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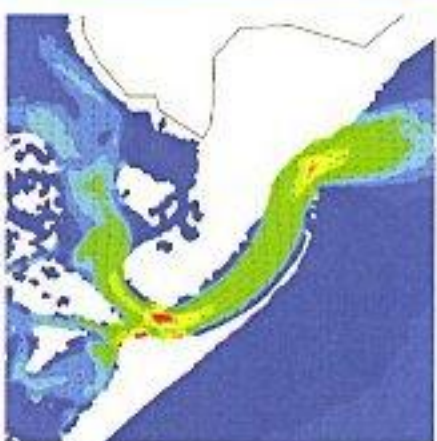
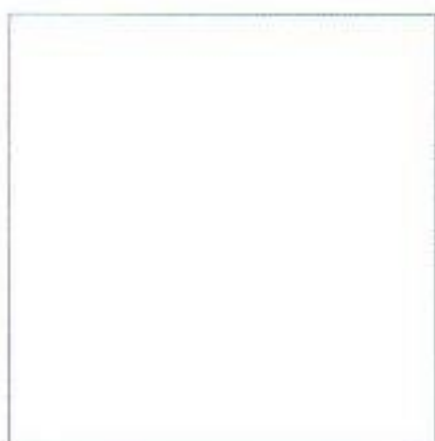
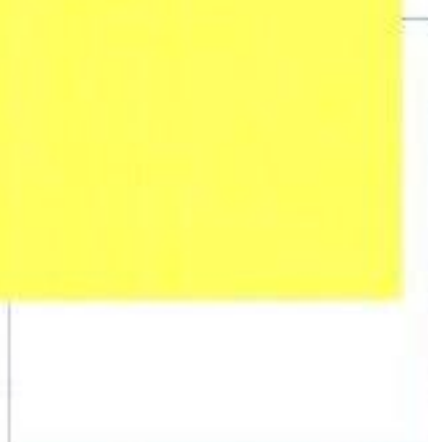


Hydrodynamic Modelling Report

Review of numerical modelling work undertaken to inform the Southmoor Managed Realignment Project

July 2017

APPENDIX V
HYDRODYNAMIC
MODELLING.



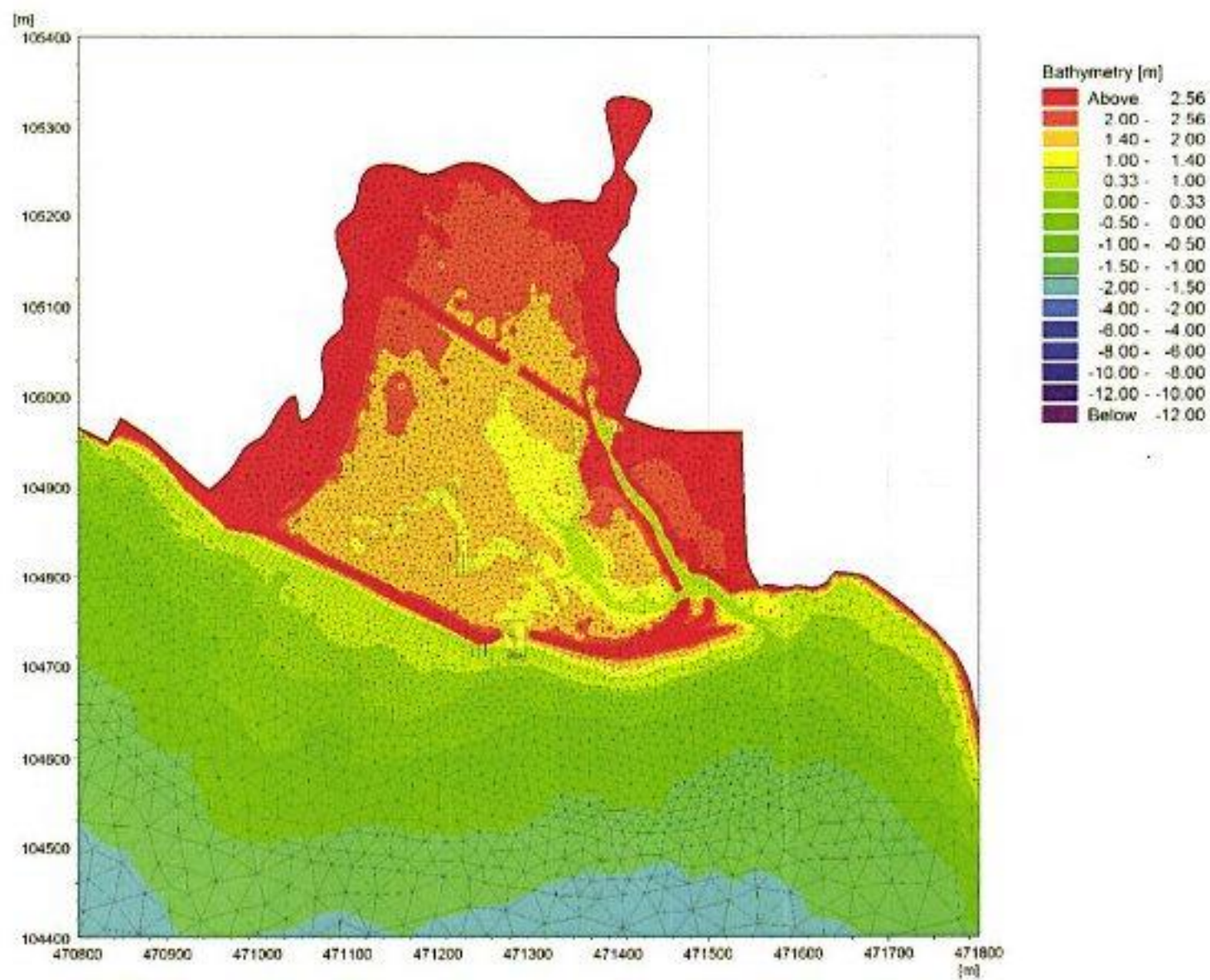
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1 Introduction

On behalf of the Environment Agency, AECOM and ABPmer are working together to develop the proposed Southmoor Managed Realignment scheme (hereafter referred to as "the proposed scheme") which is located in the northeast corner of Langstone Harbour, Havant (see Figure 1). The existing concrete sea defences along this site's frontage are privately owned and in a poor state of repair. Intervention is therefore required to avoid the risk of defence failure which would increase the risk of flooding to the hinterland and nearby residential and commercial properties. To inform the assessment and design work on this project, ABPmer has been commissioned by AECOM to carry out a high level hydrodynamic modelling study of the proposed scheme.

The objectives of the proposed scheme are to provide a sustainable flood and coastal erosion management scheme with an appropriate standard of protection, whilst also addressing the pressing need for creating new intertidal habitat to replace losses across the Solent. A further aim for the Environment Agency is to promote the participation of communities during the planning and development phases of the project.

The Portchester Castle to Emsworth Flood and Coastal Erosion Risk Management Strategy identified managed realignment as the preferred option at the Southmoor site. This option would involve building new defences inland from the coast, undertaking a deliberate breach of the existing seawall and allowing a new intertidal area to form seaward of these new defences (this area is referred to in the following as the 'managed realignment area').

The new defences that are to be constructed behind the original line will be less exposed to waves. As the tidal currents that enter through the breach are slowed, suspended sediments will settle resulting in sediment accretion and a slight increase in bed levels within the site. The creation of intertidal habitat, namely saltmarsh, will further help to absorb wave energy and accrete sediment. The result is an effective, sustainable solution to flood and erosion risk at the coast.

A tidal model of the Southmoor site and the wider harbour areas has been configured and applied to assess the functionality of the managed realignment area, to determine the manner in which the managed realignment area will evolve over the short term and to identify any impacts of the proposed scheme on fluvial flood risk and the local tidal hydrodynamics. This report presents the findings of this work and has been structured as follows:

Section 2:	Site Characteristics;
Section 3:	Scheme Design;
Section 4:	Site Functionality;
Section 5:	Impact of Realignment; and
Section 6:	Summary.

Additional details pertaining to the general model build and the model performance are presented in Annex A; Model Calibration.

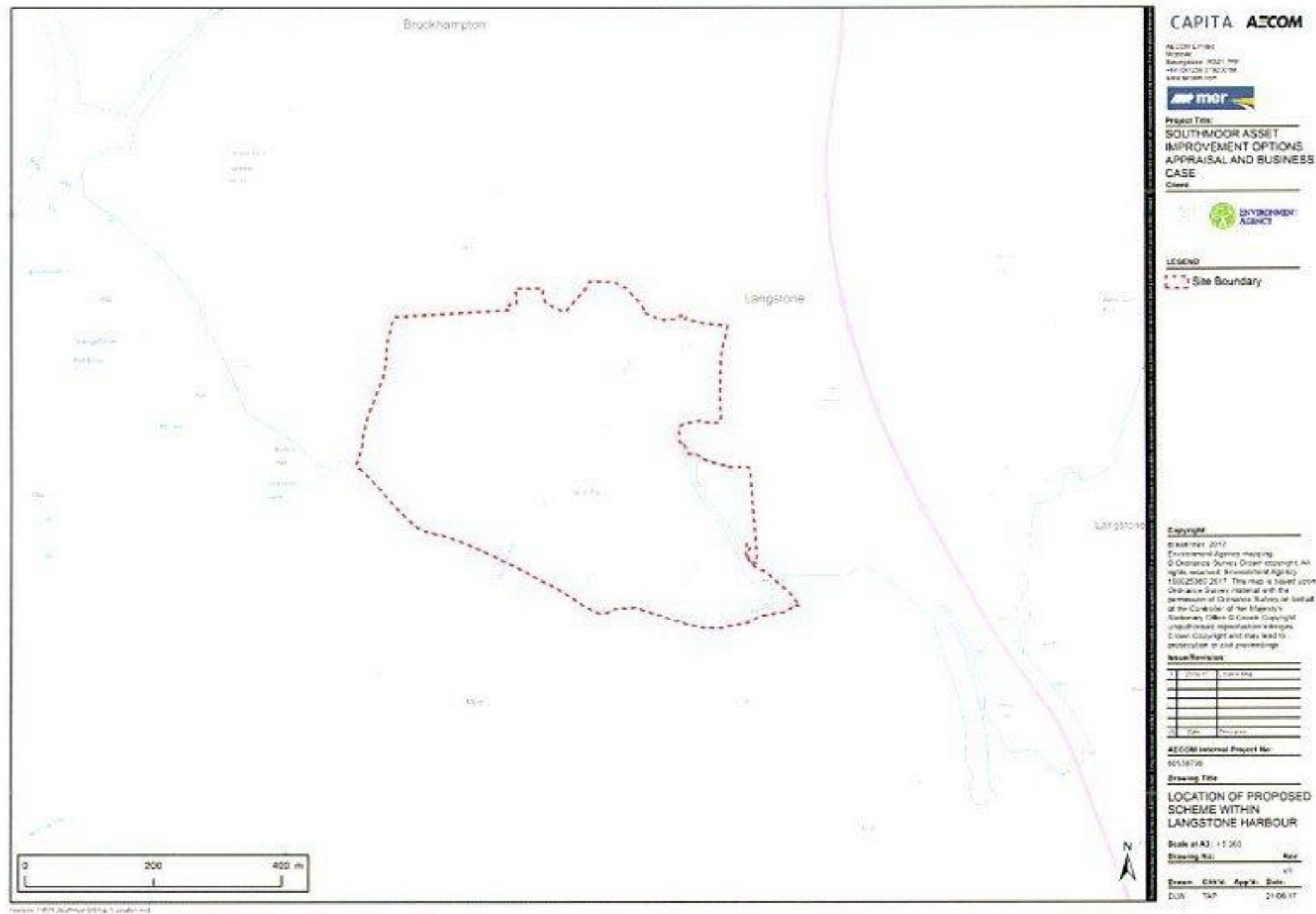


Figure 1. Location of the proposed scheme within Langstone Harbour

2 Site Characteristics

In order to develop a suitable scheme design it is necessary to understand the local tidal characteristics and how the elevations within the site (and in particular within the proposed realignment area) relate to them; these factors will determine the volumes of water that would inundate the proposed realignment area and the types of habitat that will be created.

Southmoor is located within Langstone Harbour, close to the area where Chichester and Langstone Harbours meet. Tidal levels at Chichester (the closest standard port location, UKHO, 2017) are given in Table 1. Comparisons of modelled water levels at Chichester and Southmoor were used in conjunction with measured tidal levels at Chichester to obtain projections of tidal levels at the site entrance; these projected levels are also provided in Table 1. Levels are quoted relative to Ordnance Datum Newlyn (ODN), which is 2.74 m below Chart Datum (CD).

The existing land elevations within the managed realignment area are predominantly between 1.4 m above ODN to 1.8 m above ODN, which is between the levels of Mean High Water Neaps (MHWN) and Mean High Water Springs (MHWS). The size of the managed realignment area in the model below MHWS is approximately 9 ha. Within the site there are a number of existing channels which help drain freshwater run-off into the adjacent River Lavant via a culvert with a tidal restricting flap (see Figure 2 for location). These channels are relatively deep compared to surrounding elevation, being up to 0.3 m above ODN in places (i.e. *circa* 1.1 to 1.5 m deep)¹.

Table 1. Tidal levels at Chichester and Southmoor

Tide	Chichester Level (m ODN)	Projected Levels at Southmoor (mODN)
Highest Astronomical Tide (HAT)	2.56	2.61
Mean High Water Spring (MHWS)	2.16	2.18
Mean High Water Neap (MHWN)	1.26	1.25
Mean Low Water Neap (MLWN)	-0.84	-0.87
Mean Low Water Spring (MLWS)	-1.84	-1.88
Lowest Astronomical Tide (LAT)	-2.54	-2.48

Sea defences extend along the front of the site, although these are deteriorating in some areas. Overhead cables run approximately southeast-northwest across the site. The proposed embankment at the back of the managed realignment area is located in front (seaward) of the electricity pylons to ensure they continue to be protected from tidal flooding and avoid the need to be rerouted. The embankment will have a finished crest height of 3.2 m above ODN to maintain the standard of protection against flooding to at least 1 in 200 (0.5%) chance of flooding in any given year.

The alignment of the new embankment links to areas of higher ground in the northwest and east of the site to minimise the height and footprint of the new embankment as much as possible and therefore limit landscape and visual intrusion effects. The initial alignment that has been modelled has been adjusted slightly during the outline design phase to follow the route of the existing Footpath 49. Opportunities for softening the alignment further and making it more curved and natural will be considered during the detailed design phase. A subsurface water pipe is also believed to traverse the site although this has not been considered as part of the modelling assessment.

¹ Part of these channels is understood to include an area where sedimentary materials were excavated for an historical sea wall reinforcement.

The representation of the site (including the managed realignment area, the River Lavant, the culvert, internal channels and sea defences) in the model is shown in Figure 2. The model mesh is comprised of both triangular and rectangular shaped elements to best represent the existing features within the study area while ensuring efficient model run times. The wider model extents are also shown in Figure 2; for full details on model setup refer to Annex A. The manner in which the modelling software includes culverts requires the model bathymetry through the culvert locations to be deepened to the culvert level. Gate structures and culverts are then implemented to control the flow in the correct manner.

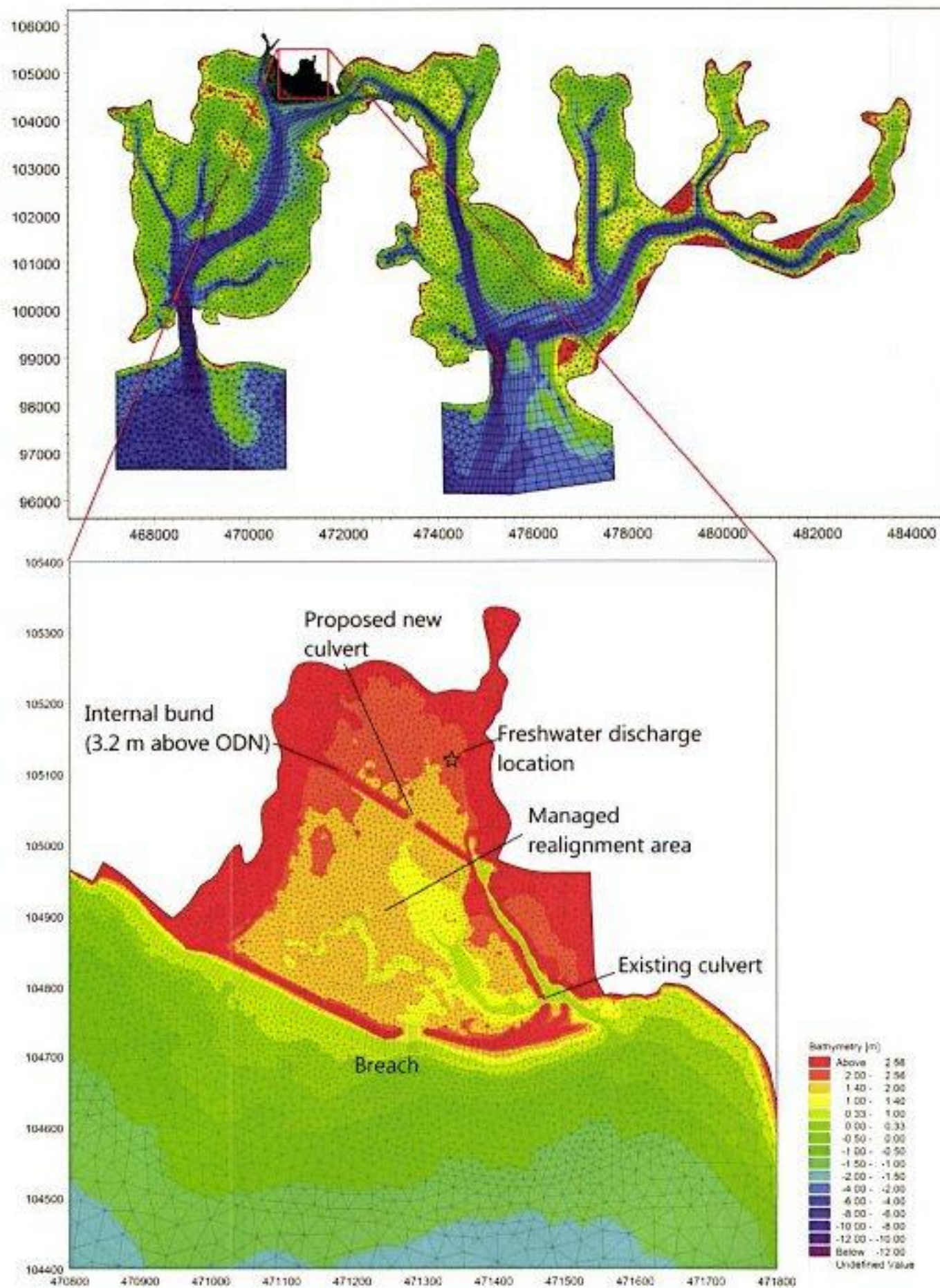


Figure 2. Representation of scheme in the hydrodynamic model

3 Scheme Design

The scheme design is focussed on a minimum intervention approach, on this basis a simple rectangular breach through the existing sea wall fronting the managed realignment area has been implemented in the model. The most suitable breach location was identified as a stretch of deteriorating seawall, at a central location along the southern boundary of the site (see Image 1). This location also has the advantage of being fronted by a relatively narrow intertidal area.



(Image taken facing west approximately one hour before the time of high water on a mean spring tide)

Image 1. Deteriorating seawall at proposed breach location

The invert level of the breach was determined based on an assessment of the existing levels within and fronting the site at the breach location (Figure 3). On this basis an invert level of 1.4 m above ODN was identified as being suitable, as this conforms approximately with existing levels in the managed realignment area as seen in Figure 3. The managed realignment area will therefore not flood on the smaller neap tides (estimated to be approximately 30 % of tides, although this will vary year to year depending on the angle of declination of the moon).

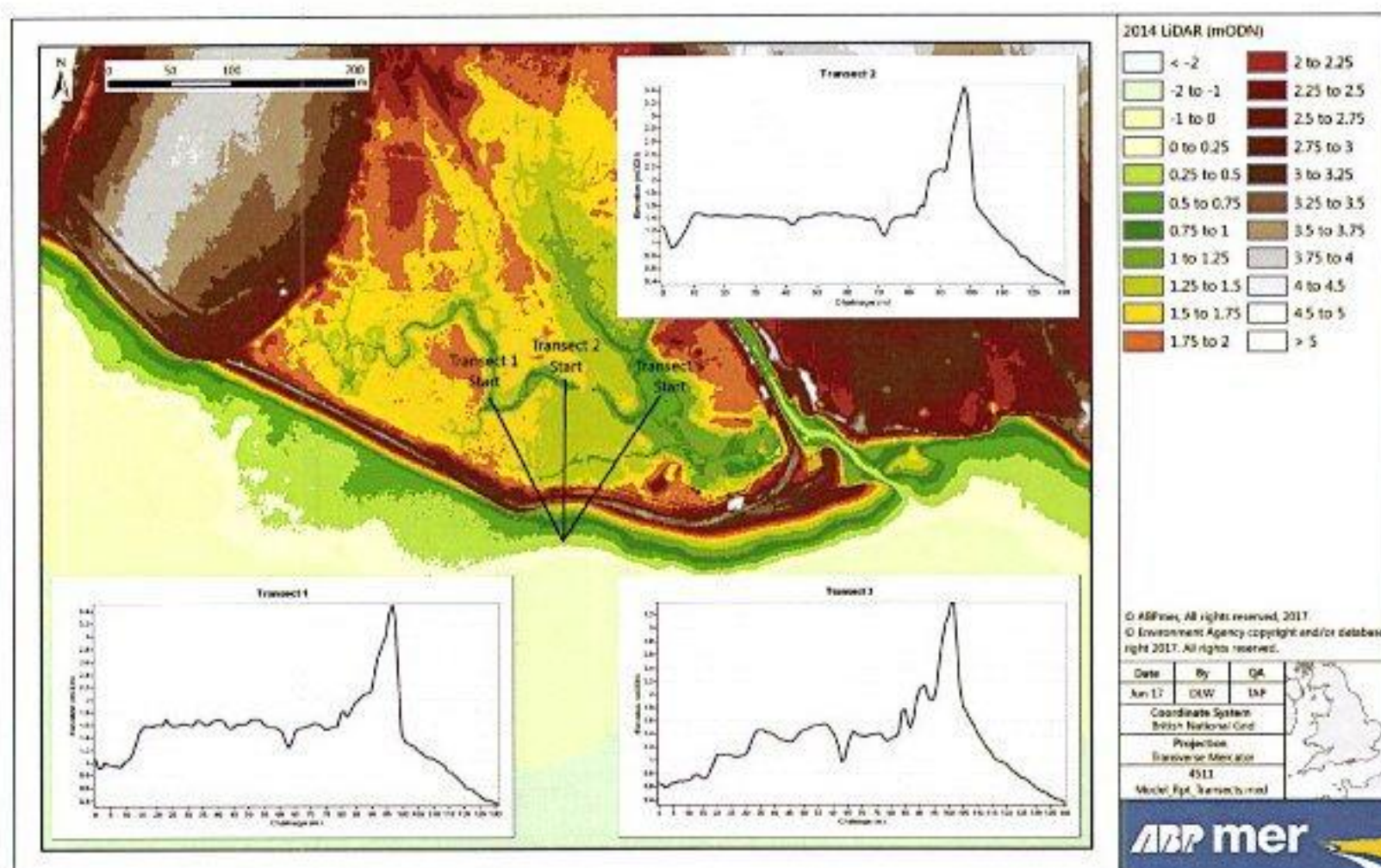


Figure 3. Site elevations with cross-sections through the breach location

The breach width was determined using the 'Fixed Sill Approach' outlined in Townend (2008). In this approach the cross-sectional area of the breach is determined by considering the volumes of water which will cause erosion (i.e. those that exceed the critical erosion threshold). For the depth of the sill (1.4 m above ODN) and the required cross-sectional area to prevent erosion, a breach width of 20 m was considered appropriate from the calculations. The breach representation in the model is shown in Figure 2. The critical erosion threshold, and hence the optimal breach design, is sensitive to the sediment type. For the purpose of this high level modelling study it has been assumed that the bed material within the breach has a relatively low bulk wet density of 1400 kg/m^3 . This represents a medium consolidated material within the existing embankment. This is considered to provide a conservative assessment of the likely sediment density. The critical bed shear stress for this material type is likely to be of the order of 2 N/m^2 , which corresponds to a critical erosion threshold velocity of 1.23 m/s . The assumptions made about sediment composition and density should be validated using survey data.

Given the minimum intervention approach being adopted, with the exception of the breach and the construction of a back wall (to avoid relocation of the overhead powerlines), no internal reworking of the bed material within the site was considered in the modelling. Additionally, it is assumed that the existing culvert to the River Lavant will not be removed and will continue to operate.

4 Site Functionality

4.1 Site inundation

To illustrate how the managed realignment area is expected to flood on a mean spring tide, maximum modelled water levels are plotted as a spatial map in Figure 4. The plot shows that almost all of the managed realignment area is inundated on spring tides, with only two small areas of higher lying land at the northwest and northeast corners remaining dry. Water levels within the managed realignment area are marginally higher than those immediately outside the site, although this is of the order of millimetres (reaching a maximum of 2.173 m inside the site, compared to 2.169 m at the entrance).

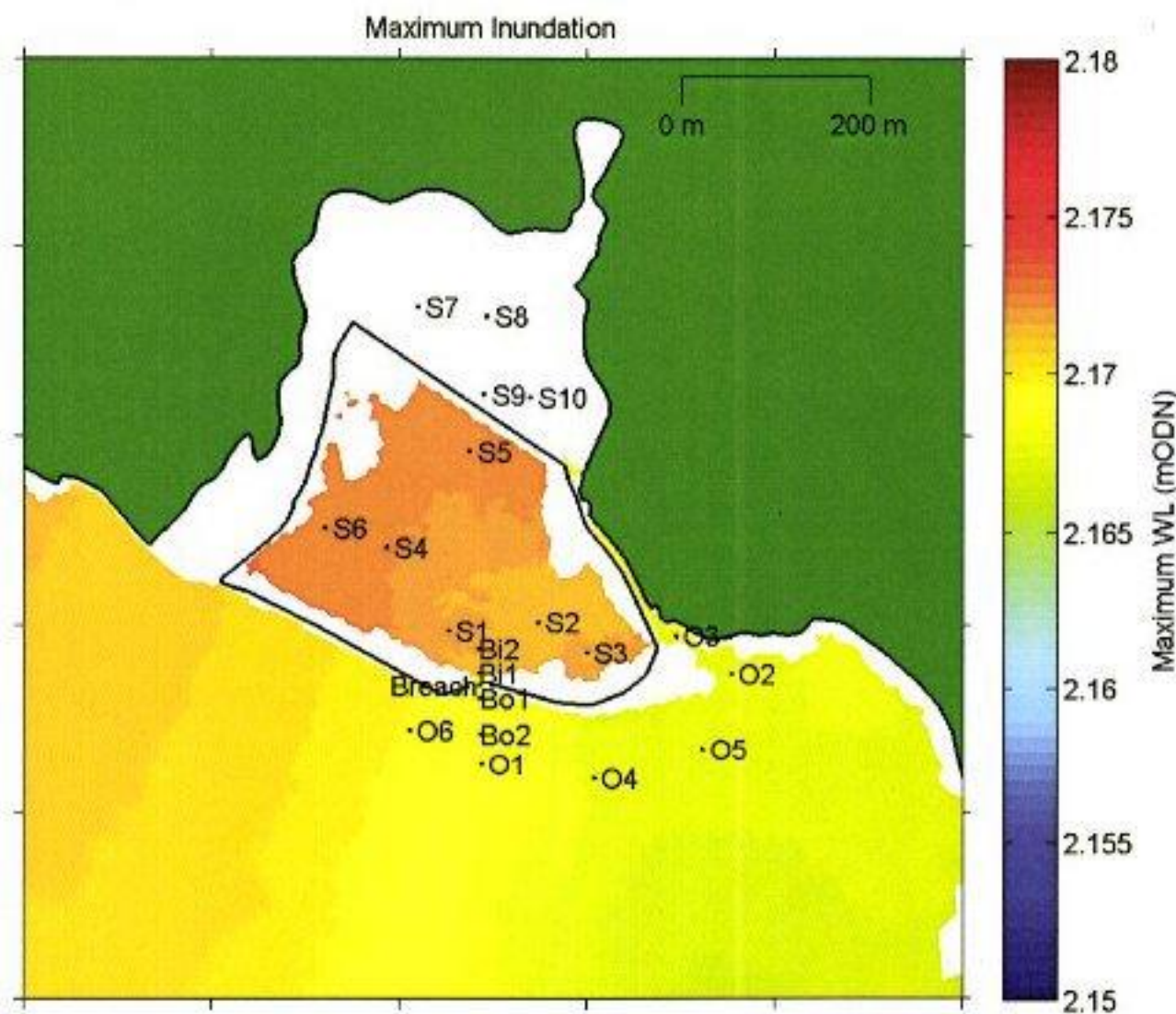


Figure 4. Maximum inundation (with extraction points) on a mean spring tide

The draining of the managed realignment area is demonstrated by considering the amount of water remaining at the following times:

- When the water level drops below the breach sill level of 1.4 m above ODN (Figure 5); and
- When the water level reaches the breach sill level on the subsequent tide (Figure 6).

A comparison of Figure 5 and Figure 6 demonstrates the role of the existing tide excluding flap culvert (which has a lower sill level than the breach, being 0.33 m above ODN) in draining the managed realignment area. On a mean spring tide the culvert drains approximately 15% of the total High Water (HW) volume. The highest flows through the culvert of 0.73 m³/s occur approximately one hour after the water level drops below the level of the breach sill. Approximately 33% of the managed realignment area remains wet once the breach is effectively 'closed', this is reduced to less than 10% of the managed realignment area once the culvert is effectively 'closed' (i.e. the remaining water has no access to the two outlets).

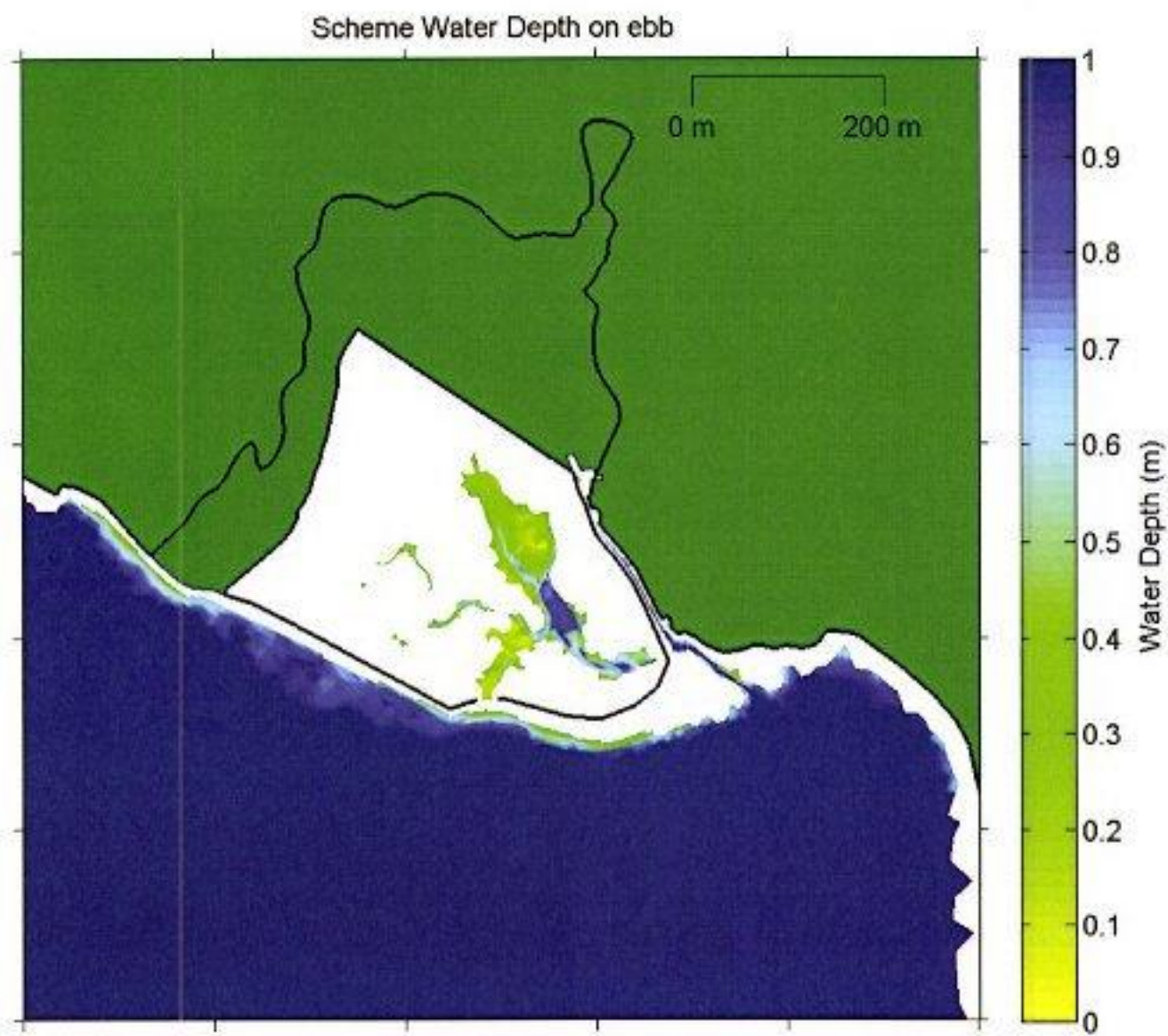


Figure 5. Water remaining on site after water level drops below breach sill

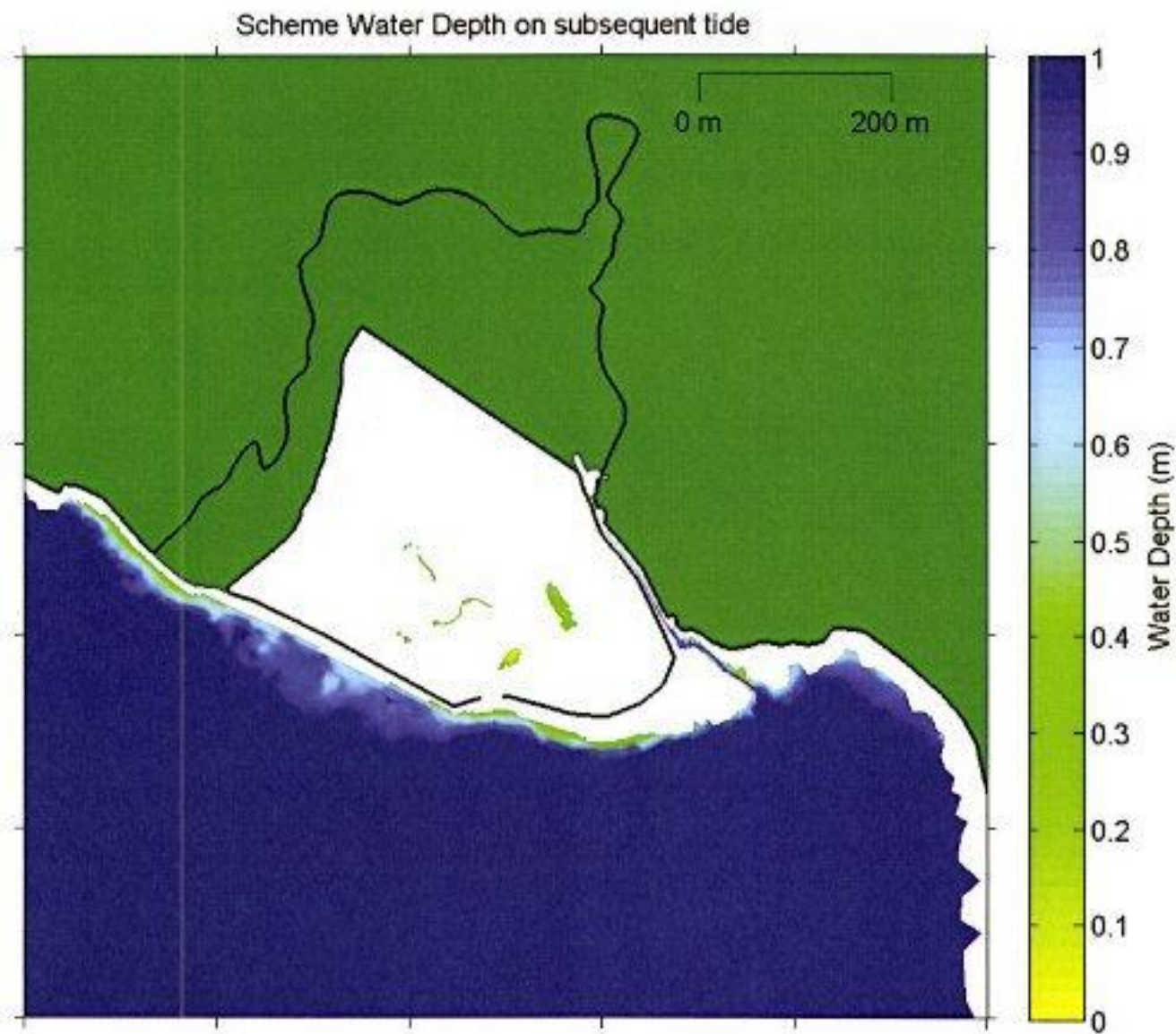


Figure 6. Water remaining on site before subsequent tide

Figure 5 shows the areas expected to remain wet in the event that the existing culvert is inoperable (either by intentional removal or natural blockage). Should the existing culvert be inoperable, channels could be excavated to link a deepened breach to the existing channels within the site to aid in draining. However, for this to be successful, a deepened channel extending further into the intertidal would need to be incorporated into the scheme.

To provide additional information on how the managed realignment would operate, time series plots of water levels at five locations through the breach and at six locations within the managed realignment area have been produced (extraction locations shown on Figure 4) and are plotted in Figure 7 and Figure 8, respectively.

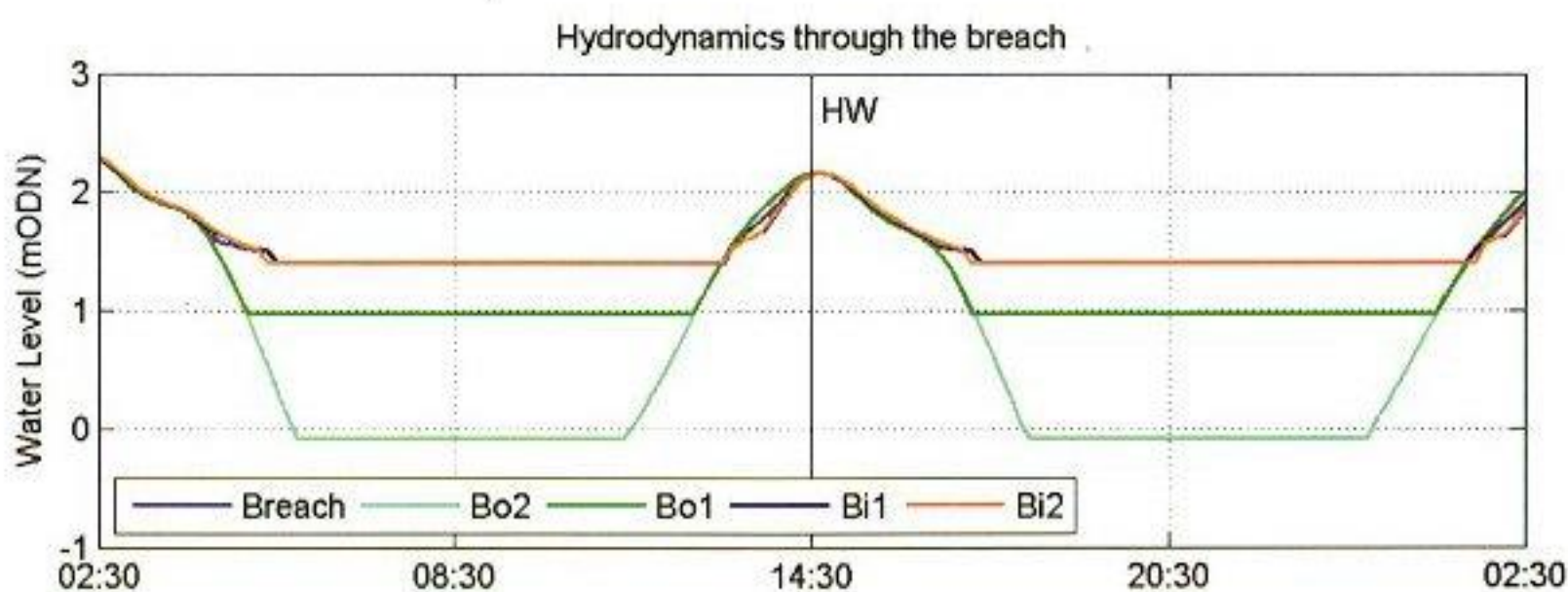


Figure 7. Time series of water levels through the breach on a mean spring tide (at locations shown in Figure 4)

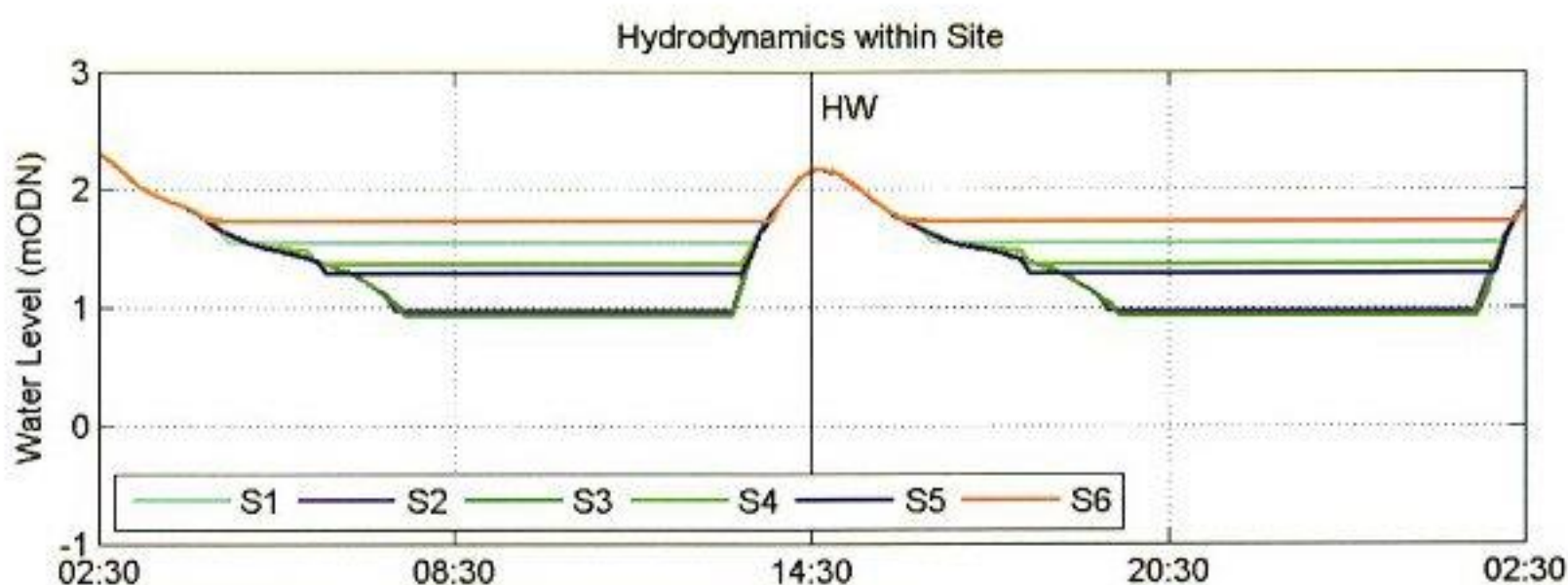


Figure 8. Time series of water levels in the managed realignment area on a mean spring tide (at locations shown in Figure 4)

The time series plots indicate that water levels are above the breach invert level for approximately a four hour period on a mean spring tide (which has a duration of approximately 12.4 hours). At the higher lying areas of the managed realignment area, periods of inundation are shorter, for example at S6 (which is at 1.6 m above ODN) the period of inundation is two and a half hours on a mean spring tide.

The model results suggest that the timing of HW does not vary significantly throughout the managed realignment area, with changes of less than 3 minutes between HW time at the breach and HW time at S5 and S6 (which lie in the north and west extremities of the site). This is a reflection of the relatively small size of the managed realignment area. The timing of HW in reality may differ by slightly more than this, particularly when the managed realignment area is first breached. This is because the existing vegetation will present a greater frictional effect on the water flooding the managed realignment area than the friction applied in the model (which was selected to represent a more evolved site friction, once vegetation has died away). Sensitivity tests have been undertaken with a friction value representative of the vegetation currently within the managed realignment area; the effect of this on the timing of HW within the managed realignment area was to further delay HW by slightly less than one minute. This is considered to be insignificant with respect to the overall functionality of the scheme.

4.2 Site flow and sedimentary characteristics

Vector plots showing flows onto and off of the managed realignment area at various times throughout a mean spring tide are provided in Figure 9. These show the rapid flooding of the managed realignment area and the more gradual draining. The plots also show how the existing culvert continues to drain water from the managed realignment area after the water levels drop below the sill level of the breach. Flows throughout the managed realignment area and outside of the site are typically low, being around 0.2 m/s or less. Highest flows, exceeding 0.5 m/s, occur through the breach and in the outer part of the Lavant.

To assess the potential for localised erosion, Figure 10 and Figure 11 show the maximum flow speeds and Bed Shear Stresses (BSS) on a mean spring tide. The BSS values are derived from the modelled flow speed, modelled water depth and an assumed sediment grain size, taken to be 50 μm (i.e. coarse silt), believed to be representative of the sediment type within the managed realignment area. Where the BSS exceeds the critical BSS (2 N/m²) there is the potential for erosion to occur. Erosion within the managed realignment area is therefore expected to be constrained to a relatively small area immediately to the north of the breach (at Bi1) and at a small location to the northeast of the breach (at S2).

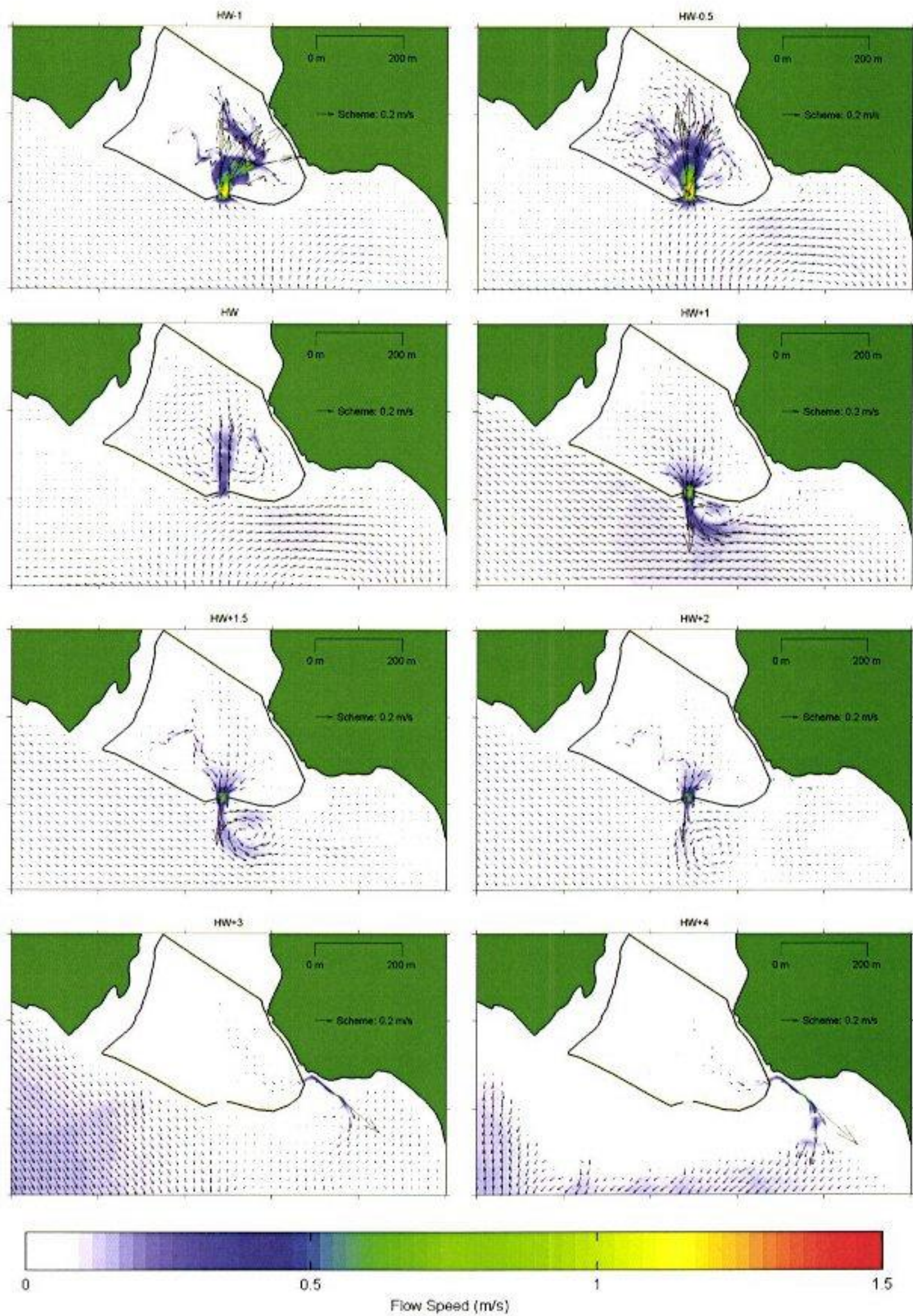


Figure 9. Vector plots at various times through the mean spring tide

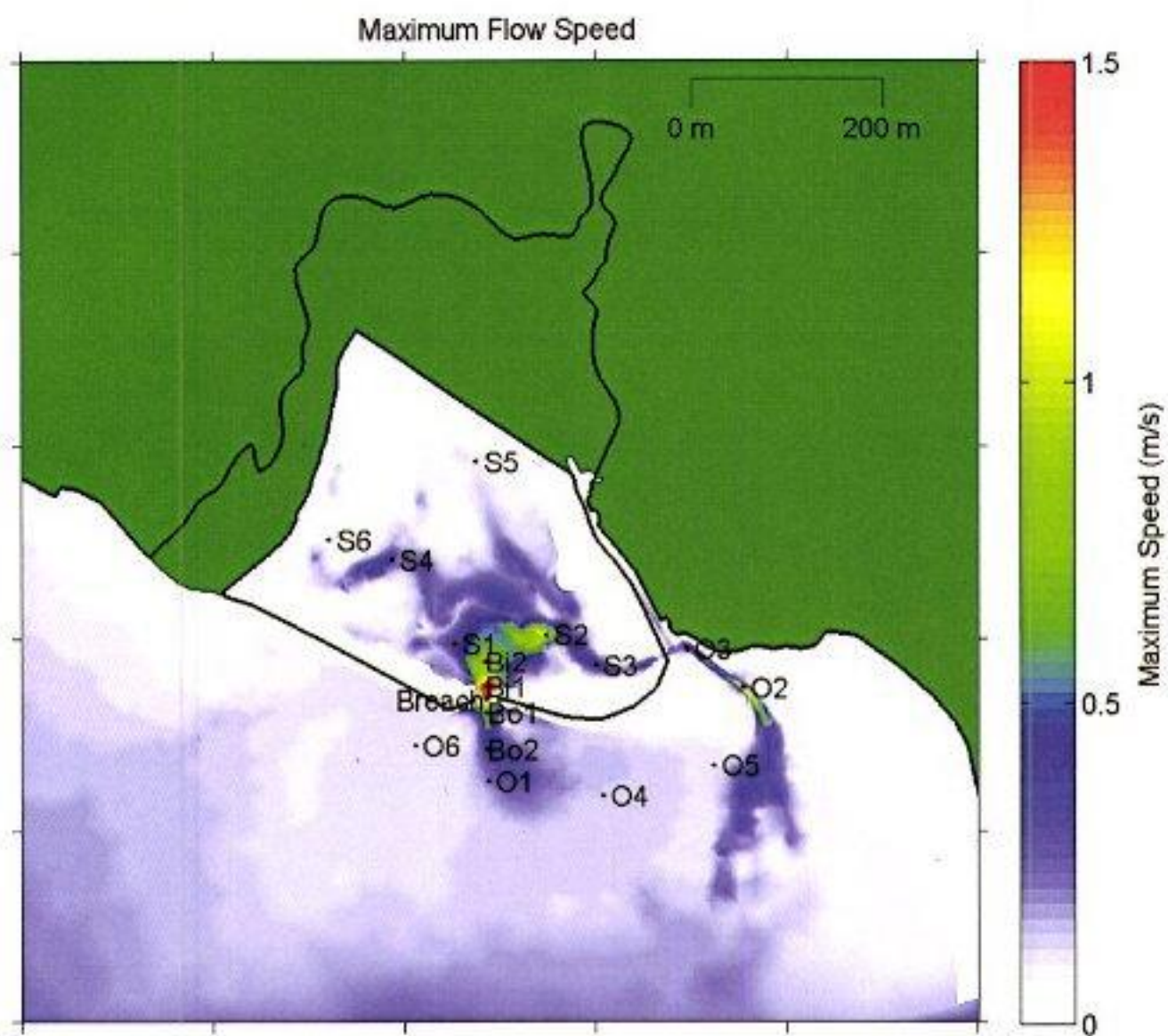


Figure 10. Maximum flow speeds on a mean spring tide

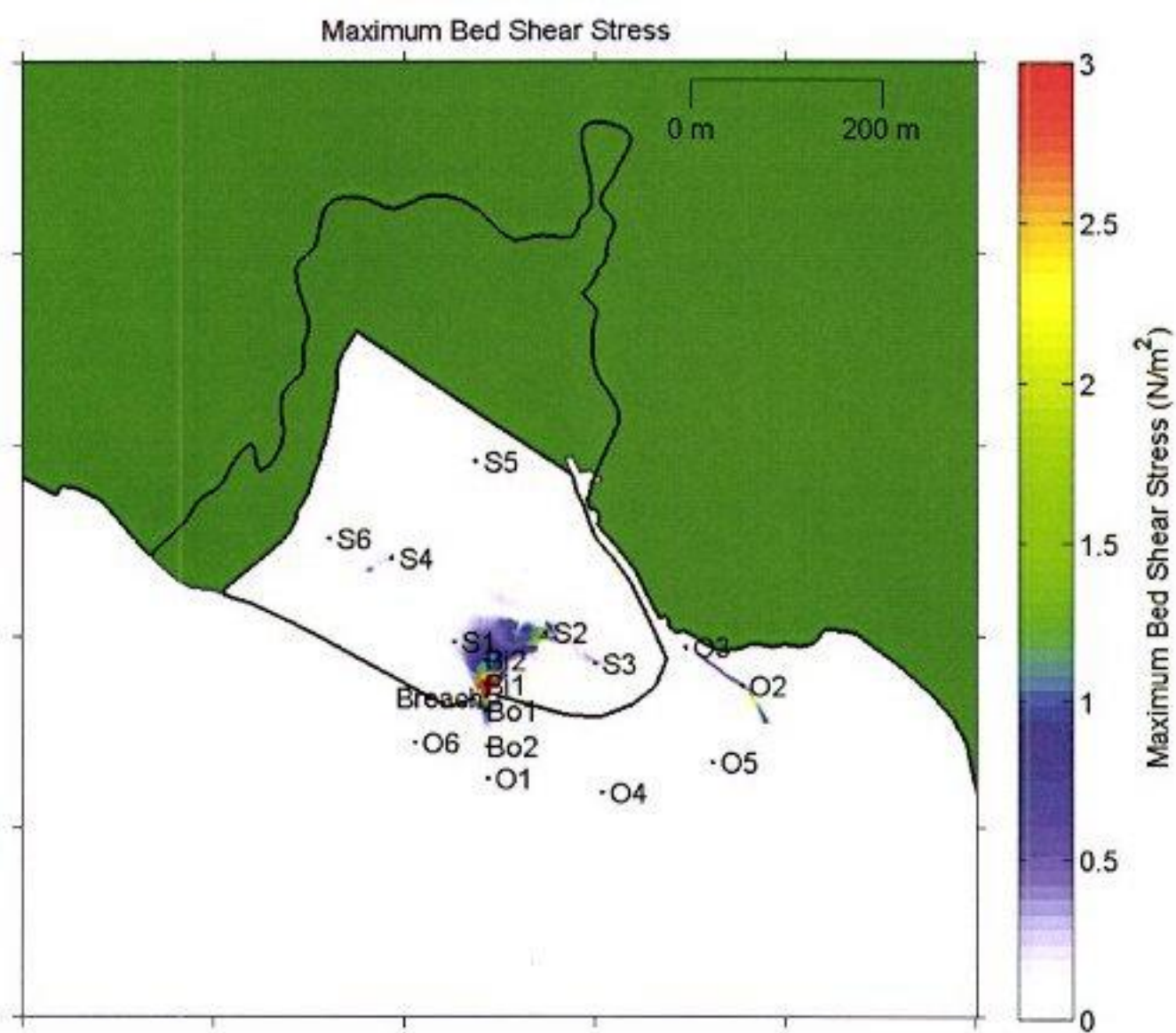


Figure 11. Maximum bed shear stress on a mean spring tide

Time series plots of flow speeds at five locations through the breach and at six locations within the managed realignment area (extraction locations shown on Figure 10) are plotted in Figure 12 and Figure 13, respectively. Where maximum BSS is above the critical value of 2 N/m^2 , time series plots of BSS are also shown.

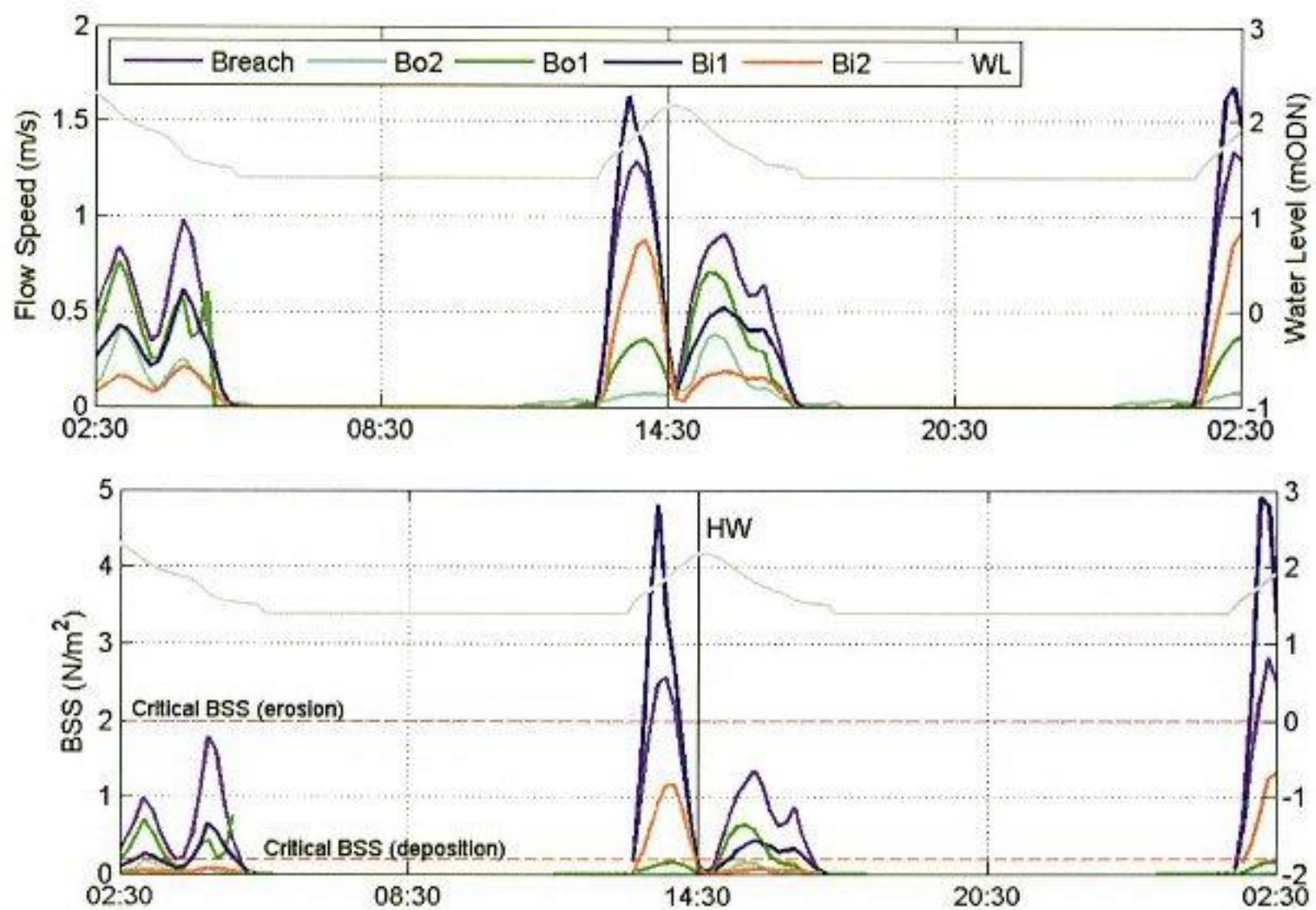


Figure 12. Time series of flows and BSS through the breach on a mean spring tide (at locations shown in Figure 10)

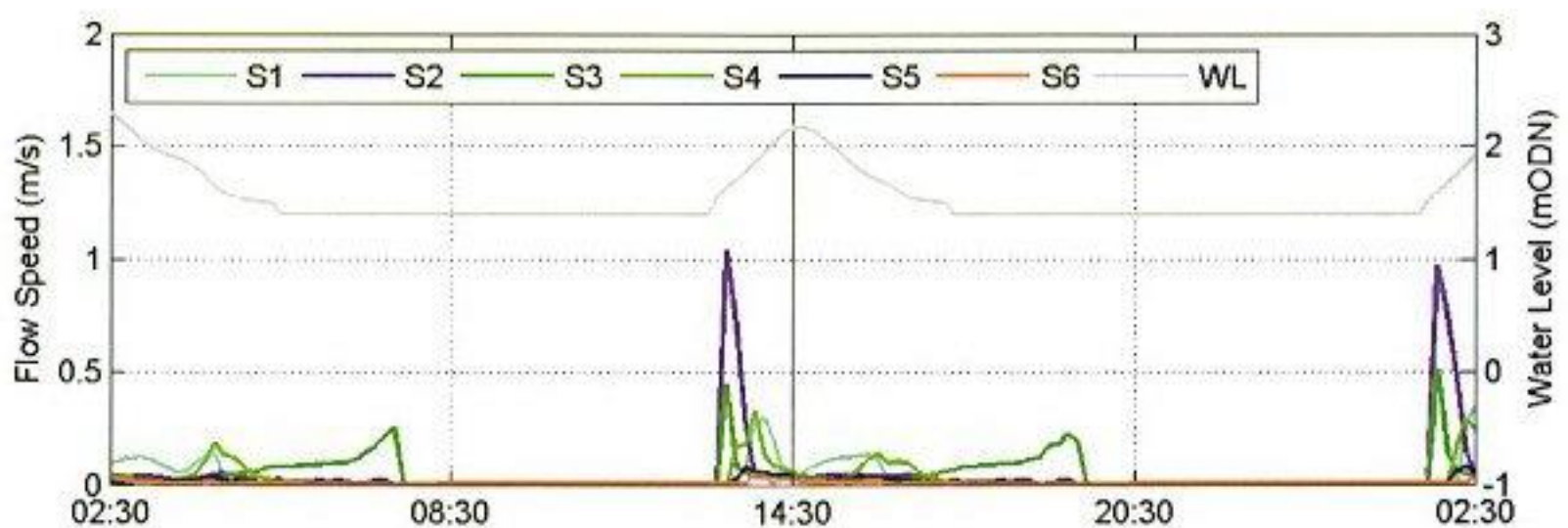


Figure 13. Time series of flows within the managed realignment area on a mean spring tide (at locations shown in Figure 10)

Flows through the breach are fastest on the flood tide (Figure 12), peaking at 1.4 m/s compared to 0.8 m/s on the ebb. BSS through the breach is below the critical threshold for erosion except for approximately a one hour period in the middle of the breach and at Bi1. BSS values are highest at Bi1 where there is a slight narrowing of the inner part of the breach due to a small convergence in the model cells. In reality the breach would be constructed to be a constant width through the sea defences and such peaks in flows are unlikely to occur. Any small 'bumps' remaining in the breach (either on the bed or at the edges) immediately after construction would be expected to be eroded until the design breach cross-section is achieved.

Flows within the managed realignment area are typically less than 0.5 m/s except at S2 where flows exceed 1 m/s (Figure 11). This peak in flood flow speed is short lived (less than half an hour), occurring immediately after the water levels overtop the sill and water rapidly flows in to fill the existing channels and pools. Flows at this location are more typically 0.1 m/s once this initial inundation is complete. Ebb flows are at a maximum when they are confined to the existing channel system, draining to the culvert once the breach is dry.

As noted above, the flow speeds across the managed realignment area are relatively low and as a result the BSS will be below or close to the critical BSS for deposition of the fine sediments within the water column (estimated to be about 0.18 N/m² for the site). Flows on the ebb tide are not predicted to be high enough to cause erosion of deposited sediment, therefore all sediment entering the managed realignment area and settling, will be retained causing deposition.

An estimate of the maximum likely accretion rates which could occur within the managed realignment area was obtained using Suspended Sediment Concentration (SSC) data collected within Langstone Harbour by the Environment Agency between 2000 and 2007. The following assumptions have been made to derive an estimate of annual sedimentation:

- all water flooding the managed realignment area has a SSC of 10 mg/l; and
- all sediment entering the managed realignment area in suspension will settle uniformly over the site.

While these assumptions are simplistic, they are useful for obtaining estimates of initial potential accretion rates. Estimated accretion rates from this method are of the order of 0.015 m/yr (1.5 cm/year) of freshly deposited sediment. The sediment entering the managed realignment area is more likely to accrete within the deeper channel areas and as such accretion within the channels may be slightly higher and accretion outside of the channels may be slightly lower than the quoted value. As the site accretes the volume of water exchanged will fall and the accretion rates will reduce.

The plots of maximum flow speed and BSS (Figure 10 and Figure 11), coupled with the time series plots (Figure 12 and Figure 13) indicate that erosion within the managed realignment area is expected to be limited both spatially and temporally with only small periods of critical flows speeds occurring within the breach and existing channels. These critical flows may assist in maintaining the breach, removing any fresh sedimentation deposited during periods of slower flow, however these flows are not expected to significantly modify the breach. Based on the low flow speeds for the majority of the tide (especially during draining) and throughout the rest of the managed realignment area, it is expected that any eroded sediment will be redistributed within the site.

5 Impact of Realignment

5.1 Tidal hydrodynamics

To assess the impact of the realignment on the adjacent harbour area, map plots of the difference in water levels and flows between the scheme (i.e. with the managed realignment area included) and the baseline model runs have been produced at various times throughout a mean spring tide. Positive values indicate an increase with the scheme in place, while negative values indicate a reduction.

A map plot of the difference in water level at the time of Low Water is shown in Figure 14; differences at High Water are not shown as they are less than 0.001 m (1 mm) which is below the level of confidence of the modelled water levels. Changes in low water levels of more than 0.01 m are constrained to an area within the channel of the Lavant. In this area, the scheme increases modelled low water levels due to the culvert discharge which continues to drain the managed realignment area into the Lavant after the water levels drop below the implemented breach sill height. Increases in low water levels in this area are of the order of 0.01 to 0.04 m. The existing culvert currently drains freshwater from the managed realignment area following periods of high rainfall and as such these modified conditions within the Lavant already occur, albeit less frequently than would occur following realignment, should the culvert remain operable.

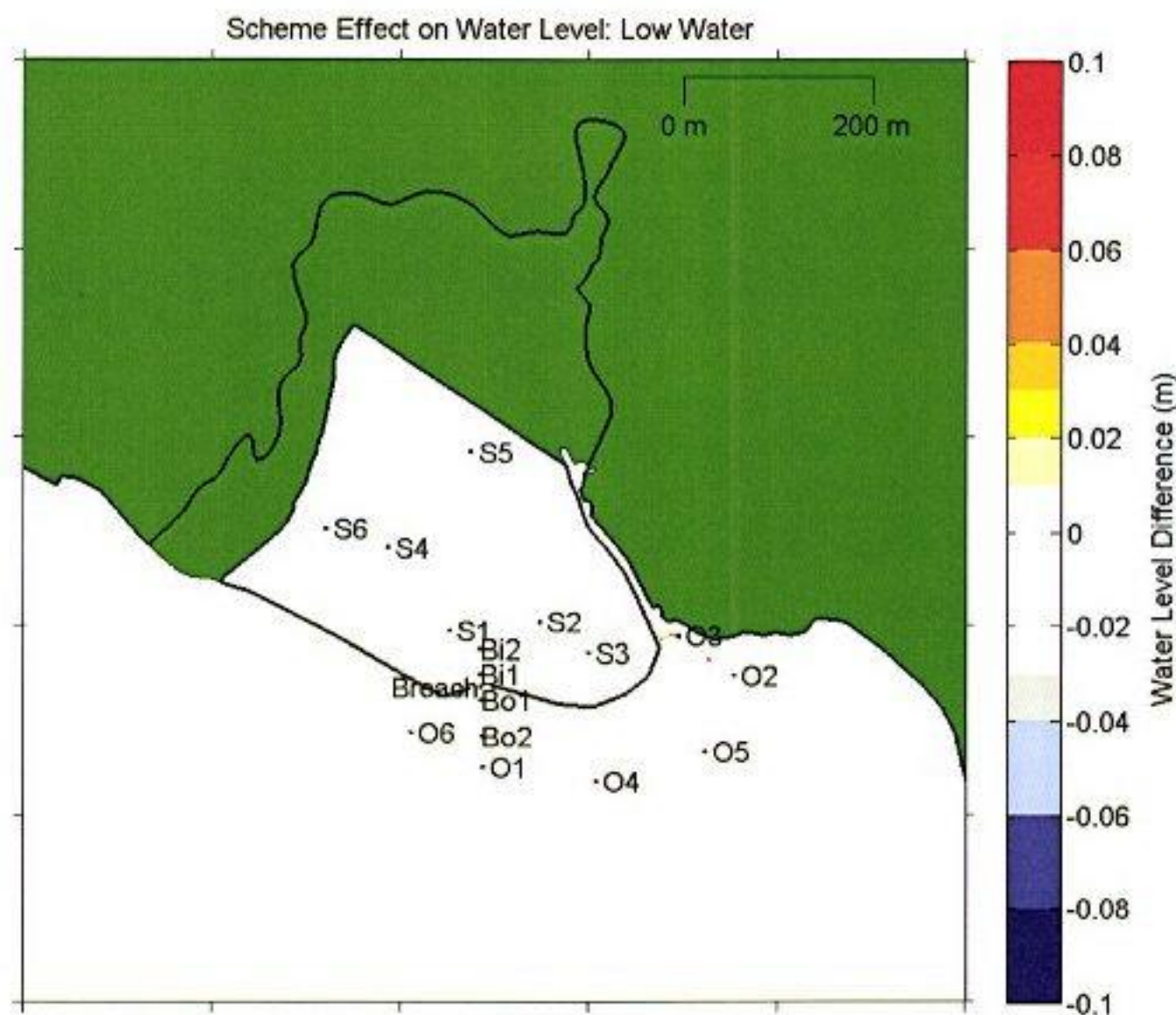


Figure 14. Change in spring tide low water level (change occurs due to culvert)

Map plots of the differences in flow speeds are shown at the time of peak flow onto the site (i.e. flood) and at the time of peak flow out of the managed realignment area (i.e. ebb) in Figure 15 and Figure 16 respectively. Changes of more than 0.01 m/s are constrained to a relatively small area adjacent to the managed realignment area (of the order of less than 0.5 km) with a general increase in flows to the south and southeast of the breach and a smaller reduction in flows to either side.

Time series of water levels and flow speeds at eight locations (Bo1, Bo2 and O1 to O6 as shown in Figure 16) are plotted in Figure 17 to Figure 24. As for all plots, results are shown for an approximate mean spring tide. Figure 17 to Figure 19 show the comparison of water levels and flows for the model runs without (baseline) and with (scheme) the realignment implemented at locations south of the breach at Bo1, Bo2 and O1, respectively.

The time series show no identifiable change in water levels, but large changes in flow speeds particularly notable on the ebb when the site is draining. During this time, flows for the scheme run are 0.7 m/s, 0.4 m/s and 0.2 m/s at Bo1, Bo2 and O1, respectively, compared to baseline flows of 0.1 m/s. The material on the intertidal is likely to be at a lower density than material through the breach and would therefore erode at a lower flow speed. Depending on the sediment composition on the foreshore, the modelled flows on the ebb are likely to be sufficient to reduce deposition of fines and potentially cause erosion of the bed for around 2 hours on a spring tide. A short channel across the upper intertidal is expected to form, probably in a meandering form. The development of the channel is expected to reach an equilibrium form in a matter of a few months. The actual channel shape and size will depend on the sediment composition of the intertidal foreshore. The channel that forms will also be sensitive to the actual breach invert level, for example if the breach is implemented at a lower level, a longer channel across the intertidal will form.

Time series of water levels and flows at O2 and O3 (which are located within the channel of the Lavant), are shown in Figure 20 and Figure 21, respectively. The baseline and scheme flows are similar throughout much of the tide, until around two hours after HW when flows from the scheme run show a significant increase, particularly at O2 where peak flows reach 1.6 m/s (compared to baseline flows of zero when the area was dry). Increases in flows at O3 are much smaller, being around 0.3 m/s. These increased flows are a result of water draining the managed realignment area via the existing culvert which at present drains freshwater runoff into the Lavant (although this freshwater run off and flow through the culvert is not included in the baseline model run).

The period of enhanced flows persist for around 3 hours, until the level inside the managed realignment area falls below the culvert invert level. Water levels at these locations also show an increase during this period, with scheme water levels 0.1 to 0.2 m higher than baseline levels. While the flow at O2 indicates a significant increase from the baseline run, flows of this magnitude could occur naturally (albeit less frequently) following periods of high rainfall. In addition, it is important to note that the model's representation of the Lavant is somewhat limited by the availability of detailed bathymetry. In view of this, the model depths within the Lavant are likely to be lower than reality, and as such the predicted change may be over-exaggerated.

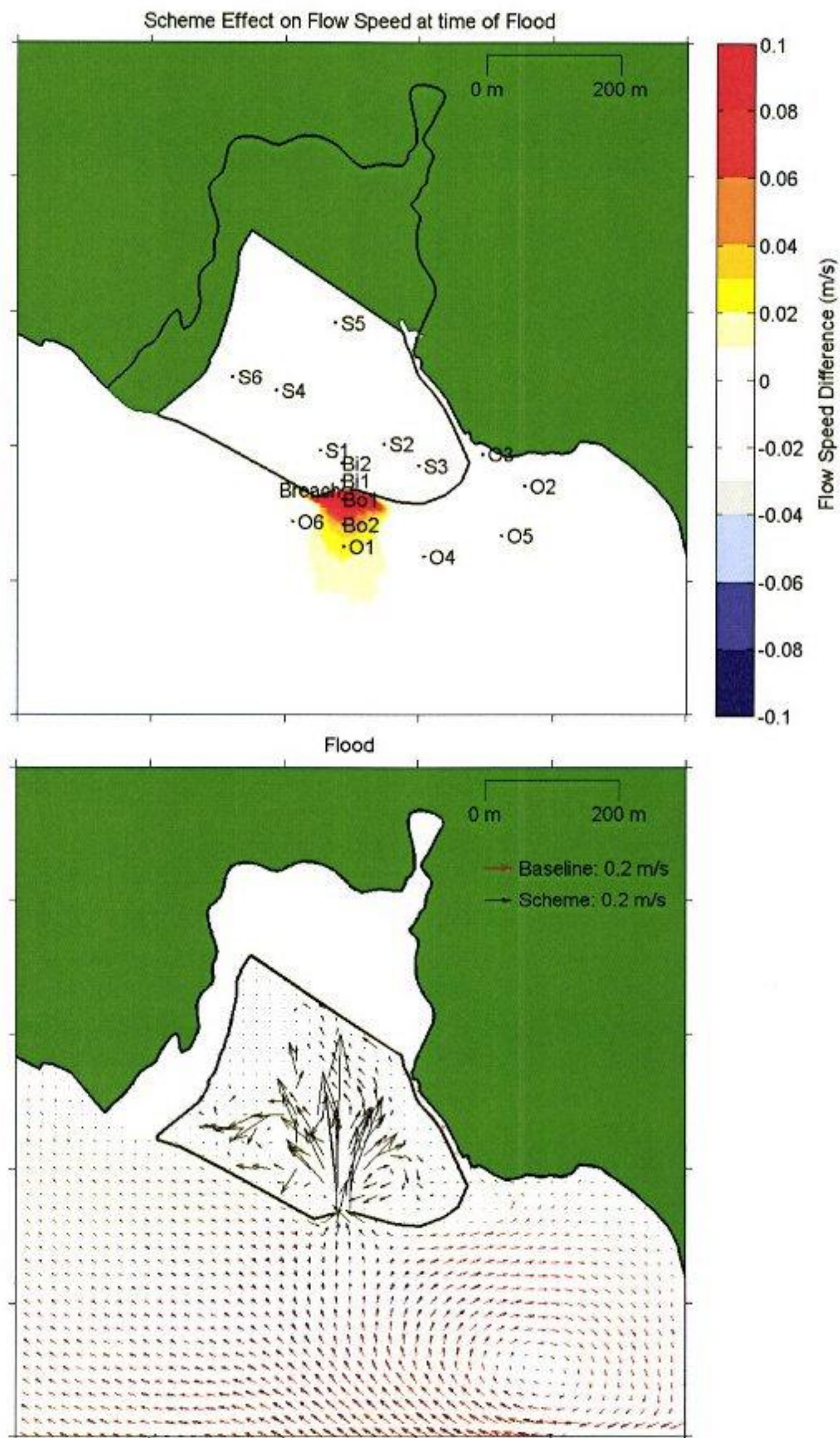


Figure 15. Change in spring tide flow speeds (upper panel) and baseline and scheme vectors (lower panel) at time of peak flow onto site

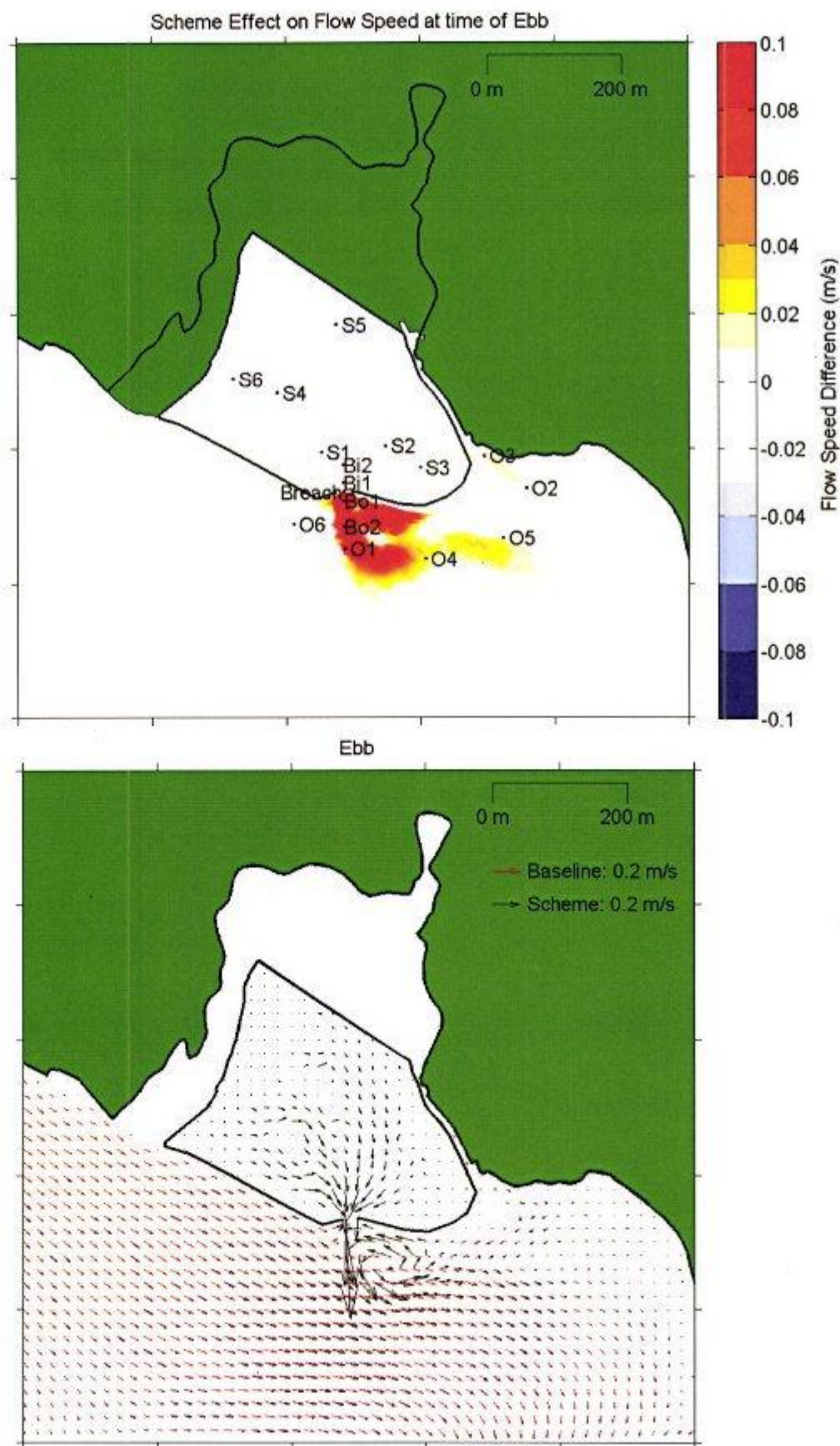


Figure 16. Change in spring tide flow speeds (upper panel) and baseline and scheme vectors (lower panel) at time of peak flow off of site

Inspection of the model bathymetry at location O2, shows this is the location of a 'bar' across the outer part of the Lavant channel (see Figure 3). The bathymetry also shows a constriction of the channel. As noted above, the confidence in the accuracy of the model bathymetry is lower in the channel than elsewhere and the channel is more likely to be narrower and/or shallower than exists. This location could also vary with time due to wave activity. As a result, the flows speeds are considered to be over-exaggerated in the model. Should the modelled flows occur then some erosion (deepening/ widening) of the channel in the vicinity of the location O2 could be expected to form a new equilibrium and depths at the bar area are likely to marginally increase.

Time series of water levels and flows at O4, O5 and O6 are shown in Figure 22 to Figure 24. In these locations baseline flows are low (around 0.15 m/s) and the impact of the realignment is negligible. This indicates that the majority of the flow will be confined to predominantly ebb flow dominated channels both from the breach and in the River Lavant. There is expected to be no change to the intertidal outside of these channels.

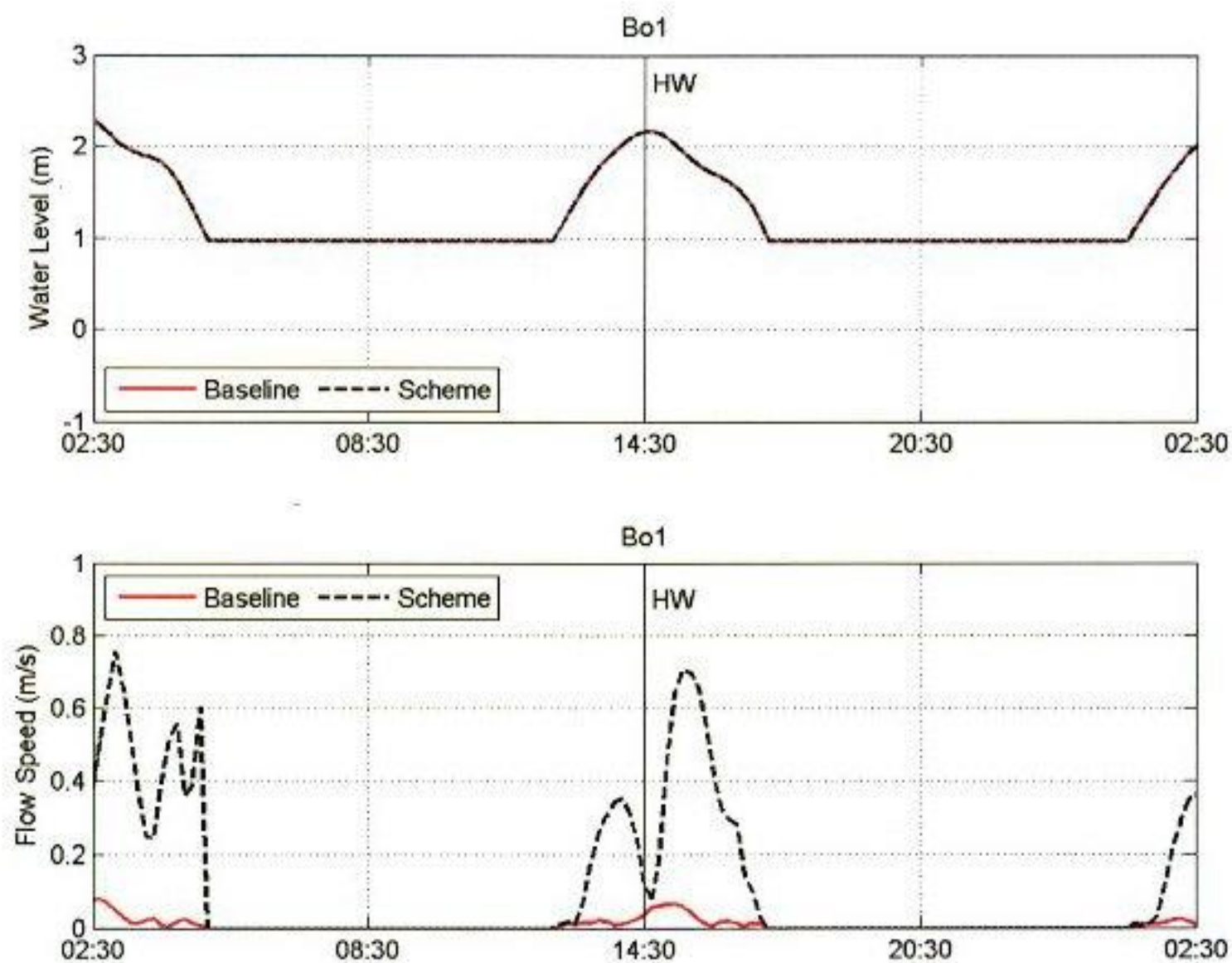


Figure 17. Time series of water levels and flows at Bo1 on a mean spring tide

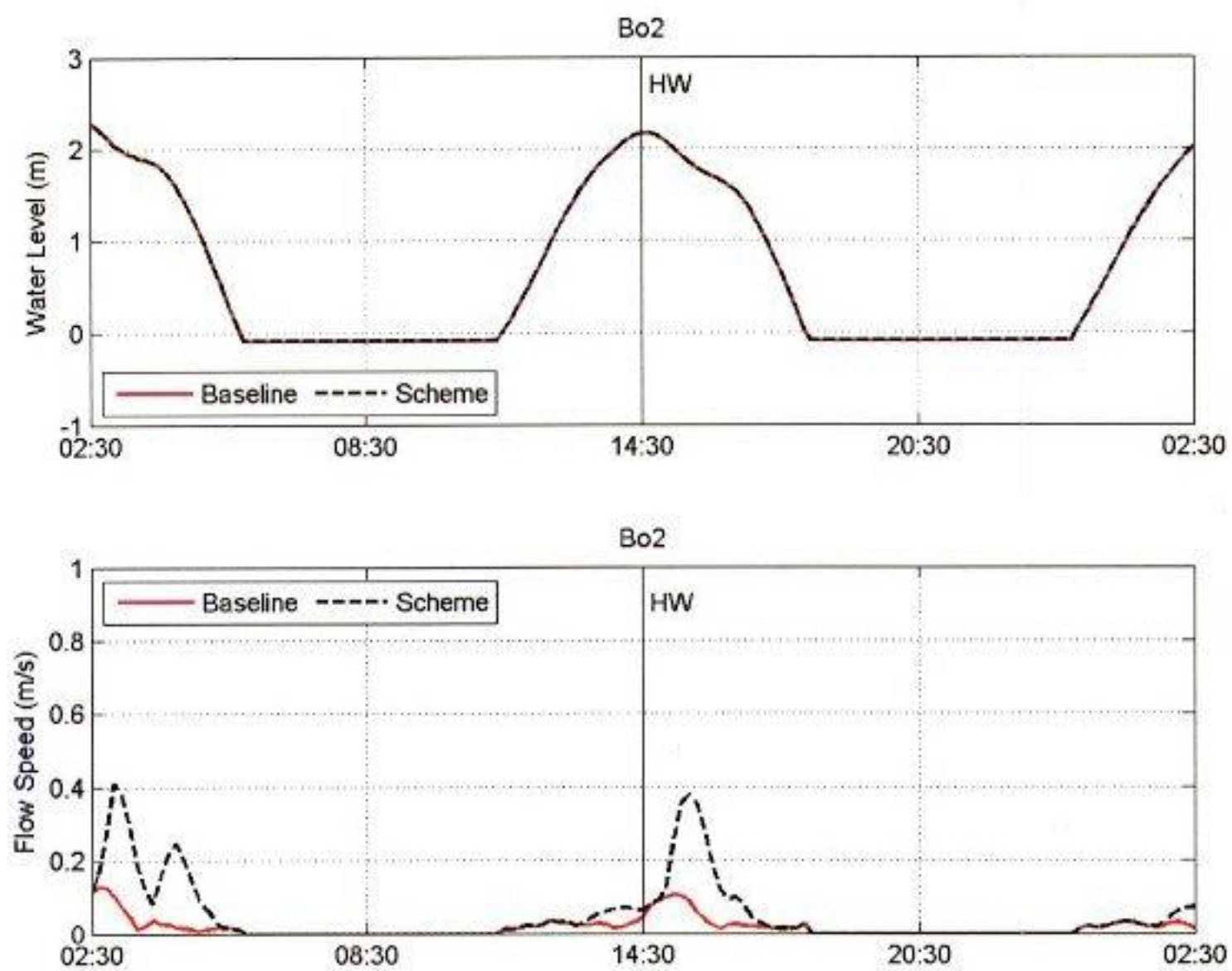


Figure 18. Time series of water levels and flows at Bo2 on a mean spring tide

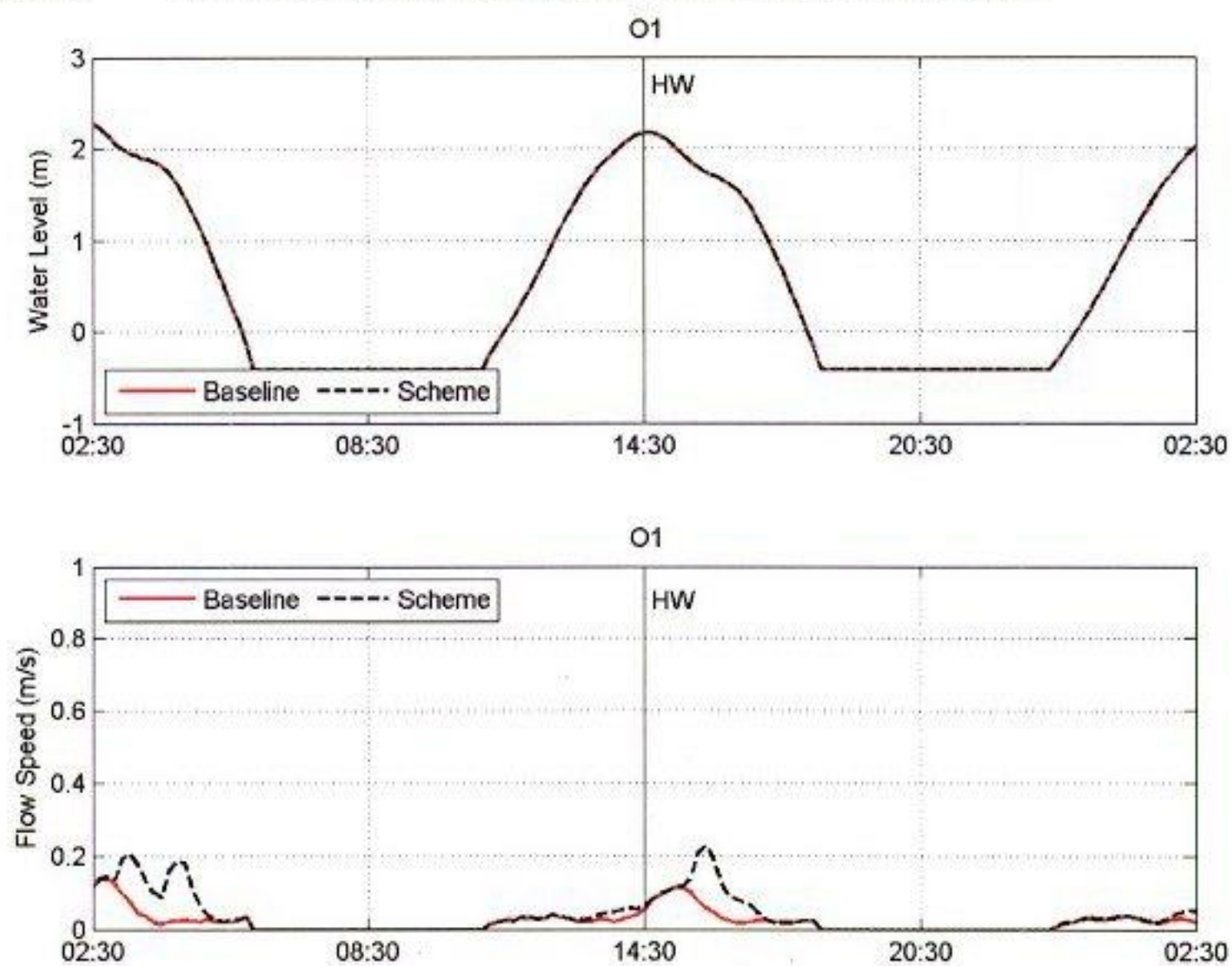


Figure 19. Time series of water levels and flows at O1 on a mean spring tide

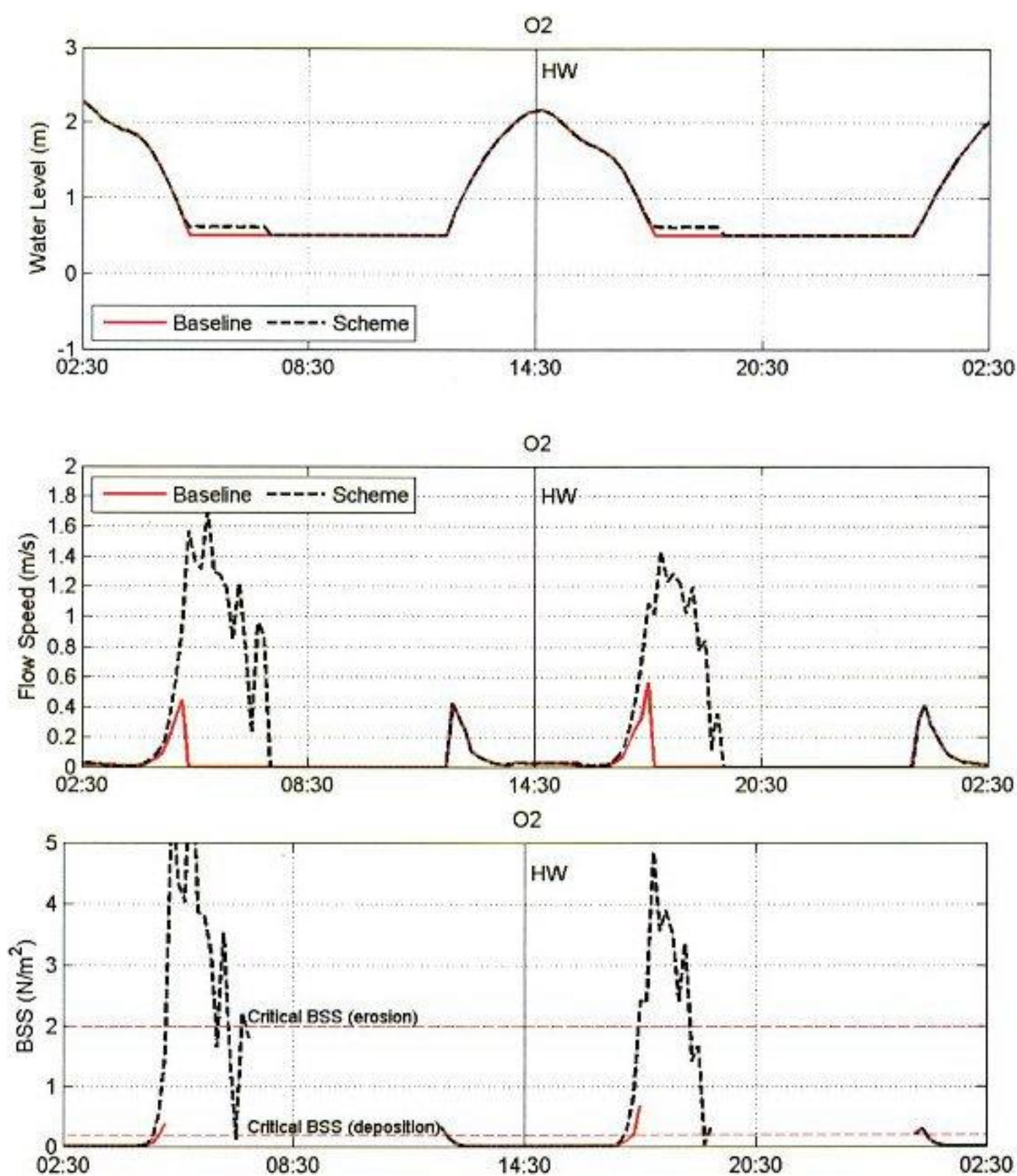


Figure 20. Time series of water levels, flows and bed shear stress at O2 on a mean spring tide

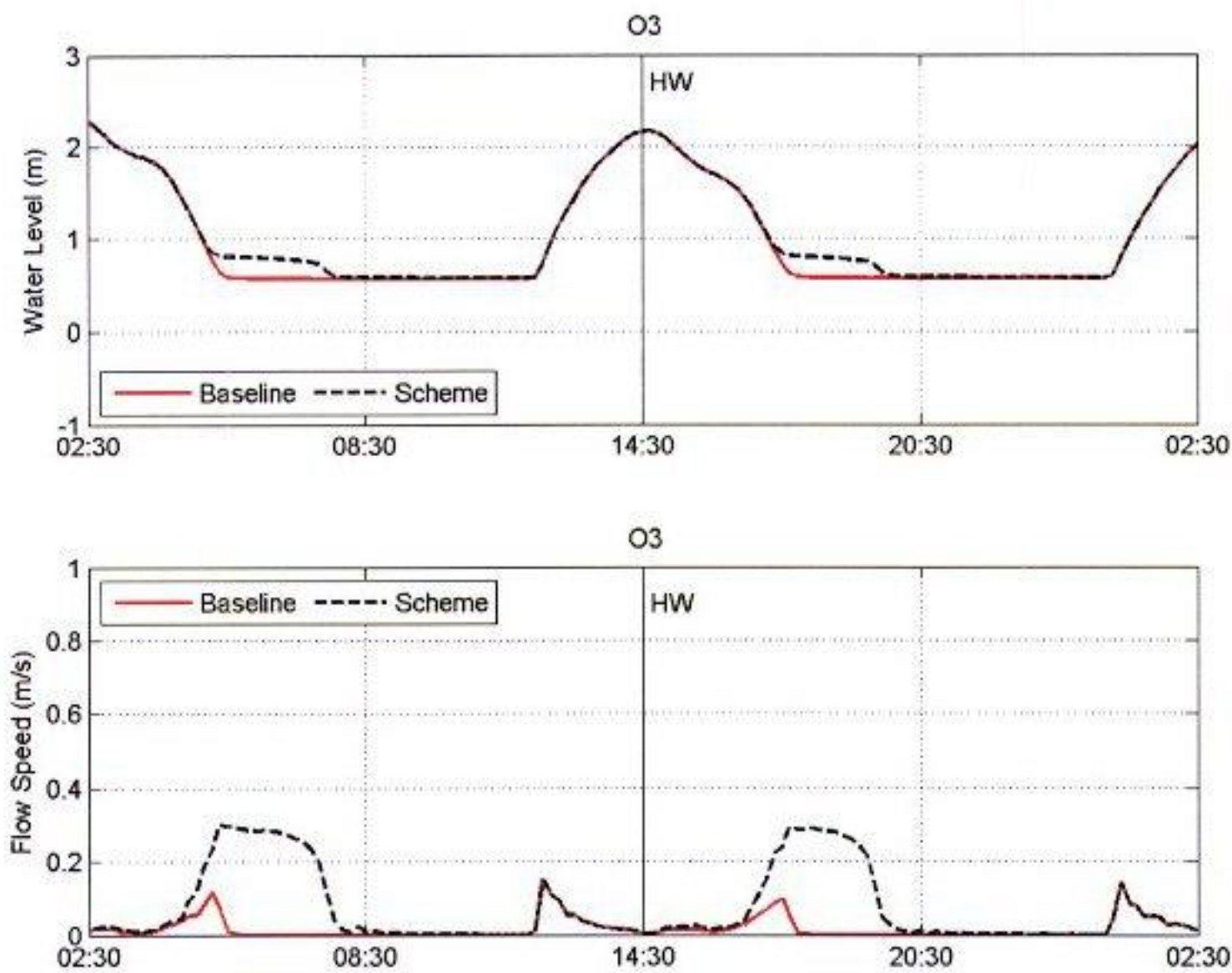


Figure 21. Time series of water levels and flows at O3 on a mean spring tide

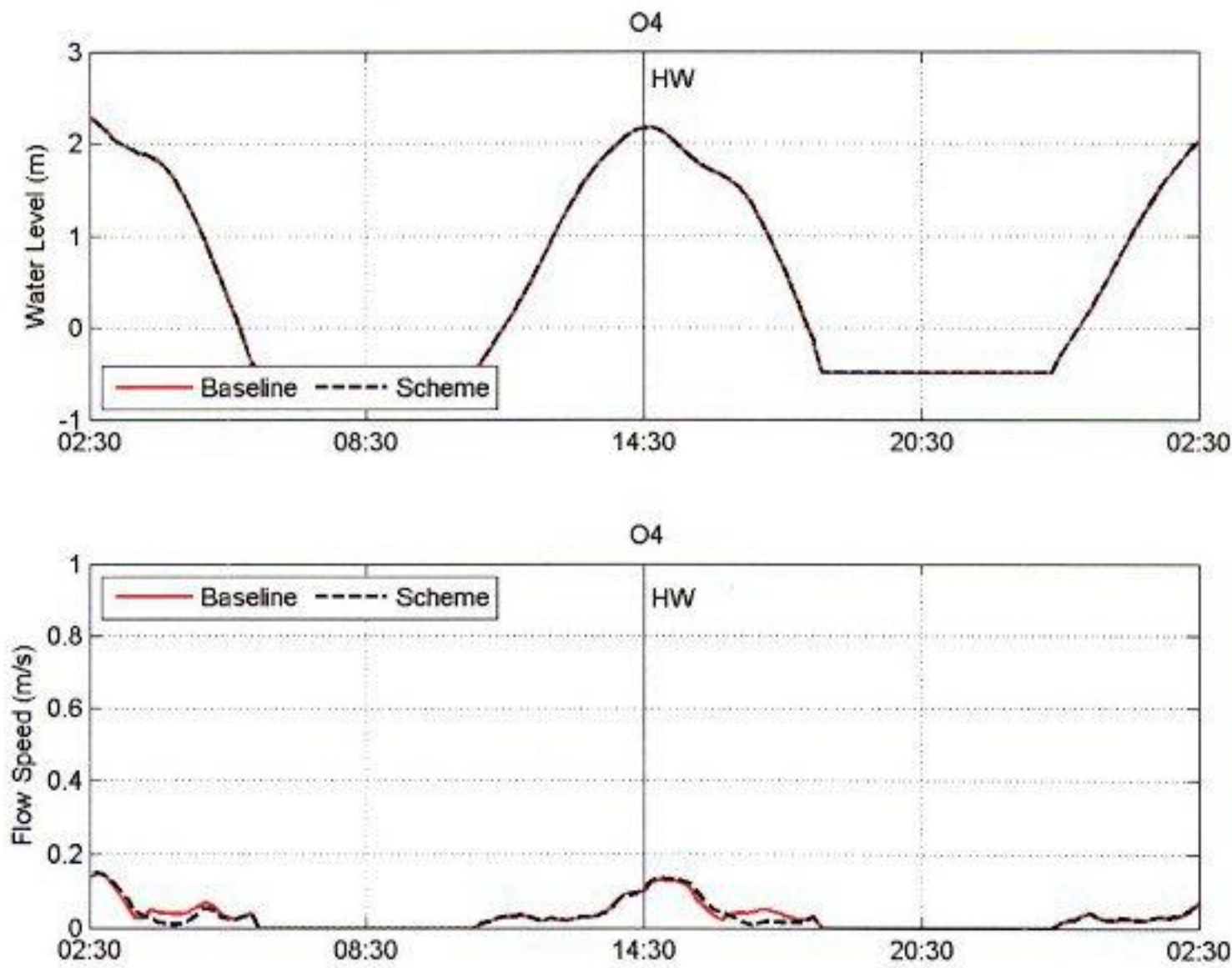


Figure 22. Time series of water levels and flows at O4 on a mean spring tide

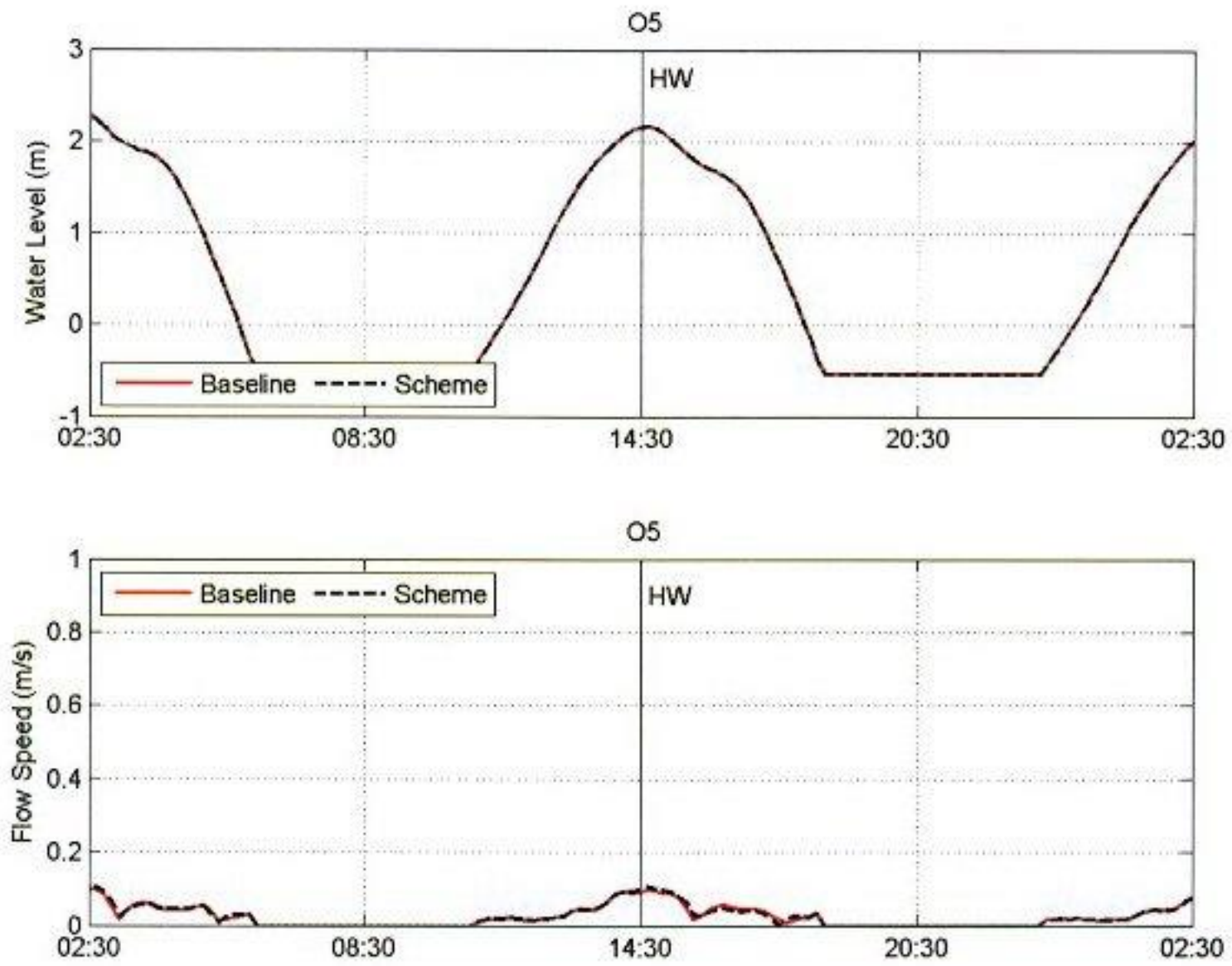


Figure 23. Time series of water levels and flows at O5 on a mean spring tide

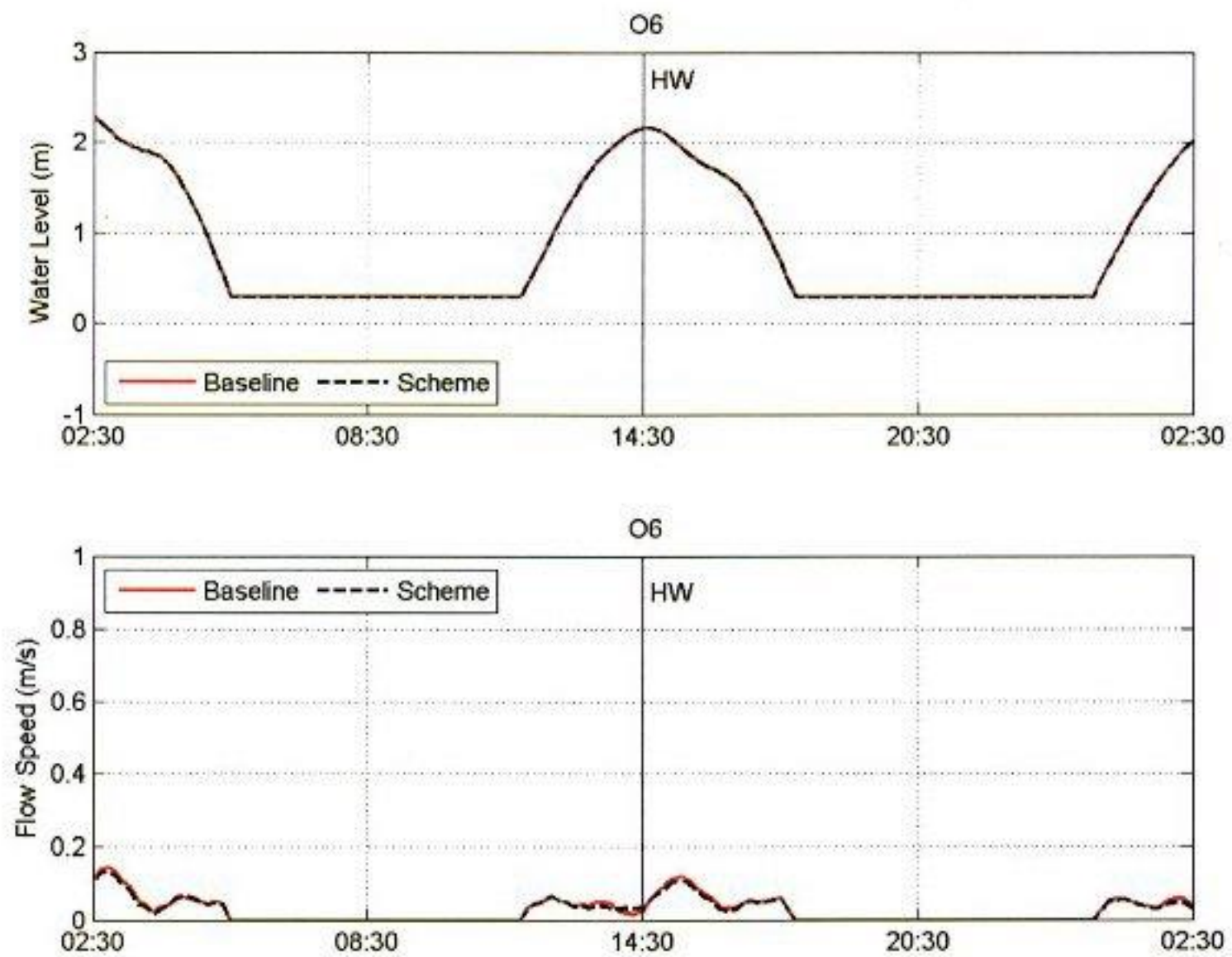


Figure 24. Time series of water levels and flows at O6 on a mean spring tide

5.2 Fluvial flood risk

The area in and around Southmoor has been subject to fluvial flooding in the past (for example in December 2013 and February 2014). To identify how the proposed realignment may affect the ability of terrestrial floodwater to drain from the site, the model has been re-run with a time-series discharge of freshwater applied at a location to the north of the managed realignment area, at a location known to be part of the wider flood plain of the River Lavant (see Figure 2).

The applied freshwater discharge is representative of a 1 in 100 year flood event hydrograph, derived from the Havant Flood Mapping Study (Atkins, 2008). The discharge was applied so that the time of maximum discharge coincided with the time of HW on a mean spring tide. The model was then run on for a period of increasing spring tides and subsequent lower range tides to assess how the flood water would drain from the site. To assist in draining, a 1 m diameter circular culvert was applied in the model through the internal bund (see Figure 2). In addition, fluvial flood water is expected to overtop the defences and flow into the Lavant to the east of the site. LiDAR data along this stretch indicates defences elevations of 2.4 m above ODN.

A spatial map plot of the maximum flood extent is shown in Figure 25. The maximum water depth during the model simulation is shown in Figure 26. These results are shown for a slightly larger spring tide than shown in Figure 4 to Figure 24 (with a HW of 2.22 m, compared to 2.17 m), since it was considered most conservative to apply the discharge on a period of rising range tides while previous results are shown for the closest tide to a mean spring tide, which occurred during a period of falling range tides. These map plots show that freshwater volume is contained within the Southmoor site or overtopped into the Lavant, rather than flooding onto other adjacent terrestrial areas.

Time series of the applied freshwater discharge into the site, the discharge through the culvert into the realignment site and the estimated overtopping discharge into the Lavant are shown in Figure 27. The freshwater discharge applied results in an increase in water on site for approximately one day; after this time water overtops into the Lavant and the combined overtopping into the Lavant and the draining of the site via the culvert in the bund keep up with the rate of discharge into the site. The model indicates that the freshwater would take approximately 4 days to drain once discharge rates drop to more normal levels. On the higher range tides, modelled tidal flows overtop the Lavant into the site where the flood defences are low; this does not typically occur and is likely to be either a result of the limited representation in the Lavant within the model or an inaccurate representation of the sea defences at this location. The representation of the Lavant and the height of defences in this region should be verified.

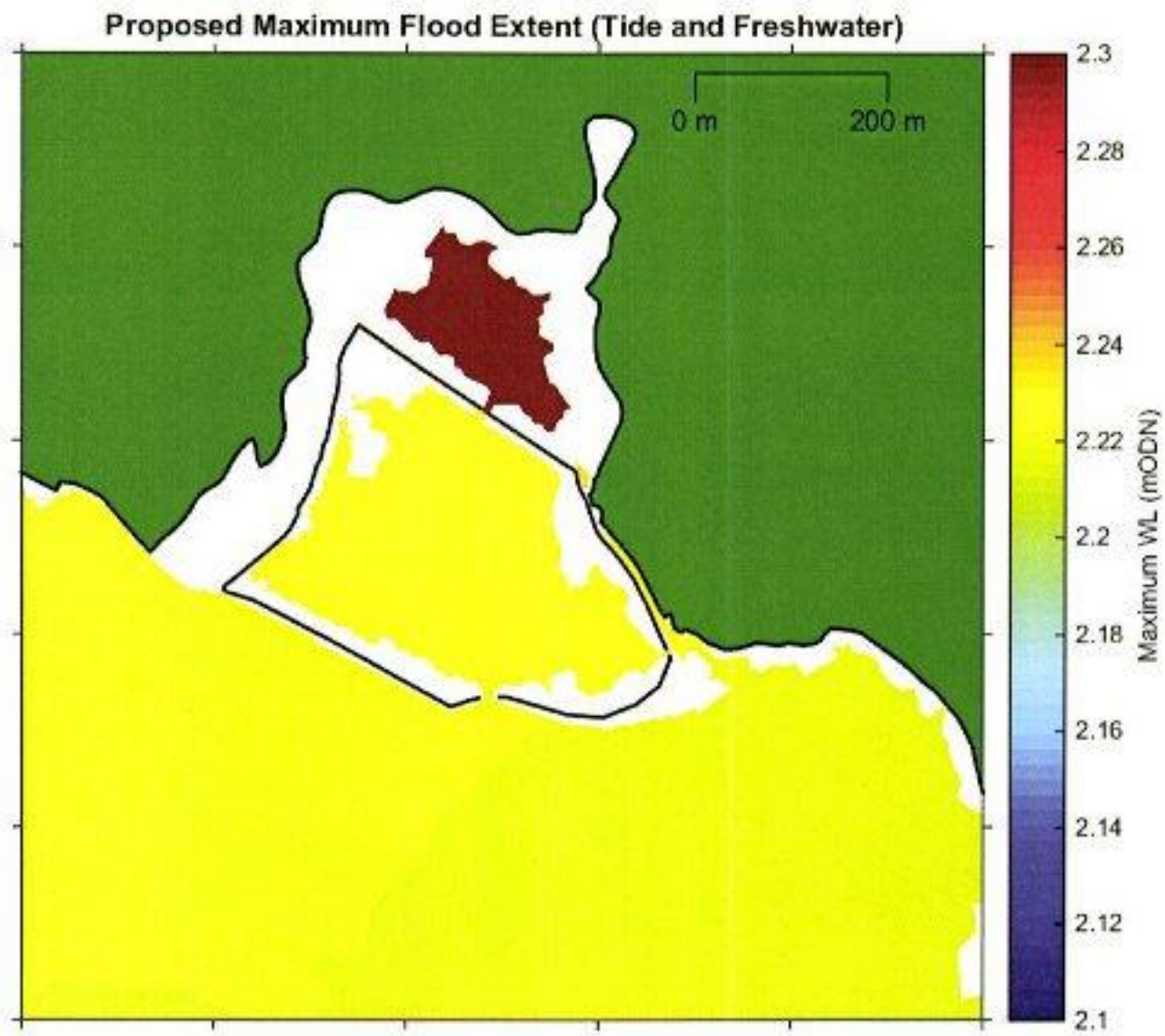


Figure 25. Maximum inundation for 1 in 100 year fluvial flood event

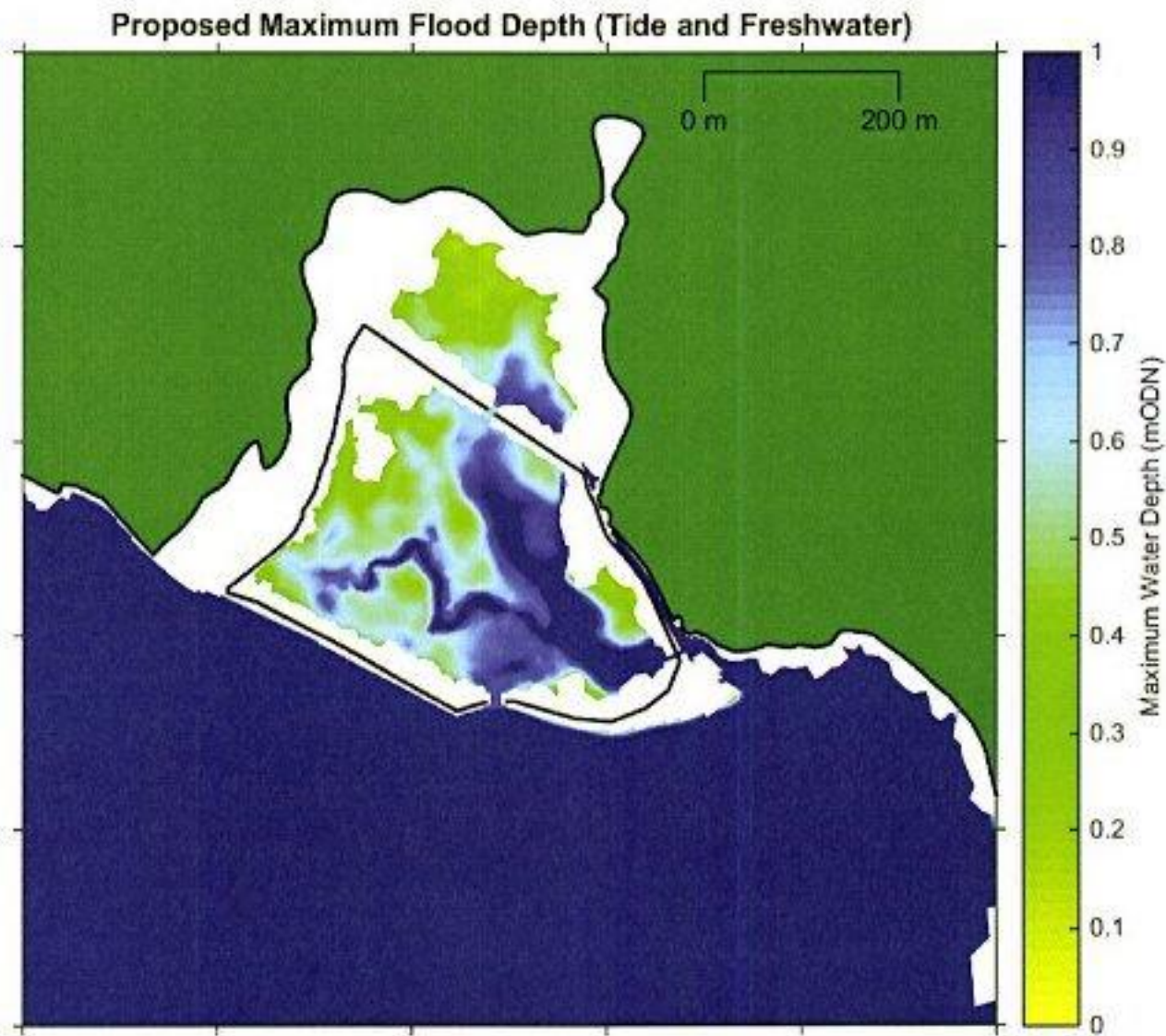


Figure 26. Maximum flood depth for 1 in 100 year fluvial flood event

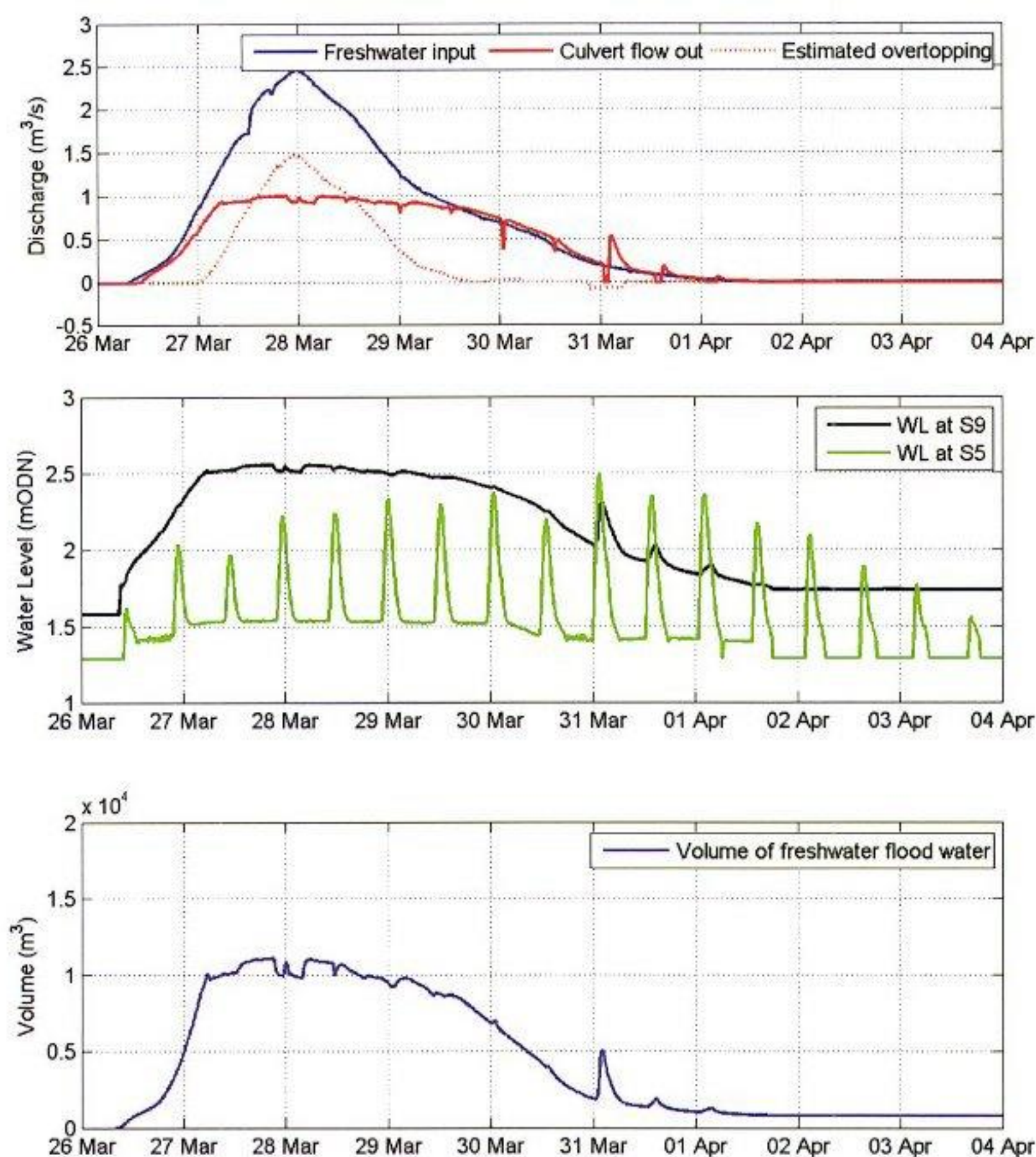


Figure 27. Time series of water levels and water volume for fluvial flooding scenario

A map plot of maximum flow speed is shown in Figure 28. Flow speeds within the wider flood plain area are low, being around 0.1 m/s. Maximum flow speeds within the managed realignment area and within the adjacent inter and sub-tidal areas show a similar pattern to the maximum flows without the inclusion of the freshwater discharge (Figure 10). A difference plot of maximum flow speed with and without the freshwater discharge is shown in Figure 29. This comparison plot is shown for the slightly larger spring tide which is coincident with the time of peak discharge. Maximum flows typically show a reduction within the managed realignment, except in the region where the new culvert discharges. The reduction in flows is a result of the blocking effect of freshwater draining across the managed realignment site to flows entering the site through the breach (tidal locking). Outside of the managed realignment site the maximum flows are increased. The increase in flows is more extensive than the impact of the managed realignment without the extreme freshwater event.

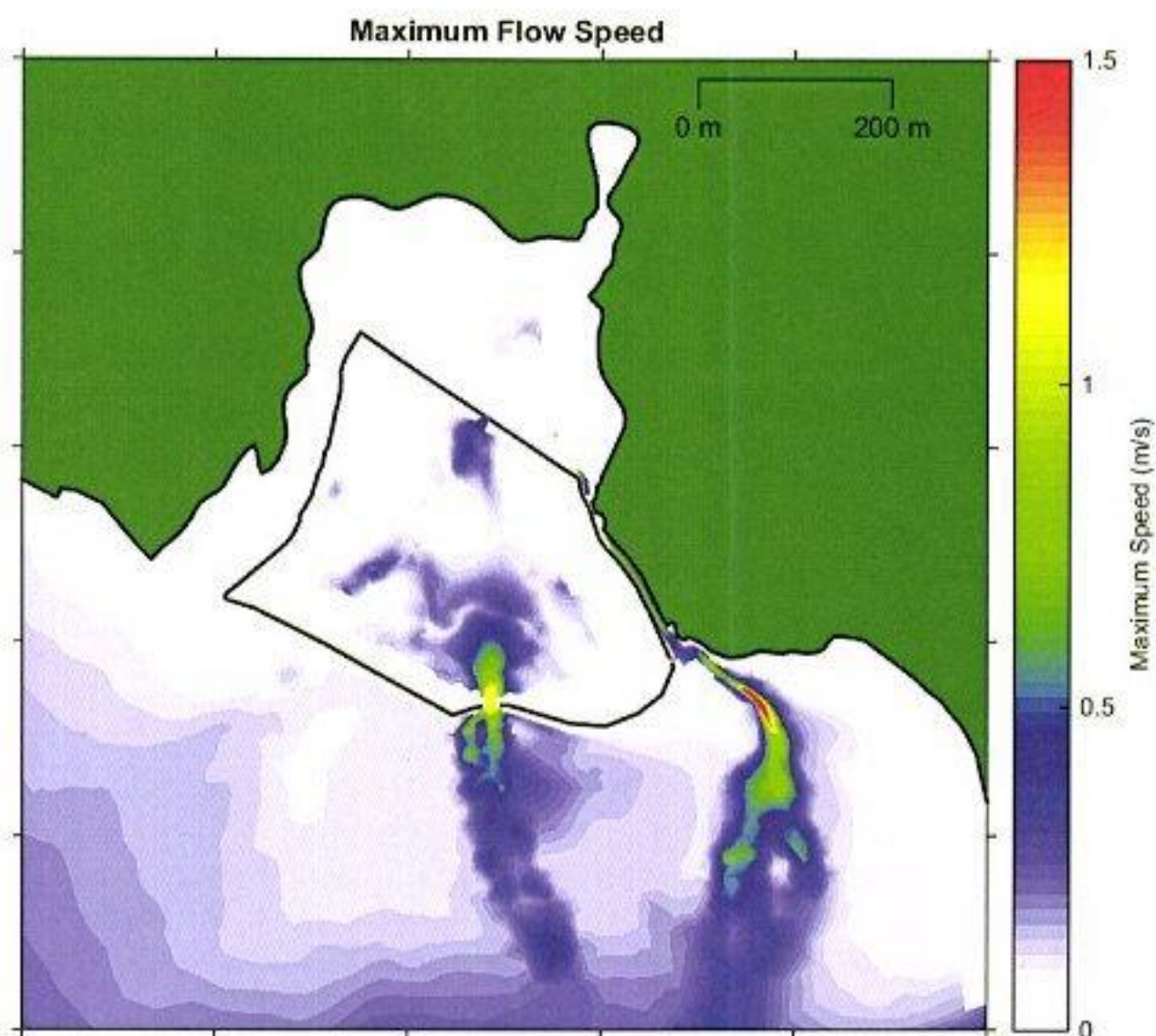


Figure 28. Maximum flow speed on a mean spring tide

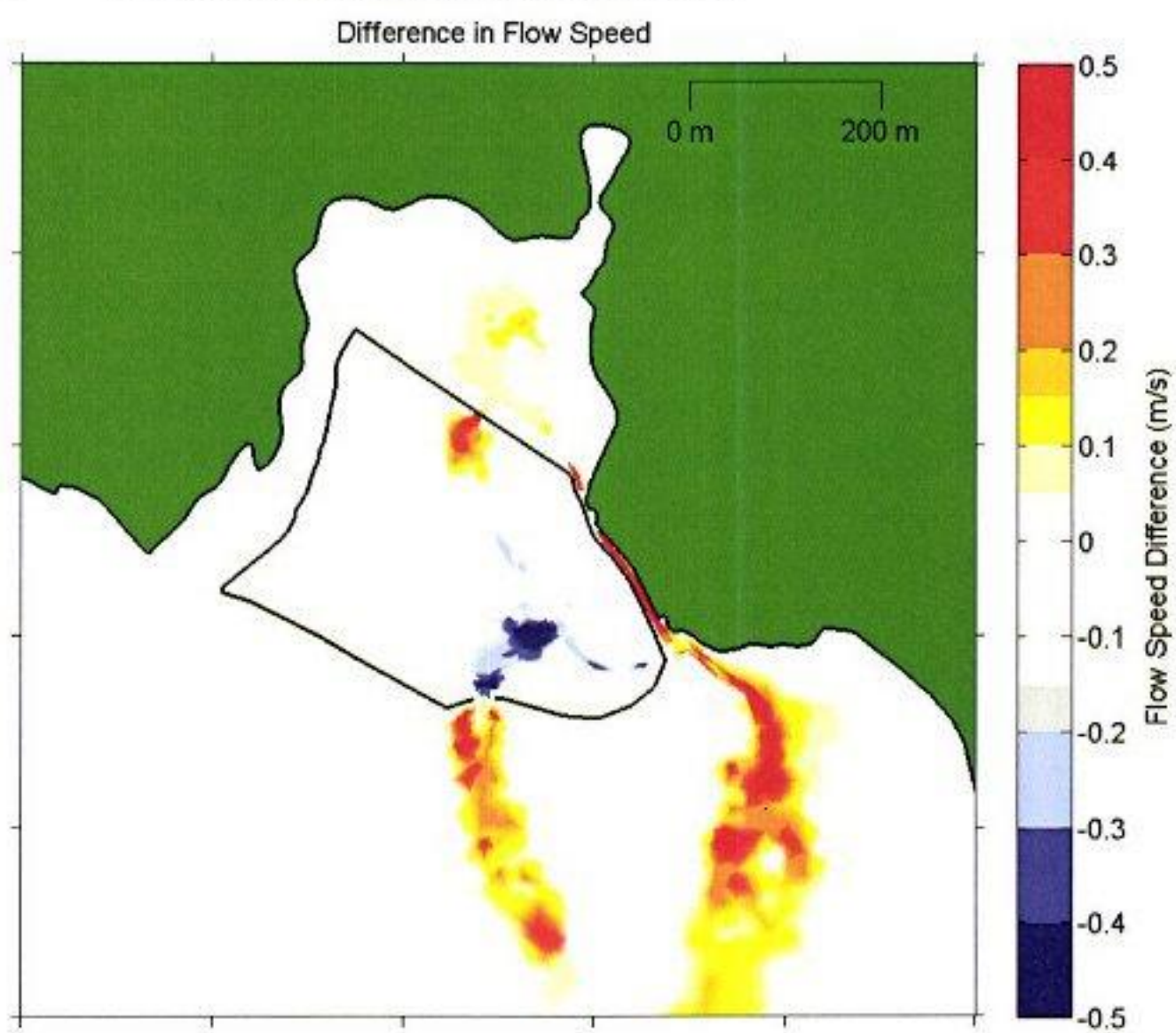


Figure 29. Difference in maximum flow speed for freshwater flooding event

6 Summary

The modelling work undertaken has shown that the inclusion of a breach (20 m wide at 1.4 m above ODN) through the central part of the existing sea defences fronting the Southmoor site would result in 84% of the managed realignment area flooding on a mean spring tide. The period of inundation varies throughout the managed realignment area depending on the bed level; the breach itself is inundated for a period of approximately 4 hours on a mean spring tide.

The existing channels within the site (which cover approximately 33% of the surface area) are lower than the applied breach invert level and as such will not drain via the breach. However, the existing culvert which presently drains fluvial water into the Lavant would help drain the water in the channels, should it remain operable. If the culvert is to be removed, a lower breach sill level with additional channels connecting the breach to the existing internal channel network would be required if the areas of 'pooling' (lagoons) are to be reduced.

Modelled flows within the managed realignment area are typically low, particularly during the draining of the site, and as such deposition is expected. Estimated accretion rates (based on the volumes of water exchanged and the concentration of sediment in suspension) are initially of the order of 0.015 m/yr. This estimated rate assumes a uniform settling of sediment across the managed realignment area. In reality sediment entering the managed realignment area in suspension will have a higher rate of settlement in the deeper channel areas and as such accretion within the channels may be slightly higher and accretion outside the channels may be slightly lower than the quoted value.

Modelled flows through the breach during the flood tide indicate that some localised erosion of the breach could occur for short periods on the flood tide; however this is a result of a small narrowing of the breach through the sea defences which is an artefact of a small convergence in model grid cells. In reality the breach would be constructed at a constant width and elevation and the breach is not expected to be significantly modified by flows post construction.

The implementation of the proposed scheme is not expected to significantly alter water levels outside of the site; only small increases (of 0.1 to 0.2 m) in water levels within the channel of the River Lavant are expected at lower tidal levels as drainage occurs through the existing culvert. This increase in water levels results from the draining of the managed realignment area via the culvert during a period when water levels are between the breach sill level and the culvert sill level (approximately 3 hours on a mean spring tide); increases in water level do not occur during periods close to high water and as such the predicted impact does not affect flood risk. During the period of increased water levels, flow speeds are also enhanced, particularly across the outer part of the Lavant Channel. In the area of most notable flow enhancement the model bathymetry shows a slight constriction of the channel and the presence of a 'bar'. The model's representation of the Lavant is however limited by the availability of detailed bathymetry and the modelled channel is more likely to be narrower and/or shallower than exists. As a result flow speeds are considered to be over-exaggerated in the model. If the modelled flows were to occur then some localised erosion within the Lavant Channel would be expected to occur until a new equilibrium is reached. It should be noted that this area is exposed to wave activity and therefore the channel could vary significantly in this area compared to that modelled.

At present the existing culvert drains freshwater from the managed realignment area following periods of high rainfall and as such these modified conditions within the Lavant already occur, albeit less frequently than would occur following realignment should the culvert remain operable.

The modelling of a 1 in 100 year flood event with the scheme in place indicates that the freshwater volume is contained within the Southmoor site or is overtopped into the Lavant, rather than flooding onto other adjacent areas. However, it should be noted that the defence elevations in the area of overtopping have not been verified (they are derived from 1 m LiDAR data) and the representation of the Lavant in the model is not considered suitable for a detailed flood risk study.

Given the potential limitations and taking the worst case of the peak of the river flood hydrograph occurring at the time of HW on spring tides, tidal locking is shown to occur which would take around four days to drain away following the return to more normal freshwater flows.

7 Modelling Uncertainties

The modelling study undertaken provides a high level assessment of the functionality and stability of the proposed scheme, as well as an indication of the likely impact on the surrounding area. Going forward it is recommended that the knowledge gained in this initial assessment is used to inform a final scheme design and that more detailed modelling of this final scheme design should be undertaken to address any uncertainty identified in the present study. The potential factors for further consideration are detailed below:

- It is our understanding that the existing culvert is likely to be decommissioned and as such will not be functioning following realignment. Should this be the case, depending on the desired level of draining within the managed realignment area, it may be necessary to undertake additional reworking of material within the site (e.g. re-profiling or creation of interlinking channels);
- The model representation of the Lavant could be improved; this would require additional survey data, in particular more detailed bathymetry data along the length of the River Lavant, as well as information on the bridge structures and their blocking effect. Additionally, the elevation of the flood defences in the area where the River Lavant overtops into the site on high range tides as is indicated in the model should be verified. This would be necessary should detailed flood risk assessment work be required as part of the final scheme design assessment;
- Finalise the back wall alignment; this will determine the final managed realignment area and volumes, although any changes are expected to be minimal and are not likely to significantly affect the tidal prism of the managed realignment area; and
- Determine the sediment characteristics within and around the site (either from pre-existing or additional survey work) and/or undertake sensitivity tests to determine the effect of the assumptions made relating to the sediment characteristics in the modelling work.

8 References

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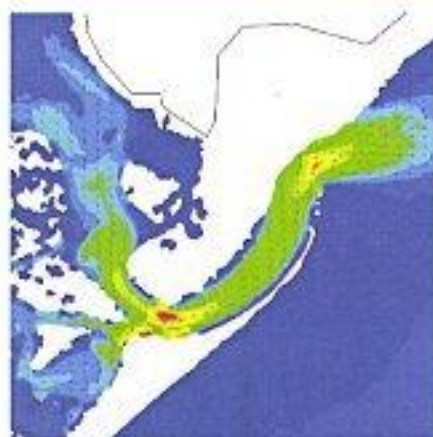
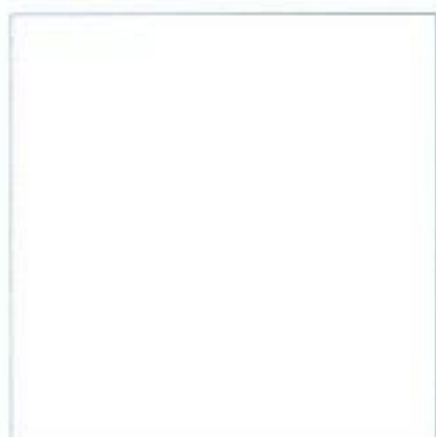
9 Abbreviations/Acronyms

2D	Two-Dimension(al)
AWAC	Acoustic Wave And Current Profiler
BSS	Bed Shear Stresses
CCO	Channel Coastal Observatory
CD	Chart Datum
DHI	Danish Hydraulic Institute
FM	Flexible Mesh
HAT	Highest Astronomical Tide
HW	High Water
LAT	Lowest Astronomical Tide
LiDAR	Light Detection and Ranging
LW	Low Water
ODN	Ordnance Datum Newlyn
mODN	Metres relative to Ordnance Datum Newlyn
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
ODN	Ordnance Datum Newlyn
RMS	Root Mean Square
SSC	Suspended Sediment Concentrations
UKHO	United Kingdom Hydrographic Office
WL	Water Level(s)

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Annex



Innovative Thinking - Sustainable Solutions

A Model Calibration

A.1 Introduction

A bespoke two dimensional (2D) hydrodynamic model of the harbours of Langstone and Chichester on the south coast of England has been developed to assess the potential for realigning the existing sea defences to a landward position in an area adjacent to the Langstone Bridge (which connects Hayling Island to the main land - see Figure A1 for study location). The managed realignment area covers an area of approximately 9 Hectares (Ha) below the level of Mean High Water Springs (MHWS).

This annex provides additional detail on the model setup, calibration and validation to demonstrate that the model is a useful and appropriate tool for the assessment work being undertaken. The report is has been structured as follows;

Section A.2: Model Build;
Section A.3: Model Calibration and Validation; and
Section A.4: Summary;

A.2 Model Build

A.2.1 Software

To simulate the tidal hydrodynamics at Southmoor, a model covering the harbours of Langstone and Chichester has been configured in the MIKE 21 Flexible Mesh (MIKE FM) modelling software package. The MIKE FM software is internationally recognised and has been widely applied for a multitude of studies in the coastal and estuarine environments. The MIKE FM modelling software undergoes continuous development with updates regularly released by the Danish Hydraulic Institute (DHI). This project used the most up to date version of the software available at the time of project commencement (MIKE 2016, Service Pack 2).

A.2.2 Model mesh

The model mesh covers the harbours of Chichester and Langstone, which, with the exception of narrow entrance channels, are almost entirely landlocked. The two harbours are joined by a narrow stretch of water extending between the south coast of England and Hayling Island. The harbours are characterised by large areas of mudflats, with numerous dendritic tidal channels which assist the flooding and draining.

A flexible mesh using both rectangular and triangular elements to best represent the complex bathymetric features within Chichester and Langstone Harbours (and within the managed realignment area) has been developed. The mesh resolution varies throughout the model domain, with a 200 m resolution outside of the harbours, 100 m within the harbours, 10 m within the Southmoor site and 5 m within the channels within the managed realignment area. The channels within the harbours are resolved by three to five cells across. The model mesh is shown in Figure A1.

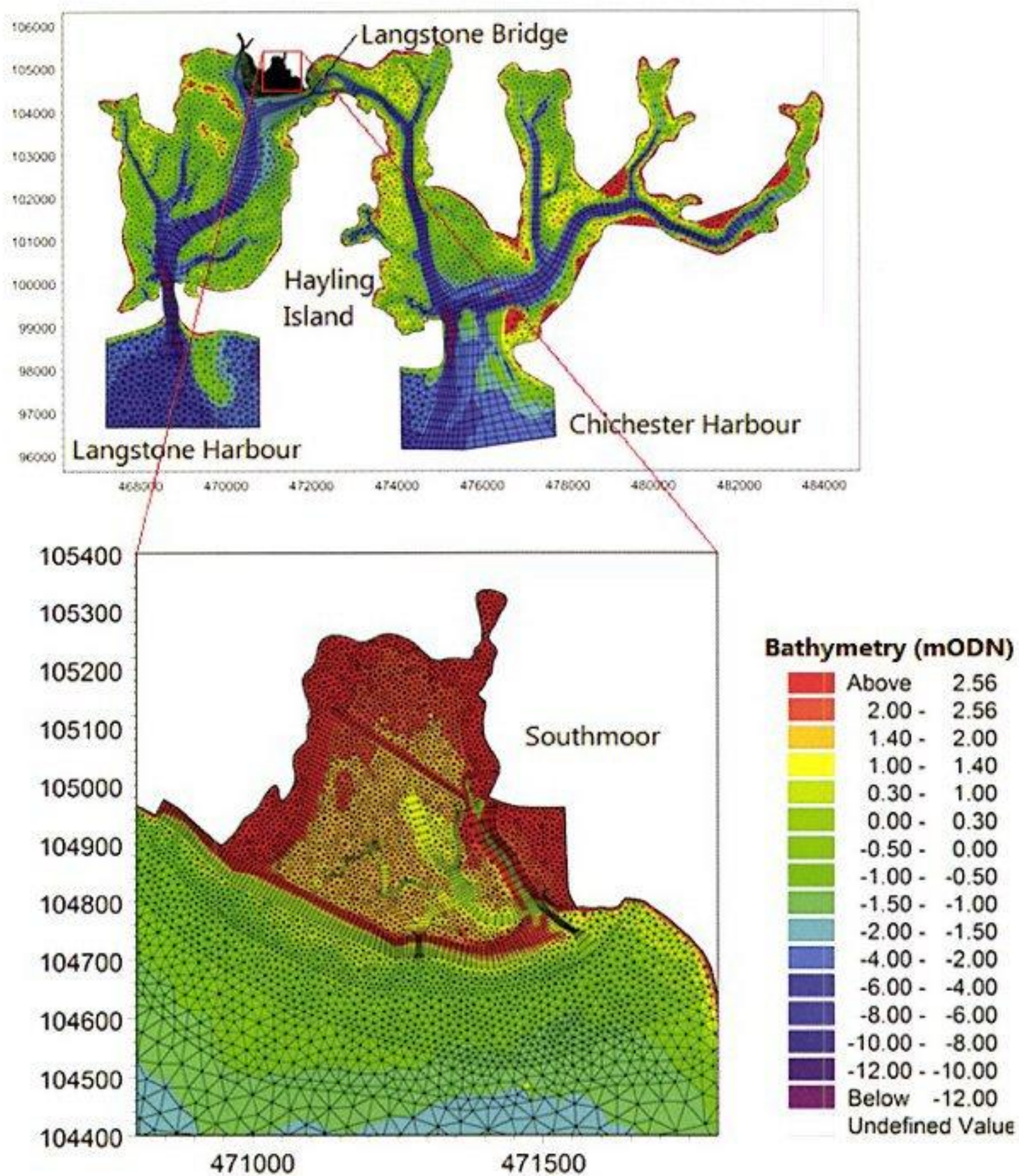


Figure A1. Model study area and mesh

A.2.3 Model bathymetry

The model bathymetry is based on four main data sources:

- Environment Agency LiDAR data from 2014. This data was ground truthed against topographic survey data collected at more than 250 points within and around Southmoor. Accordingly LiDAR points within the Site were offset by -0.045 m before interpolation onto the model mesh;
- Single beam Channel Coastal Observatory (CCO) hydrographic survey data of Langstone and Chichester Harbours from 2007 and 2008;
- CCO LiDAR data from 2005; and
- Bathymetry from ABPmer's English Channel Model (ABPmer, 2016). This was used for the area outside the harbour entrances and is mainly comprised of CCO survey data and data from the UKHO Inspire portal. Details on the English Channel Model bathymetry are provided in Appendix A of ABPmer (2016).

The coverage of the bathymetric data is shown in Figure A2.

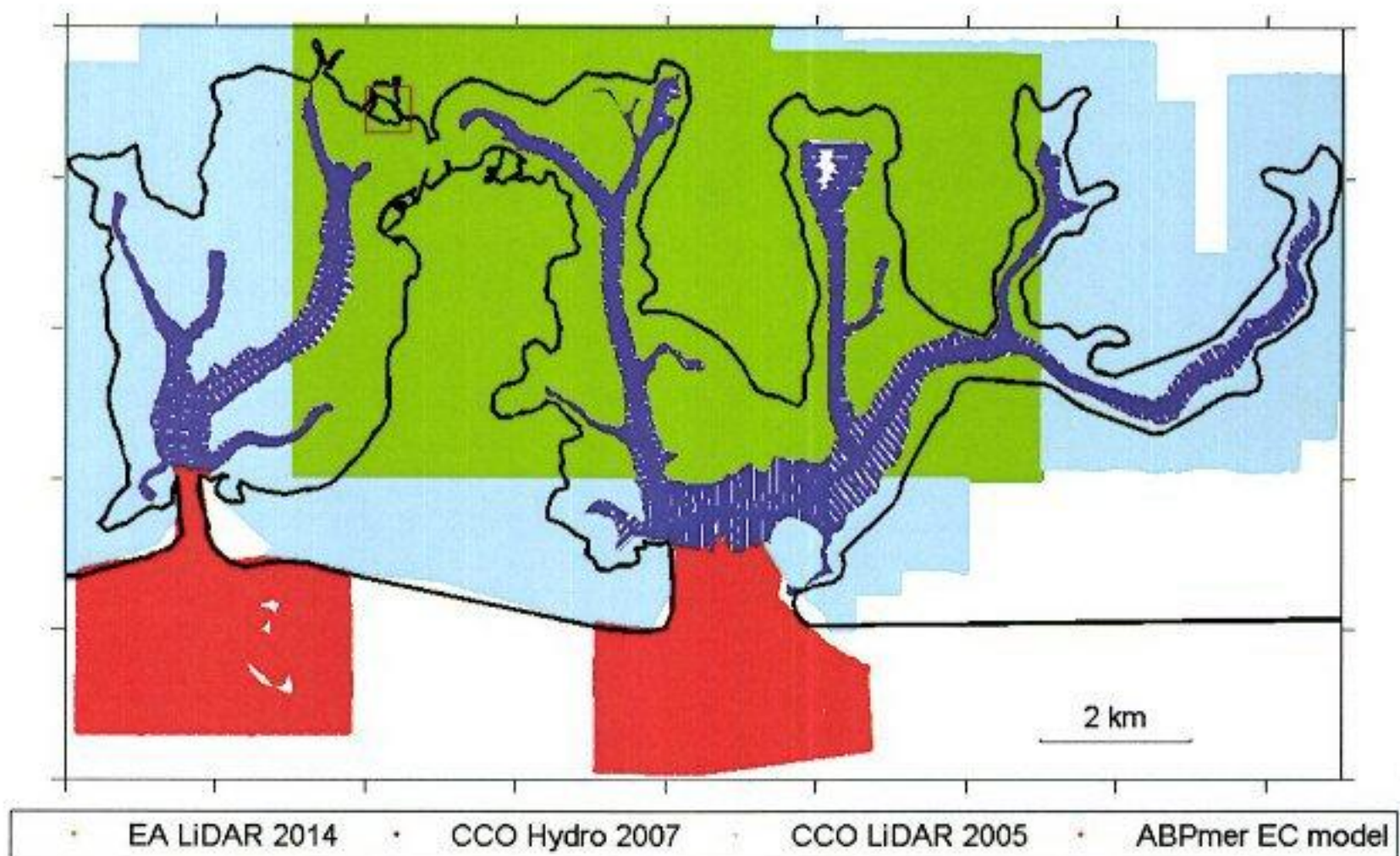


Figure A2. Bathymetry datasets

The bathymetry data was interpolated onto the model mesh and then visually compared against Admiralty Chart 3418 (Langstone and Chichester Harbours) from the UKHO to ensure that the main surveyed features of the Harbours were represented in the model. The model bathymetry is shown in Figure A3; the bathymetry has been coloured up for ease of comparison with the Admiralty Chart. The model bathymetry captures the main channel features and intertidal banks within the harbours.

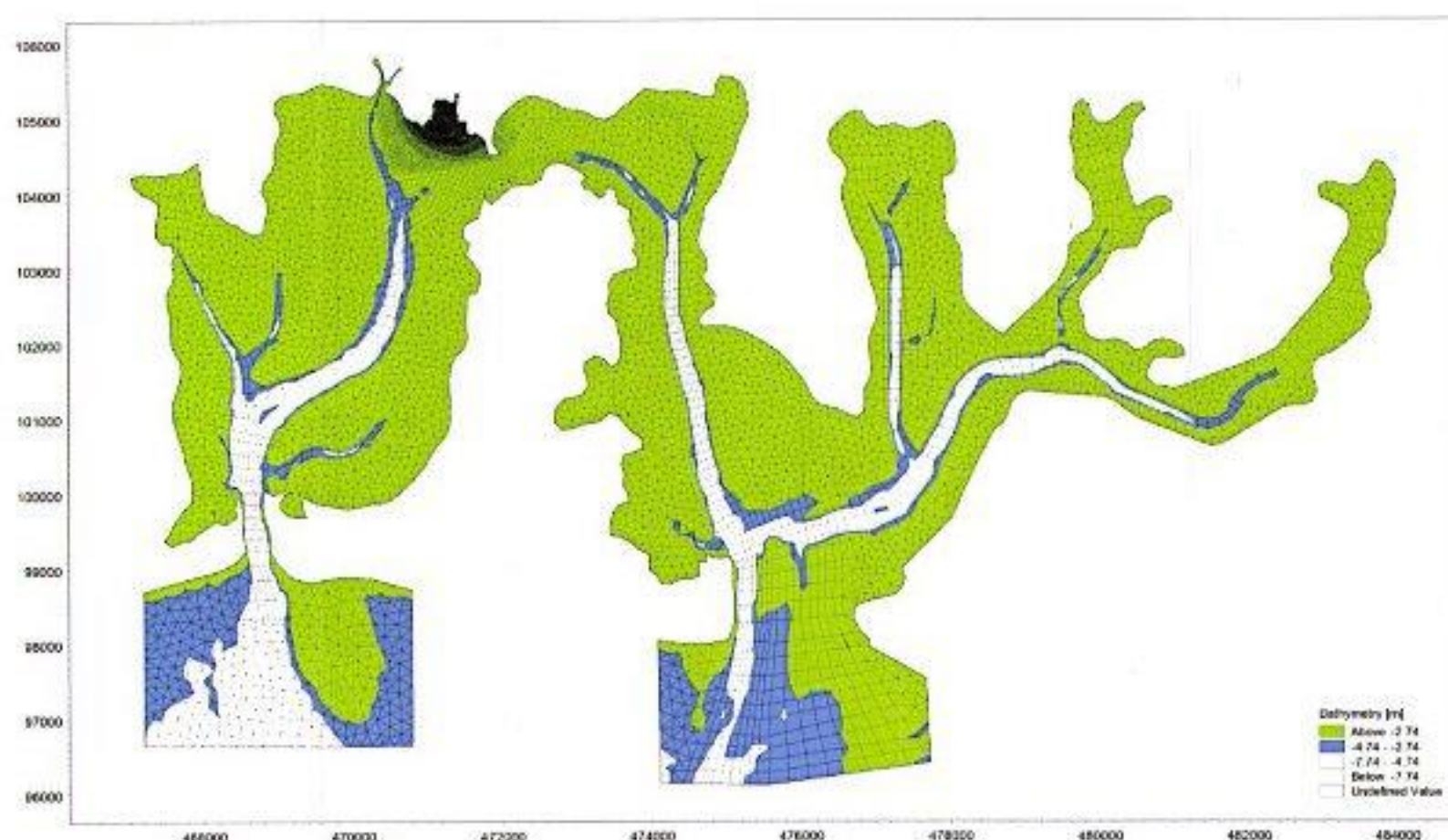


Figure A3. Model bathymetry; depths given in meters relative to ODN

Figure A3 shows the large percentage of low lying intertidal areas within the harbours and the relatively deep dendritic channel features. In the vicinity of the Langstone Bridge the depths are less than 2.74 m below Ordnance Datum Newlyn (ODN), which is equivalent to 0 m Chart Datum (CD). There is no hydrographic survey data in this area and as such the model bathymetry is based on LiDAR data. Discussion with local residents (during the public stakeholder event held at the Langstone Sailing Club in May 2017) suggests that the tidal channel under the bridge does not dry out, even on large range tides around the time of low water. Based on this, it is expected that the depths in the LiDAR are under presented and the model bathymetry has been manually edited to include a channel which links Chichester and Langstone Harbours with depths of 2.54 m below ODN, equivalent to Lowest Astronomical Tide (LAT) and is therefore expected to remain wet.

A.2.4 Model boundaries

Time series of water levels were used to drive the hydrodynamic model at the offshore boundaries. The applied water levels were based on an observational record from the Chichester Bar, approximately one mile offshore of the entrance of Chichester Harbour (collected by the Solentmet Support Group and provided freely online at www.chimet.co.uk). A small time and amplitude shift was applied to the water levels before applying at the offshore boundary at Langstone Harbour. The applied time and amplitude shift was informed by an analysis of water levels in ABPmer's English Channel Model (ABPmer, 2016). The applied water level boundaries improved the model performance in comparison to when modelled water levels from a regional hydrodynamic model were applied; the regional model did not fully capture the particular features of the Solent tide including the Young Flood Stand and double high water period and the hydrodynamics within the harbour areas were found to be sensitive to these features.

A.3 Model Calibration and Validation

A calibration and validation exercise is a common requirement to demonstrate the suitability of the model. The calibration process is an exercise in tuning the model performance through the adjustment of model setup parameters (such as boundary conditions, bathymetry and bed roughness) to achieve the best model performance against measured data and known local characteristics. Further validation of the model without any additional adjustments to model settings is carried out over a different time period than that used for calibration to verify the model performance against an alternative (preferably independent) dataset. The calibration and validation process is described in the following sections.

A.3.1 Calibration data

The model was primarily calibrated to reproduce water levels and flows measured along the foreshore at Southmoor during a one week period (28 March 2017 to 3 April 2017). The data was collected using a Nortek Aquadopp profiler deployed at a location 250 m south of the Southmoor site (Figure A4). During the survey two tidal gauge instruments were also deployed in the Lavant Stream. Unfortunately these instruments were not recovered and as such no data is available at these locations for model calibration.

To provide an indication of model performance throughout the wider model domain, water levels and flows from the admiralties' TotalTide software package have also been considered. The hydrodynamics from the TotalTide package are generated from measurements which may have only been collected over a short period and at relatively low temporal resolution and then scaled to provide values for different range tides assuming a linear relationship. Such an assumption is relatively crude and may not be valid in some areas. In addition tidal diamonds give flows at the surface, rather than depth average values. The TotalTide water level predictions do not accurately resolve the complex tidal features of the area such as the Young Flood Stand and the double high water, features which are evident in measured water level data. These features have a significant impact on the spatial and temporal distribution of flows within the harbours. As such the TotalTide predictions have been treated as a secondary dataset and the assessment of the model performance against such data should be somewhat relaxed (to account for the known limitations in the data).

A.3.2 Validation data

Following calibration, the model has been validated against water levels and flows measured from an Acoustic Wave and Current (AWAC) deployed in the main channel in Langstone Harbour during a one month period from 27 March 2009 to 28 April 2009. The location of the AWAC is shown in Figure A4 (labelled Main Channel). The model was also validated against water levels collected during the same period using a Nortek profiler deployed at Russells Lake and from a tide gauge deployed at Bedhampton. Further verification against water levels (Langstone, Northney and Chichester in Figure A4) and flow predictions (SN005AN, SN005AZ, SN007T and SN007U in Figure A4) from TotalTide was also undertaken, although as noted above, this data is considered as a secondary dataset. The harbour has not undergone significant morphological change since the excavation of the historic causeway to Hayling Island (known as the Wadeway) in 2006 and as such the present day hydrodynamics are expected to be largely unchanged from those surveyed in 2009. The location of all calibration and validation data points are shown in Figure A4.

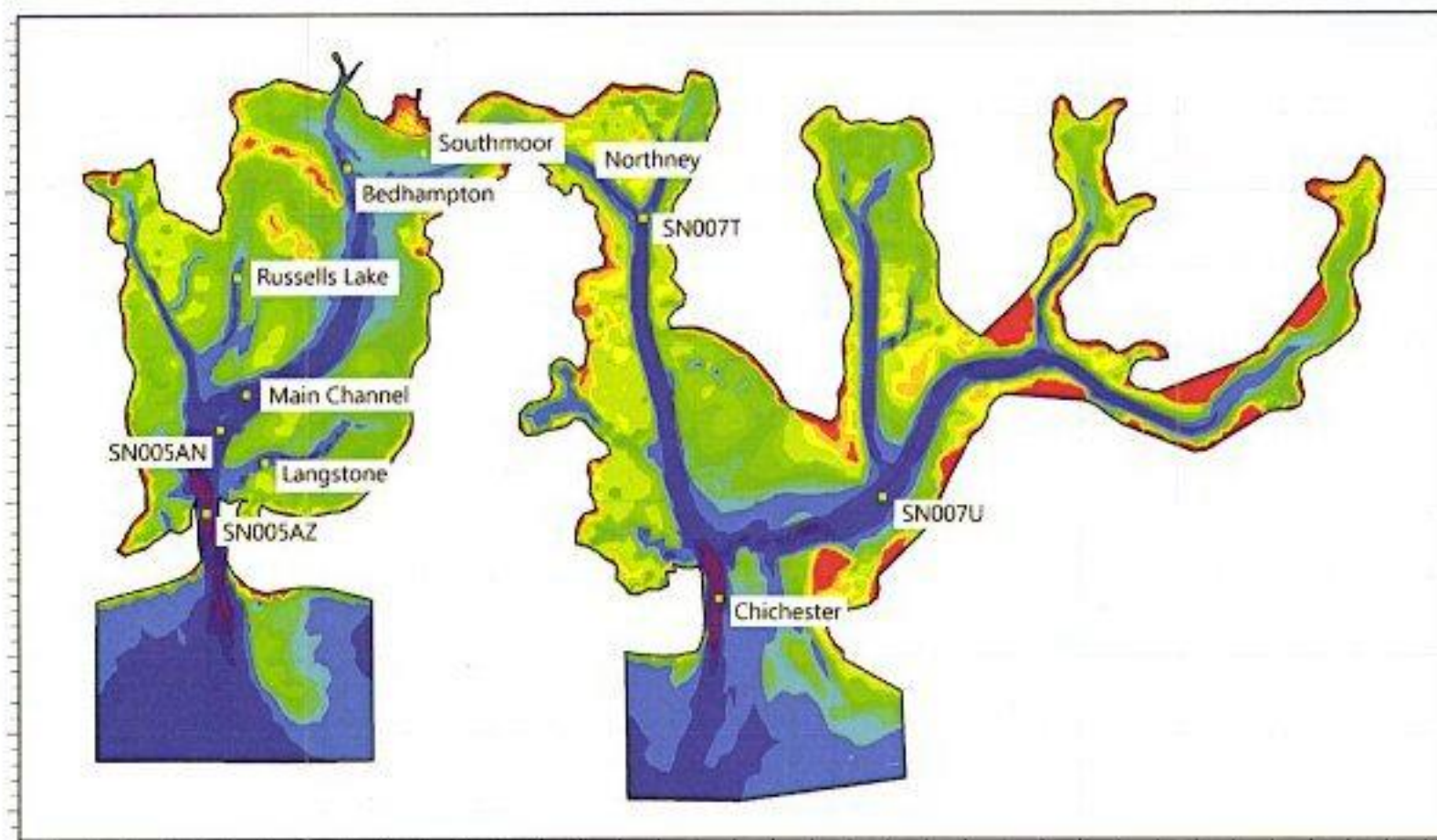


Figure A4. Calibration and validation data

A.3.3 Performance metrics

The model performance has been assessed using both visual and statistical comparisons of modelled and observed water levels and flows. The statistical measures are assessed against a set of metrics defined in an internal calibration guidance document maintained by ABPmer (ABPmer, 2014). The internal 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). 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) values.

The reason for accommodating for some level of discrepancy between the observations and model is to account for any differences in how the observational data is captured (discrete point in space and time, with meteorological forcing included) compared to the model result (depth and time averaged grid cell values from harmonically driven flow components). It is therefore not considered necessary to further justify discrepancies between modelled and measured values that lie within the defined target metrics. 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.

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.

Water levels

- **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 also expressed as a percentage of the mean tidal range;
- **Mean phase difference at HW.** Calculated as the mean magnitude of time difference at HW between the model and observed data, over a defined period;
- **Time adjusted fit.** This is the phase correction required to yield the minimum RMS between the modelled and observed water levels at all time-steps over a defined period; and
- **RMS surface elevation difference.** This value is calculated as the RMS value after the application of the time adjusted fit. Values are calculated over a defined period.

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. Within estuaries the guideline standards are slightly more relaxed with Bartlett (1998) recommending HW and LW levels should be within ± 0.1 m at the mouth and ± 0.3 m at the head.

Tidal ranges within the study region are relatively high (being 4 m on mean spring tides and around 2 m on neap tides) and thus the adoption of the absolute level criteria represents a small percentage of the levels and as such is considered an overly stringent criteria to apply when assessing model performance in this instance. The percentage criteria will therefore be the primary consideration used to assess whether the model performance achieves the guideline standards. **Water level phasing at high and low water should be to within ± 15 minutes, while RMS scores should be within 0.2 m (or to within 10% and 15% of spring and neap tidal ranges, respectively).**

Flows

- **Mean flow speed difference (at peak flood and ebb).** Calculated as the mean difference between the magnitudes at peak flood or ebb time of the tide over a defined period. This is also calculated as a percentage value relative to the maximum observed speed;
- **Mean flow direction difference (at peak flood and ebb).** Calculated as the mean of the difference in flow direction recorded at times of peak flood or ebb period of the tide over a defined period;
- **Time adjusted fit.** This is the phase correction required to yield the minimum RMS differences 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 $\pm 10^\circ$ of observed directions and phasing within ± 15 minutes. Within estuaries the guideline standards are slightly more relaxed with Bartlett (1998) recommending that speeds should be within ± 0.2 m/s and directions should be within $\pm 20^\circ$. RMS scores for flows should be less than 0.1 to 0.2 m/s (or 10-20% of the peak flow).

A.3.4 Model streamlines

Before presenting time series plots demonstrating model performance at discrete location points it is useful to have an understanding of the spatial distribution of flows within the model domain. Streamline plots have therefore been produced at hourly intervals during a mean spring tide from six hours before to six hours after High Water and these are provided in Figure A5 to Figure A7 (regional scale showing flows throughout the model domain) and Figure A8 and Figure A9 (local scale, showing flows in the study area). Times are given relative to HW at Chichester. Flows are also shown for the calibration data.

The model streamline plots indicate a large degree of spatial variability in flows within the harbours, particularly in areas where the channels split. In addition to missing the key features of the Solent tides, the TotalTide tidal diamonds are typically located close to areas where channels split and as such the flow predictions at these points are likely to be sensitive to the exact location of the observation point relative to the channel features. Flows are fastest through the entrance channels, with particularly fast flows during the ebb tide.

The model indicates that flows close to Southmoor are typically relatively slow (of the order 0.2 m/s) and complex in nature with the following characteristics;

- Eastward flows occurring from 6 hours before to 4 hours before HW;
- Convergence of flows occurring from 3 hours to 2 hours before HW;
- Westward flows occurring from 1 hour before to 2 hours after HW with an eddy forming on the intertidal fronting the managed realignment area; and
- Divergence of flows occurring from 3 hours to 5 hours after HW.

The exact timing of the tidal variations in flows (and the location of any eddies forming in the lee of the Langstone bridge) will be sensitive to the relative volumes of water entering from Langstone and Chichester harbours and to the relative geometry of the harbours. The currents in the area fronting Southmoor are therefore expected to be sensitive to meteorological forcing, particularly in view of the low tidal flows occurring. These complex flow characteristics will be considered when assessing the model performance.

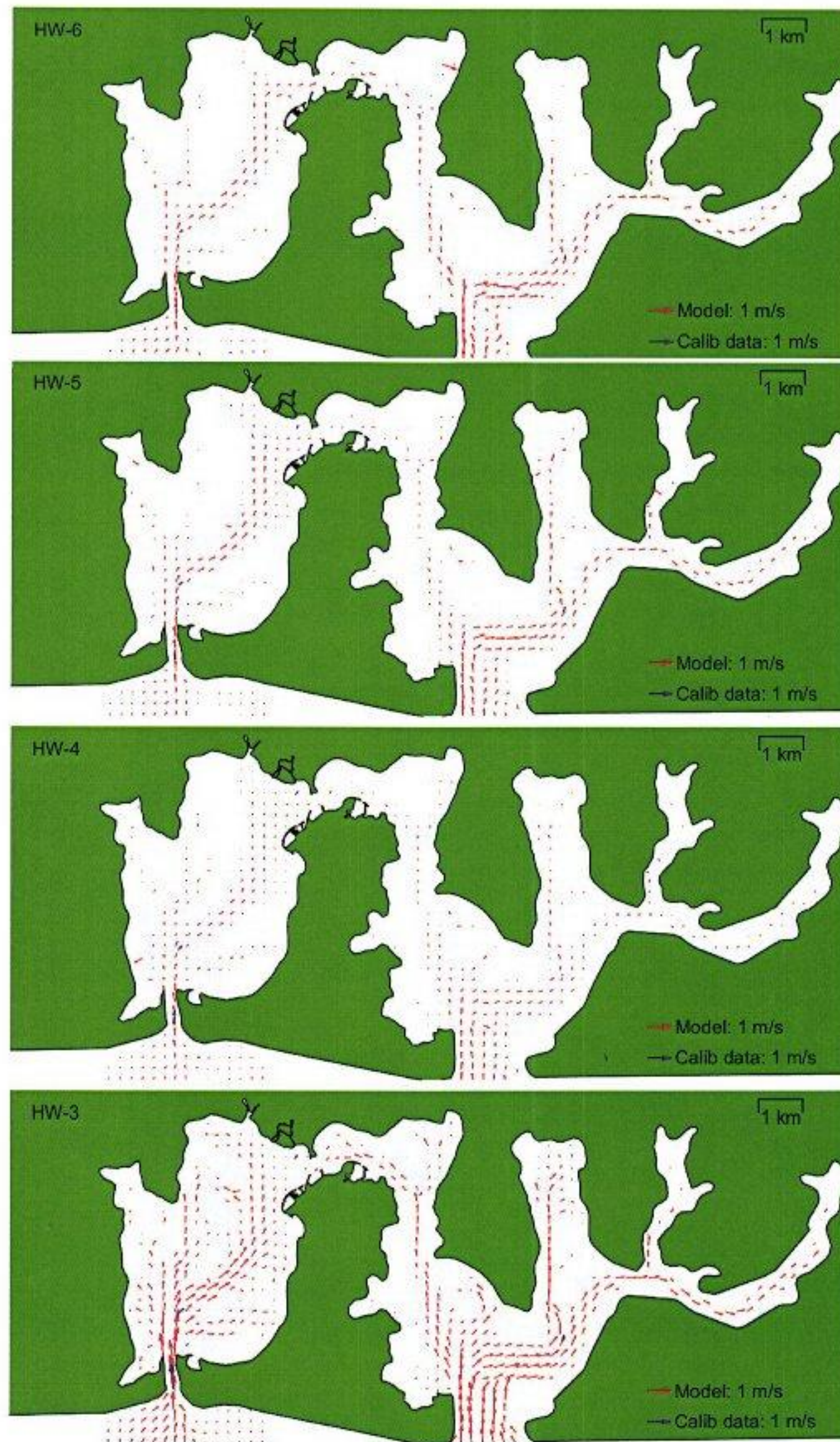


Figure A5. Flow maps at hourly intervals on a mean spring tide (at 6 hours, 5 hours, 4 hours and 3 hours before HW)

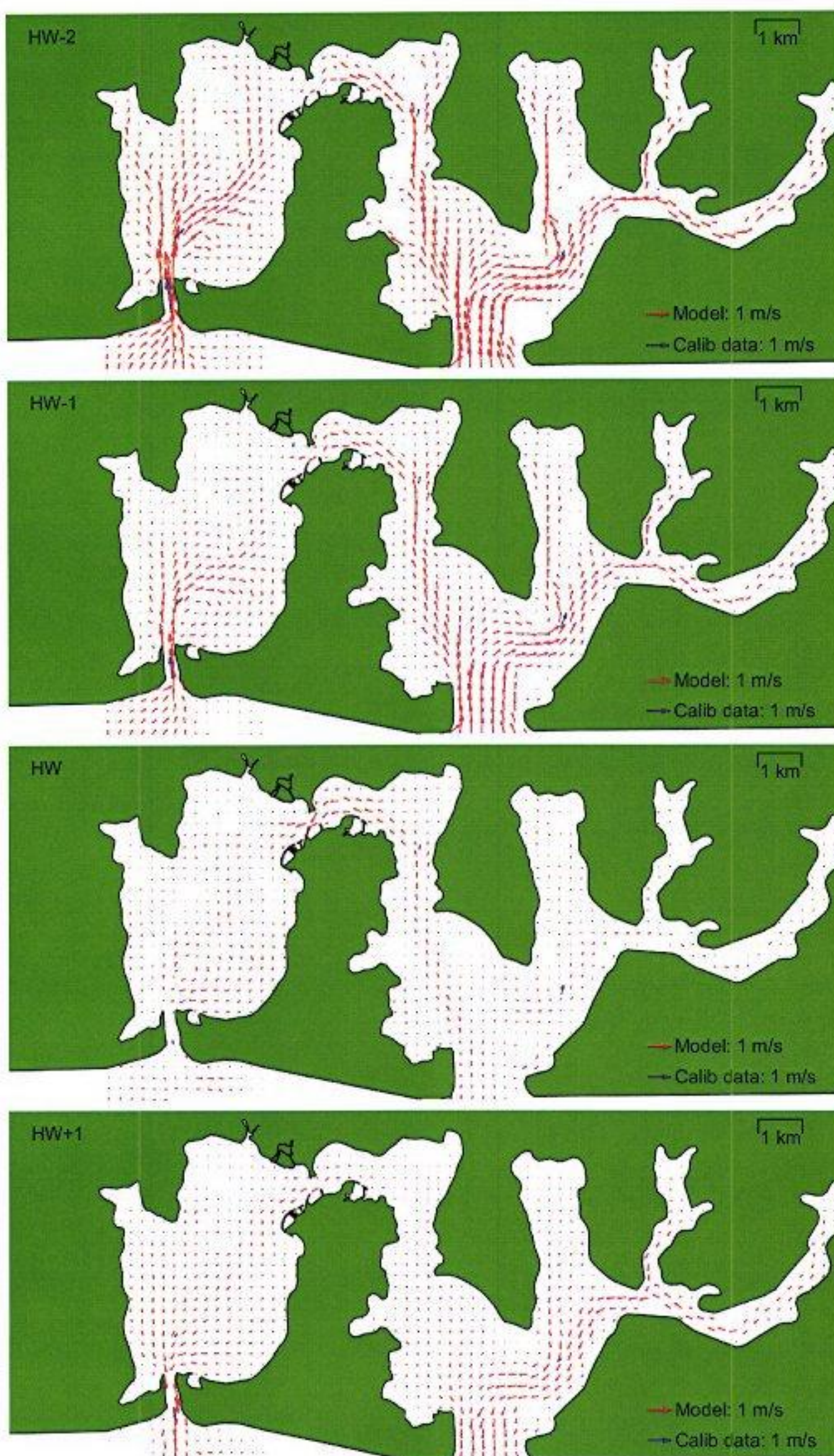


Figure A6. Flow maps at hourly intervals on a mean spring tide (at 2 hours and 1 hour before HW, HW and 1 hour after HW)

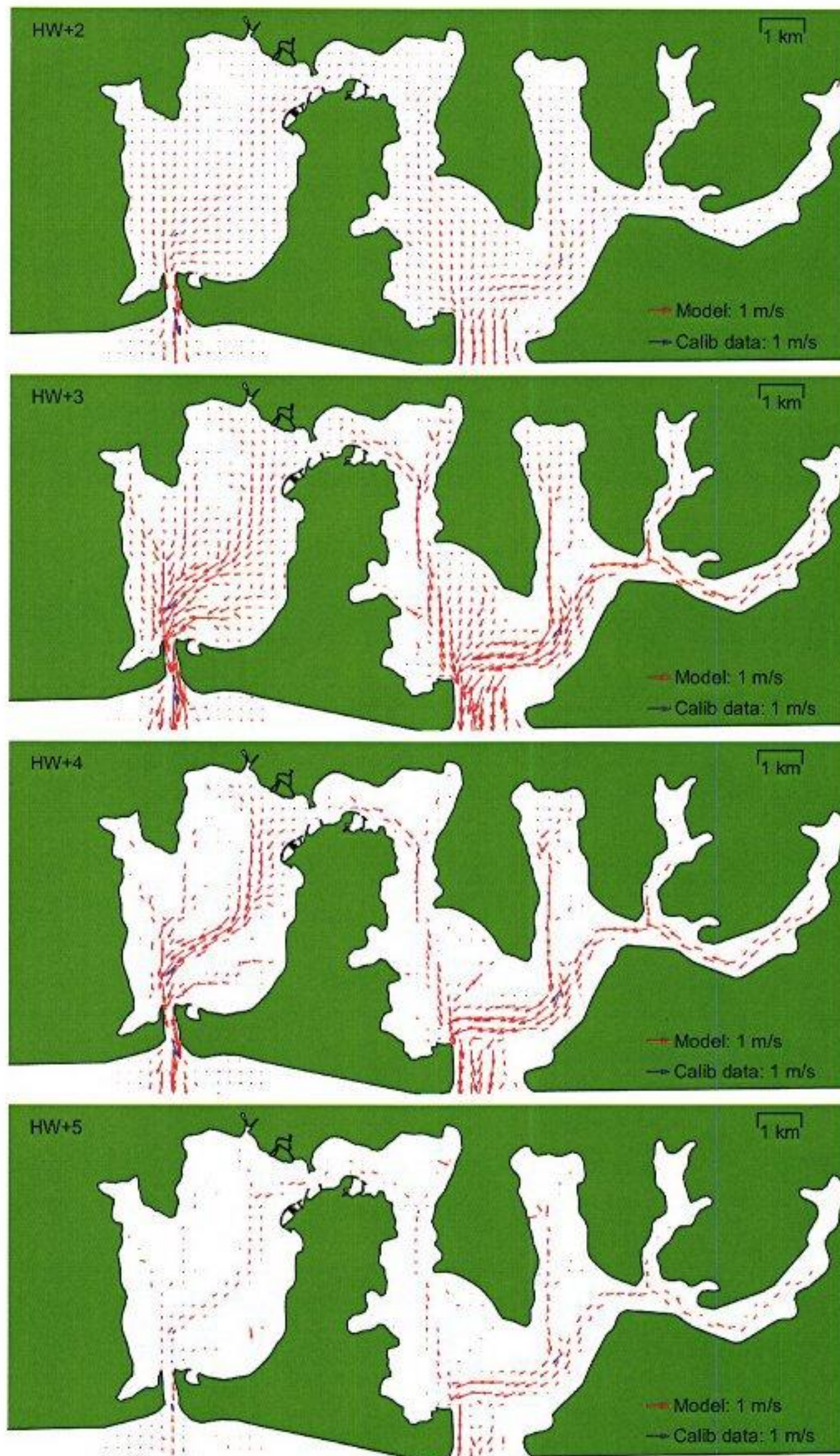


Figure A7. Flow maps at hourly intervals on a mean spring tide (at 2 hours, 3 hours, 4 hours and 5 hours after HW)

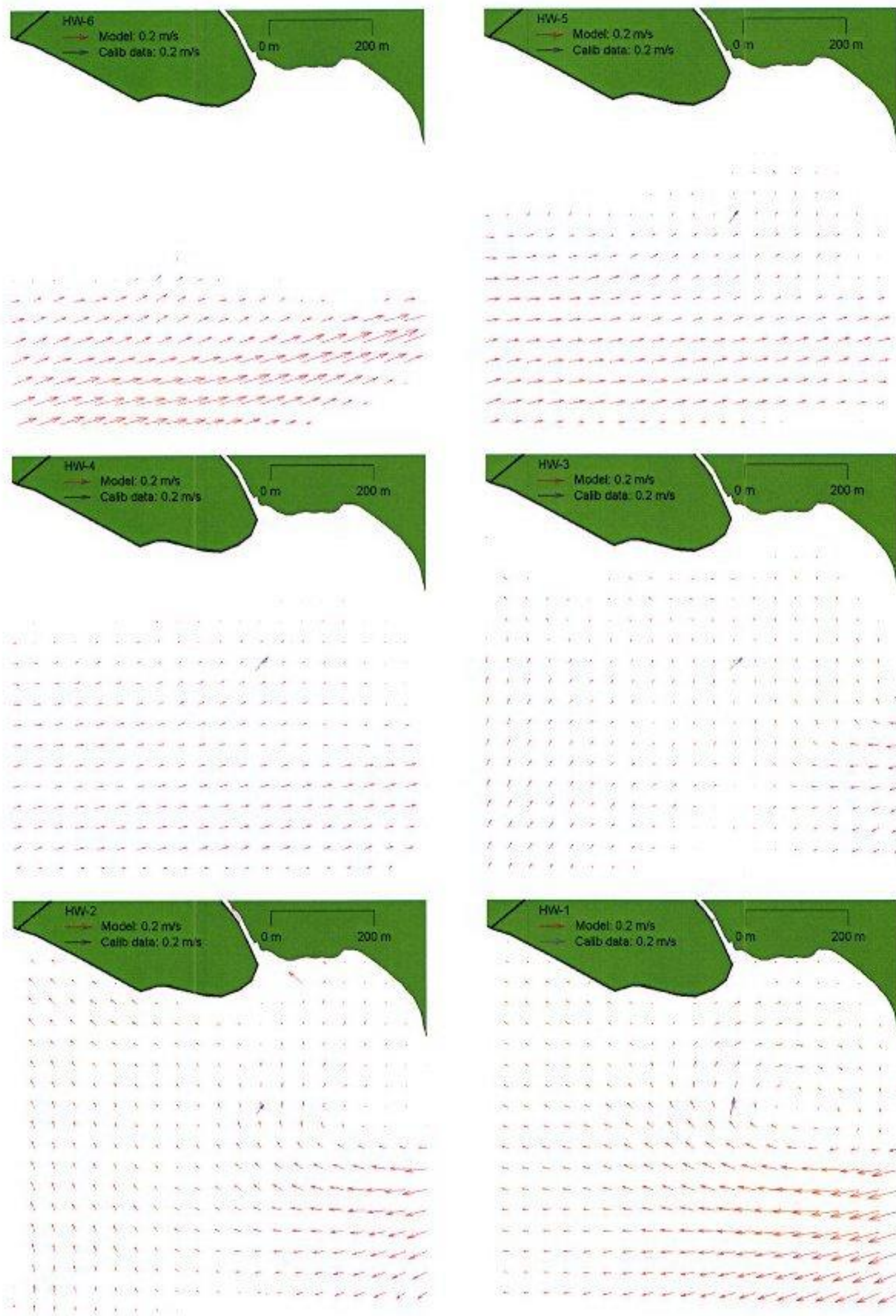


Figure A8. Local flow maps at hourly intervals on a mean spring tide (at 6 hours, 5 hours, 4 hours, 3 hours, 2 hours and 1 hour before HW)

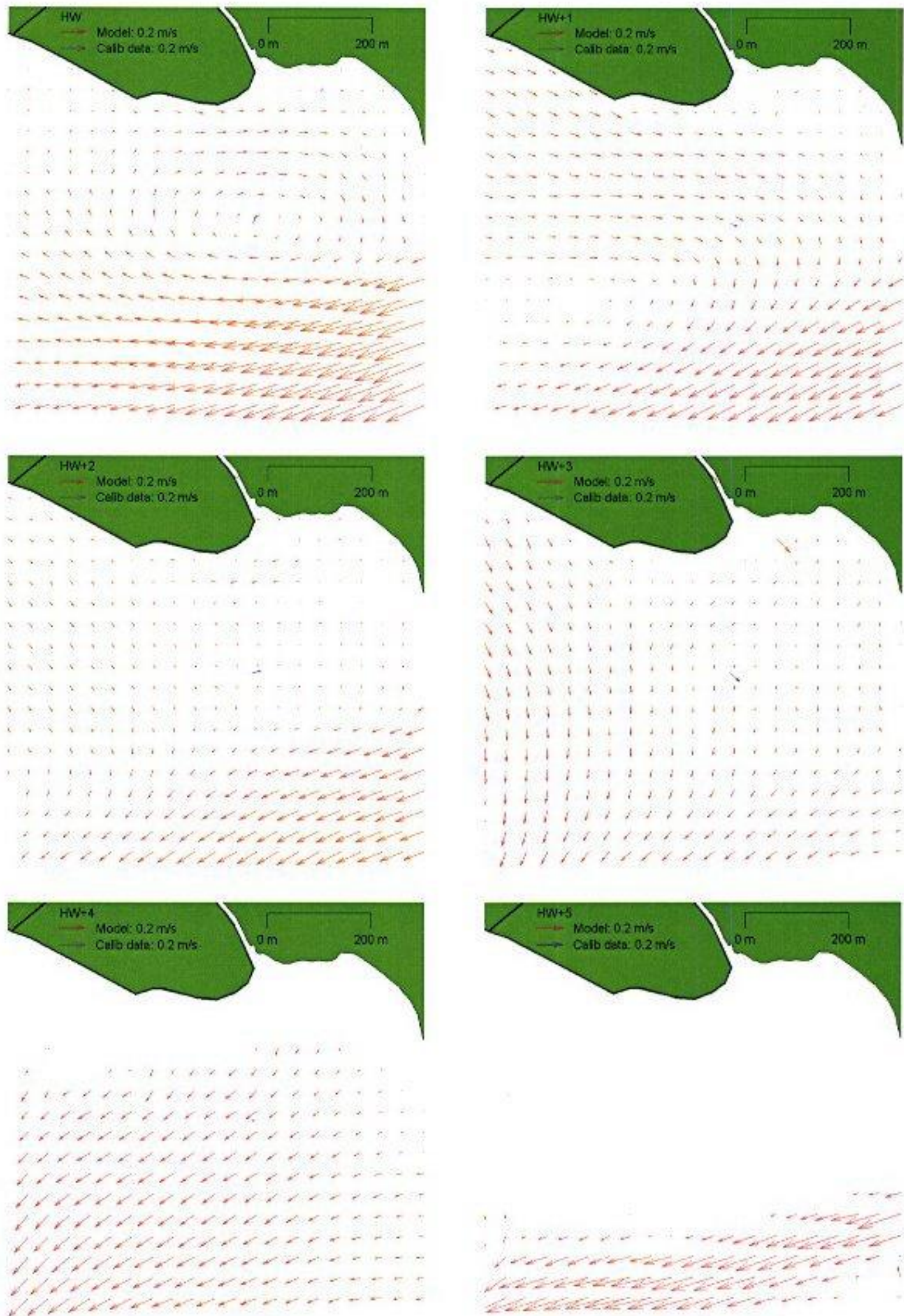


Figure A9. Local flow maps at hourly intervals on a mean spring tide (at HW, 1 hour, 2 hours, 3 hours, 4 hours and 5 hours after HW)

A.3.5 Model performance: Calibration

During the model calibration process a number of model setup parameters were iteratively modified until the best agreement with observed water levels and flows was achieved. Model boundary conditions and bed roughness were the main parameters tuned to improve model performance. As noted in Section A.3, the model calibration is focussed on data collected at Southmoor with a prime objective of replicating the observed water levels (as required to undertake modelling of managed realignment schemes). A time series plot of modelled water levels and observed water levels at Southmoor is shown in Figure A10.

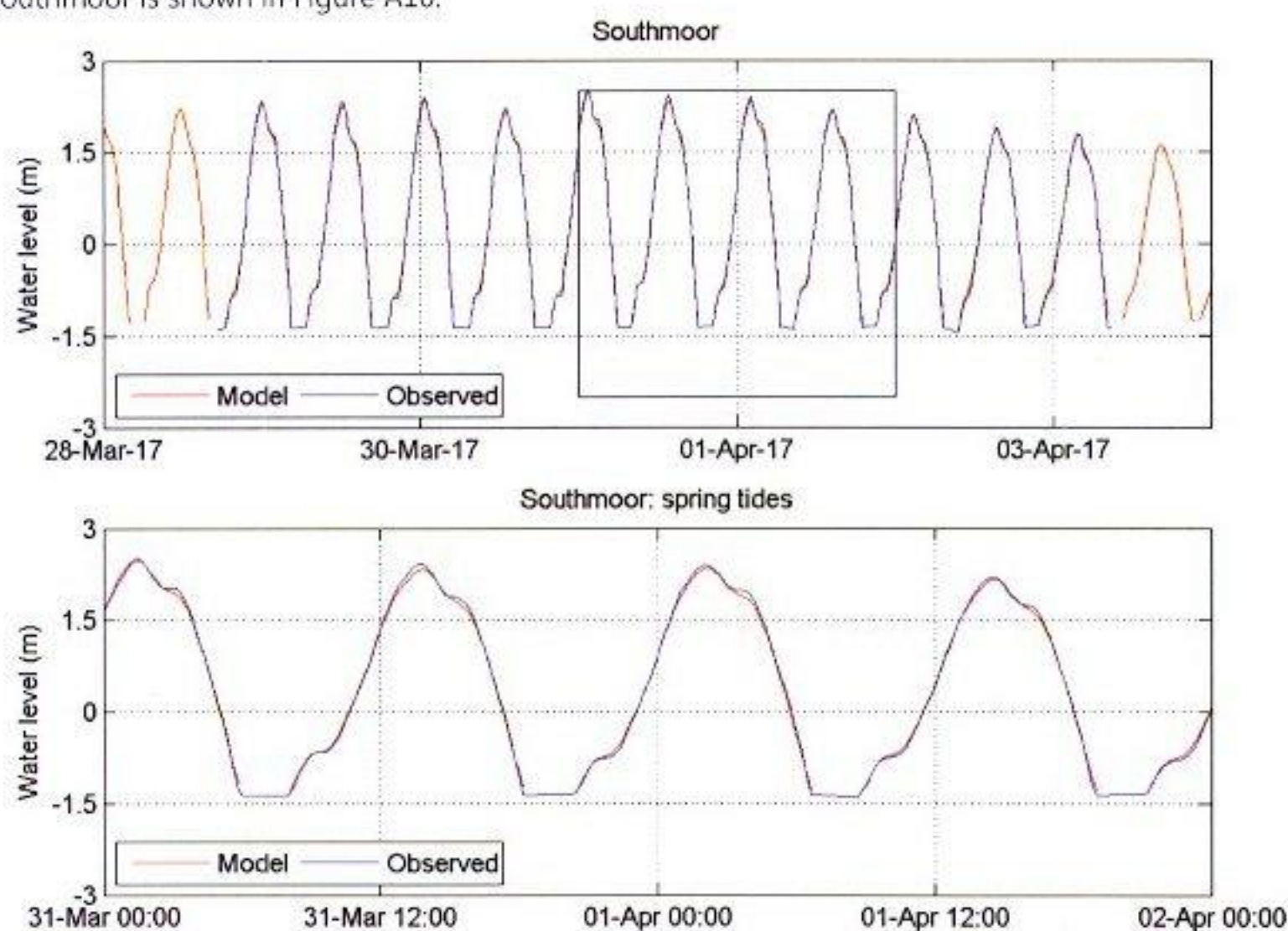


Figure A10. Model calibration against Southmoor Aquadopp water levels

The modelled water levels agree very well with the observed levels, replicating the Young Flood Stand and the prolonged HW period as well as capturing the rates of inundation and draining. The results from the statistical comparison of modelled and observed water levels (calculated over a 15 day spring-neap cycle and given in Table A1) support this assessment, with the performance metrics quoted in Section A.3.3 being achieved.

Table A1. Calibration water level statistics (2017)

Station	Mean Difference at HW		Mean Difference at LW		RMS Difference (m)	HW Phase Difference (minutes)	Time Adjusted Fit
	m	%	m	%			
Primary Dataset							
Southmoor Aquadopp	-0.04	-1	-	-	0.08	3	-1
Secondary Datasets							
Chichester	0.04	1	0.08	2	0.17	-8	6
Langstone	-0.05	-2	0.10	3	0.14	10	8
Northney	0.19	5	0.39	11	0.42	-14	2
Values in bold are above guideline standards							

Values in bold are above guideline standards

Time series of modelled flows and observed flows at Southmoor are plotted in Figure A11.

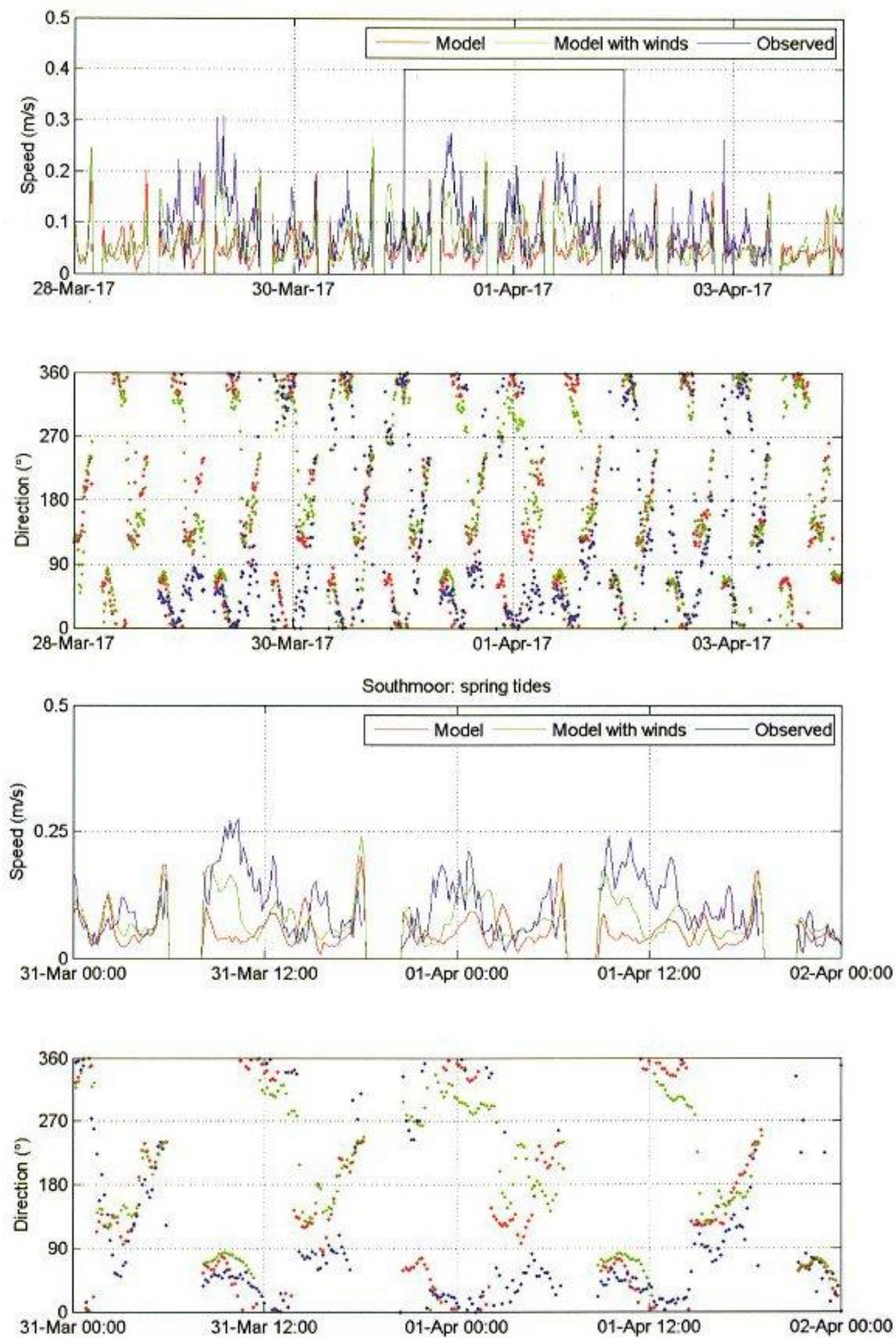


Figure A11. Model calibration against Southmoor Aquadopp flows

The observed flows at this location show a large degree of temporal variability with peaks in flood and ebb difficult to identify (due to the relatively low flows and likely presence of an eddy during times of the tidal cycle) and with no consistent trend between subsequent tides (expected to be due to the influence of meteorological forcing on flows). Modelled flows are shown for two different simulations; one with only tidal forcing driving the flows and one with tidal and wind forcing. The wind forcing is applied as a spatially constant but temporally varying field, based on winds measured at Chichester Bar (by the Solentmet Support Group). The latter simulation was undertaken to demonstrate the sensitivity of the flows on the intertidal fronting the managed realignment area to meteorological forcing. Taking account of the effect of the meteorological forcing on the observed flows, it is considered that the model does a reasonable job of replicating the observed flows, capturing both the typical mean speeds and the large degree of temporal variability (if not fully replicating the exact timing in peak flows which are expected to be sensitive to meteorological forcing). The statistical comparison of modelled and observed flows at Southmoor is given in Table A2. With the exception of the time adjusted fit, the statistics achieve the performance metrics quoted in Section A.3.3; the application of winds in the model improves the time adjusted fit, resulting in the modelled flows achieving the performance criteria.

Table A2. Calibration flow statistics (2017)

Station	Mean Speed Difference (m/s)		Mean Direction Difference (°)		Time Adjusted Fit (minutes)	RMS Difference (m/s)
	Flood	Ebb	Flood	Ebb		
Primary Datasets						
Southmoor Aquadopp	-0.08	0.00	7	-	-22	0.07
Southmoor Aquadopp – with winds	-0.06	0.01	-6	-	-4	0.05
Secondary Datasets						
SN005AZ	-0.20	0.32	3	9	17	0.27
SN005AN	0.15	0.13	-8	-20	10	0.14
SN007U	-0.11	-0.05	27	4	-15	0.11
SN007T	0.01	-0.09	20	3	-5	0.05
Values in bold are above guideline standards						

Values in bold are above guideline standards

Modelled water levels are compared against TotalTide water levels in Figure A12 to Figure A14, with statistics (calculated for a 15 day spring-neap cycle) provided in Table A1. The modelled levels and TotalTide levels are broadly consistent, notwithstanding the limitations of the TotalTide data. The modelled levels are believed to provide a more accurate representation of the actual levels than the TotalTide predictions and where the performance metrics are not met is likely to be indicative of limitations with the TotalTide predictions (as discussed in Section A.3.1), particularly in view of the good agreement in modelled levels against observed data at Southmoor.

Modelled flows are compared against flows from TotalTide tidal diamonds in Figure A15 to Figure A18, with statistics (calculated for a 15 day spring-neap cycle) provided in Table A2. As with the water levels, the modelled flows are believed to provide a more accurate representation of the actual flows than the TotalTide predictions and where the performance metrics are not met is likely to be indicative of limitations with the TotalTide predictions (as discussed in Section A.3.1).

For example, at SN005AZ which lies in the entrance to Langstone Harbour, TotalTide flows are flood dominant, while the model is ebb dominant. Consequently it appears that modelled ebb flows are over predicted. However, predicted flows from SN005AN and observed flows from an AWAC in the main channel within Langstone Harbour (approximately 1.2 and 2 km further north, respectively) both show an ebb dominance and it is likely that ebb flows at SN005AZ are therefore under predicted by

TotalTide. Flows at SN005AZ are likely to be sensitive to depths across the entrance channel; notable changes in bathymetry are known to occur in this region as a result of shifts in the location of the banks of East Winner and West Winner after gales. The performance of modelled flows against observed flows in the main channel in Langstone Harbour is discussed in more detail in Section A.3.6.

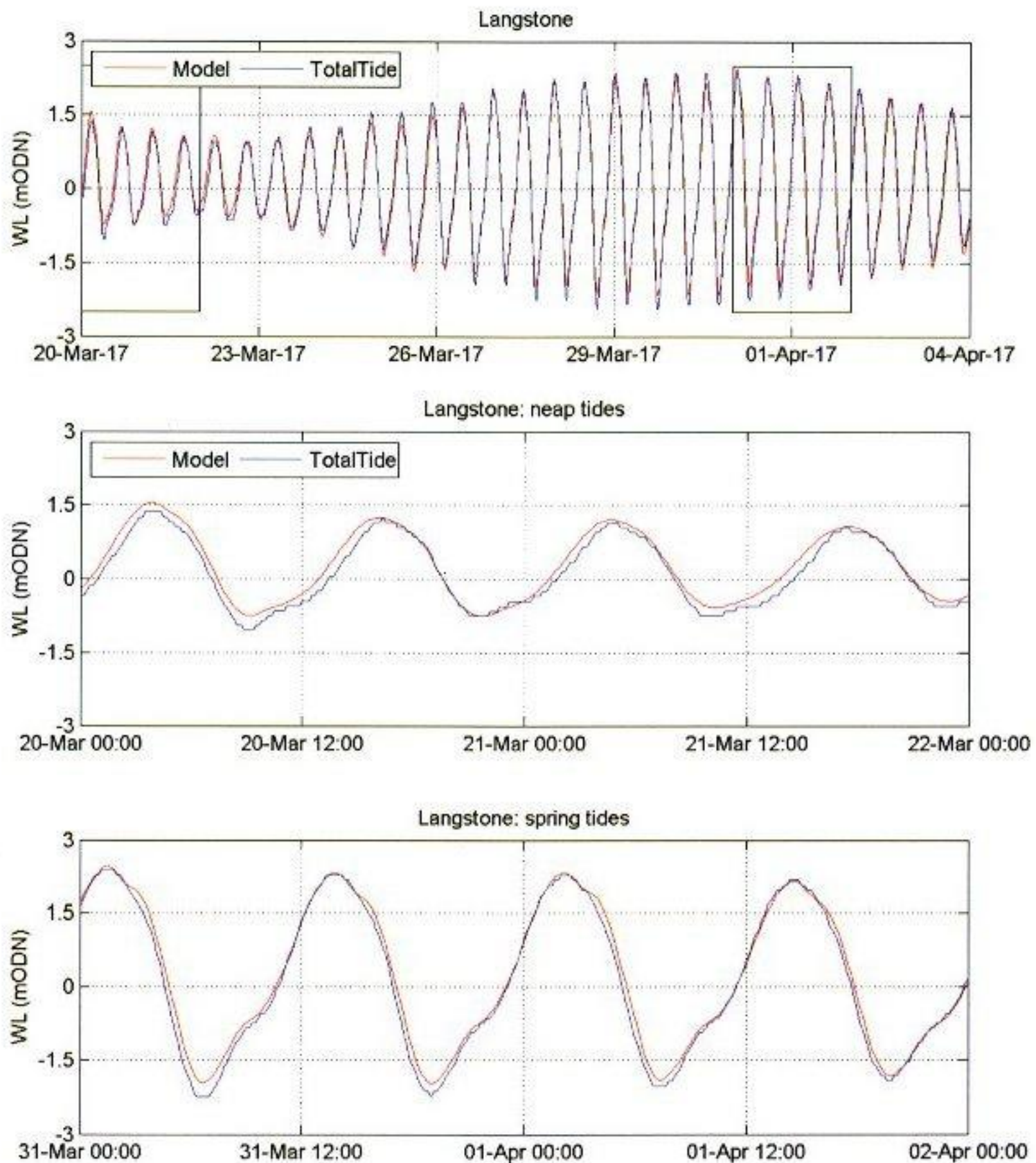


Figure A12. Model calibration of water levels at Langstone against TotalTide predictions

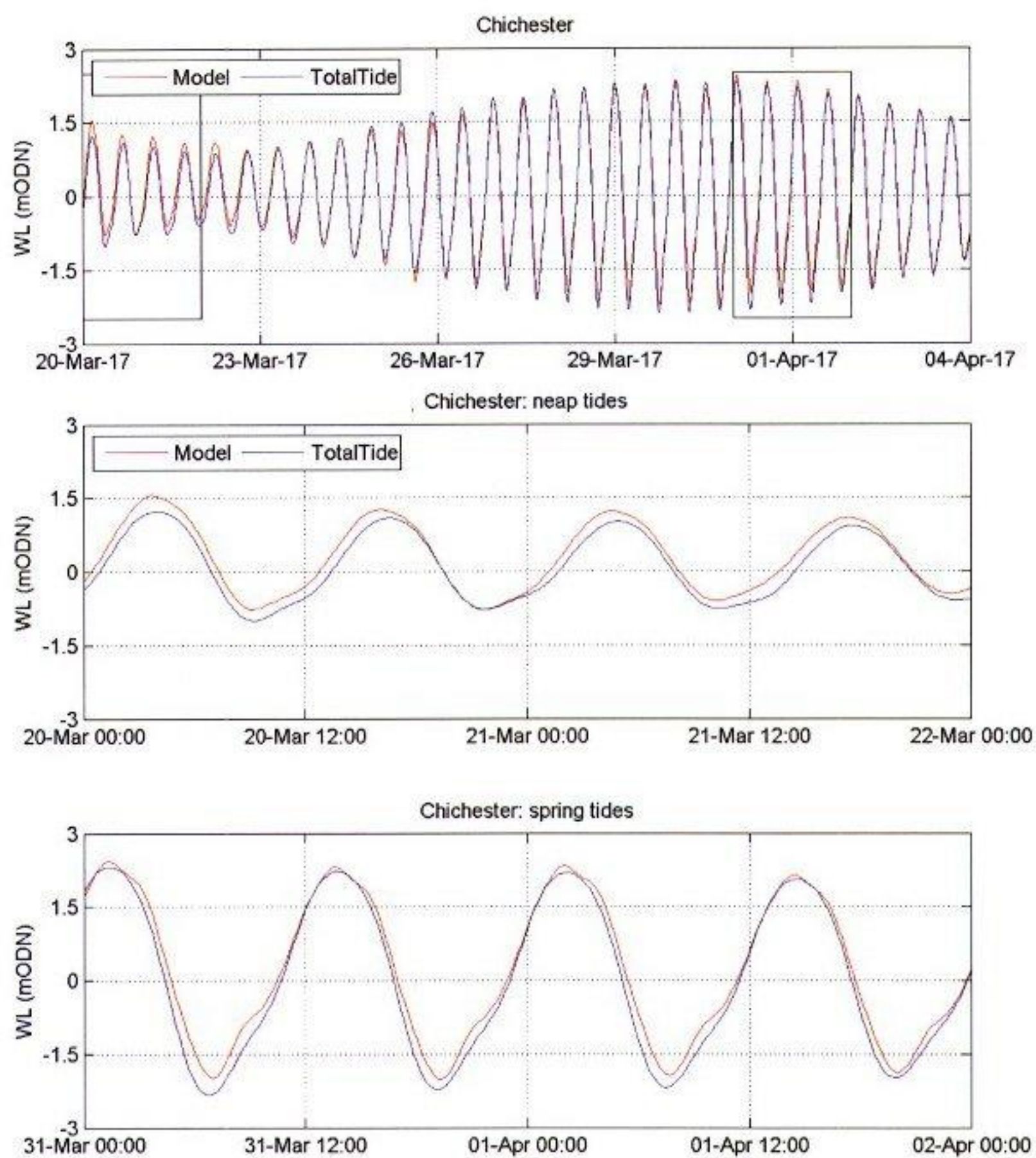


Figure A13. Model calibration of water levels at Chichester against TotalTide predictions

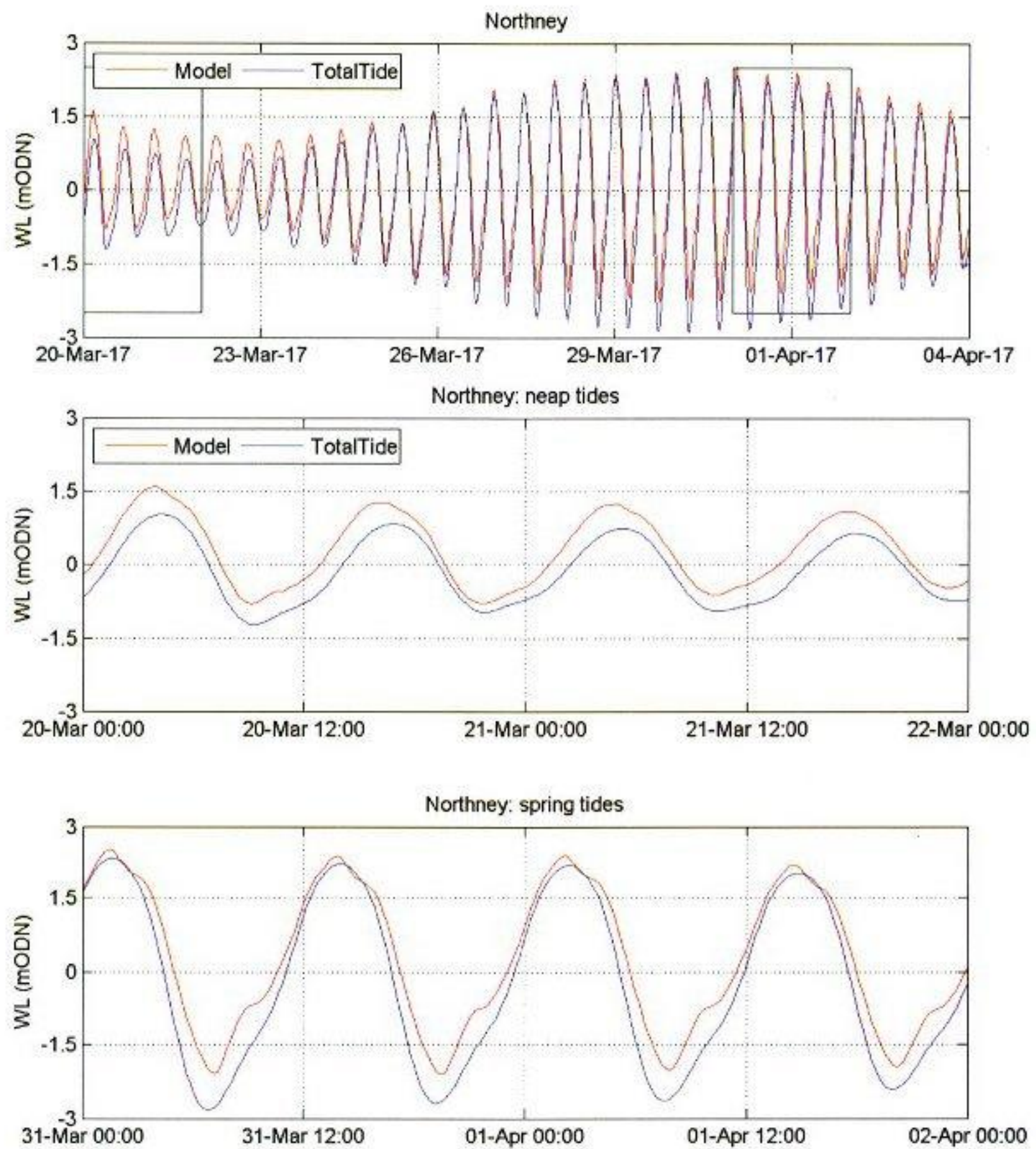


Figure A14. Model calibration of water levels at Northney against TotalTide predictions

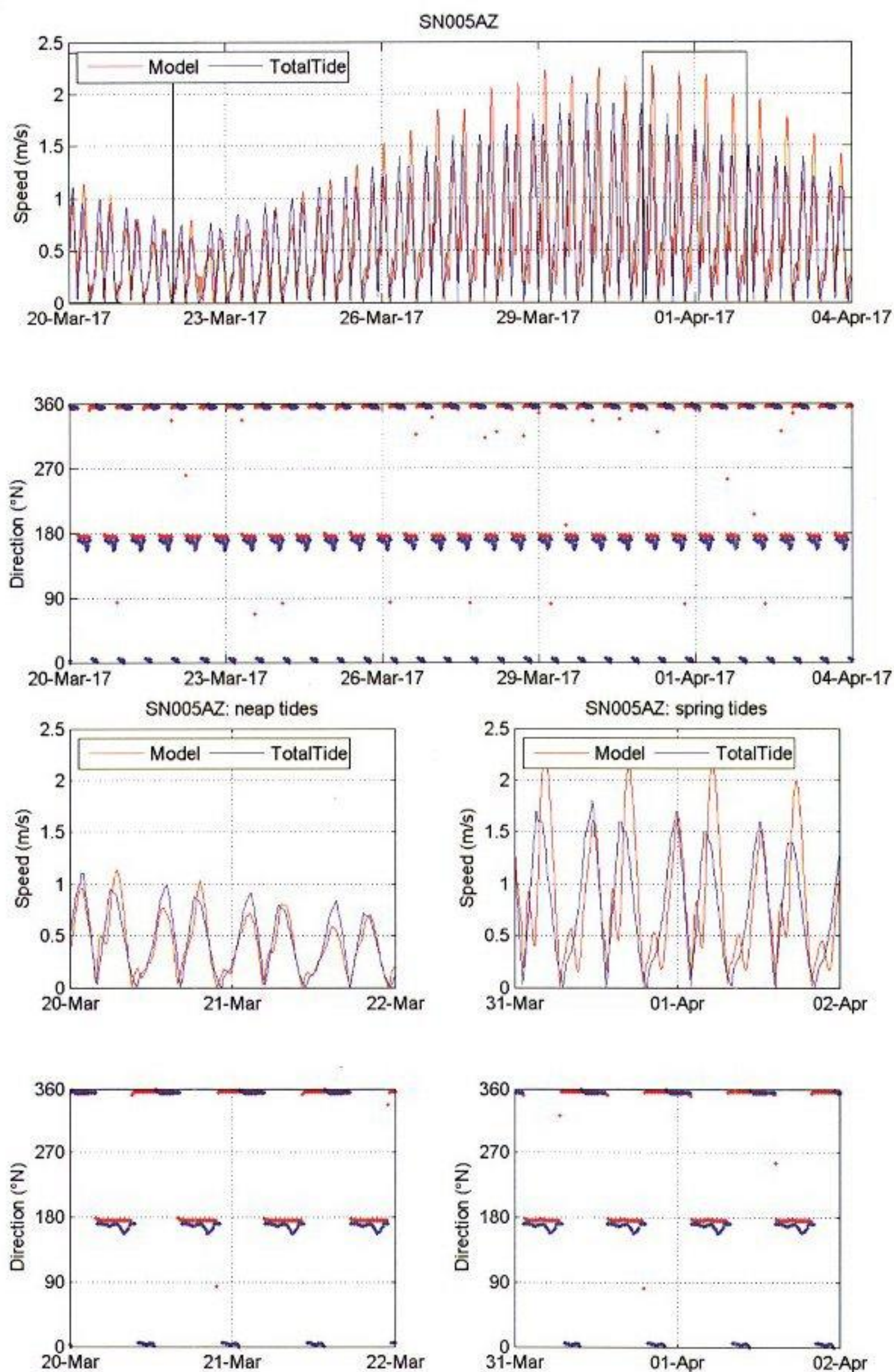


Figure A15. Model calibration of flows against TotalTide predictions at SN005AZ

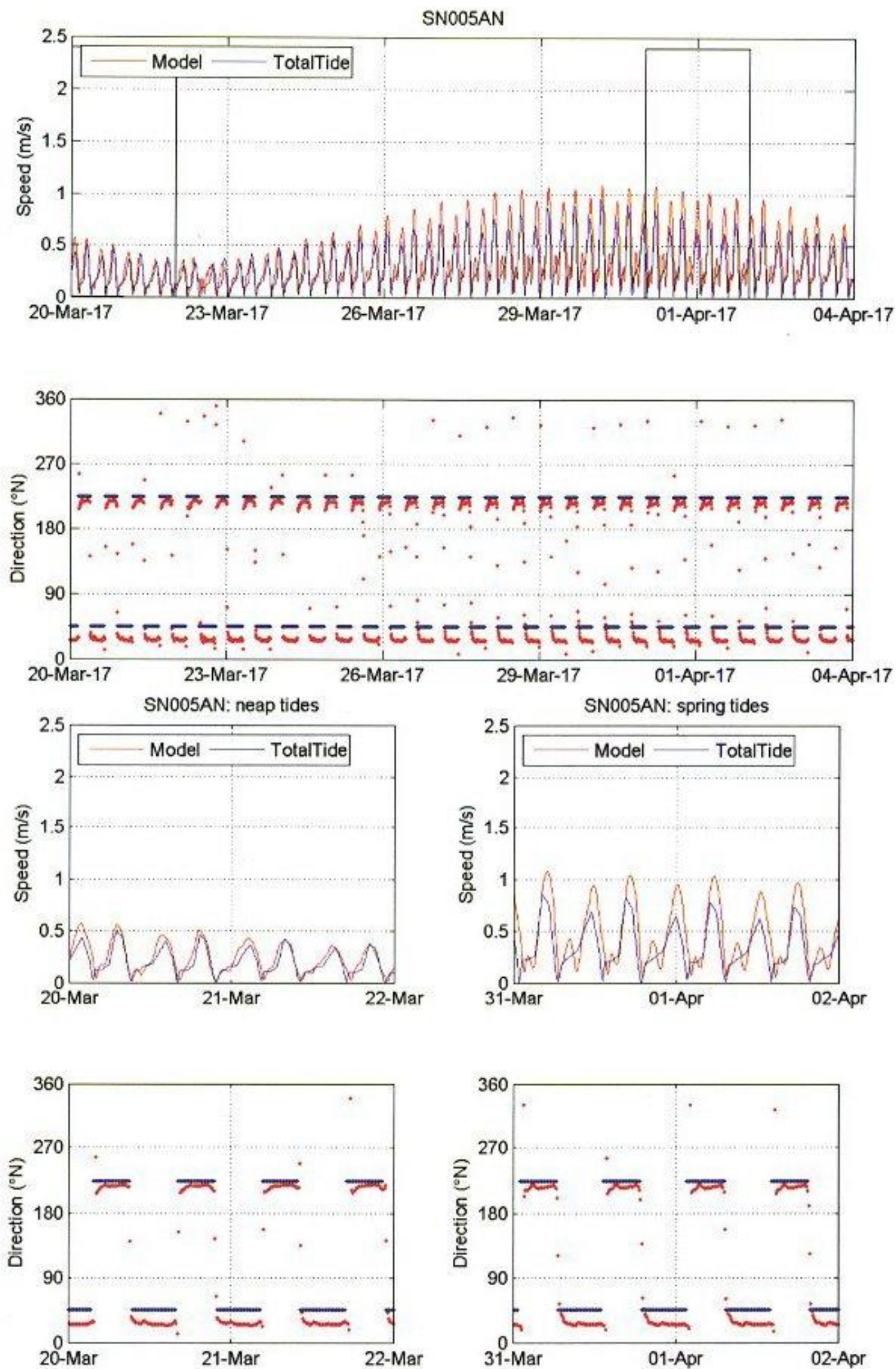


Figure A16. Model calibration of flows against TotalTide predictions at SN005AN

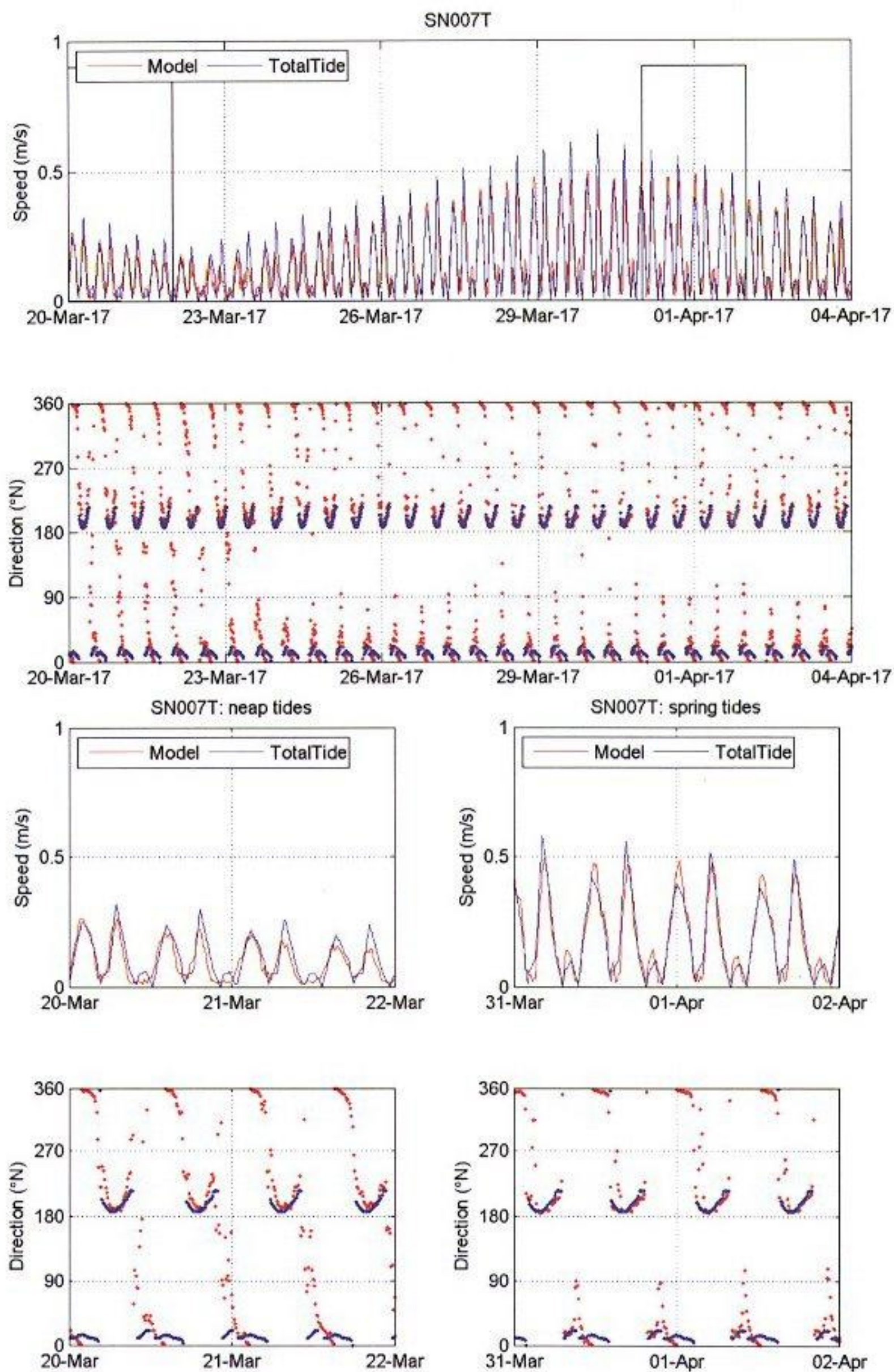


Figure A17. Model calibration of flows against TotalTide predictions at SN007T

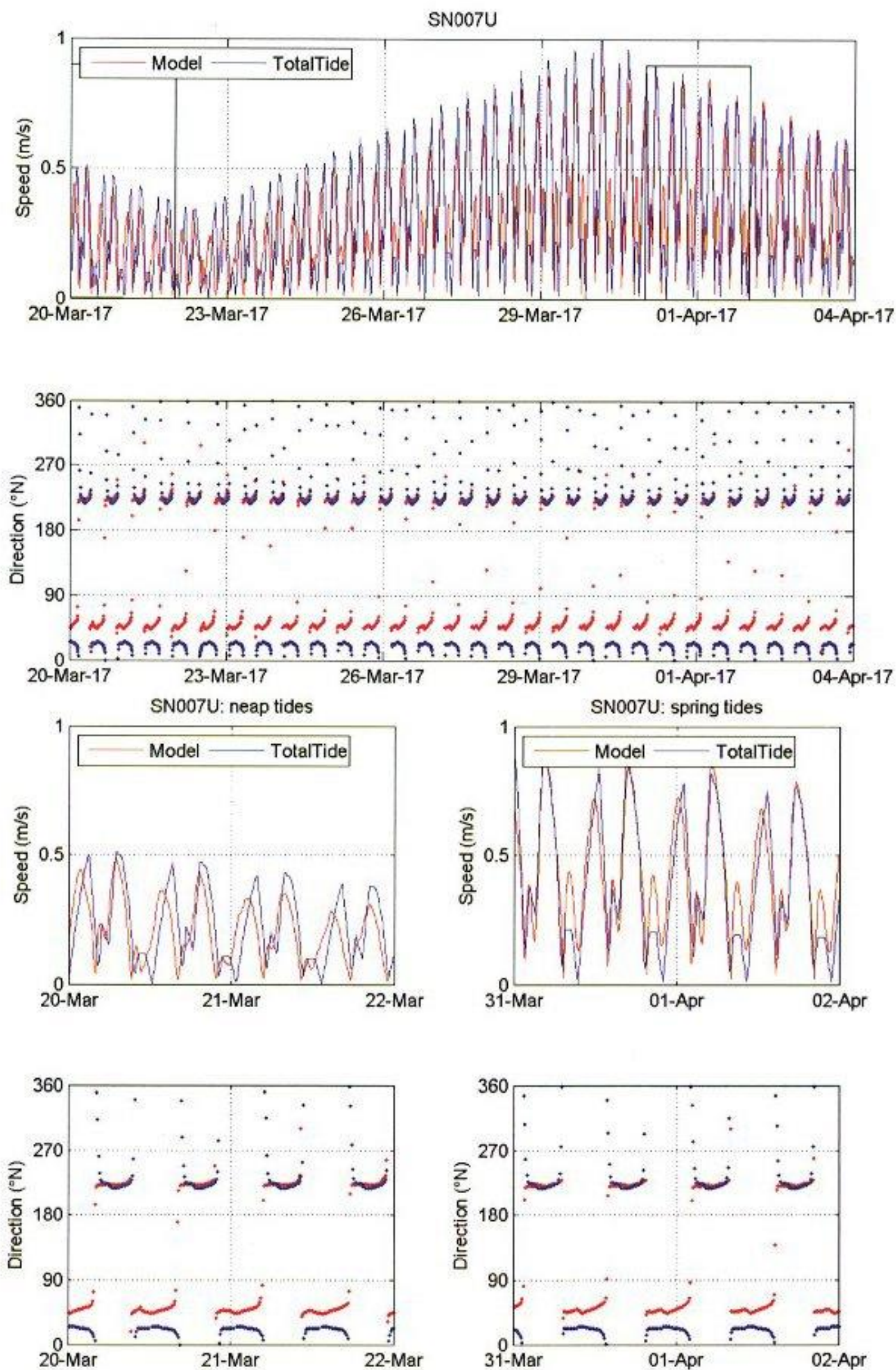


Figure A18. Model calibration of flows against TotalTide predictions at SN007U

A.3.6 Model performance: Validation

Time series of modelled and observed water levels during the validation period are shown in Figure A19 to Figure A21. As during the calibration period, the modelled water levels show a very good agreement with the observational water levels, with the main features of the Solent tide well replicated and the performance targets being met (see Table A3) at these three sites.

Table A3. Validation water level statistics (2009)

Station	Mean Difference at HW		Mean Difference at LW		RMS Difference (m)	HW Phase Difference (minutes)	Time Adjusted Fit
	m	%	m	%			
Primary Dataset							
Main Channel AWAC	-0.01	0	0.06	2	0.07	3	-1
Russells Lake Profiler	-0.02	-1	0.13	4	0.07	4	1
Bedhampton gauge	0.00	0	-	-	0.11	2	0
Secondary Datasets							
Chichester	0.14	4	0.05	2	0.16	-7	7
Langstone	0.08	3	-0.02	-1	0.10	18	3
Northney	0.31	9	0.33	10	0.42	-15	3
Values in bold are above guideline standards							

Time series of modelled and predicted water levels from TotalTide are plotted in Figure A22 to Figure A24. Modelled water levels at Northney do not meet the performance targets but this is expected to be due to the limited accuracy of the TotalTide levels, rather than an inaccuracy in the model.

Time series of modelled and observed flows in the main channel in Langstone Harbour are plotted in Figure A25. Both the model and observations indicate an ebb dominance, with the observed ebb flows slightly faster than those in the model (with peaks on spring tides of 0.85 m/s in the model compared to observed peaks of 1.1 m/s). Despite this, RMS differences in flow are 0.09 m/s, which is within the guideline standards (see Table A4).

Table A4. Validation flow statistics (2009)

Station	Mean Speed Difference (m/s)		Mean Direction Difference (°)		Time Adjusted Fit (minutes)	RMS Difference (m/s)
	Flood	Ebb	Flood	Ebb		
Primary Datasets						
Main Channel AWAC	-0.04	-0.15	8	2	-1	0.09
Secondary Datasets						
SN005AZ	-0.11	0.39	9	3	20	0.24
SN005AN	0.18	0.17	-20	-8	7	0.15
SN007U	-0.07	-0.01	27	4	-18	0.10
SN007T	0.03	-0.06	-16	0	-7	0.04
Values in bold are above guideline standards						

Modelled flows and TotalTide predictions of flows at the tidal diamonds are shown in Figure A26 to Figure A29 and results of the statistical comparison are provided in Table A4. The model performance against TotalTide predictions during the validation period is consistent with that achieved during the calibration period.

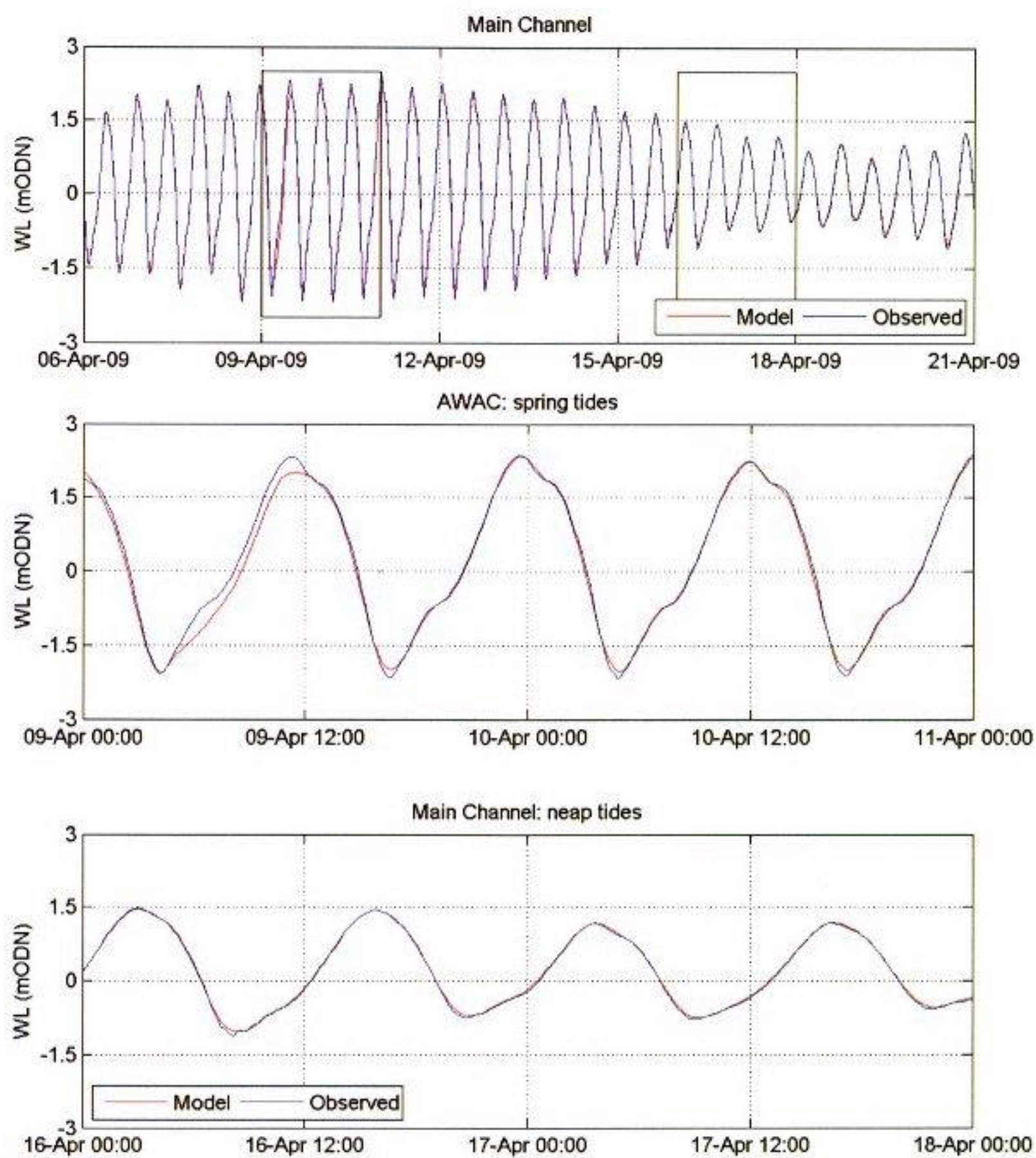


Figure A19. Model validation of water levels in the Main Channel against AWAC data

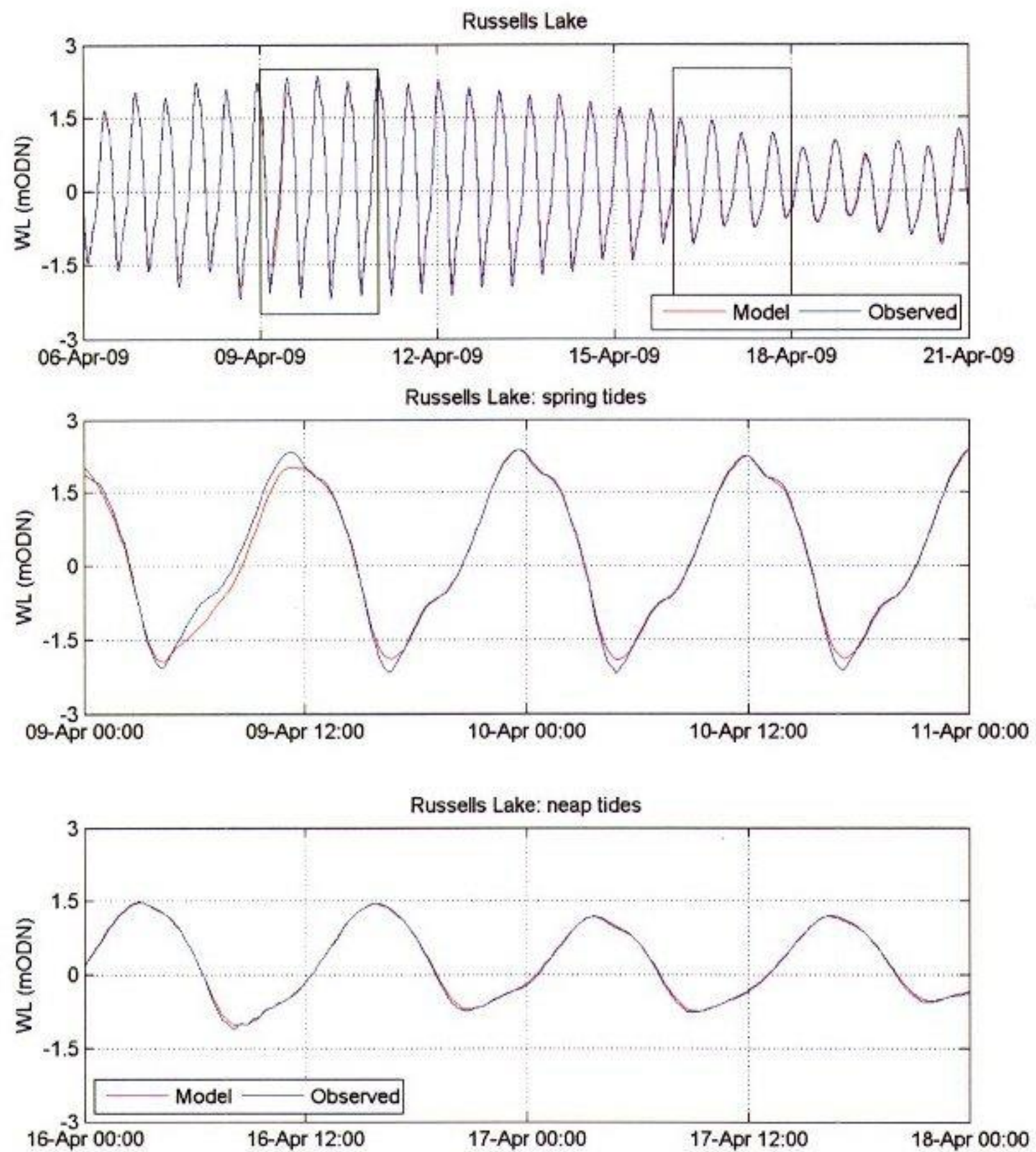


Figure A20. Model validation of water levels at Russells Lake against Profiler data

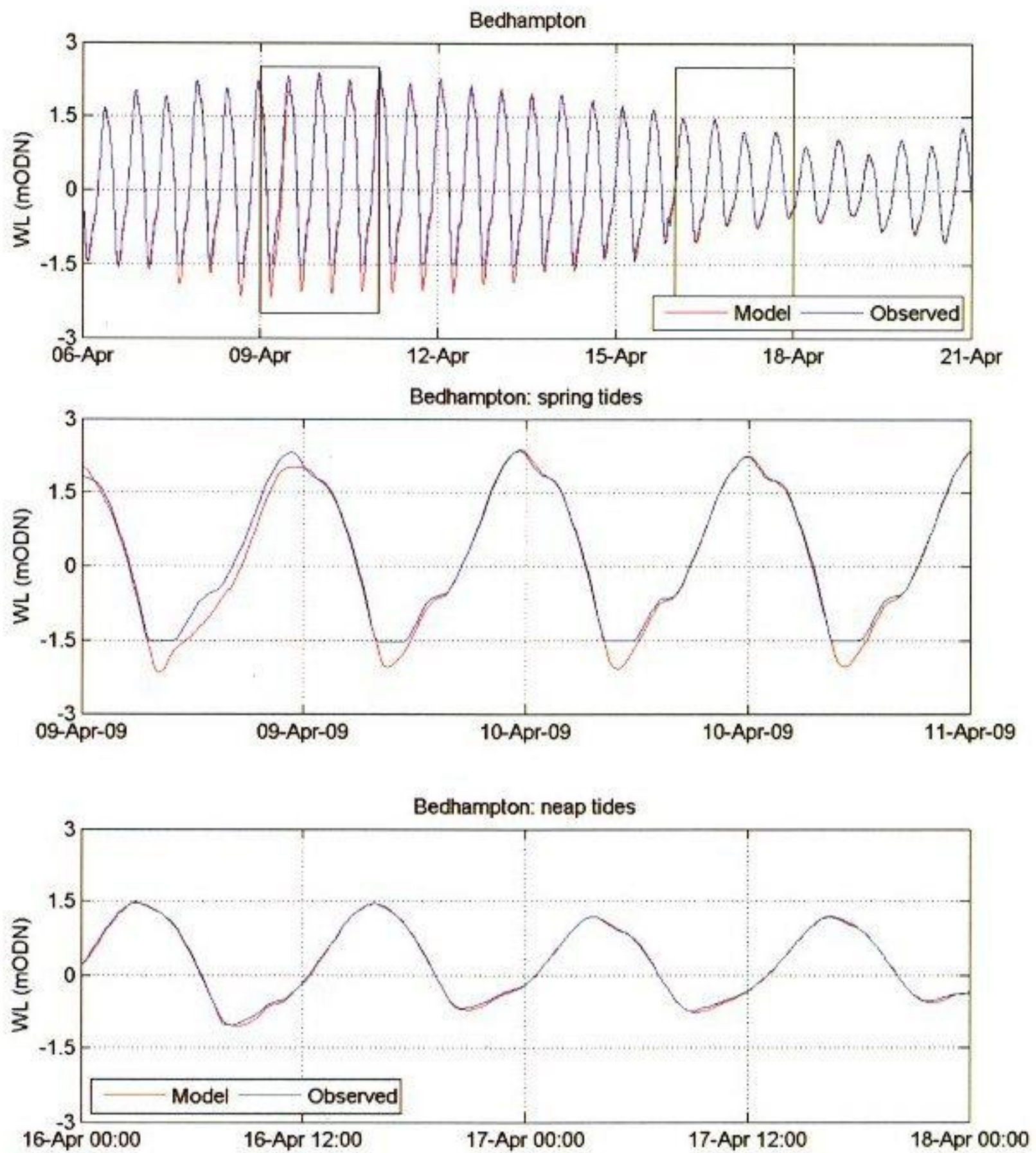


Figure A21. Model validation of water levels at Bedhampton against tide gauge data

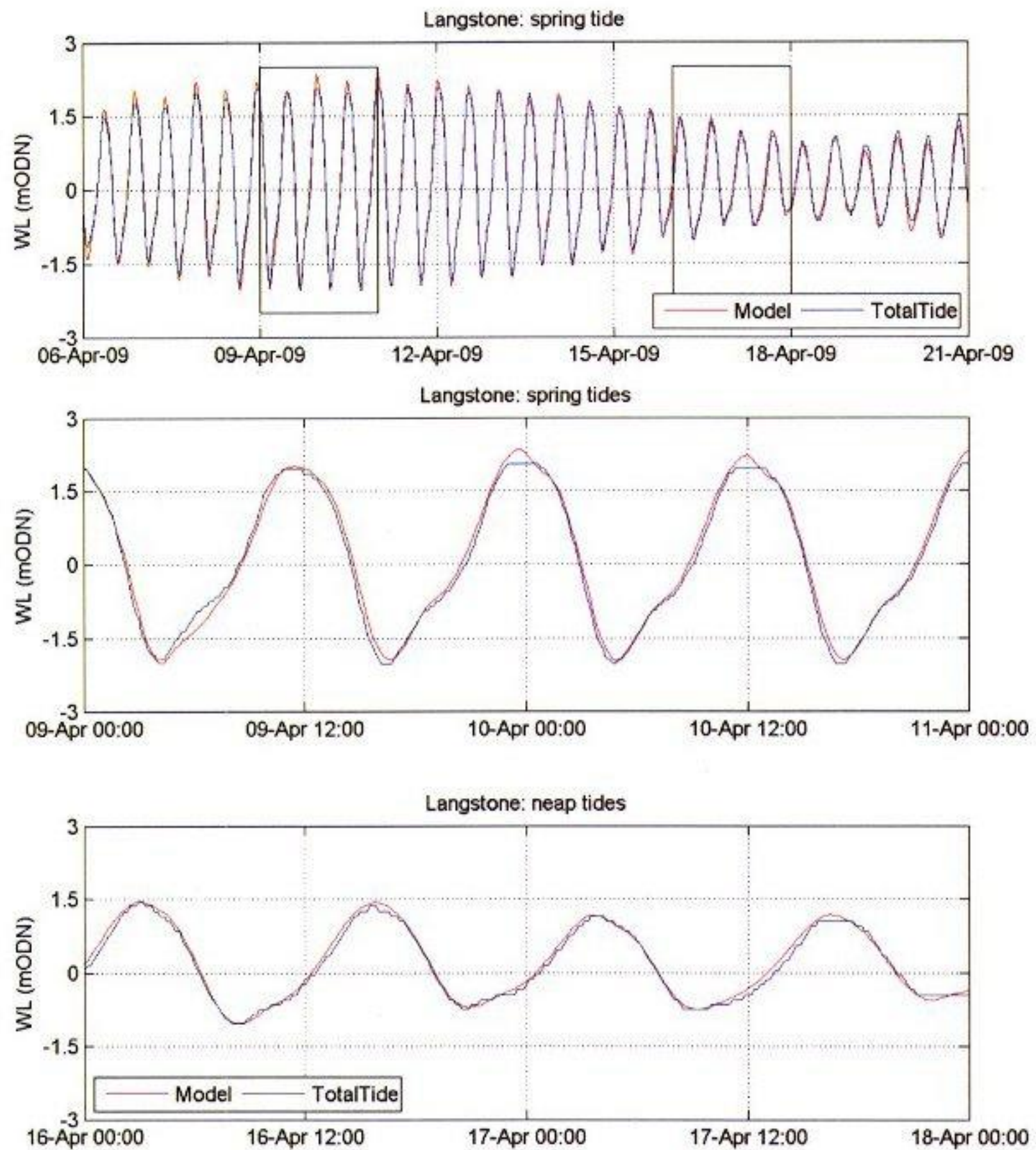


Figure A22. Model validation of water levels at Langstone against TotalTide predictions

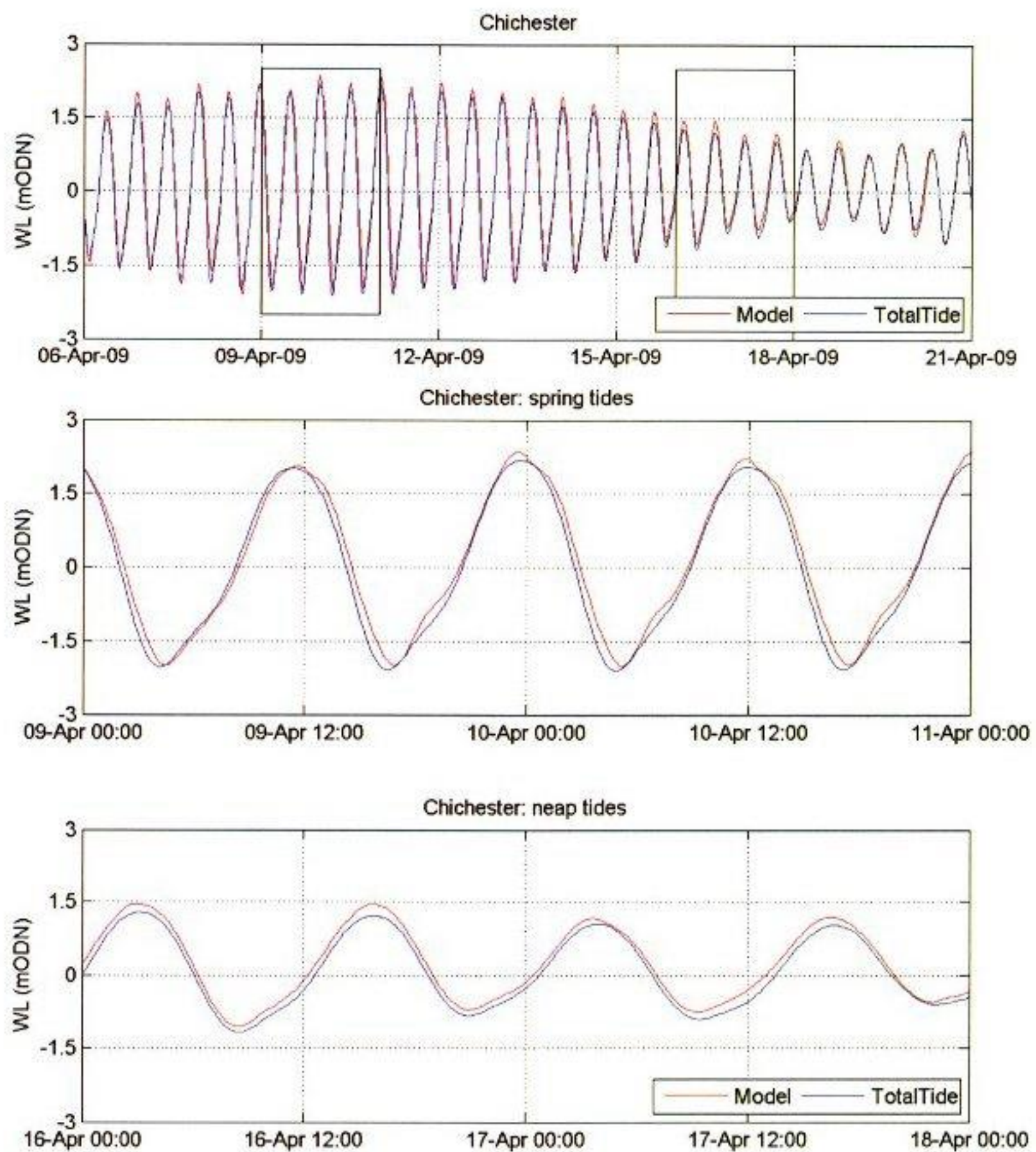


Figure A23. Model validation of water levels at Chichester against TotalTide predictions

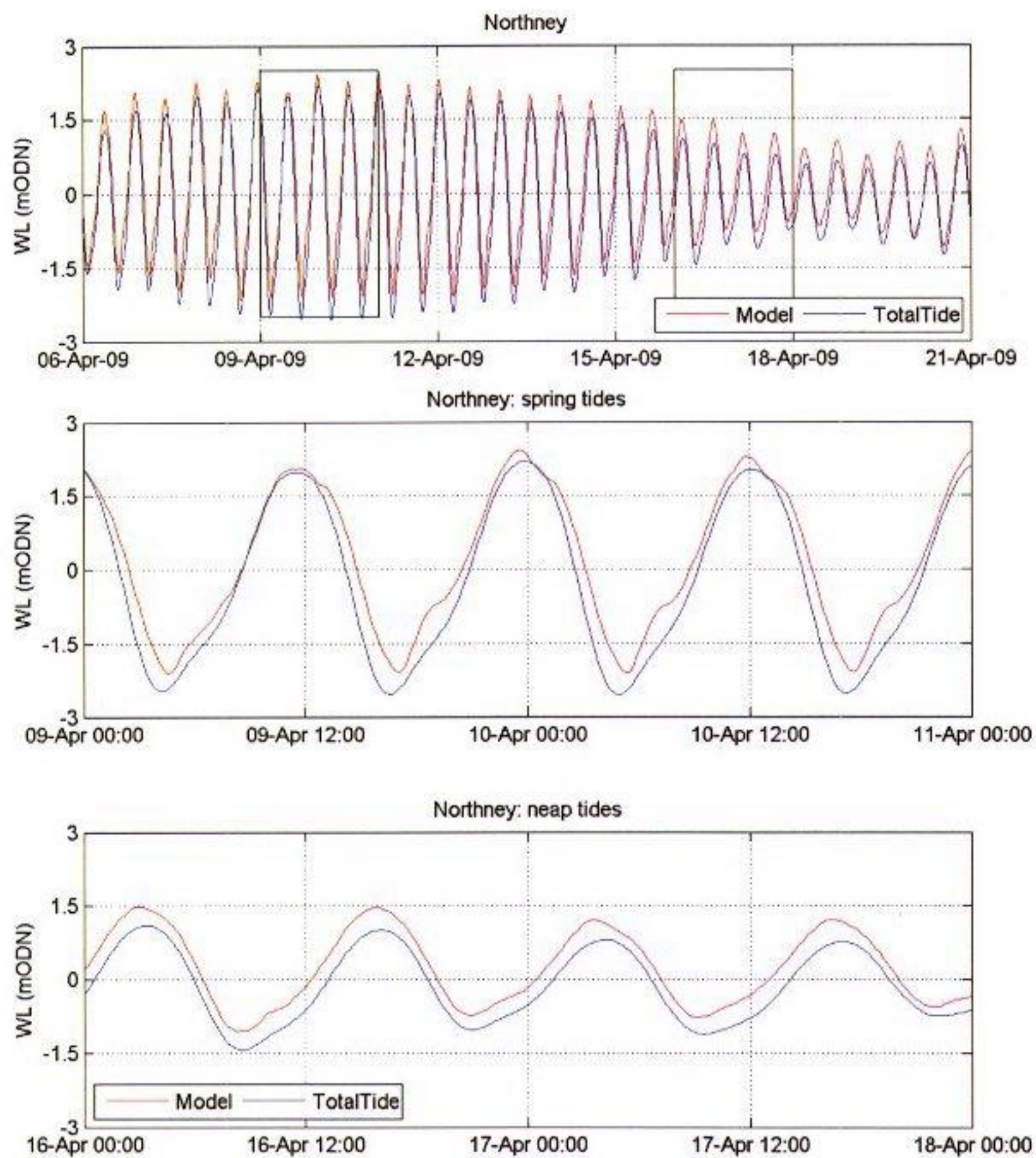


Figure A24. Model validation of water levels at Northney against TotalTide predictions

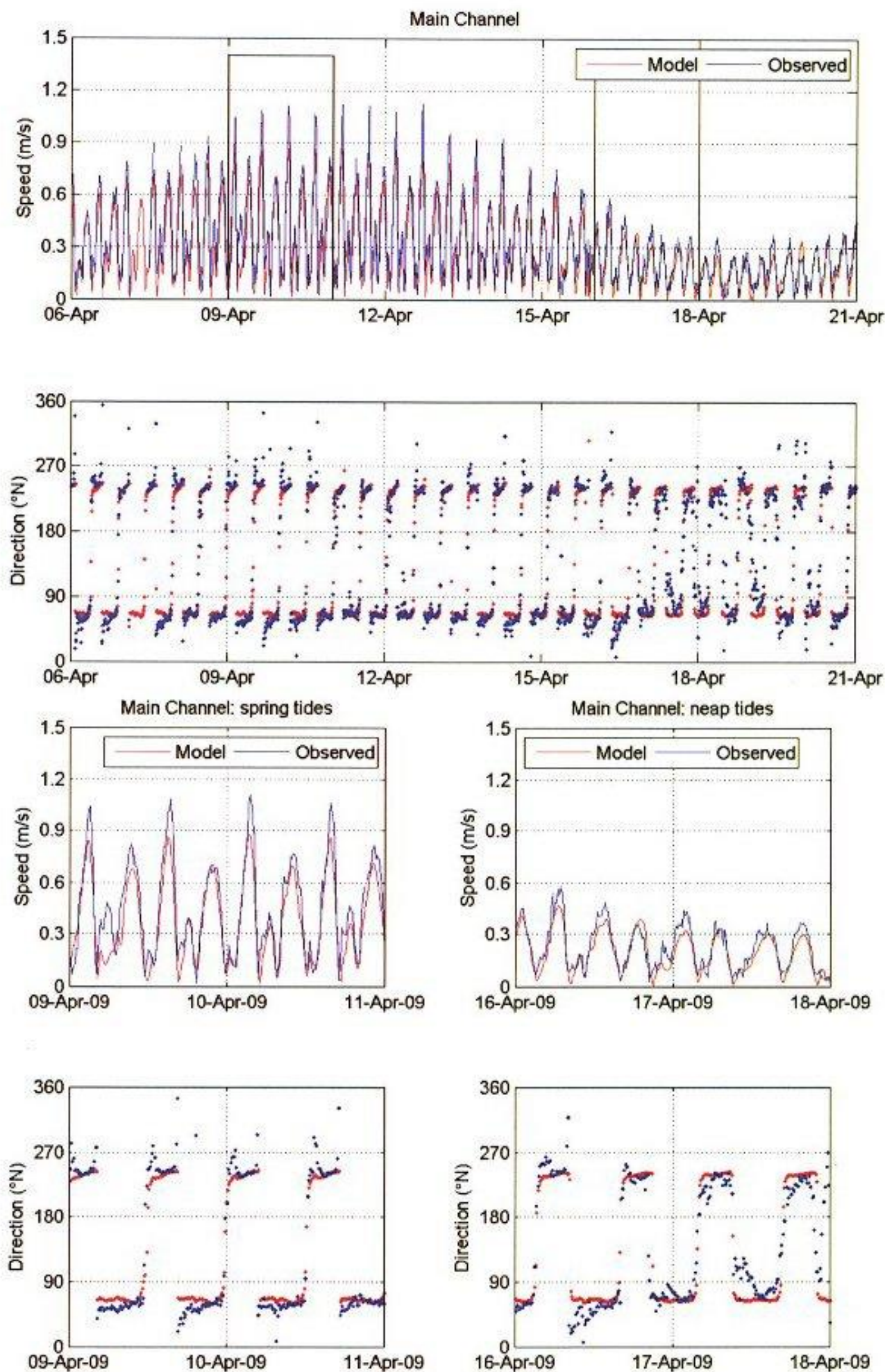


Figure A25. Model validation of flows against flows in the Main Channel against AWAC data

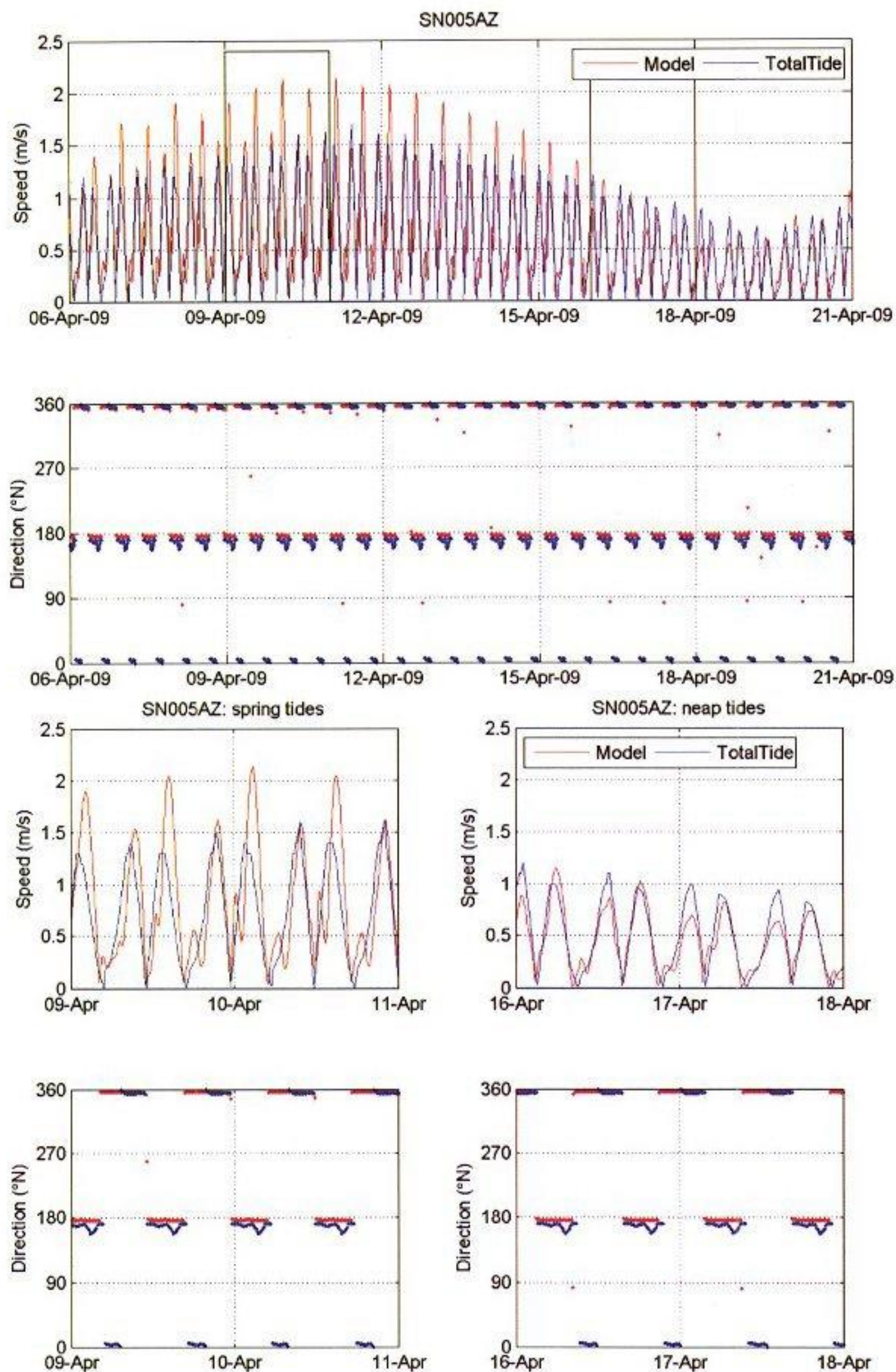


Figure A26. Model validation of flows against TotalTide predictions at SN005AZ

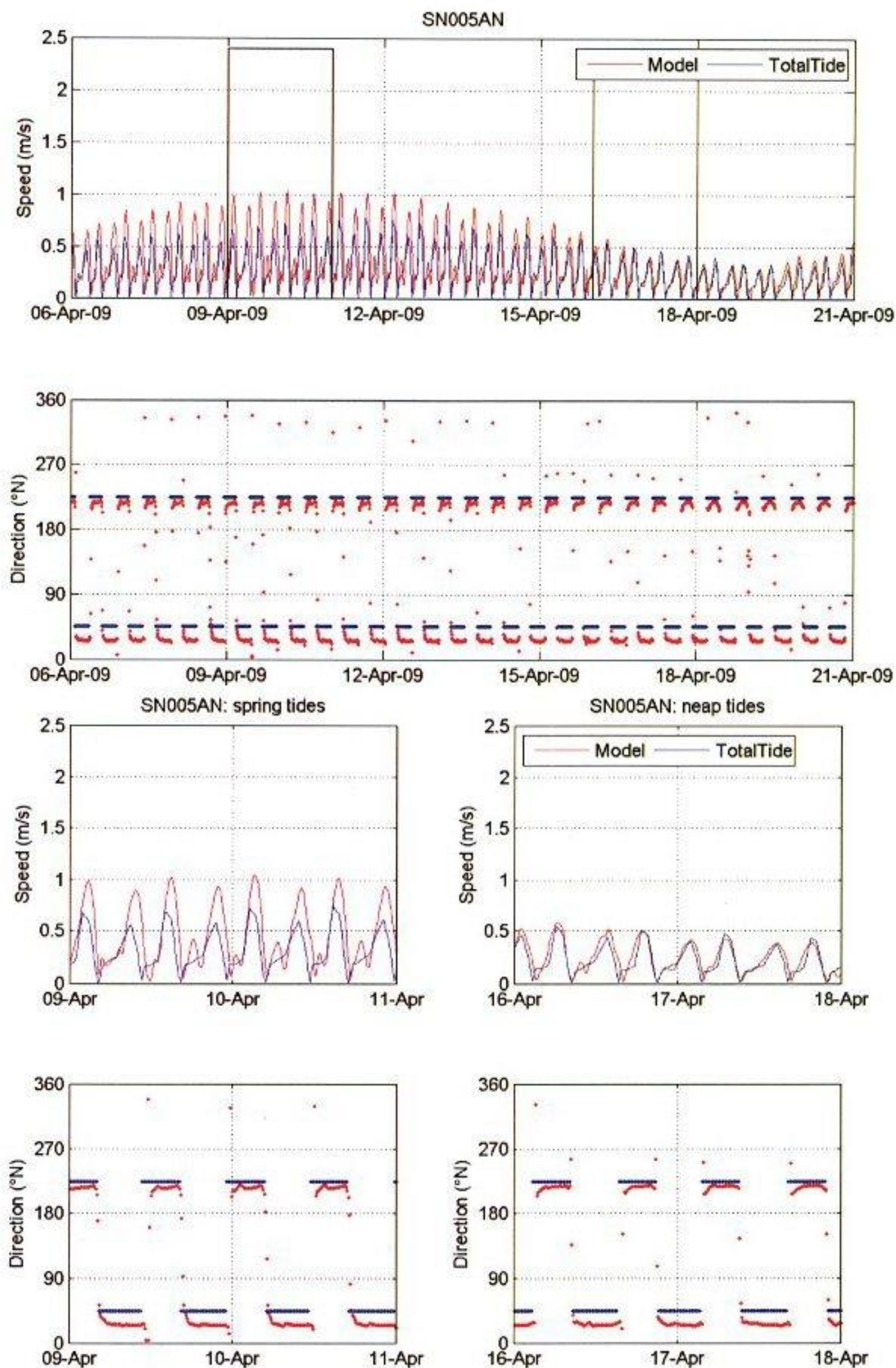


Figure A27. Model validation of flows against TotalTide predictions at SN005AN

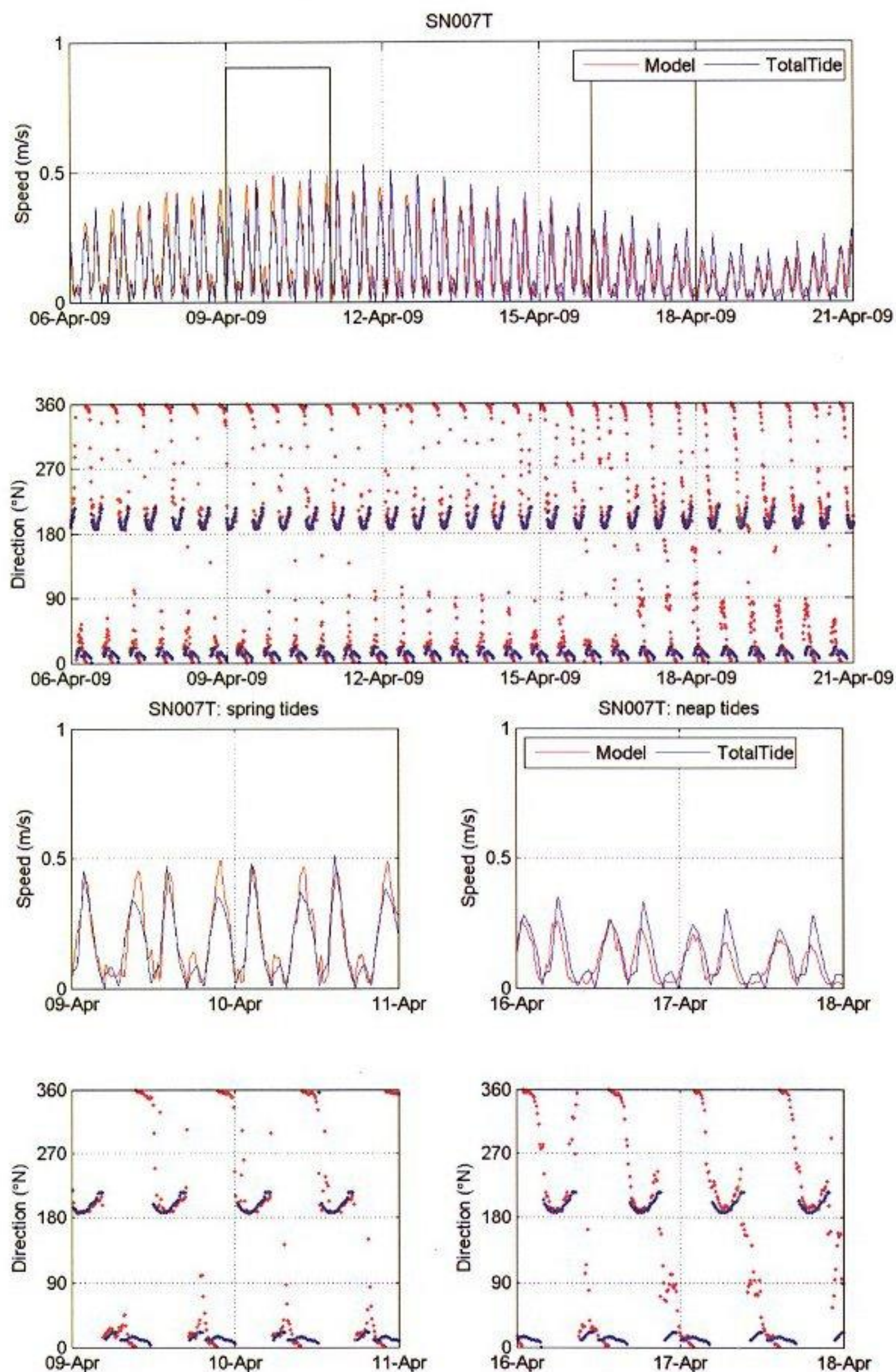


Figure A28. Model validation of flows against TotalTide predictions at SN007T

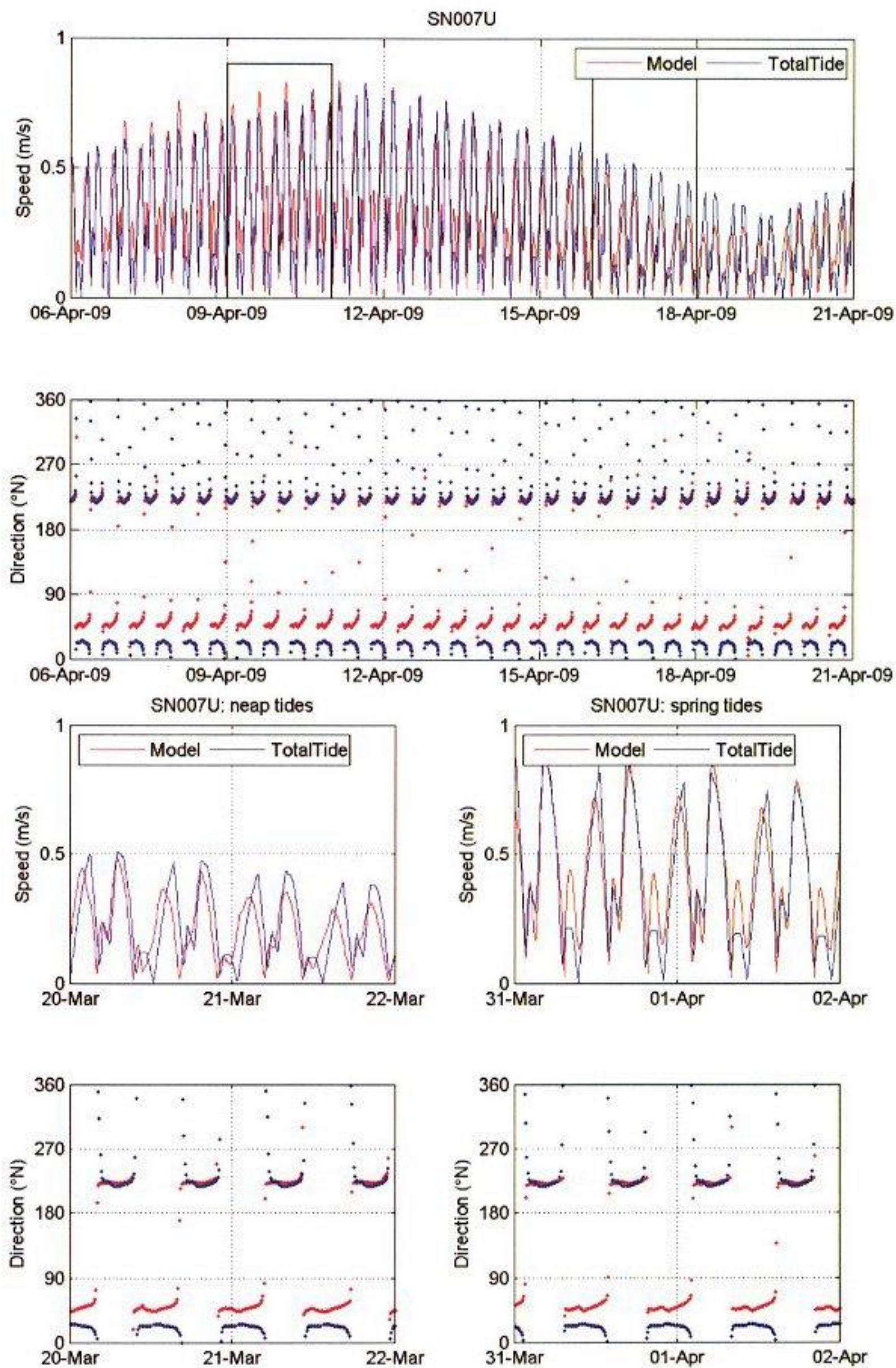


Figure A29. Model validation of flows against TotalTide predictions at SN007U

A.4 Summary

A tidal model of Langstone and Chichester Harbours has been configured in the MIKE 21 FM software suite and the modelled water levels and flows have been calibrated against available data. Notwithstanding limitations in the available observational records, the model is found to replicate the key flow patterns in the harbours.

The model performs particularly well at replicating observed water levels at Southmoor. RMS errors between modelled and observed water levels are 0.08 m for an eight day period in 2017 when the mean high water was 2.33 m (the profiler dried at -1.2 m on all tides during this eight day period). High water in the model is 0.04 m lower than measured, which is a very small percentage difference of the actual high water level (which varied between 2.02 and 2.58 m during the eight days considered).

Flows at the Southmoor site are generally low (around 0.2 m/s or less) and exhibit a high degree of temporal variability with no clear ebb and flood peaks (likely to be due to the presence of an eddy) and with no consistent trend between subsequent tides (due to the effect of meteorological forcing on the flows). Despite this, the model does a reasonable job at replicating the observed flows (albeit generally underrepresenting the flow speed), particularly when wind forcing is included in the model.

Based on the model performance, particularly the models ability to accurately replicate the tidal levels, the tidal model is considered to be a useful and appropriate tool to apply to assess the functionality and impact of a managed realignment within the model domain at Southmoor. The very good representation of the water levels means that the model will also inform the effects of the scheme with respect to flood risk in the area of the realignment.

A.5 References

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