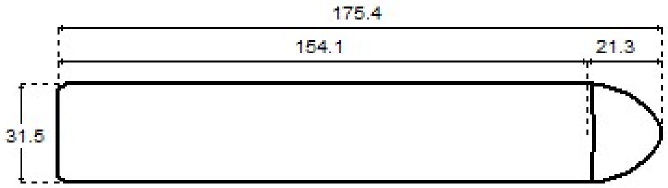
PERFORMANCE MAY DIFFER FROM THIS RECORD DUE TO ENVIRONMENT, HULL AND LOADING CONDITION

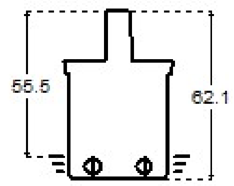
PILOT CARD

Ship name	Passenger car ferry 2 (Dis.20300t) TRANSAS 2.31.10.0 *			Date	05.02.2016
IMO Number	7907659	Call Sign	SKPZ	Year built	1987
Load Condition	Full load				
Displacement	20300 tons		Draft forward	6.65 m / 21 ft 10 in	
Deadweight	3832 tons		Draft forward extreme	6.65 m / 21 ft 10 in	
Capacity			Draft after	6.65 m / 21 ft 10 in	
Air draft	55.5 m / 182 ft 6 in		Draft after extreme	6.65 m / 21 ft 10 in	

Ship's Particulars

Length overall	175.4 m	Type of bow	Bulbous
Breadth	31.5 m	Type of stern	Cruiser
Anchor(s) (No./types)	2 (PortBow / StbdBow)		
No. of shackles	15 / 15	(1 shackle =25 m / 13.7 fathoms)	
Max. rate of heaving, m/min	11.4 / 11.4		





Steering characteristics

Steering device(s) (type/No.)	Semisuspended / 2	Number of bow thrusters	2
Maximum angle	35	Power	1120 kW / 1120 kW
Rudder angle for neutral effect	0 degrees	Number of stern thrusters	N/A
Hard over to over(2 pumps)	32 seconds	Power	N/A
Flanking Rudder(s)	0	Auxiliary Steering Device(s)	N/A

Stopping			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAH to FAS	119.2 s	2.77 cbls	Advance	2.59 cbls
HAH to HAS	134.6 s	2.53 cbls	Transfer	0.93 cbls
SAH to SAS	143.4 s	1.77 cbls	Tactical diameter	2.35 cbls

Main Engine(s)

Type of Main Engine	Medium speed diesel	Number of propellers	2
Number of Main Engine(s)	2	Propeller rotation	Outward
Maximum power per shaft	2 x 30800 kW	Propeller type	CPP
Astern power	85 % ahead	Min. RPM	80
Time limit astern	N/A	Emergency FAH to FAS	47.2 seconds

Engine Telegraph Table

Engine Order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	19	58520	124	1.26
"FAH"	17.4	40400	117.2	1.19
"HAH"	15.6	29200	105.2	1.19
"SAH"	10.4	9100	92.3	0.77
"DSAH"	6.3	4220	86.1	0.34
"DSAS"	-3.2	4400	93	-0.34
"SAS"	-6	13800	104	-0.8
"HAS"	-8	25200	113.1	-0.91
"FAS"	-10	38320	124	-1.03
"FSAS"	-11	49740	124.1	-1.14

WHEELHOUSE POSTER

Ship's name Passenger car ferry 2 (Dis.20300t) TRANSAS 2.31.10.0 , Call sign SKPZ ,
Gross tonnage N/A , Net tonnage N/A , Load Condition Full load , Displacement 20300 tons , Deadweight 3832 tons

DRAFTS IN PRESENT CONDITION	
Forward	6.65 m
Forward extreme	6.65 m
After	6.65 m
After extreme	6.65 m

STEERING PARTICULARS	
Type of rudder	Semisuspended
Maximum rudder angle	35 degrees
Hard-over to hard-over(1/2 pumps)	65 sec/32 sec
Neutral effect angle	0 degrees
Flanking Rudders	0

ANCHORS INFO	
Anchor(s) (No./types)	2 (PortBow / StbdBow)
No. of shackles	15 / 15
Max. rate of heaving, m/min	11.4 / 11.4
(1 shackle =25 m / 13.7 fathoms)	

PROPULSION PARTICULARS			
Type of Main Engine	Medium speed diesel	Number of propellers	2
No. of Main Engines	2	Propeller rotation	Outward
Max. power per shaft	2 x 30800 kW	Propeller type	CPP
Astern power	85 % ahead	Min. RPM	80
Time limit astern	N/A	Emergency FAH to FAS	47.2 seconds

Engine Telegraph Table

Engine Order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	19	58520	124	1.26
"FAH"	17.4	40400	117.2	1.19
"HAH"	15.6	29200	105.2	1.19
"SAH"	10.4	9100	92.3	0.77
"DSAH"	6.3	4220	86.1	0.34
"DSAS"	-3.2	4400	93	-0.34
"SAS"	-6	13800	104	-0.8
"HAS"	-8	25200	113.1	-0.91
"FAS"	-10	38320	124	-1.03
"FSAS"	-11	49740	124.1	-1.14

THRUSTER EFFECT

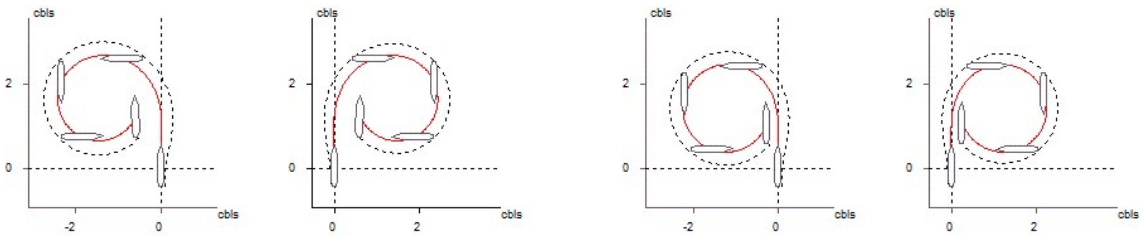
Thruster (s)	No. of units	Power (kW)	Time delay for full thrust(s)	Turning rate at zero speed(degrees/min)	Time delay to reverse full thrust(s)	Not effective above speed (knots)
Bow	2	2240	9.5	45.67	19	6
Stern	N/A					
Combined	N/A					

Auxiliary Steering Device(s): N/A

DRAFT INCREASE IN PRESENT CONDITION

Under keel clearance	Squat effect			Heel effect	
	Ship's speed	Bow squat	Stern squat	Heel angle	Draft increase
3m	15.18 knots	0.01 m	0.39 m	2 deg	0.41 m
	14.53 knots	0.1 m	0.34 m	4 deg	0.79 m
	13.75 knots	0.19 m	0.28 m	8 deg	1.52 m
2 m	14.74 knots	-0.06 m	0.45 m	12 deg	2.18 m
	14.12 knots	0.05 m	0.39 m	16 deg	2.78 m

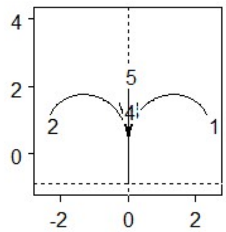
Deep Water TURNING CIRCLES Shallow Water*



Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	2.59 cbls	0.93 cbls	2.35 cbls	89 deg/min	9 knots	251.2 s
100	-35	2.59 cbls	-0.93 cbls	-2.35 cbls	-89 deg/min	9 knots	251.2 s

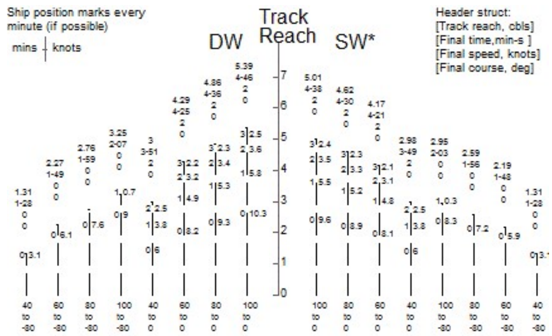
Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	2.4 cbls	0.86 cbls	2.18 cbls	86 deg/min	9 knots	255.6 s
100	-35	2.4 cbls	-0.86 cbls	-2.18 cbls	-86 deg/min	9 knots	255.6 s

Emergency Manoeuvers(DW)

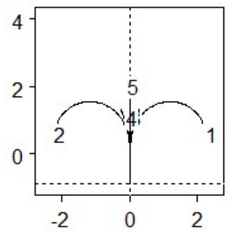


No.	Rudd.	Eng.	Full time	Head reach	Side reach
1	35	100	130.2 s	2.01 cbls	2.35 cbls
2	-35	100	130.2 s	2.01 cbls	-2.35 cbls
3	35	-80	95 s	2.46 cbls	-0.27 cbls
4	-35	-80	95 s	2.46 cbls	0.27 cbls
5	0	-80	115.9 s	3.11 cbls	0 cbls

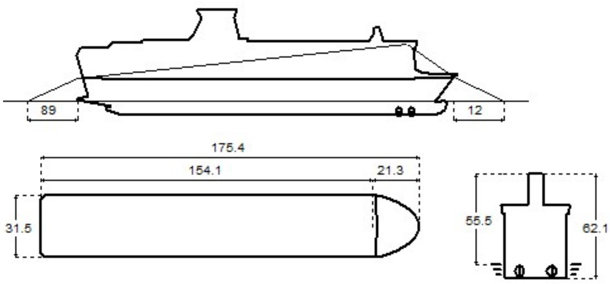
STOPPING CHARACTERISTICS



Emergency Manoeuvers(SW*)



No.	Rudd.	Eng.	Full time	Head reach	Side reach
1	35	100	130.2 s	1.75 cbls	2.18 cbls
2	-35	100	130.2 s	1.75 cbls	-2.18 cbls
3	35	-80	89.5 s	2.25 cbls	-0.26 cbls
4	-35	-80	89.5 s	2.25 cbls	0.26 cbls
5	0	-80	112.6 s	2.83 cbls	0 cbls



MAN OVERBOARD RESCUE MANOEUVRE

SEQUENCE OF ACTION TO BE TAKEN:

- TO CAST A BUOY
- TO GIVE THE HELM ORDER
- TO SOUND THE ALARM
- TO KEEP THE LOOK OUT

Approximate Maneuver Program

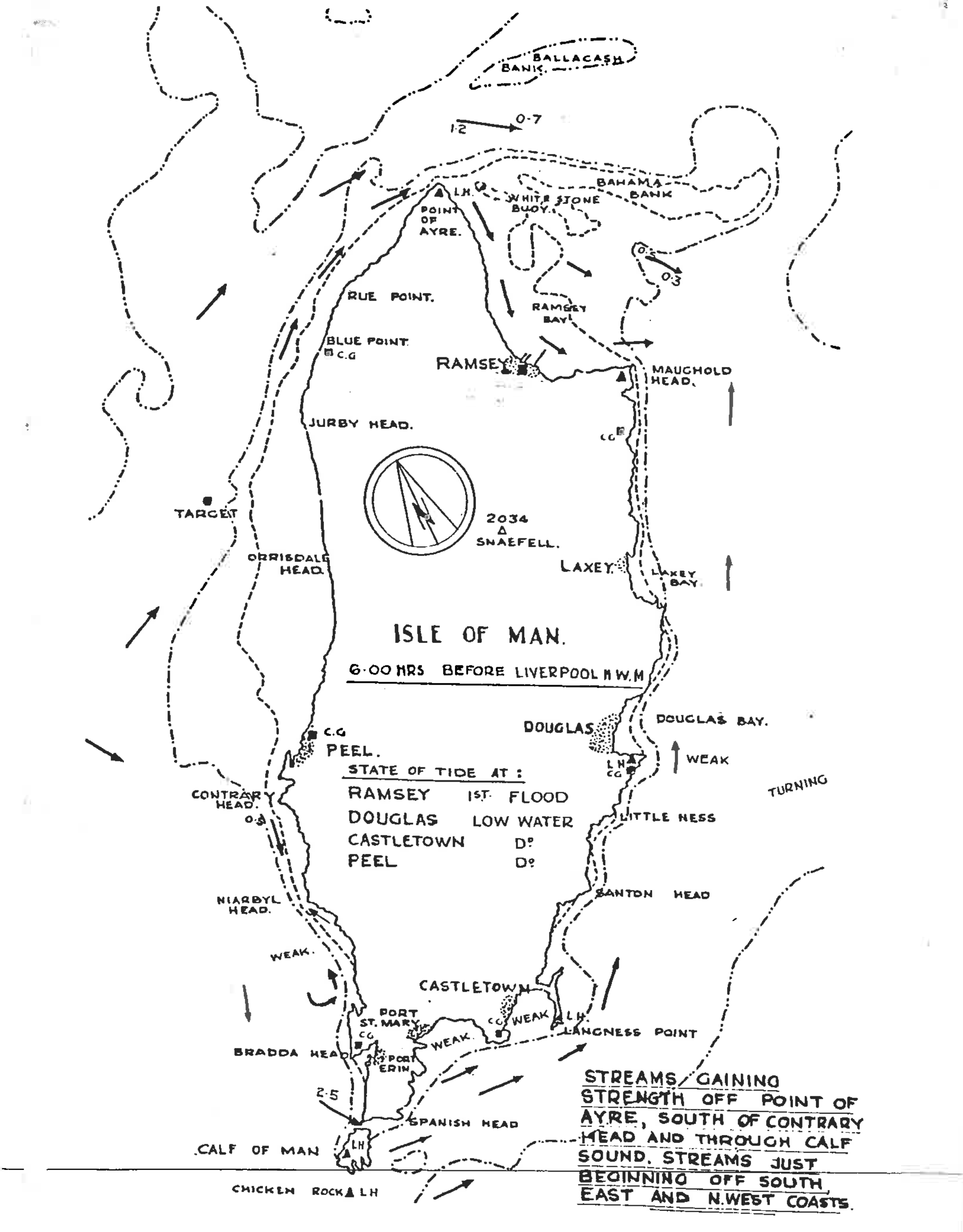
Time	Action
0 s	Set rudder 35 STBD. Wait till ship course altered to 30 degrees from initial.
30 s	Set rudder 35 PORT. Wait till course altered to -170 degrees from initial.
203 s	Turn AP on. The difference between AP course and initial course must be 180 degrees.

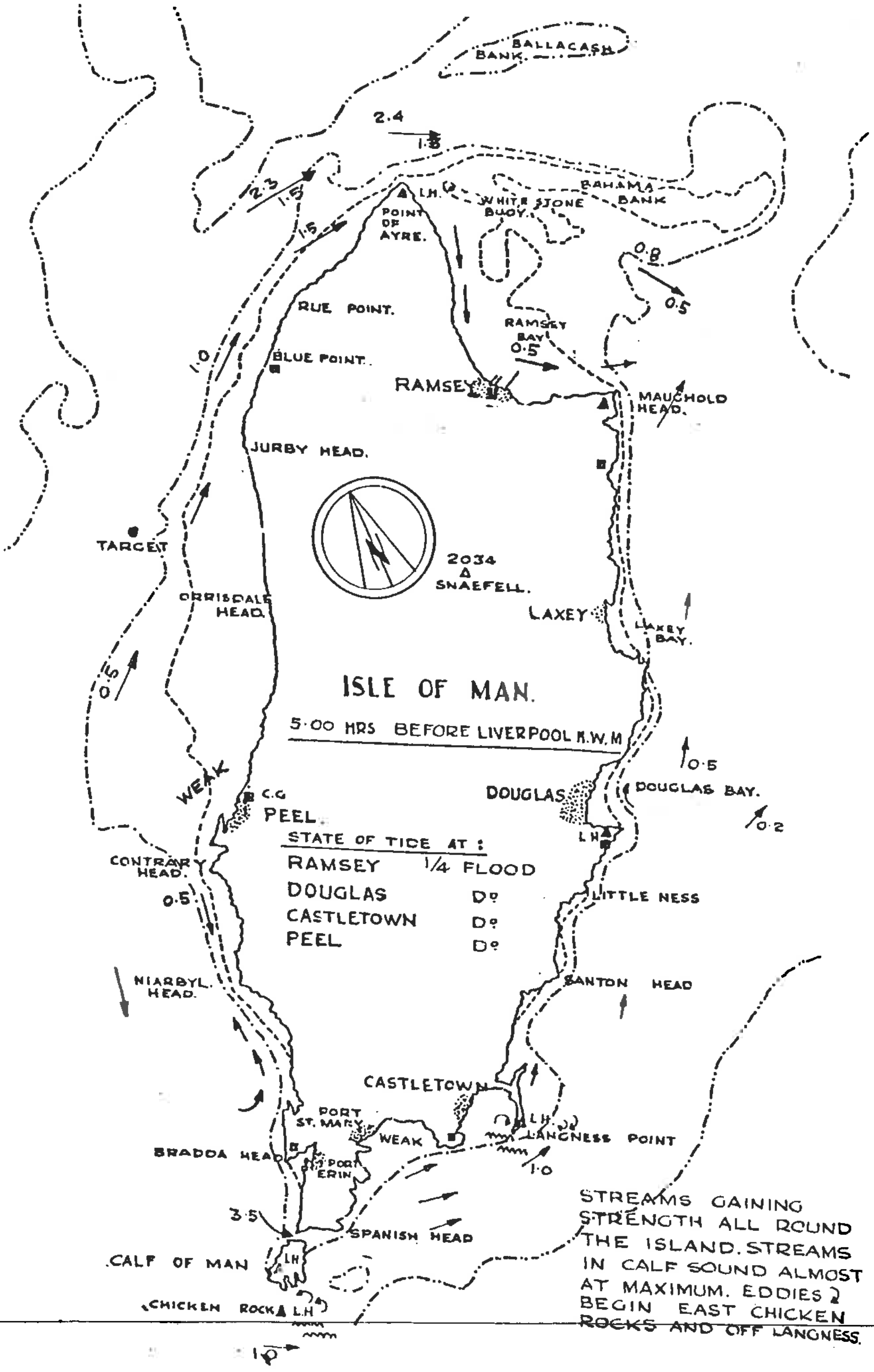
Bridge To Stern(A)	154.1 m	Length of Midbody(D)	131.55 m	Air Draft(G)	55.5 m / 182 ft 6 in
Bridge To Bow(B)	21.3 m	Length Overall(E)	175.4 m	Forward Blind Zone(I)	12 m
Breadth(C)	30.3 m	Height(F)	62.15 m	Backward Blind Zone(J)	89 m

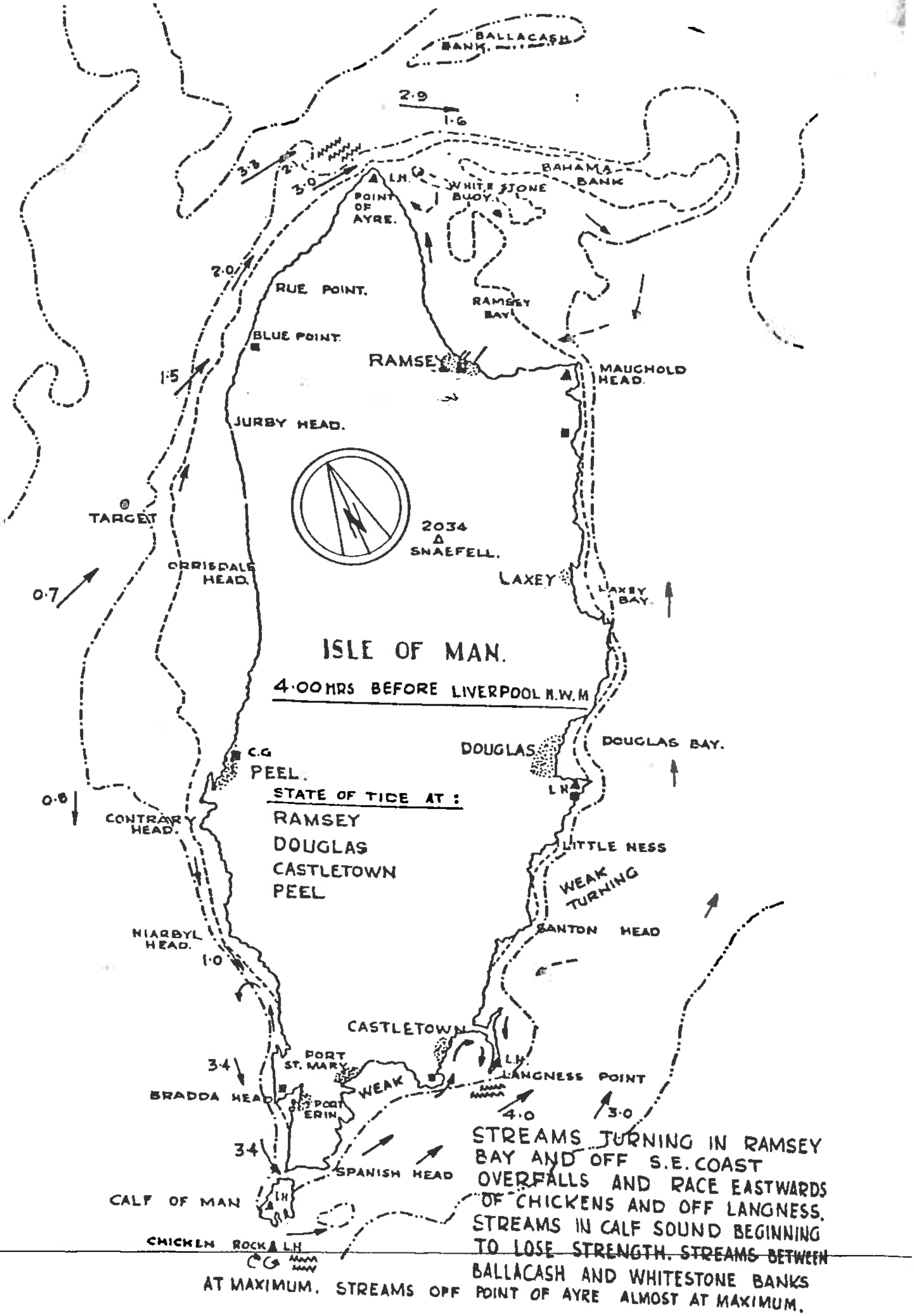
* Shallow Water: depth is equal 2 Draft ** Model: 2.166.1432.129; VSY02: 2.91.3084.0;

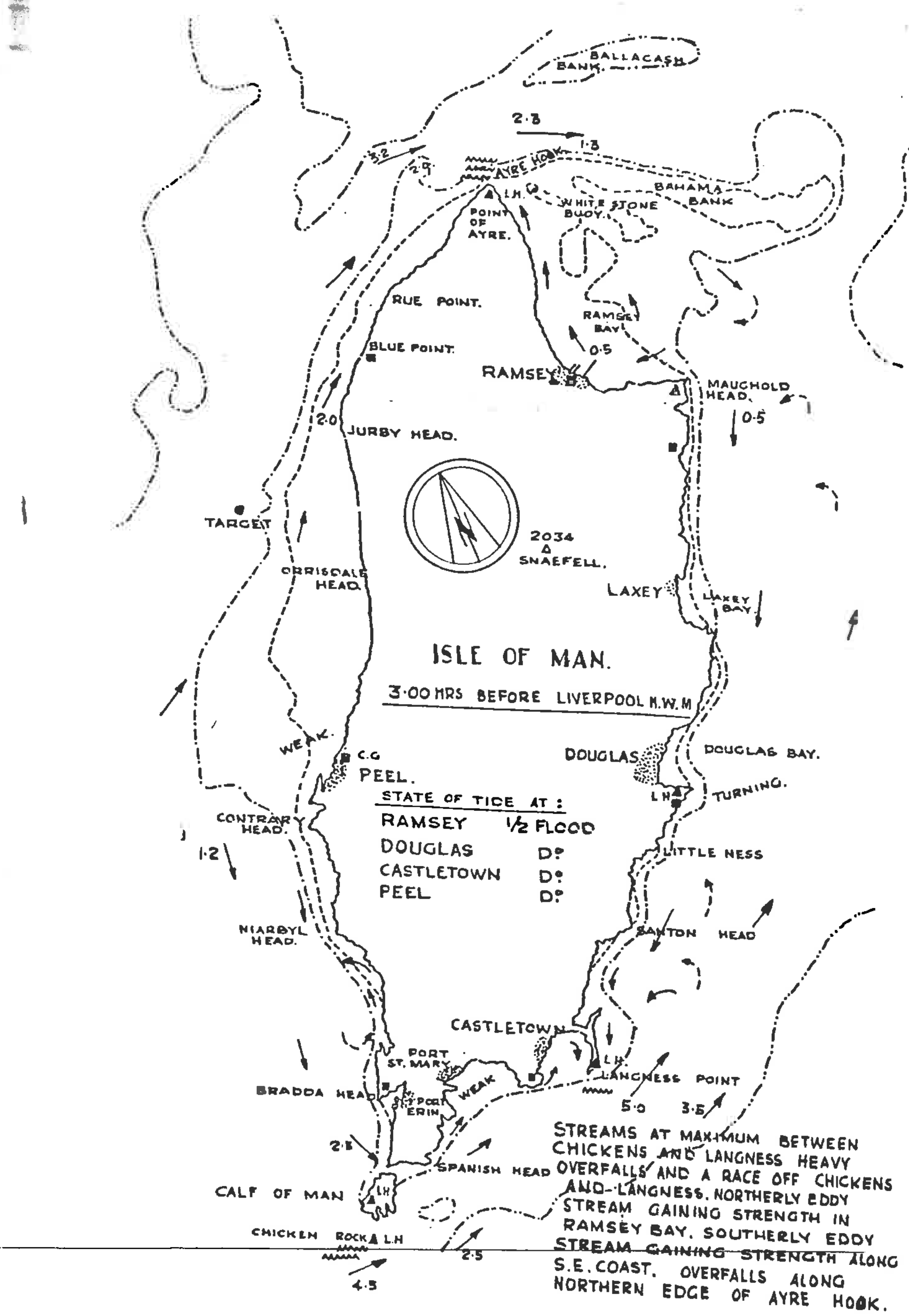
PERFORMANCE MAY DIFFER FROM THIS RECORD DUE TO ENVIRONMENT, HULL AND LOADING CONDITION

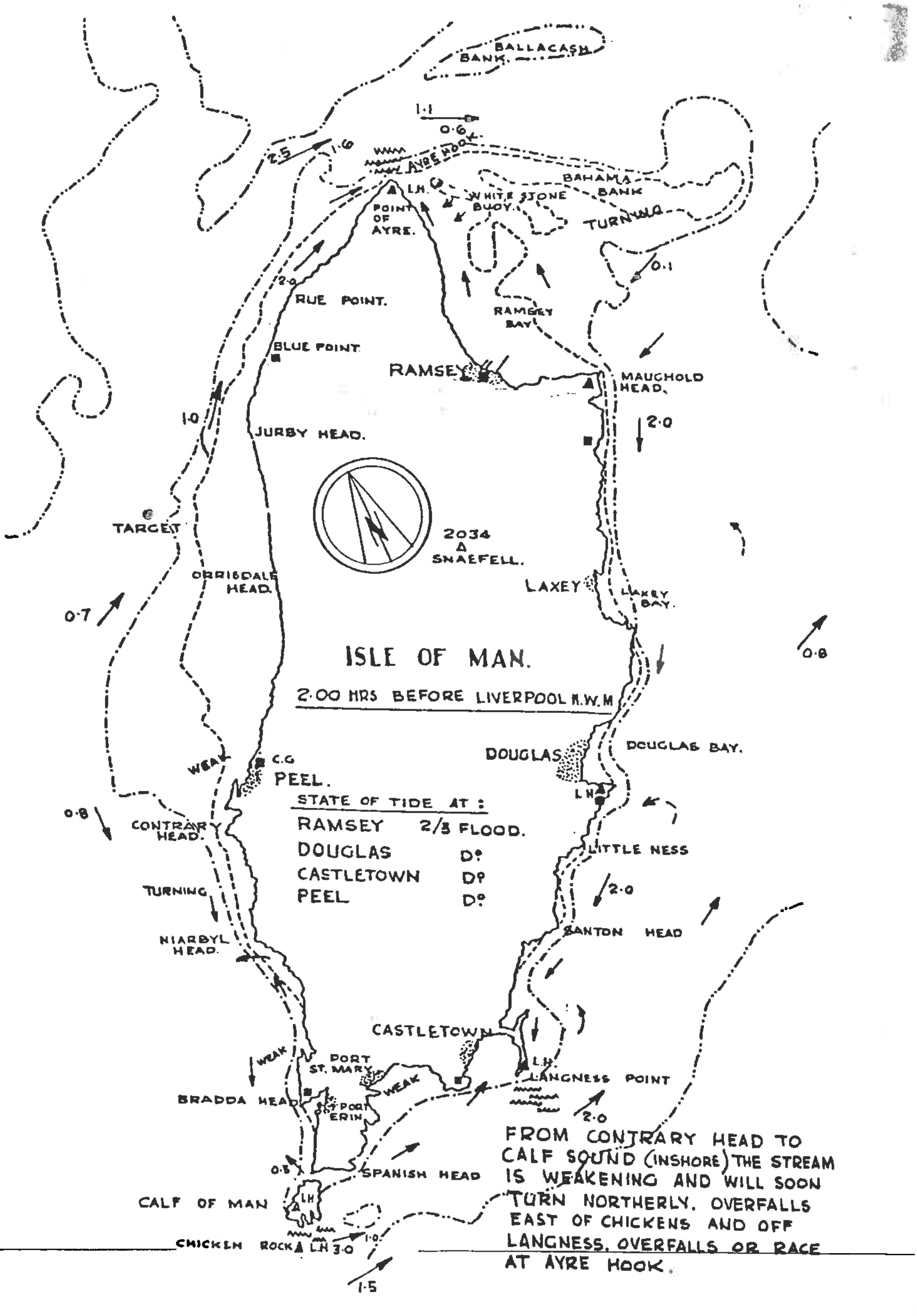
D Tidal Streams around the Isle of Man


BALLACASH BANK
1·2
0·7
BAHAMA BANK
L.H.
POINT OF AYRE.
WHITE STONE BUOY
0·5
0·3
RUE POINT.
RAMSEY BAY
BLUE POINT
C.G
RAMSEY
MAUGHOLD HEAD.
JURBY HEAD.
C.G
2034
SNAEFELL.
TARGET
ORRISDALE HEAD
LAXEY
LAXEY BAY
ISLE OF MAN.
6·00 HRS BEFORE LIVERPOOL H.W.M
C.G
PEEL.
DOUGLAS
DOUGLAS BAY.
L.H
C.G
WEAK
STATE OF TIDE AT :
RAMSEY 1ST. FLOOD
DOUGLAS LOW WATER
CASTLETOWN Do
PEEL Do
TURNING
CONTRARY HEAD.
0·5
LITTLE NESS
NIARBYL HEAD.
SANTON HEAD
WEAK.
CASTLETOWN
PORT ST. MARY
C.G
WEAK
L.H.
LANGNESS POINT
WEAK.
BRADDA HEAD
PORT ERIN
2·5
SPANISH HEAD
CALF OF MAN
L.H
CHICKEN ROCK L.H
STREAMS GAINING STRENGTH OFF POINT OF AYRE, SOUTH OF CONTRARY HEAD AND THROUGH CALF SOUND. STREAMS JUST BEGINNING OFF SOUTH EAST AND N.WEST COASTS.

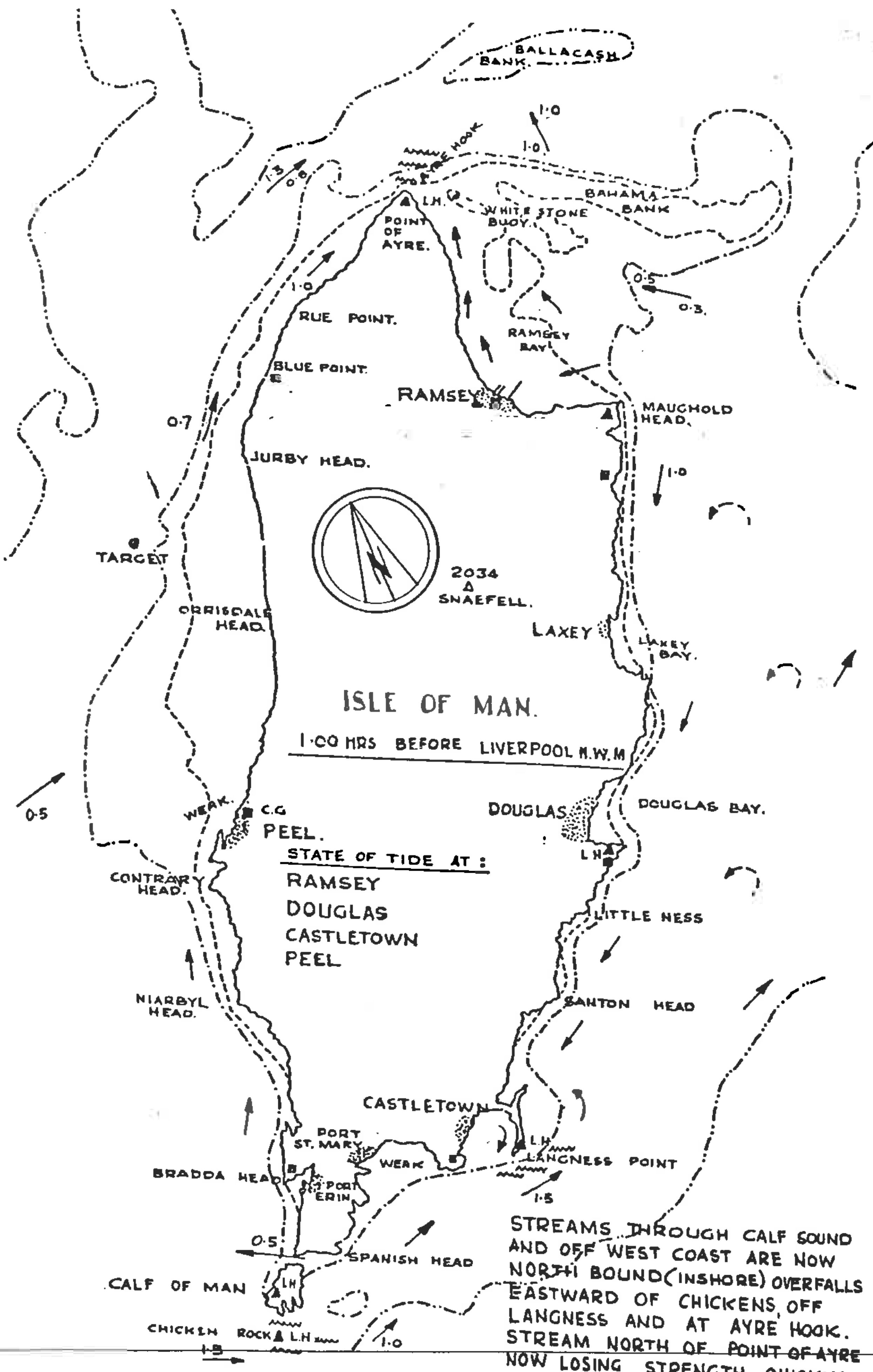

BALLACASH BANK
2.4
1.8
2.3
1.5
1.5
L.H.
POINT OF AYRE.
WHITE STONE BUOY.
BAHAMA BANK
0.8
0.5
RUE POINT.
RAMSEY BAY
0.5
BLUE POINT.
1.0
RAMSEY
MAUGHOLD HEAD.
JURBY HEAD.
TARGET
2034
SNAEFELL.
ORRISDALE HEAD.
LAXEY
LAXEY BAY.
0.5
ISLE OF MAN.
5.00 HRS BEFORE LIVERPOOL H.W.M
0.5
WEAK
C.G
PEEL.
DOUGLAS
DOUGLAS BAY.
0.2
L.H.
STATE OF TIDE AT :
RAMSEY 1/4 FLOOD
DOUGLAS D°
CASTLETOWN D°
PEEL D°
CONTRARY HEAD.
0.5
LITTLE NESS
NIARBYL HEAD.
SANTON HEAD
CASTLETOWN
PORT ST. MARY
WEAK
L.H.
LANGNESS POINT
BRADDA HEAD
PORT ERIN
1.0
3.5
SPANISH HEAD
CALF OF MAN
L.H.
CHICKEN ROCK L.H
1.0
STREAMS GAINING STRENGTH ALL ROUND THE ISLAND. STREAMS IN CALF SOUND ALMOST AT MAXIMUM. EDDIES BEGIN EAST CHICKEN ROCKS AND OFF LANGNESS.


BALLACASH BANK
2·9
1·6
3·3
2·1
3·0
L.H.
POINT OF AYRE.
WHITE STONE BUOY.
BAHAMA BANK
2·0
RUE POINT.
BLUE POINT.
RAMSEY BAY
RAMSEY
MAUGHOLD HEAD.
1·5
JURBY HEAD.
TARGET
2034
SNAEFELL.
ORRISDALE HEAD.
0·7
LAXEY
LAXEY BAY.
ISLE OF MAN.
4·00 HRS BEFORE LIVERPOOL H.W.M
C.G
PEEL.
DOUGLAS
DOUGLAS BAY.
L.H.
0·8
CONTRARY HEAD.
STATE OF TIDE AT :
RAMSEY
DOUGLAS
CASTLETOWN
PEEL
LITTLE NESS
WEAK TURNING
NIARBYL HEAD.
SANTON HEAD
1·0
CASTLETOWN
PORT ST. MARY
L.H.
LANGNESS POINT
3·4
BRADDA HEAD
PORT ERIN
WEAK
4·0
3·0
3·4
SPANISH HEAD
CALF OF MAN
L.H.
CHICKEN ROCK L.H.
STREAMS TURNING IN RAMSEY BAY AND OFF S.E. COAST
OVERFALLS AND RACE EASTWARDS OF CHICKENS AND OFF LANGNESS.
STREAMS IN CALF SOUND BEGINNING TO LOSE STRENGTH. STREAMS BETWEEN BALLACASH AND WHITESTONE BANKS AT MAXIMUM. STREAMS OFF POINT OF AYRE ALMOST AT MAXIMUM.

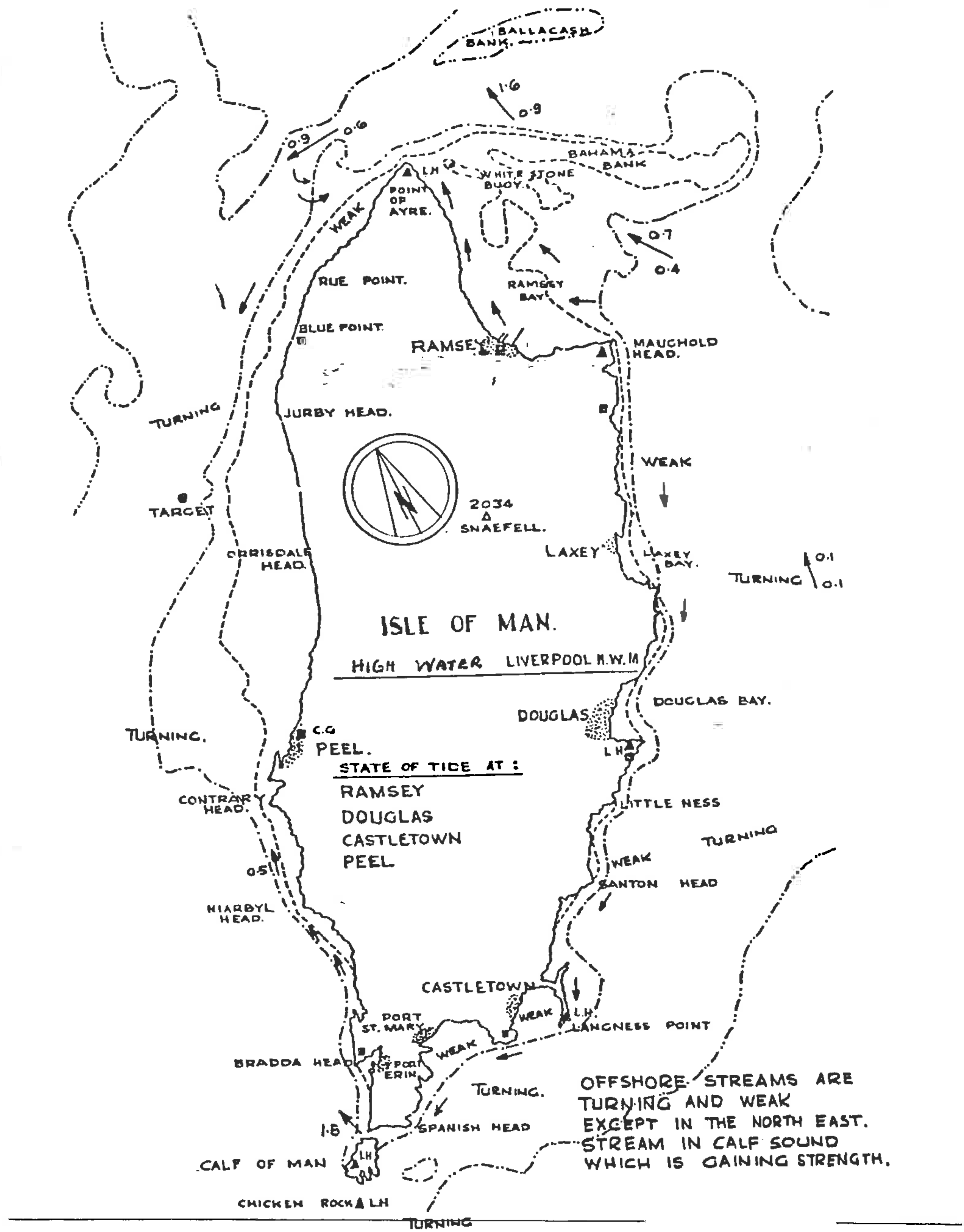

BALLACASH BANK
2·3
1·3
3·2
2·9
AYRE HOOK
L.H.
BAHAMA BANK
WHITE STONE BUOY
POINT OF AYRE.
RUE POINT.
RAMSEY BAY
BLUE POINT
0·5
RAMSEY
MAUGHOLD HEAD.
0·5
2·0
JURBY HEAD.
TARGET
2034
SNAEFELL.
ORRISDALE HEAD.
LAXEY
LAXEY BAY.
ISLE OF MAN.
3·00 HRS BEFORE LIVERPOOL H.W.M
WEAK.
C.G
PEEL.
DOUGLAS
DOUGLAS BAY.
L.H.
TURNING.
STATE OF TIDE AT :
RAMSEY 1/2 FLOOD
DOUGLAS D°
CASTLETOWN D°
PEEL D°
CONTRARY HEAD.
1·2
LITTLE NESS
NIARBYL HEAD.
SANTON HEAD
CASTLETOWN
L.H.
PORT ST. MARY
LANGNESS POINT
WEAK
BRADDA HEAD
PORT ERIN
5·0
3·5
2·5
SPANISH HEAD
CALF OF MAN
L.H
CHICKEN ROCK L.H
2·5
4·5
STREAMS AT MAXIMUM BETWEEN CHICKENS AND LANGNESS HEAVY OVERFALLS AND A RACE OFF CHICKENS AND LANGNESS. NORTHERLY EDDY STREAM GAINING STRENGTH IN RAMSEY BAY. SOUTHERLY EDDY STREAM GAINING STRENGTH ALONG S.E. COAST. OVERFALLS ALONG NORTHERN EDGE OF AYRE HOOK.



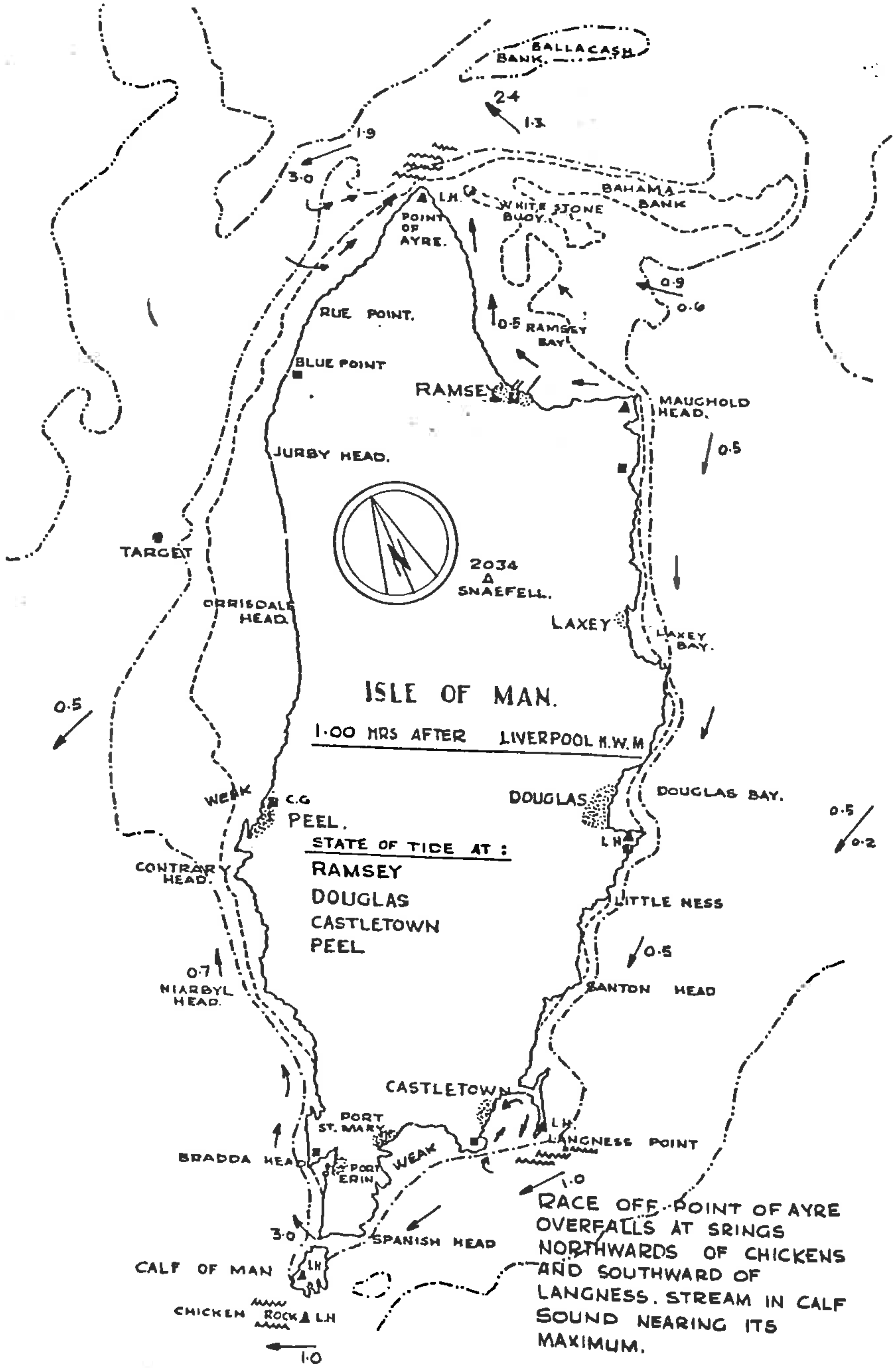
BALLACASH BANK
1·1
0·6
AYRE HOOK
2·5
1·6
BAHAMA BANK
L.H.
WHITE STONE BUOY
POINT OF AYRE
TURNING
0·1
2·0
RUE POINT
RAMSEY BAY
BLUE POINT
RAMSEY
MAUGHOLD HEAD
1·0
2·0
JURBY HEAD
TARGET
2034
SNAEFELL
ORRISDALE HEAD
LAXEY
LAXEY BAY
0·7
0·8
ISLE OF MAN.
2·00 HRS BEFORE LIVERPOOL H.W.M
WEAK
C.G
PEEL
DOUGLAS
DOUGLAS BAY
L.H.
STATE OF TIDE AT :
RAMSEY 2/3 FLOOD.
DOUGLAS D°
CASTLETOWN D°
PEEL D°
0·8
CONTRARY HEAD
LITTLE NESS
TURNING
2·0
NIARBYL HEAD
SANTON HEAD
CASTLETOWN
WEAK
PORT ST. MARY
L.H.
WEAK
LANGNESS POINT
BRADDA HEAD
PORT ERIN
2·0
0·5
SPANISH HEAD
CALF OF MAN
L.H.
CHICKEN ROCK
L.H
3·0
1·0
1·5
FROM CONTRARY HEAD TO CALF SOUND (INSHORE) THE STREAM IS WEAKENING AND WILL SOON TURN NORTHERLY. OVERFALLS EAST OF CHICKENS AND OFF LANGNESS. OVERFALLS OR RACE AT AYRE HOOK.

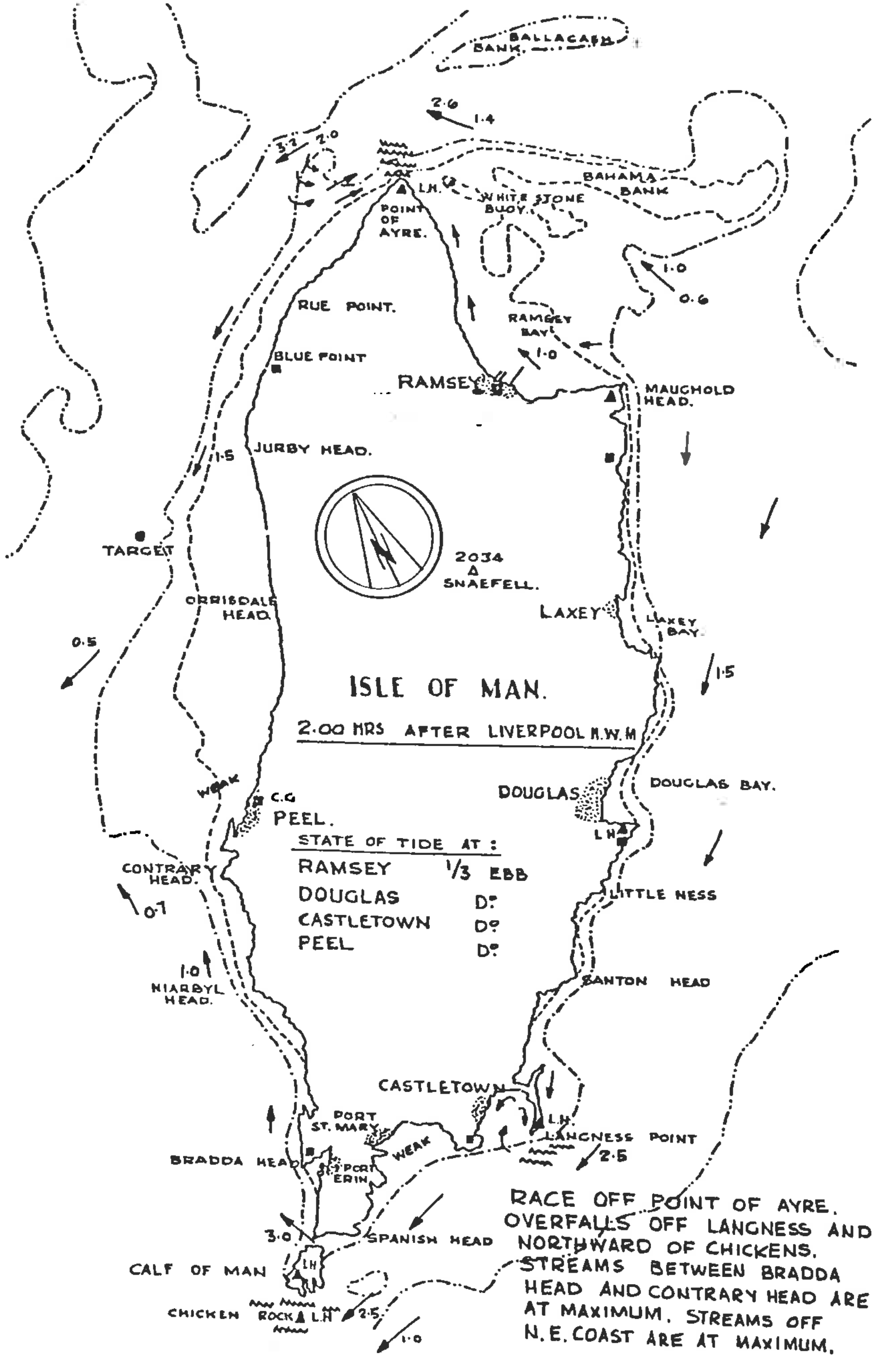


STREAMS THROUGH CALF SOUND AND OFF WEST COAST ARE NOW NORTH BOUND (INSHORE) OVERFALLS EASTWARD OF CHICKENS, OFF LANGNESS AND AT AYRE HOOK. STREAM NORTH OF POINT OF AYRE NOW LOSING STRENGTH QUICKLY.

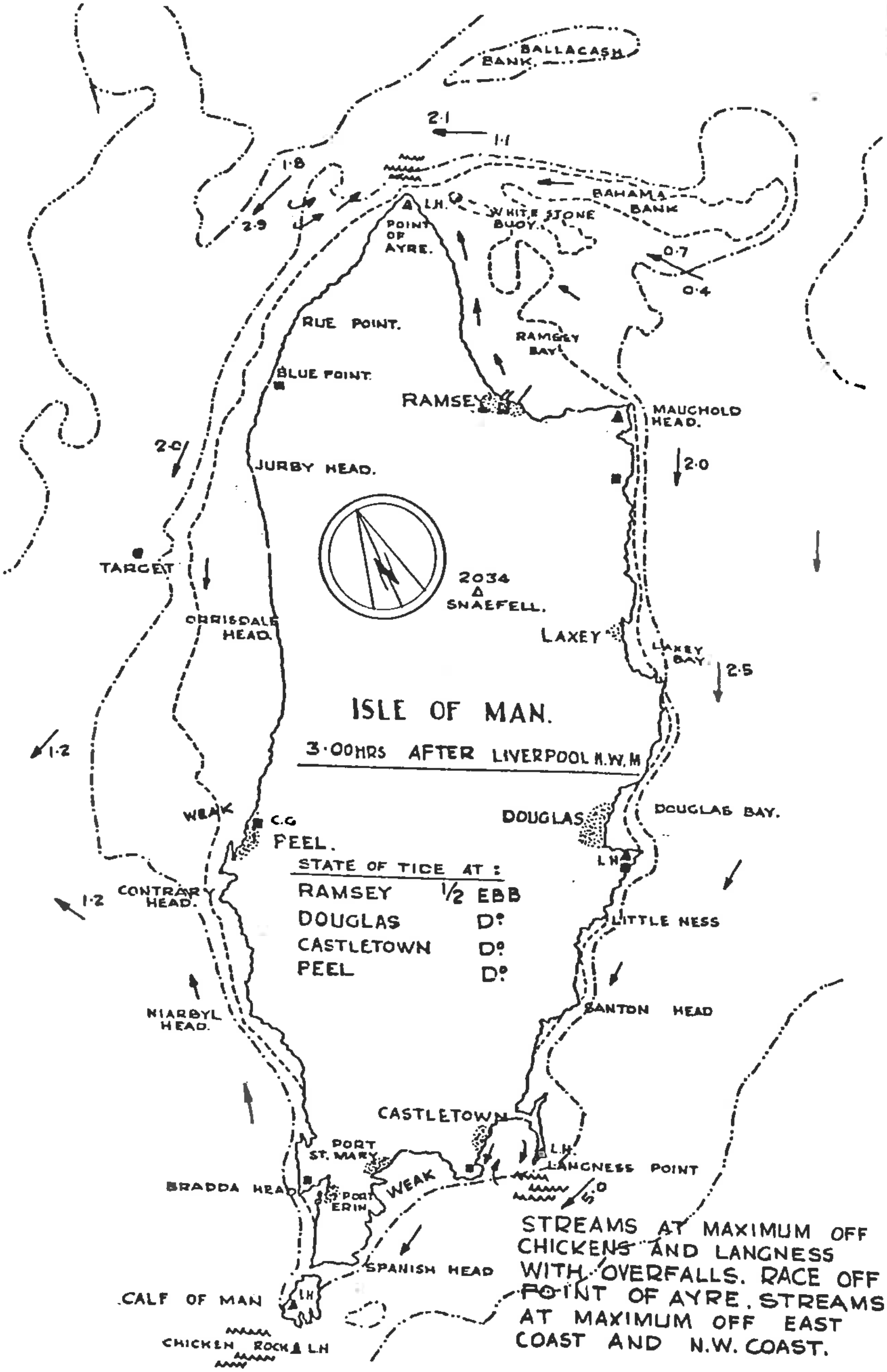


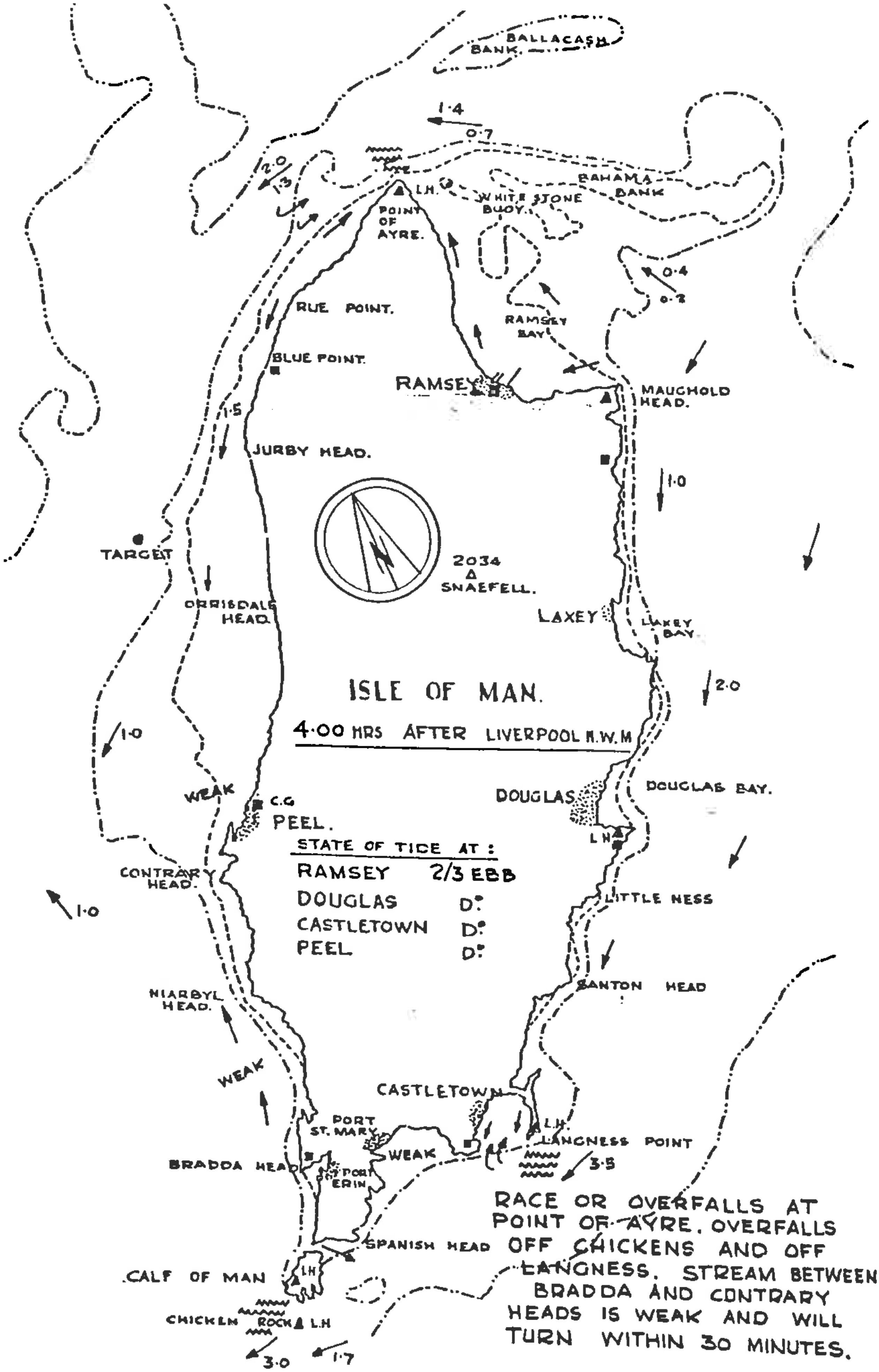
BALLACASH BANK.
1·6
0·9
0·9
0·6
BAHAMA BANK
LH
WHITE STONE BUOY.
POINT OF AYRE.
WEAK
0·7
0·4
RUE POINT.
RAMSEY BAY
BLUE POINT
RAMSEY
MAUGHOLD HEAD.
TURNING
JURBY HEAD.
WEAK
TARGET
2034
SNAEFELL.
ORRISDALE HEAD.
LAXEY
LAXEY BAY.
TURNING
0·1
0·1
ISLE OF MAN.
HIGH WATER LIVERPOOL H.W. IH
DOUGLAS BAY.
DOUGLAS
TURNING.
C.G
PEEL.
LH
STATE OF TIDE AT:
RAMSEY
DOUGLAS
CASTLETOWN
PEEL
CONTRARY HEAD.
LITTLE NESS
TURNING
WEAK
0·5
SANTON HEAD
NIARBYL HEAD.
CASTLETOWN
WEAK
L.H.
PORT ST. MARY
LANGNESS POINT
WEAK
BRADDA HEAD
PORT ERIN
TURNING.
OFFSHORE STREAMS ARE TURNING AND WEAK EXCEPT IN THE NORTH EAST. STREAM IN CALF SOUND WHICH IS GAINING STRENGTH.
1·8
SPANISH HEAD
CALF OF MAN
LH
CHICKEN ROCK LH
TURNING

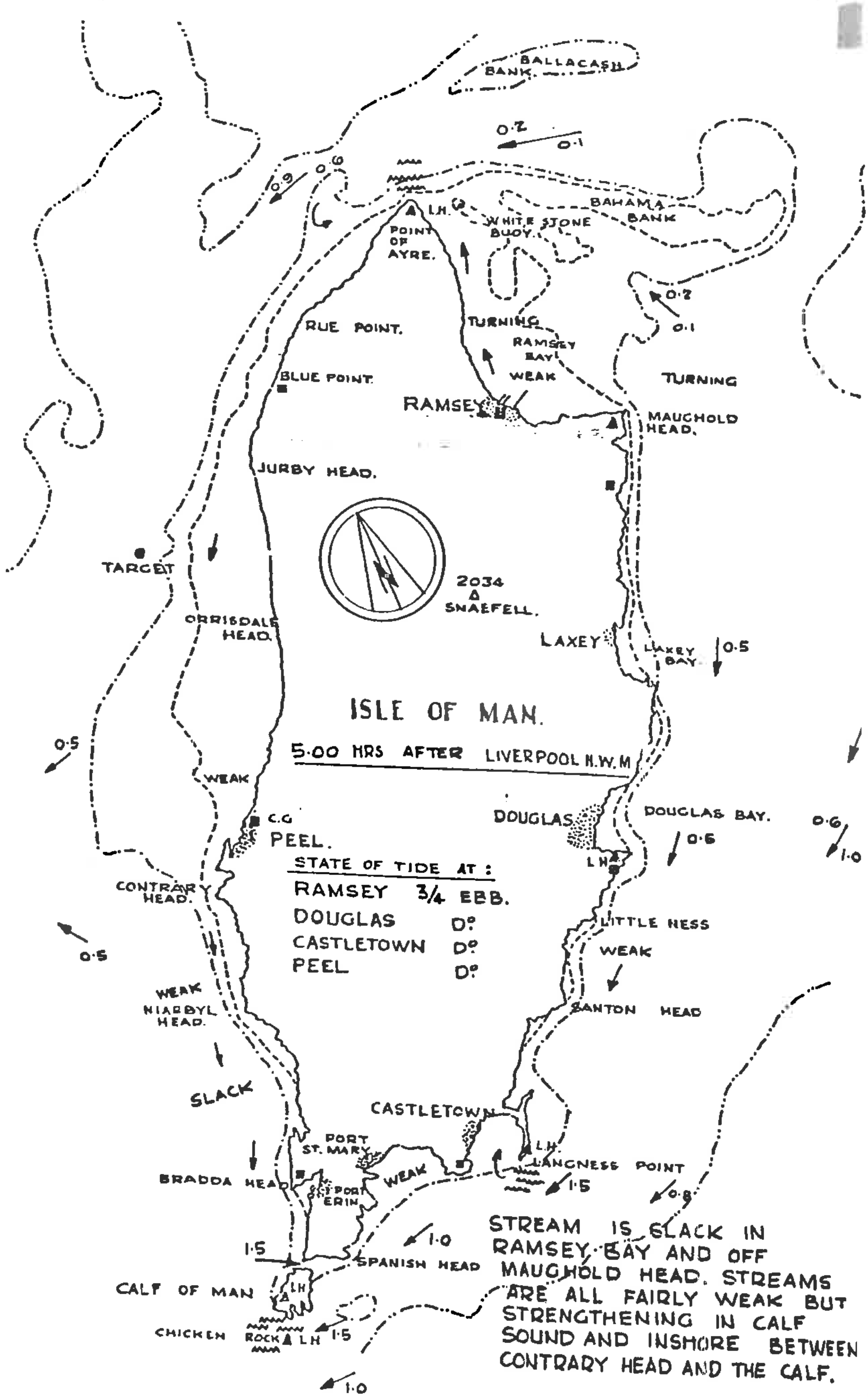

BALLACASH BANK.
2·4
1·3
1·9
3·0
L.H.
POINT OF AYRE.
WHITE STONE BUOY.
BAHAMA BANK
0·9
0·6
RUE POINT.
0·5
RAMSEY BAY
BLUE POINT
RAMSEY
MAUGHOLD HEAD.
0·5
JURBY HEAD.
2034
SNAEFELL.
TARGET
ORRISDALE HEAD.
LAXEY
LAXEY BAY.
0·5
ISLE OF MAN.
1·00 HRS AFTER LIVERPOOL H.W.M
WEAK
C.G
PEEL.
DOUGLAS
DOUGLAS BAY.
0·5
0·2
L.H.
STATE OF TIDE AT :
RAMSEY
DOUGLAS
CASTLETOWN
PEEL
CONTRARY HEAD.
LITTLE NESS
0·5
0·7
NIARBYL HEAD.
SANTON HEAD
CASTLETOWN
PORT ST. MARY
L.H.
LANGNESS POINT
BRADDA HEAD
PORT ERIN
WEAK
1·0
RACE OFF POINT OF AYRE
OVERFALLS AT SRINGS
NORTHWARDS OF CHICKENS
AND SOUTHWARD OF
LANGNESS. STREAM IN CALF
SOUND NEARING ITS
MAXIMUM.
3·0
SPANISH HEAD
CALF OF MAN
L.H
CHICKEN ROCK L.H
1·0



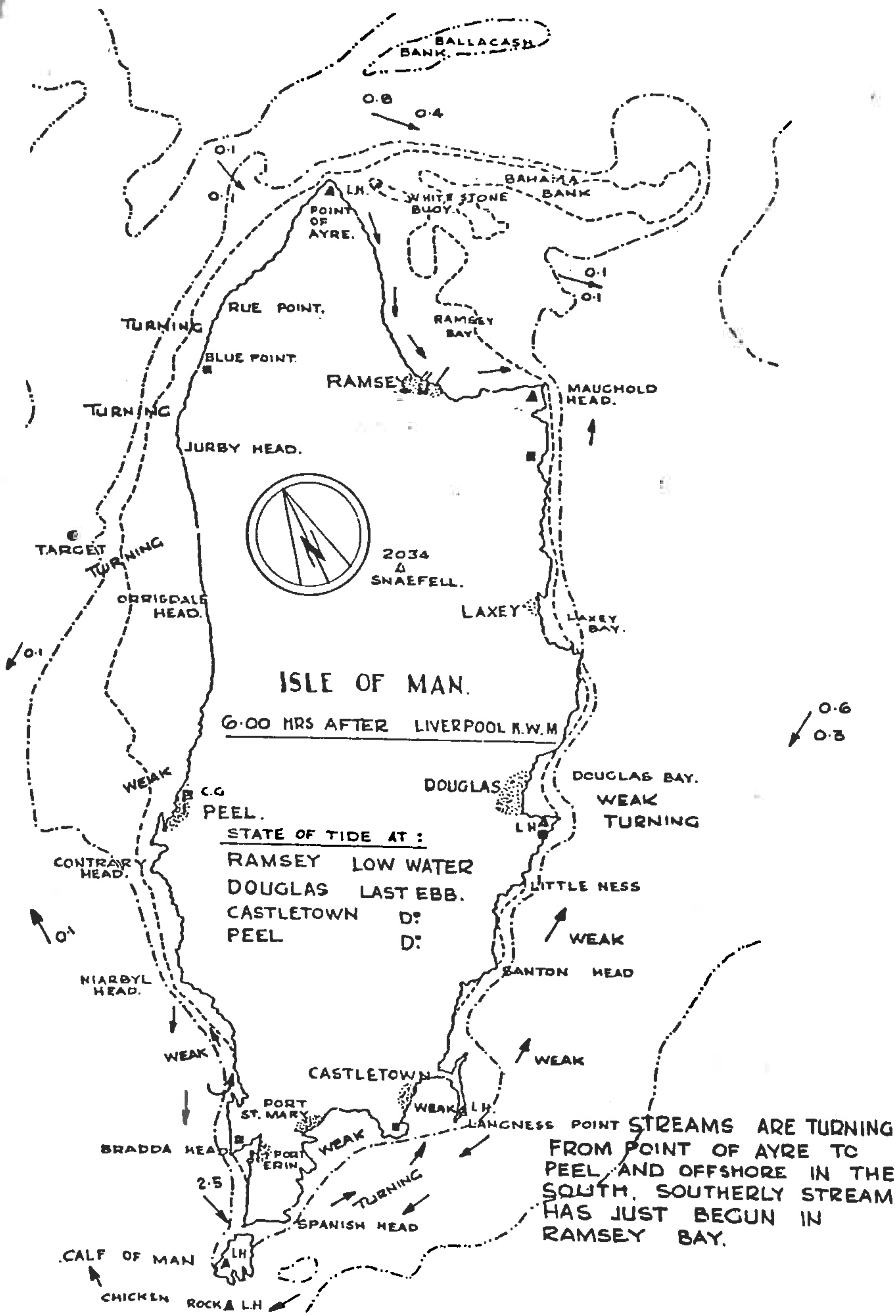
RACE OFF POINT OF AYRE. OVERFALLS OFF LANGNESS AND NORTHWARD OF CHICKENS. STREAMS BETWEEN BRADDA HEAD AND CONTRARY HEAD ARE AT MAXIMUM. STREAMS OFF N.E. COAST ARE AT MAXIMUM.


BALLACASH BANK
2·1
1·1
1·8
2·9
BAHAMA BANK
L.H.
POINT OF AYRE.
WHITE STONE BUOY.
0·7
0·4
RUE POINT.
RAMSEY BAY
BLUE POINT.
RAMSEY
MAUGHOLD HEAD.
2·0
JURBY HEAD.
2·0
TARGET
2034
SNAEFELL.
ORRISDALE HEAD.
LAXEY
LAXEY BAY.
2·5
ISLE OF MAN.
3·00HRS AFTER LIVERPOOL H.W.M
1·2
WEAK
C.G
PEEL.
DOUGLAS
DOUGLAS BAY.
L.H.
STATE OF TIDE AT :
RAMSEY 1/2 EBB
DOUGLAS D°
CASTLETOWN D°
PEEL D°
1·2
CONTRARY HEAD.
LITTLE NESS
NIARBYL HEAD.
SANTON HEAD
CASTLETOWN
PORT ST. MARY
L.H.
LANGNESS POINT
BRADDA HEAD
PORT ERIN
WEAK
5·0
SPANISH HEAD
CALF OF MAN
LH
CHICKEN ROCK L.H
STREAMS AT MAXIMUM OFF CHICKENS AND LANGNESS WITH OVERFALLS. RACE OFF POINT OF AYRE. STREAMS AT MAXIMUM OFF EAST COAST AND N.W. COAST.


BALLACASH BANK.
1·4
0·7
2·0
1·3
L.H.
POINT OF AYRE.
WHITE STONE BUOY.
BAHAMA BANK
0·4
0·2
RUE POINT.
BLUE POINT.
RAMSEY BAY
RAMSEY
MAUGHOLD HEAD.
1·5
JURBY HEAD.
1·0
TARGET
2034
SNAEFELL.
ORRISDALE HEAD.
LAXEY
LAXEY BAY.
ISLE OF MAN.
4·00 HRS AFTER LIVERPOOL H.W.M
2·0
1·0
WEAK
C.G
PEEL.
DOUGLAS
DOUGLAS BAY.
L.H.
STATE OF TIDE AT :
RAMSEY 2/3 EBB
DOUGLAS D°
CASTLETOWN D°
PEEL D°
CONTRARY HEAD.
1·0
LITTLE NESS
NIARBYL HEAD.
SANTON HEAD
WEAK
CASTLETOWN
PORT ST. MARY
L.H.
LANGNESS POINT
WEAK
BRADDA HEAD
PORT ERIN
3·5
SPANISH HEAD
L.H.
CALF OF MAN
CHICKEN ROCK L.H
3·0
1·7
RACE OR OVERFALLS AT POINT OF AYRE. OVERFALLS OFF CHICKENS AND OFF LANGNESS. STREAM BETWEEN BRADDA AND CONTRARY HEADS IS WEAK AND WILL TURN WITHIN 30 MINUTES.

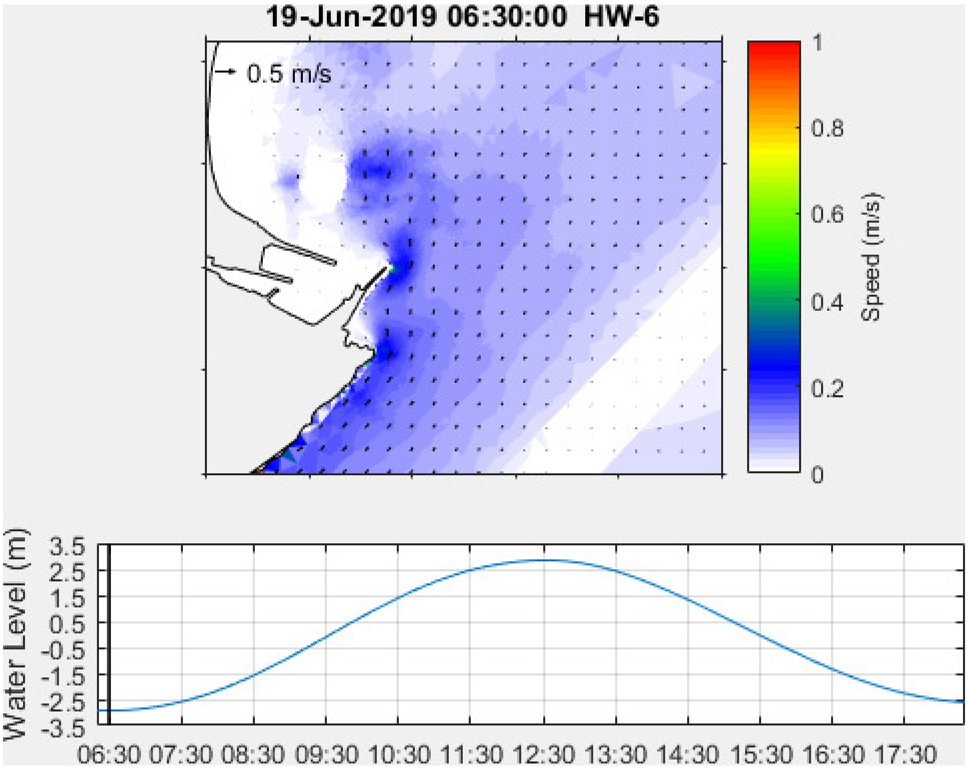


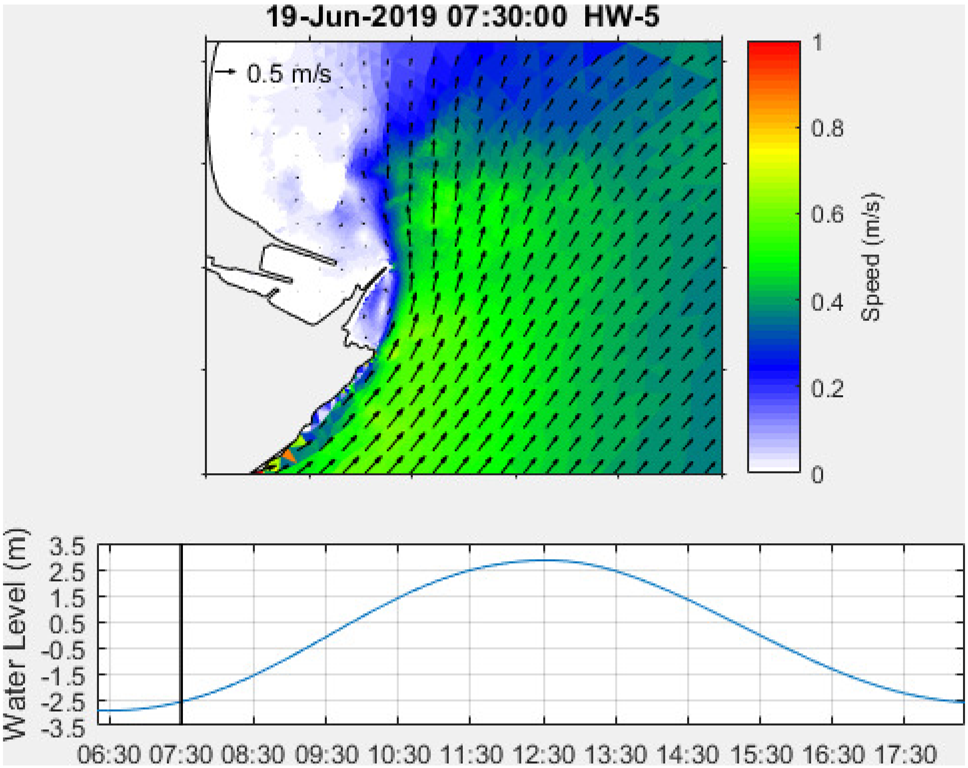
BALLACASH BANK
0·2
0·1
0·9
0·6
BAHAMA BANK
L.H.
WHITE STONE BUOY
POINT OF AYRE.
0·2
0·1
RUE POINT.
TURNING
RAMSEY BAY
WEAK
TURNING
BLUE POINT
RAMSEY
MAUGHOLD HEAD.
JURBY HEAD.
TARGET
2034
SNAEFELL.
ORRISDALE HEAD.
LAXEY
LAXEY BAY
0·5
ISLE OF MAN.
5·00 HRS AFTER LIVERPOOL H.W.M
0·5
WEAK
C.G
PEEL.
DOUGLAS
DOUGLAS BAY.
0·6
0·6
1·0
L.H.
STATE OF TIDE AT :
RAMSEY 3/4 EBB.
DOUGLAS D°
CASTLETOWN D°
PEEL D°
CONTRARY HEAD.
0·5
LITTLE NESS
WEAK
WEAK
NIARBYL HEAD.
SANTON HEAD
SLACK
CASTLETOWN
PORT ST. MARY
L.H.
LANGNESS POINT
BRADDA HEAD
WEAK
PORT ERIN
1·5
0·8
1·0
1·5
SPANISH HEAD
CALF OF MAN
L.H.
CHICKEN ROCK
L.H.
1·5
1·0
STREAM IS SLACK IN RAMSEY BAY AND OFF MAUGHOLD HEAD. STREAMS ARE ALL FAIRLY WEAK BUT STRENGTHENING IN CALF SOUND AND INSHORE BETWEEN CONTRARY HEAD AND THE CALF.

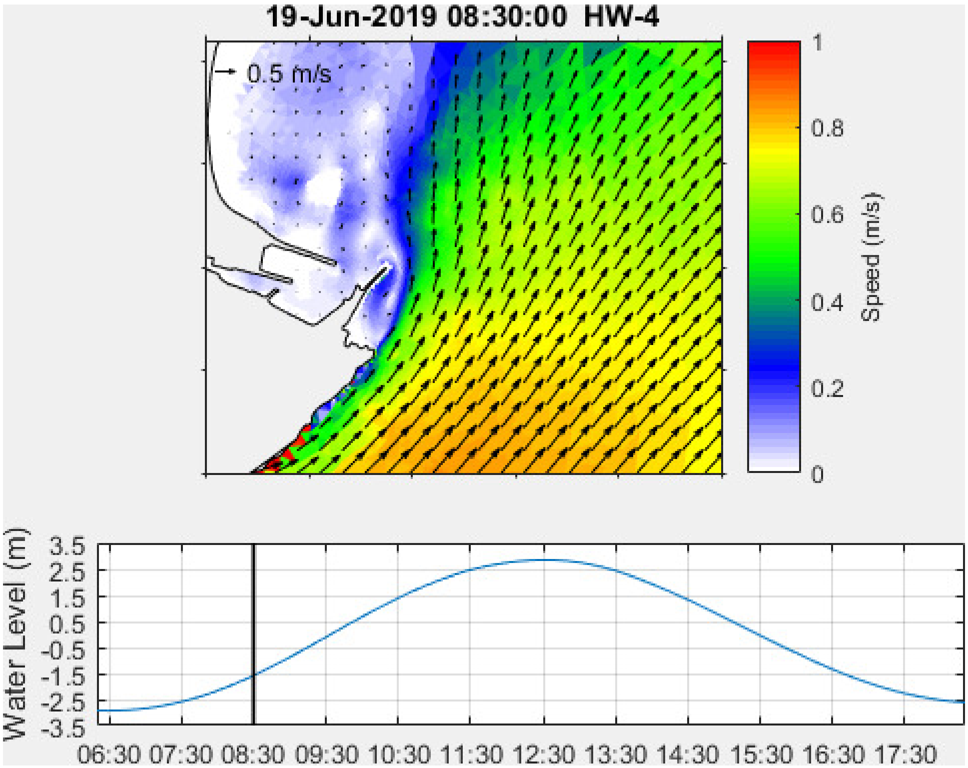

BALLACASH BANK.
0·8
0·4
0·1
0·1
BAHAMA BANK
POINT OF AYRE.
L.H.
WHITE STONE BUOY.
0·1
0·1
RUE POINT.
TURNING
RAMSEY BAY
BLUE POINT
RAMSEY
MAUGHOLD HEAD.
TURNING
JURBY HEAD.
TARGET
TURNING
2034
SNAEFELL.
ORRISDALE HEAD.
LAXEY
LAXEY BAY.
0·1
ISLE OF MAN.
6·00 HRS AFTER LIVERPOOL H.W.M
0·6
0·3
WEAK
C.G
PEEL.
DOUGLAS
DOUGLAS BAY.
WEAK
TURNING
L.H.
STATE OF TIDE AT :
RAMSEY LOW WATER
DOUGLAS LAST EBB.
CASTLETOWN D°
PEEL D°
CONTRARY HEAD.
LITTLE NESS
0·1
WEAK
NIARBYL HEAD.
SANTON HEAD
WEAK
WEAK
CASTLETOWN
PORT ST. MARY
WEAK
L.H.
LANGNESS POINT
STREAMS ARE TURNING FROM POINT OF AYRE TO PEEL AND OFFSHORE IN THE SOUTH. SOUTHERLY STREAM HAS JUST BEGUN IN RAMSEY BAY.
BRADDA HEAD
PORT ERIN
WEAK
2·5
TURNING
SPANISH HEAD
CALF OF MAN
L.H
CHICKEN ROCK L.H

E Baseline Flow Regime: Hourly Vectors Relative to HW

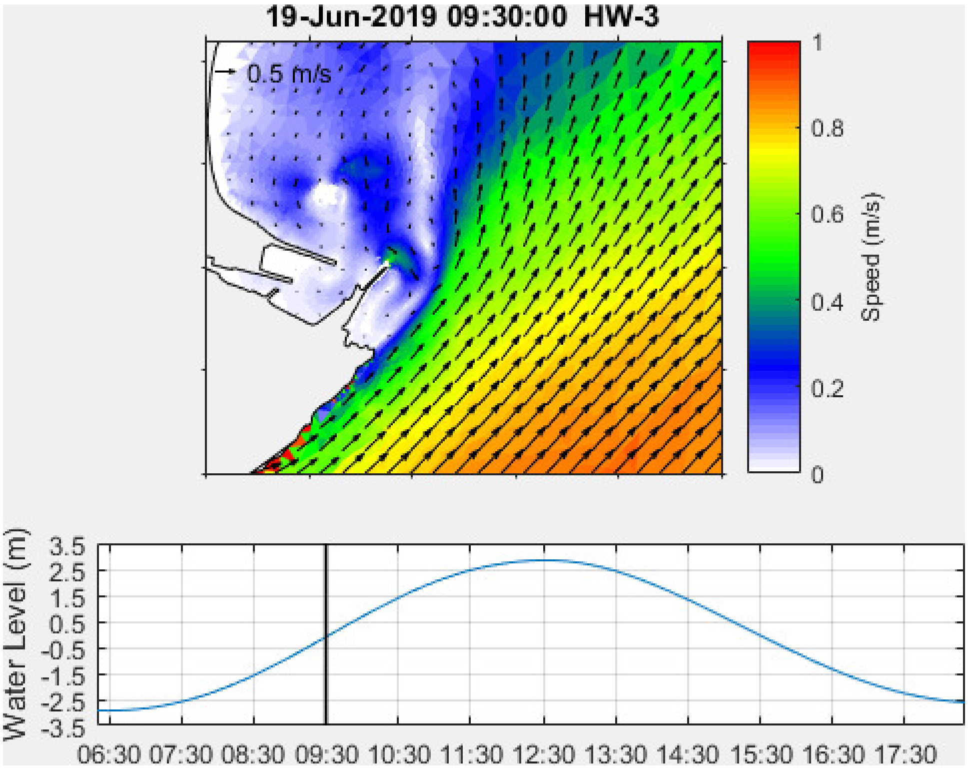
Douglas- Baseline model hourly flow vectors – Spring Tide



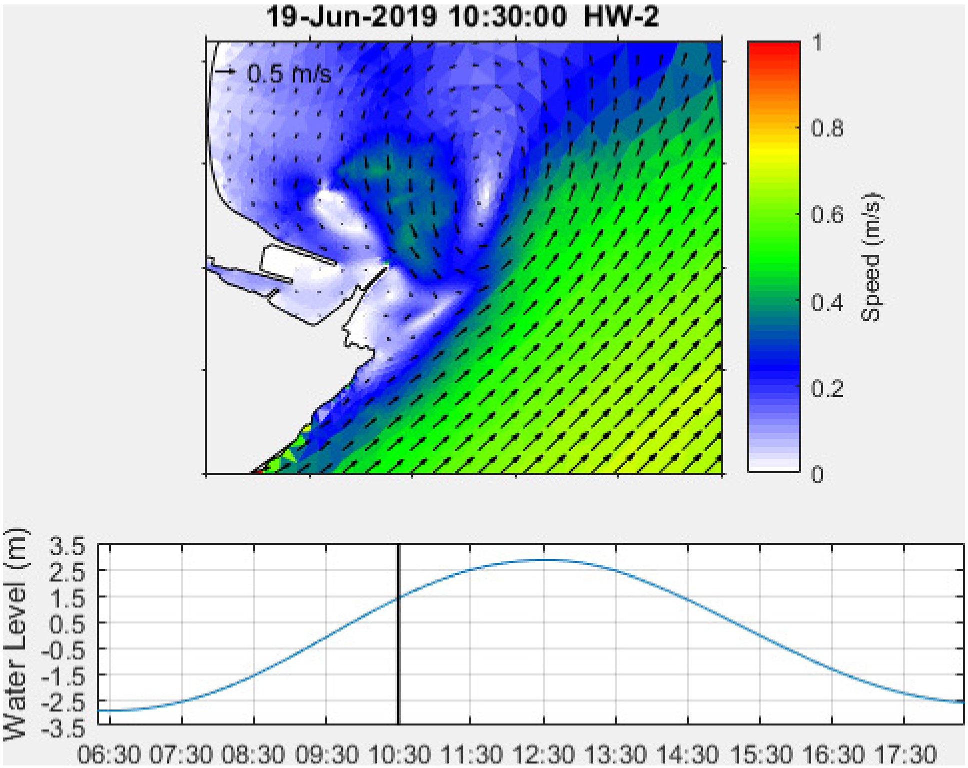


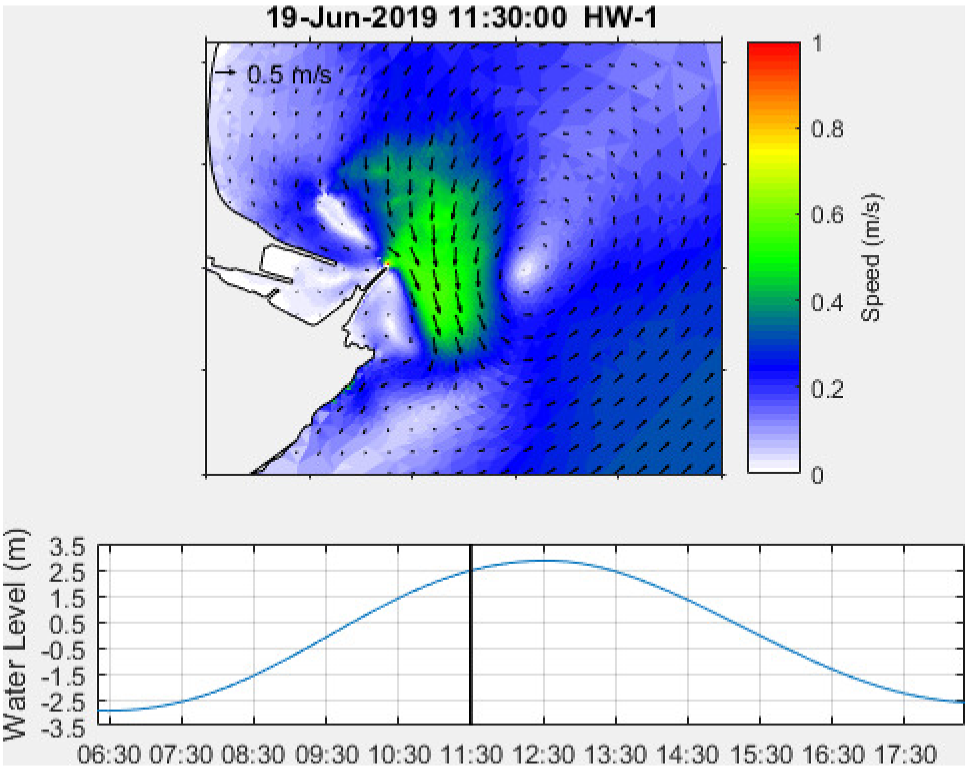


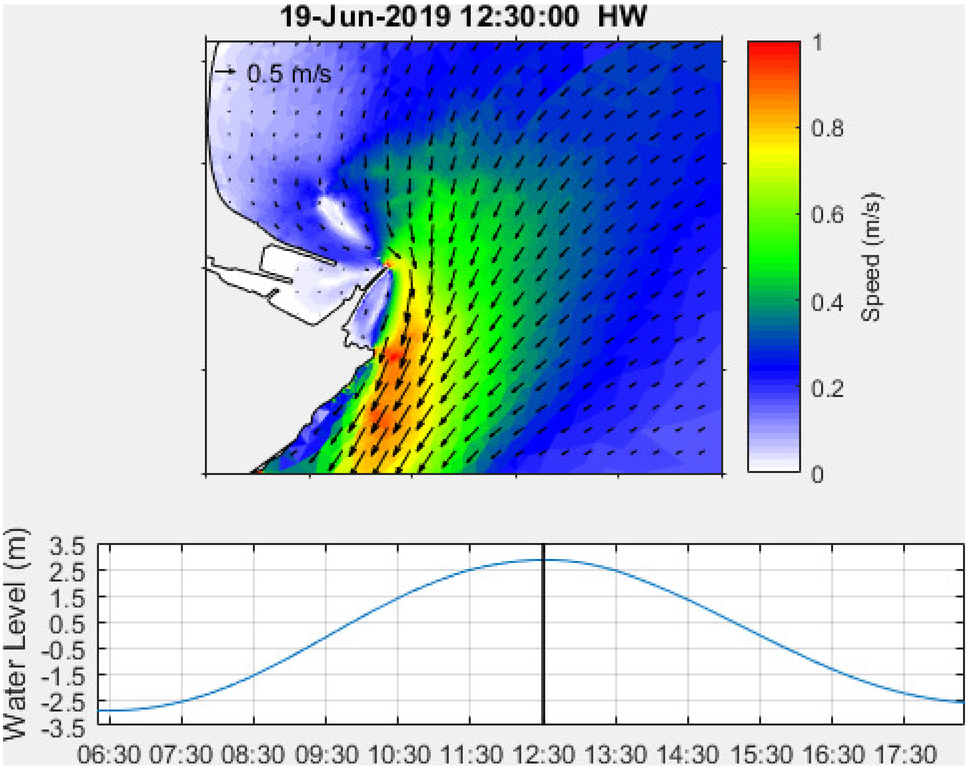
19-Jun-2019 08:30:00 HW-4
0.5 m/s
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
Water Level (m)
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30

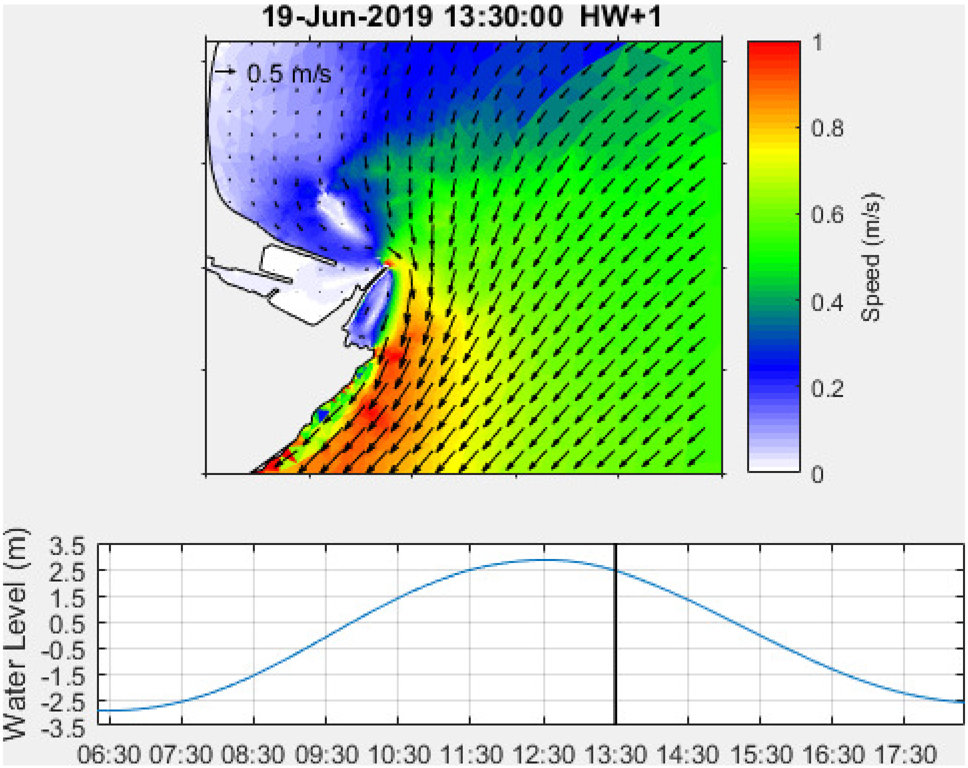


19-Jun-2019 09:30:00 HW-3
0.5 m/s
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
Water Level (m)
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30

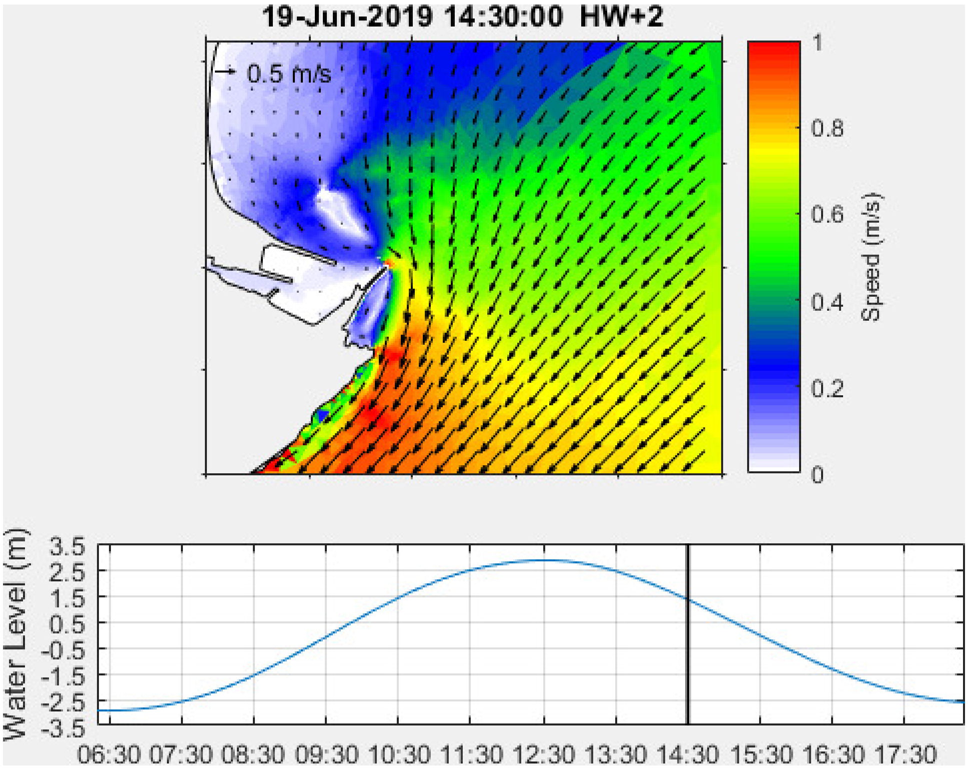

19-Jun-2019 10:30:00 HW-2
0.5 m/s
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
Water Level (m)
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30


19-Jun-2019 11:30:00 HW-1
0.5 m/s
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
Water Level (m)
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30

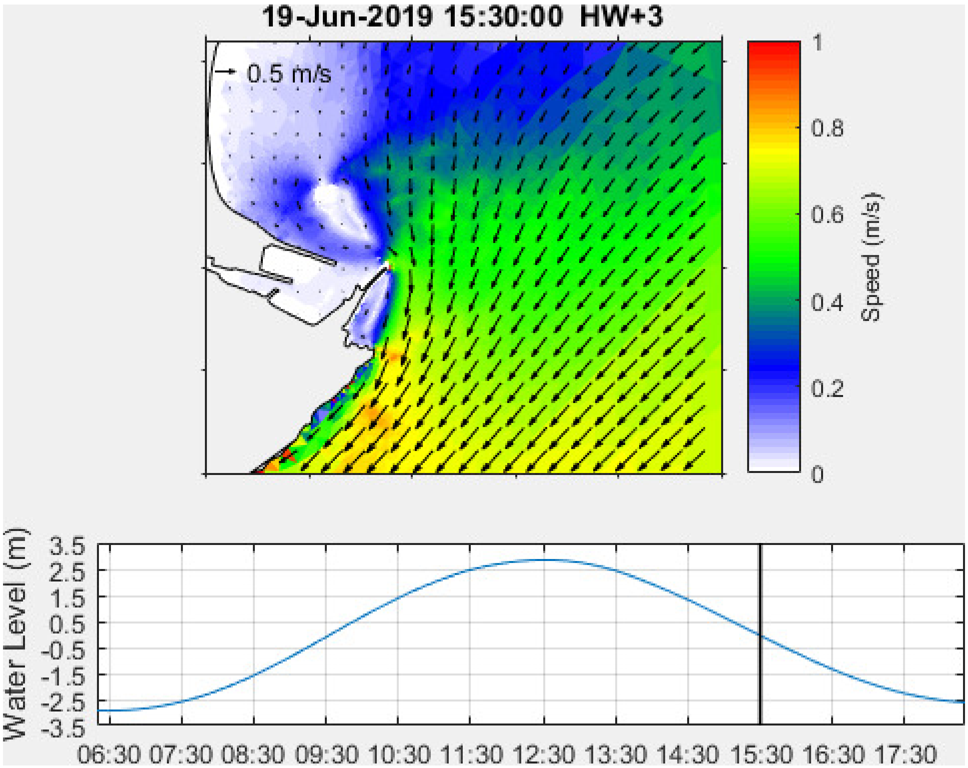

19-Jun-2019 12:30:00 HW
0.5 m/s
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
Water Level (m)
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30

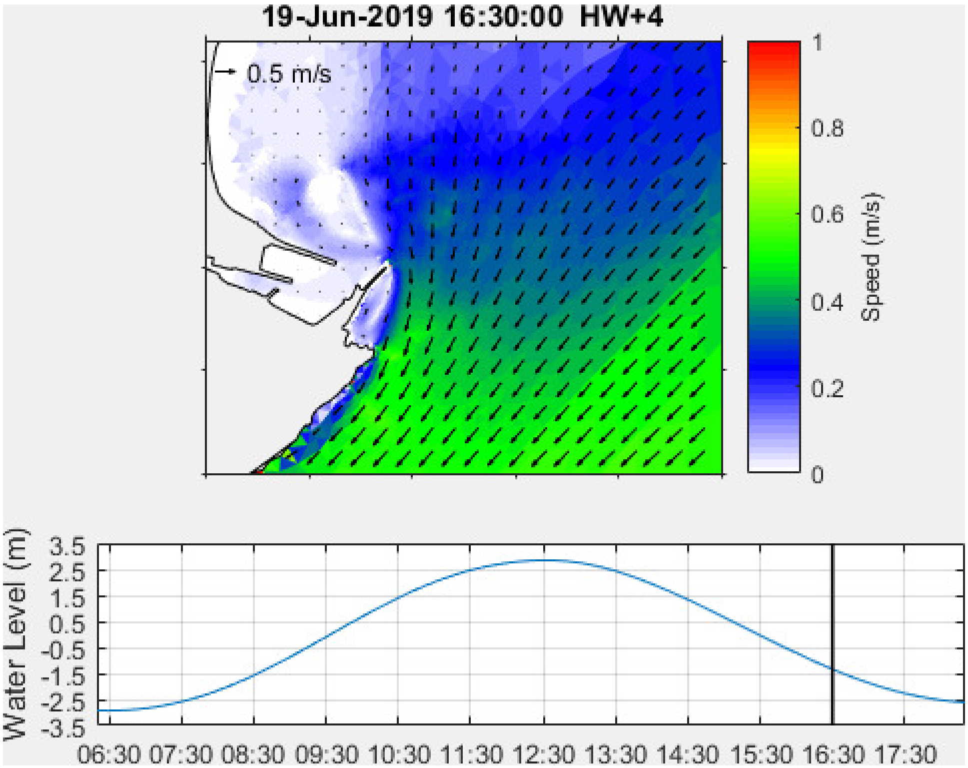


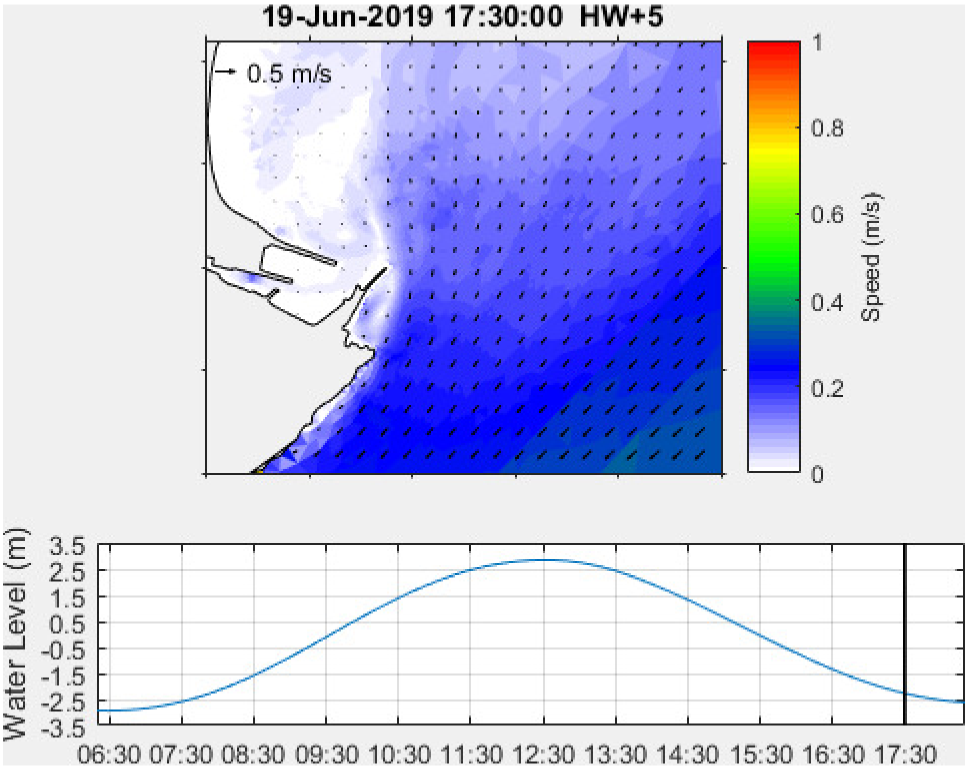
19-Jun-2019 13:30:00 HW+1
0.5 m/s
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
Water Level (m)
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30



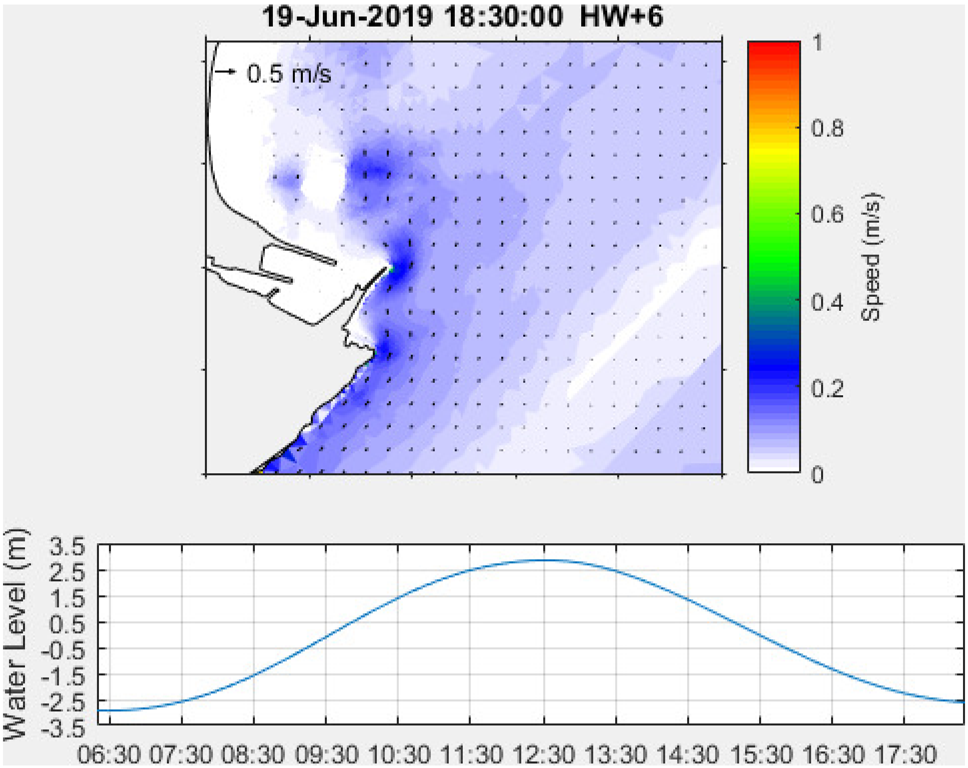
19-Jun-2019 14:30:00 HW+2
0.5 m/s
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
Water Level (m)
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30


19-Jun-2019 15:30:00 HW+3
0.5 m/s
Speed (m/s)
0
0.2
0.4
0.6
0.8
1
Water Level (m)
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30


19-Jun-2019 16:30:00 HW+4
0.5 m/s
Speed (m/s)
0
0.2
0.4
0.6
0.8
1
Water Level (m)
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30

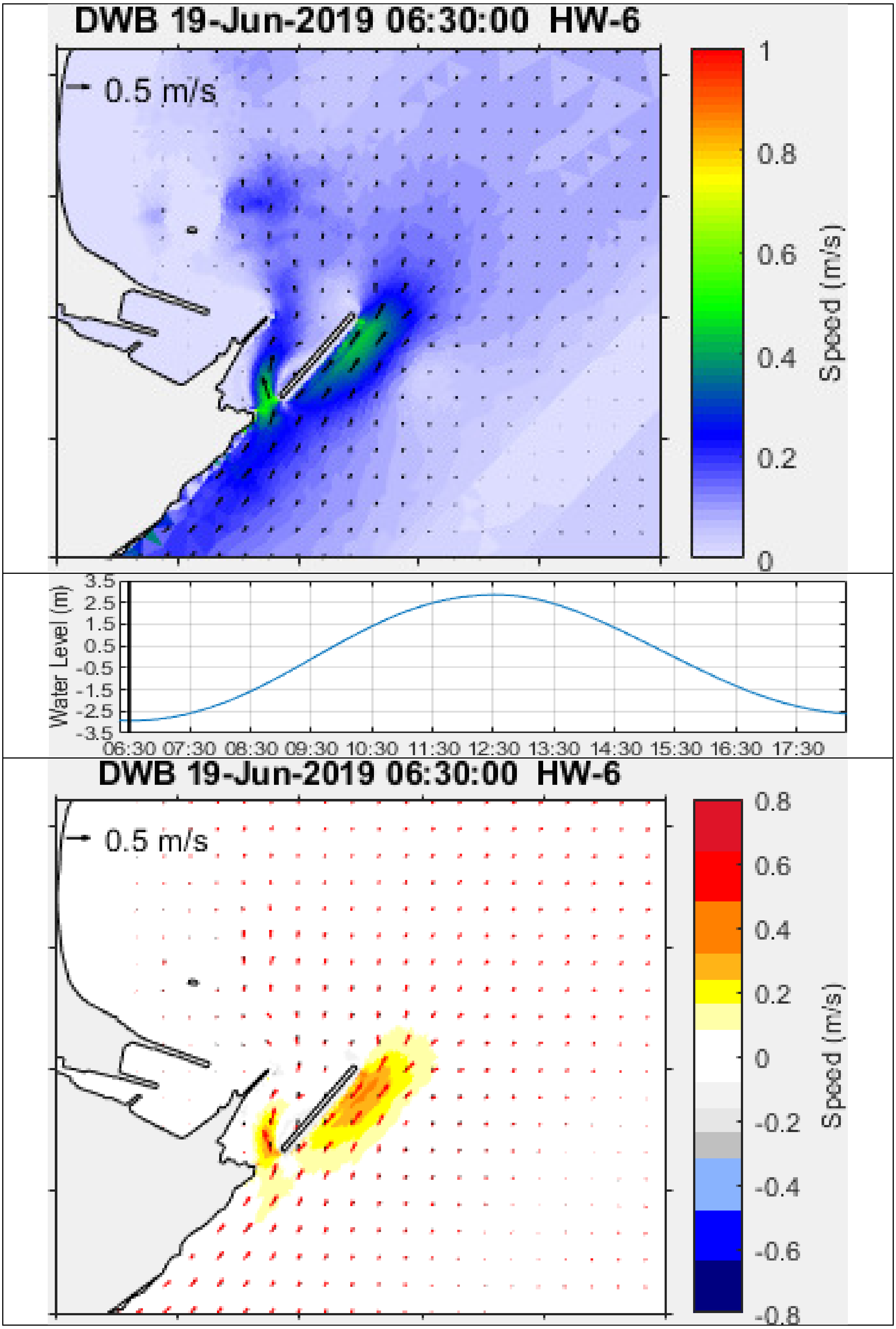


19-Jun-2019 17:30:00 HW+5
0.5 m/s
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
Water Level (m)
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30

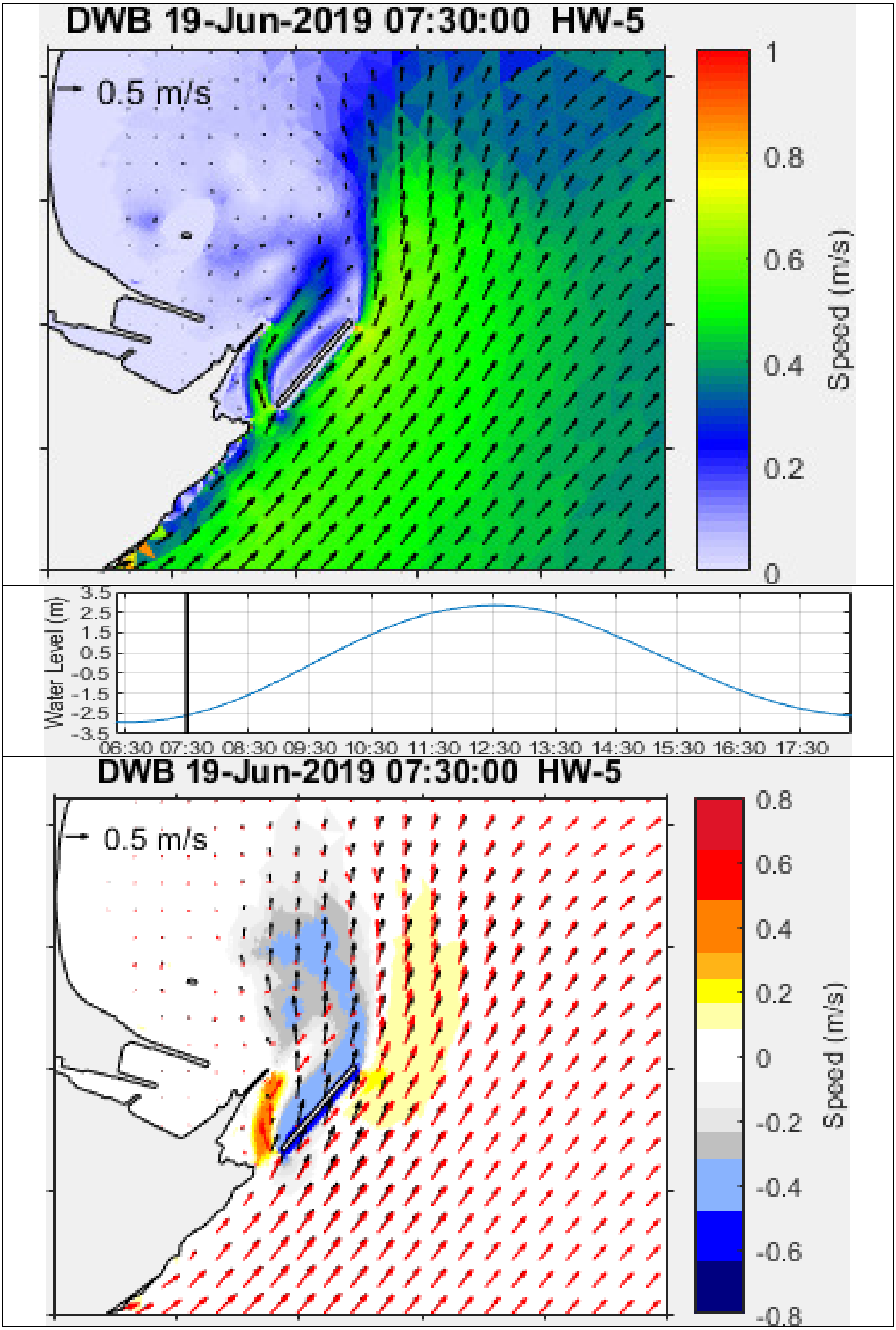


19-Jun-2019 18:30:00 HW+6
0.5 m/s
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
Water Level (m)
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30

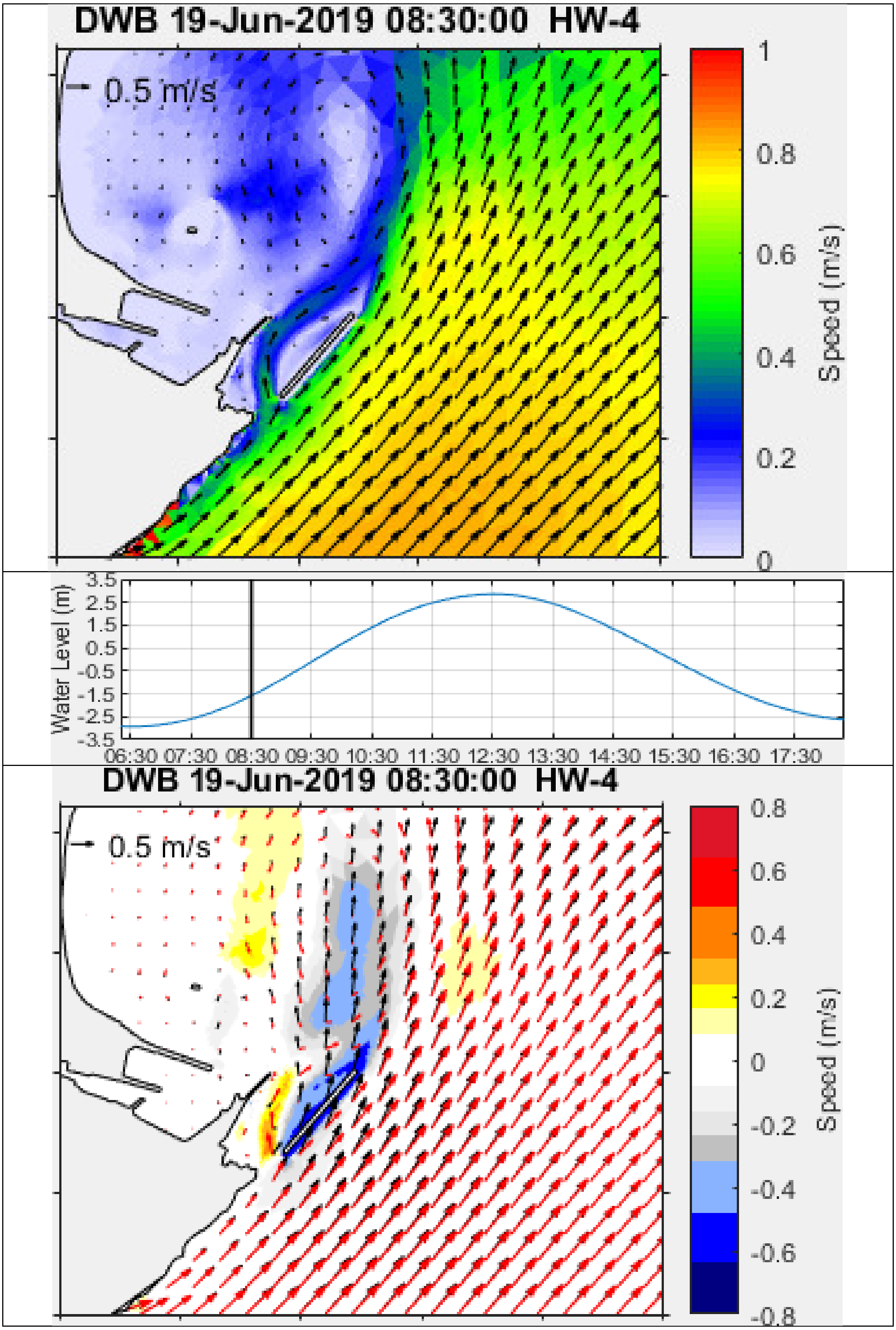
F Deep-Water Berth Flow Regime: Hourly Vectors and Difference Plots from the Baseline Regime Relative to HW



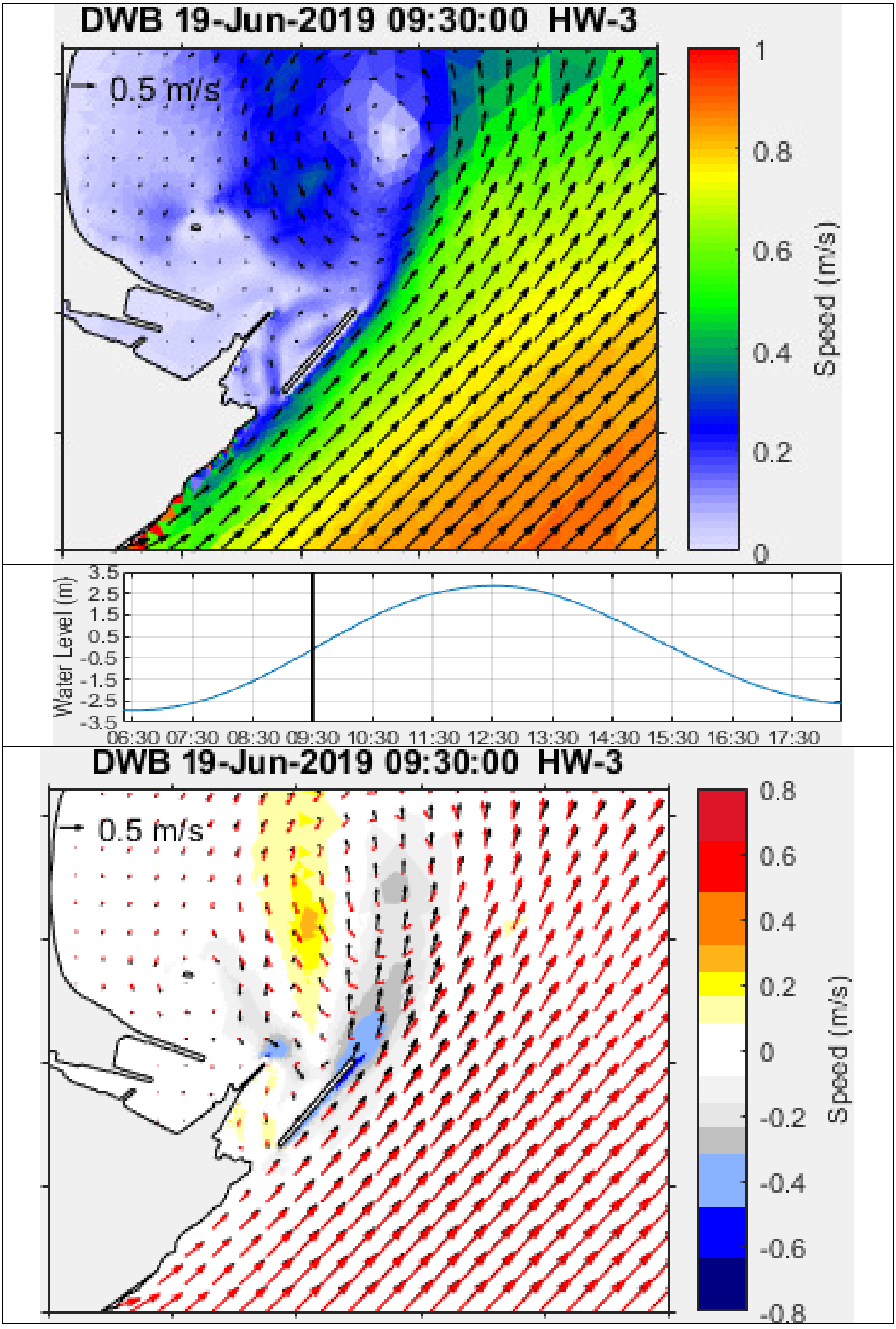
Black vector = Baseline, Red vector = Scheme



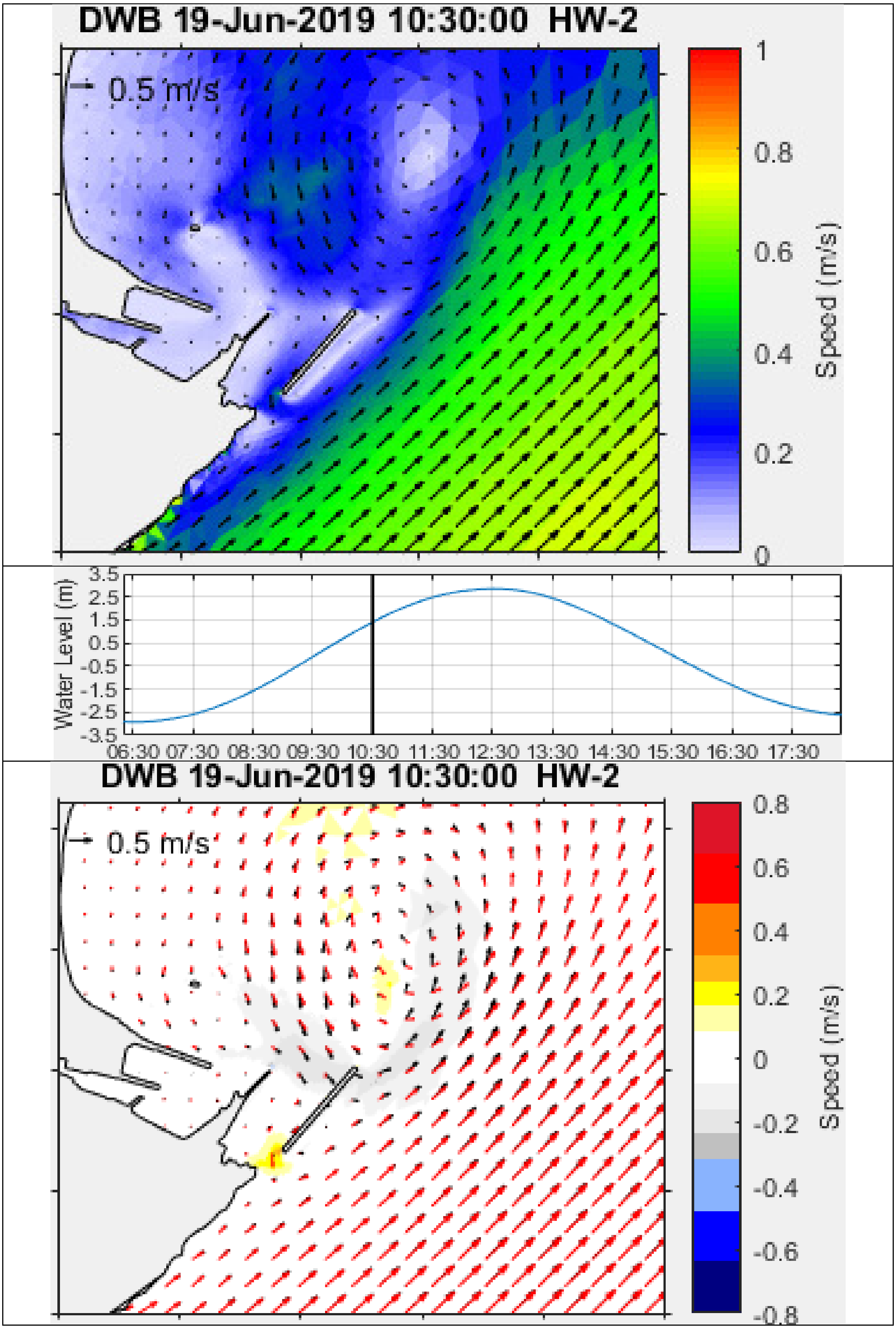
Black vector = Baseline, Red vector = Scheme



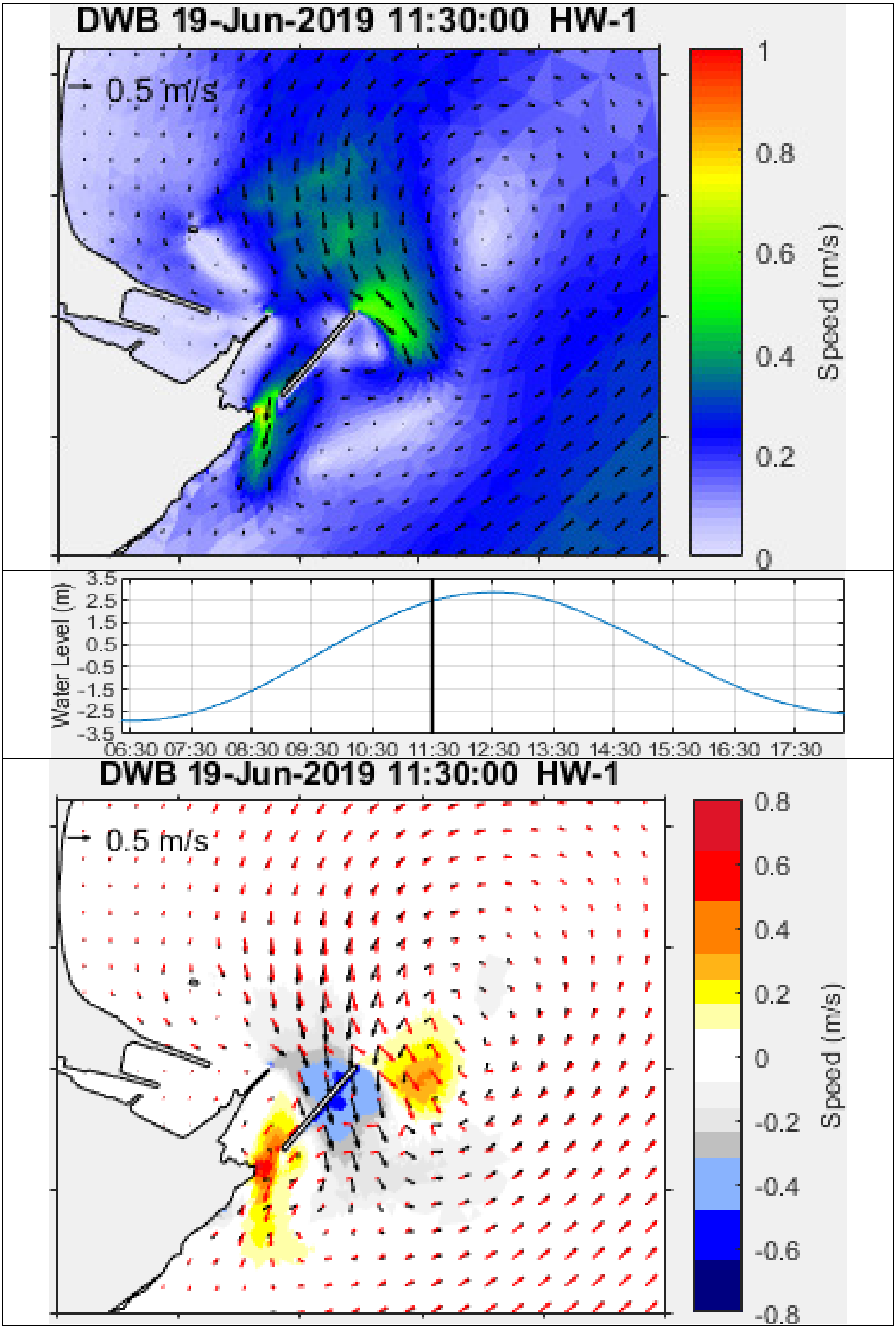
Black vector = Baseline, Red vector = Scheme



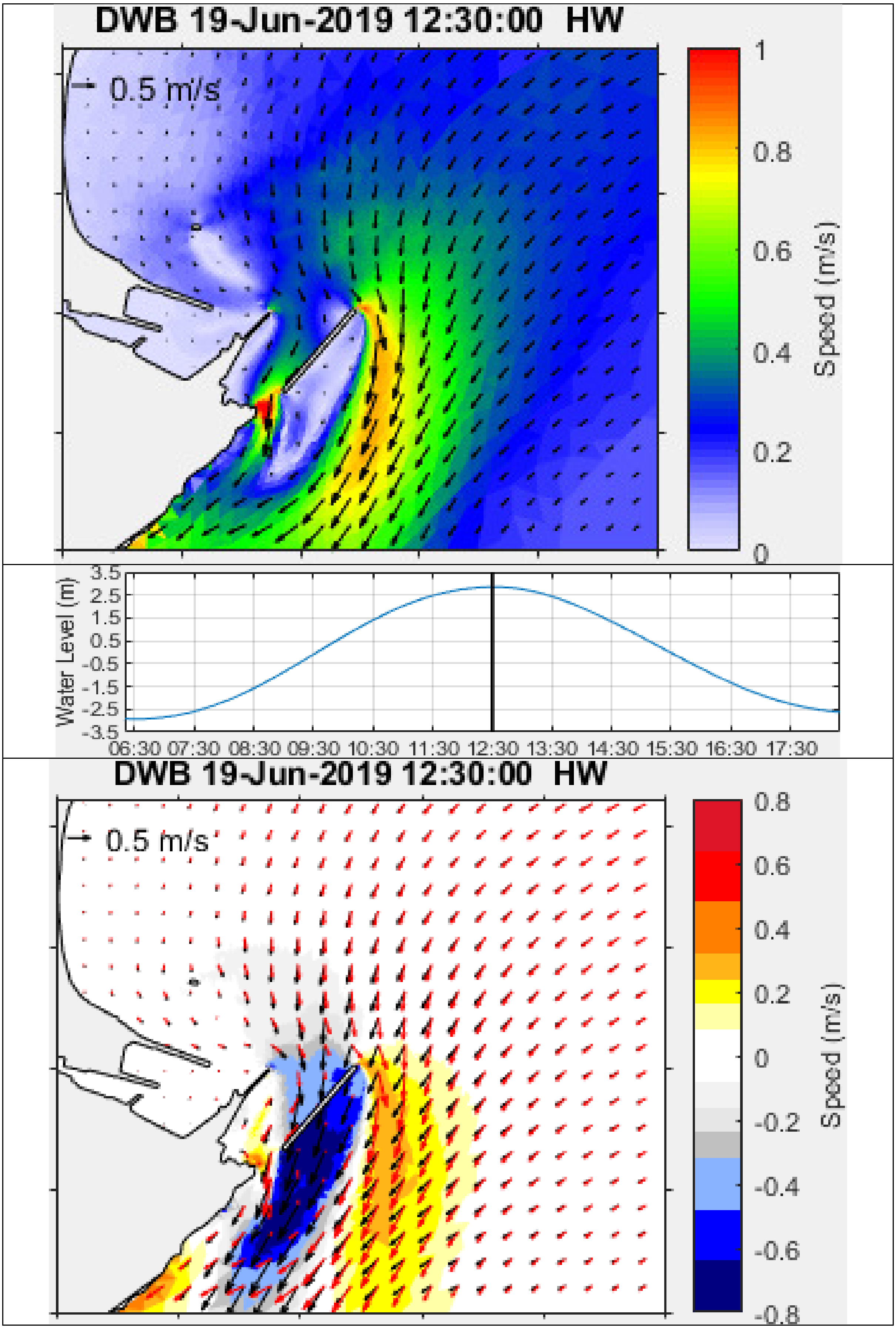
Black vector = Baseline, Red vector = Scheme



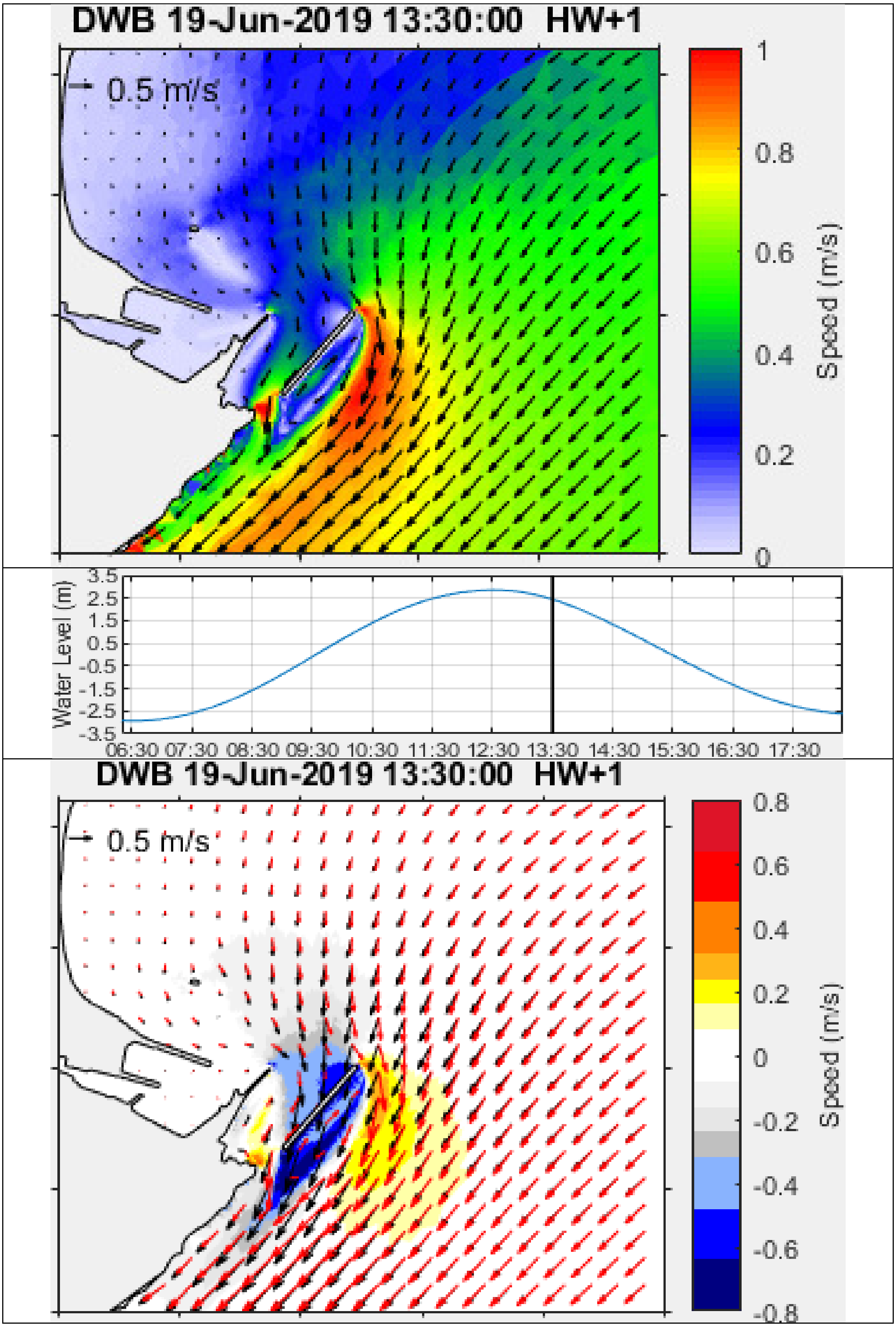
Black vector = Baseline, Red vector = Scheme



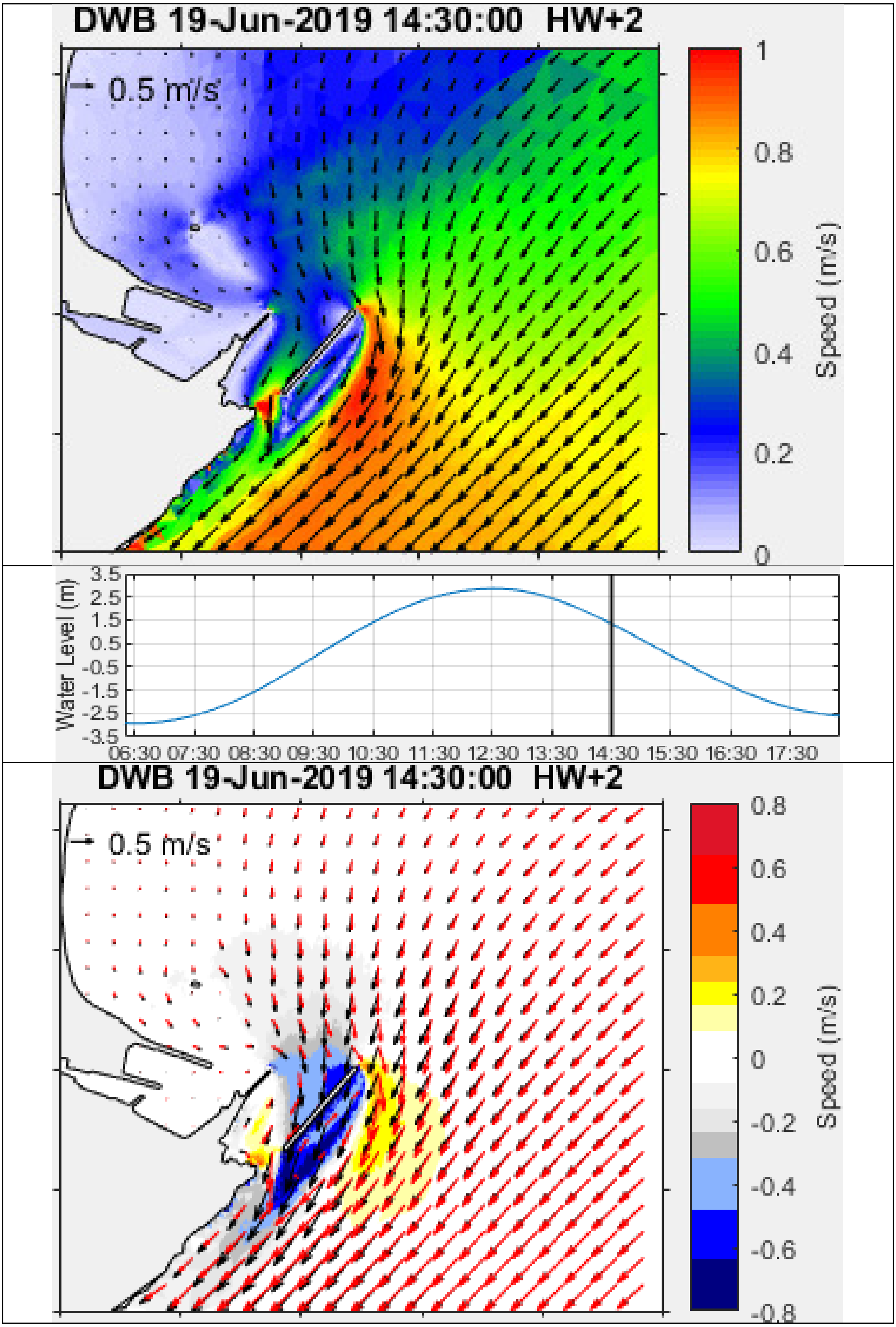
Black vector = Baseline, Red vector = Scheme



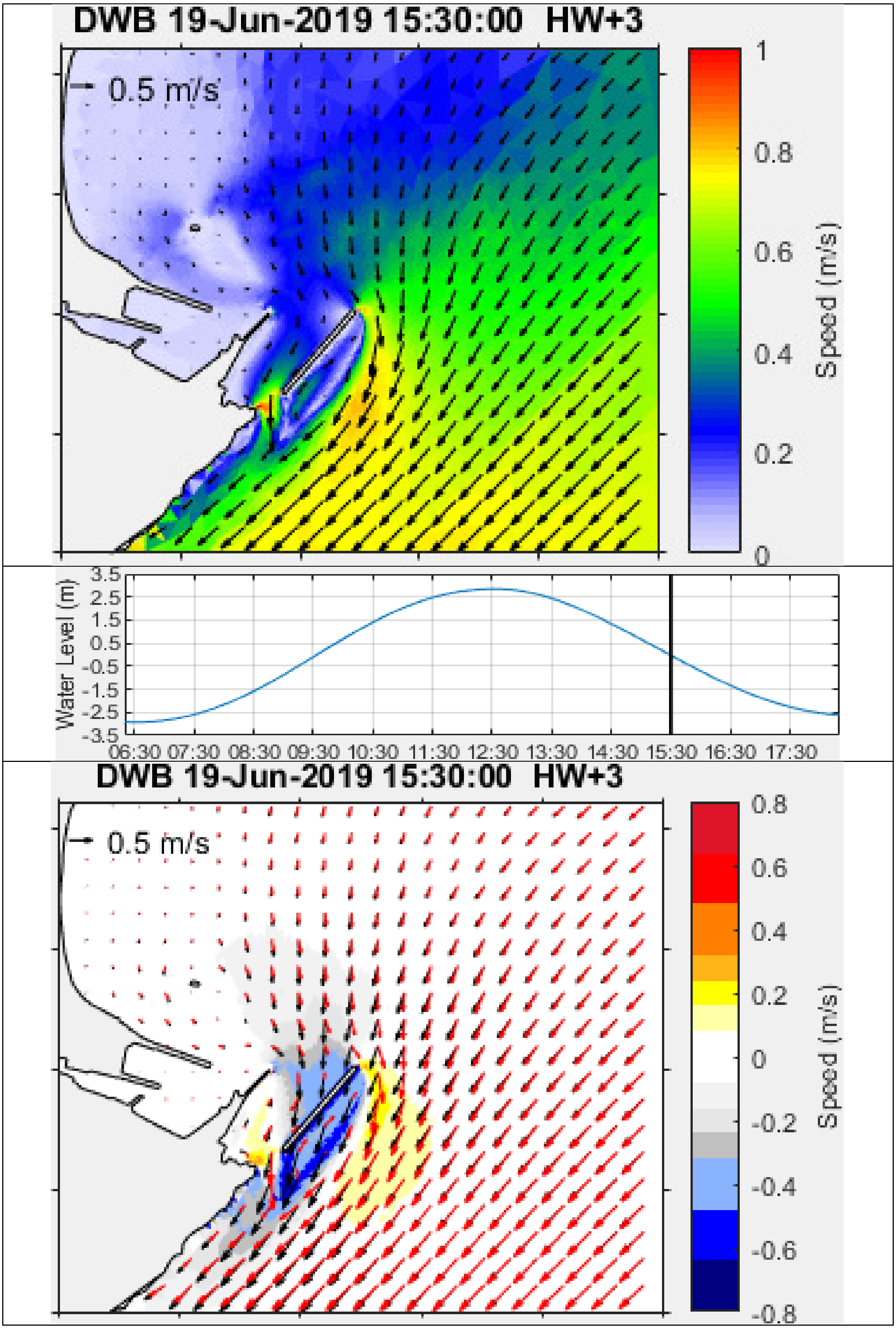
Black vector = Baseline, Red vector = Scheme



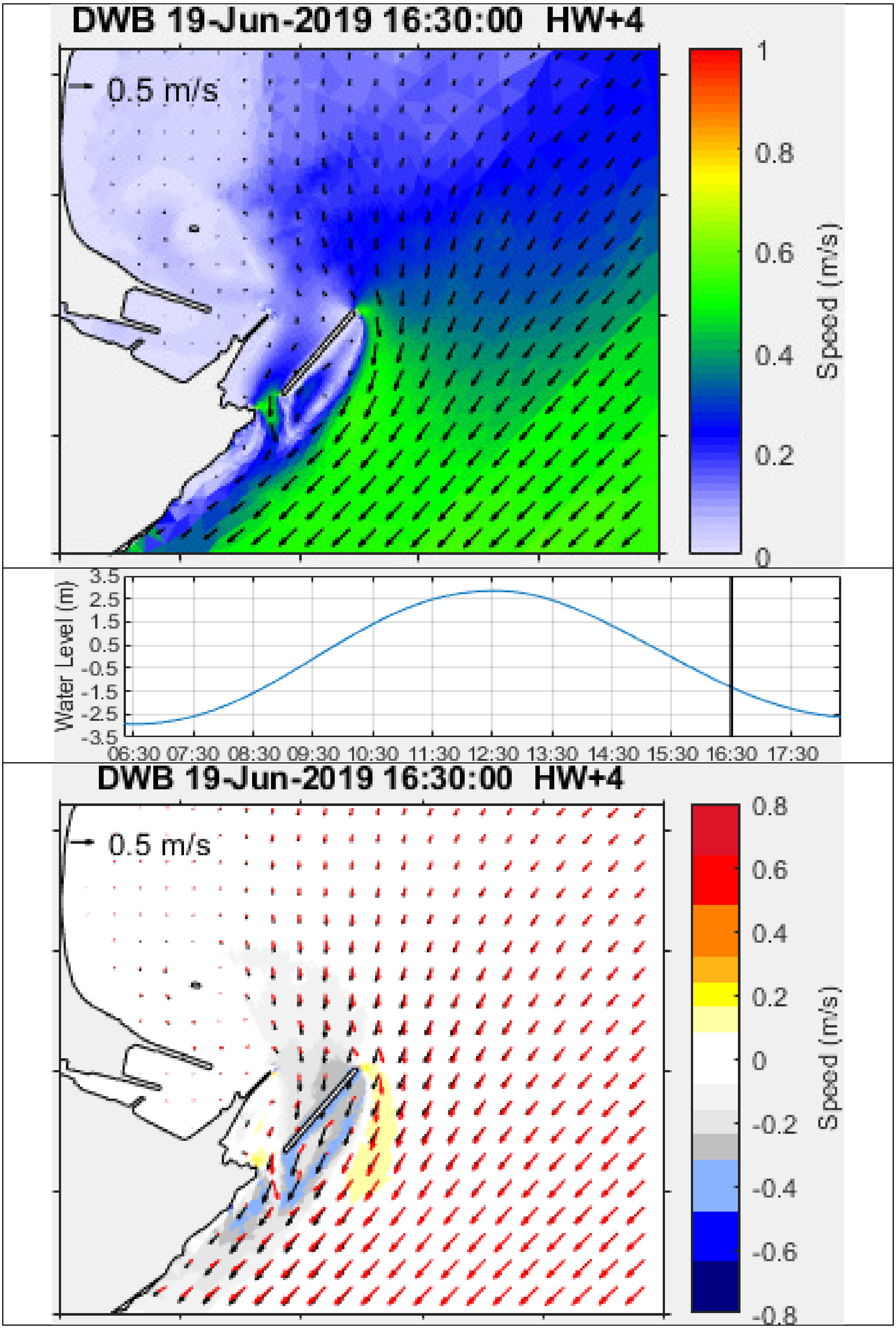
Black vector = Baseline, Red vector = Scheme



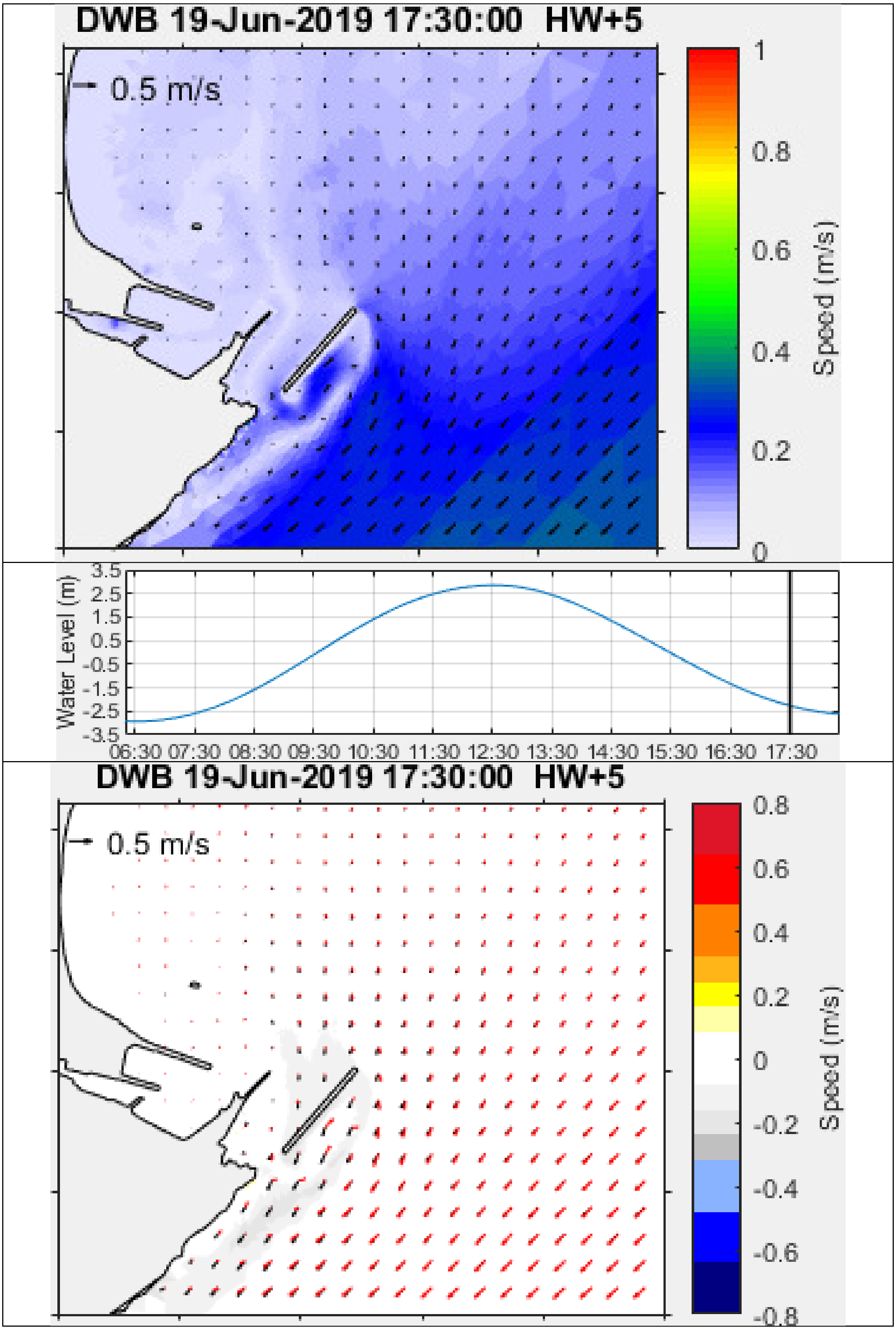
Black vector = Baseline, Red vector = Scheme



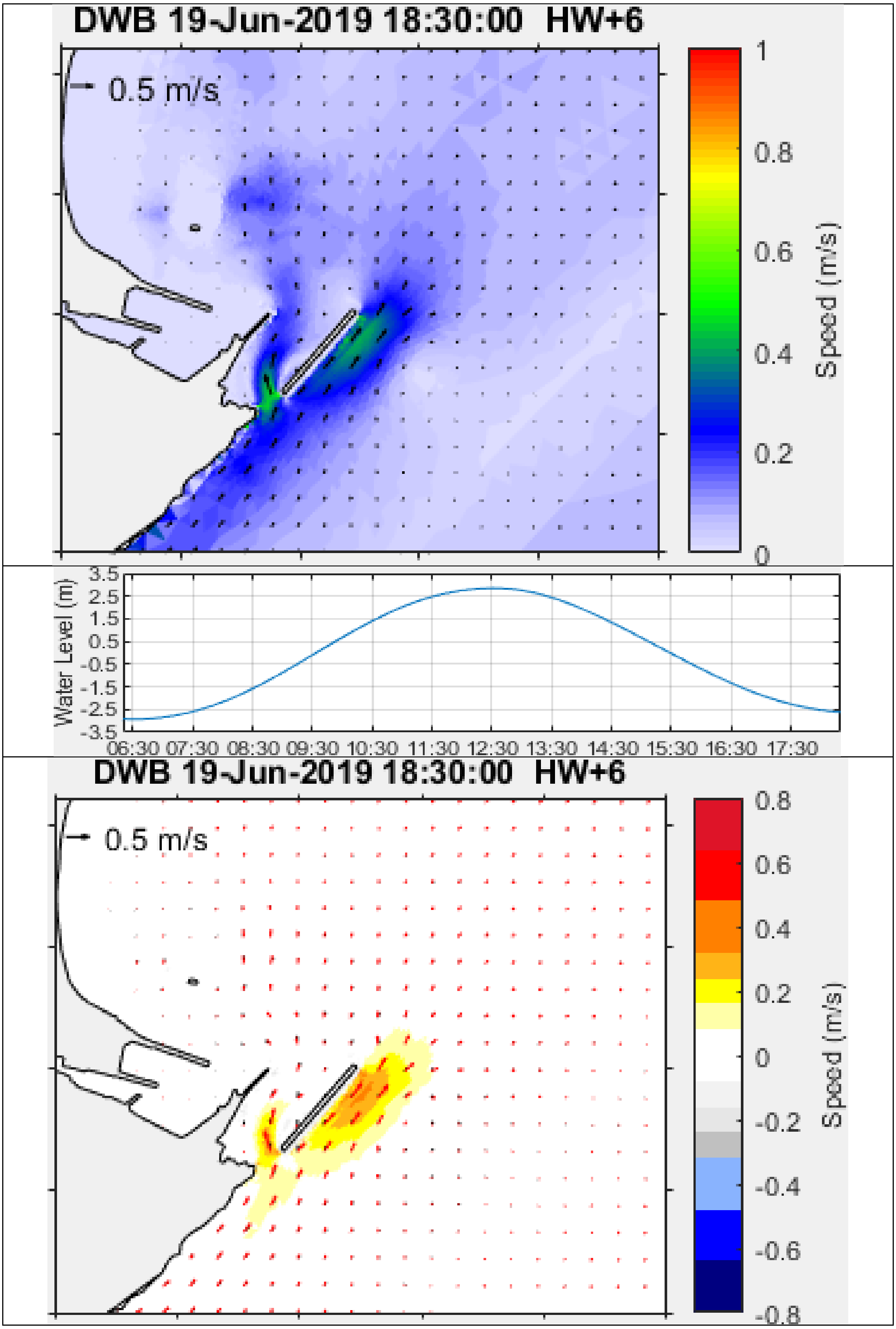
Black vector = Baseline, Red vector = Scheme



Black vector = Baseline, Red vector = Scheme



Black vector = Baseline, Red vector = Scheme



Black vector = Baseline, Red vector = Scheme

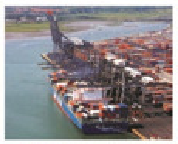
G Fast-time Simulations

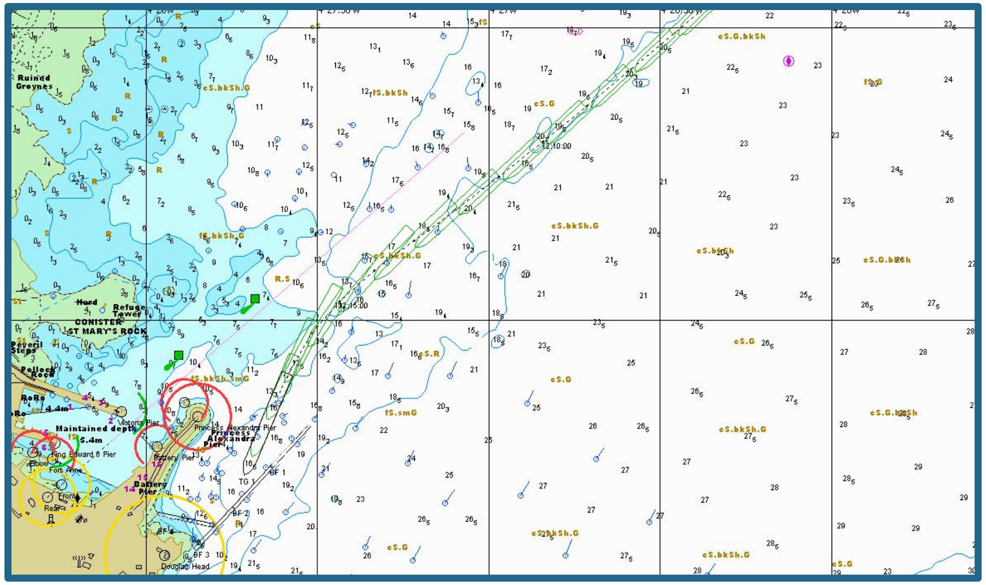
Fast-time vessel simulation

Fast-time simulation is a computer based assessment tool for the identification of external factors on the handling of vessels. Twenty five simulation runs were conducted for five different states of tide and five different weather conditions for each of these states of tide. The environmental conditions for the various runs with the simulation identification code is shown in the table below.

Fast-time runs are used to identify the effects of environmental influences on the rudiments of ship handling within the approaches to Douglas Harbour. Fast-time simulations are computer controlled and show the base influence of external forces on the ability of a vessel to maintain a track using standard ship handling and non-intuitive direction, otherwise provided by an experienced mariner.

Simulation	Tide	Runs				
1.1	HW -4	1.1.1 Calm	1.1.2 S - 20 Kts	1.1.3 N - 20 Kts	1.1.4 SW - 20 Kts	1.1.5 E - 20 Kts
1.2	HW -2	1.2.1 Calm	1.2.2 S - 20 Kts	1.2.3 N - 20 Kts	1.2.4 SW - 20 Kts	1.2.5 E - 20 Kts
1.3	HW	1.3.1 Calm	1.3.2 S - 20 Kts	1.3.3 N - 20 Kts	1.3.4 SW - 20 Kts	1.3.5 E - 20 Kts
1.4	HW +2	1.4.1 Calm	1.4.2 S - 20 Kts	1.4.3 N - 20 Kts	1.4.4 SW - 20 Kts	1.4.5 E - 20 Kts
1.5	HW +4	1.5.1 Calm	1.5.2 S - 20 Kts	1.5.3 N - 20 Kts	1.5.4 SW - 20 Kts	1.5.5 E - 20Kts

Fast-time simulations were conducted using the facilities at Fleetwood Nautical College. The model vessel used was given six degrees of movement, allowing for realistic response from the effects of current, wind and other influences.

For each run tidal state and weather conditions were loaded into the simulation model and a track to follow provided with speeds to maintain. Throughout each of these runs the behaviour of the vessel and actions taken to meet set courses and speeds were monitored and assessed to establish the affects of the conditions on ship handling.

The following graphical plots summarise the results of the different Fast- time simulation runs.

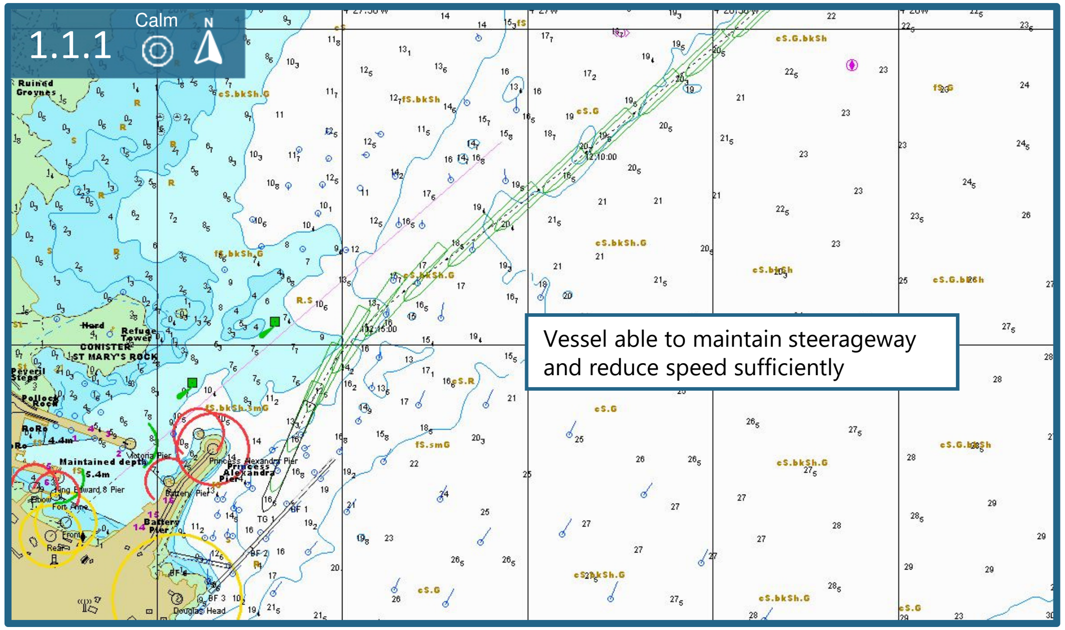
ABP mer

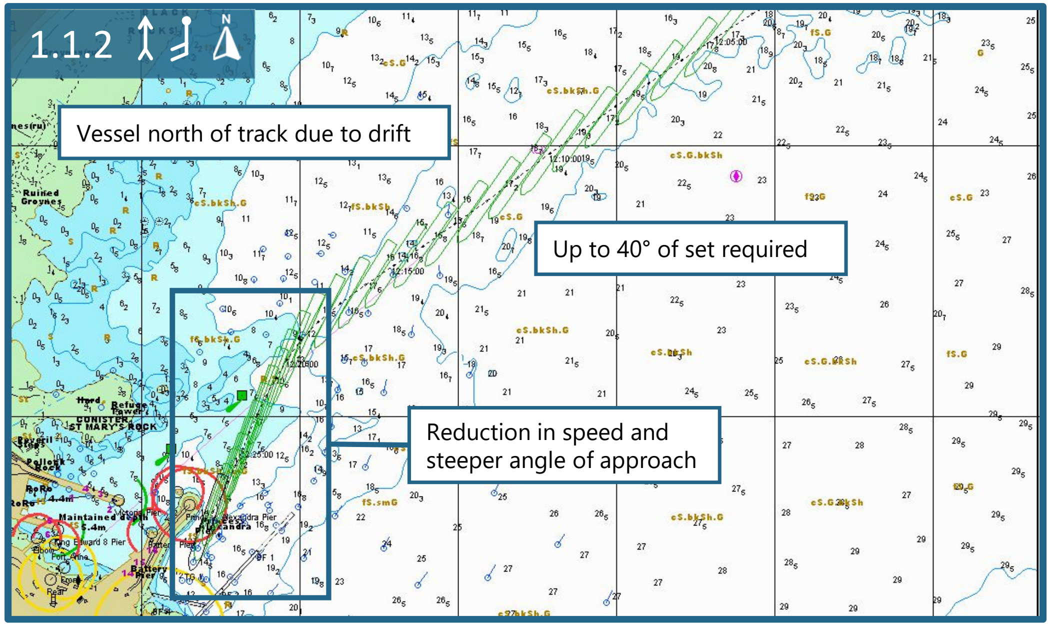
Fast-time simulation 1.1
Arrival to deep-water berth
Large cruise vessel

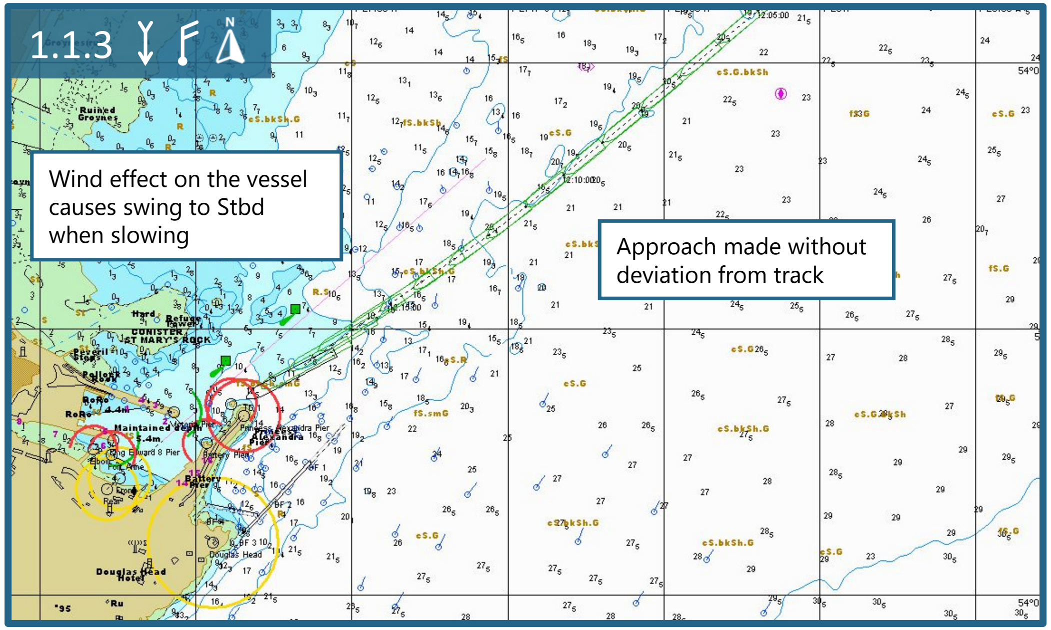
HW -4

Fast-time simulator run 1.1 tests the feasibility of approaching the DWB at HW -4 with different wind conditions. Issues identified will be taken forward to real-time simulations.

Run	Wind-state	Observations
1.1.1	Calm	Vessel achieved approach without deviation
1.1.2	S - 20 Kts	20° of set to Port experienced. Northerly drift created a steeper point of approach to the berth
1.1.3	N - 20 Kts	When reducing speed the wind brought the vessel to Stbd
1.1.4	SW - 20 Kts	Approach made a t a slower speed, further reduction in speed when turning Stern swing checked by wind during turn Higher speed to be maintained until inside the dock
1.1.5	E - 20 Kts	Excessive speed required with 5-6 Kts required to maintain the track Excessive swing encountered when turning

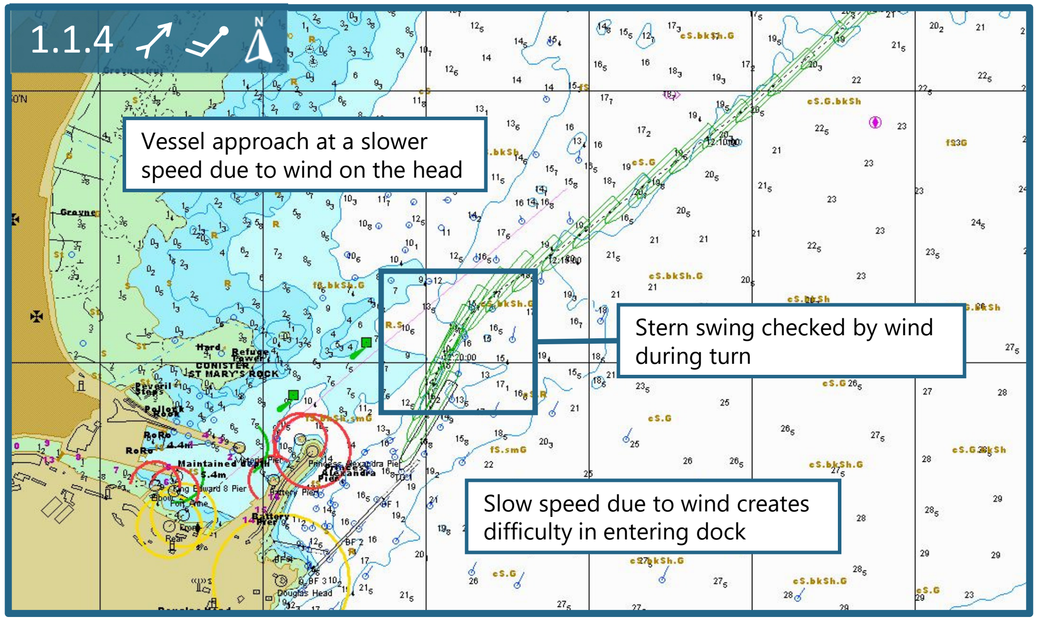


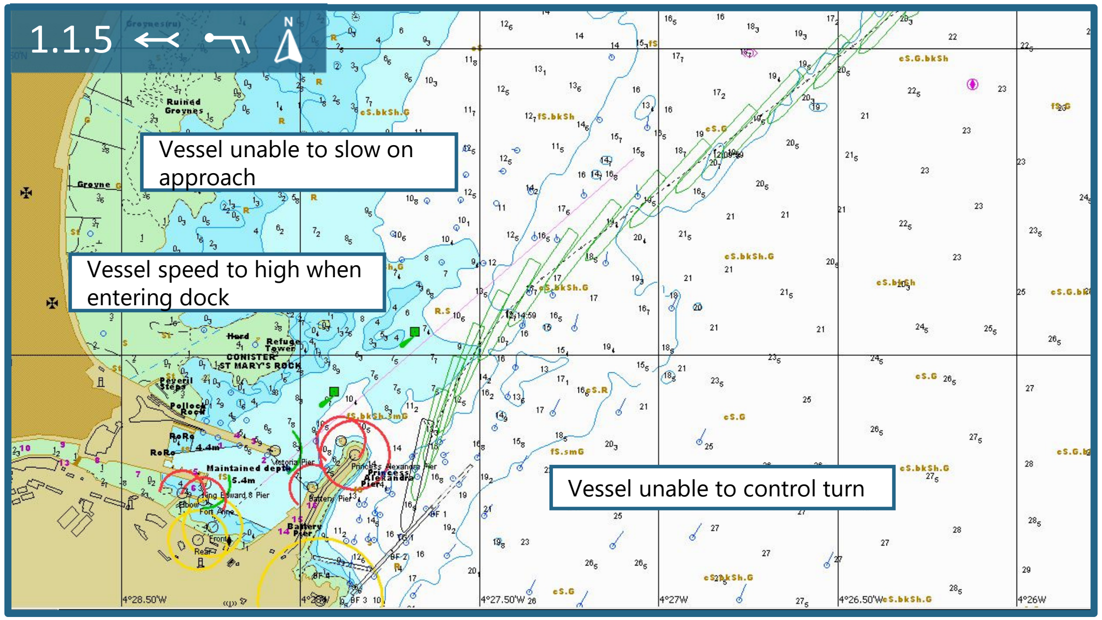




Fast-time simulation 1.1
Arrival to deep-water berth
Large vessel

HW -4



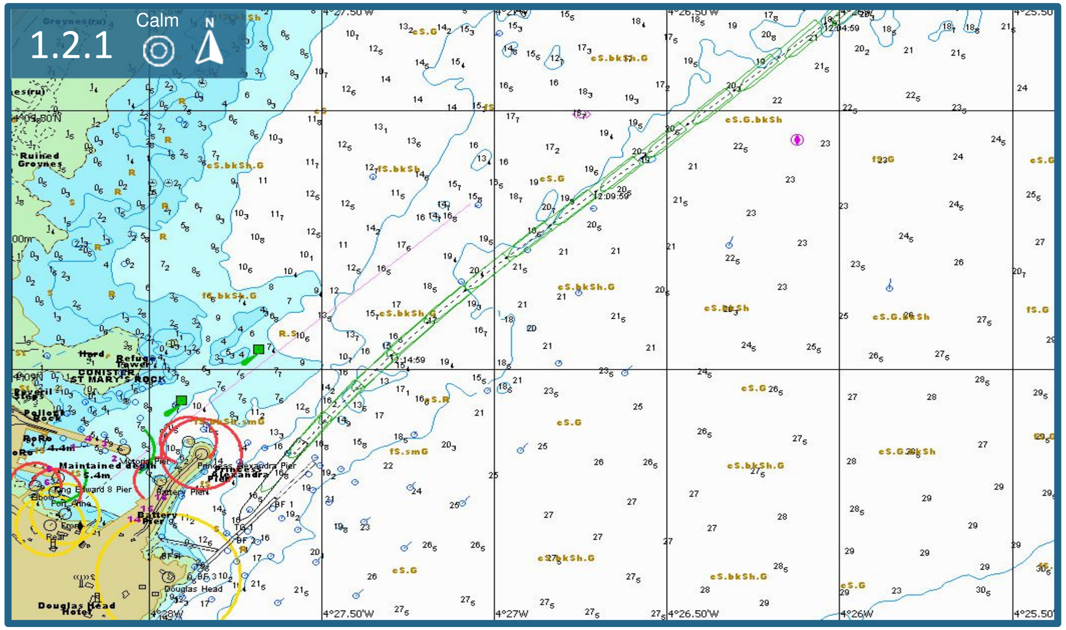


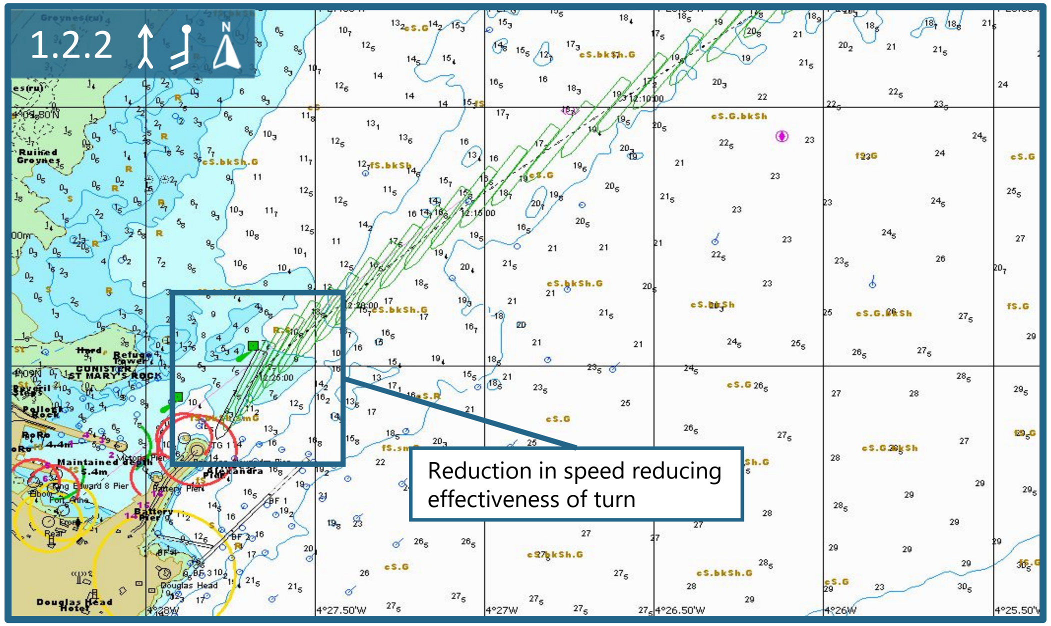
Fast-time simulation 1.2
Arrival to deep-water berth
Large vessel

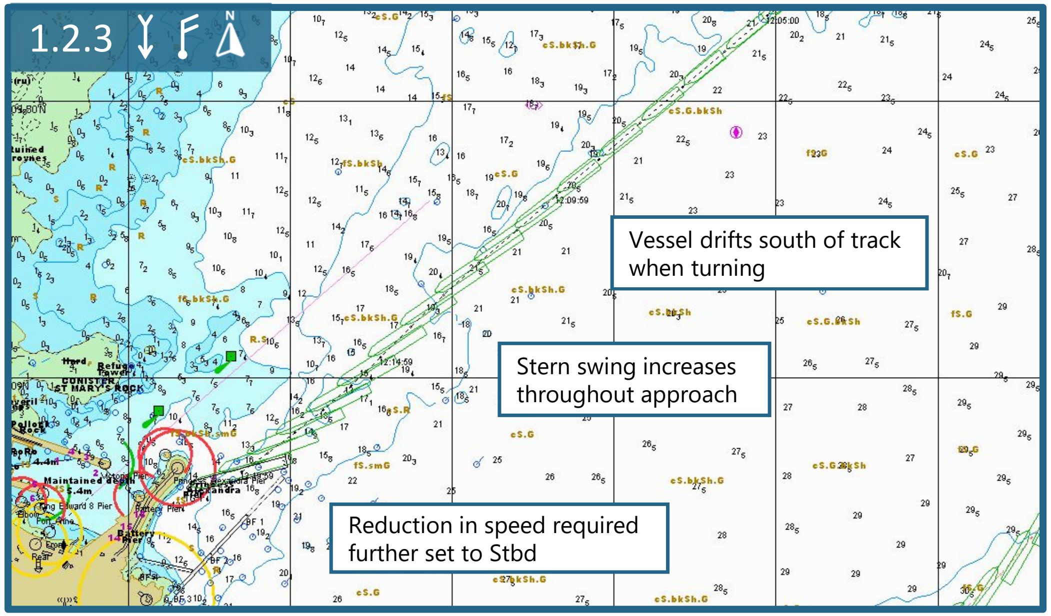
HW -2

Fast-time simulator run 1.2 tests the feasibility of approaching the DWB at HW -2 with different wind conditions. Issues identified will be taken forward to real-time simulations.

Run	Wind-state	Observations
1.2.1	Calm	Vessel achieved approach without deviation
1.2.2	S - 20 Kts	Vessel unable to regain track after drifting north, 20° of set experienced Difficulty in regaining track compounded by reduction in speed.
1.2.3	N - 20 Kts	Vessel drift to south when turning, loss of control of swing Set to Stbd increases stern swing, exaggerated with reduction in speed
1.2.4	SW - 20 Kts	Slower approach with good steerage Vessel ferry glided to final position
1.2.5	E - 20 Kts	Increase speed on approach Loss of control on swing to Port

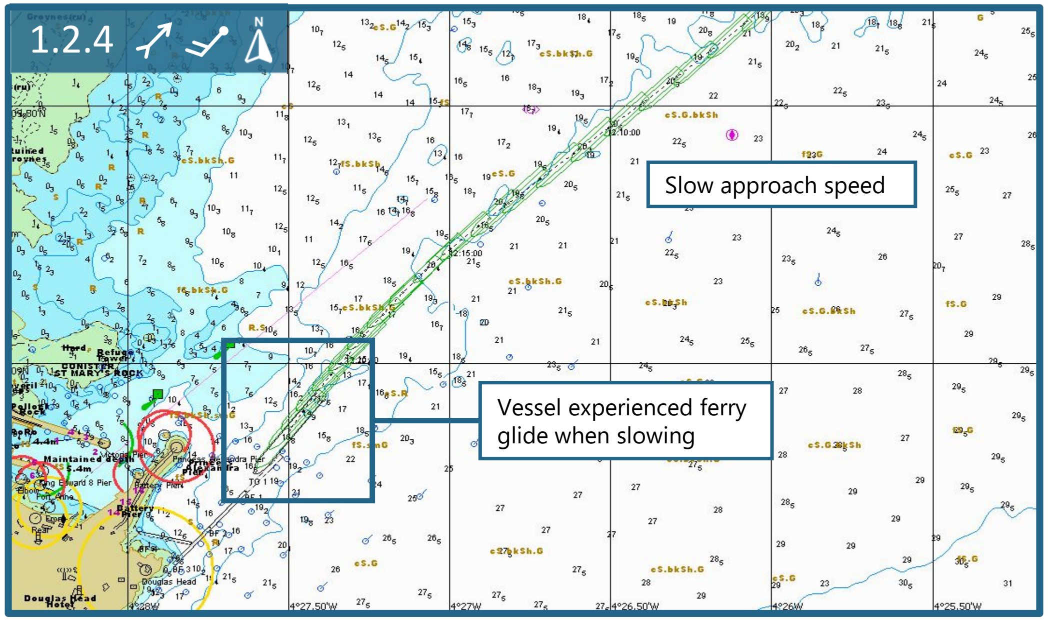


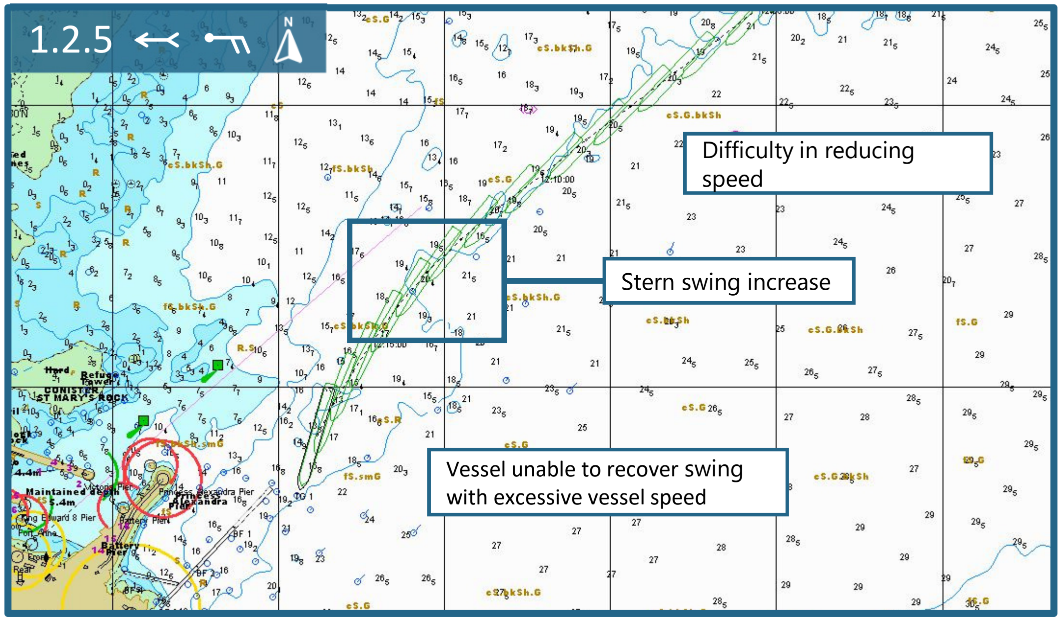




Fast-time simulation 1.2
Arrival to deep-water berth
Large vessel

HW -2



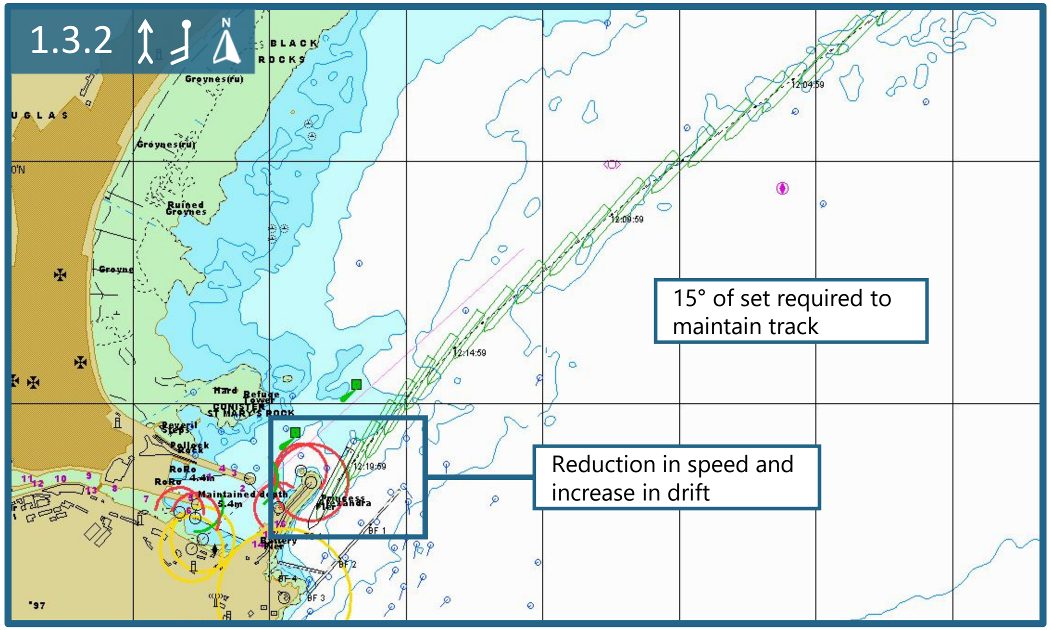


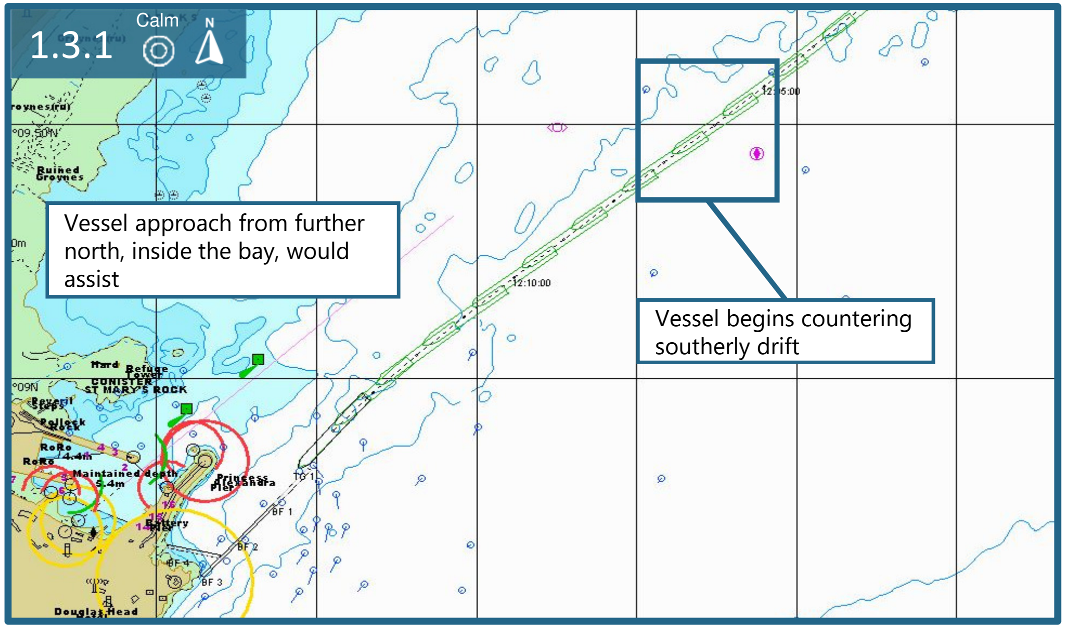
Fast-time simulation 1.3
Arrival to deep-water berth
Large vessel

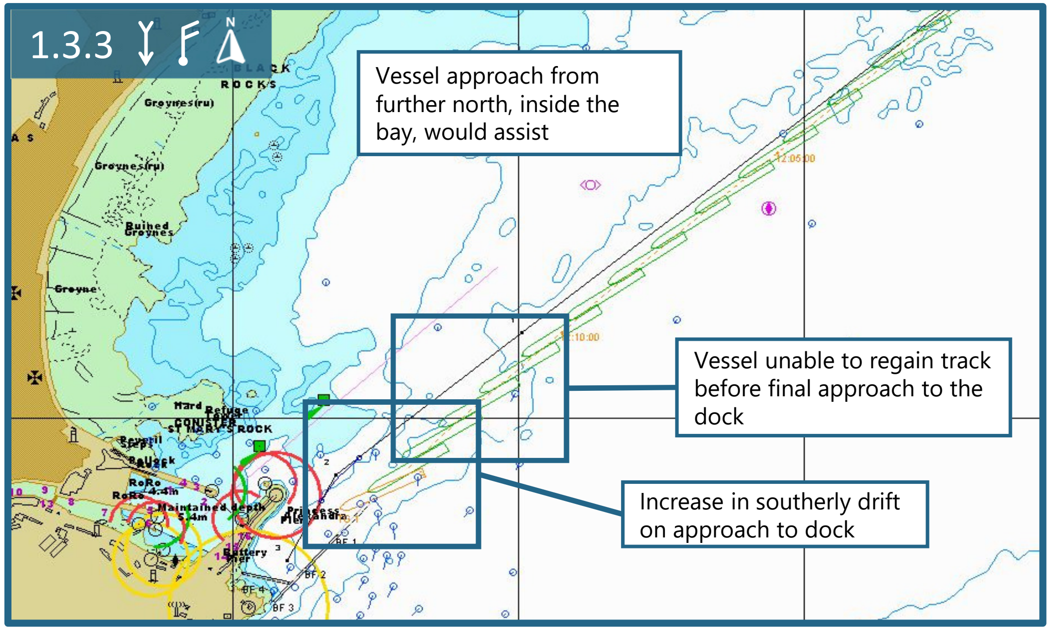
HW

Fast-time simulator run 1.3 tests the feasibility of approaching the DWB at HW with different wind conditions. Issues identified will be taken forward to real-time simulations.

Run	Wind-state	Observations
1.3.1	Calm	Approach to the dock from north of track would counter increased drift near pier head
1.3.2	S - 20 Kts	Drift to north creating 15° of set Vessel drift increased on slowing below 4 kts
1.3.3	N - 20 Kts	Excessive speed on approach Southerly drift increasing on approach to the dock
1.3.4	SW - 20 Kts	Track maintained on approach Increased southerly drift and reduction in speed preventing final approach
1.3.5	E - 20 Kts	Difficulty in reducing speed throughout Bow drifting south combining with stern swing to Stbd on turn

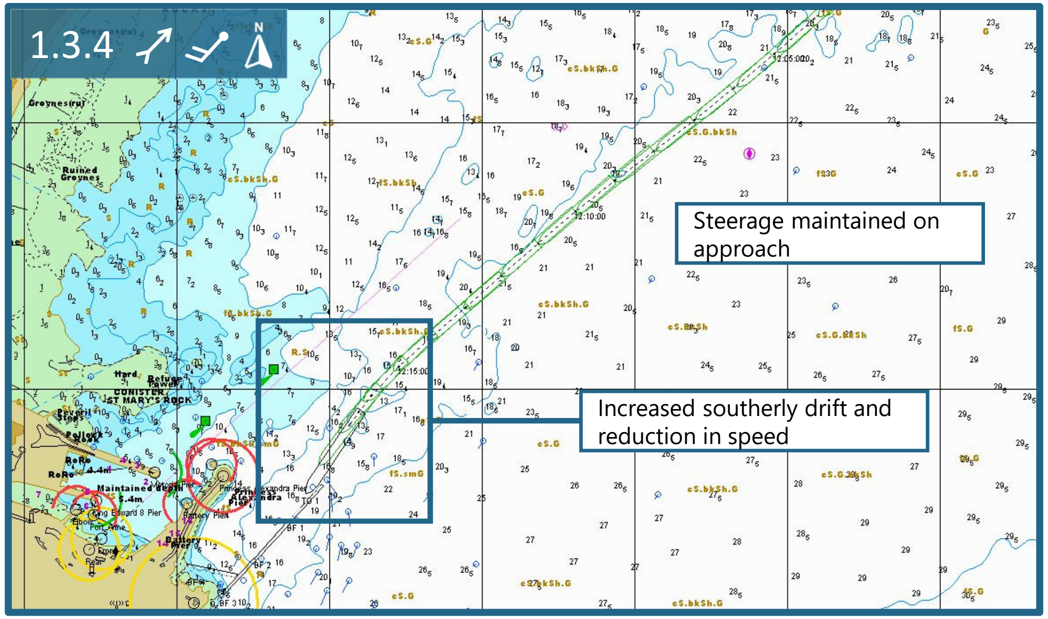


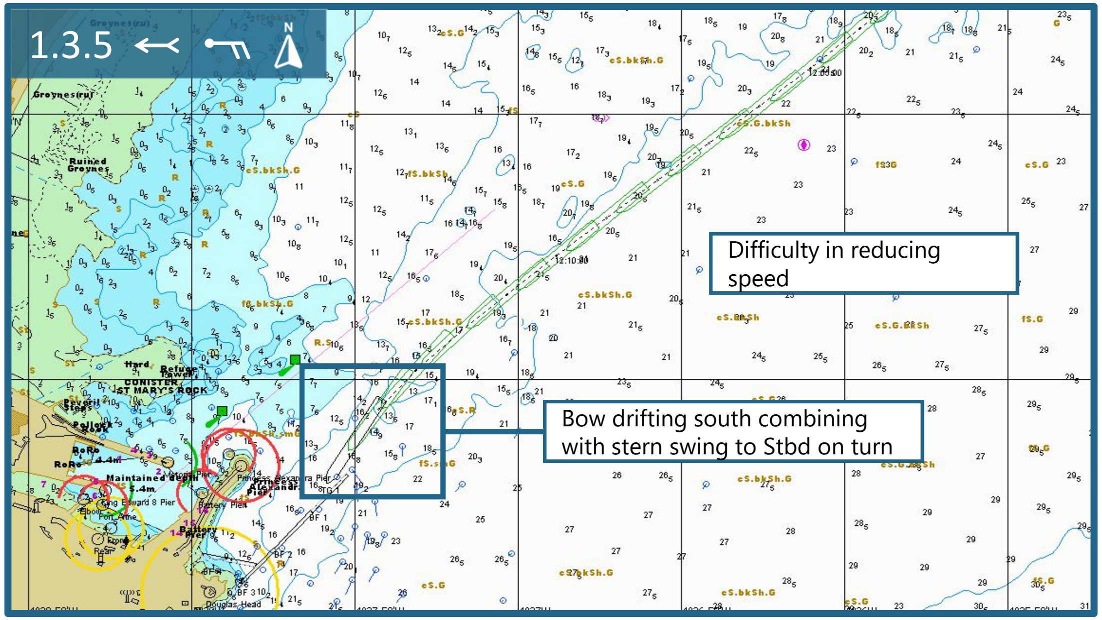




Fast-time simulation 1.3
Arrival to deep-water berth
Large vessel

HW



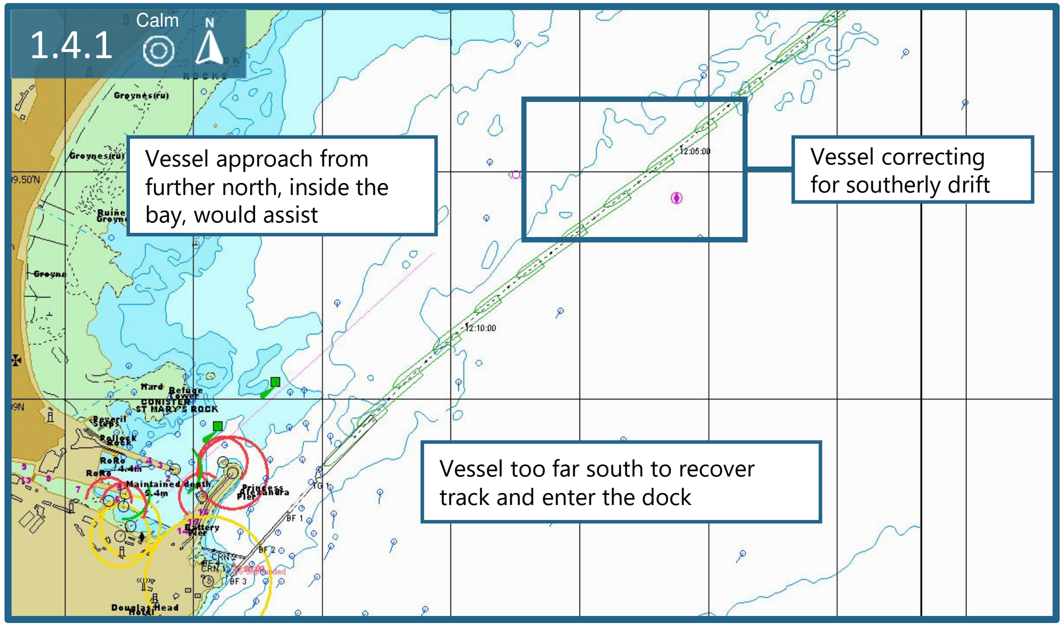


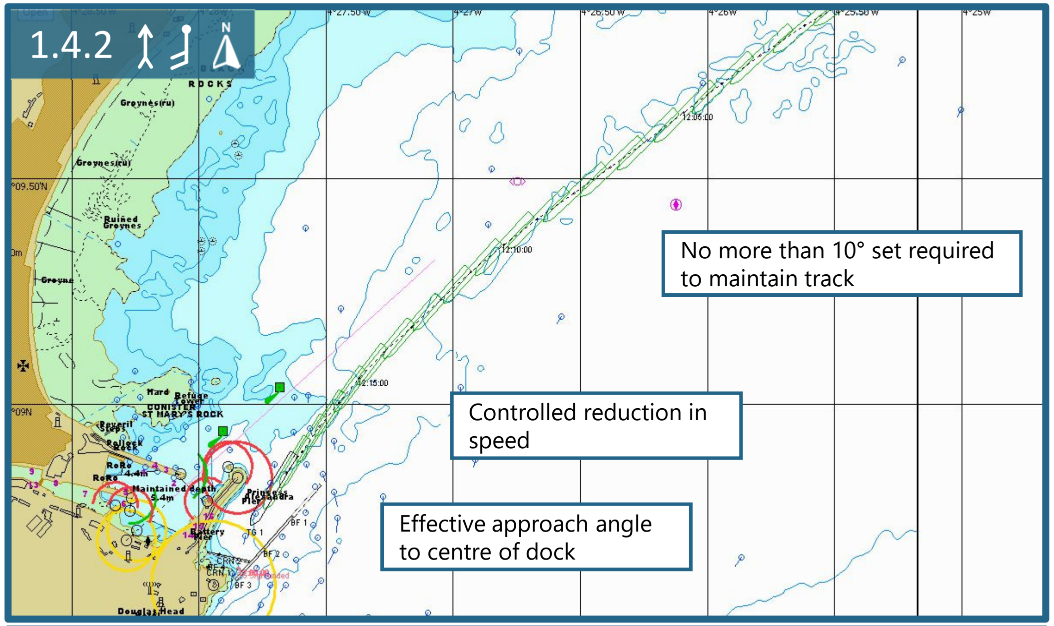
Fast-time simulation 1.4
Arrival to deep-water berth
Large vessel

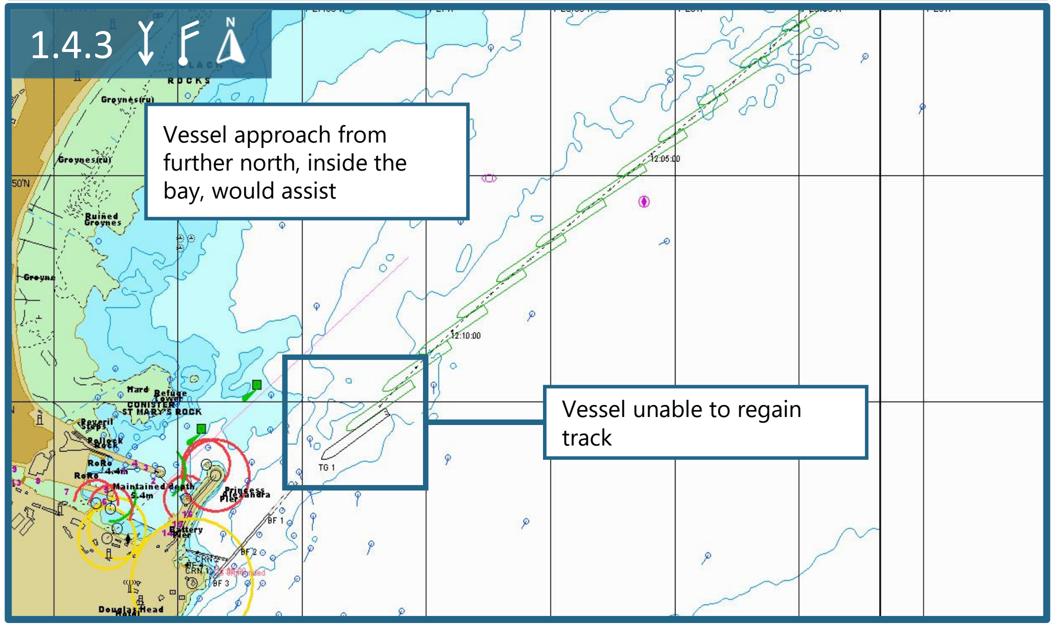
HW +2

Fast-time simulator run 1.4 tests the feasibility of approaching the DWB at HW +2 with different wind conditions. Issues identified will be taken forward to real-time simulations.

Run	Wind-state	Observations
1.4.1	Calm	Approach to the dock from north of track would counter increased drift near pier head
1.4.2	S - 20 Kts	Vessel achieved approach without deviation Vessel manoeuvred well throughout
1.4.3	N - 20 Kts	Southerly drift increasing on approach to the dock Vessel unable to recover track
1.4.4	SW - 20 Kts	Effective steerage above 5 kts More northerly point of approach required due to increase southerly drift near pier head
1.4.5	E - 20 Kts	Difficulty in reducing speed throughout Bow swing to Port due to increase southerly drift near pier head

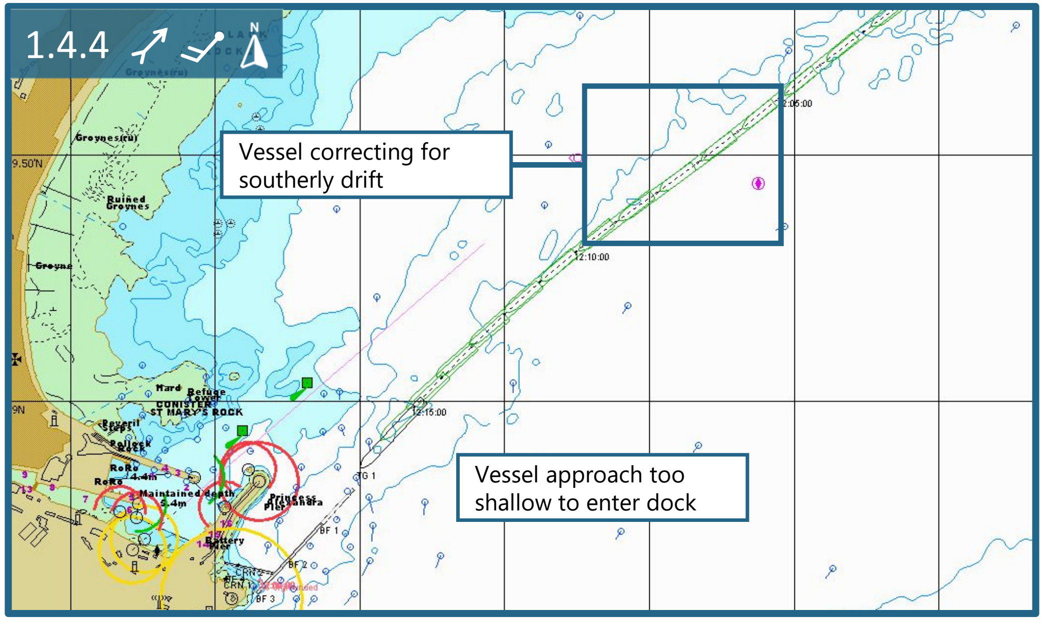


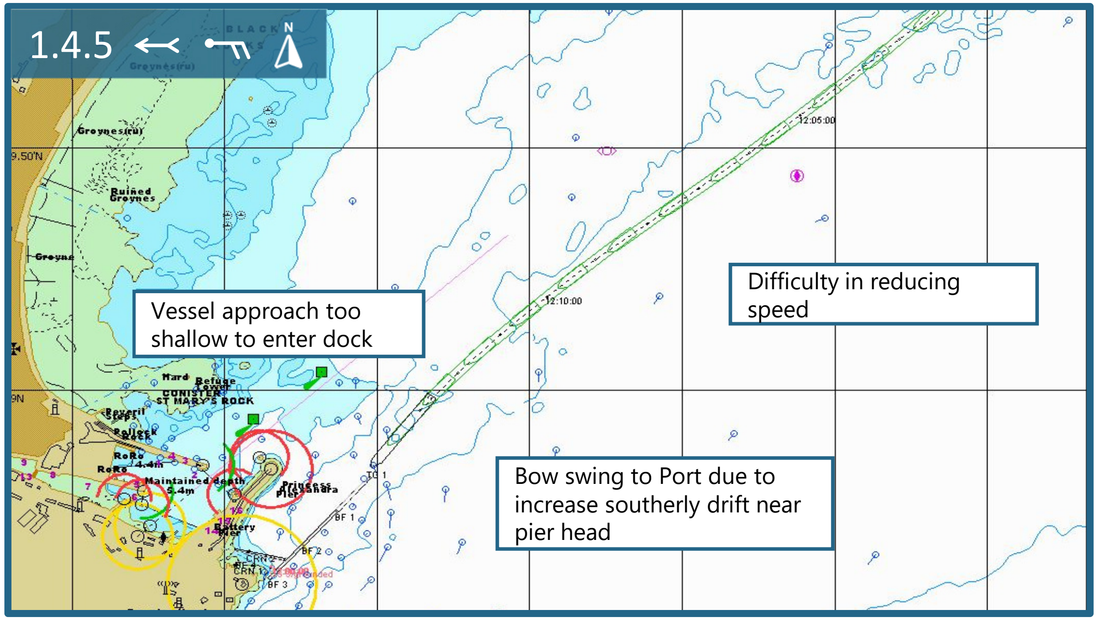




Fast-time simulation 1.4
Arrival to deep-water berth
Large vessel

HW +2



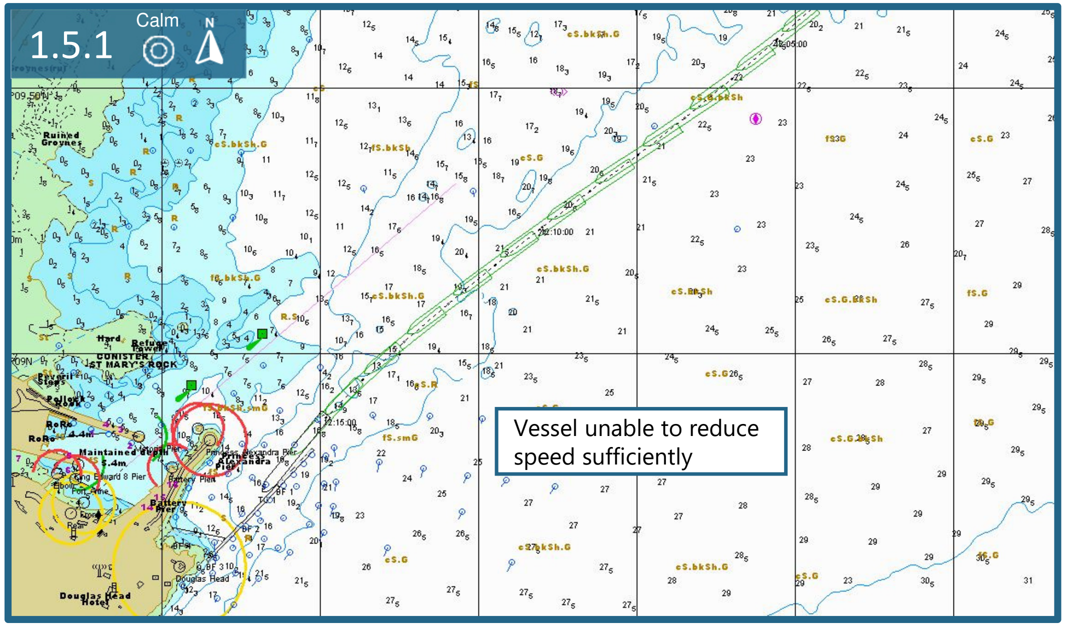


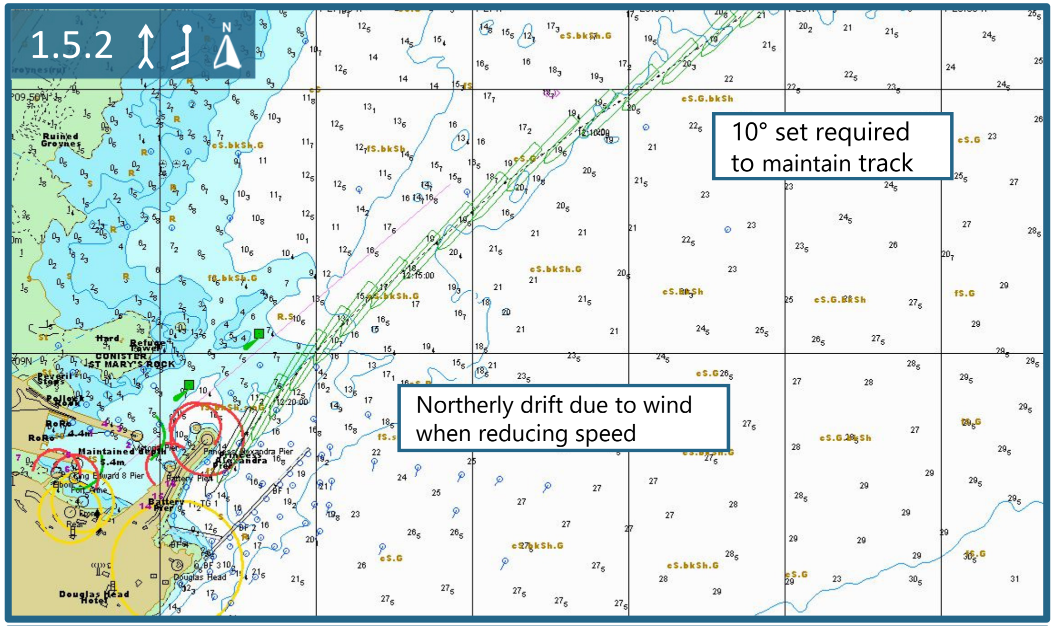
Fast-time simulation 1.5
Arrival to deep-water berth
Large vessel

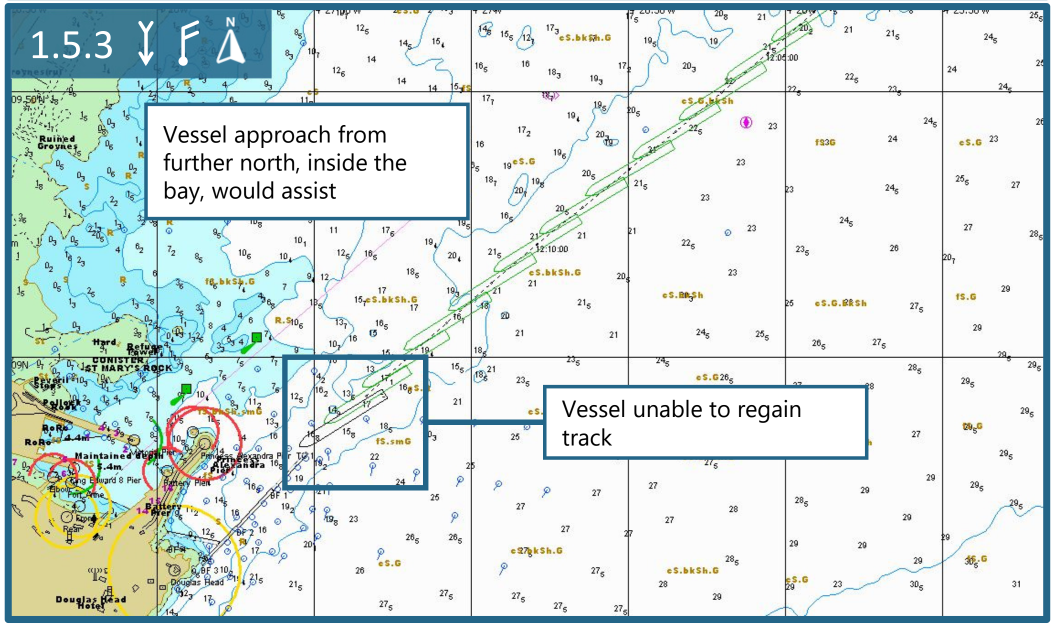
HW +4

Fast-time simulator run 1.5 tests the feasibility of approaching the DWB at HW +4 with different wind conditions. Issues identified will be taken forward to real-time simulations.

Run	Wind-state	Observations
1.5.1	Calm	Vessel achieved approach without deviation Difficulty in reducing speed on final approach
1.5.2	S - 20 Kts	Increased stern swing when reducing speed Vessel should line-up with centre of dock earlier
1.5.3	N - 20 Kts	Southerly drift increasing on approach to the dock Vessel unable to recover track
1.5.4	SW - 20 Kts	Vessel achieved approach without deviation
1.5.5	E - 20 Kts	Difficulty in reducing speed throughout Vessel speed to great in dock

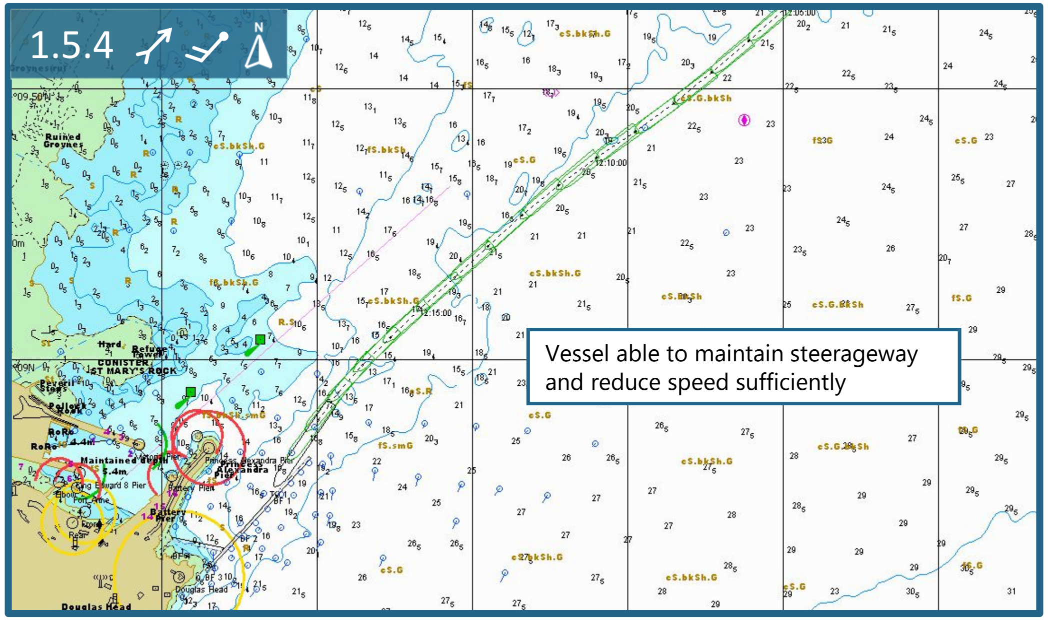


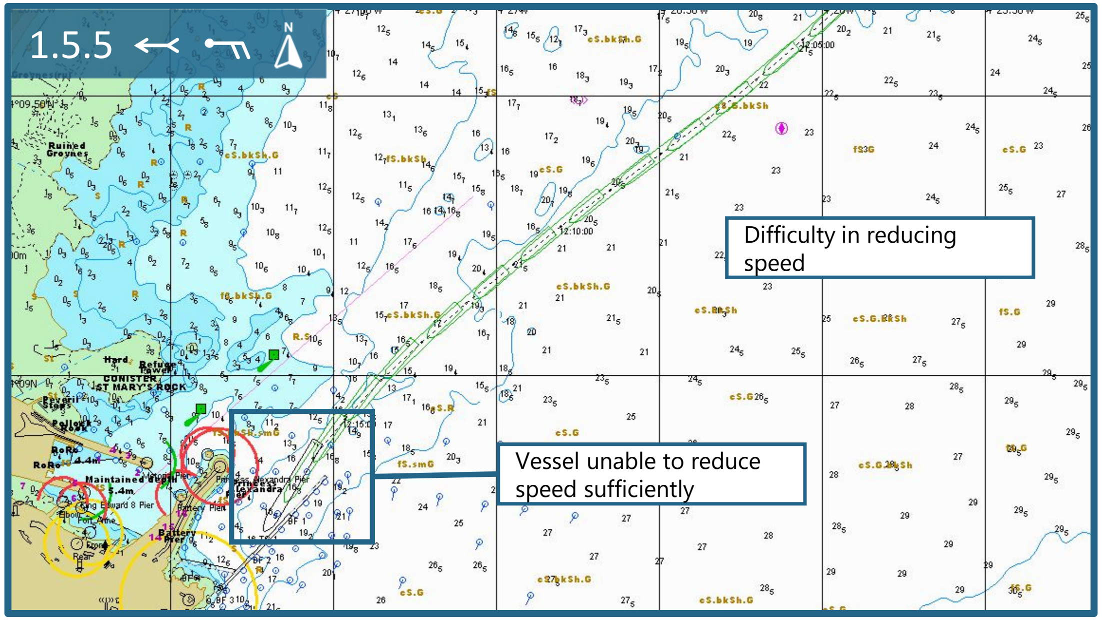




Fast-time simulation 1.5
Arrival to deep-water berth
Large vessel

HW +4



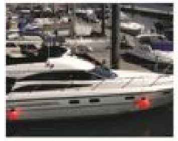


H Real-time Simulations

Real-time vessel simulation

Real-time simulation scenarios were selected based on the analysis conducted through chart assessment and the affects on ship handling identified from the Fast-time vessel simulations. Where possible further scenarios were conducted to explore limitations identified during Real-time assessment. The table below summarises the environmental conditions associated with each simulation run.

Simulation	Tide	Wind	Waves	Approach	Location	Visibility	Vessel
1.1.1	HW +4	Light	Calm	Arrival PST	DWB	Day >10Nm	Large
1.1.2	HW +4	Light	Calm	Departure PST	DWB	Day >10Nm	Large
1.2.1	HW +2	N 20 kts	Force 6	Arrival PST	DWB	Day >10Nm	Large
1.2.2	HW +2	N 20 kts	Force 6	Arrival PST	DWB	Day >10Nm	Large
1.3.1	HW +2	SW 20 Kts	Force 6	Arrival PST	DWB	Day >10Nm	Large
1.3.2	HW +2	SW 20 Kts	Force 6	Departure PST	DWB	Day >10Nm	Large
2.1.1	HW -4	Light	Calm	Arrival PST	QVP	Day >10Nm	Stnd
2.1.2	HW -4	Light	Calm	Departure PST	QVP	Day >10Nm	Stnd
2.1.3	HW -4	Light	Calm	Arrival SST	QVP	Day >10Nm	Stnd
2.2.1	HW +2	NE 20 Kts	Force 6	Arrival PST	QVP	Day >10Nm	Stnd
2.2.2	HW +2	NE 20 Kts	Force 6	Departure PST	QVP	Day >10Nm	Stnd
2.2.3	HW +4	SW 12 Kts	Force 4	Arrival SST	QVP	Day >10Nm	Stnd
2.2.4	HW +4	SW 12 Kts	Force 4	Departure SST	QVP	Day >10Nm	Stnd



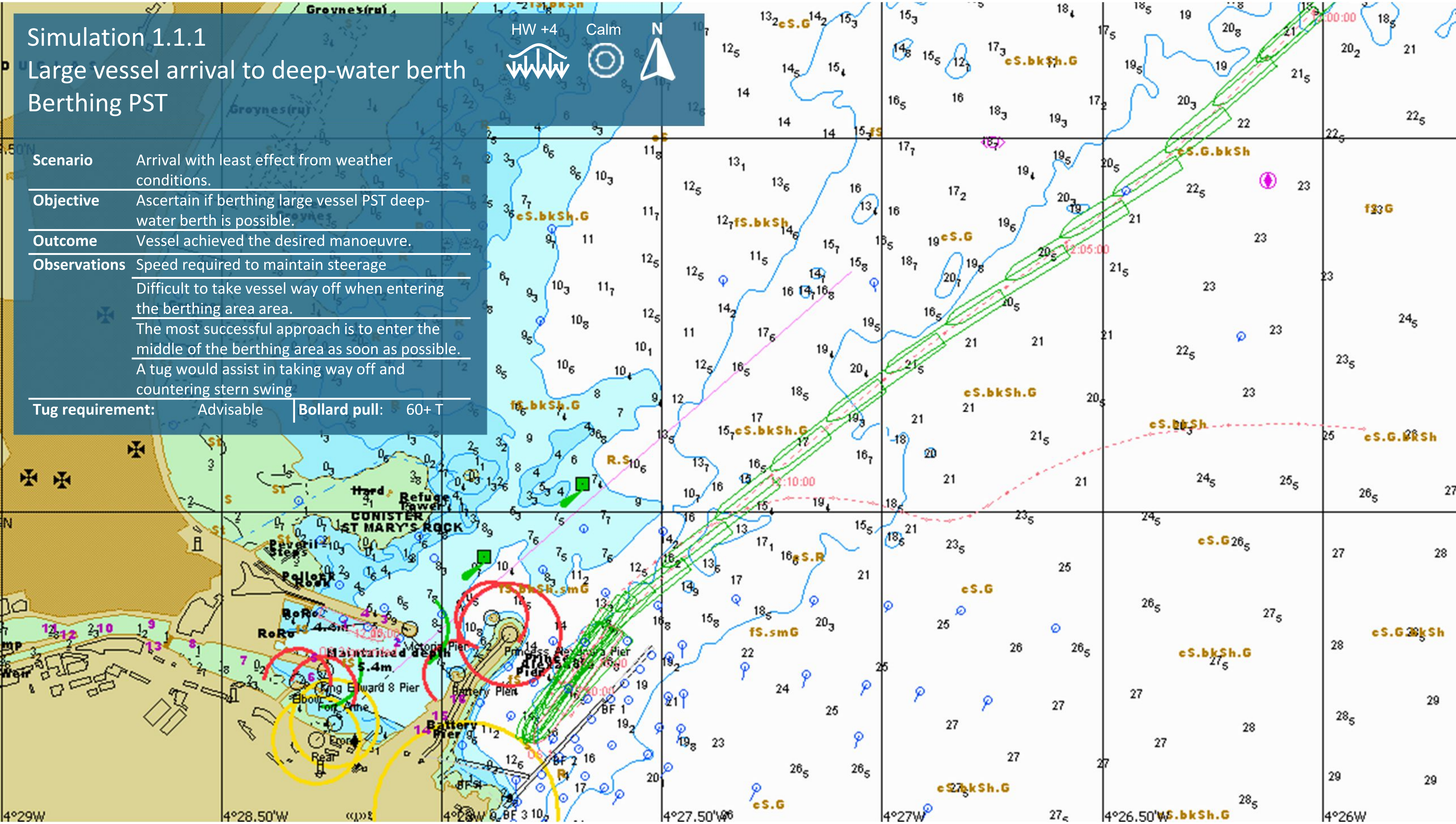


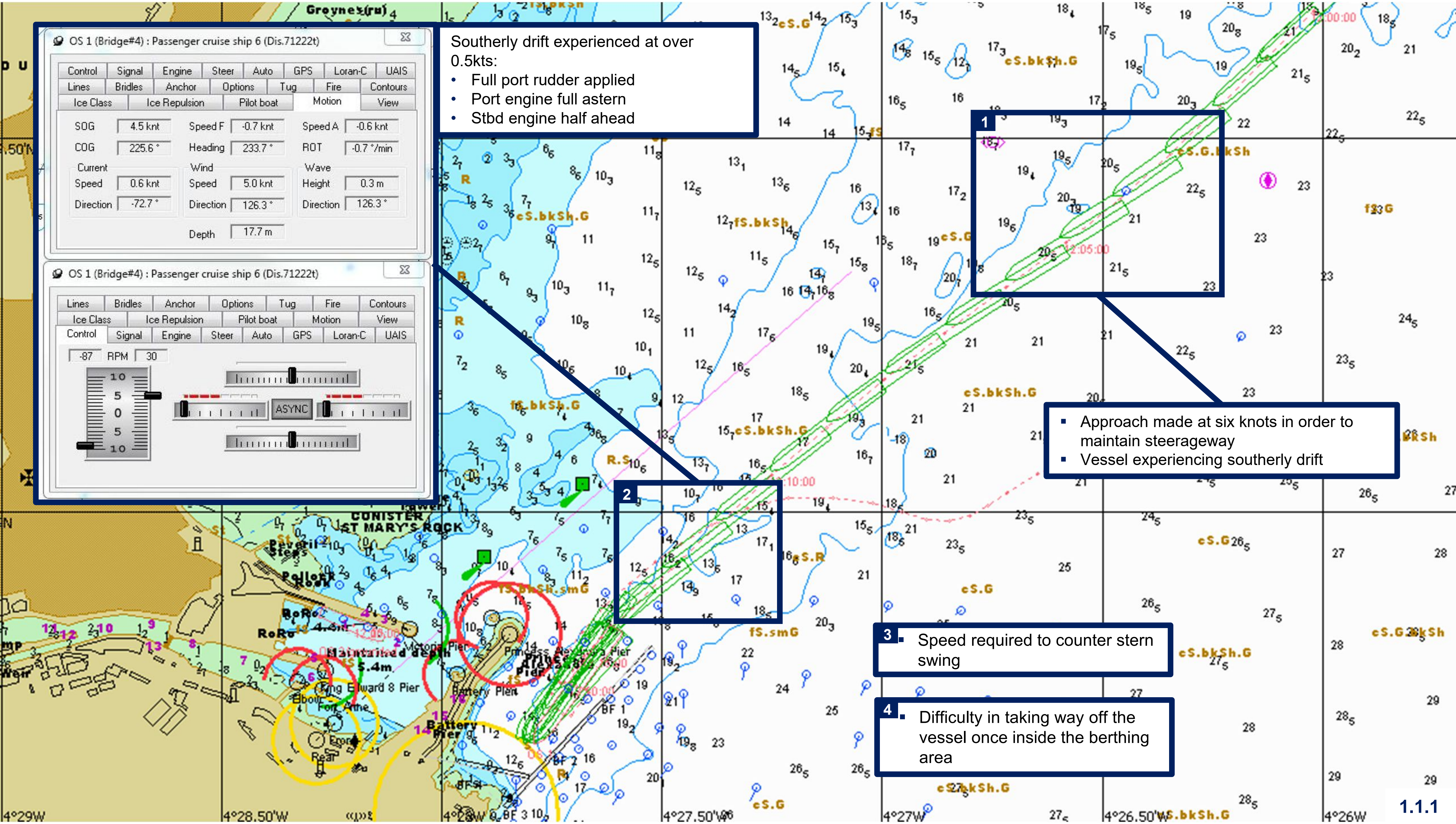
Simulation 1.1.1
Large vessel arrival to deep-water berth
Berthing PST

HW +4 | Calm | N

Scenario	Arrival with least effect from weather conditions.
Objective	Ascertain if berthing large vessel PST deep-water berth is possible.
Outcome	Vessel achieved the desired manoeuvre.
Observations	Speed required to maintain steerage
	Difficult to take vessel way off when entering the berthing area area.
	The most successful approach is to enter the middle of the berthing area as soon as possible.
	A tug would assist in taking way off and countering stern swing

Tug requirement: Advisable | **Bollard pull**: 60+ T

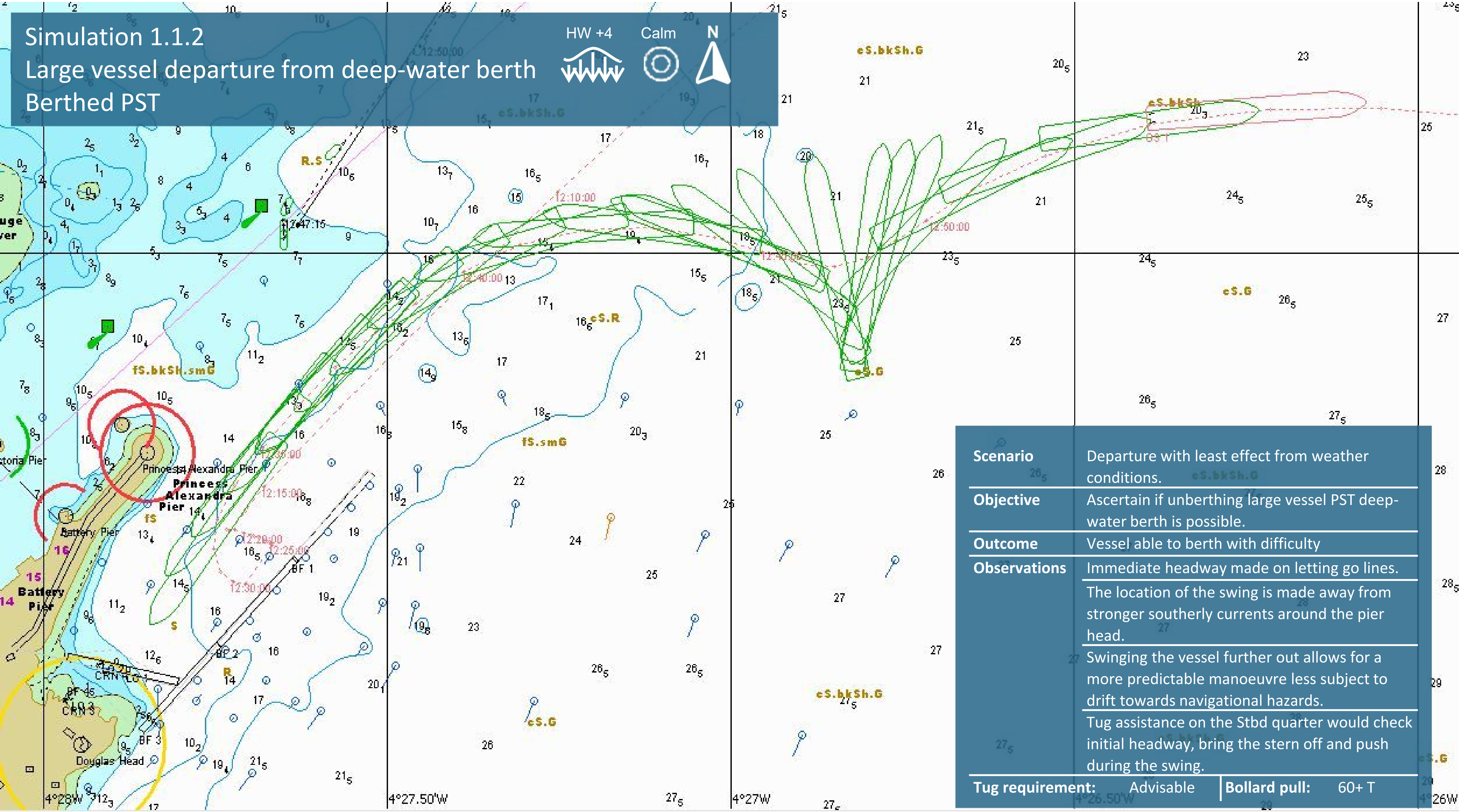




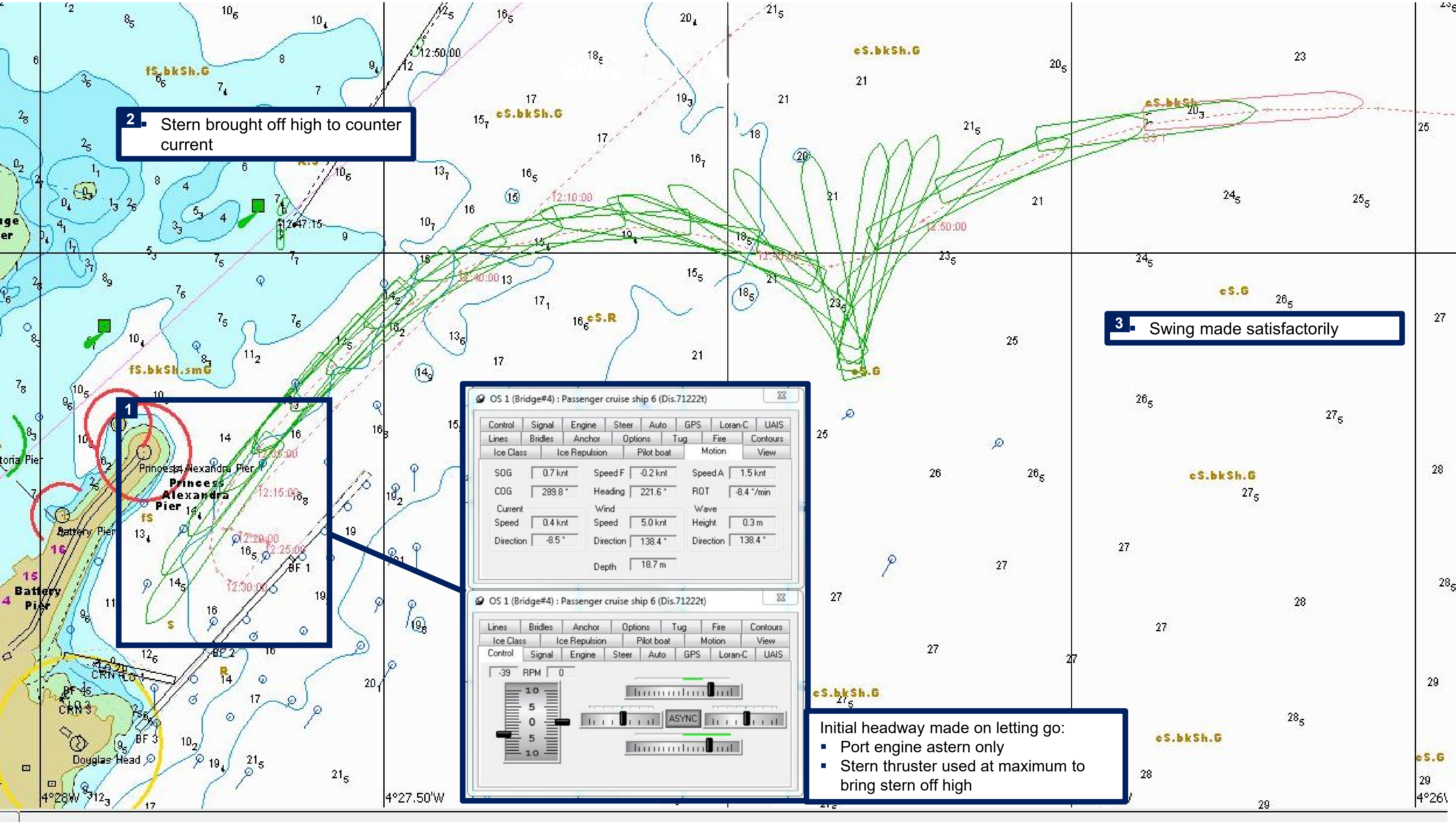
Southerly drift experienced at over 0.5kts:
• Full port rudder applied
• Port engine full astern
• Stbd engine half ahead
1 ▪ Approach made at six knots in order to maintain steerageway
▪ Vessel experiencing southerly drift
2
3 ▪ Speed required to counter stern swing
4 ▪ Difficulty in taking way off the vessel once inside the berthing area
OS 1 (Bridge#4) : Passenger cruise ship 6 (Dis.71222t)
Control Signal Engine Steer Auto GPS Loran-C UAIS
Lines Bridles Anchor Options Tug Fire Contours
Ice Class Ice Repulsion Pilot boat Motion View
SOG 4.5 knt
COG 225.6 °
Speed F -0.7 knt
Heading 233.7 °
Speed A -0.6 knt
ROT -0.7 °/min
Current Speed 0.6 knt Direction -72.7 °
Wind Speed 5.0 knt Direction 126.3 °
Wave Height 0.3 m Direction 126.3 °
Depth 17.7 m
-87 RPM 30
ASYNC
Groynes(ru)
CONISTER
ST MARY'S ROCK
Pollock Rock
Victoria Pier
King Edward 8 Pier
Fort Anne
Battery Pier
Maintained depth 5.4m
4°29W
4°28.50'W
4°28W
4°27.50'W
4°27W
4°26.50'W
4°26W
1.1.1

Simulation 1.1.2
Large vessel departure from deep-water berth
Berthed PST

HW +4 | Calm | N



Scenario	Departure with least effect from weather conditions.
Objective	Ascertain if unberthing large vessel PST deep-water berth is possible.
Outcome	Vessel able to berth with difficulty
Observations	Immediate headway made on letting go lines.
	The location of the swing is made away from stronger southerly currents around the pier head.
	Swinging the vessel further out allows for a more predictable manoeuvre less subject to drift towards navigational hazards.
	Tug assistance on the Stbd quarter would check initial headway, bring the stern off and push during the swing.
Tug requirement: Advisable	**Bollard pull:** 60+ T



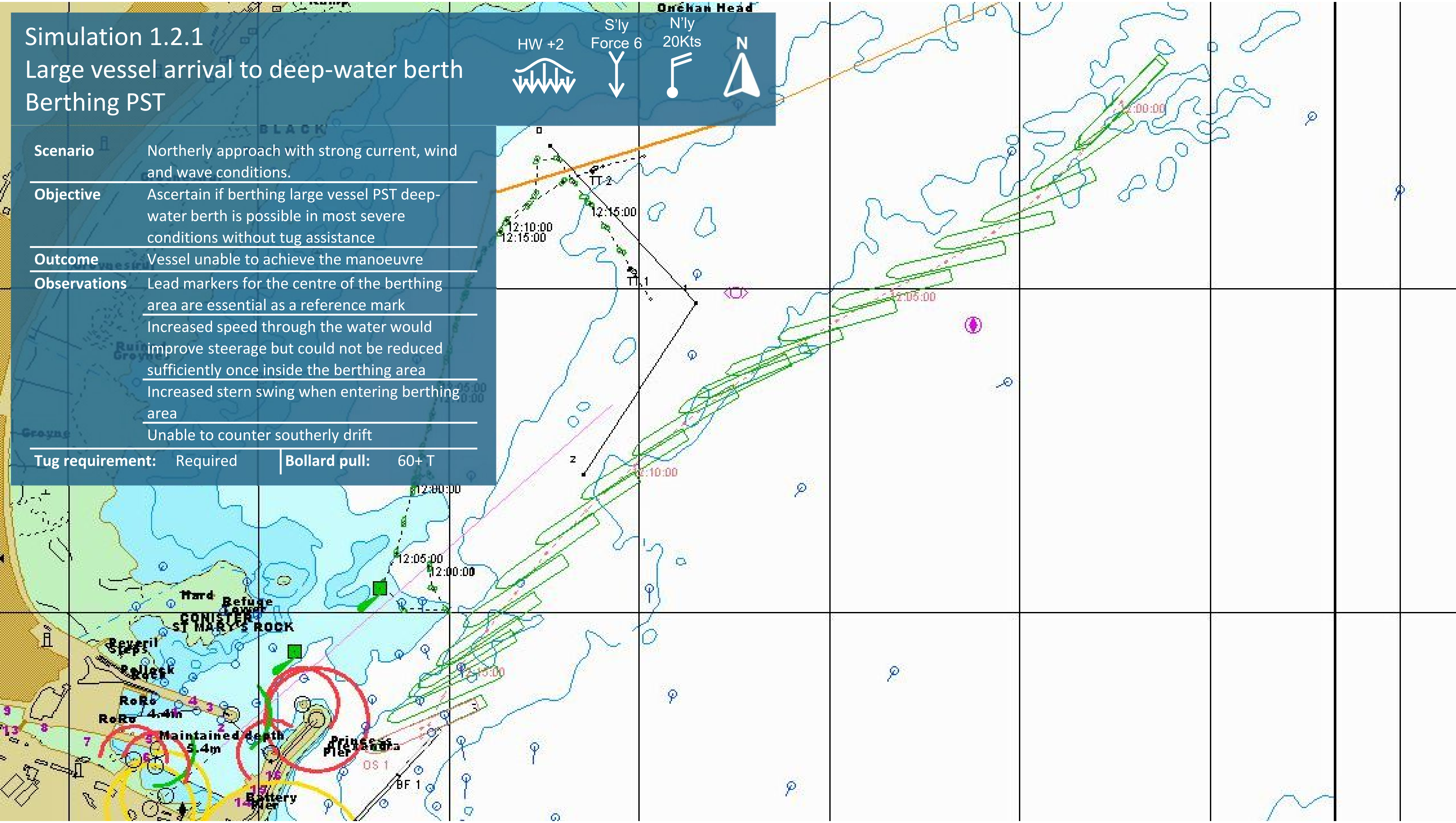
1
2 Stern brought off high to counter current
3 Swing made satisfactorily
Initial headway made on letting go:
Port engine astern only
Stern thruster used at maximum to bring stern off high
Princess Alexandra Pier
Battery Pier
Douglas Head
OS 1 (Bridge#4) : Passenger cruise ship 6 (Dis.71222t)
SOG 0.7 knt
COG 289.8 °
Speed F -0.2 knt
Heading 221.6 °
Speed A 1.5 knt
ROT -8.4 °/min
Current Speed 0.4 knt Direction -8.5 °
Wind Speed 5.0 knt Direction 138.4 °
Wave Height 0.3 m Direction 138.4 °
Depth 18.7 m
-39 RPM 0
ASYNC
4°28'W
4°27.50'W

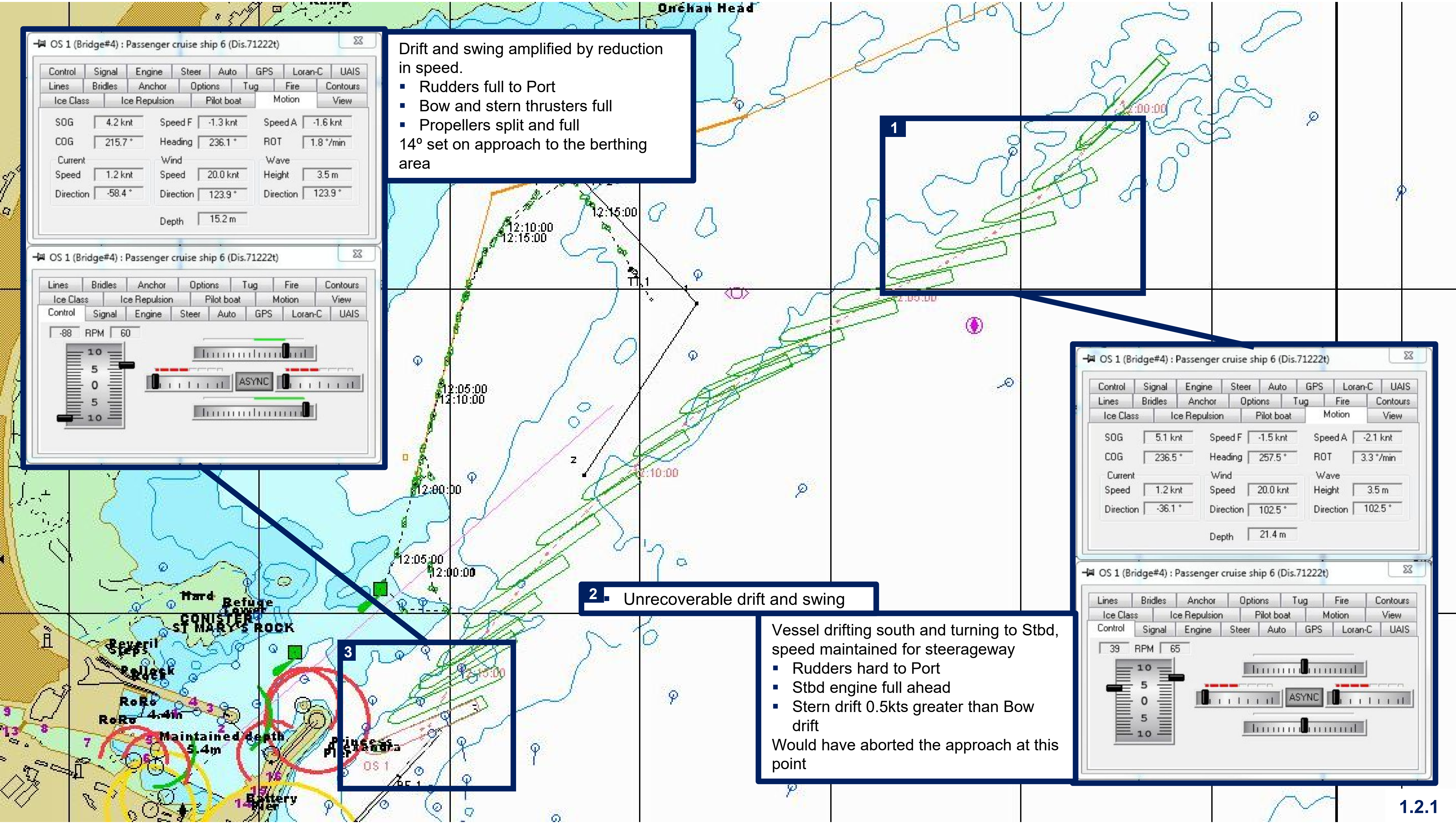
Simulation 1.2.1
Large vessel arrival to deep-water berth
Berthing PST

HW +2 | S'ly Force 6 | N'ly 20Kts | N

Scenario	Northerly approach with strong current, wind and wave conditions.
Objective	Ascertain if berthing large vessel PST deep-water berth is possible in most severe conditions without tug assistance
Outcome	Vessel unable to achieve the manoeuvre
Observations	Lead markers for the centre of the berthing area are essential as a reference mark
	Increased speed through the water would improve steerage but could not be reduced sufficiently once inside the berthing area
	Increased stern swing when entering berthing area
	Unable to counter southerly drift

Tug requirement:	Required	**Bollard pull:**	60+ T




Drift and swing amplified by reduction in speed.
Rudders full to Port
Bow and stern thrusters full
Propellers split and full
14º set on approach to the berthing area
1
2
Unrecoverable drift and swing
3
Vessel drifting south and turning to Stbd, speed maintained for steerageway
Rudders hard to Port
Stbd engine full ahead
Stern drift 0.5kts greater than Bow drift
Would have aborted the approach at this point
OS 1 (Bridge#4) : Passenger cruise ship 6 (Dis.71222t)
SOG 4.2 knt
COG 215.7 °
Speed F -1.3 knt
Heading 236.1 °
Speed A -1.6 knt
ROT 1.8 °/min
Current Speed 1.2 knt
Current Direction -58.4 °
Wind Speed 20.0 knt
Wind Direction 123.9 °
Wave Height 3.5 m
Wave Direction 123.9 °
Depth 15.2 m
-88 RPM 60
ASYNC
SOG 5.1 knt
COG 236.5 °
Speed F -1.5 knt
Heading 257.5 °
Speed A -2.1 knt
ROT 3.3 °/min
Current Speed 1.2 knt
Current Direction -36.1 °
Wind Speed 20.0 knt
Wind Direction 102.5 °
Wave Height 3.5 m
Wave Direction 102.5 °
Depth 21.4 m
39 RPM 65
Onchan Head
12:15:00
12:10:00
12:05:00
12:00:00
Hard
Refuge Tower
CONISTER
ST MARY'S ROCK
Princess Alexandra Pier
Maintained depth 5.4m
RoRo
OS 1
Battery Pier

1.2.1

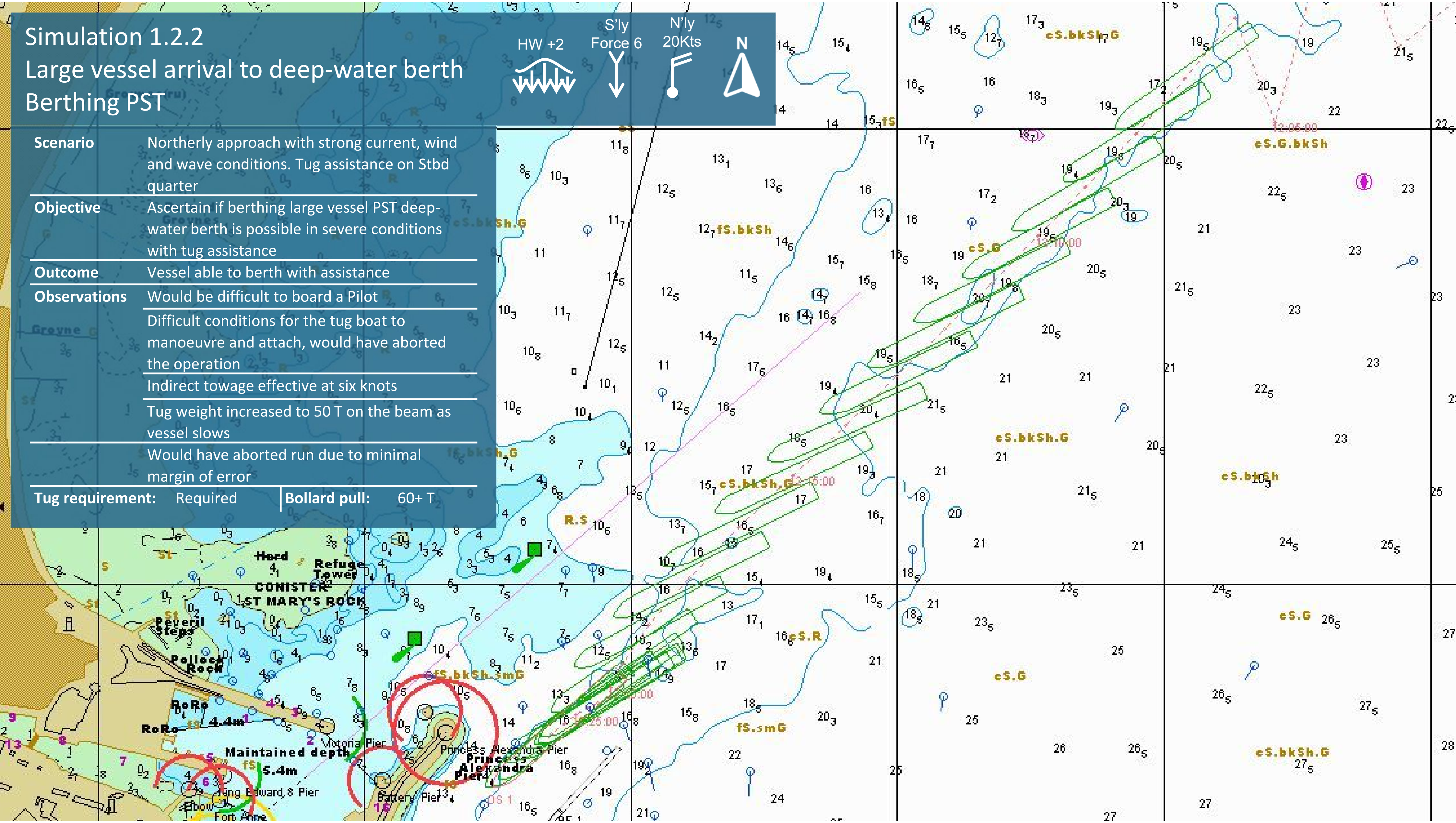
Simulation 1.2.2

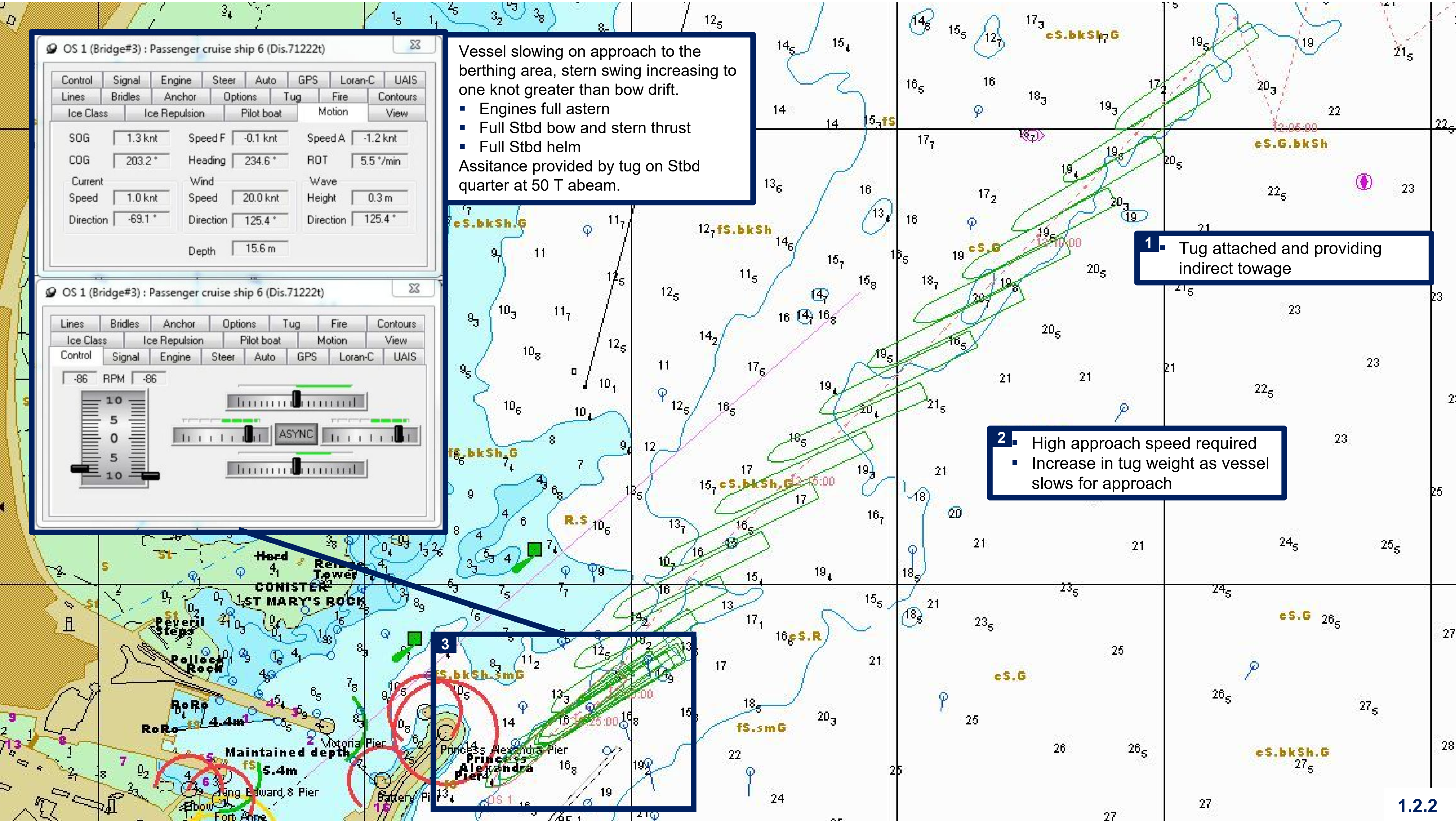
Large vessel arrival to deep-water berth Berthing PST

HW +2 | S'ly Force 6 | N'ly 20Kts | N

Scenario	Northerly approach with strong current, wind and wave conditions. Tug assistance on Stbd quarter
Objective	Ascertain if berthing large vessel PST deep-water berth is possible in severe conditions with tug assistance
Outcome	Vessel able to berth with assistance
Observations	Would be difficult to board a Pilot
	Difficult conditions for the tug boat to manoeuvre and attach, would have aborted the operation
	Indirect towage effective at six knots
	Tug weight increased to 50 T on the beam as vessel slows
	Would have aborted run due to minimal margin of error

Tug requirement: Required | **Bollard pull:** 60+ T



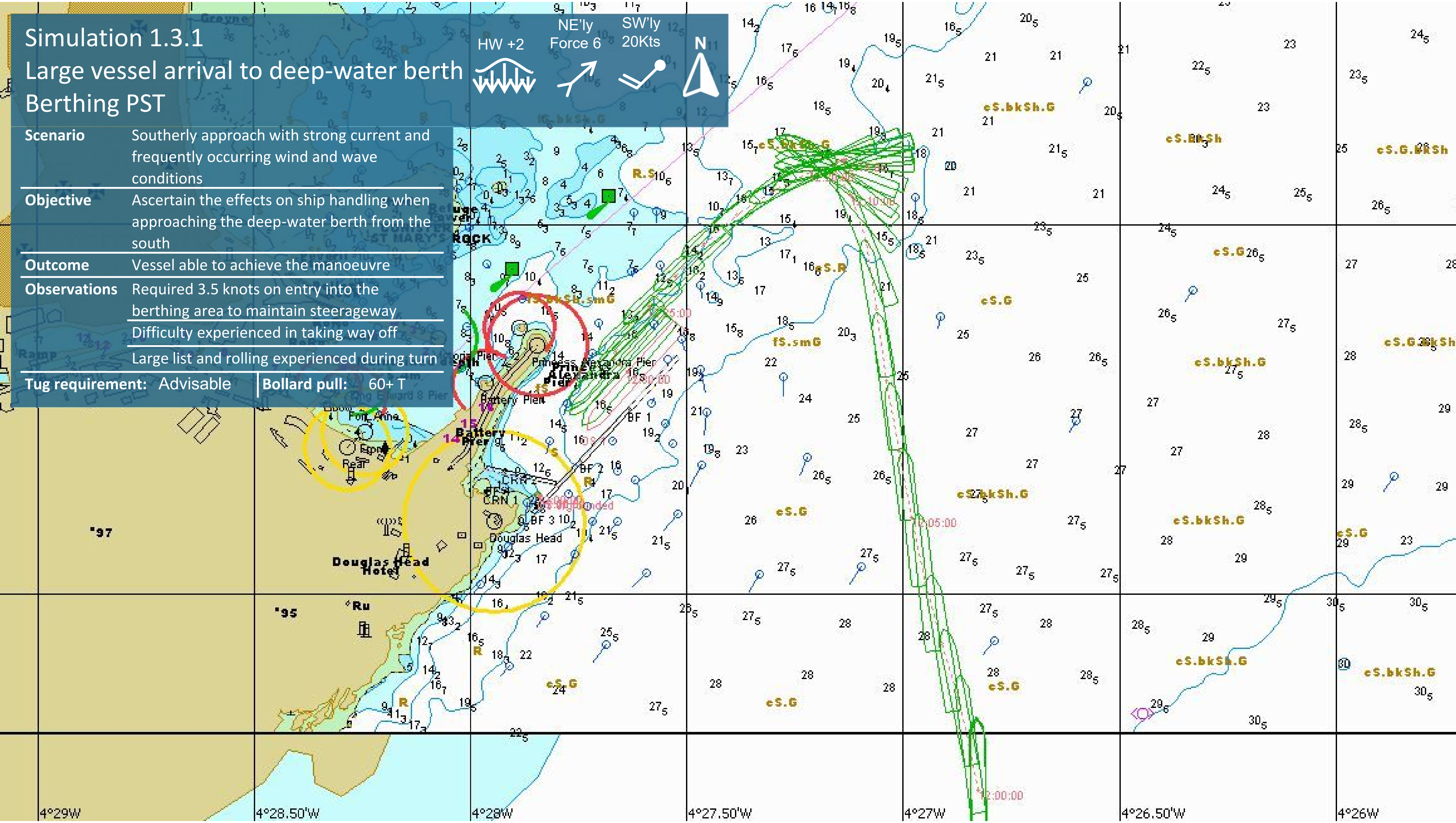

OS 1 (Bridge#3) : Passenger cruise ship 6 (Dis.71222t)
Control Signal Engine Steer Auto GPS Loran-C UAIS
Lines Bridles Anchor Options Tug Fire Contours
Ice Class Ice Repulsion Pilot boat Motion View
SOG 1.3 knt Speed F -0.1 knt Speed A -1.2 knt
COG 203.2 ° Heading 234.6 ° ROT 5.5 °/min
Current Wind Wave
Speed 1.0 knt Speed 20.0 knt Height 0.3 m
Direction -69.1 ° Direction 125.4 ° Direction 125.4 °
Depth 15.6 m
OS 1 (Bridge#3) : Passenger cruise ship 6 (Dis.71222t)
-86 RPM -86
ASYNC
Vessel slowing on approach to the berthing area, stern swing increasing to one knot greater than bow drift.
Engines full astern
Full Stbd bow and stern thrust
Full Stbd helm
Assitance provided by tug on Stbd quarter at 50 T abeam.
1
Tug attached and providing indirect towage
2
High approach speed required
Increase in tug weight as vessel slows for approach
3
Victoria Pier
Princess Alexandra Pier
Maintained depth
King Edward 8 Pier
Battery Pier
Fort Anne
Conister
St Mary's Rock
Peveril Steps
Pollock Rock
RoRo
Elbow
1.2.2

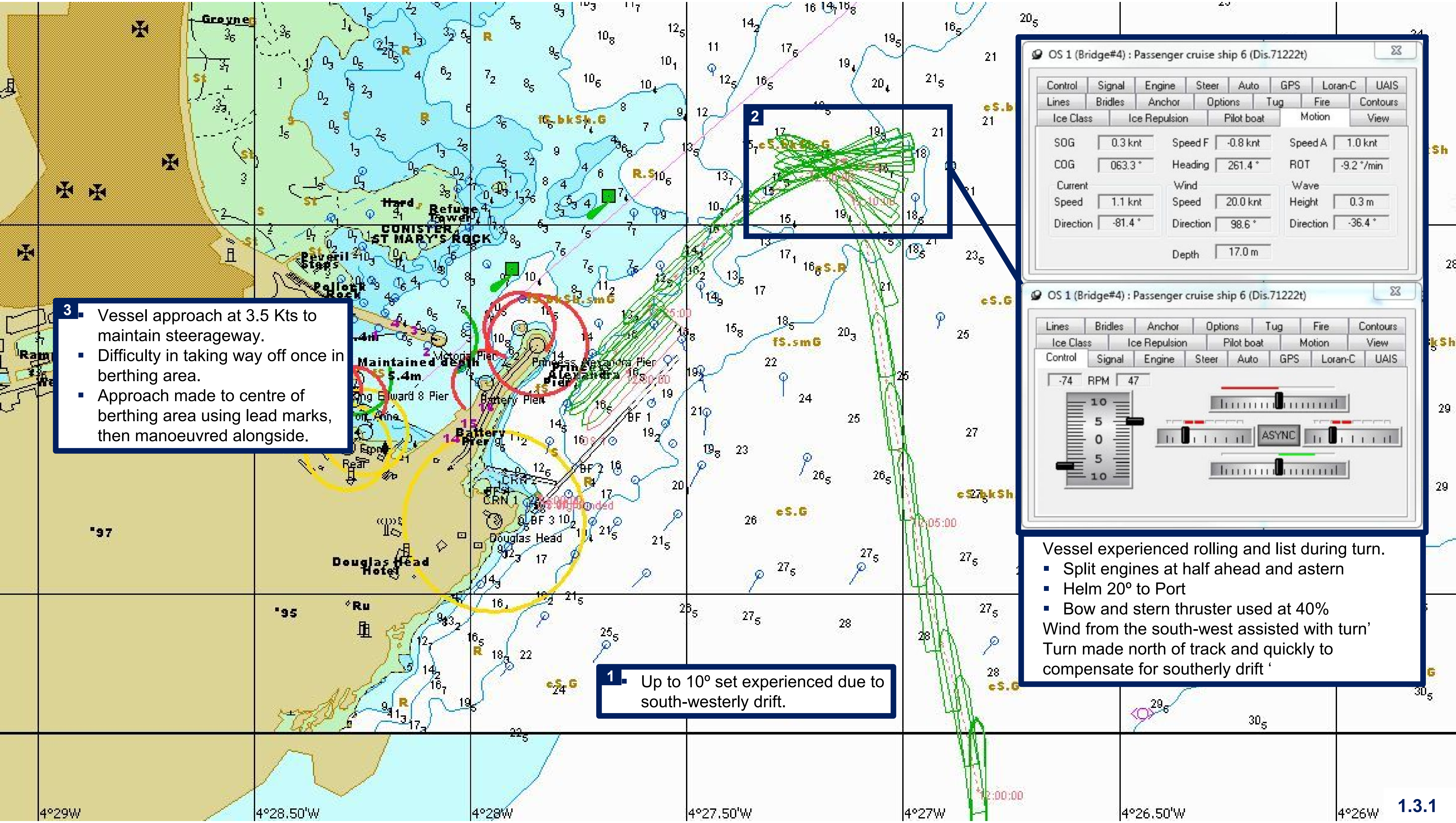
Simulation 1.3.1
Large vessel arrival to deep-water berth
Berthing PST

HW +2 | NE'ly Force 6 | SW'ly 20Kts | N

Scenario	Southerly approach with strong current and frequently occurring wind and wave conditions
Objective	Ascertain the effects on ship handling when approaching the deep-water berth from the south
Outcome	Vessel able to achieve the manoeuvre
Observations	Required 3.5 knots on entry into the berthing area to maintain steerageway
	Difficulty experienced in taking way off
	Large list and rolling experienced during turn

Tug requirement: Advisable | **Bollard pull:** 60+ T





1
Up to 10º set experienced due to south-westerly drift.
2
3
Vessel approach at 3.5 Kts to maintain steerageway.
Difficulty in taking way off once in berthing area.
Approach made to centre of berthing area using lead marks, then manoeuvred alongside.
Vessel experienced rolling and list during turn.
Split engines at half ahead and astern
Helm 20º to Port
Bow and stern thruster used at 40%
Wind from the south-west assisted with turn’
Turn made north of track and quickly to compensate for southerly drift ‘
OS 1 (Bridge#4) : Passenger cruise ship 6 (Dis.71222t)
SOG 0.3 knt
COG 063.3 °
Speed F -0.8 knt
Heading 261.4 °
Speed A 1.0 knt
ROT -9.2 °/min
Current Speed 1.1 knt Direction -81.4 °
Wind Speed 20.0 knt Direction 98.6 °
Wave Height 0.3 m Direction -36.4 °
Depth 17.0 m
-74 RPM 47
ASYNC
Douglas Head
Douglas Head Hotel
Battery Pier
Victoria Pier
Princess Alexandra Pier
King Edward 8 Pier
Maintained depth 5.4m
CONISTER ST MARY'S ROCK
Refuge Tower
Pollock Rock
Peveril Steps
Groyne
4°29W
4°28.50'W
4°28W
4°27.50'W
4°27W
4°26.50'W
4°26W

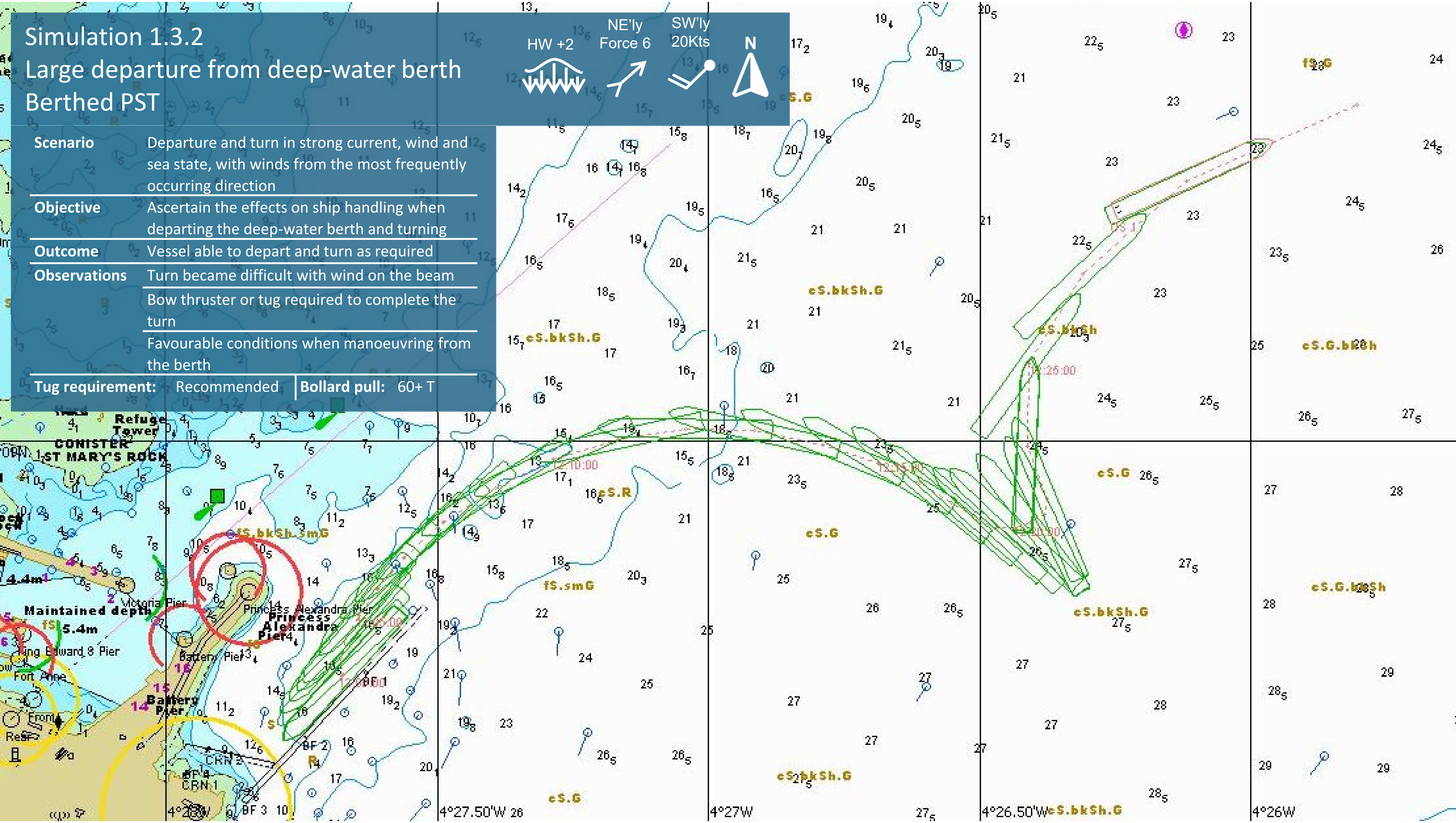
1.3.1

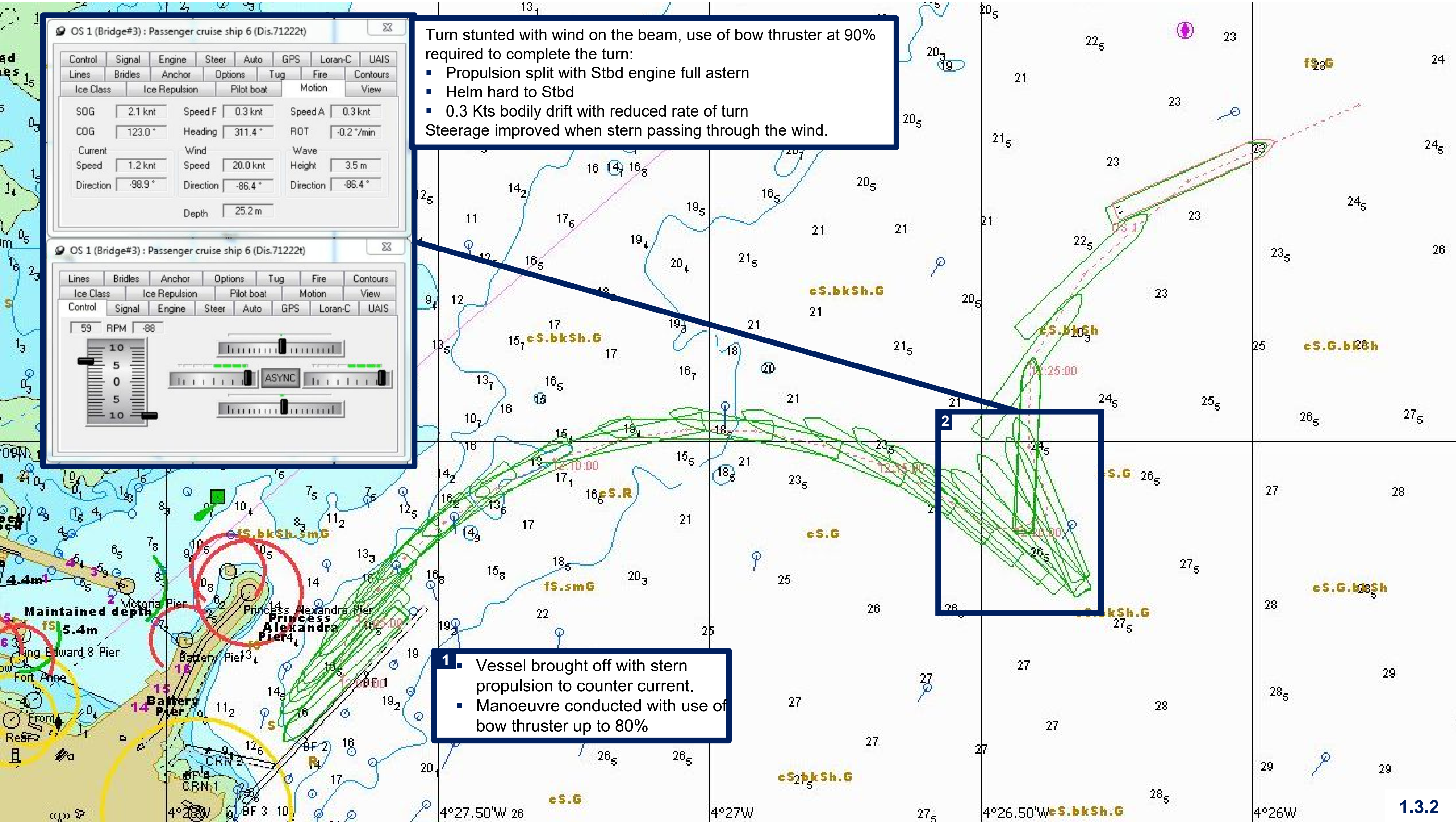
Simulation 1.3.2
Large departure from deep-water berth
Berthed PST

HW +2 | NE'ly Force 6 | SW'ly 20Kts | N

Scenario	Departure and turn in strong current, wind and sea state, with winds from the most frequently occurring direction
Objective	Ascertain the effects on ship handling when departing the deep-water berth and turning
Outcome	Vessel able to depart and turn as required
Observations	Turn became difficult with wind on the beam
	Bow thruster or tug required to complete the turn
	Favourable conditions when manoeuvring from the berth

Tug requirement: Recommended | **Bollard pull:** 60+ T





OS 1 (Bridge#3) : Passenger cruise ship 6 (Dis.71222t)
Control Signal Engine Steer Auto GPS Loran-C UAIS
Lines Bridles Anchor Options Tug Fire Contours
Ice Class Ice Repulsion Pilot boat Motion View
SOG 2.1 knt Speed F 0.3 knt Speed A 0.3 knt
COG 123.0 ° Heading 311.4 ° ROT -0.2 °/min
Current Speed 1.2 knt Direction -98.9 °
Wind Speed 20.0 knt Direction -86.4 °
Wave Height 3.5 m Direction -86.4 °
Depth 25.2 m
OS 1 (Bridge#3) : Passenger cruise ship 6 (Dis.71222t)
59 RPM -88
ASYNC
Turn stunted with wind on the beam, use of bow thruster at 90% required to complete the turn:
Propulsion split with Stbd engine full astern
Helm hard to Stbd
0.3 Kts bodily drift with reduced rate of turn
Steerage improved when stern passing through the wind.
1
Vessel brought off with stern propulsion to counter current.
Manoeuvre conducted with use of bow thruster up to 80%
2
Maintained depth
Victoria Pier
Princess Alexandra Pier
King Edward 8 Pier
Battery Pier
Fort Anne
4°27.50'W
4°27W
4°26.50'W
4°26W

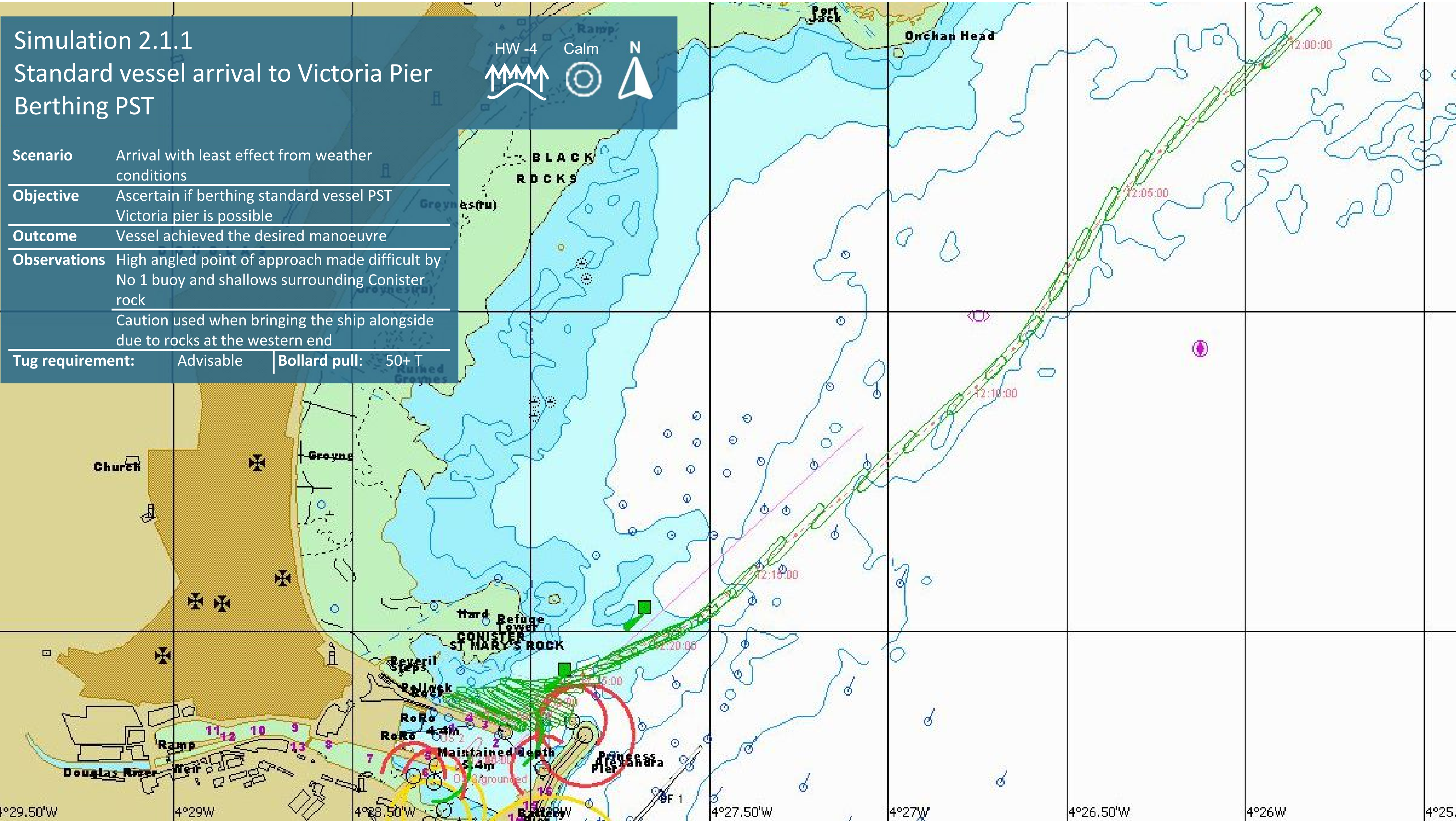
1.3.2

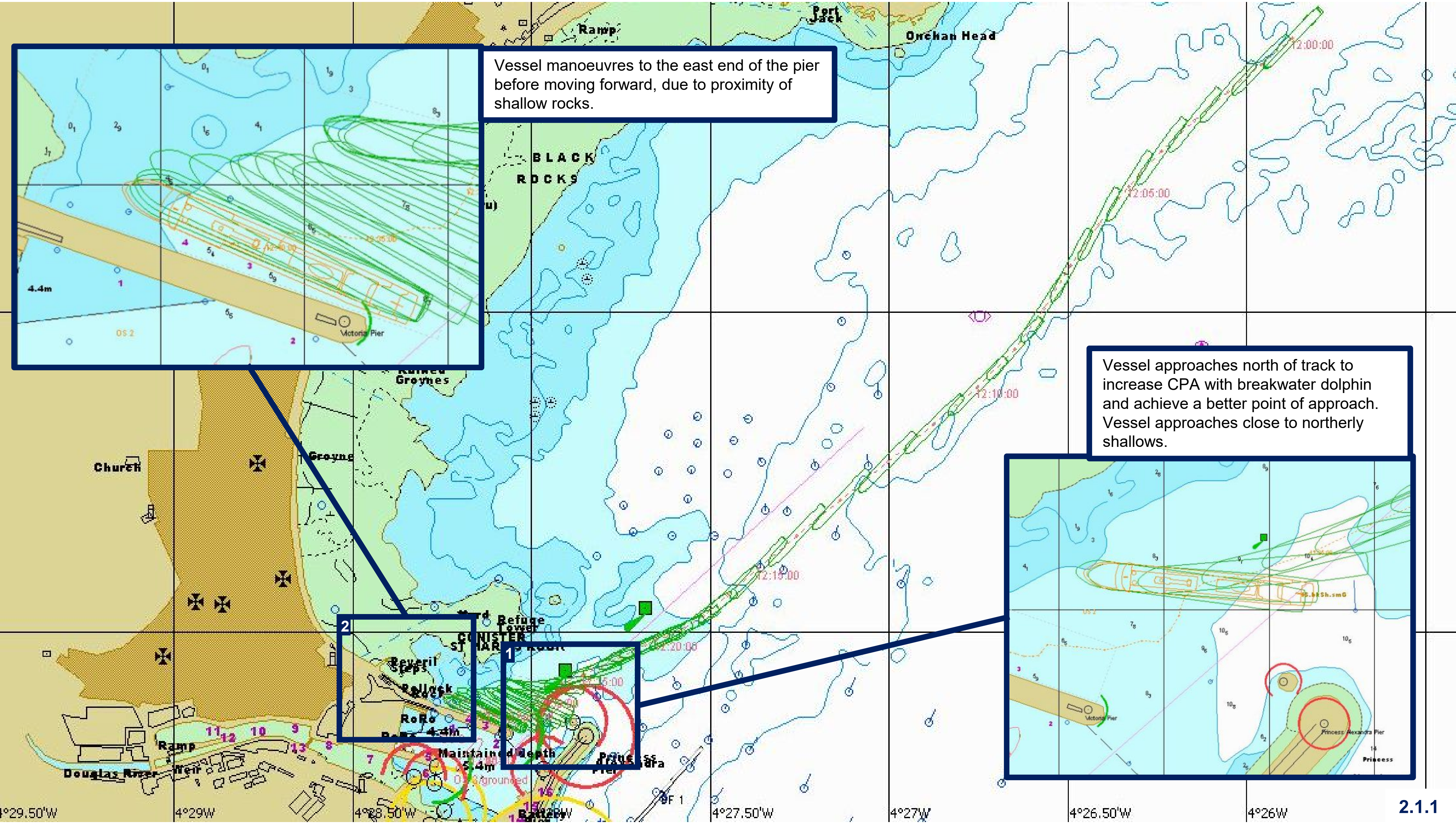
Simulation 2.1.1
Standard vessel arrival to Victoria Pier Berthing PST

HW -4 | Calm | N

Scenario	Arrival with least effect from weather conditions
Objective	Ascertain if berthing standard vessel PST Victoria pier is possible
Outcome	Vessel achieved the desired manoeuvre
Observations	High angled point of approach made difficult by No 1 buoy and shallows surrounding Conister rock
	Caution used when bringing the ship alongside due to rocks at the western end

Tug requirement: Advisable | **Bollard pull**: 50+ T

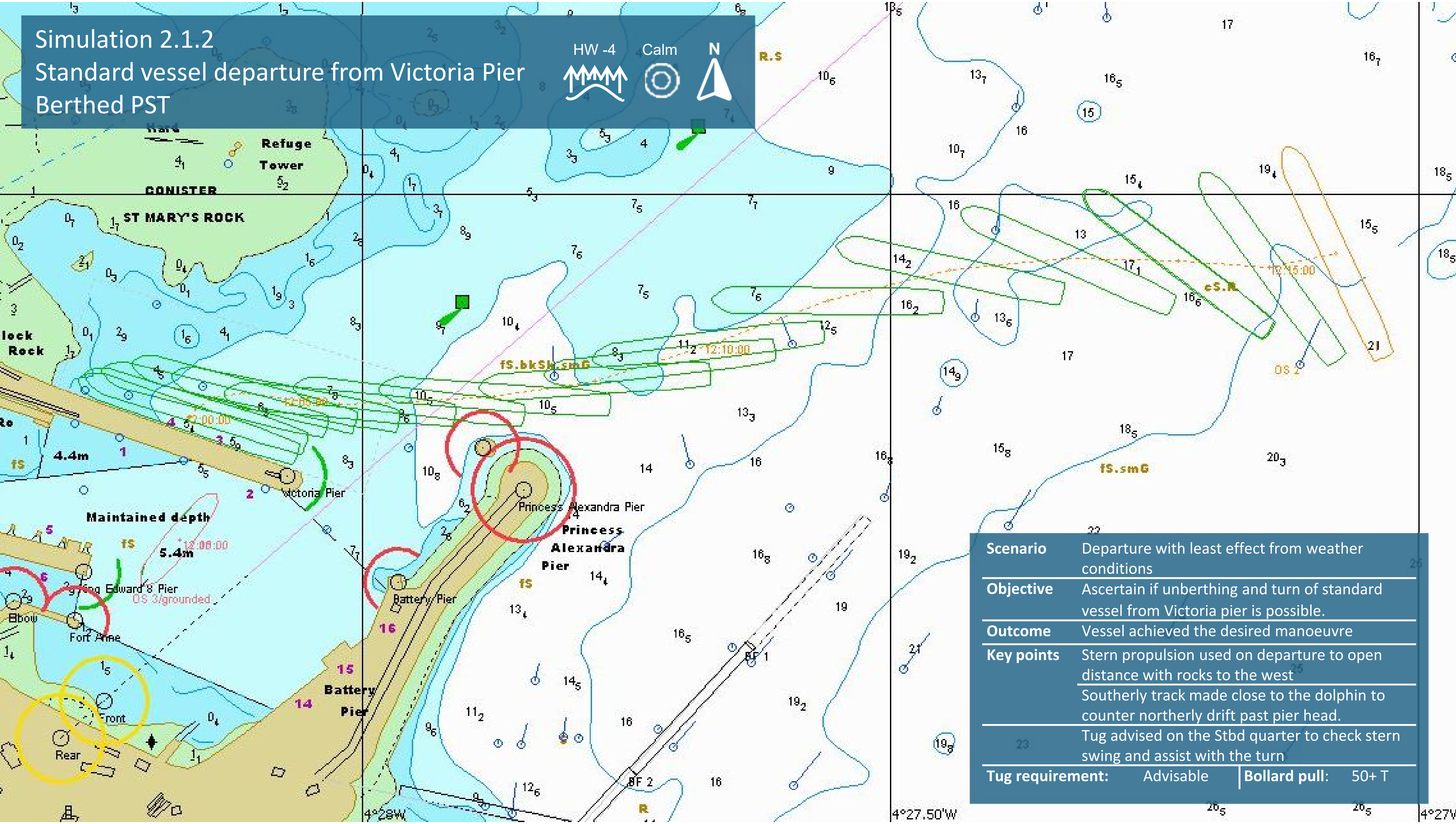



Vessel manoeuvres to the east end of the pier before moving forward, due to proximity of shallow rocks.
Vessel approaches north of track to increase CPA with breakwater dolphin and achieve a better point of approach. Vessel approaches close to northerly shallows.
Port Jack
Onchan Head
Ramp
BLACK ROCKS
Groynes
Groyne
Church
Refuge Tower
CONISTER
Beveril Steps
Pollock Rock
RoRo
Maintained depth
Princess Alexandra Pier
Douglas River
Weir
Victoria Pier
12:00:00
12:05:00
12:10:00
12:15:00
12:20:00
4.4m
1
2
4°29.50'W
4°29'W
4°28.50'W
4°27.50'W
4°27'W
4°26.50'W
4°26'W

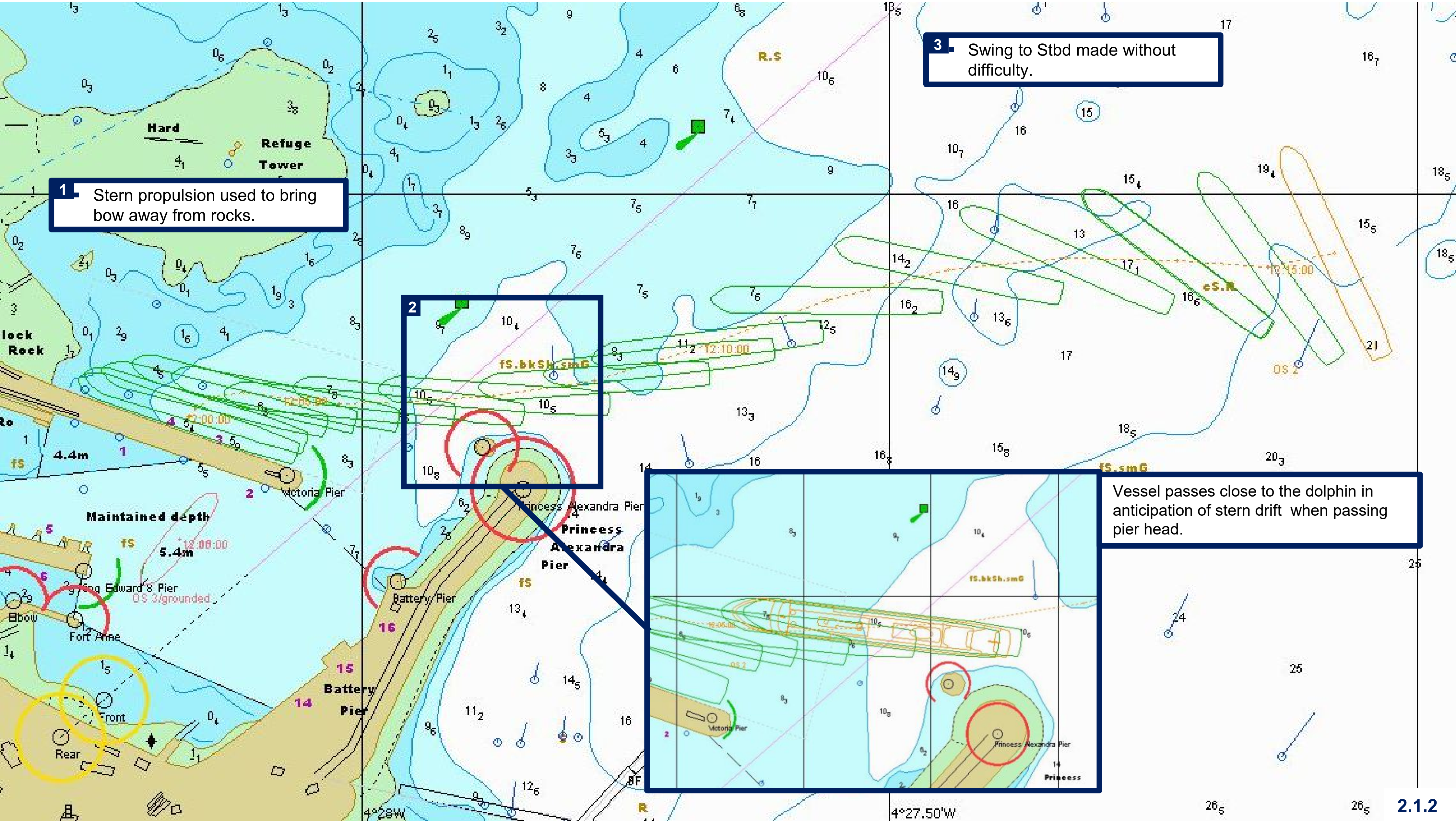
2.1.1

Simulation 2.1.2
Standard vessel departure from Victoria Pier
Berthed PST

HW -4 | Calm | N



Scenario	Departure with least effect from weather conditions
Objective	Ascertain if unberthing and turn of standard vessel from Victoria pier is possible.
Outcome	Vessel achieved the desired manoeuvre
Key points	Stern propulsion used on departure to open distance with rocks to the west
	Southerly track made close to the dolphin to counter northerly drift past pier head.
	Tug advised on the Stbd quarter to check stern swing and assist with the turn
Tug requirement: Advisable	**Bollard pull:** 50+ T

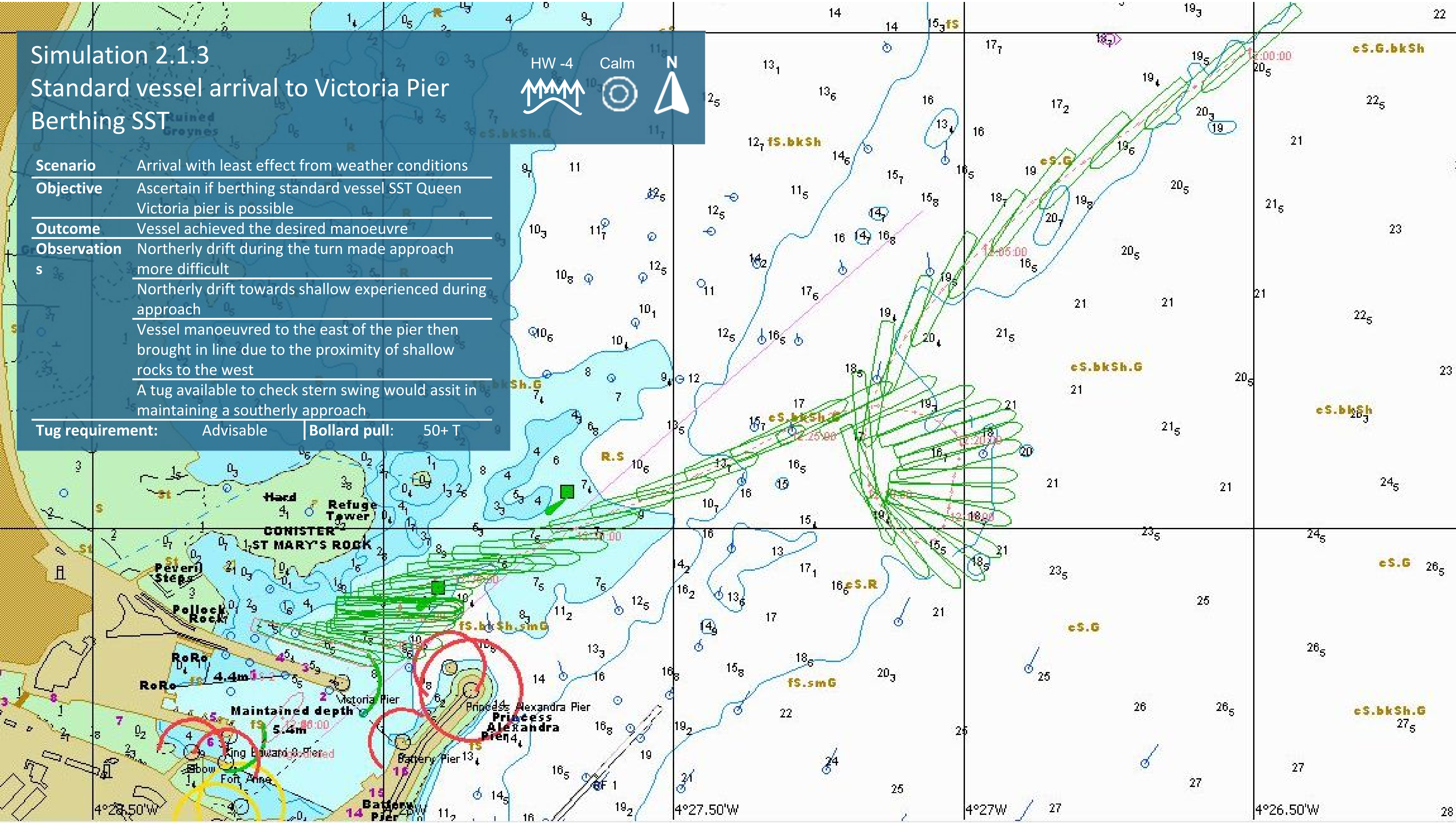

1 Stern propulsion used to bring bow away from rocks.
2
3 Swing to Stbd made without difficulty.
Vessel passes close to the dolphin in anticipation of stern drift when passing pier head.
Hard
Refuge Tower
lock Rock
Maintained depth
4.4m
5.4m
Victoria Pier
Princess Alexandra Pier
Princess Alexandra Pier
Battery Pier
Battery Pier
King Edward 8 Pier
OS 3/grounded
Elbow
Fort Anne
Front
Rear
R.S
fS.bkSh.smG
fS.smG
cS.R
12:00:00
12:05:00
12:06:00
12:10:00
12:15:00
4°28'W
4°27.50'W

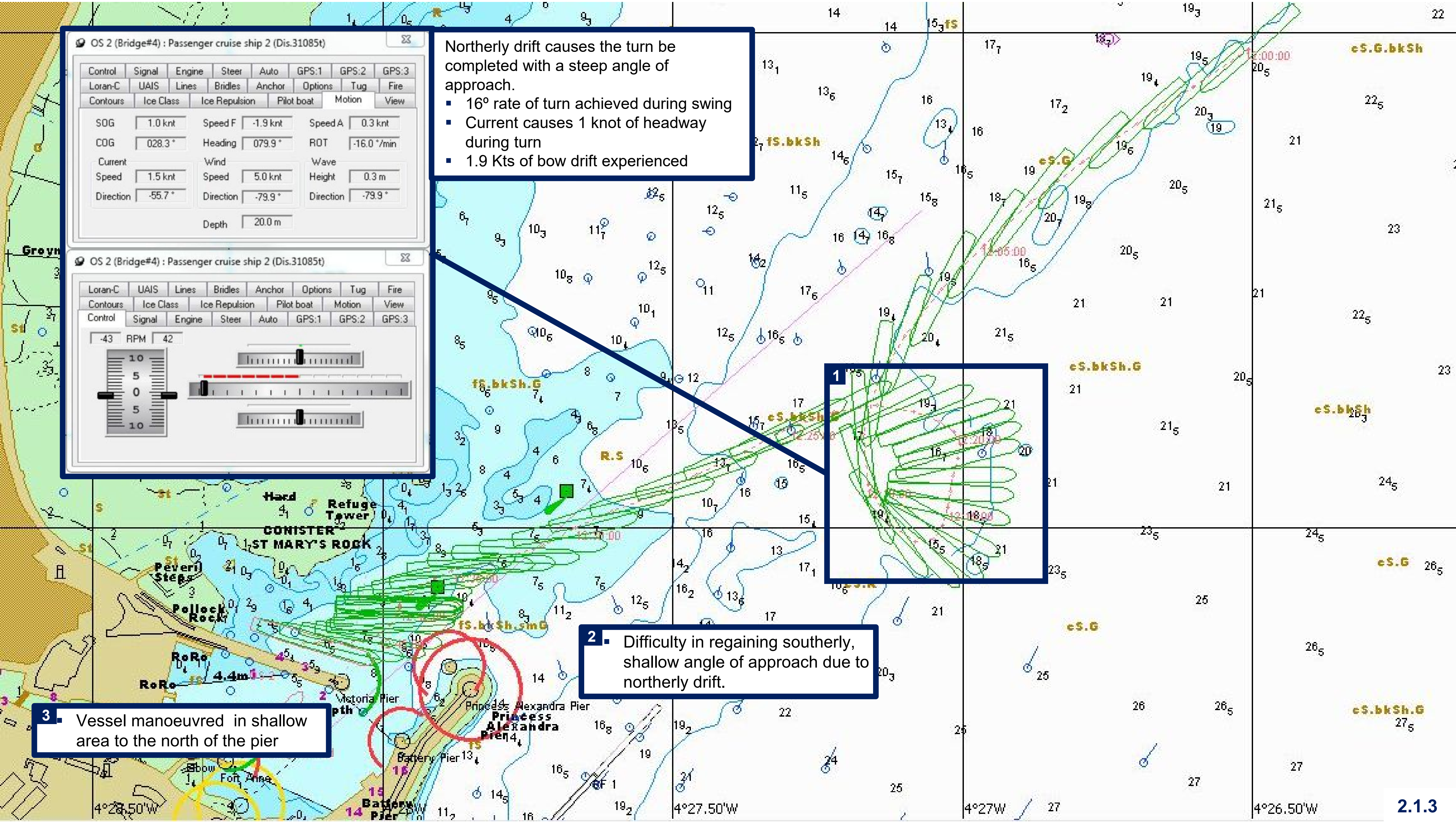
2.1.2

Simulation 2.1.3
Standard vessel arrival to Victoria Pier Berthing SST

HW -4 | Calm | N

Scenario	Arrival with least effect from weather conditions
Objective	Ascertain if berthing standard vessel SST Queen Victoria pier is possible
Outcome	Vessel achieved the desired manoeuvre
Observations	Northerly drift during the turn made approach more difficult
	Northerly drift towards shallow experienced during approach
	Vessel manoeuvred to the east of the pier then brought in line due to the proximity of shallow rocks to the west
	A tug available to check stern swing would assit in maintaining a southerly approach
Tug requirement: Advisable	**Bollard pull:** 50+ T





OS 2 (Bridge#4) : Passenger cruise ship 2 (Dis.31085t)
Control Signal Engine Steer Auto GPS:1 GPS:2 GPS:3
Loran-C UAIS Lines Bridles Anchor Options Tug Fire
Contours Ice Class Ice Repulsion Pilot boat Motion View
SOG 1.0 knt
COG 028.3 °
Speed F -1.9 knt
Heading 079.9 °
Speed A 0.3 knt
ROT -16.0 °/min
Current Speed 1.5 knt Direction -55.7 °
Wind Speed 5.0 knt Direction -79.9 °
Wave Height 0.3 m Direction -79.9 °
Depth 20.0 m
OS 2 (Bridge#4) : Passenger cruise ship 2 (Dis.31085t)
Loran-C UAIS Lines Bridles Anchor Options Tug Fire
Contours Ice Class Ice Repulsion Pilot boat Motion View
Control Signal Engine Steer Auto GPS:1 GPS:2 GPS:3
-43 RPM 42
Northerly drift causes the turn be completed with a steep angle of approach.
16º rate of turn achieved during swing
Current causes 1 knot of headway during turn
1.9 Kts of bow drift experienced
1
2
Difficulty in regaining southerly, shallow angle of approach due to northerly drift.
3
Vessel manoeuvred in shallow area to the north of the pier
Groyne
Hard
Refuge Tower
CONISTER
ST MARY'S ROCK
Peveril Steps
Pollock Rock
RoRo
4.4m
Victoria Pier
Princess Alexandra Pier
Battery Pier
Fort Anne
4°28.50'W
4°27.50'W
4°27W
4°26.50'W

2.1.3

Simulation 2.2.1
Standard vessel arrival to Victoria Pier Berthing PST

HW +2

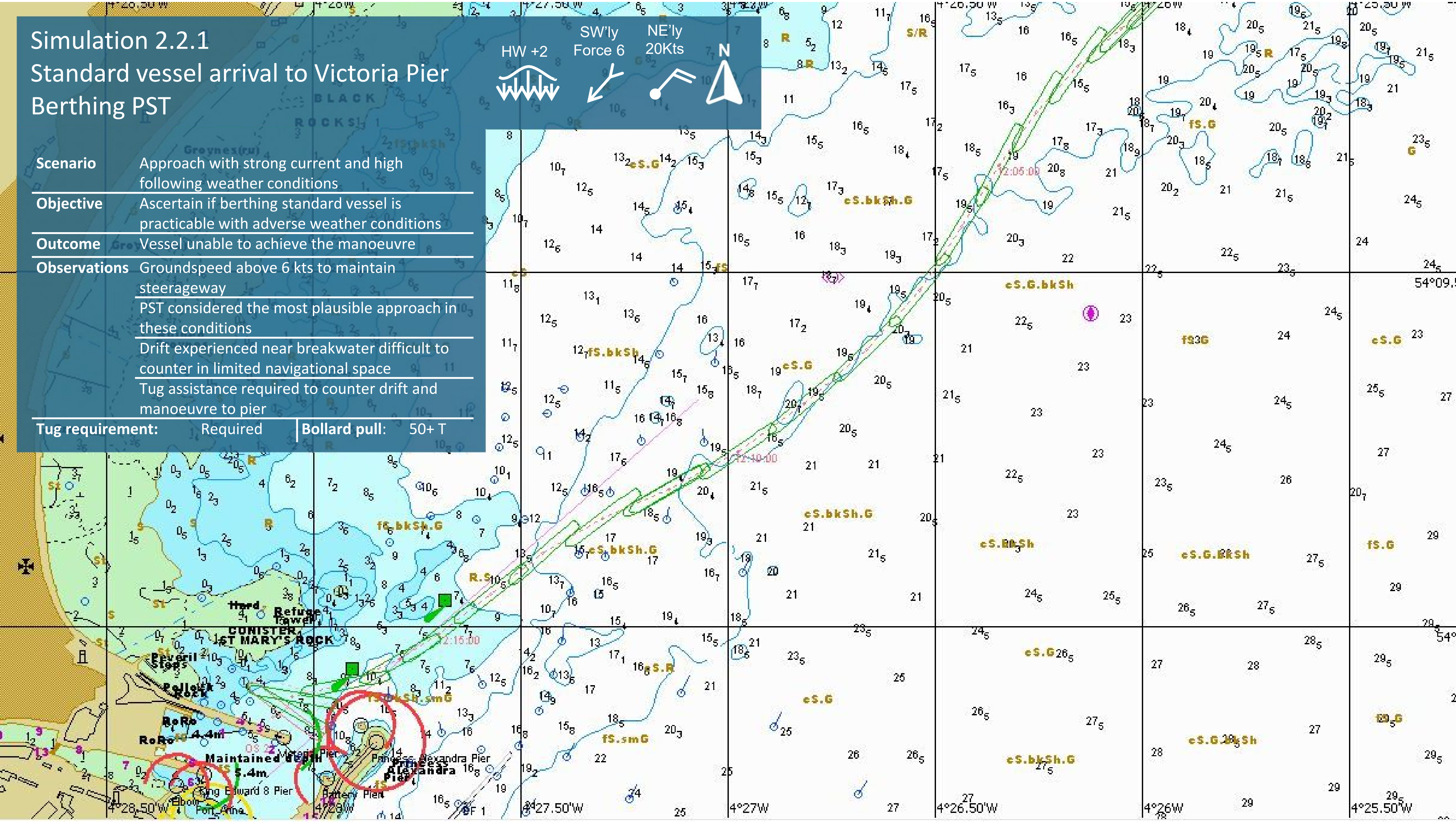
SW'ly Force 6

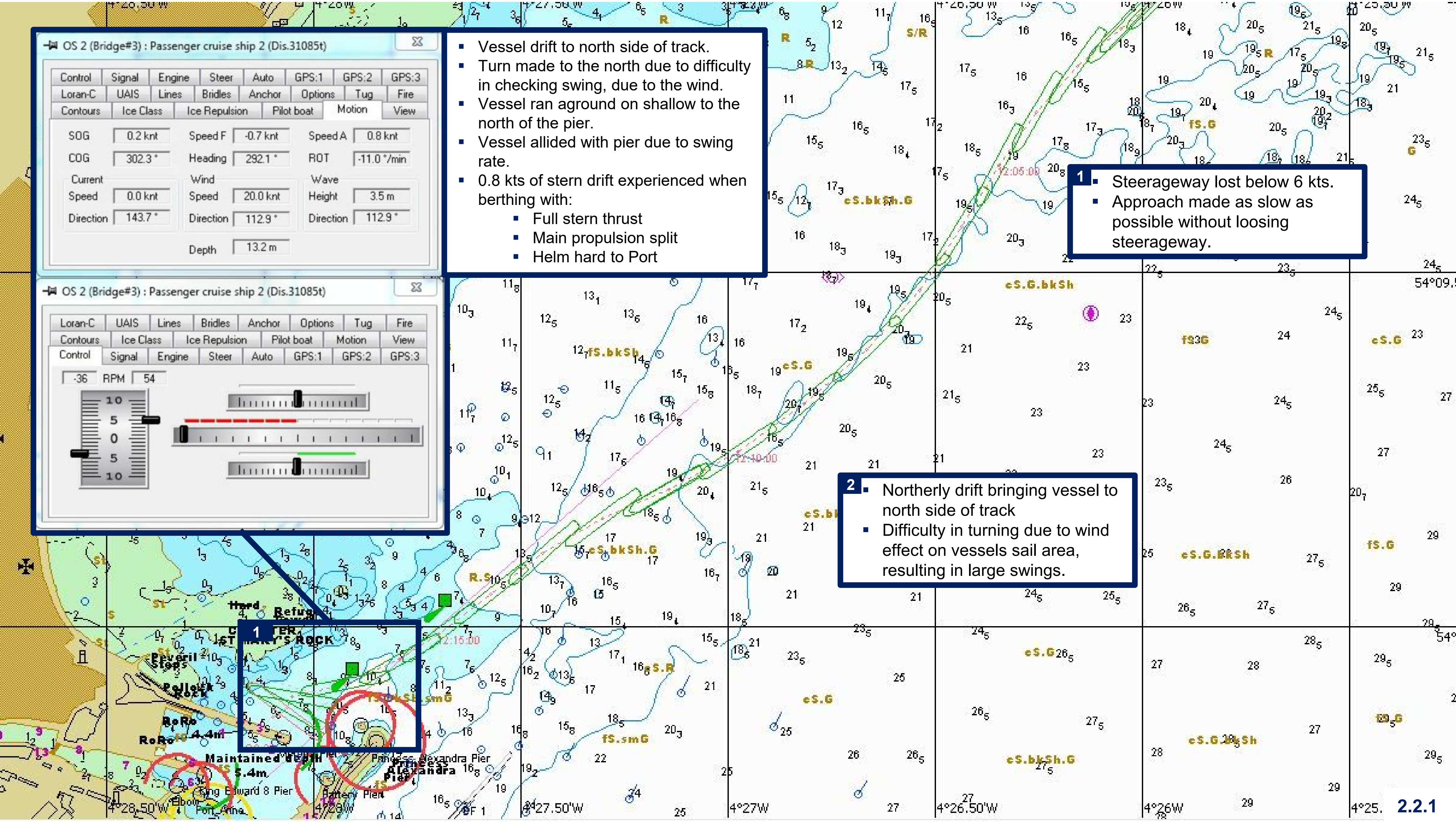
NE'ly 20Kts

N

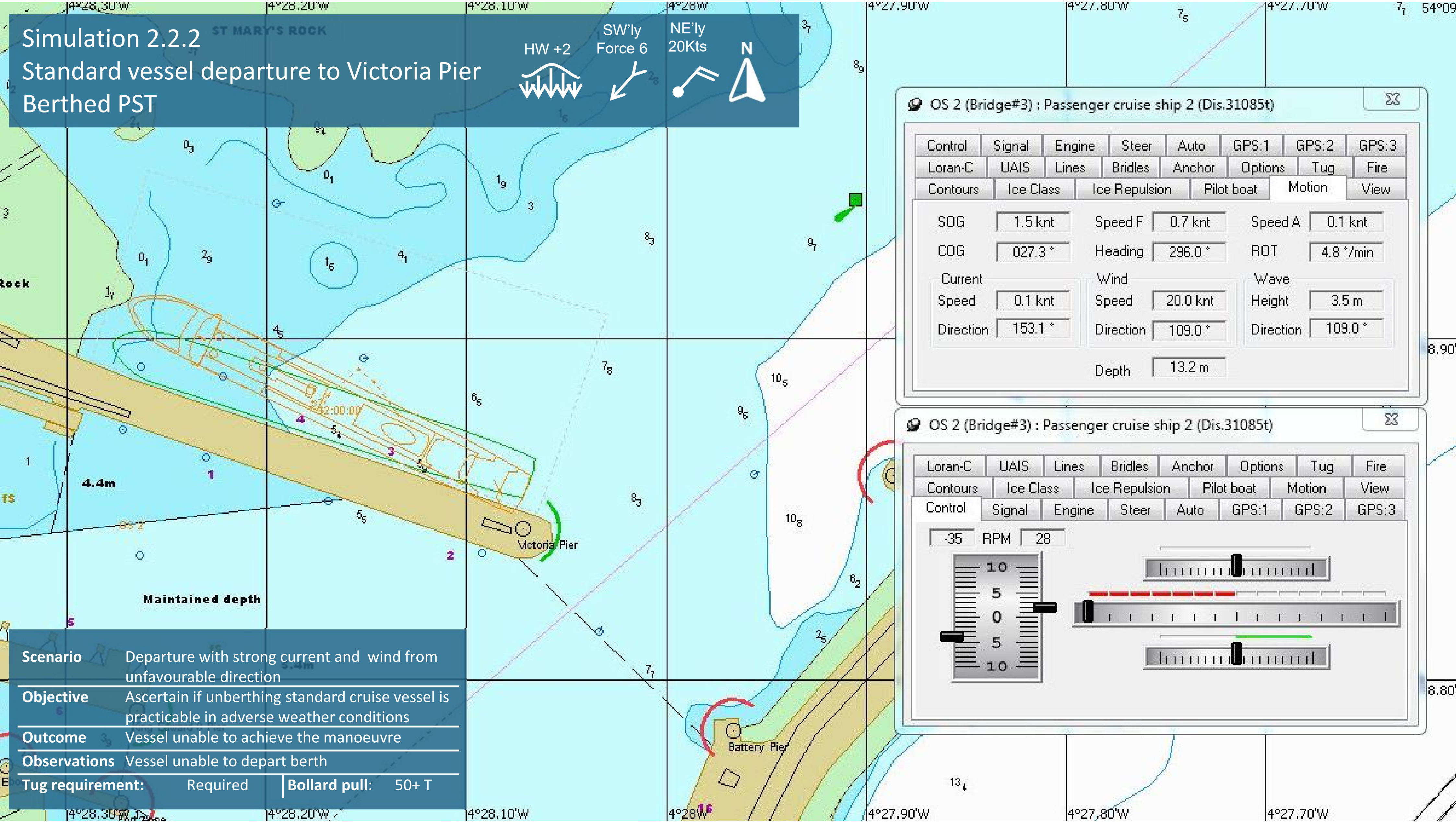
Scenario	Approach with strong current and high following weather conditions
Objective	Ascertain if berthing standard vessel is practicable with adverse weather conditions
Outcome	Vessel unable to achieve the manoeuvre
Observations	Groundspeed above 6 kts to maintain steerageway
	PST considered the most plausible approach in these conditions
	Drift experienced near breakwater difficult to counter in limited navigational space
	Tug assistance required to counter drift and manoeuvre to pier

Tug requirement: Required | **Bollard pull:** 50+ T




OS 2 (Bridge#3) : Passenger cruise ship 2 (Dis.31085t)
Control Signal Engine Steer Auto GPS:1 GPS:2 GPS:3
Loran-C UAIS Lines Bridles Anchor Options Tug Fire
Contours Ice Class Ice Repulsion Pilot boat Motion View
SOG 0.2 knt
COG 302.3 °
Speed F -0.7 knt
Heading 292.1 °
Speed A 0.8 knt
ROT -11.0 °/min
Current Speed 0.0 knt Direction 143.7 °
Wind Speed 20.0 knt Direction 112.9 °
Wave Height 3.5 m Direction 112.9 °
Depth 13.2 m
OS 2 (Bridge#3) : Passenger cruise ship 2 (Dis.31085t)
-36 RPM 54
Vessel drift to north side of track.
Turn made to the north due to difficulty in checking swing, due to the wind.
Vessel ran aground on shallow to the north of the pier.
Vessel allided with pier due to swing rate.
0.8 kts of stern drift experienced when berthing with:
Full stern thrust
Main propulsion split
Helm hard to Port
1
Steerageway lost below 6 kts.
Approach made as slow as possible without loosing steerageway.
2
Northerly drift bringing vessel to north side of track
Difficulty in turning due to wind effect on vessels sail area, resulting in large swings.
1
St Mary's Rock
Peveril Steps
Pollock Rock
Maintained depth 5.4m
Princess Alexandra Pier
King Edward 8 Pier
Battery Pier
Fort Anne
4°28.50'W
4°28'W
4°27.50'W
4°27'W
4°26.50'W
4°26'W
54°09.5
12:05:00
12:10:00
12:15:00
2.2.1

Simulation 2.2.2
Standard vessel departure to Victoria Pier Berthed PST



Scenario	Departure with strong current and wind from unfavourable direction
Objective	Ascertain if unberthing standard cruise vessel is practicable in adverse weather conditions
Outcome	Vessel unable to achieve the manoeuvre
Observations	Vessel unable to depart berth
Tug requirement: Required	**Bollard pull**: 50+ T

Simulation 2.2.3
Standard vessel arrival to Victoria Pier Berthing SST

HW +4

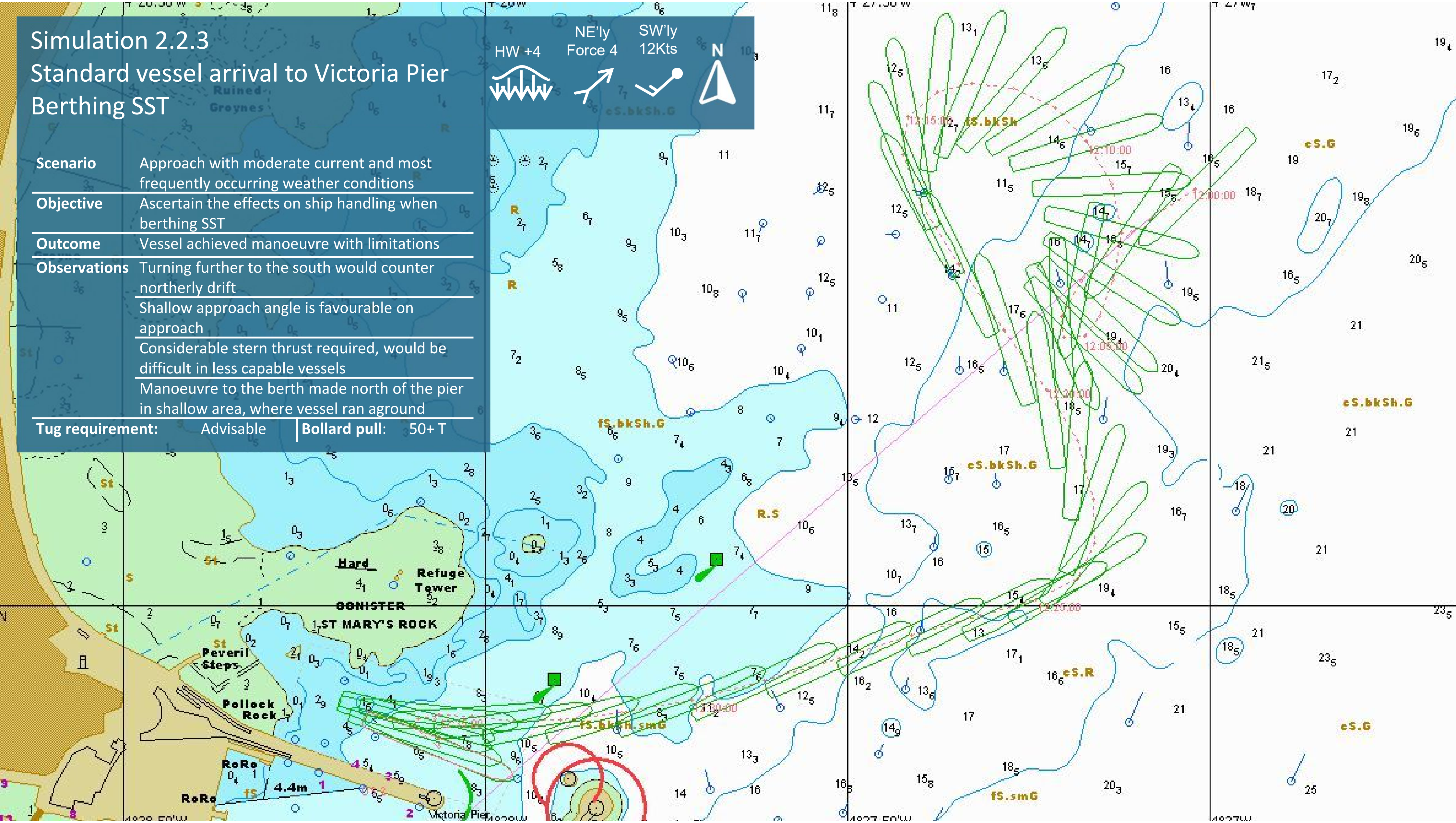
NE'ly Force 4

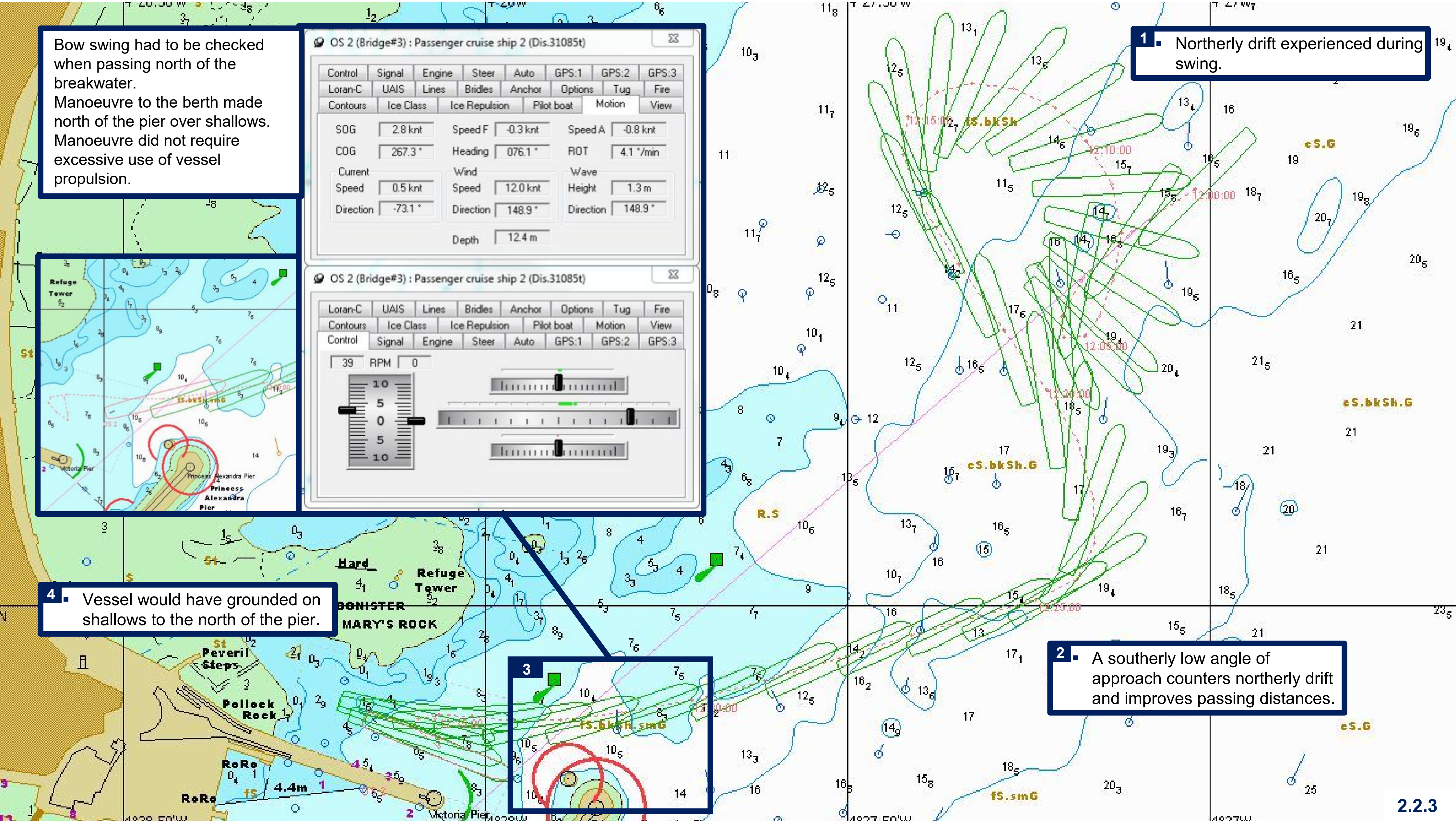
SW'ly 12Kts

N

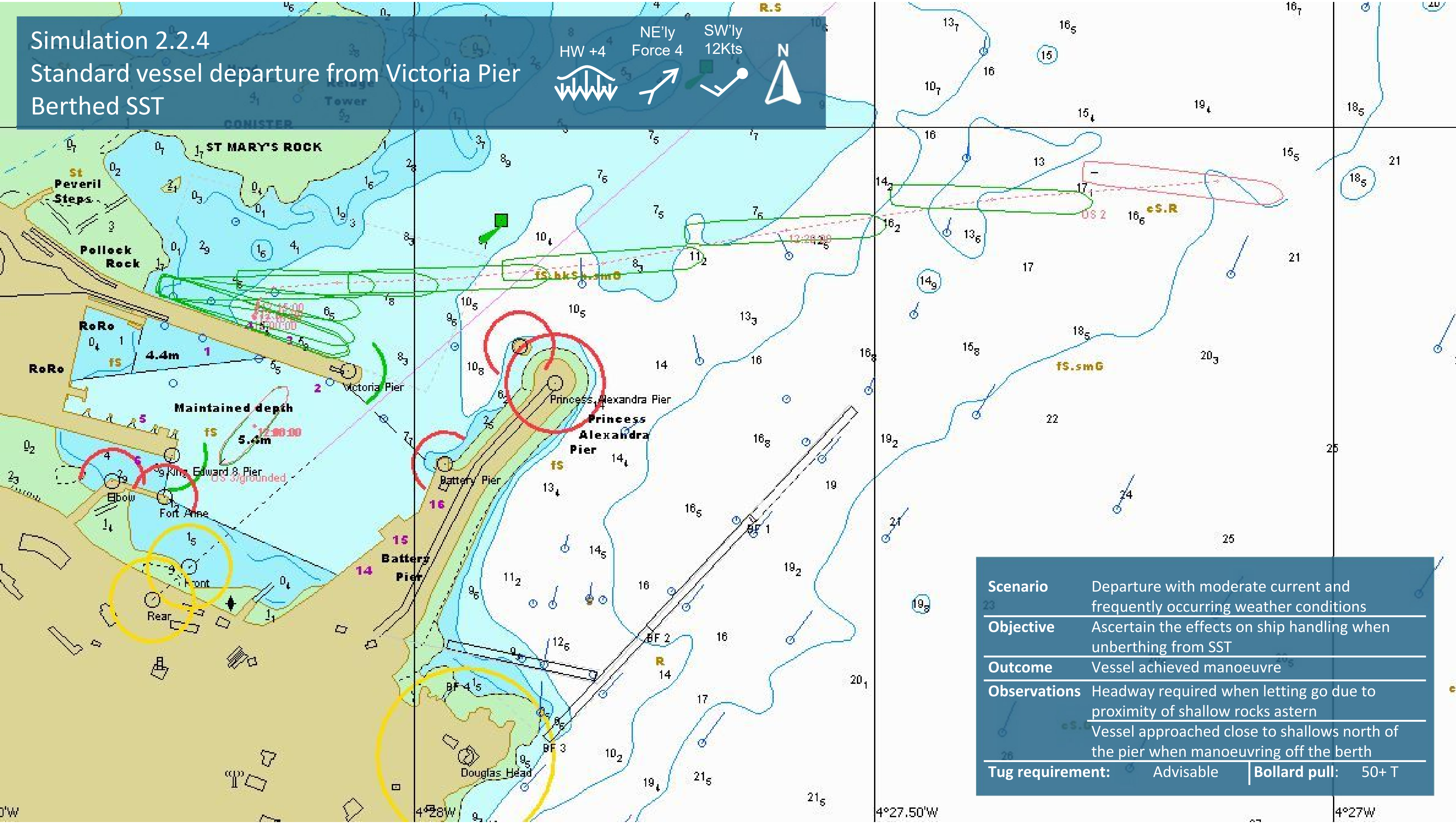
Scenario	Approach with moderate current and most frequently occurring weather conditions
Objective	Ascertain the effects on ship handling when berthing SST
Outcome	Vessel achieved manoeuvre with limitations
Observations	Turning further to the south would counter northerly drift
	Shallow approach angle is favourable on approach
	Considerable stern thrust required, would be difficult in less capable vessels
	Manoeuvre to the berth made north of the pier in shallow area, where vessel ran aground

Tug requirement: Advisable | **Bollard pull:** 50+ T

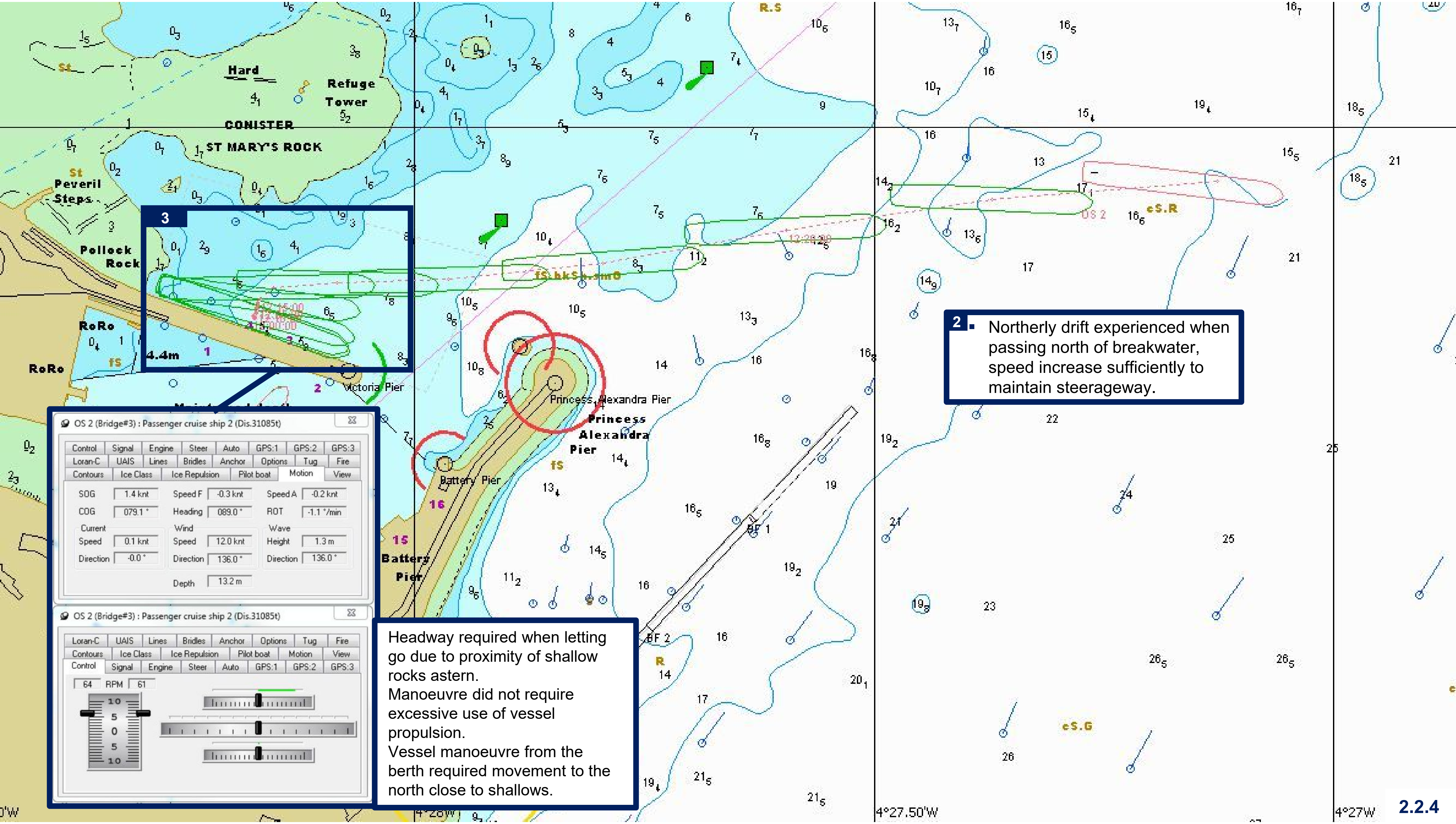



Bow swing had to be checked when passing north of the breakwater.
Manoeuvre to the berth made north of the pier over shallows.
Manoeuvre did not require excessive use of vessel propulsion.
1 Northerly drift experienced during swing.
2 A southerly low angle of approach counters northerly drift and improves passing distances.
3
4 Vessel would have grounded on shallows to the north of the pier.
OS 2 (Bridge#3) : Passenger cruise ship 2 (Dis.31085t)
SOG 2.8 knt
COG 267.3 °
Speed F -0.3 knt
Heading 076.1 °
Speed A -0.8 knt
ROT 4.1 °/min
Current Speed 0.5 knt Direction -73.1 °
Wind Speed 12.0 knt Direction 148.9 °
Wave Height 1.3 m Direction 148.9 °
Depth 12.4 m
39 RPM 0
Refuge Tower
Princess Alexandra Pier
Victoria Pier
BONISTER
MARY'S ROCK
Peveril Steps
Pollock Rock
RoRo
4.4m
2.2.3

Simulation 2.2.4
Standard vessel departure from Victoria Pier
Berthed SST



Scenario	Departure with moderate current and frequently occurring weather conditions
Objective	Ascertain the effects on ship handling when unberthing from SST
Outcome	Vessel achieved manoeuvre
Observations	Headway required when letting go due to proximity of shallow rocks astern
	Vessel approached close to shallows north of the pier when manoeuvring off the berth
Tug requirement: Advisable	**Bollard pull:** 50+ T


2
Northerly drift experienced when passing north of breakwater, speed increase sufficiently to maintain steerageway.
3
Headway required when letting go due to proximity of shallow rocks astern.
Manoeuvre did not require excessive use of vessel propulsion.
Vessel manoeuvre from the berth required movement to the north close to shallows.
OS 2 (Bridge#3) : Passenger cruise ship 2 (Dis.31085t)
Control Signal Engine Steer Auto GPS:1 GPS:2 GPS:3
Loran-C UAIS Lines Bridles Anchor Options Tug Fire
Contours Ice Class Ice Repulsion Pilot boat Motion View
SOG 1.4 knt
COG 079.1 °
Speed F -0.3 knt
Heading 089.0 °
Speed A -0.2 knt
ROT -1.1 °/min
Current
Speed 0.1 knt
Direction -0.0 °
Wind
Speed 12.0 knt
Direction 136.0 °
Wave
Height 1.3 m
Direction 136.0 °
Depth 13.2 m
OS 2 (Bridge#3) : Passenger cruise ship 2 (Dis.31085t)
64 RPM 61
Hard
Refuge Tower
CONISTER
ST MARY'S ROCK
Peveril Steps
Pollock Rock
RoRo
Victoria Pier
Princess Alexandra Pier
Battery Pier
4.4m
OS 2
4°27.50'W
4°27W
2.2.4

I Navigation Terms Glossary

Baseline document	The baseline condition refers to present layout and use and includes; vessel traffic, port services, accidents/incidents, infrastructure and use of aids to navigation.
Berth	An area of pier or quay designated for the handling of ships alongside.
Closest point of approach	The least distance at which a vessel is expected to pass a specific point on the current direction of travel.
Conventional vessels	Vessels with either single or twin rudders and either a fixed or CPP shaft and propeller arrangement.
Dock	An area of water used by vessels when manoeuvring onto and off berths. A port may consist of one or a number of docks within its harbour limits.
Drift	The bodily movements of a vessel through the water caused by current and winds
Ferry gliding	A technique used when manoeuvring a vessel. A lateral movement is created due to the vessels angle from a current or wind.
Indirect towing	The effect of a tugs drag through the water when attached to a vessel.
Knot	The speed unit used in ship handling, one knot is the time taken to travel one nautical mile in an hour
Pier	Infrastructure built away from the mainland, fixed to either the sea bed or attached to the shore, usually used for the handling of ships alongside.
Point of approach	The angle and direction at which a vessel travels to reach a desired point.
Quay	Infrastructure built at the water's edge to facilitate the handling of ships and cargo.
Set	The angle at which a vessel must steer from the intended direction of travel to compensate for currents and wind.
Ships beam	The width of a ship, measured from outermost points. A ships beam may be given as maximum or standard.
Swept-path	The virtual increase in ships beam due to set and subsequent water-space required for the direction of travel.

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