

APPENDIX X
FRA

Southmoor Managed Realignment

Flood Risk Assessment

Environment Agency

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1. Introduction

1.1 Background

AECOM have been appointed by the Environment Agency to undertake a Flood Risk Assessment (FRA) to support the application for the Southmoor Asset Improvement Project for the proposed realignment of the seawall within Langstone Harbour, which currently protects the Southmoor site. The proposed involves a new flood defence and the partial removal of an existing seawall (approximately 20m in length). An additional embankment on the left bank of the River Lavant is also proposed. A third embankment is also proposed for the right bank of the River Lavant.

The aim of the managed realignment is to create a new inter-tidal habitat whilst reducing the risk of coastal flooding to Langstone and industrial infrastructure in Brockhampton. The proposed works aim to provide a sustainable method of managing the flood risk over the next 100 years.

This FRA has been prepared in accordance with the National Planning Policy Framework (NPPF).

The objectives of this FRA are to:

- Assess the risks posed to the site from all flood sources. This assessment has been informed by a separate hydraulic modelling report (ABPmer, 2017) which is to be read in conjunction with this FRA (see Appendix C).
- Assess the flood risk posed to third parties as a result of the scheme.

The following documents and guidance have been referred to in the development of this plan:

- National Planning Policy Framework;
- North Solent Shoreline Management Plan (SMP);
- Havant Borough Core Strategy;
- Partnership for Urban South Hampshire Strategic Flood Risk Assessment;
- Stakeholder Engagement Workshop [Materials from members of the public]; and
- Portchester Castle to Emsworth Coastal Defence Strategy.

The approach to this FRA involves a desk-based review of available information to establish the likely flooding sources and mechanisms for the site. A tidal hydraulic model has been produced by ABPmer to further inform the level of flood risk to the site. The scope of the assessment is based on the agreed scope in the Southmoor Managed Realignment Preliminary Environmental Information Report (PEIR) issued 23 May 2017.

1.2 Site Location

Southmoor is located in the area of Langstone Harbour, off Southmoor Lane, Havant (Figure 1-1). The site is located approximately 7 kilometres (km) north-east of Portsmouth and 14 km west of Chichester. It is centred on the National Grid Reference SU 71011 05070, and the nearest post code for the site is PO9 1RX. The River Lavant runs in a southerly direction along the eastern boundary of the site, which outfalls to Langstone Harbour. There are a number of weirs and sluice gates on the river, located to the west of Mill Lane in Langstone. The site occupies an approximate area of 21 hectares (ha). Appendix A shows the red line boundary for the scheme.

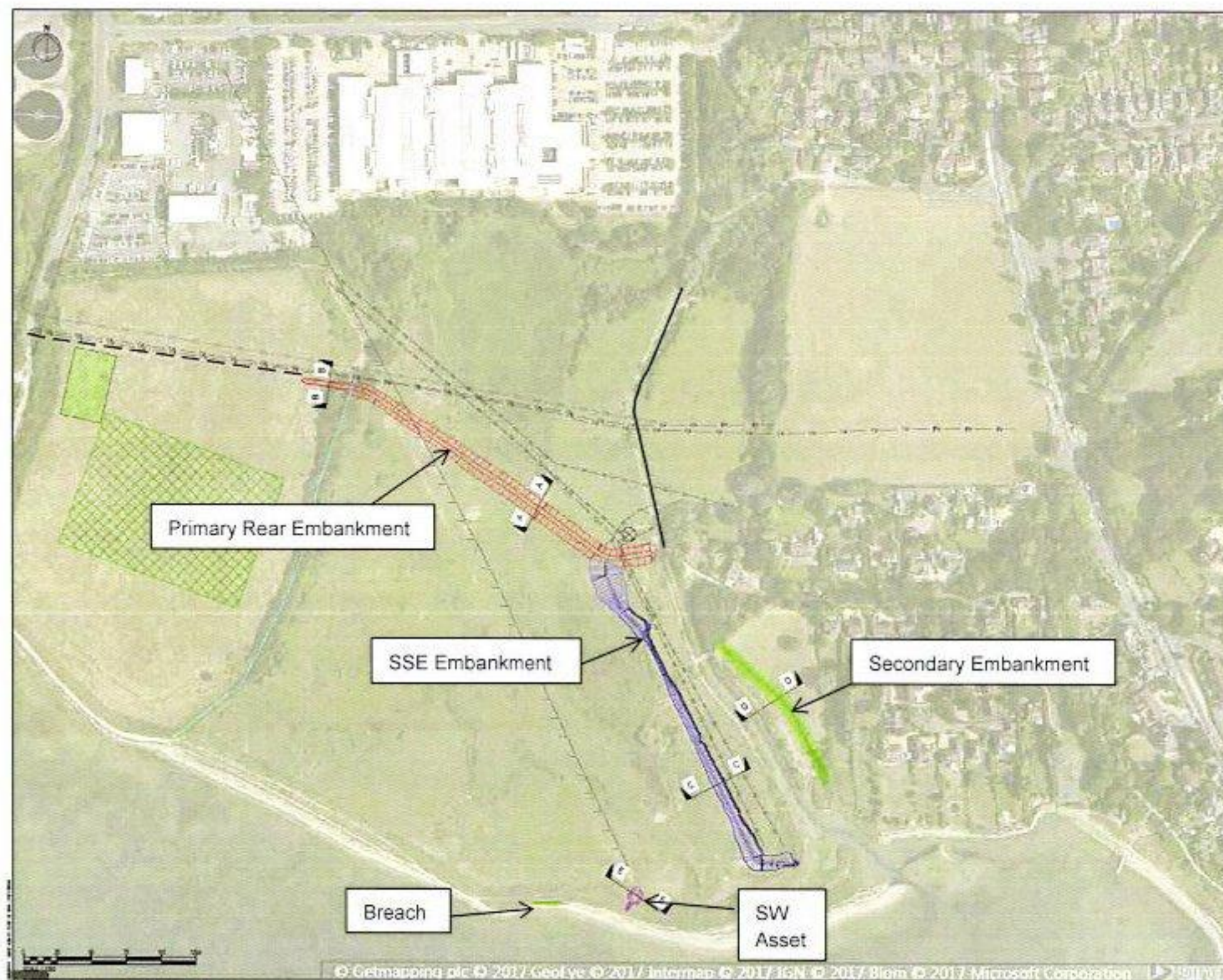


Figure 1-1: Site Location showing Scheme Proposals

To the south of the site lies the Langstone Harbour, an estuary which connects to the English Channel. To the north and east lies the village of Langstone and to the immediate north lies industrial complexes in Brockhampton. Southmoor Lane is located north and west of the site. Langstone Road (A3023) is located to the east which serves as essential highway infrastructure, linking Hayling Island to the main land and the A27 highway, 700m north of the site.

Public rights of way provide access to the east of the site by following the River Lavant in a southerly direction. The locations of the public rights of way in and around the site are shown in Figure 1-4. The public footpaths follow the right bank of the river and along the coastline, and additionally cut through the site, adjoining Southmoor Lane to the west. The proposed scheme involves aligning a new embankment with the existing public right of way that crosses the site (referred to as "Havant. 49"); details of the proposed scheme are provided in Section 1.5.

1.3 Existing Site Condition

Southmoor is currently a coastal grassland reserve, protected by an existing concrete sea wall in the south designed to provide a 0.5% Annual Exceedance Probability (AEP) level of flood protection. However, the existing sea defences at this site are privately owned and are in a poor condition (Portchester Castle to Emsworth Coastal Flood and Erosion Risk Management Strategy, Environment Agency, 2012) resulting in a 100% AEP (Figure 1-2). As a result, it is highly probable that further deterioration of the defence could result in high water levels exceeding the crest or wave overtopping. A worst case scenario could lead to a breach event of this defence. Intervention is required at this location to reduce the likelihood of defence failure, which would otherwise increase the risk of flooding to nearby residential and commercial properties.



Figure 1-2: Existing condition of the sea wall

1.4 Site Topography

A LiDAR Digital Terrain Model (DTM) of 1m grid resolution has been acquired from the Environment Agency Open Data for the site and surrounding area to assess the topography in greater detail. The DTM shows that the site on the right hand bank of the Lavant is relatively flat and low lying, although gentle undulations and drainage channels are apparent. Land rises from the south-eastern corner (less than 1 m AOD) towards the west, northern and north-eastern perimeter (Figure 1-3). Where the land is elevated the approximate ground level is around 4m AOD; note the crest level of the primary embankment is 3.2m AOD i.e. the surrounding ground is significantly elevated. There is an area of higher ground flanking the river on the right hand bank that reaches around 3m AOD. On the left hand bank of the river the ground rises from around 2m AOD to 3m AOD in a north-eastern direction.

1.5 Proposed Site Description

In accordance to the Portchester Castle to Emsworth Flood and Coastal Erosion Risk Management Strategy (Environment Agency, 2012), the most sustainable flood defence option for the Southmoor site is reported to be a managed realignment. This would involve maintaining or improving the long term standard of protection against flooding by 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.

The aim of the scheme is to improve the standard of protection to residential properties in Langstone in the long term whilst also addressing the pressing need for creating new intertidal habitat to replace losses across the Solent.

Figure 1-1 shows the location and the proposed scheme. A more detailed drawing of the proposed design is provided in Appendix B. The proposed scheme has a 50 year design life.

The proposed scheme will include, primarily, removal of a 20 m section of the existing sea wall and provision of a new clay-cored embankment, some 340 m in length, situated approximately 300 m further inland allowing the creation of a new inter-tidal habitat. The material required for the embankment will be obtained outside of the site and therefore the ground levels within the site, other than the new defence, will not change upon completion of the scheme. The embankment will maintain the intended standard of protection against flooding to at least 0.5% AEP present day chance of flooding in any given year and will have a finished crest height of +3.2m AOD. The crest width of the embankment will be approximately 2 m and the seaward and landward slopes will have a gradient of approximately 1 in 3, pending confirmation during the detailed design stage. It will be an important means of accessing the Southmoor site, especially if the existing sea wall was to fail.

A second, shorter, clay-cored embankment of 125 m in length, will be implemented adjacent to the left bank of the River Lavant to prevent outflanking of existing harbour side defences fronting the village, and fluvial flooding from the River Lavant, in order to maintain protection to properties in Langstone Village. The proposed crest level for the eastern embankment will be set at +3.5 m AOD.

A third embankment is to be constructed to provide protection to SSE 33 kV High Voltage buried cables that are situated in the raised ground along the south-eastern perimeter of the right hand bank of the Lavant. The crest level of this embankment will be +2.6 m AOD.

A 1 m x 1 m box culvert is proposed for the primary embankment where the drainage network intersects the embankment (Figure 1-4). This figure also shows the public rights of way; the route "Havant. 49" is the key route across the site that the primary embankment is aligned with. The culvert will allow freshwater to drain through the site and maintain land drainage. The culvert will have an upstream invert level of +1.7 m AOD. The design is intended to permit flood flows to discharge to the sea during the periods when the culvert is not tide locked – this should be approximately 8 hours during a 12.5 hour tidal cycle i.e. the majority of the cycle. It is designed to function during typical and extreme tides. This measure, combined with the partial removal of the sea wall, is intended to avoid retention of flood water to the north of the primary embankment and not alter existing flood risk.

There will be ground raising around a Southern Water manhole chamber, which is on the southern boundary of the main Southmoor site, bordering the existing sea wall. The raising will effectively create a 'circular embankment' with a crest level of +2.2 m AOD, tying into the existing sea wall and permitting operative access during typical spring tides.

The proposals also include improved public access (Figure 1-4). This will be achieved via a recycled plastic walkway, along the route of public right of way "Havant. 51" to the north of the primary embankment. Secondly, an existing footpath ("Havant. 45" is proposed to be diverted from the frontline of the site along the western flank of the area to be inundated to link up with the primary embankment.

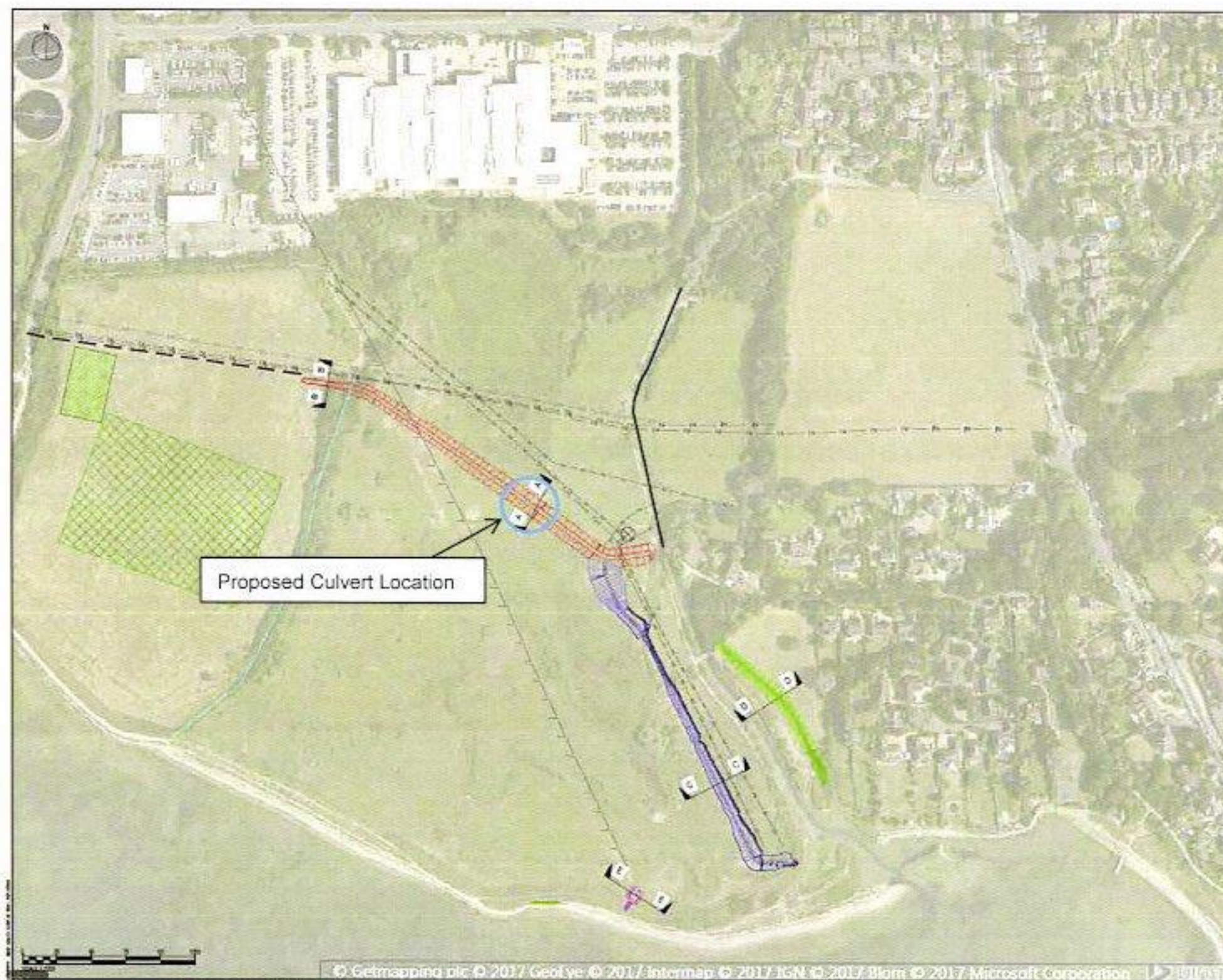


Figure 1-4: Location of proposed culvert (blue circle) in primary embankment aligned with PRoW

An access chamber belonging to Southern Water (SW) is located on the southern boundary to the east of the proposed breach location (Appendix B). It is fundamental that the asset is still accessible following the managed realignment scheme. Therefore, it is proposed to raise the surrounding earth and access chamber so they remain at the height of a Mean High Water Spring tide (+2.2 m AOD).

1.6 History of Flood Events

Southmoor has an extensive history of flooding, both from tidal and fluvial flooding with notable events occurring in December 2013, and January, February, March and May 2014.

Heavy rain upstream has previously caused the River Lavant to rise and overspill its banks in two key locations in Southmoor. This includes, south-east of the Southmoor Lane Industrial Estate at Brockhampton and west of Mill Lane (Figure 2-1). Overflows seek lower ground and it was reported that fluvial flooding occurred in Mill Dam Field behind the Mill and in residential gardens off Mill Lane to the east in March 2014. Overspill from the West Bank of the River Lavant currently leaves the Southmoor site via a sluice gate located in the south-east corner of Southmoor and re-joins the river heading out to Langstone Harbour. During extreme storm events, heavy rain has reported to close a sluice gate located by the Industrial Estate, subsequently causing the water to 'back-up' and flood the car park at the eastern end of the estate, adjacent to the Lavant.

Langstone Harbour is exposed to tidal surges and storm force winds. During an extreme tidal event greater than a 0.5% Annual Exceedance Probability (AEP) the seawall is overtopped and Southmoor becomes inundated. Langstone Village is reasonably sheltered by the arm of the road bridge to Hayling Island. However, in accordance to the EA Historic Flood Map, Langstone High Street became inundated during a tidal surge in January 2014.

In February 2014, combined fluvial and tidal flooding inundated Southmoor. The high tide slowed the outfall of the River Lavant by the Mill and exit to the Harbour, thereby causing the River Lavant to overspill its banks. The combined water rose above the concrete wall and inundated Mill Dam Field and the land west of the Lavant into Southmoor. It was reported that following the flood, the land drained well once the tide withdrew. The channels which run through the centre of the Southmoor site towards the harbour drain the land.

Figure 1-7 shows evidence of historic flood events in Southmoor and the surrounding area. The photographs were obtained from a stakeholder workshop with the public to assist in understanding the extent and impact of historic flooding within the vicinity of the site.



Photograph A facing north on the west side of the Mill. Flood water from the River Lavant overspills into Southmoor floodplain. The water gradually leaves by sluice gates into the harbour.



Photograph B facing south. Evidence of seaweed ('greyish' area) left behind from previous flooding in Mill Dam Field



Photograph C facing north-west. Evidence of seaweed on the fence indicates the water level of the flood.



Photograph D facing east showing combined fluvial and tidal flooding. The River Lavant has over spilled into Southmoor adjacent to Mill Lane south of the weirs. The sea wall has been overtopped.

Figure 1-5: Evidence of Historic Flood Events

2. Flood Risk Assessment

2.1 Introduction

The FRA report provides an overview of the following:

- The potential sources of flood risk to the existing site and associated consequences
- How the flood risk assessment has informed the proposals
- Flood risk mitigation

The NPPF specify that planning applications for development proposals of 1 ha or greater located in Flood Zone 1, and all proposals for new development located in Flood Zone 2 and Flood Zone 3 should be accompanied by an FRA. In accordance with the requirements of the NPPF, the possible flood hazards associated with the development should be assessed to identify any specific risks and to identify whether further analysis of the hazards should be undertaken. There are a number of potential sources of flooding that could affect the site, the details of which and associated risks are detailed below:

2.2 Fluvial / Tidal Flooding

Flood risk information (Product 4) has been obtained from the Environment Agency (EA). The EA Flood Map for Planning provides information on the following flood zones (Figure 2-1):

Flood Zone 3 – Shaded dark blue and shows areas that could be affected by flooding, either from rivers or the sea if there were no flood defences in place. The probability of this occurring is:

- 0.5% AEP or greater chance of happening each year (flooding from the sea)
- 1% AEP or greater chance of happening each year (fluvial flooding from a river)

Flood Zone 2 – Shaded light blue and shows the additional extent of an extreme flood from rivers or the sea. These outlying areas are likely to be affected by a major flood with up to a 0.1% AEP chance of occurring each year.

Flood Zone 1 – Areas having a less than a 0.1% AEP of fluvial flooding (outside of Flood Zones 1 and 2). These areas are unlikely to be flooded directly from the rivers represented in the EA Flood Zone for Planning Map. However, areas outside of Flood Zones 1 and 2 may be at risk of fluvial flooding from smaller watercourses.

The online flood mapping for the site published by the Environment Agency (Figure 2-1, June 2017) indicates that most of the site is located within an area of high fluvial / tidal flooding probability – Flood Zone 3 (probability of flooding 0.5% AEP tidal flooding and 1% AEP fluvial flooding).

The closest source of fluvial flooding is the River Lavant which is located in the site. Sluice gates and weirs control the water level in the River Lavant which flow in a southerly direction towards its outfall at Langstone Harbour. During extreme storm events, the River Lavant overflows into Southmoor in two locations (Figure 2-1).

There are two ordinary watercourses present within Southmoor which join as one by the site boundary; these can be seen in Figures 1-3 and 2-1. The ordinary watercourses travel in a southerly or easterly direction before outfalling to Langstone Harbour in the south-eastern corner of the main site. The ordinary watercourse drains the site from the surface water and when the site is inundated from sea wall overtopping and / or fluvial ingress from overflow of the River Lavant during extreme storm events.

Tidal flood sources include the sea and estuaries. The site lies in close proximity to Langstone Harbour which represents a major potential flood source. Although flood defences currently exist in the area (a sea wall) there is still a risk from potential flood defence failure such as overtopping or a breach of flood defences. The existing sea wall is in a poor condition and has consequently collapsed in areas, thereby reducing the standard of protection.

Fluvial and tidal flooding poses a potential risk at Southmoor. However the proposed scheme is not predicted to have a negligible impact on tidal and fluvial flood risk for the site and the surrounding land. Hydraulic modelling has been undertaken to further assess the impact of the scheme regarding flood risk which is described in more detail within Section 4.

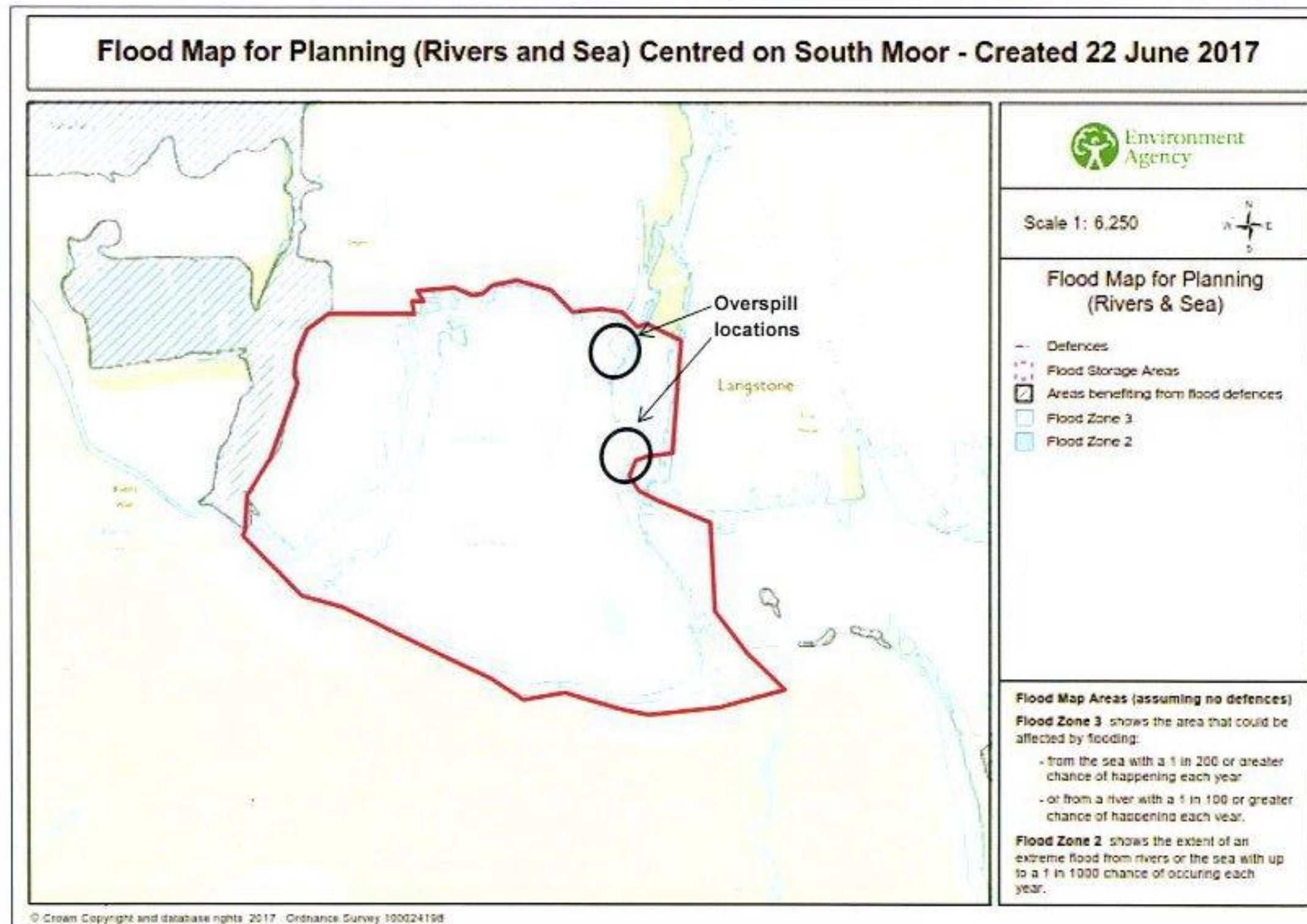


Figure 2-1: Extract of Environment Agency Flood Map for Planning (Rivers and Sea)

2.3 Pluvial Flooding

Surface water flooding arises when rainfall is unable to infiltrate the ground and therefore results in localised ponding or flows across the ground surface following topographic depressions. Surface water flooding can occur in both urban and rural environments and can be exacerbated by fluvial flooding.

The existing rainfall runoff from the site will currently discharge via overland flow paths and ordinary watercourses to either the River Lavant or seaward towards the Langstone Harbour. Additionally, existing rainfall will also discharge straight to the ground via infiltration.

The Environment Agency publishes mapping indicating areas at risk of surface water flooding. The maps show areas identified as having a:

- high risk of flooding from surface water (i.e. probability of flooding > 3.3% AEP)
- medium risk (1% - 3.3% AEP)
- low risk (0.1% - 1% AEP); and
- very low risk (< 0.1% AEP).

On the site there is a surface water flood risk ranging from Very Low to High. Most of the site is located with an area of low risk of surface water flooding. There is a relatively large extent of low risk of surface water flooding, which follows the ordinary watercourse seaward. This is to be expected with the natural topographical gradients of the land. There are also some hotspot areas with a high risk of flooding from surface water. This is likely due to lower topographical levels. There are some other areas where there is very low risk of flooding; this is apparent to the west of the site where the topography is notably elevated.

The surface water flood risk mapping for the site and surrounding area is shown in Figure 2-2.

The proposals will not change the topographical levels (since borrow pits for embankment construction are located offsite), nor increase surface water runoff following the placement of the new earth embankments through obstructing overland flow. This is because the proposed culvert, fitted with a tidal flap, intersecting the northern embankment, is designed to allow the ordinary watercourse to carry its natural course to Langstone Harbour and drain the site via the breach in the sea wall. Therefore the proposals should not increase the risk of surface water flooding to the surrounding area. Further details of the hydraulic modelling that has been undertaken to demonstrate the efficacy of the culvert is provided in Section 4, including the ability to drain the site when the culvert is tide locked.

2.4 Groundwater

Groundwater flooding occurs when water levels in the ground rise above surface elevations. It is most likely to occur in low-lying areas underlain by permeable rocks (aquifers).

The Partnership for Urban South Hampshire Strategic Flood Risk Assessment 2007 (SFRA) does not identify any incidents of groundwater flooding occurring within the vicinity of the site.

A review of data available on the British Geological Society (BGS) webpage indicates that the site is underlain by the Lewes Nodular Chalk Formation. The Head Deposits are described as clay, silt, sand and gravel. Historical borehole logs held by the BGS indicate that the ground is typically silty sandy gravel with chalk fragments of gravel at a depth from 3.05 m to 5.18 m.

In general the geology of the site comprises head deposits over chalk formation. These strata have a high permeability and therefore there is the potential risk of groundwater flooding within the site.

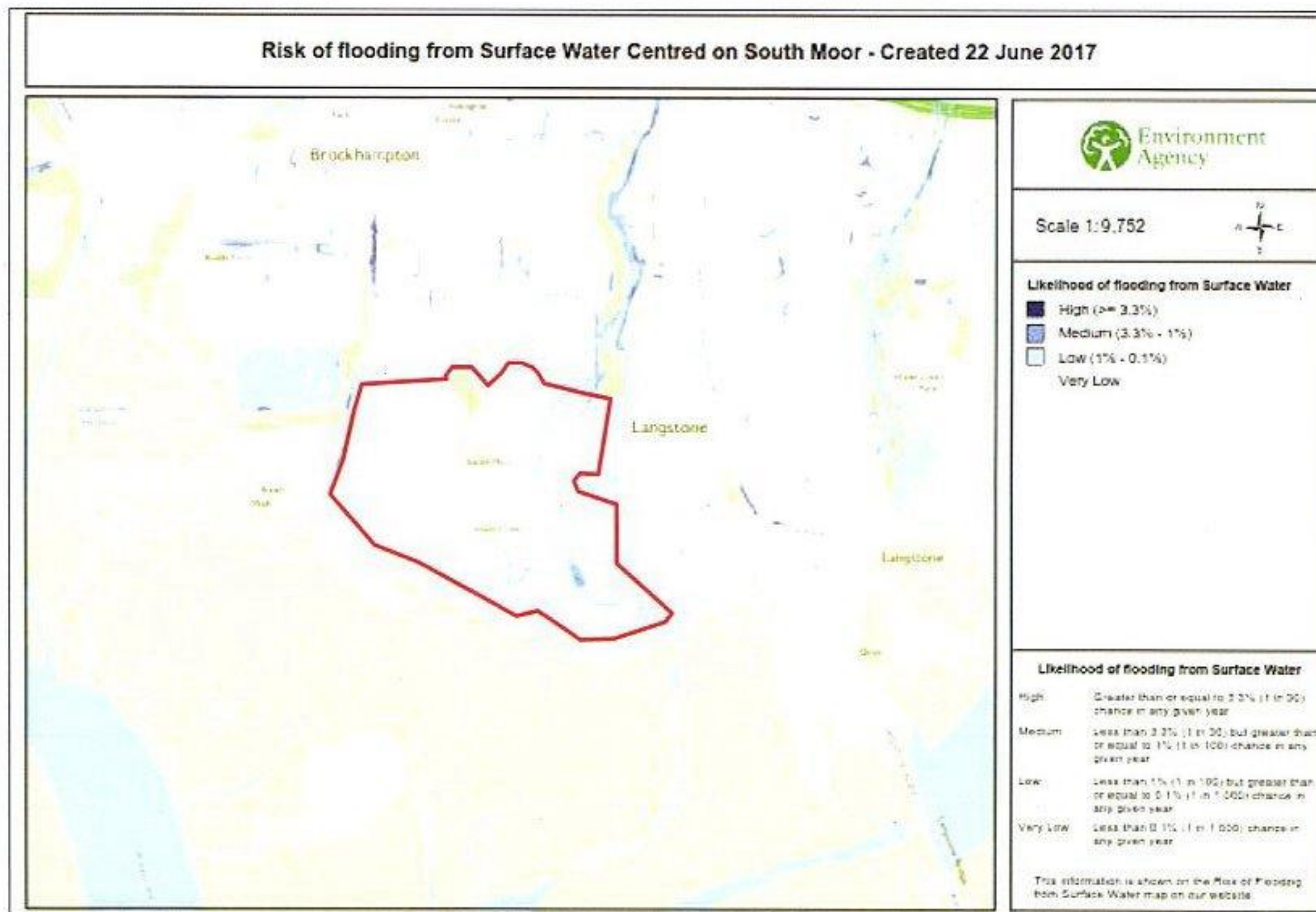


Figure 2-2: Environment Agency Flood Mapping for Surface Water

2.5 Sewer Systems

Sewer flooding can occur as a result of infrastructure failure e.g. blocked sewers or failed pumping stations.

The Budds Farm Wastewater Treatment Works (Southern Water) is located approximately 150 m west of the site which treats the wastewater from homes across Portsmouth, Havant and Hayling Island etc. There are four main outfalls within the Portsmouth and Havant system to prevent flooding. In addition an access chamber maintained by Southern Water is located within the site boundary.

There are no recorded foul water sewer flooding incidents local to the site noted within the SFRA. Therefore the site is considered to be at low risk of sewer flooding.

2.6 Artificial Sources

Artificial flood sources include raised channels such as canals or storage features such as ponds and reservoirs.

From reviewing the online flood mapping data published by the Environment Agency and the site location plan there are no indications of flooding from reservoirs or canals. There is a large water feature within the proximity of the Southern Water Wastewater Treatment Works, approximately 120 m west of Southmoor.

There are no recorded incidents of artificial sources local to the site and as such the flood risk from artificial sources is low.

3. Policy Context

3.1 National Policy

Section 10 of the NPPF provides the current guidance for planning with respect to flood risk. The NPPF advocates a sequential approach for planning process in order to steer development to areas with the lowest possible risk of flooding.

The NPPF considers the vulnerability of different forms of development to flooding and classifies proposed uses accordingly as detailed in Table 2 of the Technical Guidance. Table 3 of the Technical Guidance for the NPPF illustrates a matrix which identified which vulnerability classifications are appropriate within each Flood Zone. This table demonstrates that 'Less Vulnerable' development is permitted within all Flood Zones with the exception of Flood Zone 3b.

3.1.1 Vulnerability Classification

The NPPF Technical Guidance provides the following flood risk vulnerability classifications that are applicable for this flood risk assessment.

Table 3.1 NPPF Flood Risk Vulnerability Classification

Land Use Type	Flood Risk Vulnerability Classification
Embankment and Intertidal Habitat	Water Compatible

Source: National Planning Policy Framework 2012

3.2 Local Policy

3.2.1 Havant Borough Core Strategy

The Havant Borough Core Strategy was adopted in March 2011 and provides the spatial vision of the area, setting out the broad detail and direction of future development in the borough up to 2026. The strategy identifies the required physical and social infrastructure (including green infrastructure) necessary to support new development and meet future needs. The main policies that relate to flood risk and water management are:

CS11 – Protecting and Enhancing the Special Environment and Heritage of Havant Borough:

- Planning permission will be granted for development that protects and where possible enhance the boroughs statutory and non-statutory designated landscape, and protection and enhancement will be achieved by appropriate adaption including the creation of new habitats and waterbodies; and
- Protects wildlife habitats to prevent the fragmentation of existing habitats to allow species to respond to the impacts of climate change by making provision for habitat adaption e.g. coastal managed realignment.

CS15 – Flood and Coastal Erosion Risk:

- Development meets the sequential and exception test (where required) in relation to (the now superseded) PPS25;
- A site-specific flood risk assessment demonstrates that the development will be safe, including the access, without increasing flood risk elsewhere, and , where possible, will reduce flood risk overall;
- The scheme incorporates flood protection, flood resilience and resistance measures appropriate to the character and biodiversity of the area and the specific requirements of the site;
- All development will be required to ensure that there is no net increase in surface water run-off; and
- Development will avoid areas at risk from coastal erosion and coastal flooding and that areas required to offset coastal squeeze and prevent habitat fragmentation, to allow species to adapt to climate change, are identified and protected from development.

CS19 – Effective Provision of Infrastructure:

- Development does not result in the loss of flood protection.

3.2.2 PUSH (Partnership for Urban South Hampshire) Strategic Flood Risk Assessment

The SFRA was published in 2007. The report concluded that climate change poses a significant risk to the sub-region with predicted sea level rise to reduce the level of protection provided by most of the sub-regions flood defences. In addition increasing severity of storm events is predicted and subsequently will increase the risk of flooding from rivers.

The SFRA recommends reviewing the sustainability of raising existing defences to contend with rising sea levels. It concluded that it may be more appropriate to identify potentially higher standards that may be more appropriate in light of climate change forecasts.

3.2.3 North Solent Shoreline Management Plan

The North Solent Shoreline Management Plan (SMP) was published in 2010. The SMP provides a broad assessment of the coastal flooding and erosion risks. The shoreline is split into the different Policy Units and recommends coastal management strategies during that period (0-20 years, 20 to 50 years or 50 to 100 years).

The site is located within the 5a18 Policy Unit. The proposed policy option is outlined in the Portchester to Emsworth Coastal Defence Strategy. The policy up to 2105 is 'Hold the Line', but with agreement that 'Managed Realignment' (MR) should be explored in the medium term (2025) if the landowner becomes favourable to it. The favourable situation means the proposal to implement MR has been brought forward.

3.2.4 Portchester to Emsworth Coastal Defence Strategy

The Portchester to Emsworth Coastal Defence Strategy considers the section of mainland coastline between Portchester Castle and Emsworth, identifying the best method of managing coastal flood and erosion risk over the next 100 years. Southmoor is included within this region.

The strategies for Southmoor recommend to 'Do Minimum' for 10 years and adopt a MR for Southmoor in the long-term. The definition of each strategy is outlined below;

Do Minimum is defined as 'maintaining existing defences until they fail and then revert to no active intervention'

Manged Realignment is defined as 'allowing the shoreline to move backwards or forwards with management to control or limit movement (such as reducing erosion or building new defences on the landward side of the original defences).'

Langstone Harbour is internationally protected for the wildlife value. It is recognised that climate change is contributing to rising sea levels and in response upper salt marshes cannot migrate if they are trapped between rising sea-levels and fixed seawalls. Where defences prevent the habitat from migrating landwards, it is important to consider realigning the defences or compensating elsewhere for the habitat will be lost due to flood defences.

The Strategy reports that Southmoor cannot be protected in the long term as holding the line of the current defences will cause irreplaceable loss due to coastal squeeze of the important inter-tidal habitats in Langstone Harbour.

4. Development Proposals and Flood Risk

4.1 Introduction

Changes in the outer defence as a result of the proposed scheme require an assessment to ensure the proposed set back earth embankment will be sufficient to ensure continuity of defence to the currently defended land. This section of the report demonstrates that the development proposals have been led by the results of the FRA and modelling investigation. The development proposals have been designed with flood risk in mind and those risks identified have been mitigated and managed to ensure that the development and wider area is safe.

4.2 Climate Change

It is important to ensure that the proposed scheme takes into account the effects of climate change (specifically the impact of extreme events) and that the design is led by this information. Climate change (tidal levels and rain fall) is likely to increase the frequency and severity of extreme tidal and fluvial flooding events.

This FRA document presents the findings of the scheme's performance against an extreme fluvial event, with this event likely to increase in the frequency of occurrence as a result of changes in climate. Extreme events are a key consideration for the proposed scheme and as such have been taken into account in the design. The primary earth embankment (Shown in Red Figure 1-1) towards the back of the scheme will have as a minimum a 0.5% AEP current standard of tidal flood protection (+3.2 m AOD) based on current climate change predictions.

A present day extreme fluvial event (1% AEP) has been considered based on the results from the 1D InfoWorks model which encompasses the whole of the Havant catchment area (Atkins, 2008). This model provides a description of the fluvial source which enters the scheme during extreme events. The discharge – volume and rate (hydrograph) of fluvial water was extracted from the river model and incorporated into the coastal model to allow the assessment of the extreme fluvial event.

Specifically, the coastal model was run considers how the scheme design influences the storage capacity of the site with the new rear earth embankment significantly reducing the potential storage volume during peak fluvial events at times of high water (tide locked). This key event has been assessed and the design of the scheme modified to ensure that there is no increase to the risk of flooding as a result of the proposed scheme development.

4.2.1 Tidal

The new seawall embankments will be designed such that they will as a minimum maintain the same standard of protection against tidal flooding to at least 0.5% AEP chance of flooding in any given year. The condition of the earth embankment (nominally a 50 year design life) provides a significantly improved long-term protection in terms of design life compared to the existing sea wall. The new defences themselves also offer a greater degree of protection to future climate change as these will be constructed behind the original seawall and as such, will be less exposed to waves.

In addition, the tidal currents that enter through the breach are slowed therefore, suspended sediments will settle resulting in sediment accretion / slight increase in bed levels which in turn further increases the protection that the site offers to potential future climate change pressures. Finally, the topography of the site lends itself to the scheme by restricting the ingress of tidal waters to the Southmoor site with the surrounding topography beyond the scheme some +1.5 m greater than the 0.5% AEP water level (+3.2 m AOD).

4.2.2 Fluvial

The loss of potential storage area and therefore the potential for increase flooding to the surrounding environment has been robustly considered based on the findings from the InfoWorks 1D and MIKE FM coastal models. The calibrated and validated InfoWorks 1D river model was run for a 1% AEP fluvial event under current day conditions with current guidelines predicting that with climate change the occurrence of this extreme event is likely to increase. The fluvial model includes a 1D description of the river and surrounding areas. In order to consider the influence of the scheme, the site has been divided and described within the river model as a number of "reservoir ponds". This is an acceptable approach within a 1D model and adequately provides a description of the volume of water entering the Southmoor scheme.

4.3 Hydraulic Modelling

4.3.1 Introduction

For the proposed scheme to be considered acceptable it is fundamental to ensure the new embankments have no negligible impacts on flood risk to the site and surrounding land. Hydraulic modelling carried out by ABPmer has assessed the potential impacts of the managed realignment along the coastline, assessing the extent, velocity and depth of the water levels during a tidal breach and the function of the new embankments. An InfoWorks model has additionally assessed the volume of fluvial water reaching the site and the storage area available landward of the primary embankment. The combined findings will inform the level of flood risk and mitigation measures to the site, the left hand bank and the surrounding area.

4.3.2 Assumptions

As with all modelling assessments a number of assumptions have been applied based on the nature of the study and in agreement with the Environment Agency. These assumptions include:

1. The use of the existing calibrated 1D InfoWorks (Atkins, 2008) model is sufficient to assess the fluvial inputs for the scheme, no further edits or amendments are required. AECOM will review and run the 1D model to ensure that the model has been setup and configured appropriately and that the results provided are equal to the findings described in the modelling report (Atkins, 2008);
2. The existing calibrated 1% AEP fluvial event (Atkins 2008) is sufficient to describe the impacts of an extreme event within the project site;
3. It has been assumed that due to the position (further back behind the existing sea wall with reduced current and wave action) and condition of the proposed new earth embankment that a breach will not occur during the life time of the project;
4. An assessment of the scheme function based on surrounding land elevations (Figure 1-3) show that the current sea wall offers no tidal flood protection beyond the foot print of the proposed Managed Realignment Area (Figure 1-1). Therefore, the extreme 1 in 5 year (approx.) water level condition applied in the InfoWorks model (Atkins 2008) is sufficient. This approach is consistent with the previous modelling investigation and described in the Environment Agency Flood Inundation mapping (Product 4 outputs)

A separate hydraulic modelling report (ABPmer, 2017) produced by ABPmer should be read in conjunction with this FRA and is provided in Appendix C.

4.3.3 Tidal Breach Results

Using the existing ABPmer hydraulic model, a 20 m wide breach has been created in a central location along the southern boundary of the site, centred on an area of the existing seawall defence that is collapsing (shown above in Figure 1-2). The breach has been created by excavating the material from the seawall to an invert level of +1.4 m AOD.

The results for the flood extent, depth and velocity for the existing and proposed scheme have been extracted from the tidal hydraulic modelling produced by ABPmer and Environment Agency Product 4 information, supplied by the Environment Agency. The breach run has applied a mean spring tide (+2.2 m AOD) to inundate the site through the deliberate breach. Commentary on changes in flood extents and depths is provided below.

4.3.3.1 Flood Extents

The results for the tidal breach extents have been analysed to determine the impact of the proposed scheme may have on the site and surrounding land.

This existing flood extent has been obtained via the EA's Product 4 data; it and does not include the breach to the existing sea wall nor any of the proposed embankments. The findings from this assessment are shown in Figure 4-1. The maximum tidal inundation extent for the existing condition with an extreme fluvial event is shown in Figure 4-2. Both figures show a good level of agreement suggesting that the results from the 1% AEP are reasonably represented in the coastal model.

The combined impact of the proposed scheme on water depths and extent over an extreme fluvial event over a worst case spring tide (+2.2 m AOD) have been modelled to further assess and understand the interaction between the two waterbody's (Langstone Harbour and River Lavant) and the ability of the proposed scheme to have no detrimental impact on existing flood extents (Figure 4-3).

Figure 4-3 shows the flood extent for the proposed scheme based on the site being inundated with a mean spring tide (+2.2 m AOD) at the same time as a 1% AEP fluvial flood event from the River Lavant. Tide locking has been considered within this scenario, recognising that during part of the tide, the culvert in the primary embankment will not operate and fluvial water will be retained in the lee of the primary embankment. The model was run to ensure that the peak of the fluvial discharge into the scheme occurred at the time of high water ensuring a worst case consideration.

The results show that despite a period of tide locking of around 4 hours, the remaining 8.5 hours permit the culvert to operate and drain the northern part of the site and the seaward site is able to drain away via the proposed breach in the sea wall (Figure 4-3). The modelling shows the worst case period of the tidal cycle and it is clear, via comparison with Figure 4-2, that the area to the north of the primary embankment is smaller in extent than the existing situation. The site is able to drain fully during a single tidal cycle, because of the culvert and the breach; this would not be possible with the existing situation with the sea wall in place and relying on the small sluice in the south-eastern corner. This is despite the presence of the embankments resulting in a minor loss of the flood plain.

In terms of other scheme elements, there is no change in flood extent in the area of the secondary embankment on the left hand bank. The presence of the third SSE embankment should result in a reduction in flood extent during the combined event since the crest level is +2.6 m AOD. The impact of the recycled plastic walkway on the flood extent landward of the primary embankment should be negligible, and any loss of storage and displacement of water should have a negligible impact on flood extent. The impact of the footpath diversion should not result in flood storage loss and drainage or overland flow because it is on higher ground and it should not be inundated during a MHWS tide in isolation or combined with a 1% AEP fluvial event from the Lavant.

Therefore, the scheme shows a **betterment** in flood extent during a combined 1% AEP fluvial event and mean spring tide compared to the existing situation, as a result of the presence of the culvert and 20 m wide breach in the existing sea wall.

4.3.3.2 Flood Depths

The flood depths have been obtained from the hydraulic modelling to determine whether the proposed scheme influences the flood depths on site or the surrounding land and are also shown in Figures 4-2 and 4-3. In Figure 4-2, the flood depths obtained from the existing situation are based upon the ingress of fluvial water only from the River Lavant during a 1% AEP fluvial event. The sea wall has not been breached so there is no tidal input and the new flood embankments are absent. In Figure 4-3, the flood depths are obtained from the proposed scheme and include the breach and flood embankments. The event is a mean spring tide (+2.2 m AOD elevation) combined with the 1% AEP fluvial event from the Lavant. The comparable shape of the flood extent / depth coverage in Figures 4-2 and Figures 4-3 is clear.

In the existing scenario, the maximum water level within the site reaches a maximum water depth of >1 m AOD. The deeper parts coincide with the ordinary watercourses and drainage networks within the site heading towards the south-eastern corner of the right hand bank of the river. Additionally, on the southern boundary of the site, low topographical gradients are present which may increase the water depths. North of the site boundary the maximum water depth is significantly less, around +0.3 m AOD.

The proposed scheme (Figure 4-3) shows a reduction in water depths across the site seaward of the primary embankment. With the exception of the drainage channel networks, most of the site now occupies an approximate water depth of approximately +0.3 m AOD. Landward of the flood embankment, there is little change in flood depths. The reason for the reduction in depth is because of the culvert and sea wall breach functioning to help drain the site quicker than the existing situation. There should be a reduction in water depth in the area of the SSE embankment. The impact of the recycled plastic walkway on the flood depths landward of the primary embankment should be negligible as a consequence of loss of storage and displacement of water. The impact of the footpath diversion should not result in any impact on flood depths because it is on higher ground and it should not be inundated during a MHWS tide in isolation or combined with a 1% AEP fluvial event from the Lavant.

The proposed scheme therefore shows **betterment** to the site by minimising the flood depths within the site boundary, as well as reducing the flood extent.

4.3.3.3 Flood Flow Speed

The maximum flow speed flood for the existing and proposed scenarios has been obtained from the tidal hydraulic model. These are shown in Figure 4-4 and Figure 4-5. The existing scenario does not include any breach or flood embankments to reflect the present day. The existing scenario is based on a 1% AEP fluvial flood event. The proposed scenario has a mean spring tide (+2.2 m AOD) combined with the input of a 1% AEP fluvial event from the River Lavant. The primary embankment, culvert and breach are present for the proposed scenario.

Inspection of the results shows that over the existing site a maximum flow speed close to 0.1 m/s with the exception of approximately 0.2 m/s along the drainage channel which outfalls to the River Lavant. There is notably a high velocity where the River Lavant outfalls to the Langstone Harbour showing a maximum speed of approximately 1.5 m/s. In addition, there is an area in the northern part of the site where the Lavant is spilling into the floodplain and this area has a maximum speed of approximately 0.5 m/s.

The results for the proposed scheme shows an increase in flow speed within the realigned area to approximately 0.3 m/s which is to be expected from the tidal breach and ingress of tidal water. The velocity notably increases where the proposed breach and culvert is to be located. At the breach location, velocity levels increase to approximately 1.1 m/s. This is due to the narrow dimensions of the breach. The flow speed increases locally at the downstream end of the culvert to around 0.5 m/s as the culvert discharges flow from the floodplain. Therefore, although the velocity slightly increases in two key locations (culvert and breach), this is to be expected by virtue of the nature of the proposals. Appropriate mitigation measures (i.e. scour protection within scheme, suitable breach width estimates) will be adopted to ensure that there are no detrimental impacts to the site and surrounding land (Section 4.5).

There is a reduction in maximum flow speed by approximately 0.3 m/s landward of the primary embankment. This demonstrates the role of the culvert in lowering flood depths and results in the proposed scheme providing a betterment in the northern part of the site with regards to maximum flow speed. There is no change in velocity where the River Lavant outfalls to Langstone Harbour between the existing and proposed. The impact of the presence of the SSE embankment should result only in a minimal increase in flow speeds in close vicinity. The impact of the recycled plastic walkway on the flow speeds landward of the primary embankment should be negligible as a consequence of loss of storage and displacement of water. The impact of the footpath diversion should not result in any impact on flow speed because it is on higher ground (Figure 1-3) and will not be inundated during a MHWS tide in isolation or combined with a 1% AEP fluvial event from the River Lavant.

Therefore the proposed scheme shows **minimal increase** in velocity where the breach and culvert is located. Mitigation measures will be adopted to minimise any detrimental impacts and these are reported in Section 4.5. There is a **betterment** north of the site where the flood velocity has reduced.

Figure 4-1: Present day 1% AEP fluvial Flood extent for the existing site

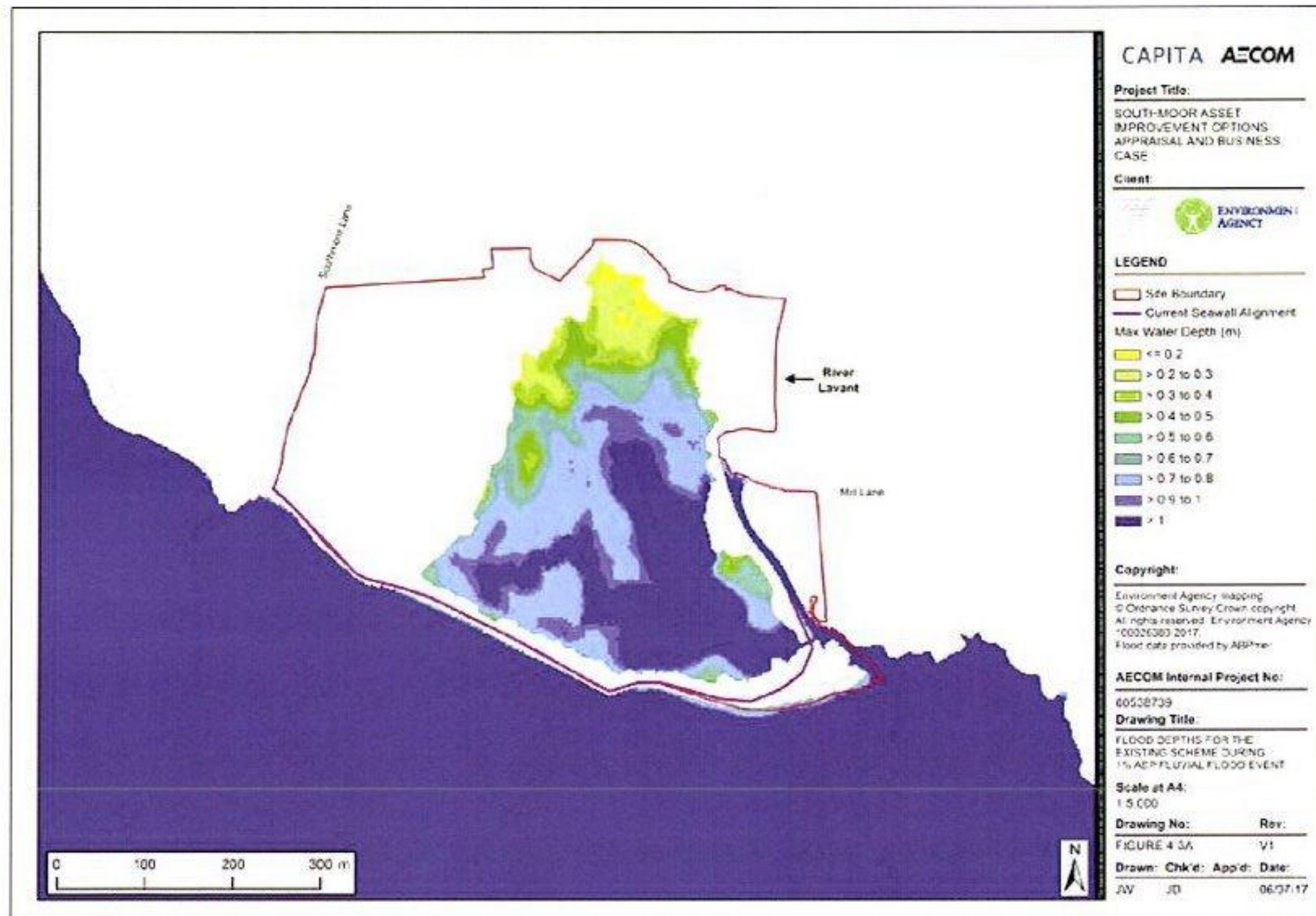


Figure 4-2: Flood depths for the existing scheme (during the 1% AEP fluvial flood event) – Excluding tidal input

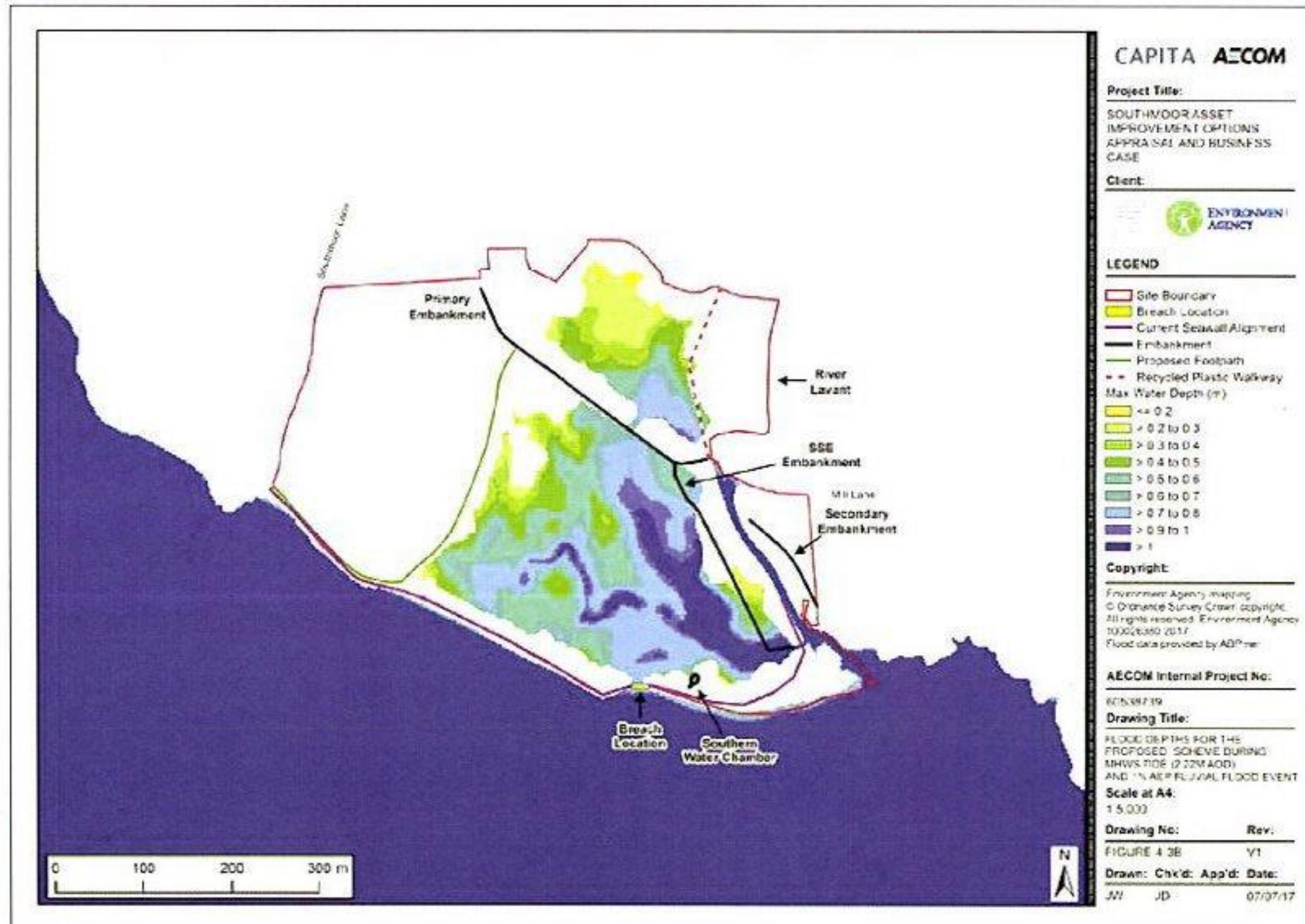


Figure 4-3: Flood depths for the proposed scheme during MHWS tide (+2.2 m AOD) and 1% AEP fluvial flood event

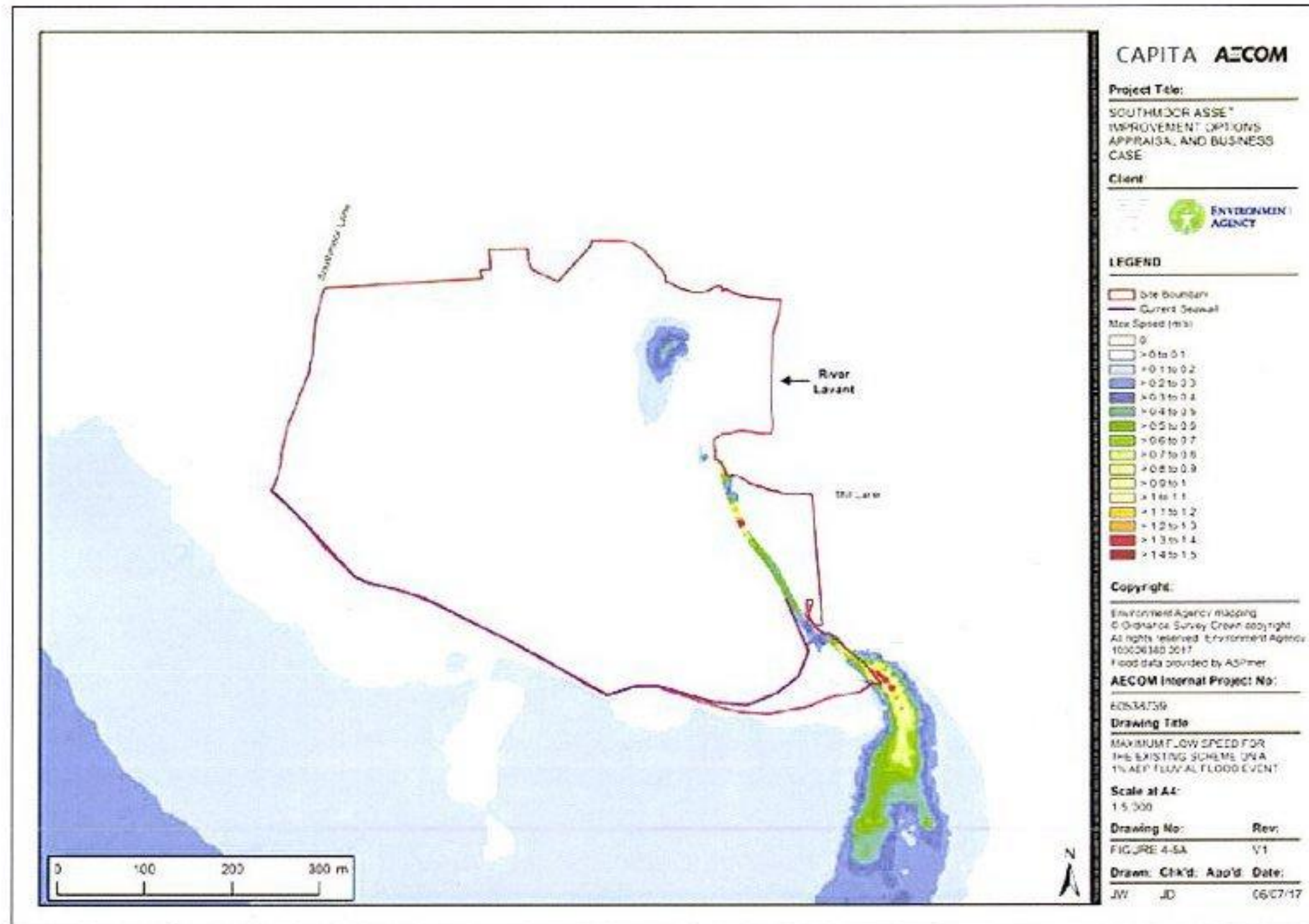


Figure 4-4: Maximum Flow Speed for the existing scheme on a 1% AEP fluvial flood event input

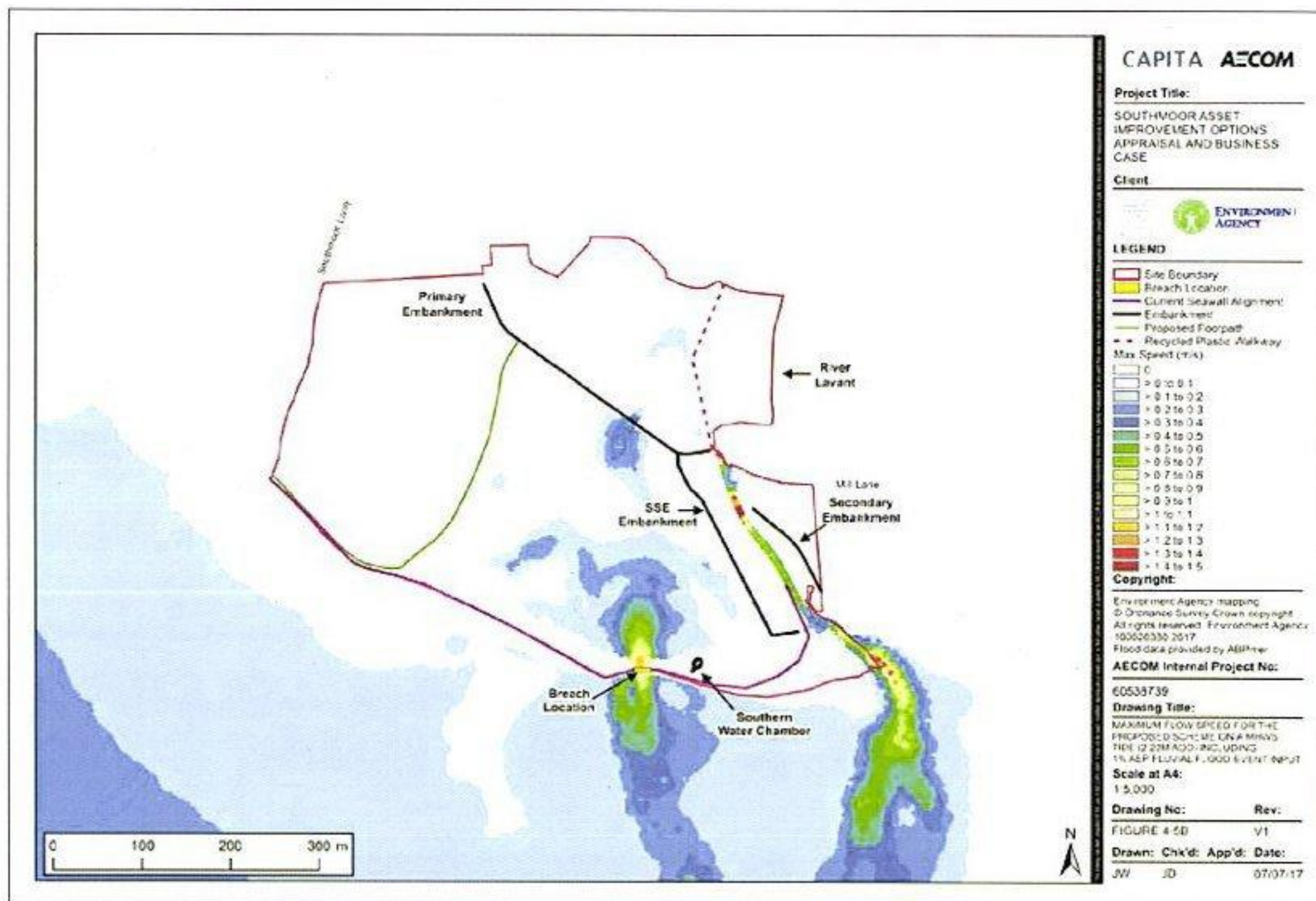


Figure 4-5: Maximum Flow Speed for the proposed scheme on a MHWS tide including 1% AEP fluvial flood event input

4.3.4 InfoWorks RS Model

An InfoWorks RS Model (v12.5) of the River Lavant has been adopted from the Havant Mapping Study by Atkins (2008) to provide another means of assessing the impact of the proposed scheme on the fluvial flood extent for a 1% AEP event. The model has been consulted to further demonstrate how the proposed culvert allows the land to drain effectively when the tide ebbs and also provides an indication of the storage area available landward of the embankment. This is important to demonstrate no detriment and any betterment as a result of the implementation of the proposed scheme. Environment Agency data in the form of Product 7 (model files) and Product 5 (associated reports) were supplied by the Environment Agency for this exercise.

AECOM have reviewed the InforWorks model to ensure that the configuration and setup of the model matched the description provided in the Havant Mapping Study (Atkins 2008) and also to assess if the southmoor scheme had been adequately represented. As described in the modelling assumptions, no alteration or re-configuration of the river model was undertaken as it was considered suitable to provide a description of the fluvial flow regime within the River Lavant and Southmoor Scheme which could then be further considered in the bespoke coastal modelling studies undertaken specifically for the study (Appendix C).

Within the fluvial model, the schematisation of the floodplain is 1D only. Thereby Southmoor is represented as a series of 1D storage areas or reservoir ponds based on high resolution topographic information (LiDAR). The storage areas are connected to one another by the 1D floodplain units which describe the natural ground profile and act as irregular weirs to control flow between the storage areas. Similarly, the flow exchange between the River Lavant and the floodplain storage areas are represented by 1D 'spill' units which describe the longitudinal bank profile to control flow.

Figure 4-6 shows the Southmoor section of the model for a 1% AEP fluvial design event which is shown by the 'blue' flood extent. This is very comparable with the 1% AEP fluvial event flood mapping provided by the EA and is shown in Figure 4-2.

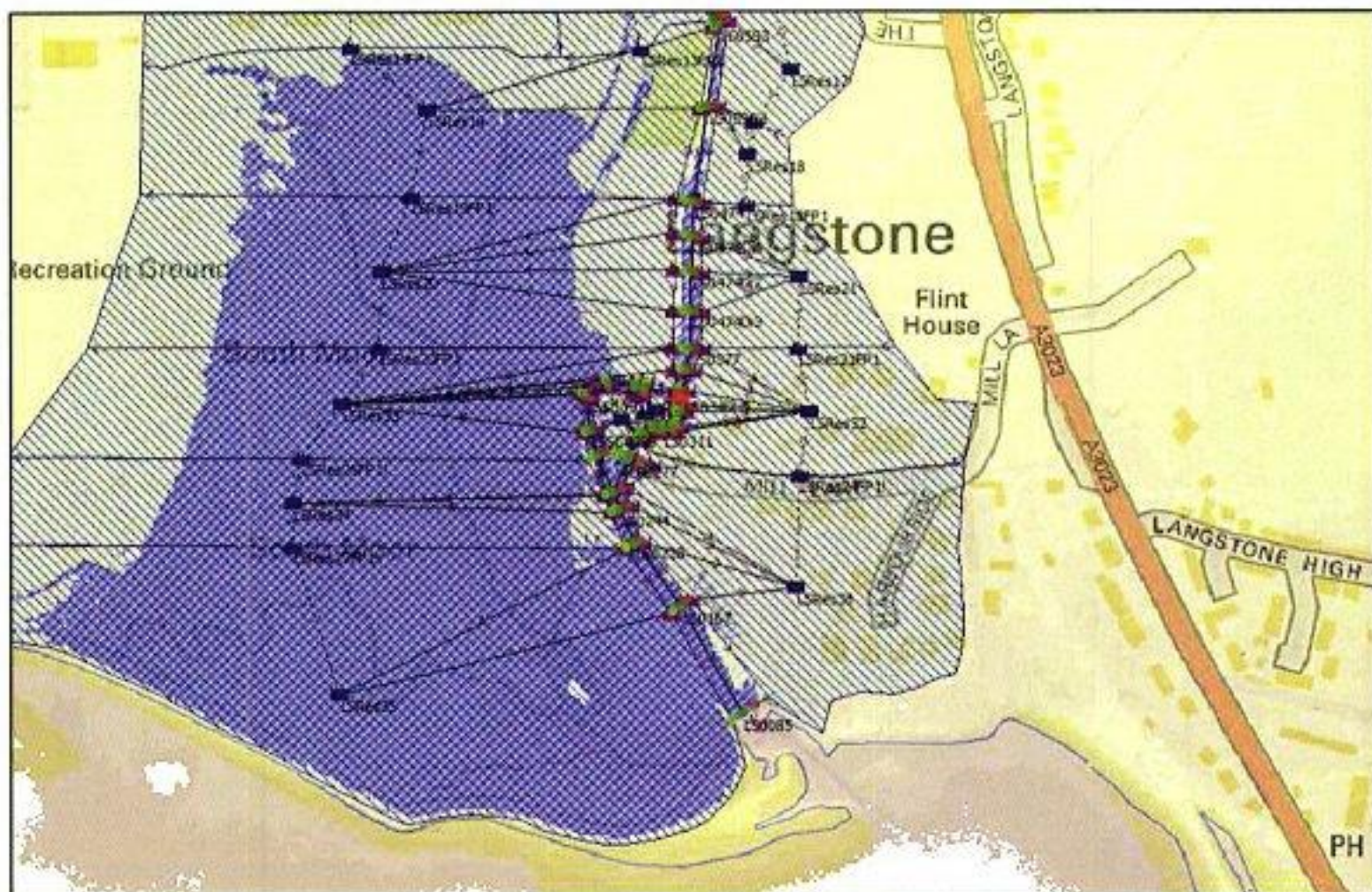


Figure 4-6: InfoWorks Model River Lavant (1% AEP fluvial flood event)

4.3.4.1 Existing Flooding Mechanism

The River Lavant runs from north to south and discharges to Langstone Harbour. At the western end of Mill Lane there is a secondary river loop which branches off the River Lavant and is understood to be a historic mill race. The flow around the mill race is controlled by a side weir with a crest elevation of +3.6 m AOD. Downstream of

the side weir, there is a second weir with a crest elevation of +3.4 m AOD. The weirs isolate the upstream reach of the River Lavant from most tidal influences except extreme tides when they may become drowned.

The InfoWorks model results were examined to show the overbank 'spills' which exchange flow between the River Lavant and the Southmoor floodplain and the return of overland flow into the Lavant.

Significant volumes of water overtop the right bank of the River Lavant approximately 250 m upstream of the mill race side weir; these locations are shown in Figure 2-1. The total peak flow overtopping the right bank at this location is approximately $2.5 \text{ m}^3/\text{s}$. Over the duration of the 1% AEP event a total volume of approximately $465,000 \text{ m}^3$ of water enters the floodplain via this mechanism.

This water fills up the Southmoor floodplain behind the existing sea wall to a level which re-enters the River Lavant via the right bank of the mill race. The model shows that approximately $373,000 \text{ m}^3$ of the volume in the floodplain, the vast majority, re-enters the Lavant via this mechanism and route, with the residual volume (around $90,000 \text{ m}^3$) remaining in the floodplain (Southmoor) as shown in Figure 4-6.

4.3.4.2 Proposed Flooding Mechanism

The proposed primary embankment will cross the Southmoor floodplain and will result in a reduction in floodplain area (Figure 4-7). However, the proposed 1 m diameter one way flapped culvert in the proposed embankment will allow fluvial flows in the northern part of Southmoor to drain through the embankment. Secondly, the breach in the existing sea defences will allow the northern part of the site to link to the southern part of Southmoor. When this area becomes inundated by seawater on a tidal cycle and is in the ebb phase, the tidal water and any residual flood volume can discharge to Langstone Harbour. During the flood phase of the tide when the tidal level exceeds the invert level of the embankment culvert, rises to High Water and stays above the culvert invert level (tide locked), outflow from the northern part of the floodplain will be prevented and flood water will temporarily be stored in the floodplain until either the tidal level drops sufficiently to allow it to evacuate via the culvert or it reaches a level at which it can overtop back into the River Lavant via the mill race.

The level at which water will flow back over the bank of the mill race from the floodplain is approximately +2.56 m AOD. An analysis of the LiDAR data for the northern part of the Southmoor floodplain (north of the proposed embankment) established an existing available storage capacity of approximately $26,000 \text{ m}^3$ up to a level of +2.6 m AOD. The available storage area is shown in Figure 4-7.



Figure 4.7: InfoWorks Model River Lavant area of available storage capacity

The volume of water flowing into the floodplain during a 1% AEP fluvial River Lavant event ($\sim 465,000 \text{ m}^3$) is significantly more than the capacity of the northern part of the floodplain ($\sim 26,000 \text{ m}^3$) up to an elevation of +2.6 m AOD. The model results show that the 1% AEP fluvial event is overtopping into the floodplain over a period of 5 days, and over this period there would be approximately 10 tidal cycles. This is shown in a spill hydrograph in Figure 4-8. Therefore, the long duration of the 1% AEP fluvial event has to be considered with the proposed scheme in place.

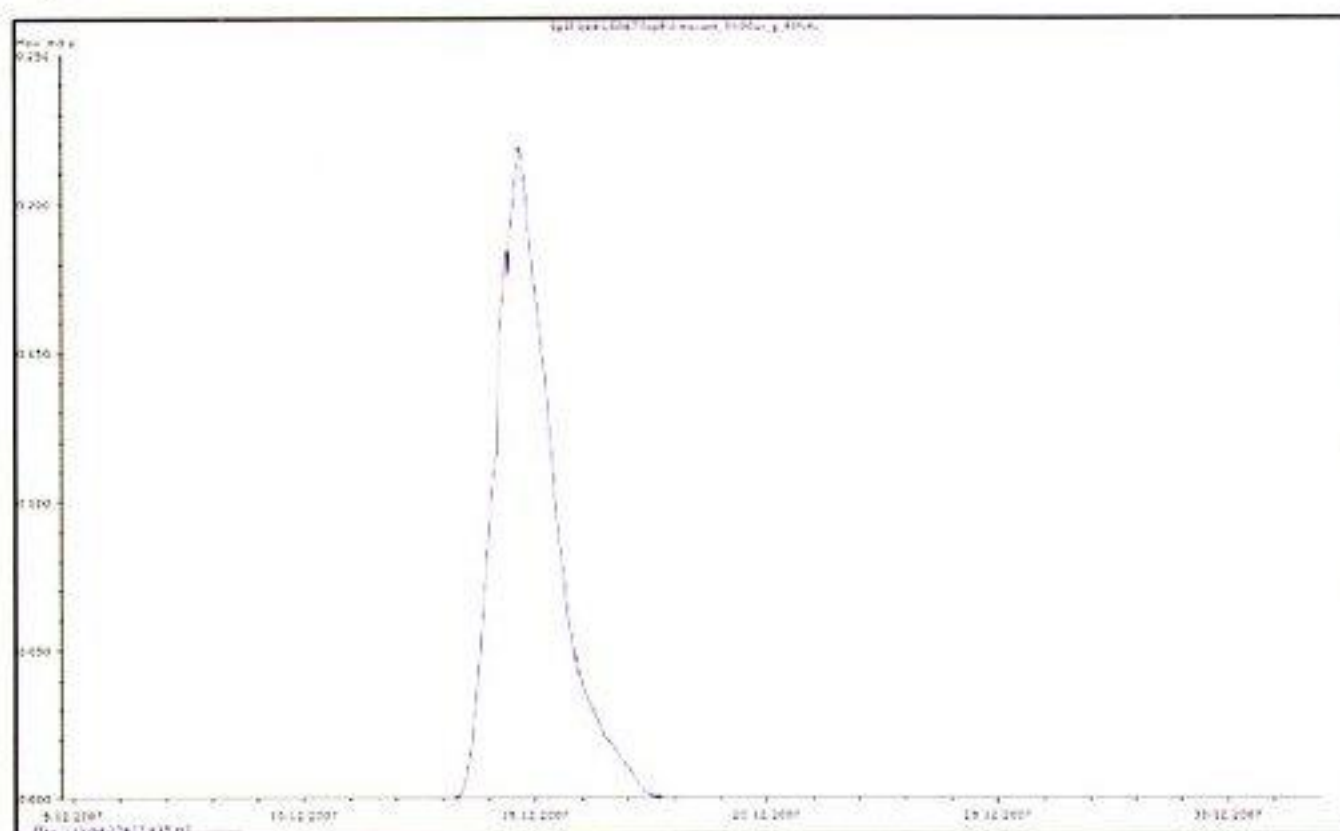


Figure 4-1: Spill hydrograph of the River Lavant (Atkins 2008)

Despite the presence of the primary embankment and reduced storage area, the observations from the InfoWorks model, combined with the tidal modelling demonstrate that the proposals should not be detrimental over a spring neap cycle and 1% AEP extreme fluvial flood event. It is considered likely that flood risk will **not be increased** against the existing situation over the duration of the hydrograph period of days and tidal cycles. As shown when comparing Figures 4-2 and 4-3 the proposed scheme should provide **betterment**.

The reasons for **betterment** are highlighted below:

The proposed culvert and breach in the sea wall effectively provide an outfall for fluvial water landward of the main embankment to flow across the site and into the harbour avoiding any potentially detrimental retention of flood water. During any tidal cycle, the amount of time that the culvert is prevented from discharging is around 4 hours. The remaining majority of time, as the tide recedes, over 8.5 hrs, permits the operation of the culvert and rapid draining of the area to the north of the embankment during one tidal cycle. In the existing situation flood water in the lee of the existing sea wall builds up over time and slowly drains to ground and via the sluice in the south-eastern corner of the site. With the proposed scheme, the area becomes frequently drained, effectively reinstating available storage volume. In addition, when flood water exceeds an elevation of +2.6 m AOD, there is also a significant flow of water back into the River Lavant via the mill race which also minimises the potential flood risk.

The hydrodynamic modelling shows that the whole of the area to the north of the primary embankment can drain the peak fluvial flow from the Lavant during a 1% AEP fluvial event combined with a mean spring tide (+2.2 m AOD) within a single tidal cycle.

4.4 Impacts Summary

A modelling study has been undertaken using the existing 2008 InfoWorks model of the River Lavant (Atkins 2008) and surrounding catchment, the outputs from this model for the 1% AEP fluvial event model were combined in the MIKEFM coastal model to inform the extent and impacts of a fluvial extreme event for both the existing and proposed Southmoor Managed Realignment scheme. The findings from this modelling study has shown that the predicted level of site inundation matches well against the images collected (Figure 1-5) and Environment Agency Product 4 results (Figure 4-1). The scheme results shown that the scheme will function effectively and it is predicted that there will be no significant impacts on flood extents, depths and flow speeds on site and the adjacent area.

The primary embankment will retain the ingress of water during a mean spring tide (+2.2 m AOD) and will effectively discharge towards Langstone Harbour. During extreme fluvial events, the inclusion of the seaward breach and scheme design provides a betterment to flooding by allowing the site to efficiently drain reducing the flood extent and subsequently reducing the flood depths.

The hydraulic modelling has shown that the proposed scheme will result in an increase in flow speeds at the locations of the proposed breach and culvert. The critical flow speed for the assumed sediment type is 1.2 m/s and therefore it is predicted that there is increased likelihood of localised erosion and scour. Subsequently there is the potential for mobilisation of sediments local to the breach which may influence sediment transport behaviour. However, over time, it is unlikely for the works to cause significant impacts on erosion and transport of sediment, and the changes should reach equilibrium over time. Mitigation measures will additionally be adopted; see section 4.5.

In terms of the impact on existing flood risk of the secondary embankment proposed for the left hand bank, it is expected that this will provide protection to the residents of Langstone during surge tides and low frequency fluvial flood events from the Lavant (less than 1% AEP).

The third embankment on the site, the SSE embankment, is modest in form, and is not expected to significantly alter the modelling findings of the primary embankment; this applies to the presence of the recycled plastic walkway and footpath diversion too. The proposed ground rising around the SW asset will only consist of minimal topographical changes and will not have any significant impact on water levels or flood risk on site and the surrounding land.

4.5 Mitigation of Impacts

To mitigate the potential impacts associated with the minimal increase in velocity at the breach and culvert, appropriate armouring will be installed around both structures up to a leave of mean high water springs. This will minimise the scope for localised scour and mobilisation of sediment to impact on the new embankment and the existing sea wall. The culvert and breach will be closely monitored for changes in bed level and regular inspections and maintenance will be applied to avoid any detrimental impacts to the site and surrounding land. Clearly the modelling of the culvert and breach has demonstrated their critical role in avoiding detrimental impacts. The inspection and maintenance regime will be key in preventing any culvert blockages and / or silting up of the breach.

Adequate signage will also be displayed by the culvert in the interest of public safety as a precautionary measure. Flow speeds of 0.5 m/s have been obtained from the hydraulic model and may present a minor risk to the public. Therefore it is fundamental to use adequate signage to inform those persons (and animals e.g. dogs) walking in the area. The improved access afforded by the recycled plastic walkway and footpath diversion should also come with appropriate signage, so regular and new visitors are aware of the environmental changes; it is important to highlight that the recycled plastic walkway does not provide dry access and egress during the combined MHWS tide and 1% AEP fluvial flood event i.e. avoid complacency.

5. Conclusion

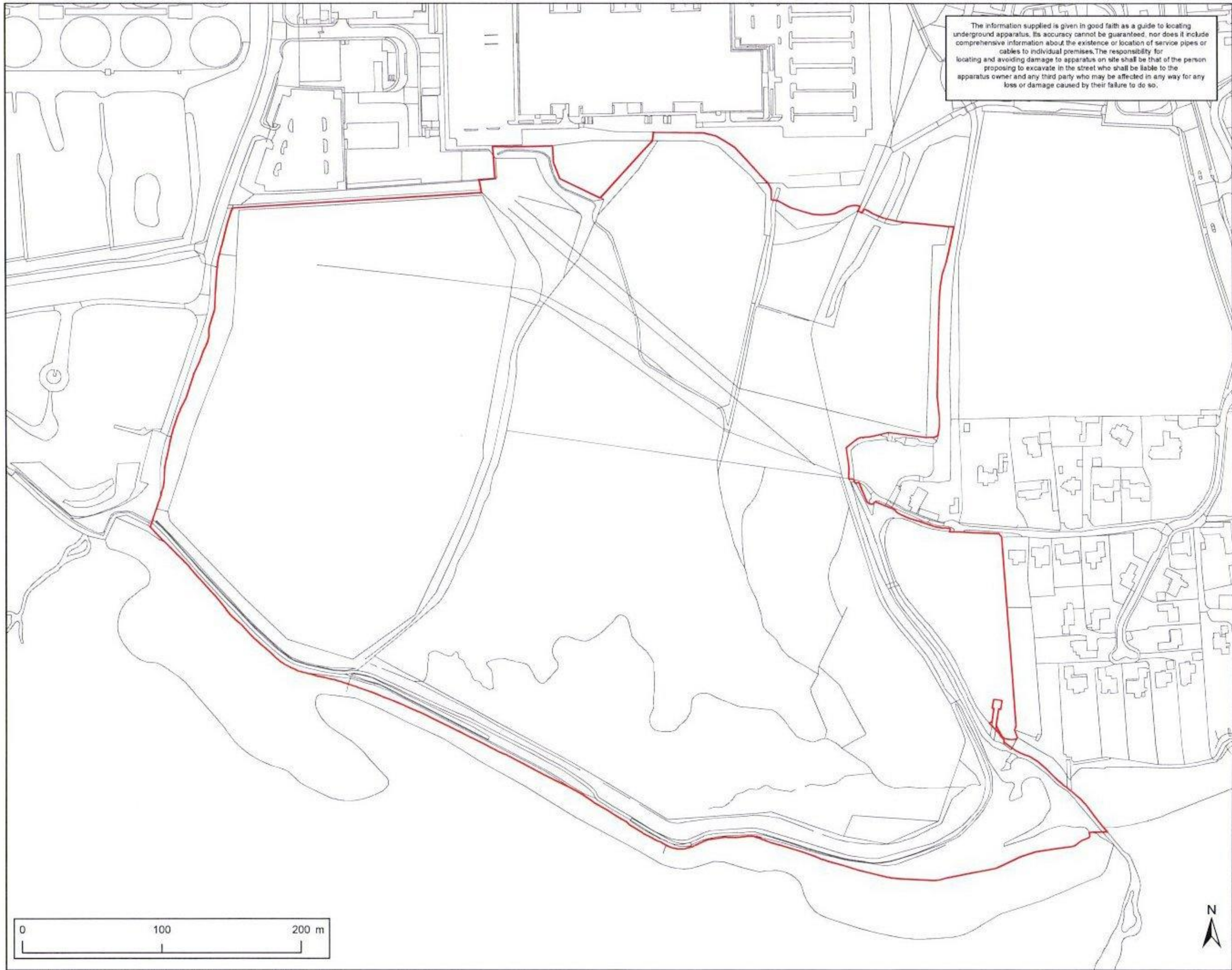
This FRA has been prepared in accordance with the requirements of the NPPF to determine the site specific risks for the proposed scheme. The following conclusions have been drawn as part of the assessment:

- The site is located within Flood Zone 3 (i.e. land with a risk of flooding >1% fluvial and >0.5% tidal);
- Most of the site is within the Low risk of Surface Water Classification although there are hot spots within the High Risk Classification along the ordinary watercourse channels;
- The site is underlain by permeable Chalk Formation and therefore there is a minimal risk of groundwater flooding within the site;
- Flooding from sewer and artificial sources is minimal within the site;
- Hydraulic tidal modelling for the existing and proposed scheme has been undertaken to inform the design of the proposed scheme. The following conclusions have been made:
 - The new primary embankment provides a significantly improved level of tidal defence condition;
 - The standard of protection will not be less than the current 0.5% AEP;
 - The 1% AEP fluvial flood extents, combined with a mean spring tide (+2.2 m AOD) show a betterment in flood depth and extent in both the north and south areas of the primary embankment with the proposed scheme in place; and
 - The flow speed changes from the proposed scheme shows a betterment across the site and increases at the culvert and breach, which are inherent aspects of the design.
- The InfoWorks River Lavant fluvial Model (Atkins, 2008) has also informed the proposed scheme. The following conclusions have been made:
 - The volume of water flowing into the floodplain during a 1% AEP River Lavant fluvial event is greater than the capacity of the northern part of the floodplain, based on the primary embankment impeding overland flows from the River Lavant over the full hydrograph duration;
 - Analysis of the results combined with hydrodynamic modelling has demonstrated that the culvert and sea wall breach successfully reduce retention of flood water permitting drainage of the site within a single tidal cycle and despite a period of tide lock (around 4 hours out of 12.5 hours);
 - Overland flow of water also enters back into the River Lavant via the mill race when water levels rise above a level greater than +2.6 m AOD which will also contribute to the reduction in potential flood risk; and
 - The net effect, therefore, is for the proposed scheme to provide betterment.

The following recommendations have been considered to ensure that the risk of flooding is minimised for the 50 year design life as defined and agreed in the Basis of Design Report for the proposed scheme

- The integrity of the new realigned defence must be subject to an appropriate maintenance and monitoring regime. Avoiding culvert blockage is particularly important in this regard.
- Appropriate armouring of the culvert and breach must be implemented to minimise scour and changes in sediment transport. Changes in bed level at the breach are particularly important in this regard
- Appropriate signage must be displayed by the culvert and in the recycled plastic walkway and footpath diversion locations as a precautionary measure, in order to inform the public of the potential safety risks and the environmental changes, and keep public access and egress safe.

Appendix A Site Boundary



The information supplied is given in good faith as a guide to locating underground apparatus. Its accuracy cannot be guaranteed, nor does it include comprehensive information about the existence or location of service pipes or cables to individual premises. The responsibility for locating and avoiding damage to apparatus on site shall be that of the person proposing to excavate in the street who shall be liable to the apparatus owner and any third party who may be affected in any way for any loss or damage caused by their failure to do so.

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Project Title:
**SOUTHMOOR ASSET
IMPROVEMENT OPTIONS
APPRAISAL AND BUSINESS
CASE**

Client:



LEGEND

Site Boundary

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Issue/Revision:

IR	Date	Description

AECOM Internal Project No:

60538739

Drawing Title:

SITE BOUNDARY

Scale at A3: 1:2,500

Drawing No: FIGURE 1 Rev: V1

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Appendix B Proposed Scheme Design

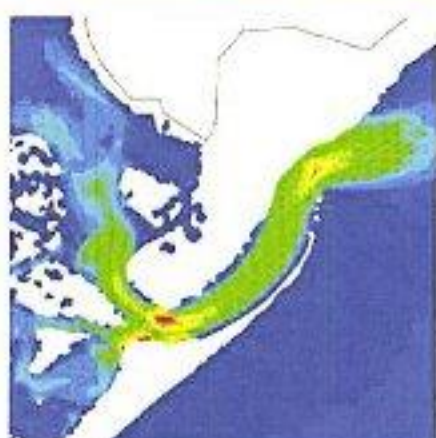
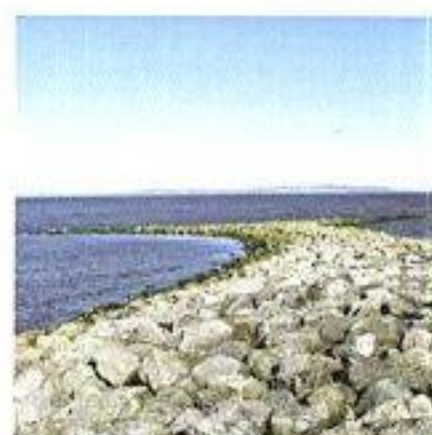
Appendix C Hydrodynamic Modelling Report (ABPmer, 2017)

AECOM

Hydrodynamic Modelling Report

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

July 2017

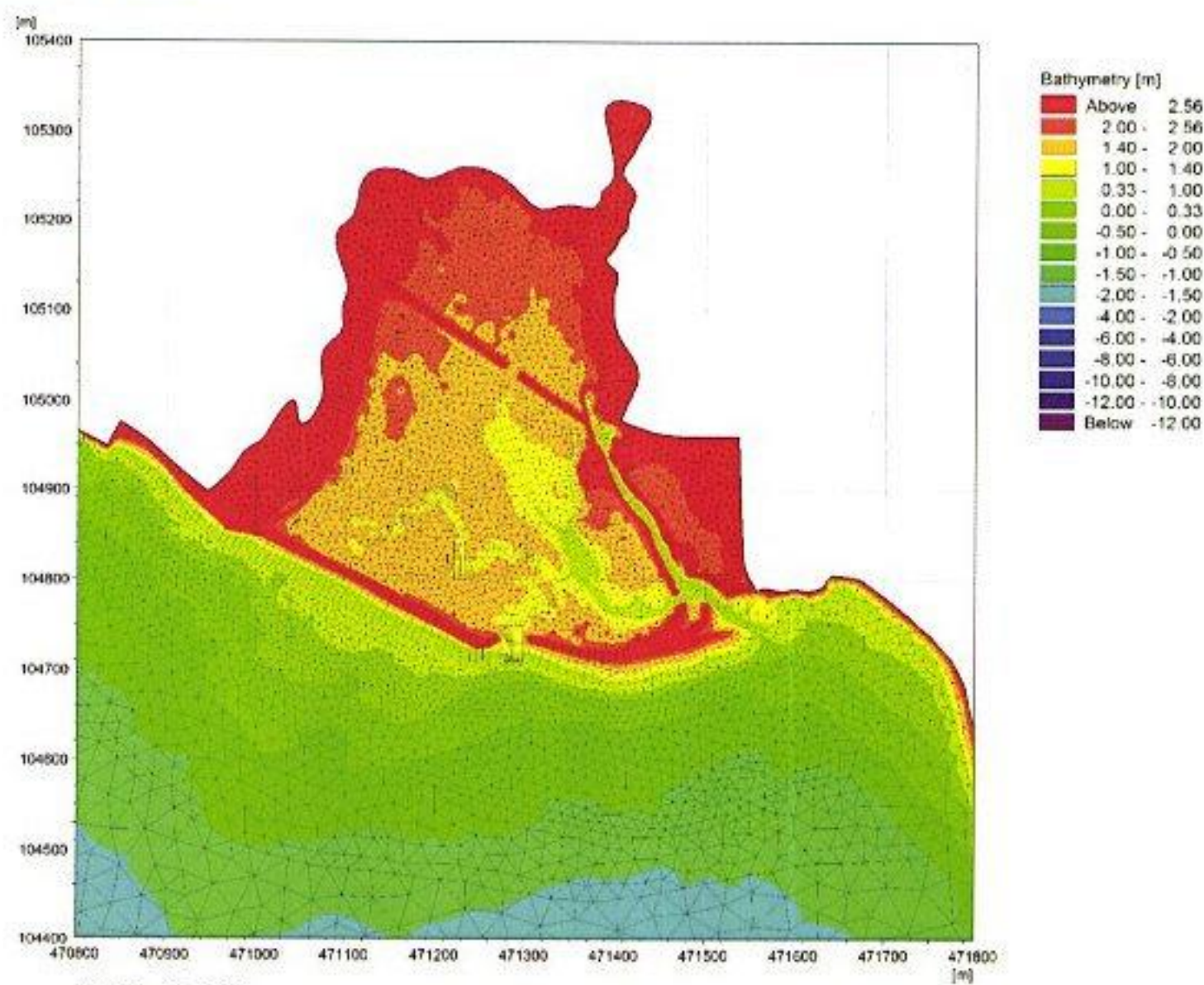


Innovative Thinking - Sustainable Solutions

Hydrodynamic Modelling Report

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

July 2017



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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.

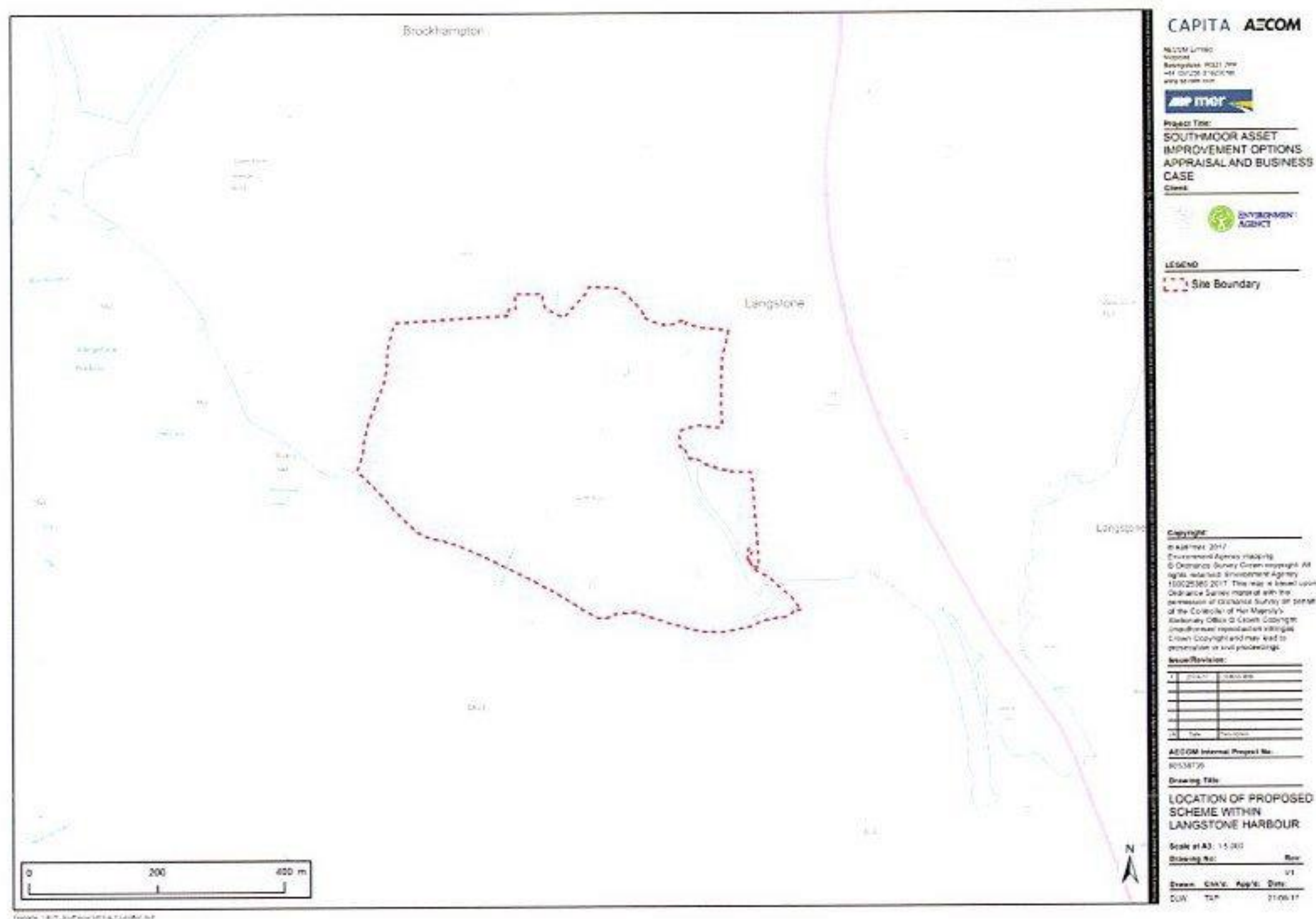


Figure 1. Location of the proposed scheme within Langstone Harbour

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.

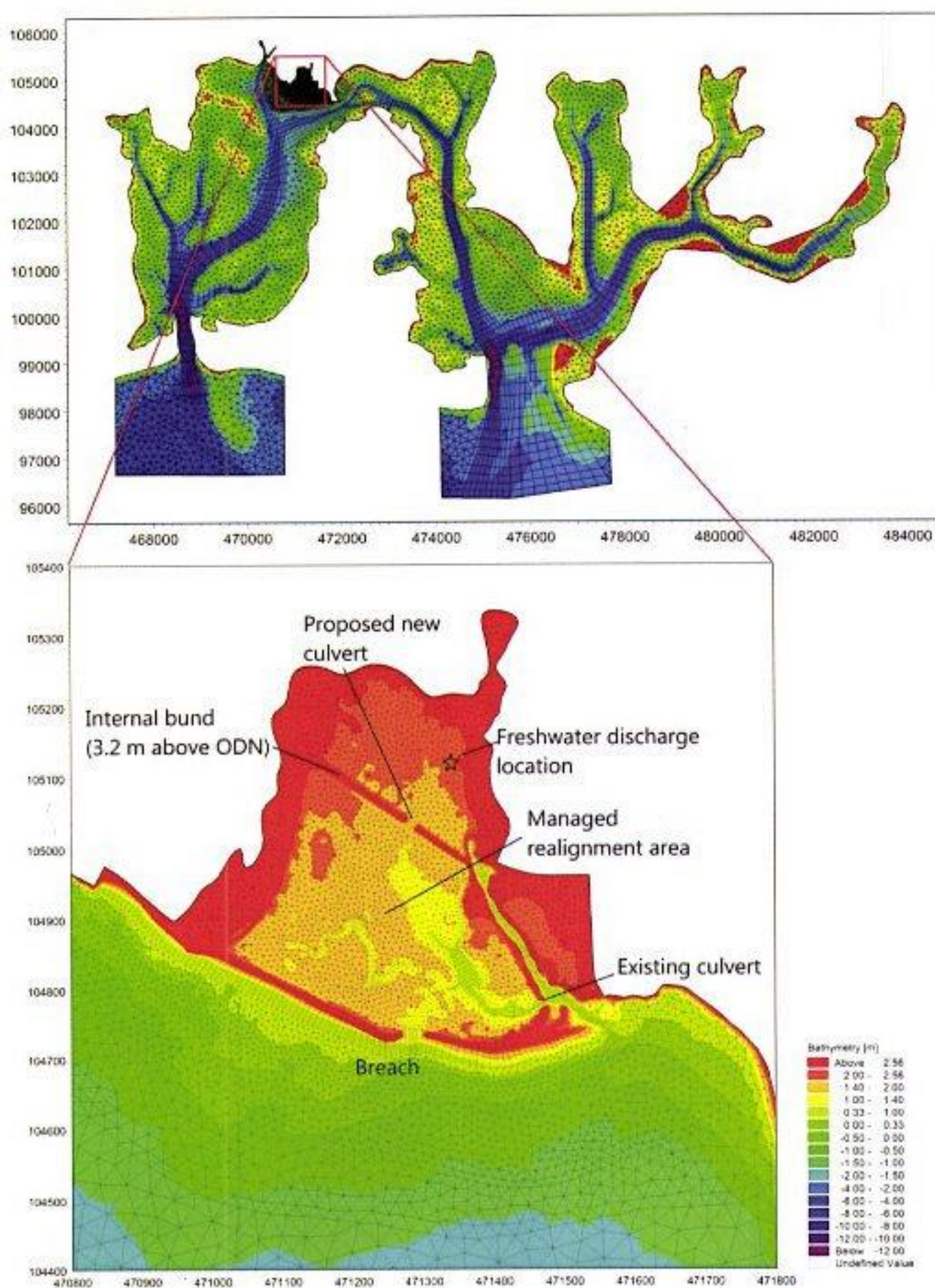


Figure 2. Representation of scheme in the hydrodynamic model

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).

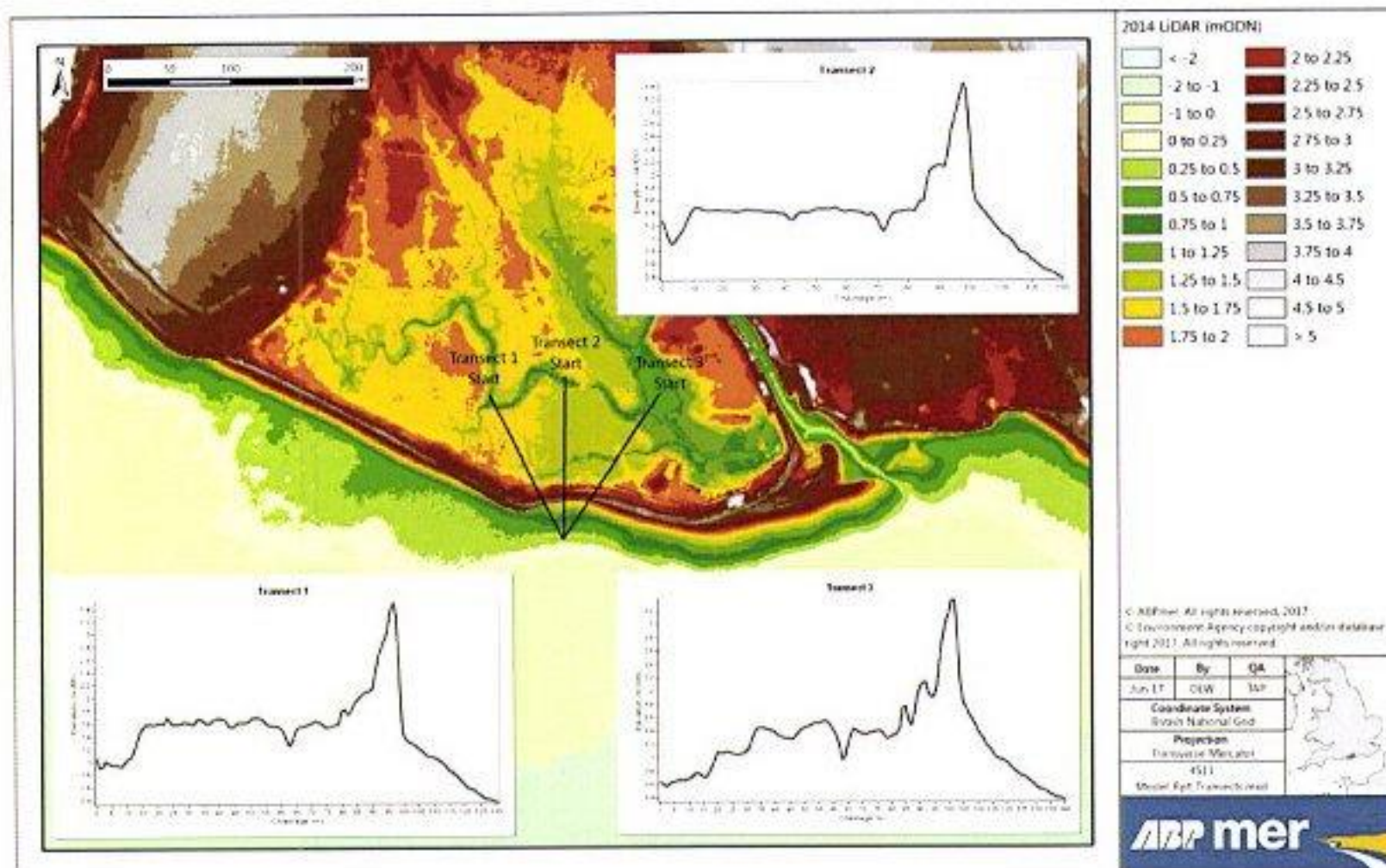


Figure 3. Site elevations with cross-sections through the breach location

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).

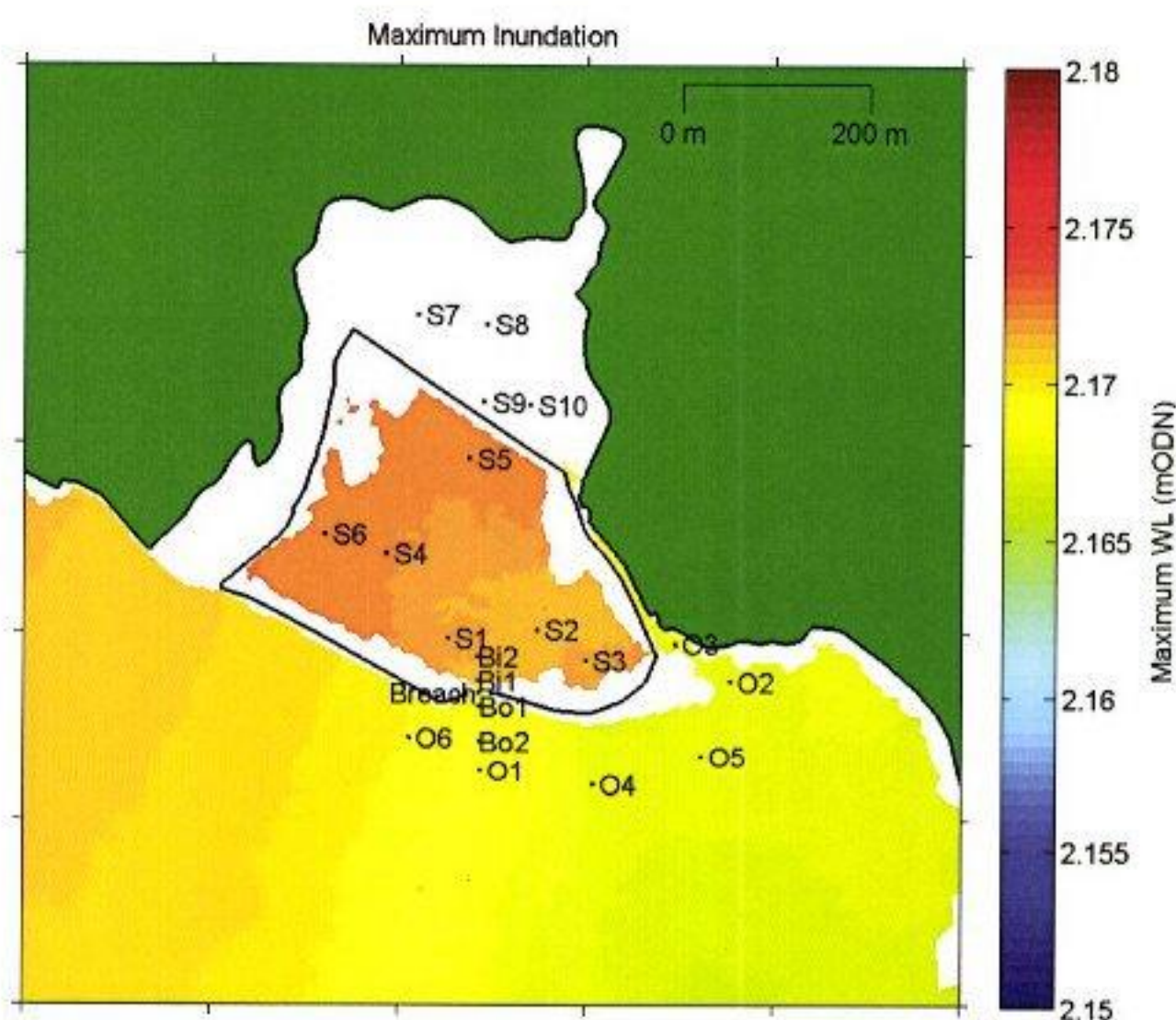


Figure 4. Maximum inundation (with extraction points) on a mean spring tide

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).

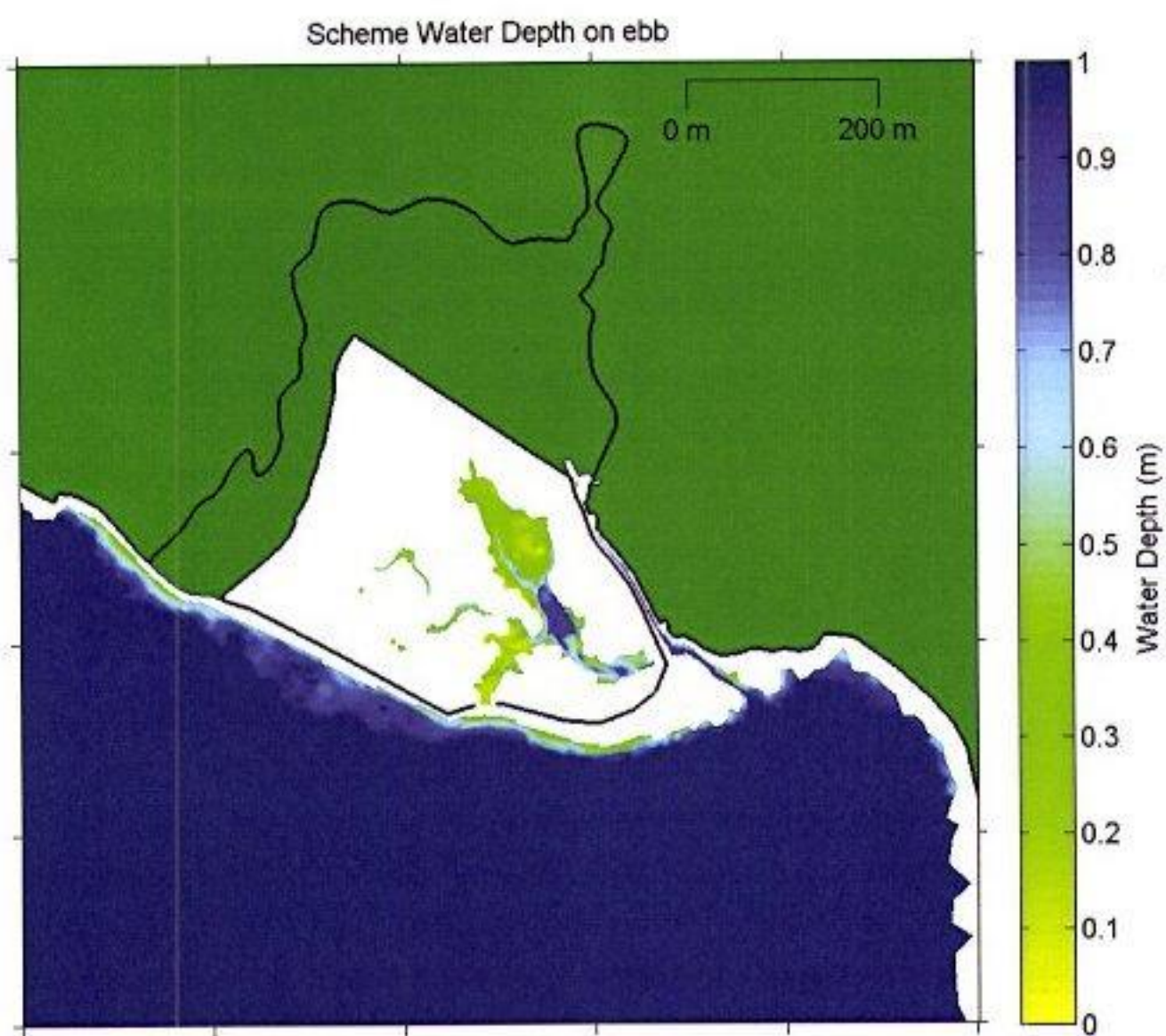


Figure 5. Water remaining on site after water level drops below breach sill

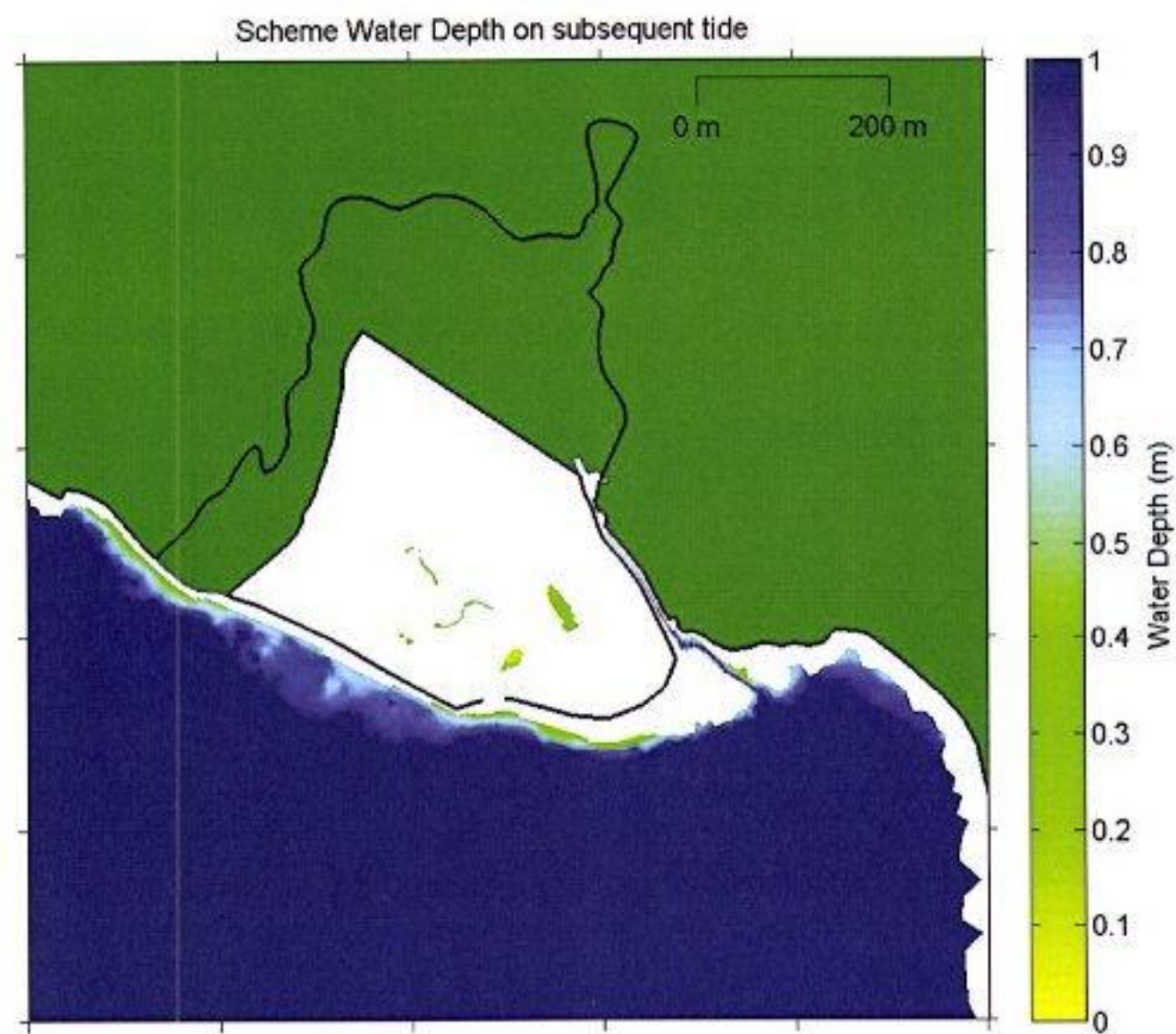


Figure 6. Water remaining on site before subsequent tide

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.

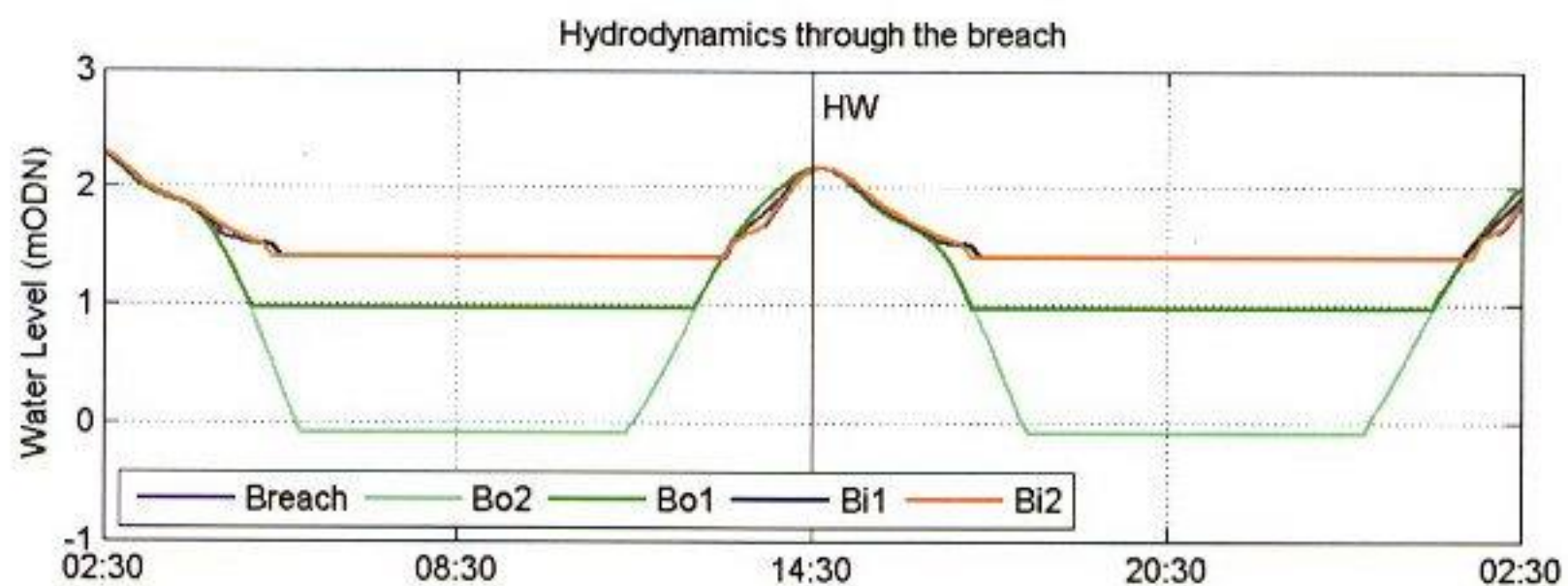


Figure 7. Time series of water levels through the breach on a mean spring tide (at locations shown in Figure 4)

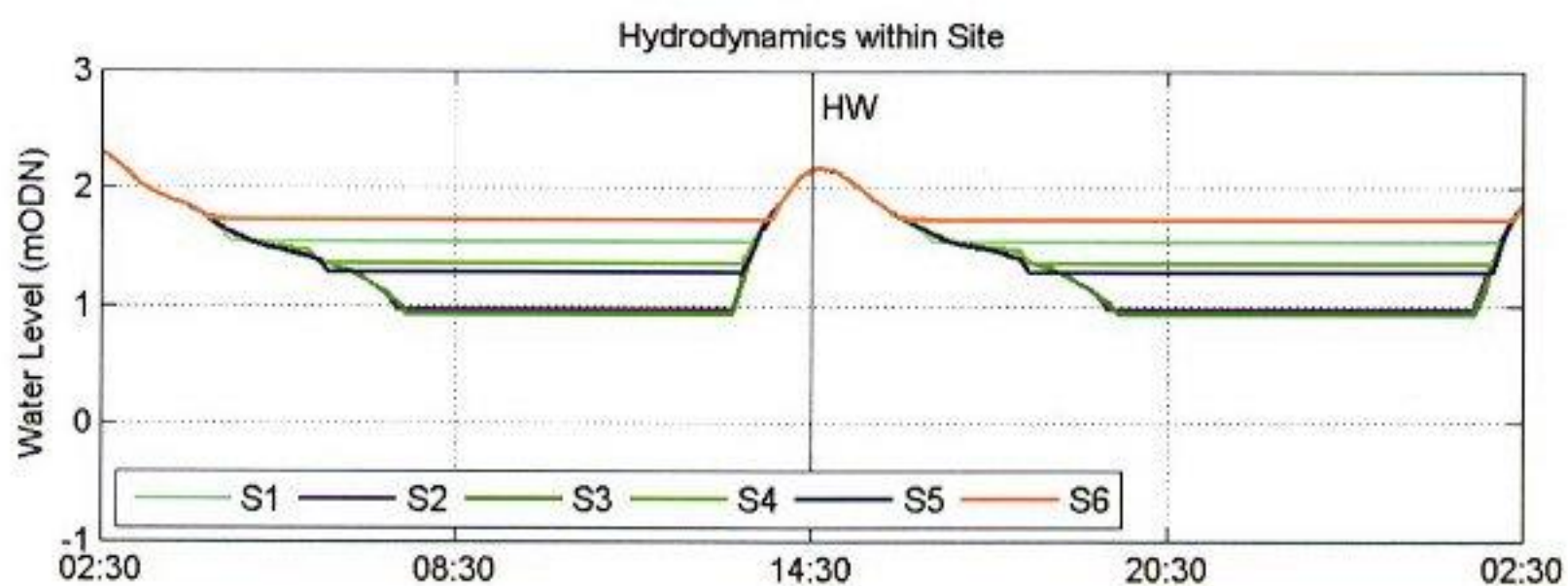


Figure 8. Time series of water levels in the managed realignment area on a mean spring tide (at locations shown in Figure 4)

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/m^2) 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).

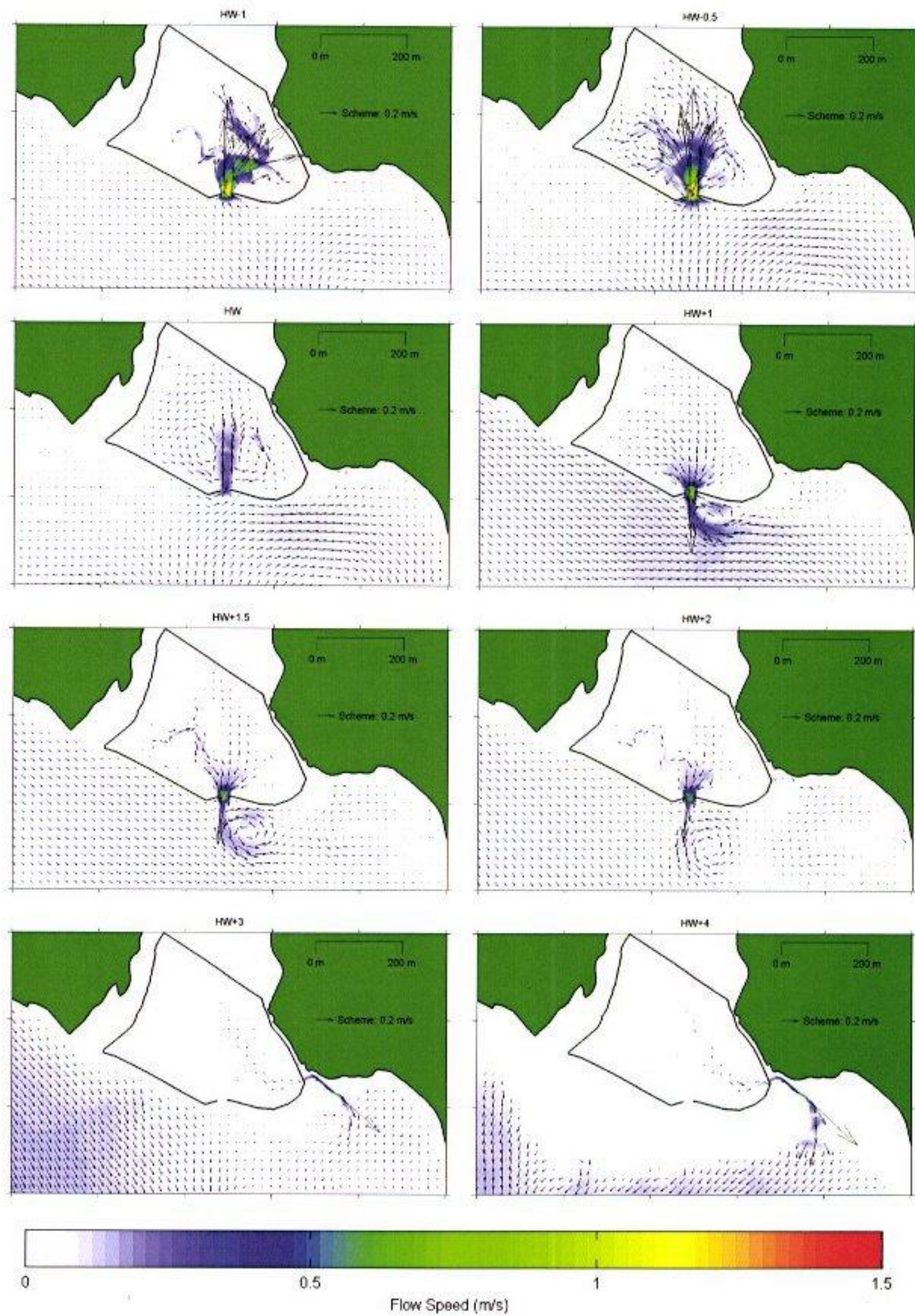


Figure 9. Vector plots at various times through the mean spring tide

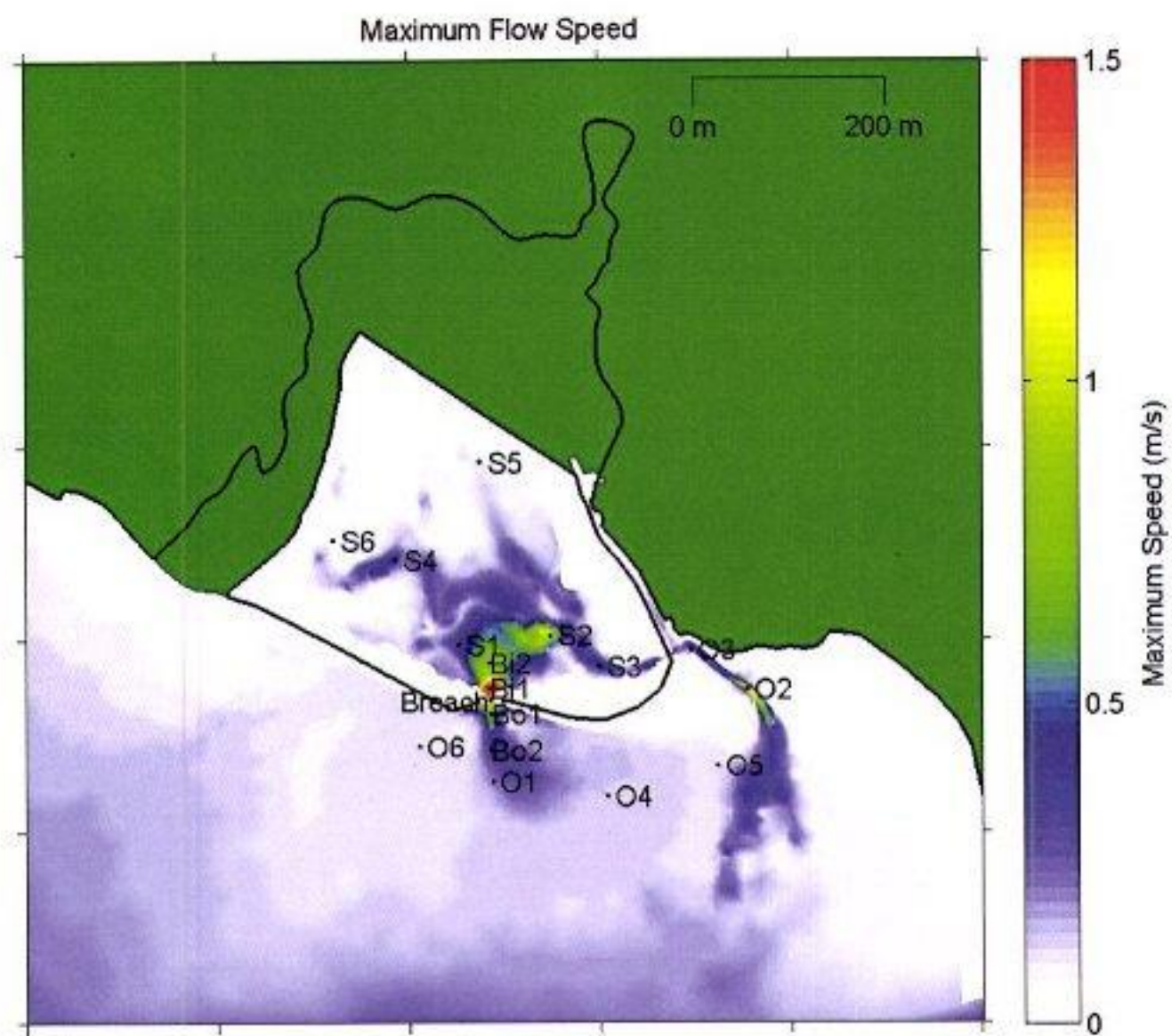


Figure 10. Maximum flow speeds on a mean spring tide

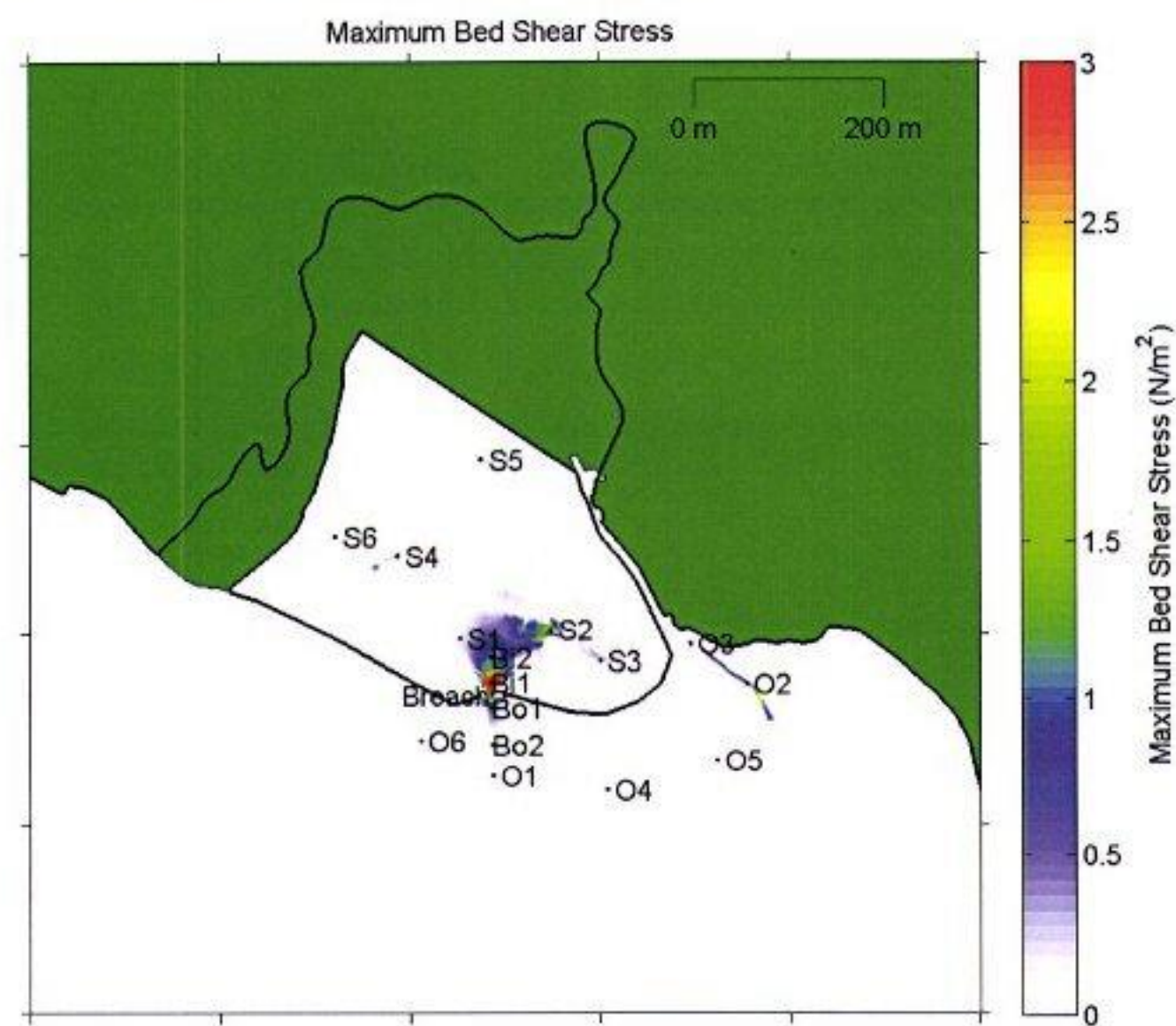


Figure 11. Maximum bed shear stress on a mean spring tide

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.

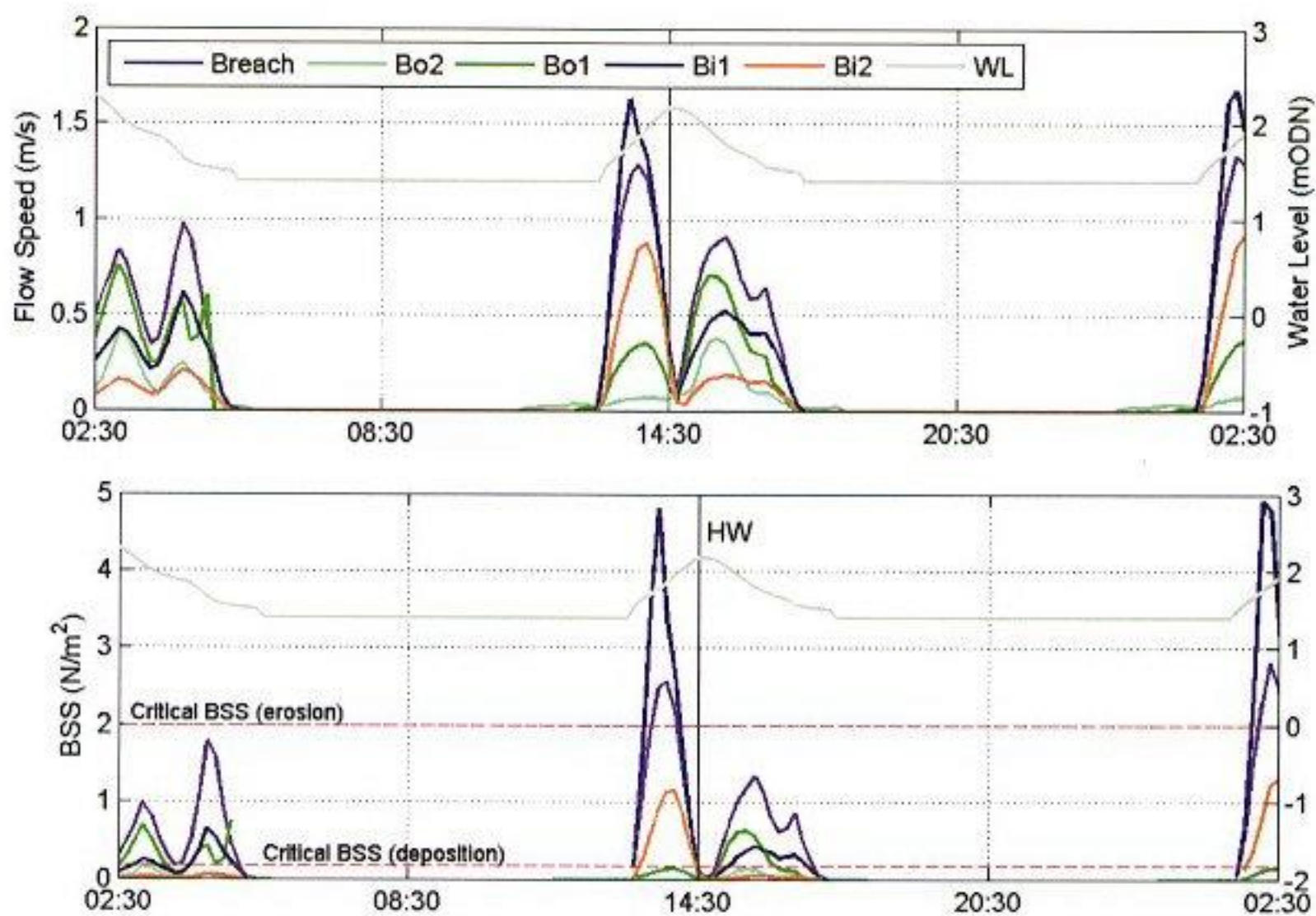


Figure 12. Time series of flows and BSS through the breach on a mean spring tide (at locations shown in Figure 10)

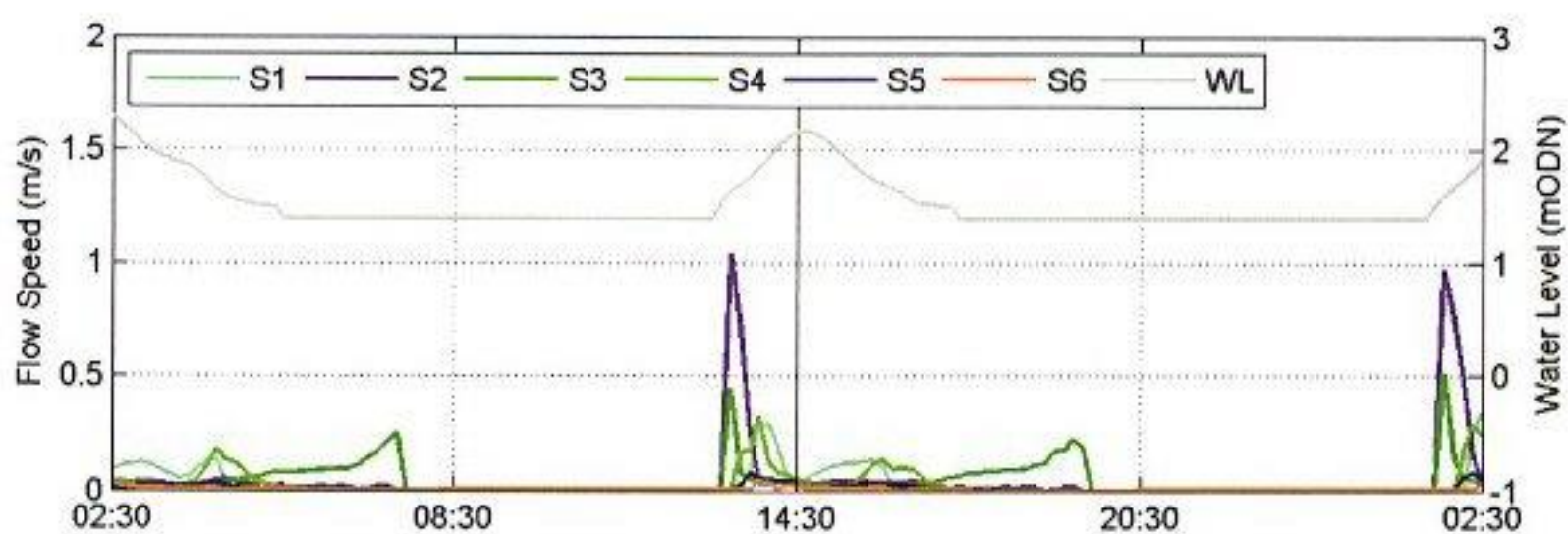


Figure 13. Time series of flows within the managed realignment area on a mean spring tide (at locations shown in Figure 10)

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.

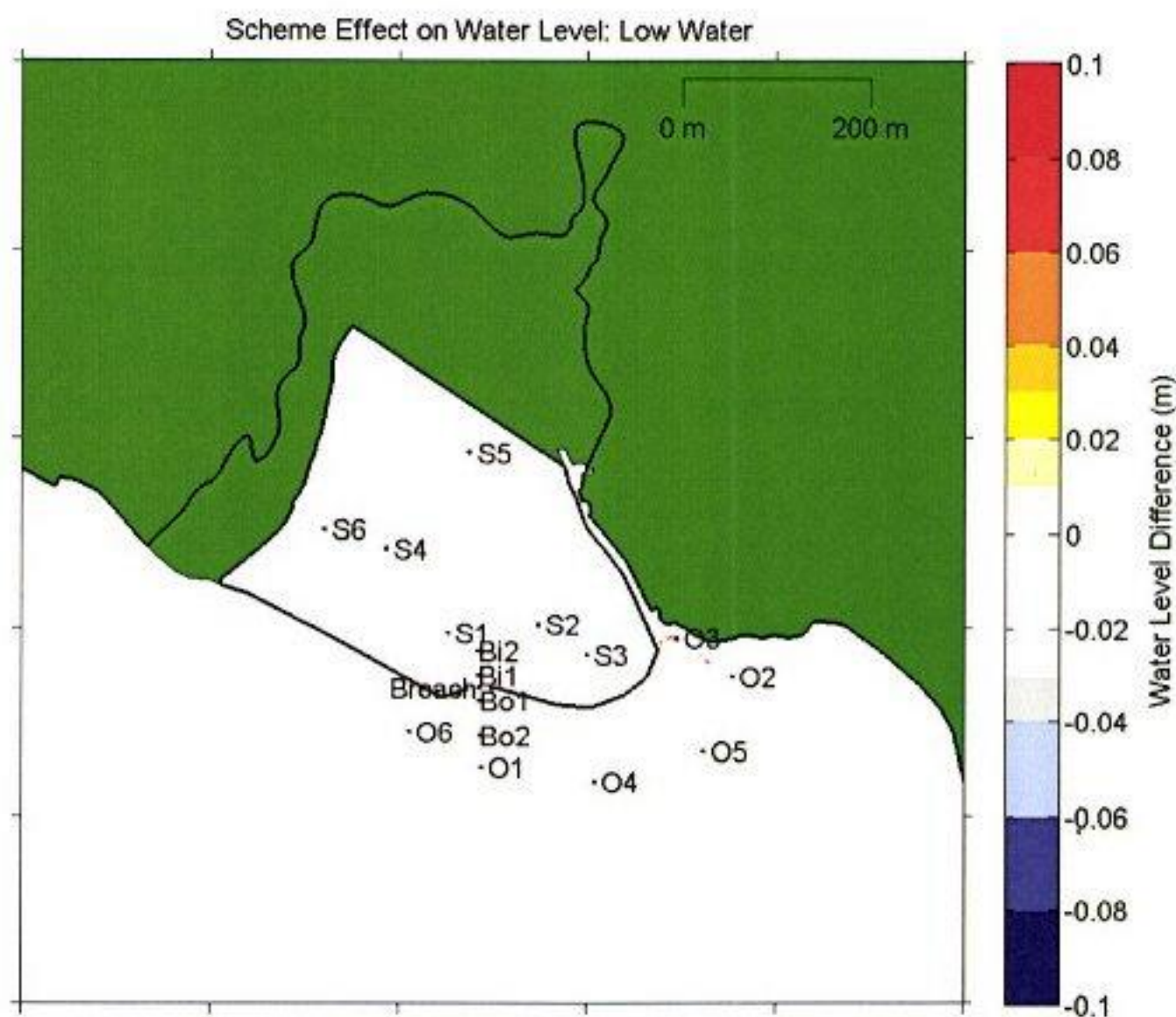


Figure 14. Change in spring tide low water level (change occurs due to culvert)

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.

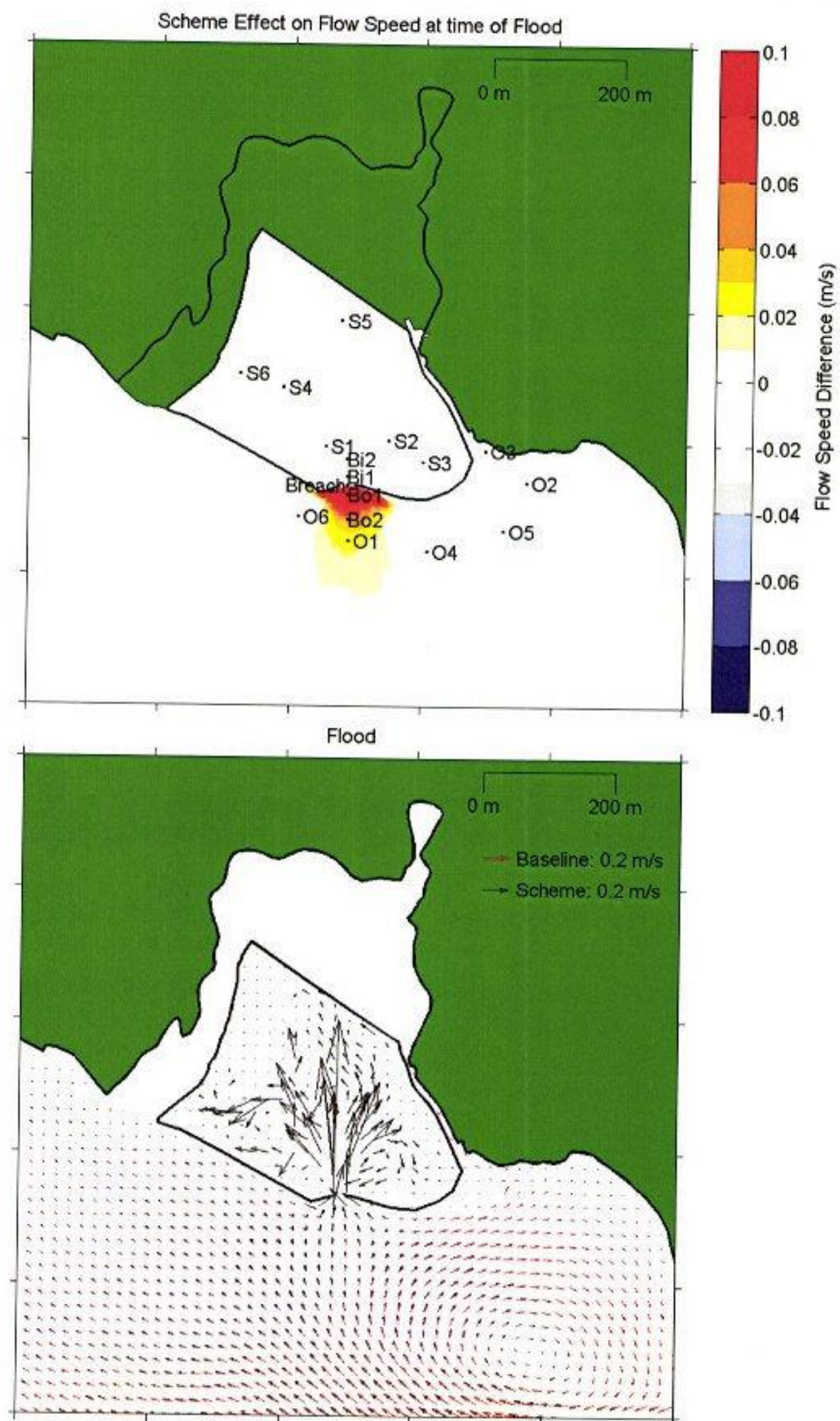


Figure 15. Change in spring tide flow speeds (upper panel) and baseline and scheme vectors (lower panel) at time of peak flow onto site

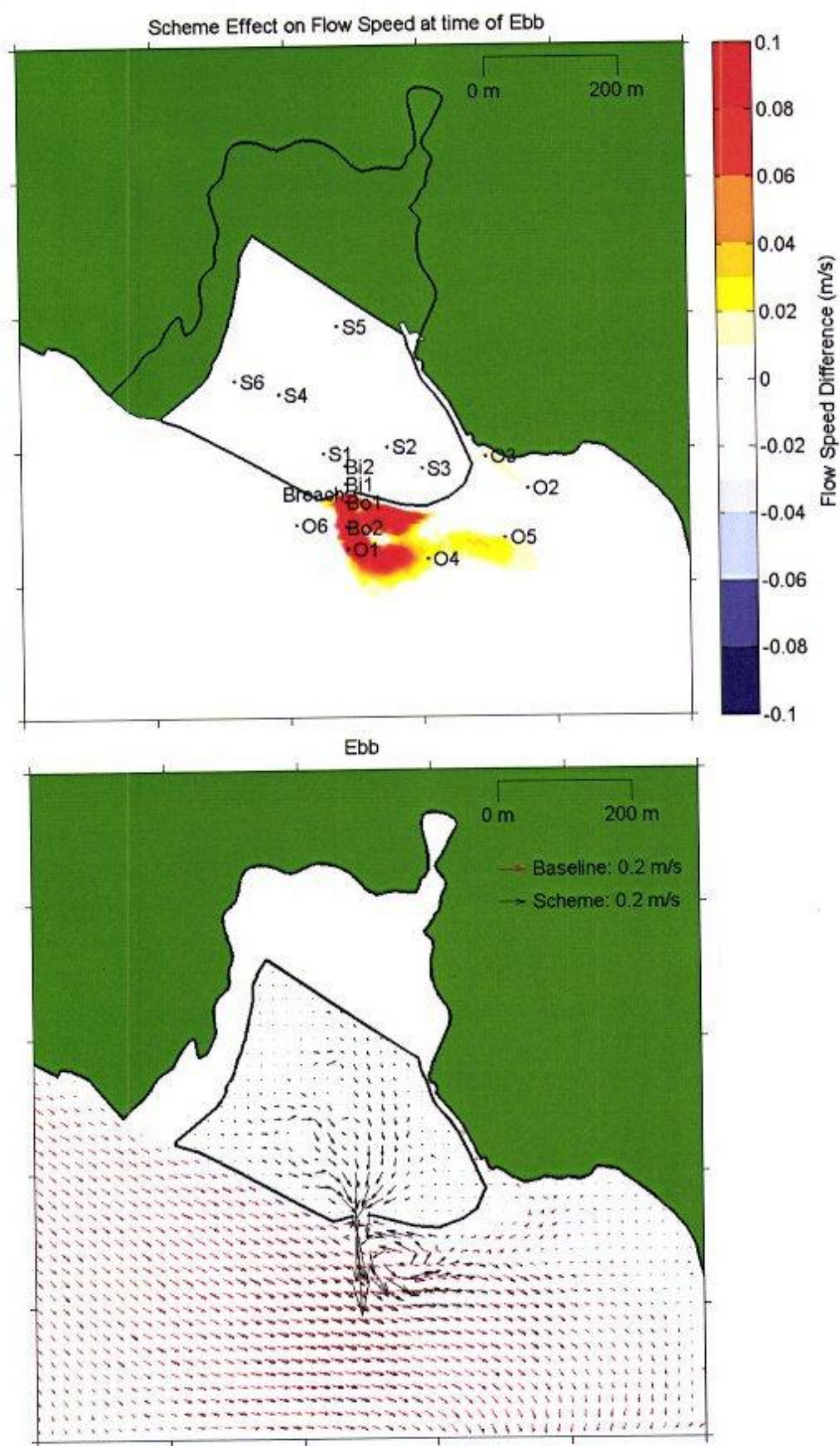


Figure 16. Change in spring tide flow speeds (upper panel) and baseline and scheme vectors (lower panel) at time of peak flow off of site

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.

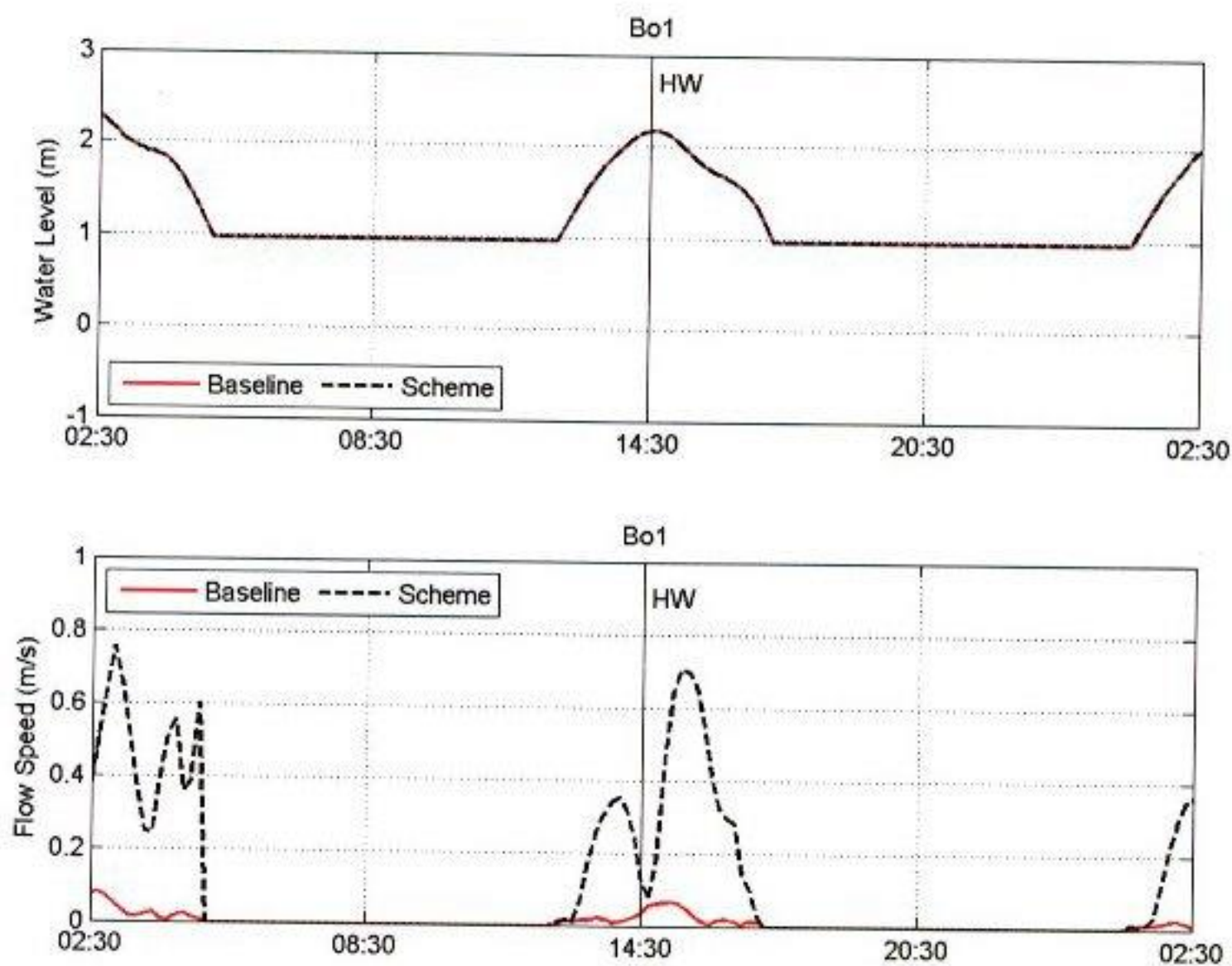


Figure 17. Time series of water levels and flows at Bo1 on a mean spring tide

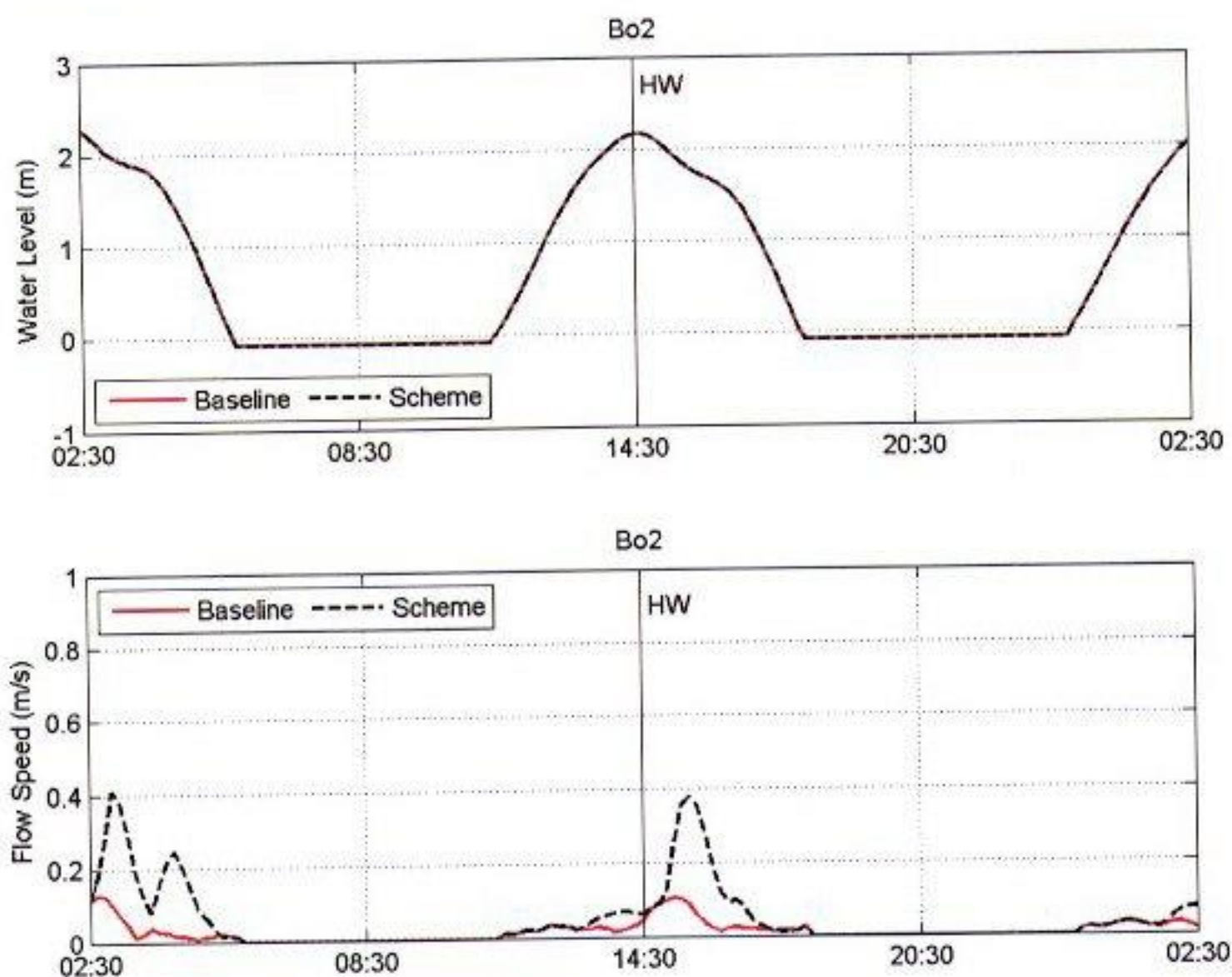


Figure 18. Time series of water levels and flows at Bo2 on a mean spring tide

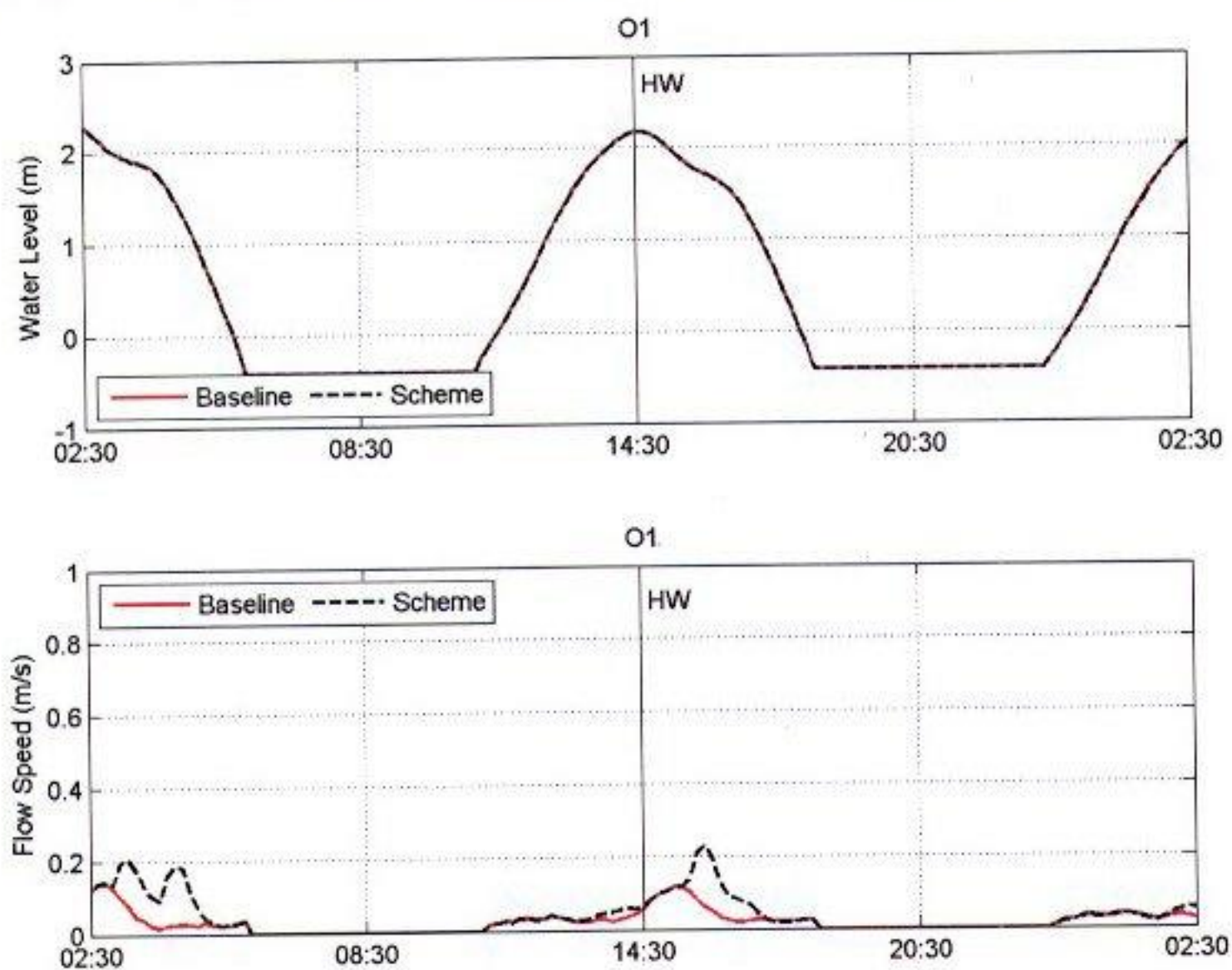


Figure 19. Time series of water levels and flows at O1 on a mean spring tide

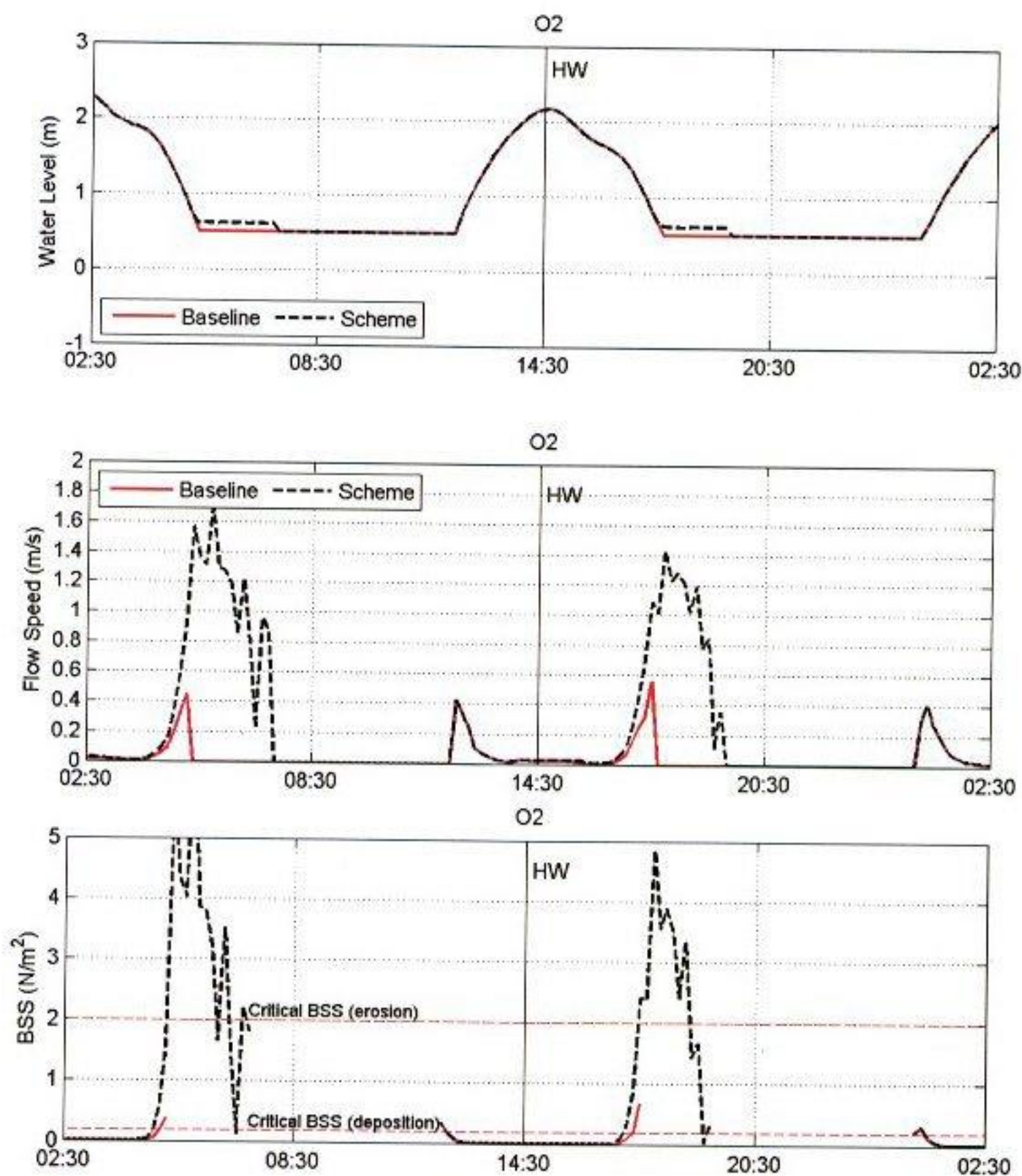


Figure 20. Time series of water levels, flows and bed shear stress at O2 on a mean spring tide

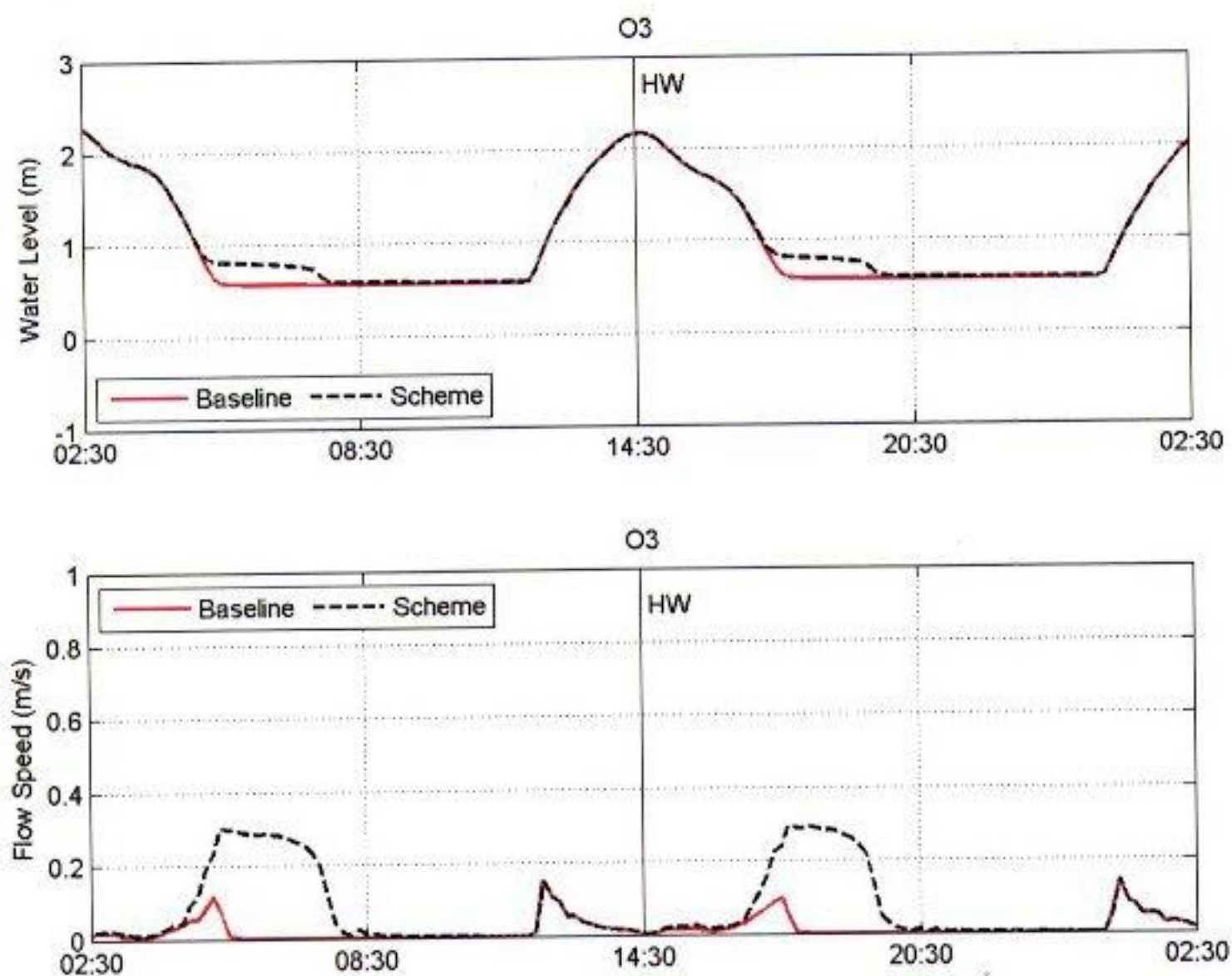


Figure 21. Time series of water levels and flows at O3 on a mean spring tide

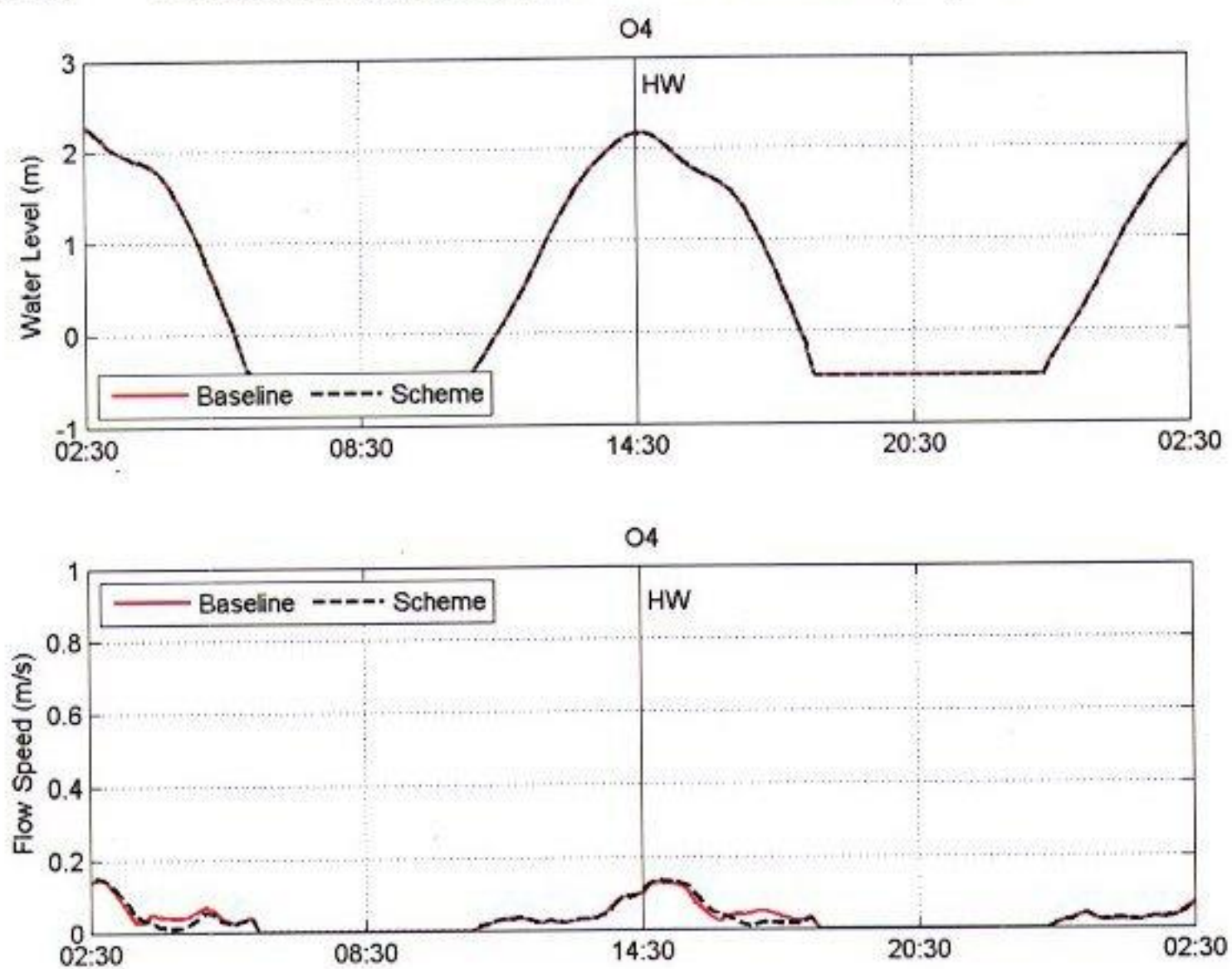


Figure 22. Time series of water levels and flows at O4 on a mean spring tide

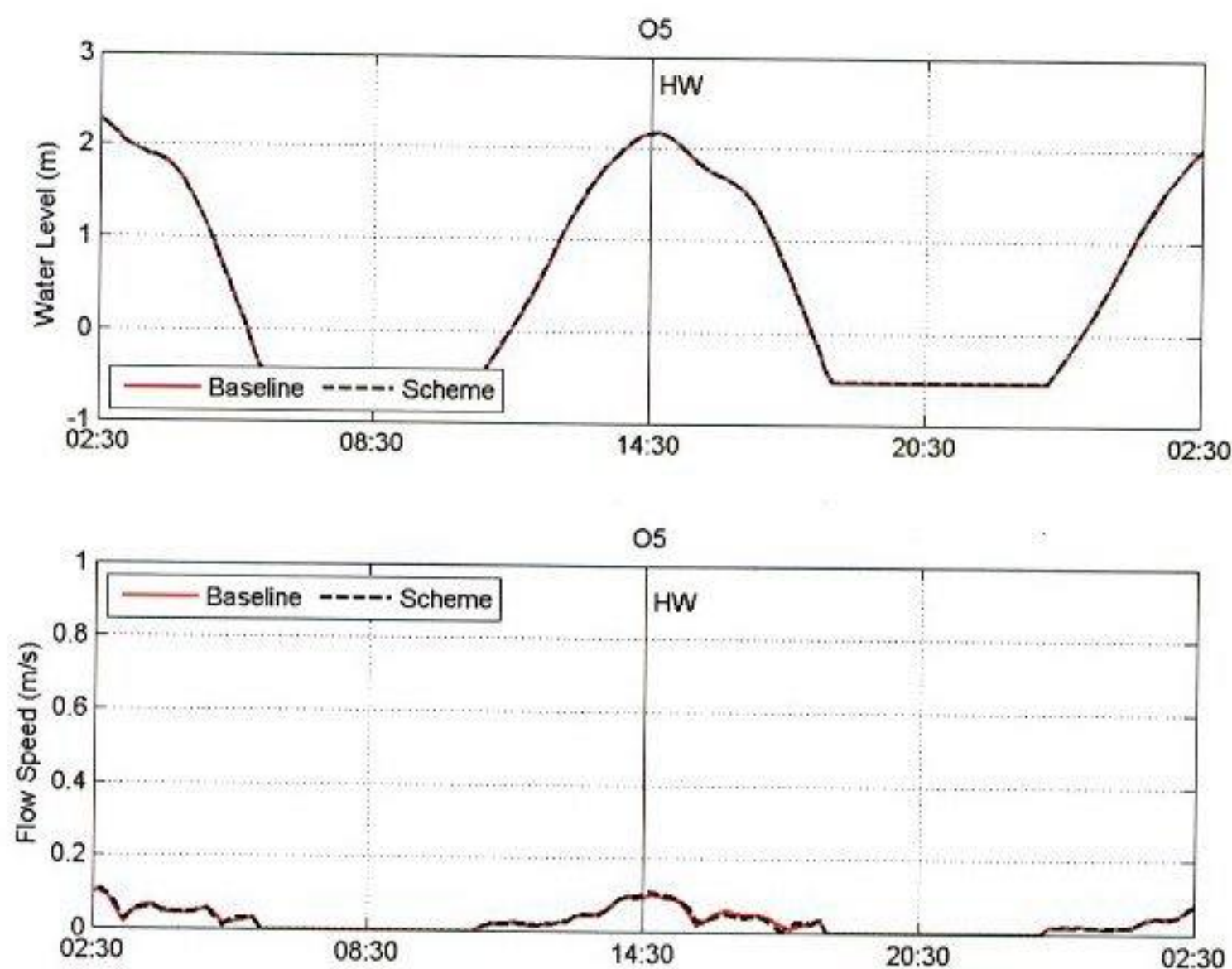


Figure 23. Time series of water levels and flows at O5 on a mean spring tide

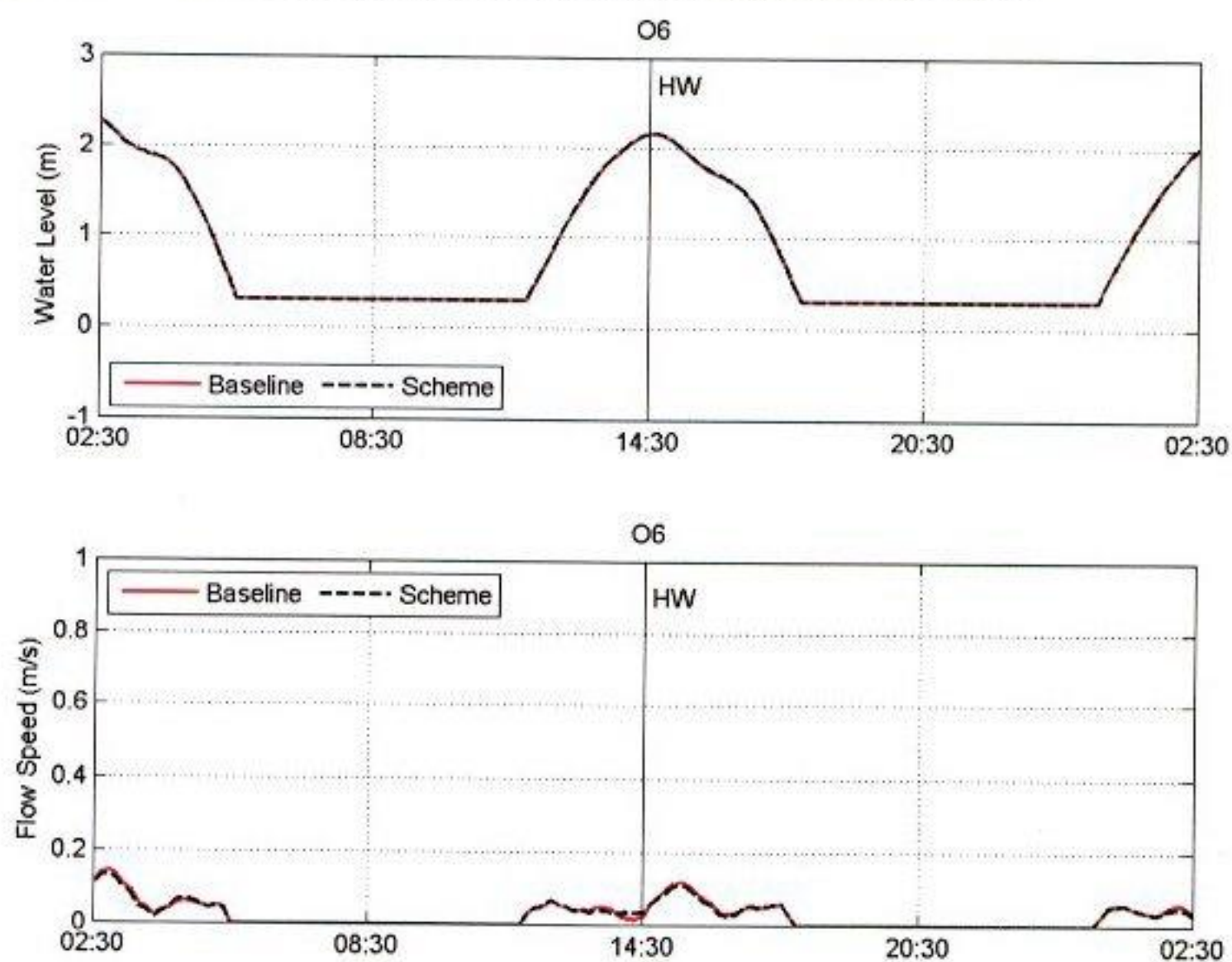


Figure 24. Time series of water levels and flows at O6 on a mean spring tide

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.

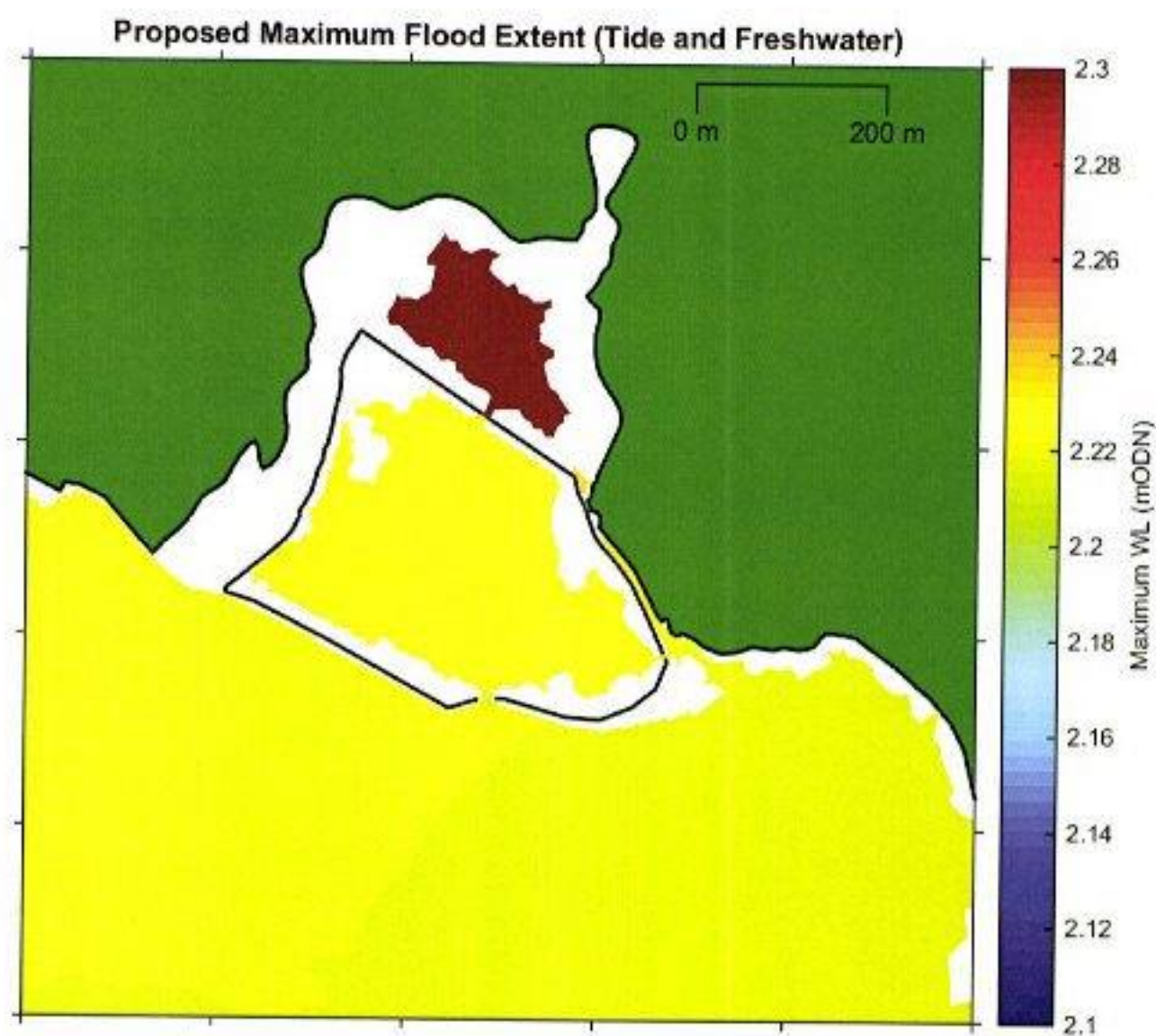


Figure 25. Maximum inundation for 1 in 100 year fluvial flood event

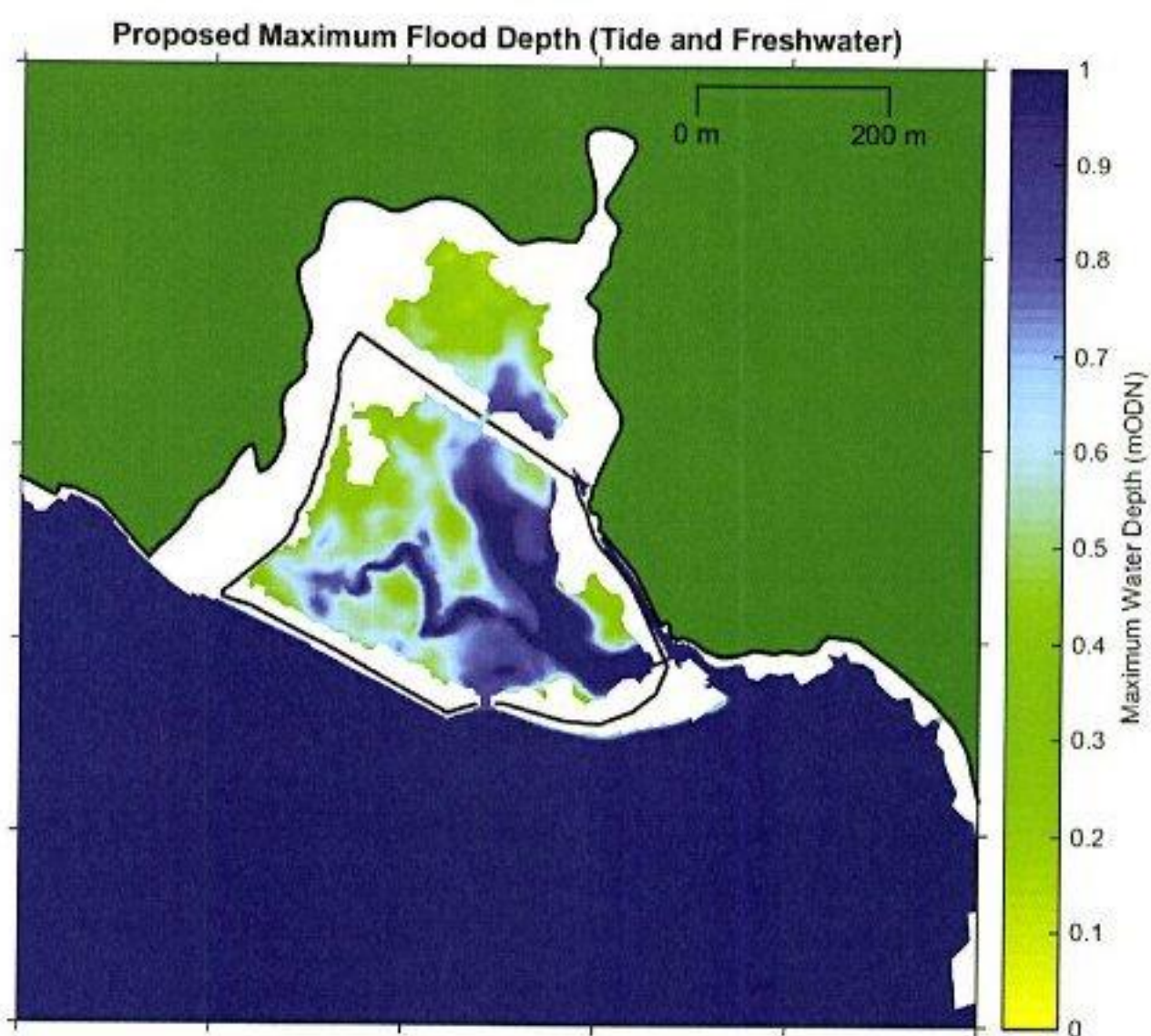


Figure 26. Maximum flood depth for 1 in 100 year fluvial flood event

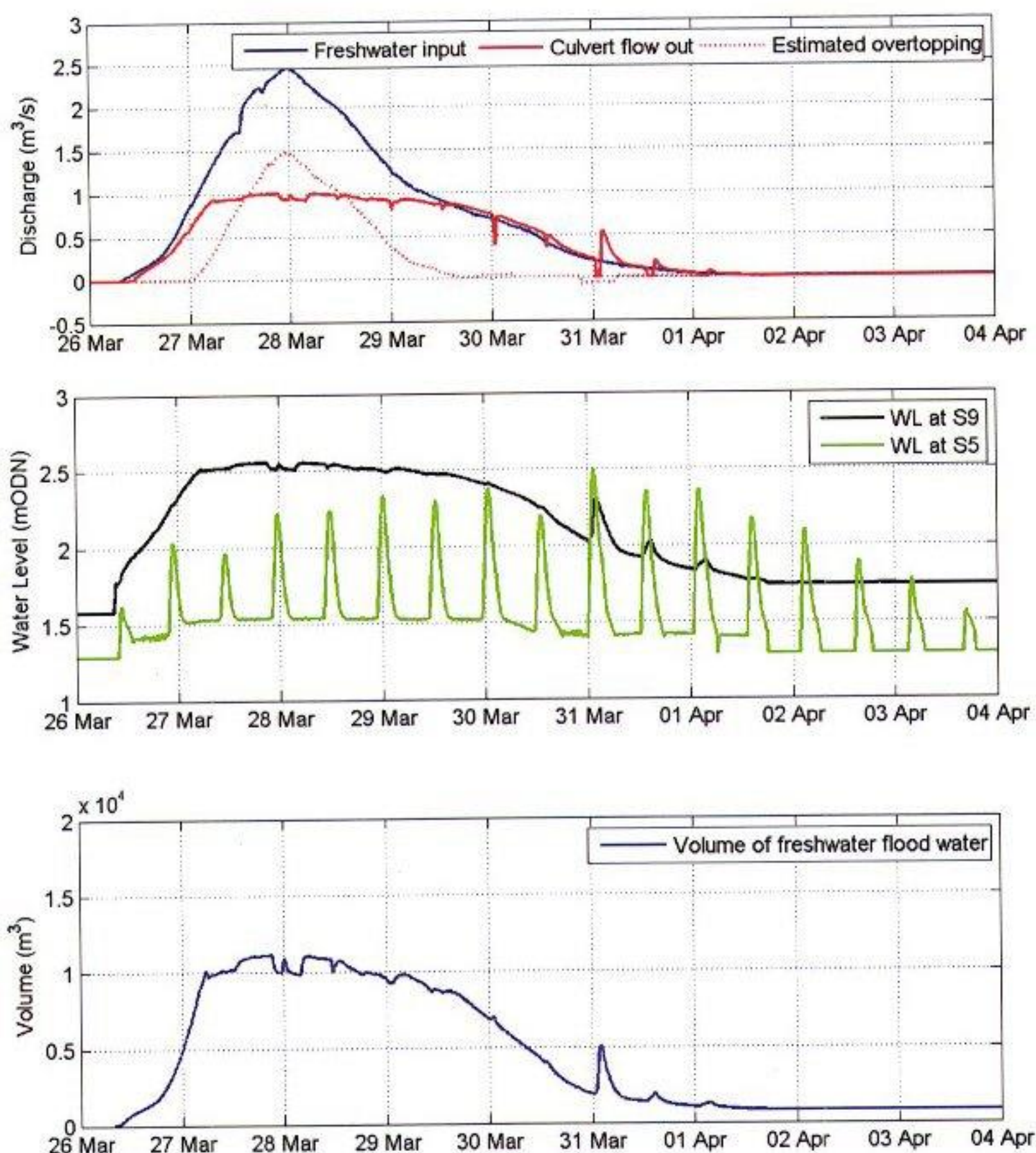


Figure 27. Time series of water levels and water volume for fluvial flooding scenario

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.

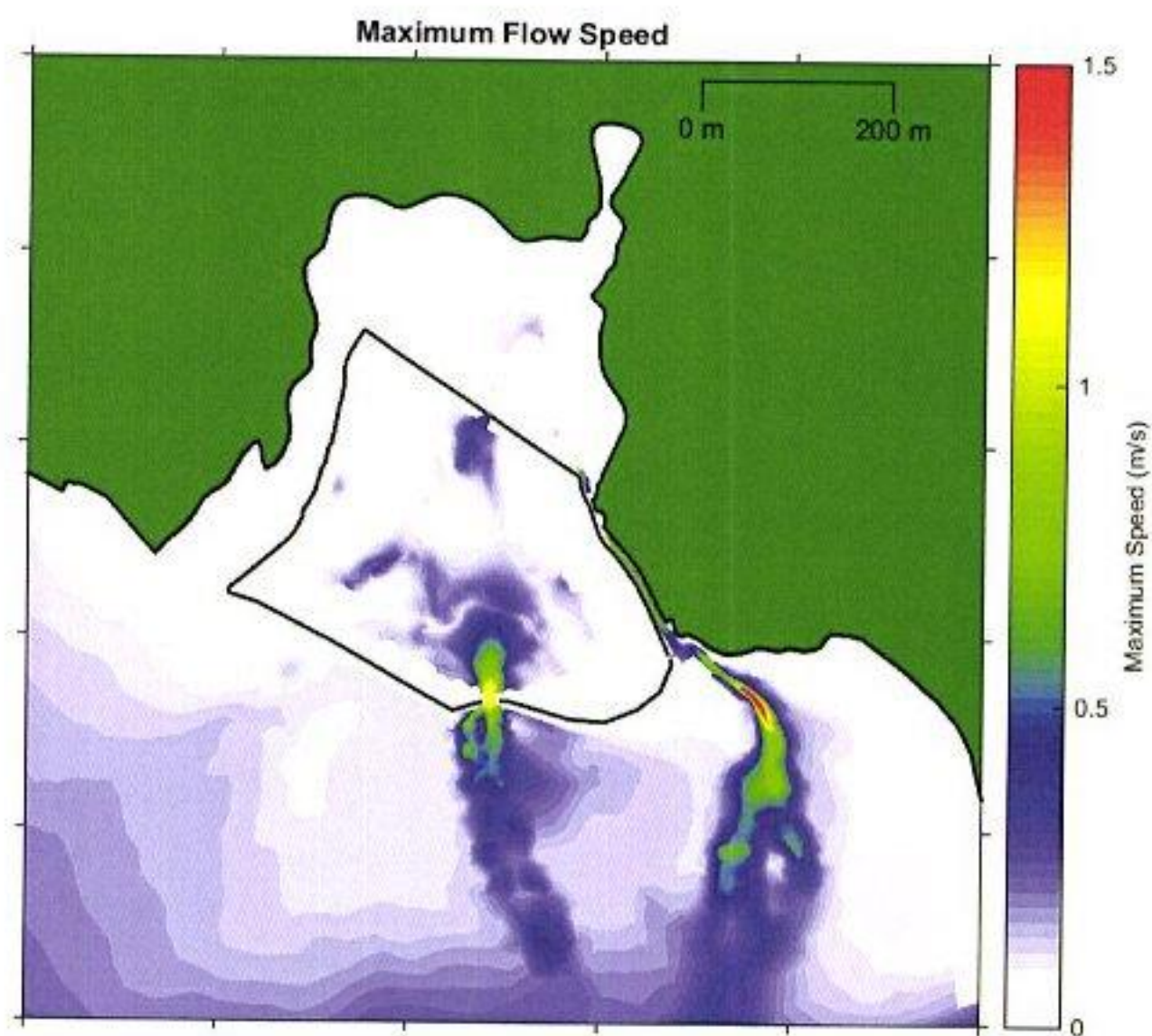


Figure 28. Maximum flow speed on a mean spring tide

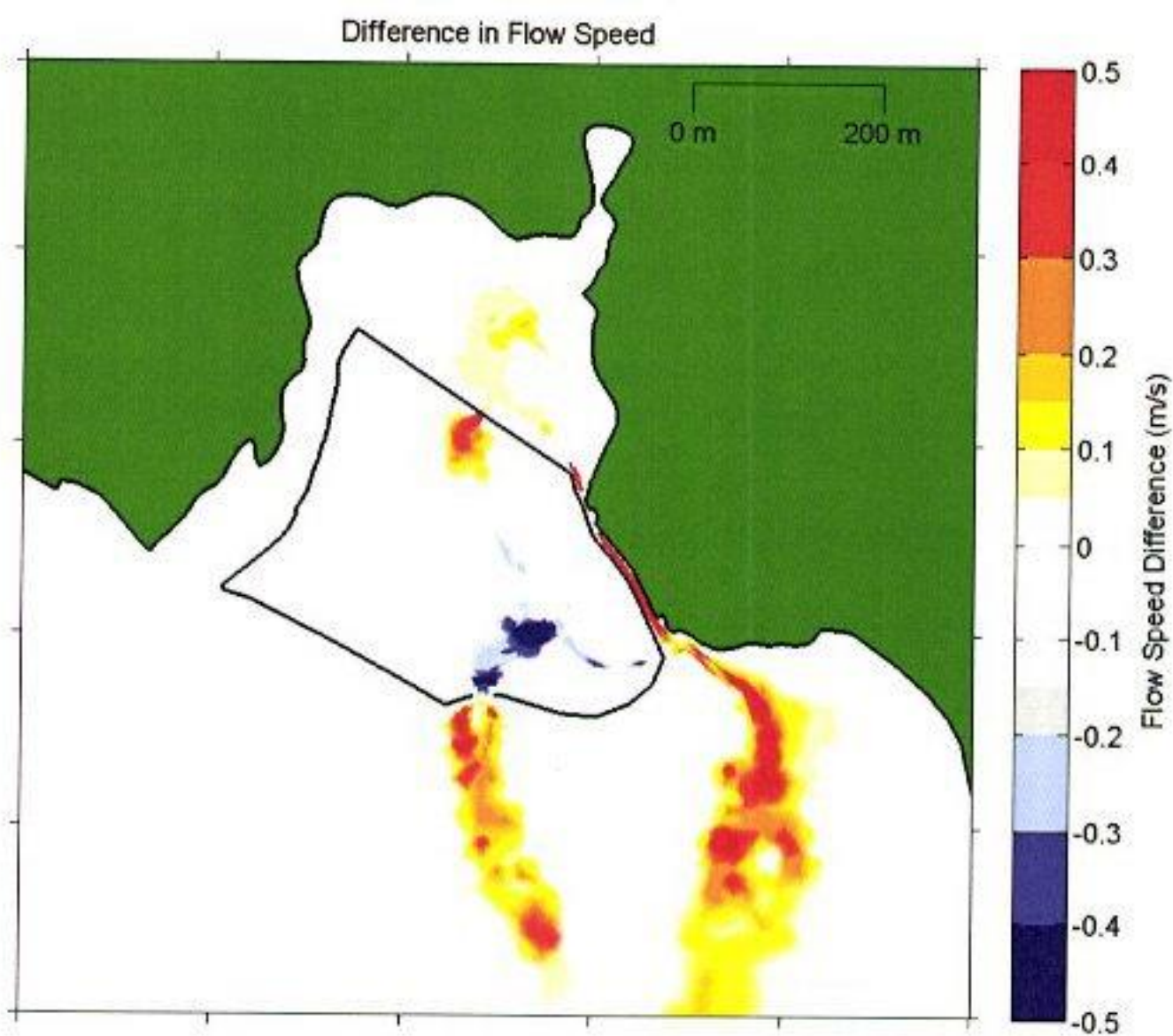


Figure 29. Difference in maximum flow speed for freshwater flooding event

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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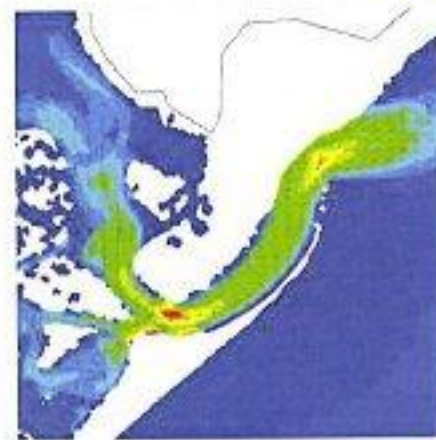
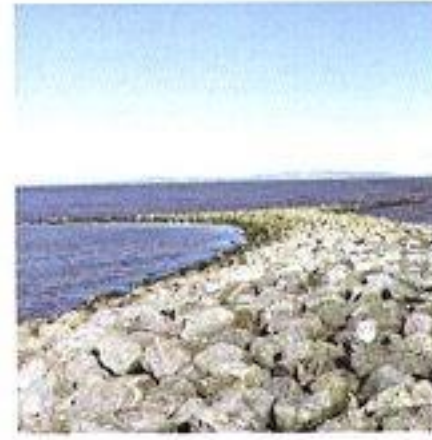
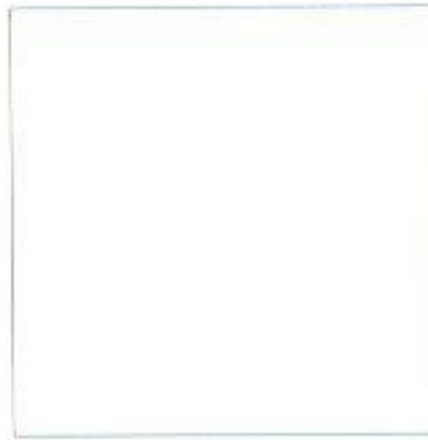
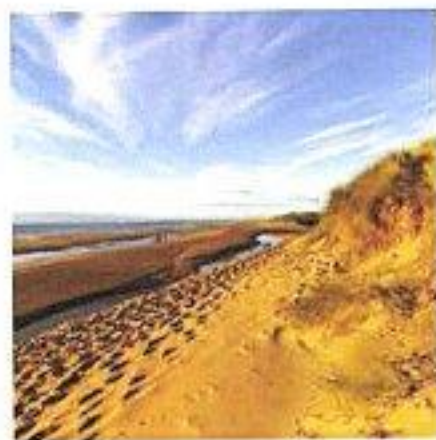
9 Abbreviations/Acronyms

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.

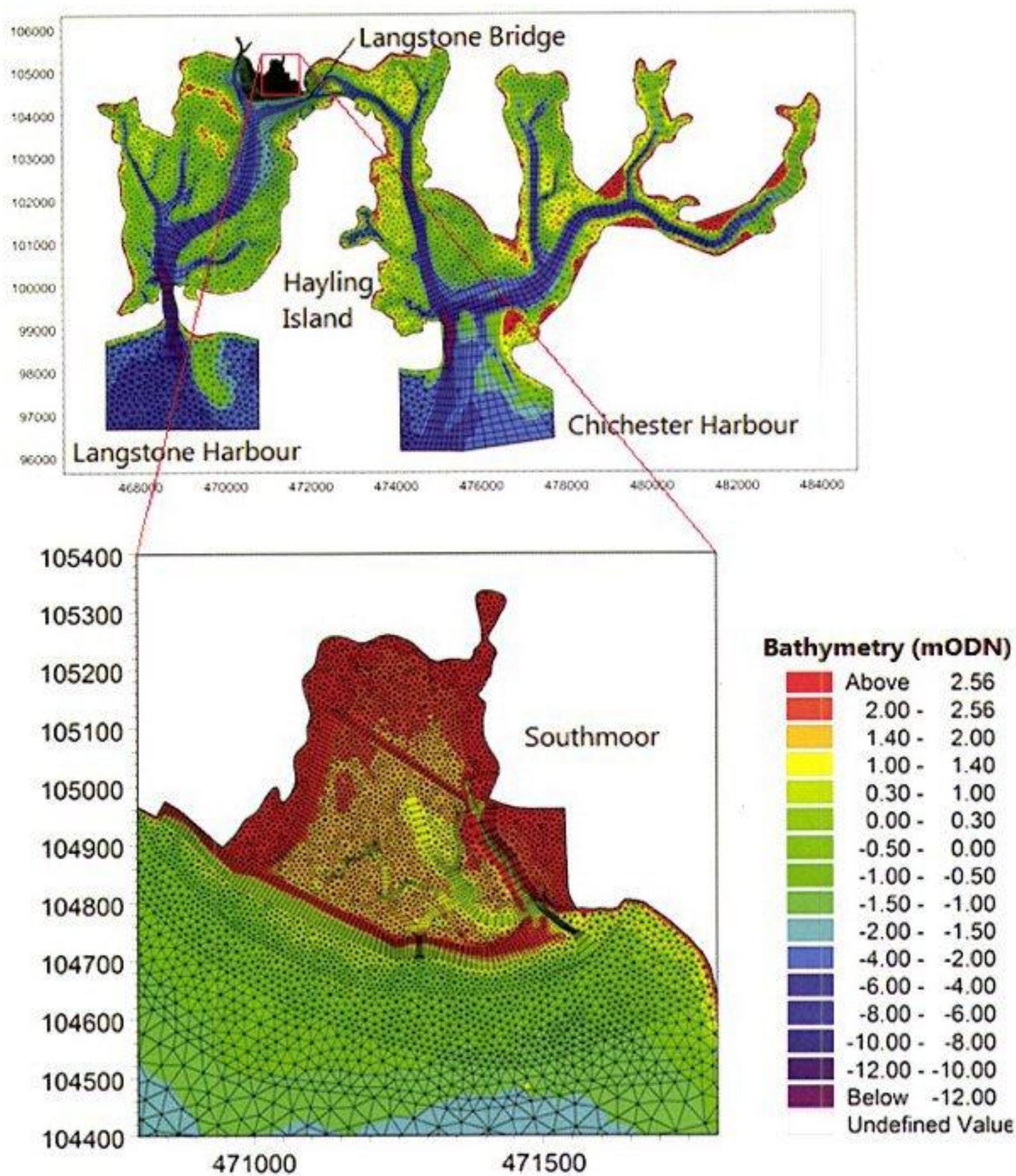


Figure A1. Model study area and mesh

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.

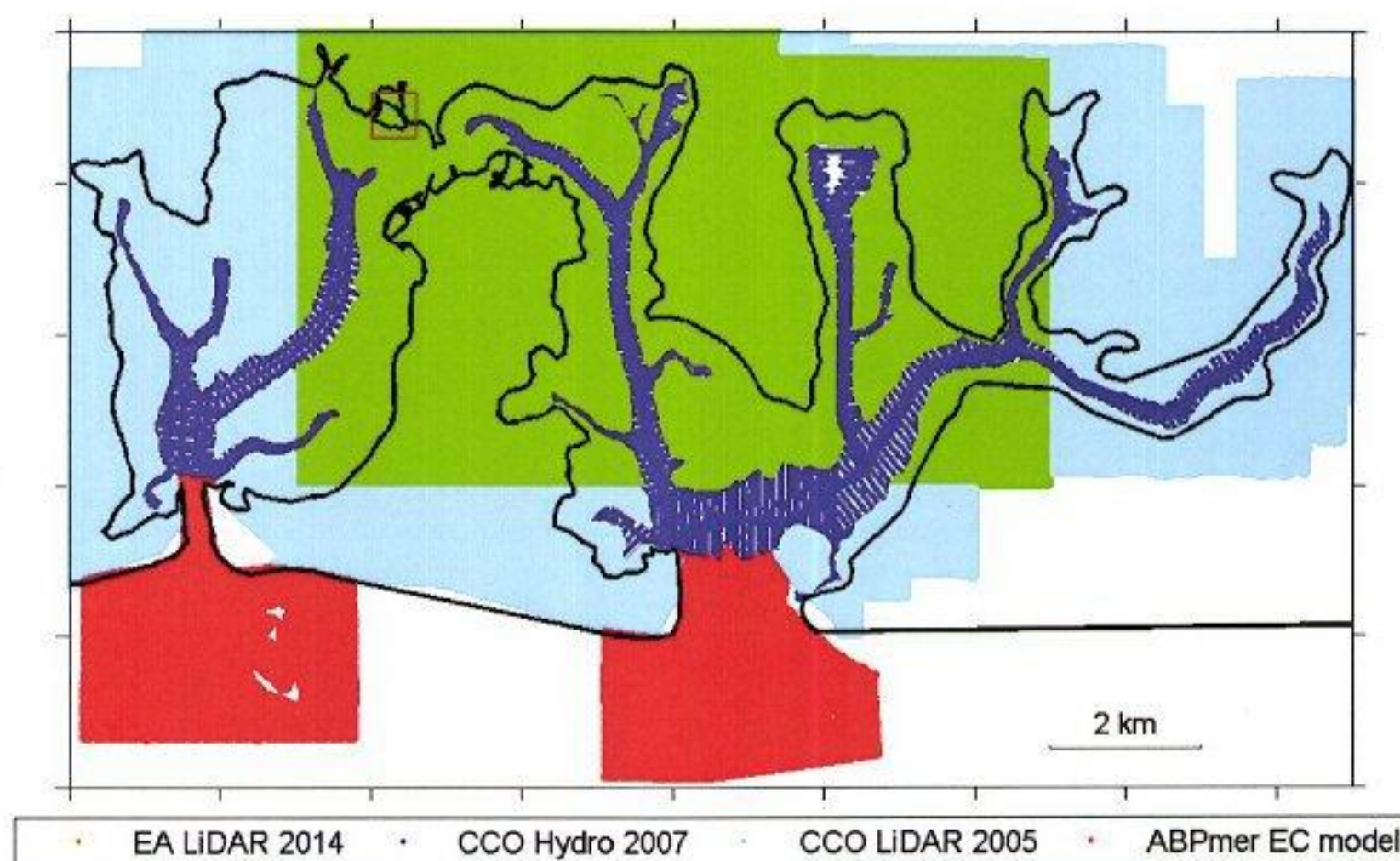


Figure A2. Bathymetry datasets

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.

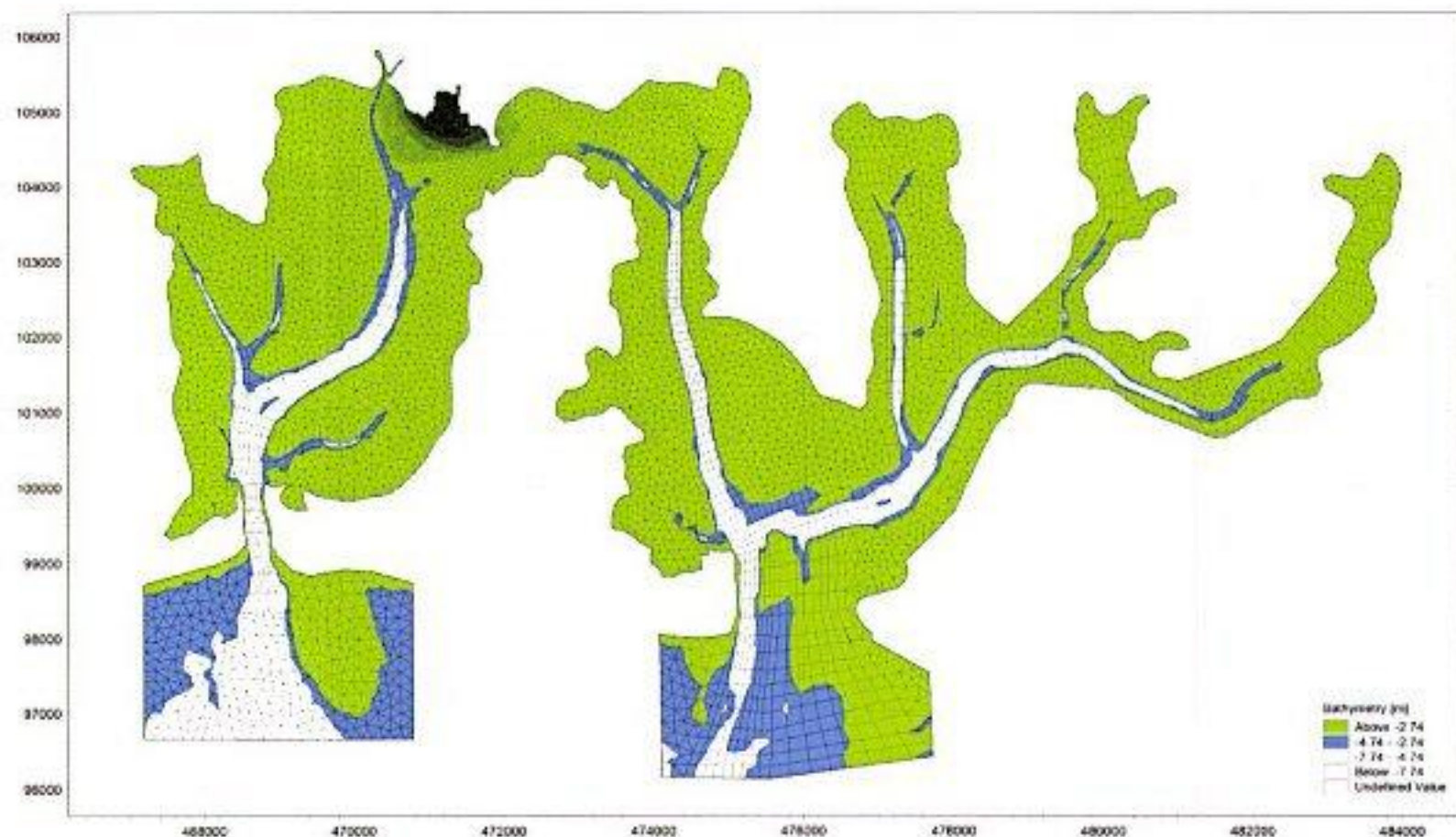


Figure A3. Model bathymetry; depths given in meters relative to ODN

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.

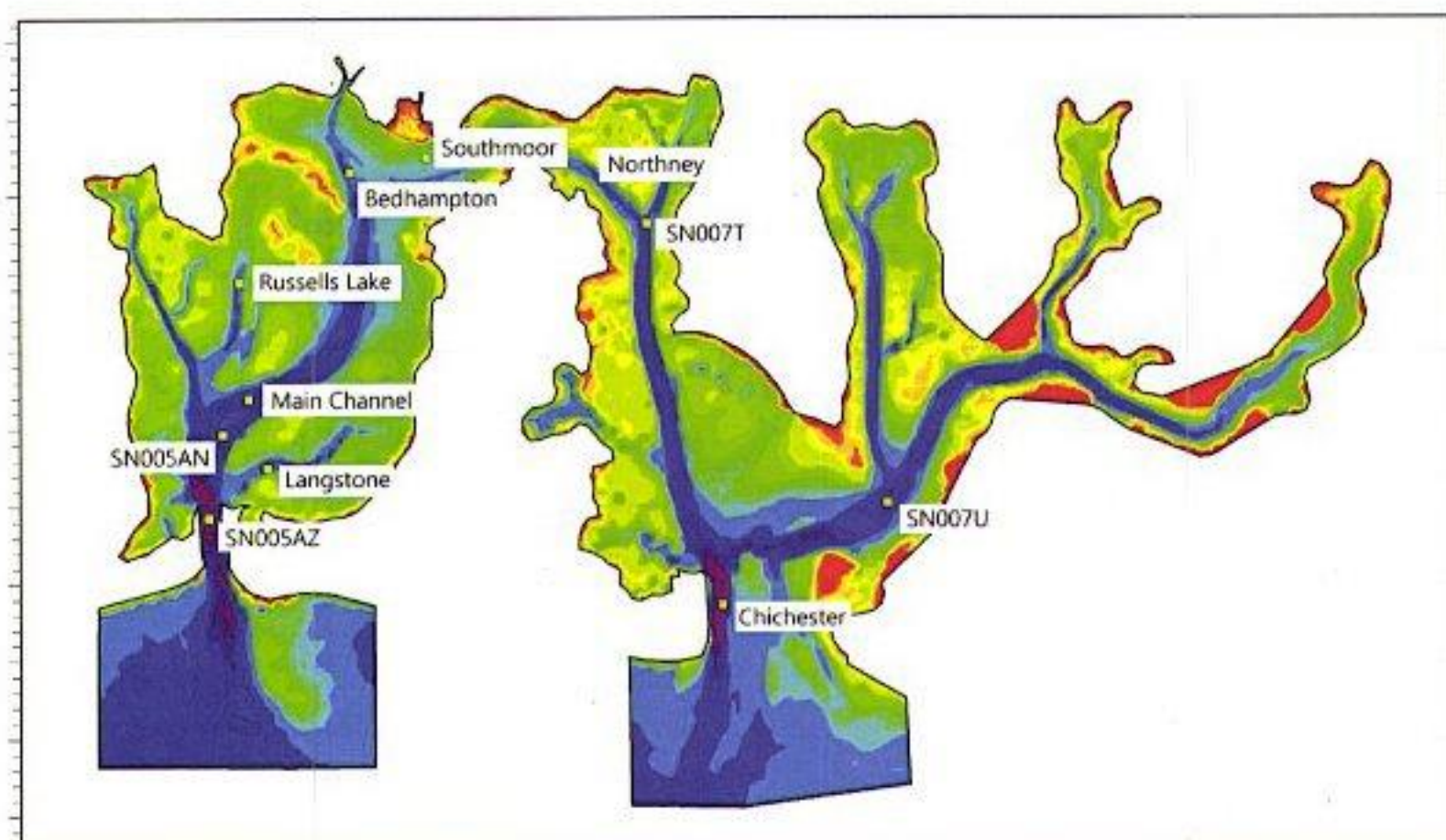


Figure A4. Calibration and validation data

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.

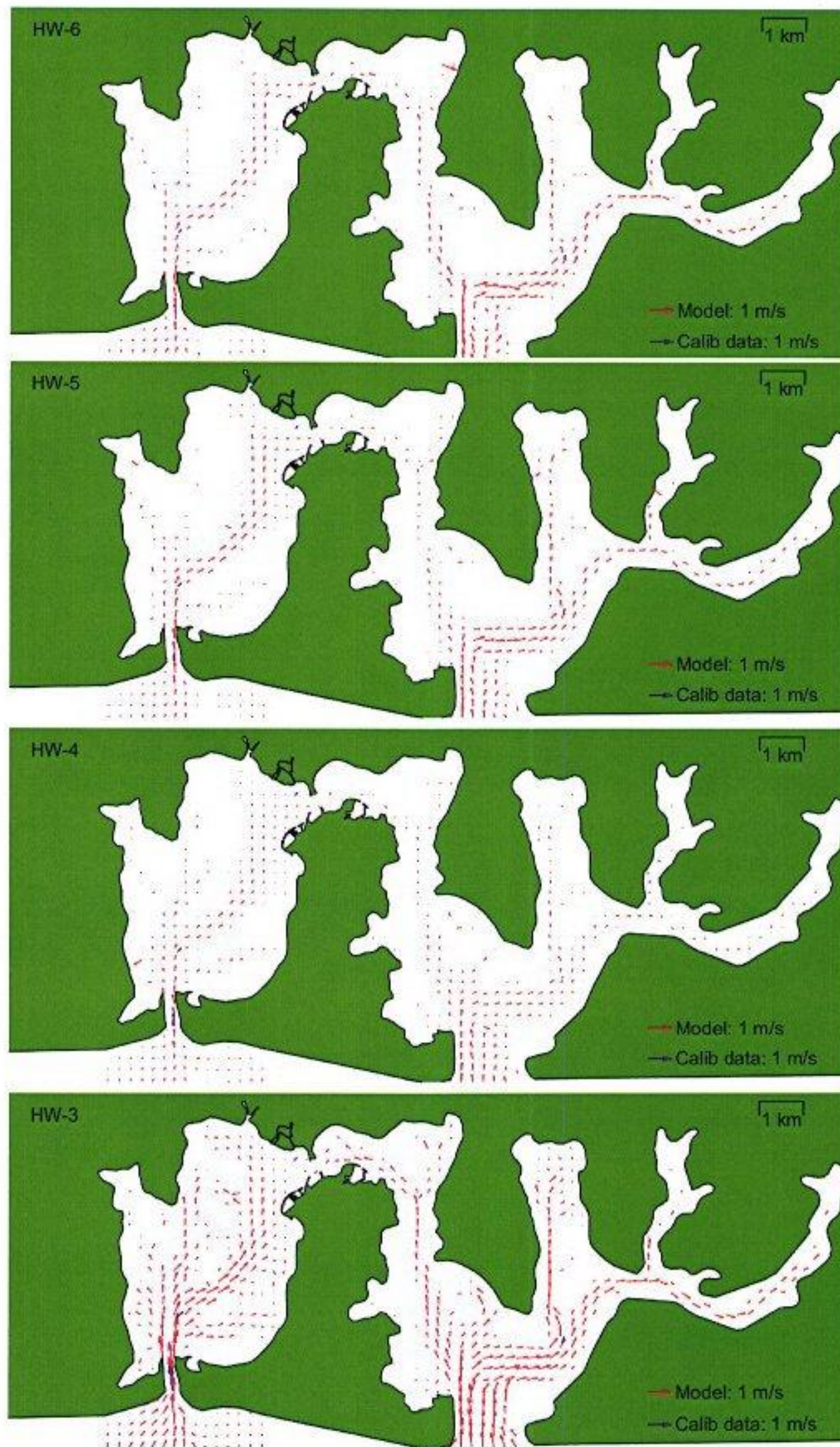


Figure A5. Flow maps at hourly intervals on a mean spring tide (at 6 hours, 5 hours, 4 hours and 3 hours before HW)

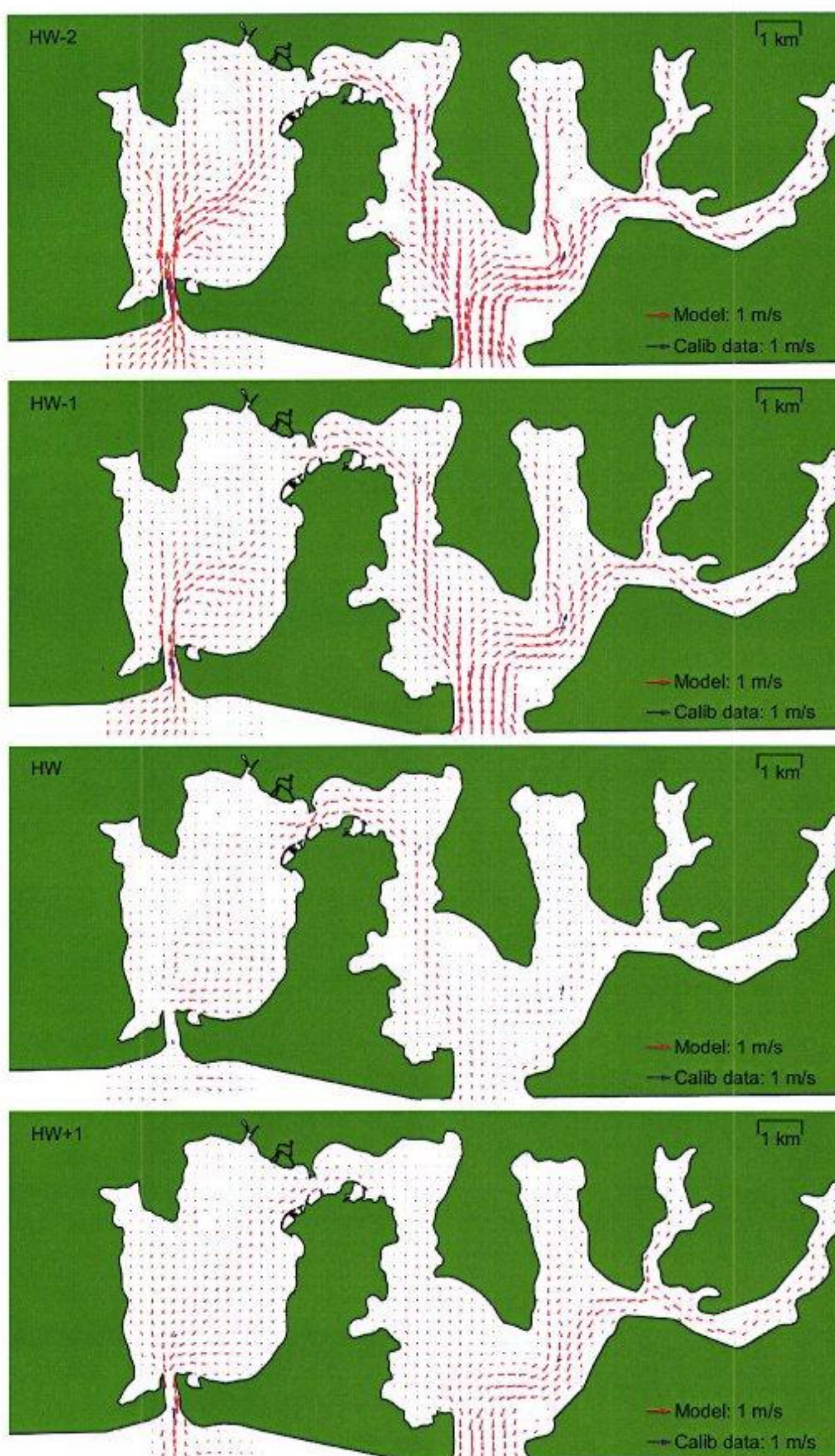


Figure A6. Flow maps at hourly intervals on a mean spring tide (at 2 hours and 1 hour before HW, HW and 1 hour after HW)

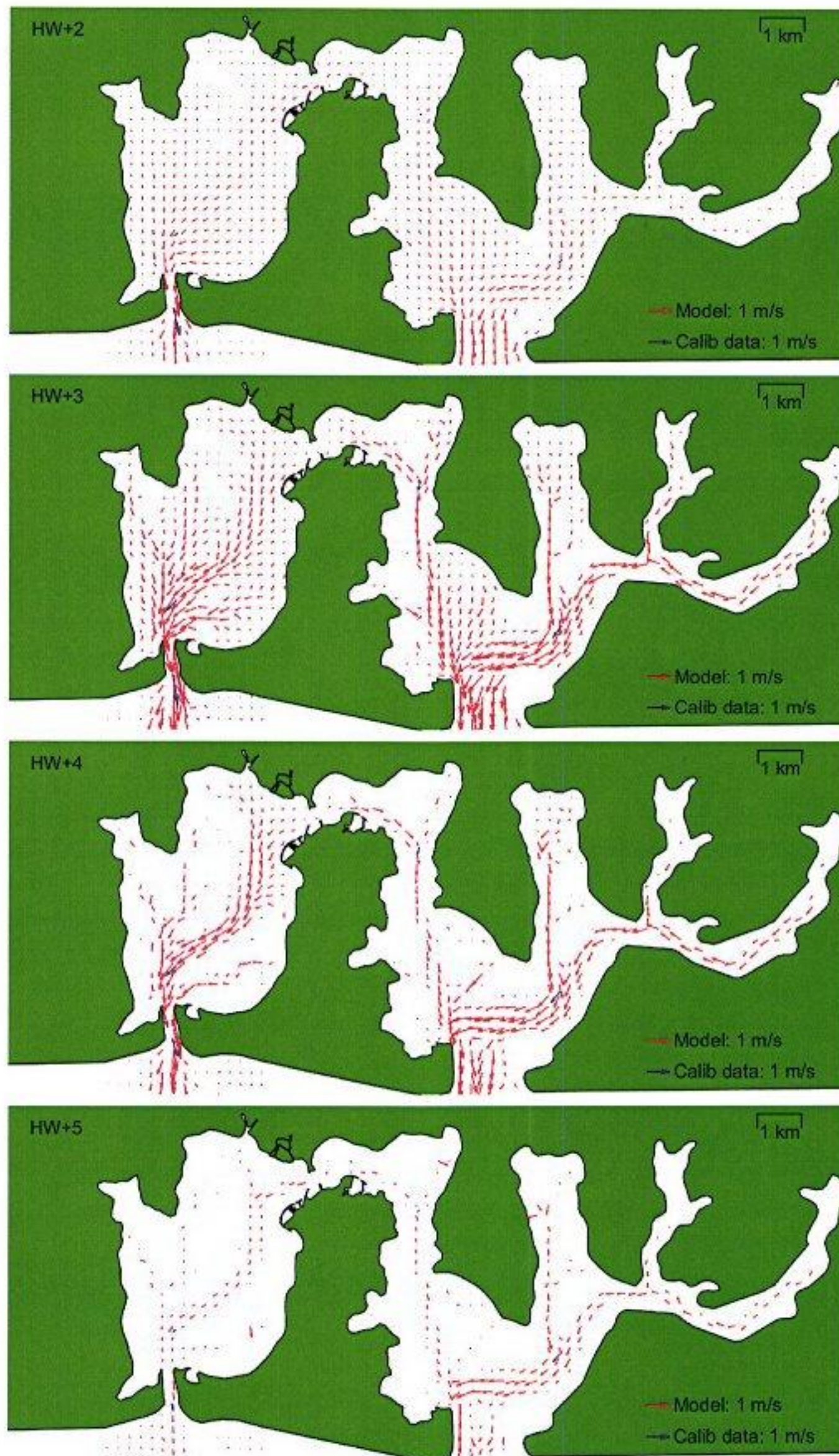


Figure A7. Flow maps at hourly intervals on a mean spring tide (at 2 hours, 3 hours, 4 hours and 5 hours after HW)

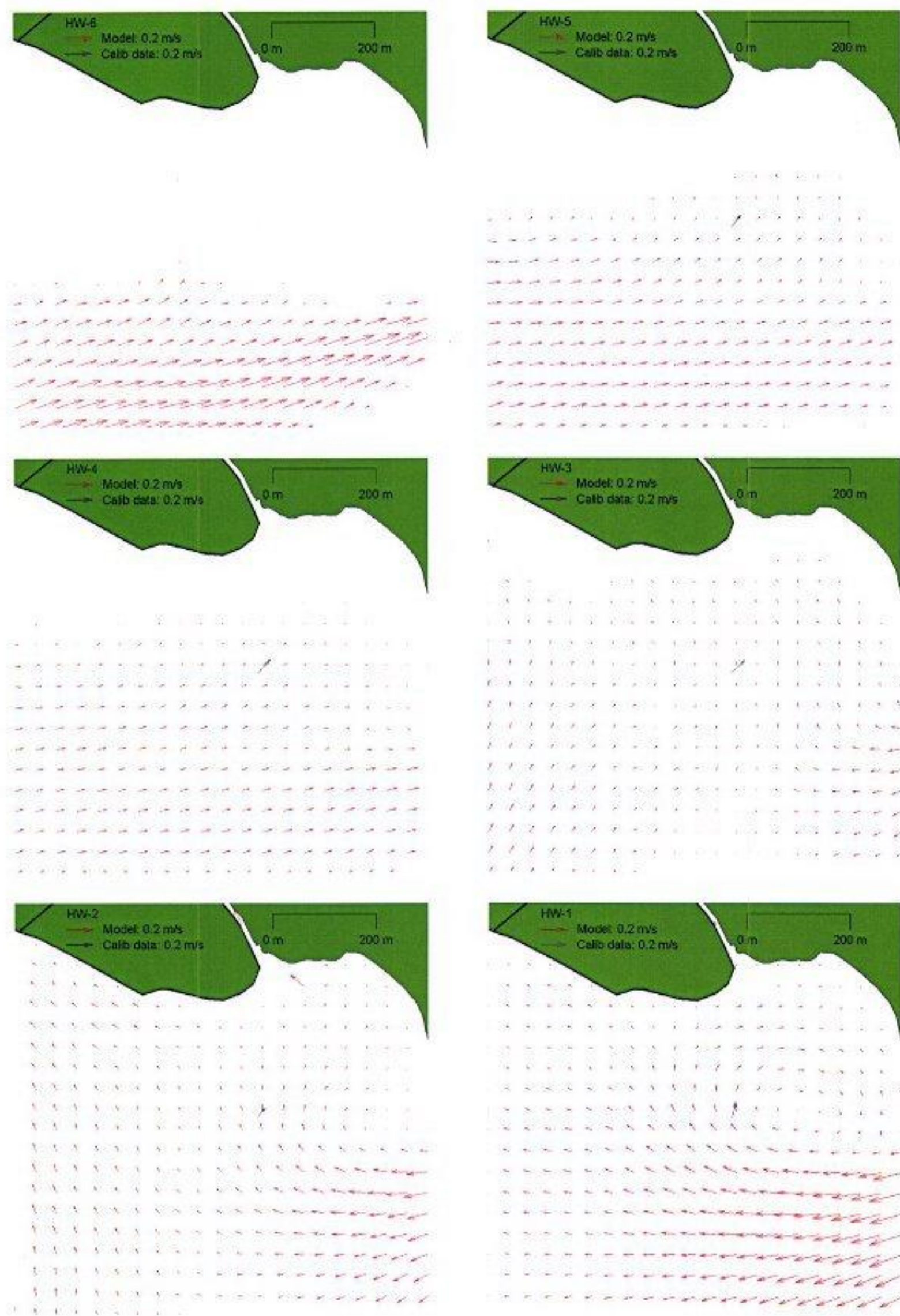


Figure A8. Local flow maps at hourly intervals on a mean spring tide (at 6 hours, 5 hours, 4 hours, 3 hours, 2 hours and 1 hour before HW)

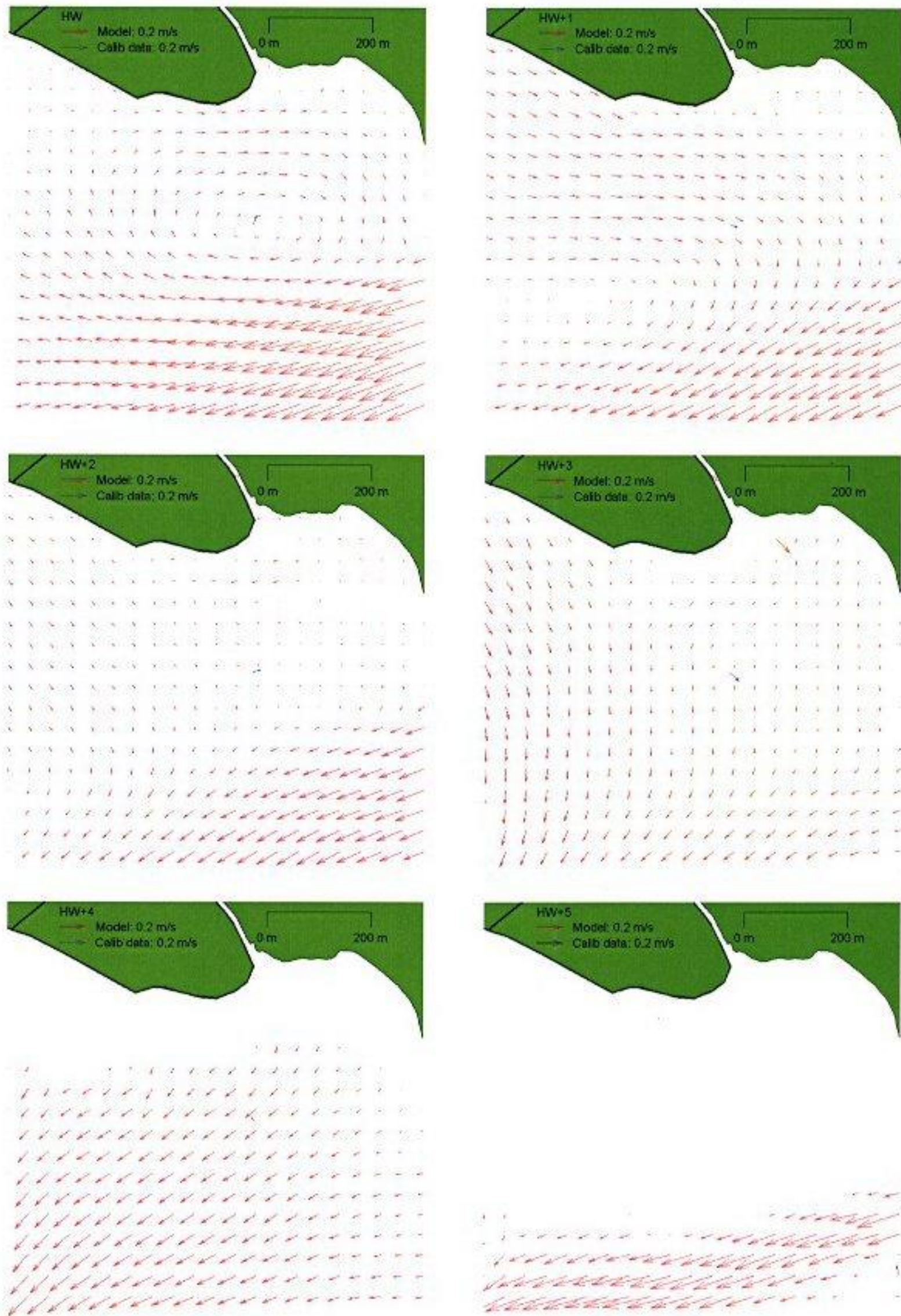


Figure A9. Local flow maps at hourly intervals on a mean spring tide (at HW, 1 hour, 2 hours, 3 hours, 4 hours and 5 hours after HW)

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.

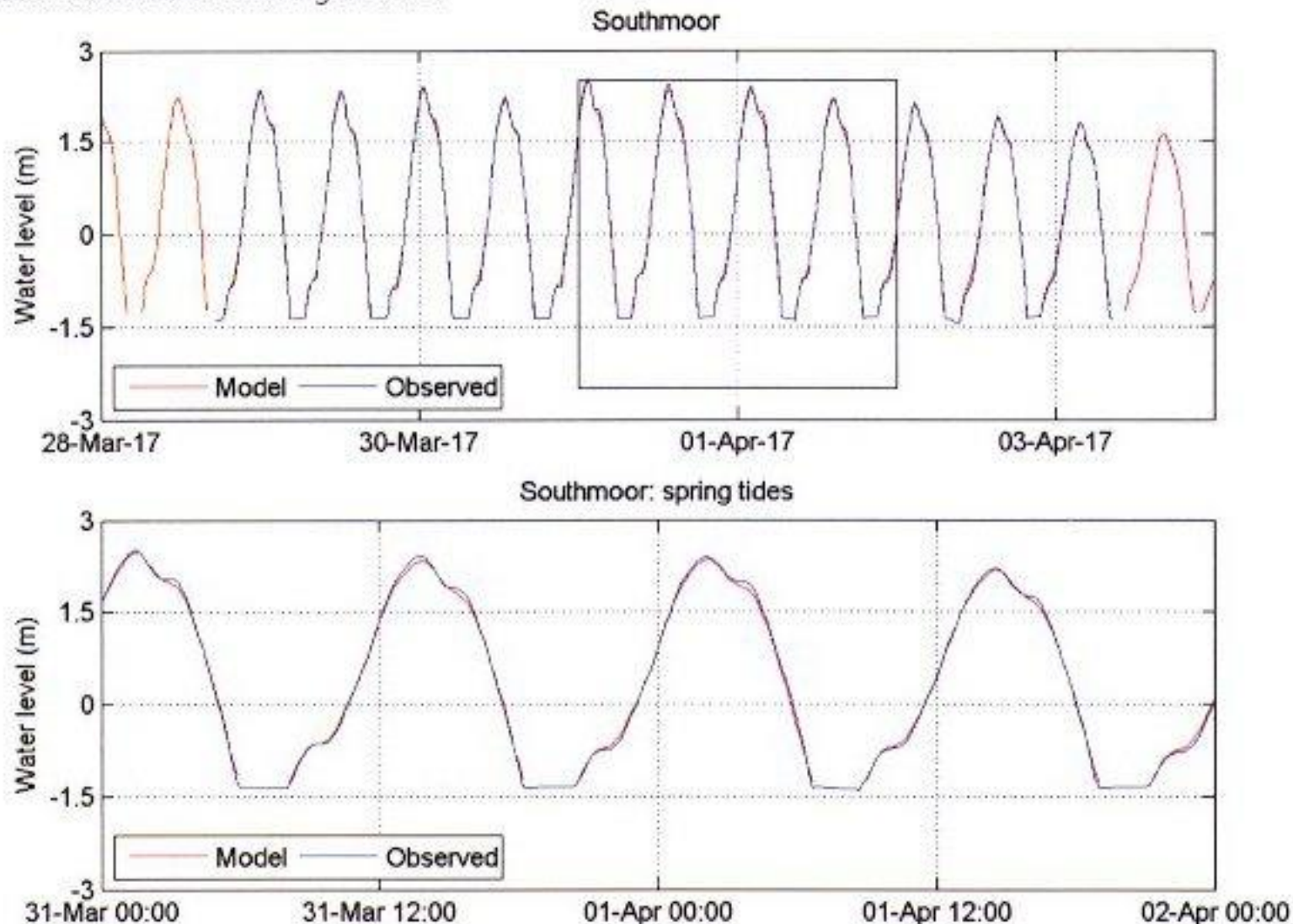


Figure A10. Model calibration against Southmoor Aquadopp water levels

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.

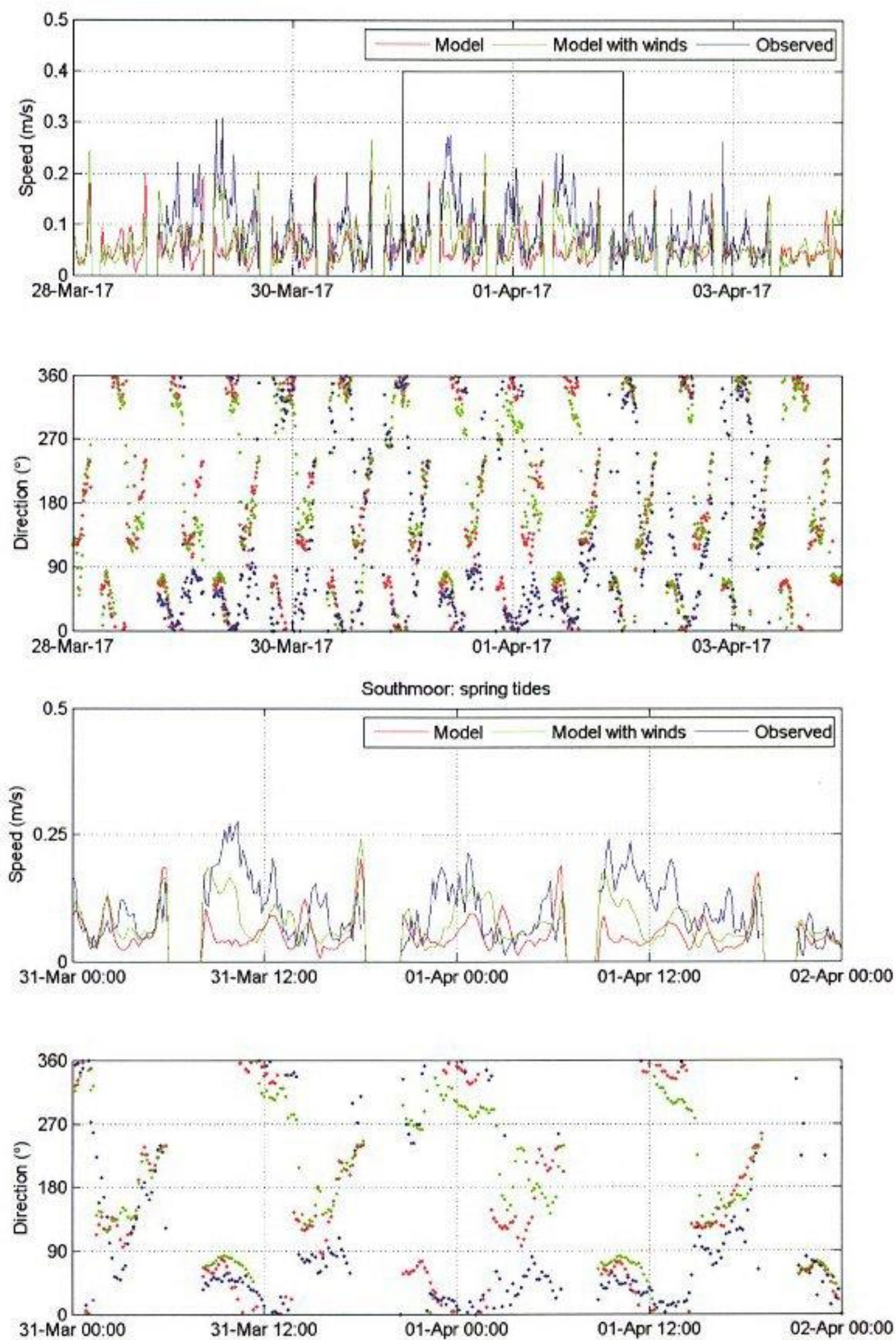


Figure A11. Model calibration against Southmoor Aquadopp flows

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.

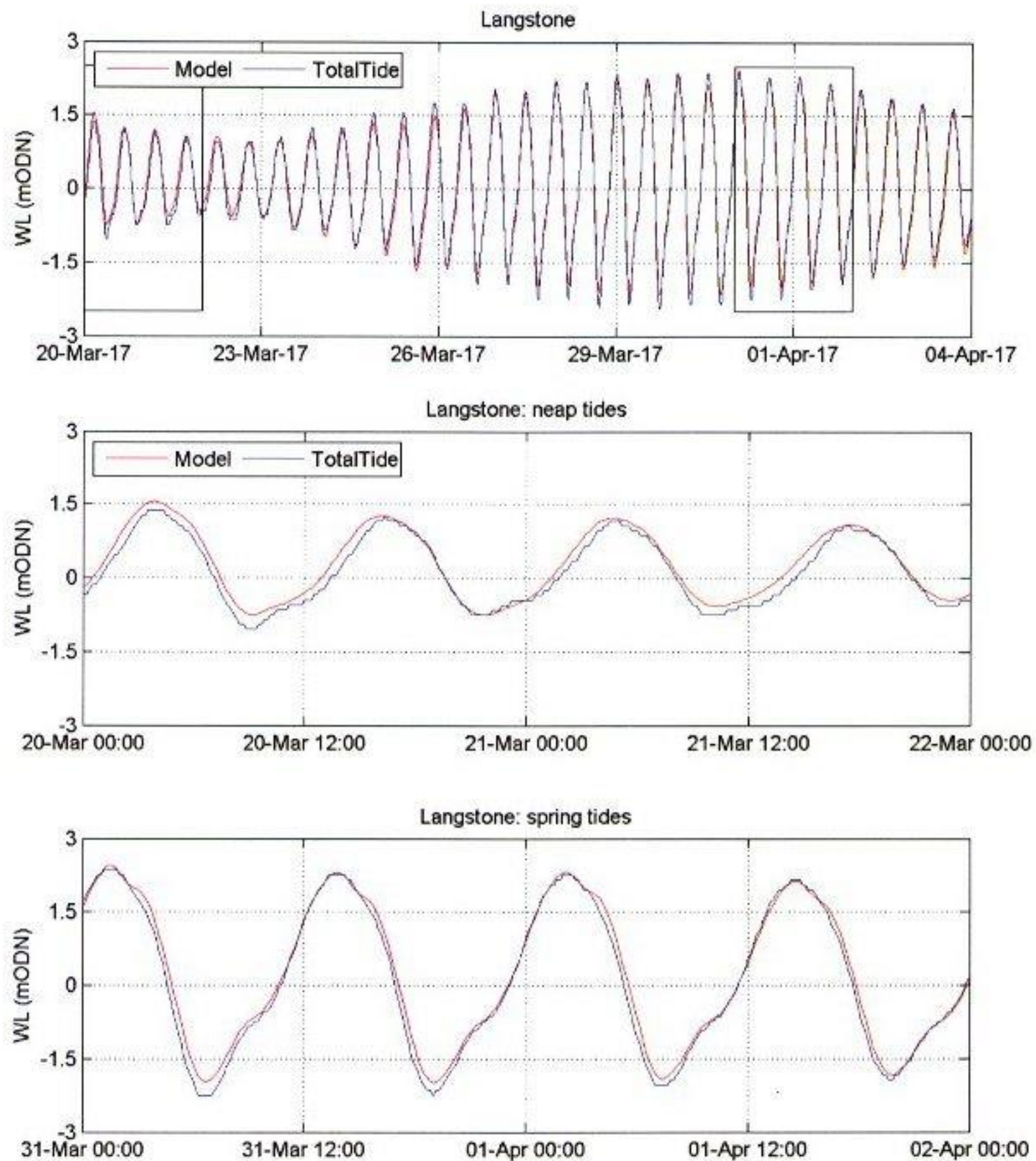


Figure A12. Model calibration of water levels at Langstone against TotalTide predictions

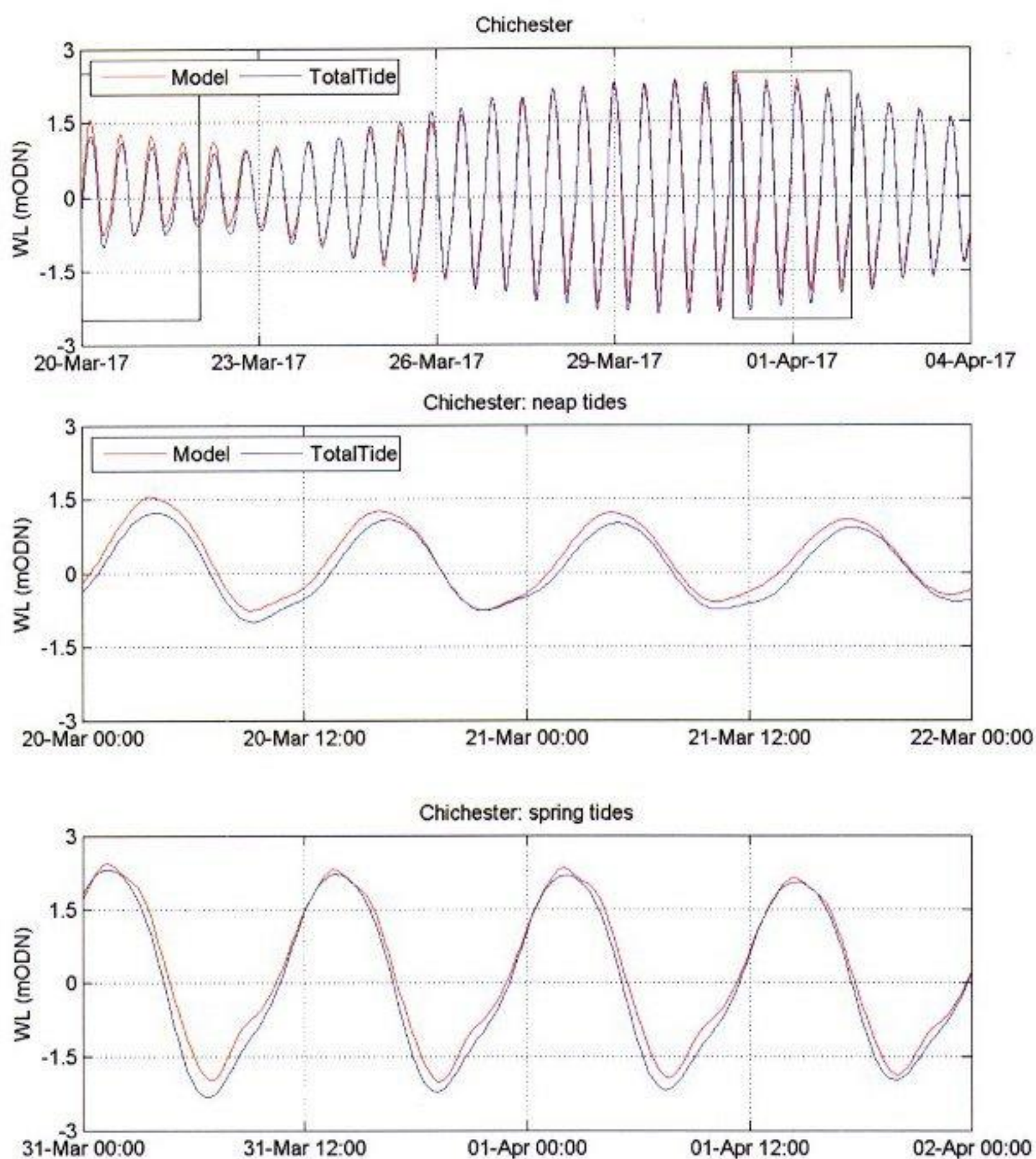


Figure A13. Model calibration of water levels at Chichester against TotalTide predictions

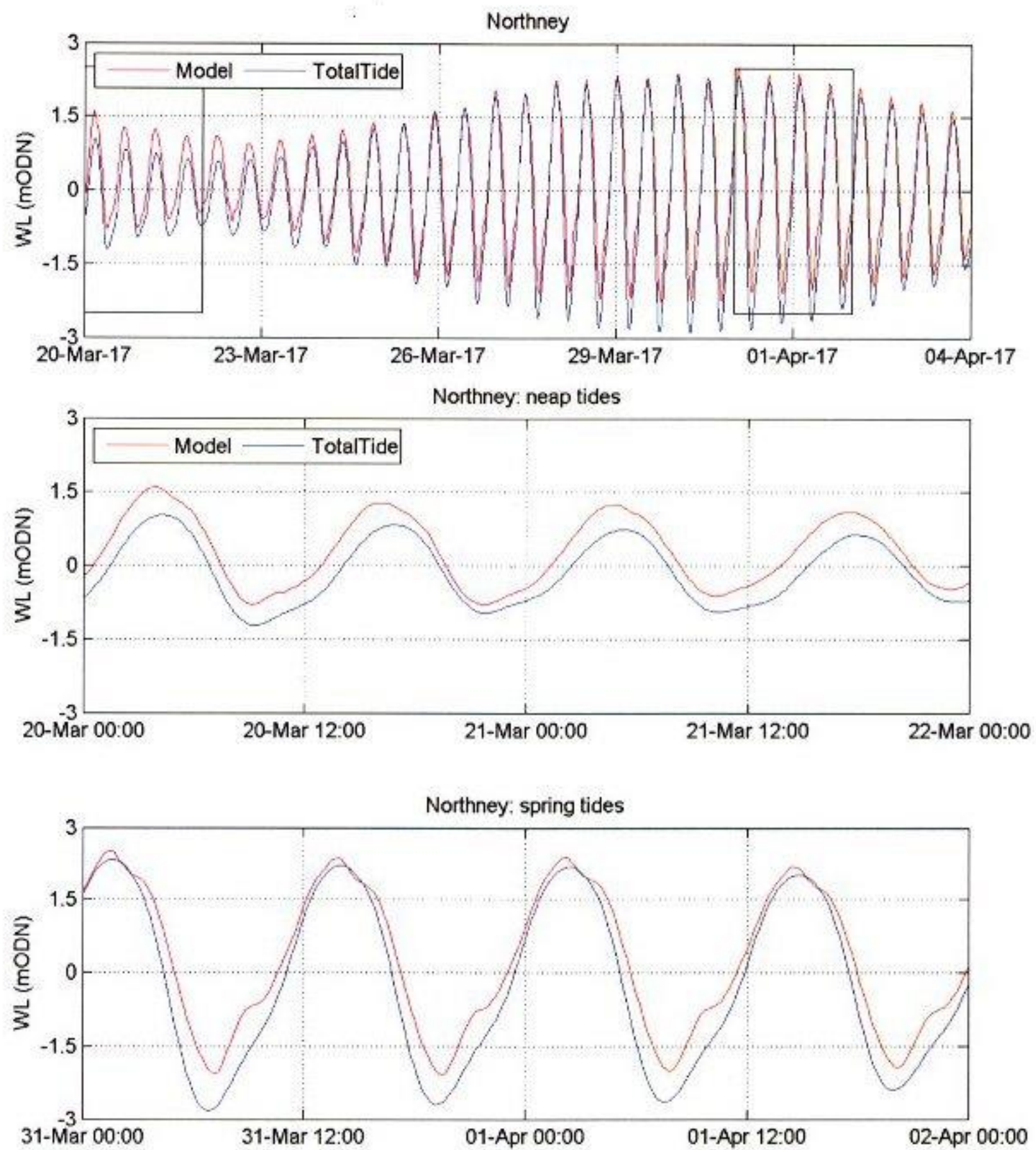


Figure A14. Model calibration of water levels at Northney against TotalTide predictions

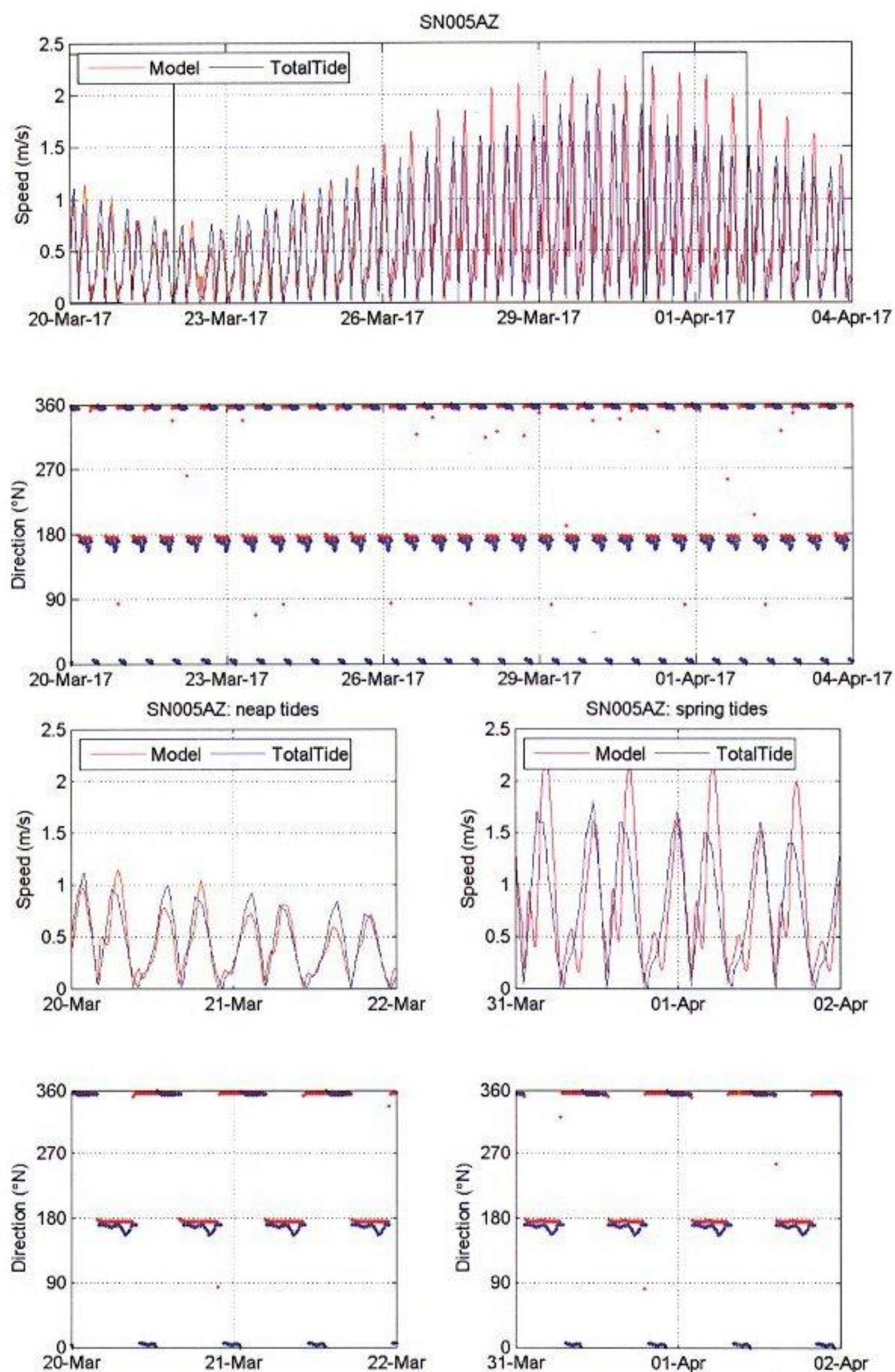


Figure A15. Model calibration of flows against TotalTide predictions at SN005AZ

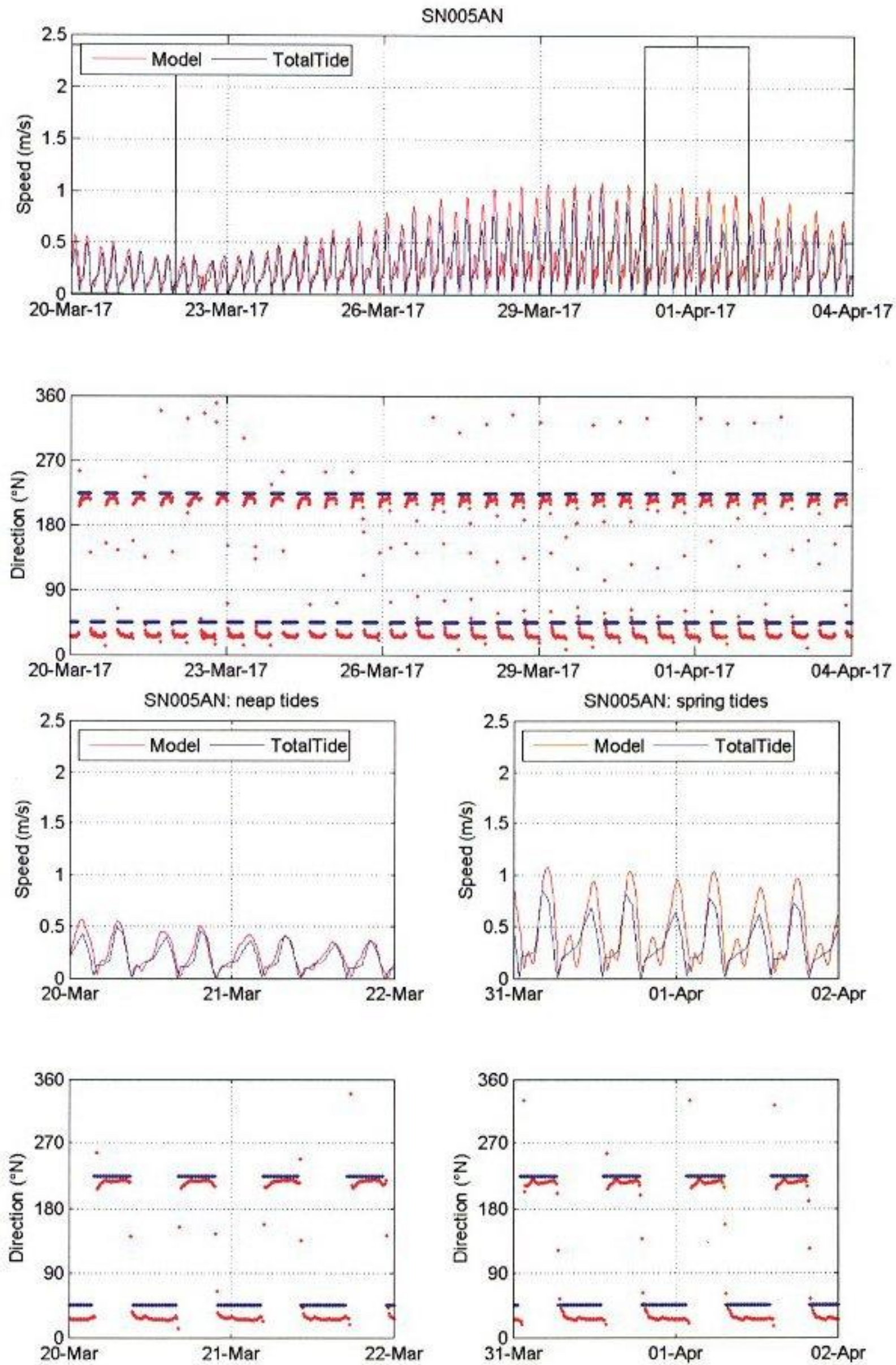


Figure A16. Model calibration of flows against TotalTide predictions at SN005AN

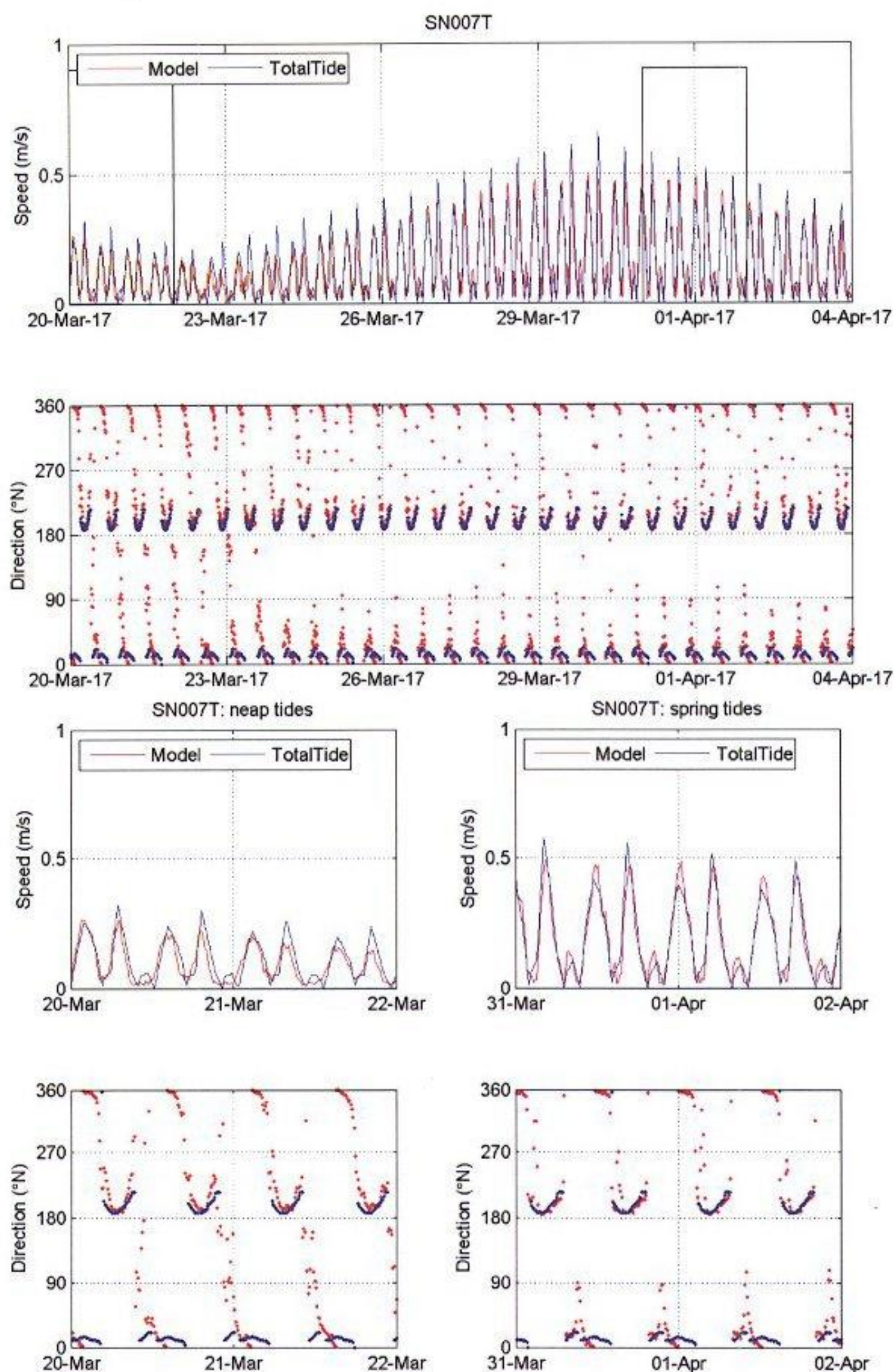


Figure A17. Model calibration of flows against TotalTide predictions at SN007T

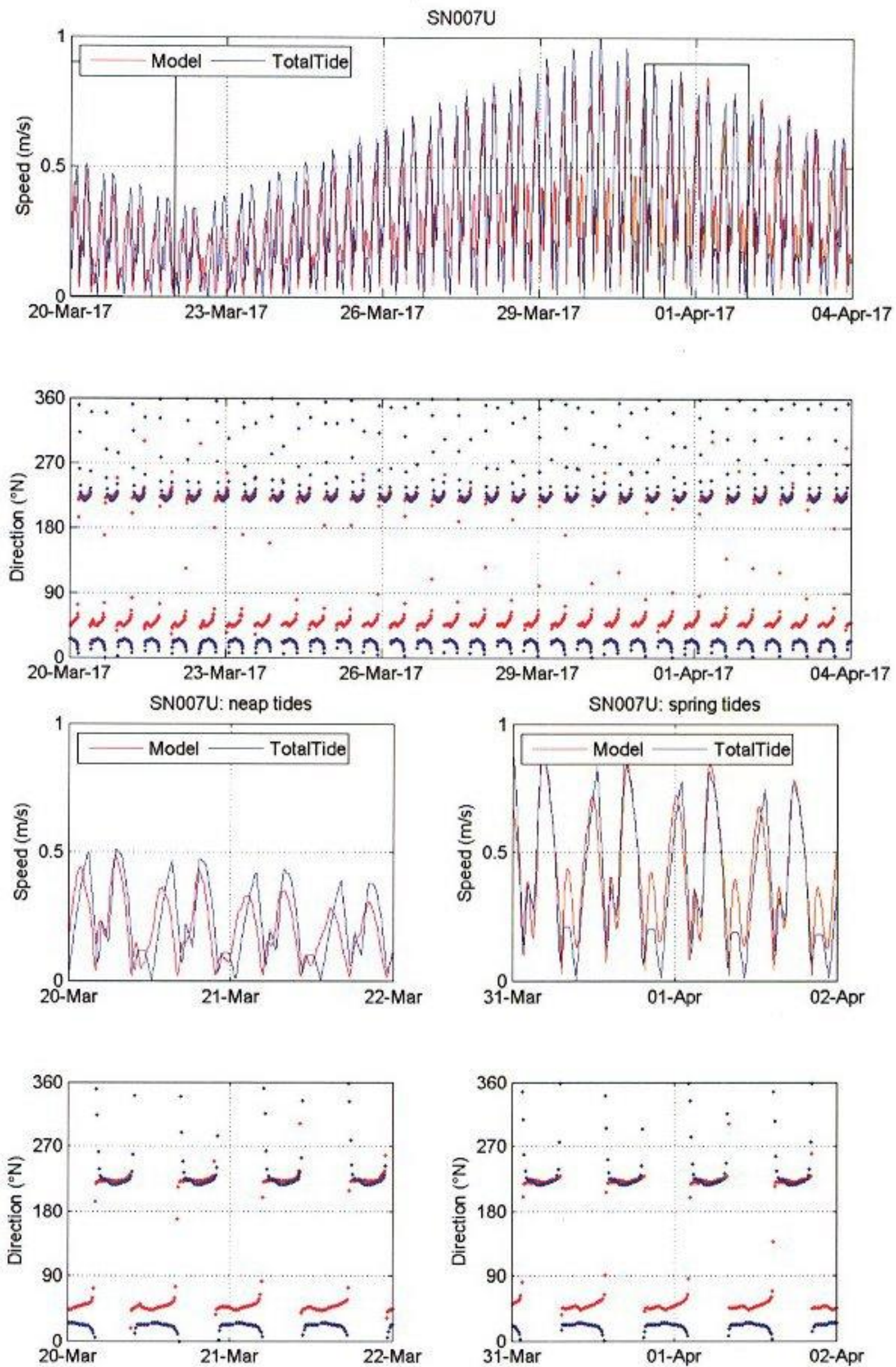


Figure A18. Model calibration of flows against TotalTide predictions at SN007U

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.

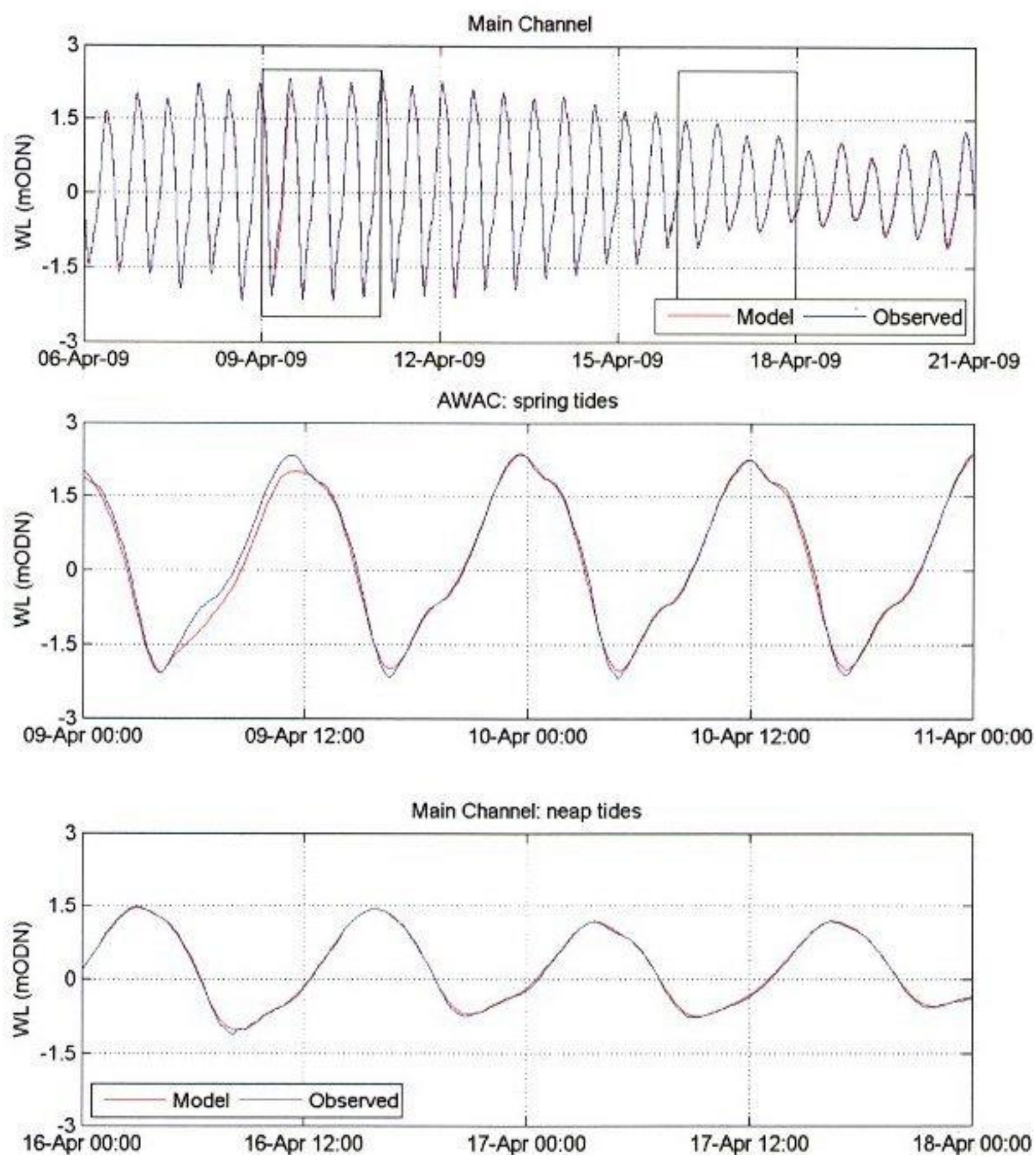


Figure A19. Model validation of water levels in the Main Channel against AWAC data

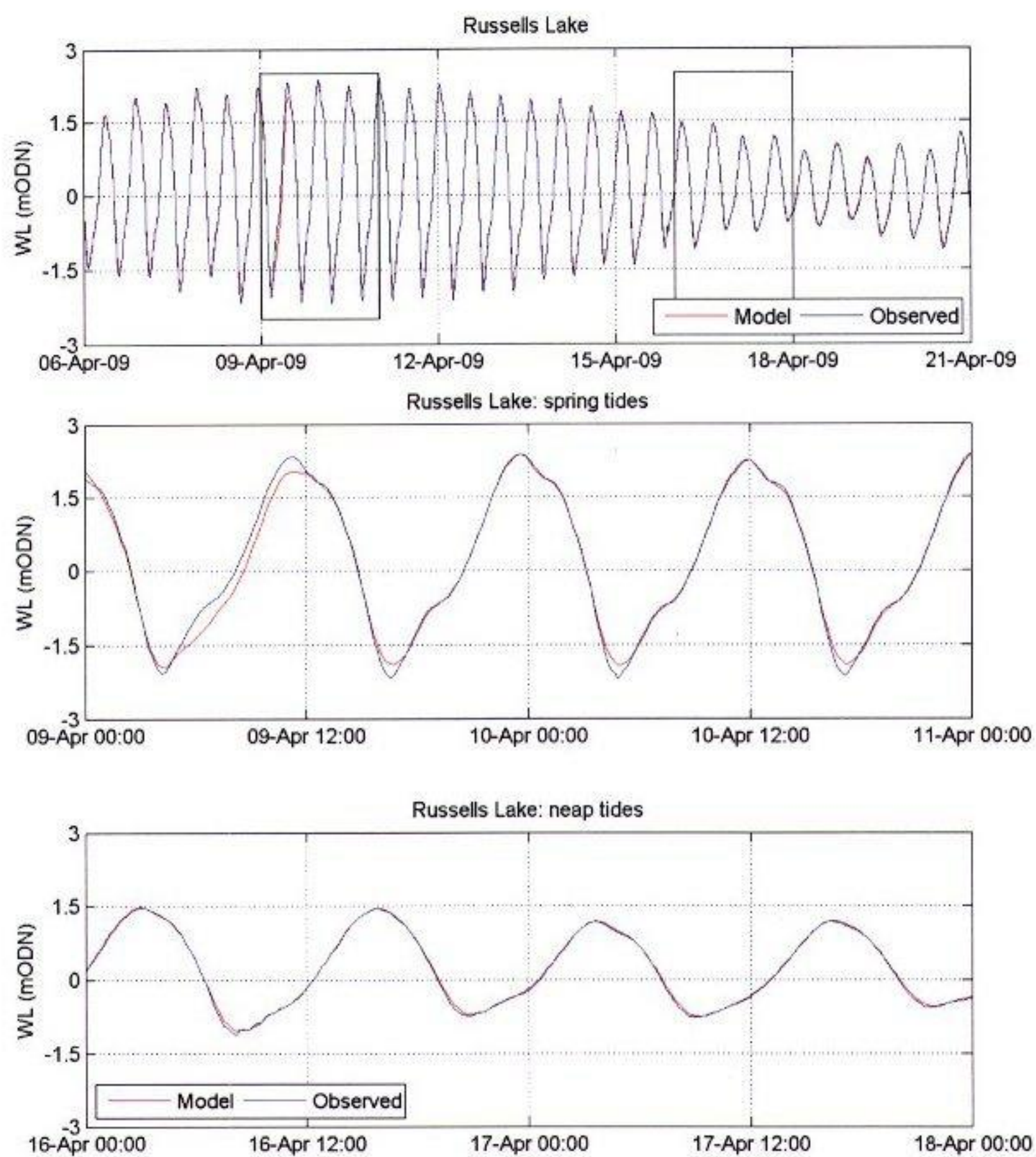


Figure A20. Model validation of water levels at Russells Lake against Profiler data

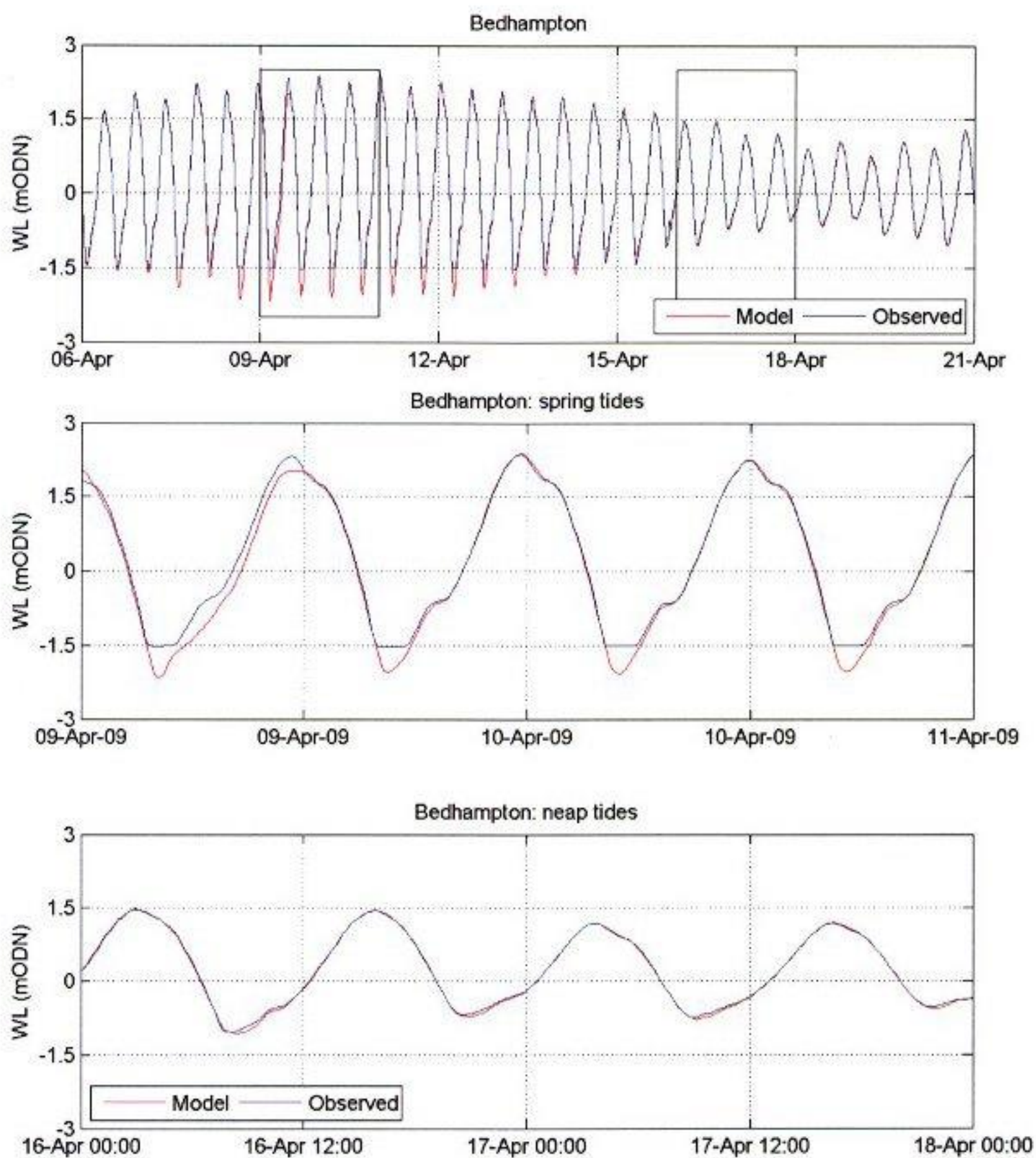


Figure A21. Model validation of water levels at Bedhampton against tide gauge data

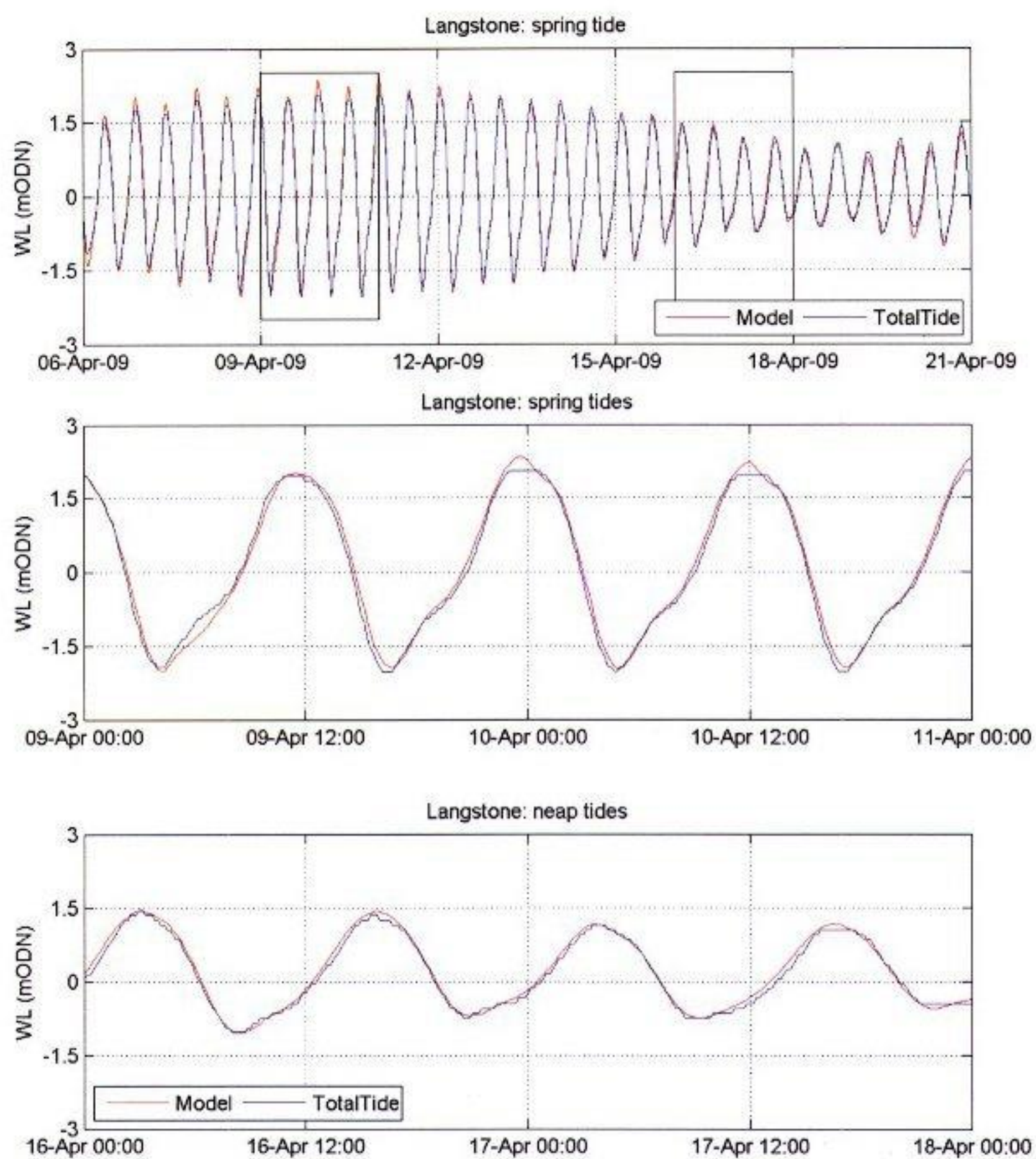


Figure A22. Model validation of water levels at Langstone against TotalTide predictions

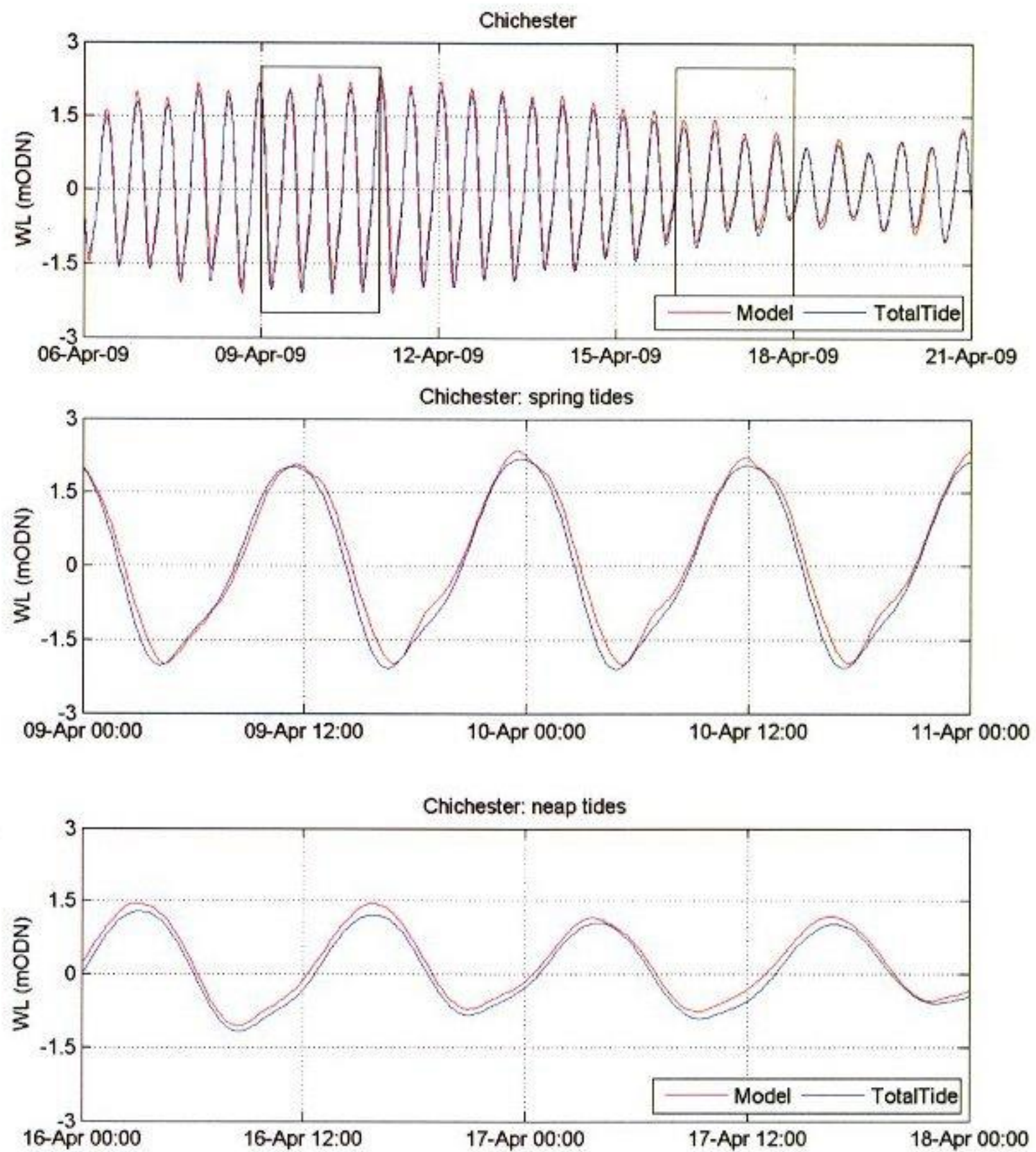


Figure A23. Model validation of water levels at Chichester against TotalTide predictions

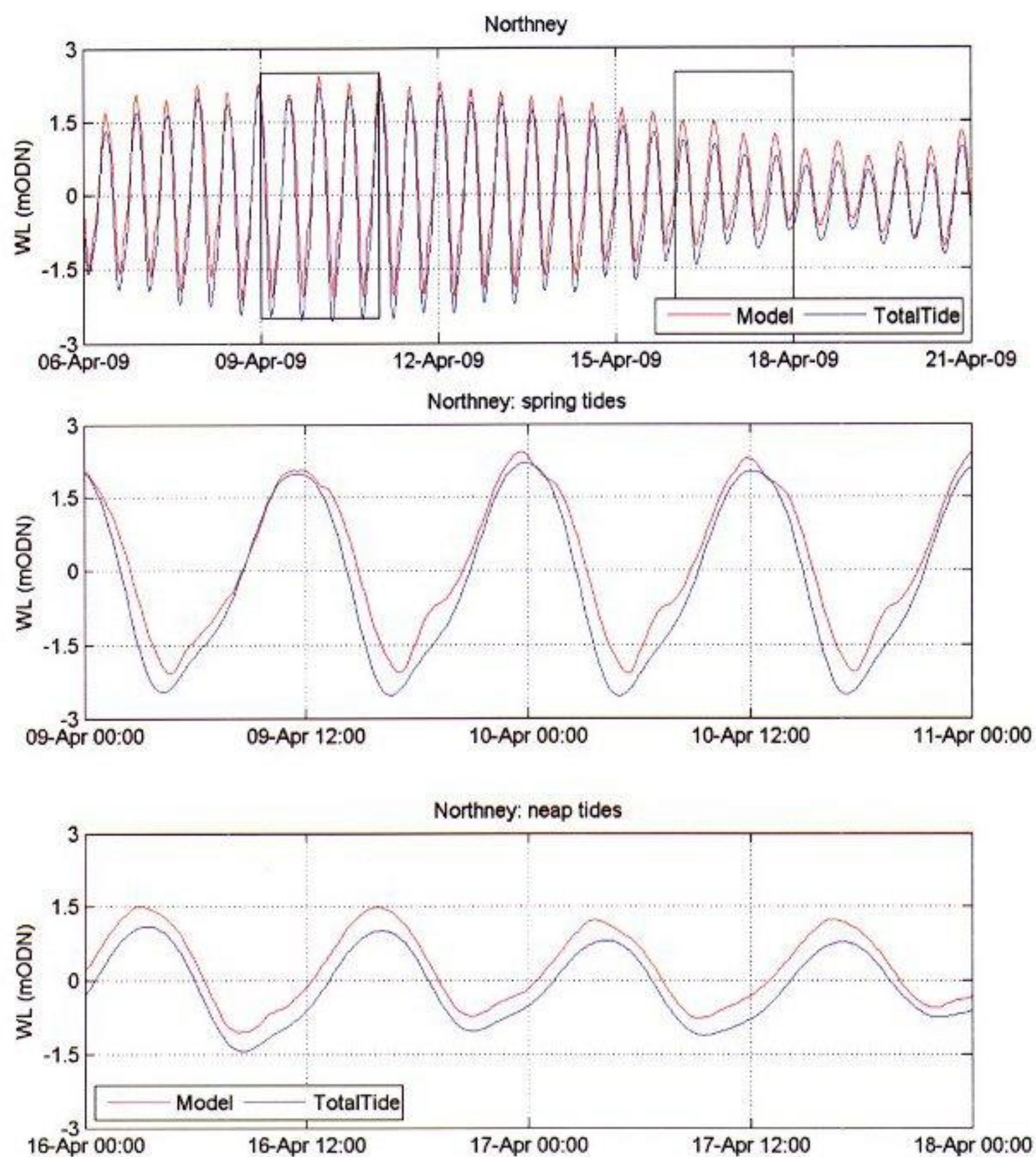


Figure A24. Model validation of water levels at Northney against TotalTide predictions

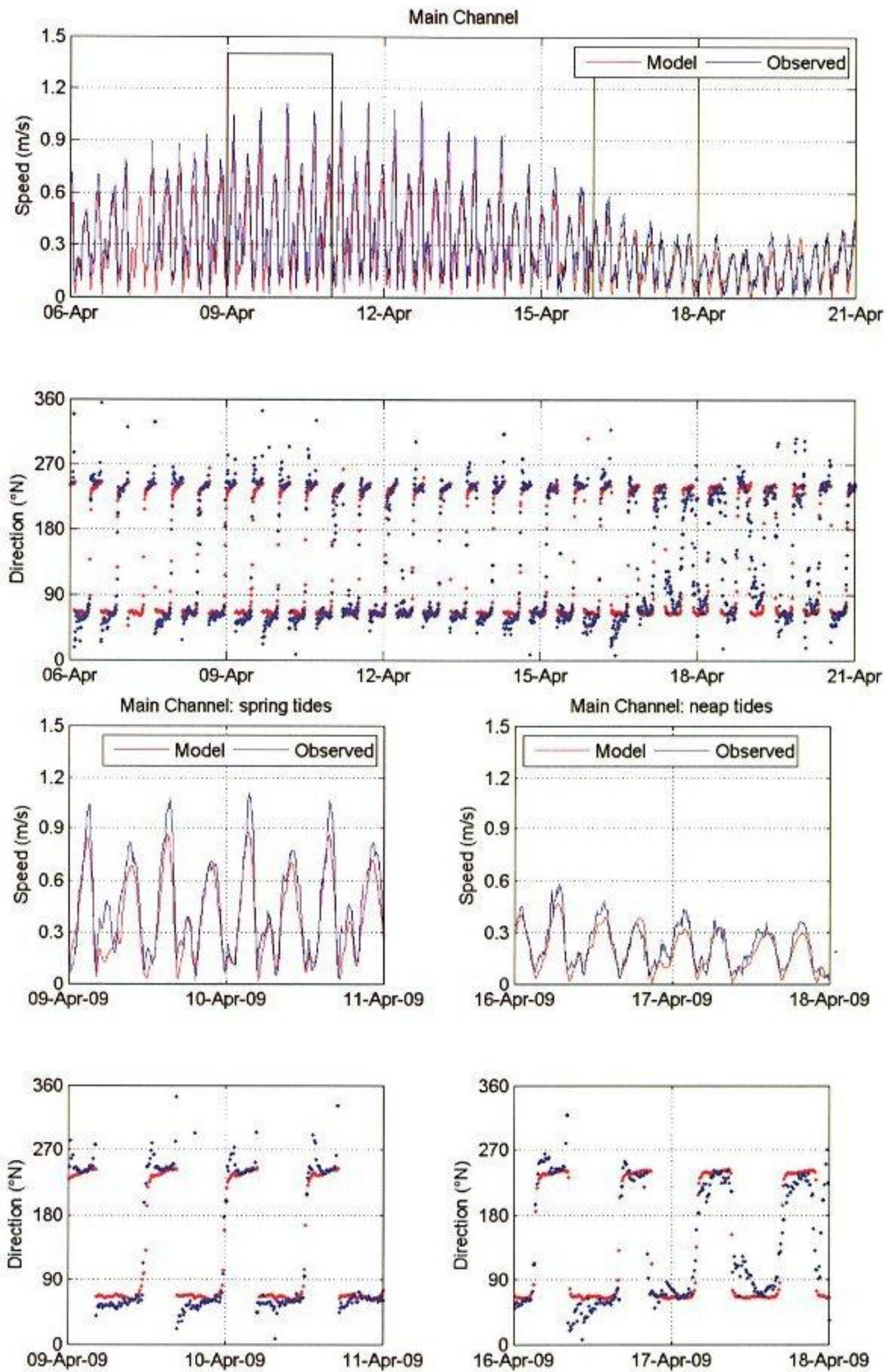


Figure A25. Model validation of flows against flows in the Main Channel against AWAC data

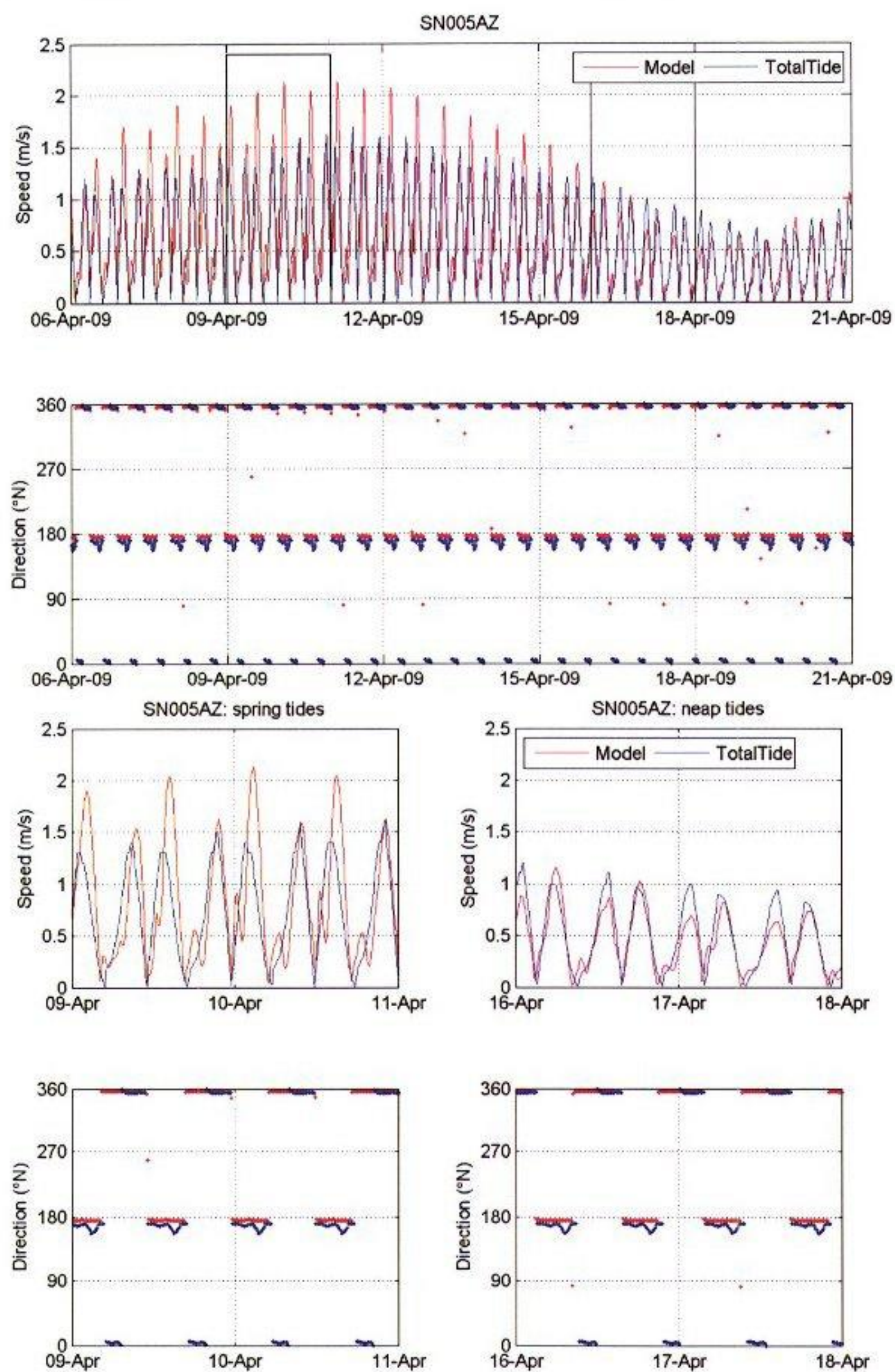


Figure A26. Model validation of flows against TotalTide predictions at SN005AZ

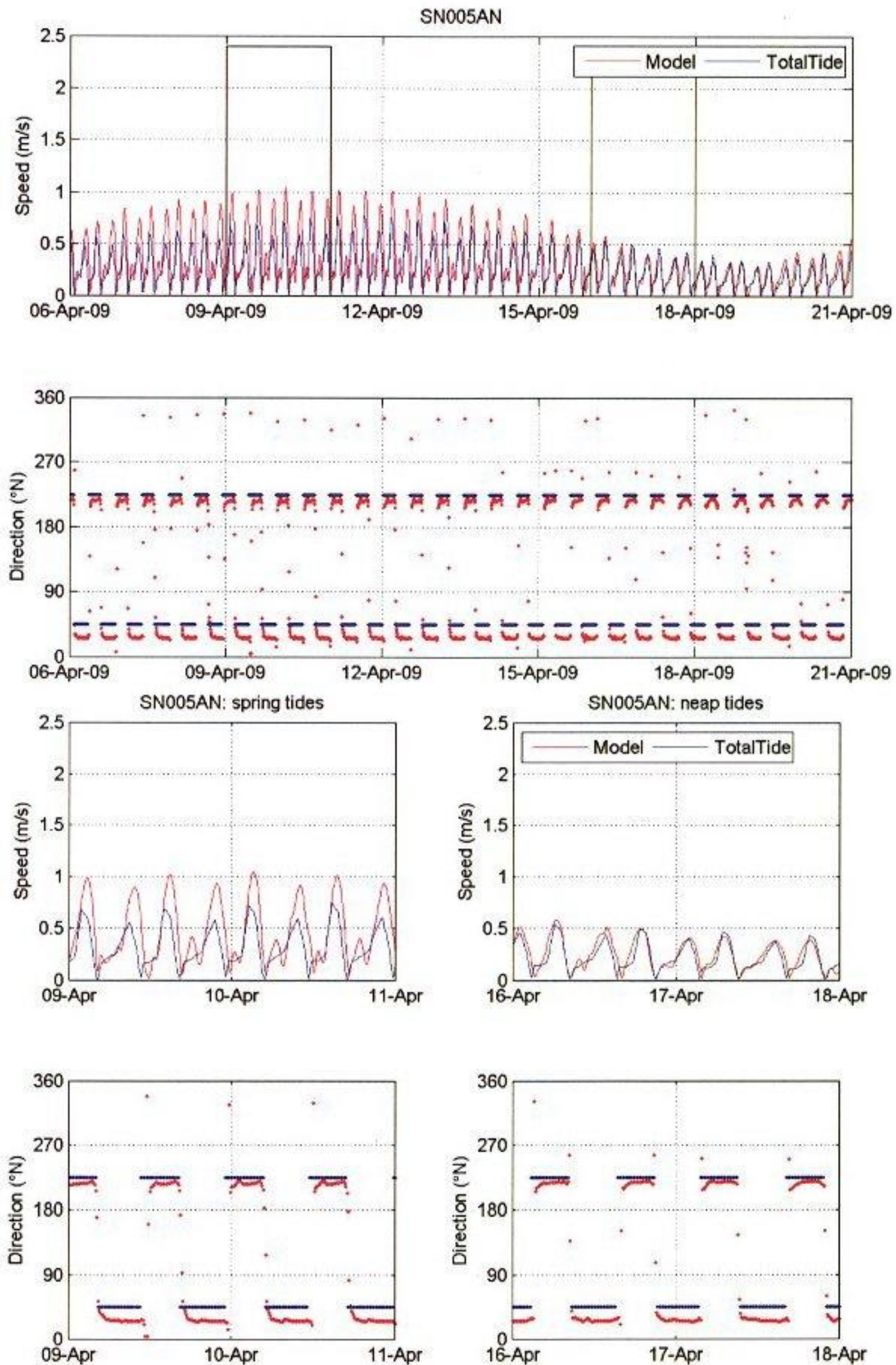


Figure A27. Model validation of flows against TotalTide predictions at SN005AN

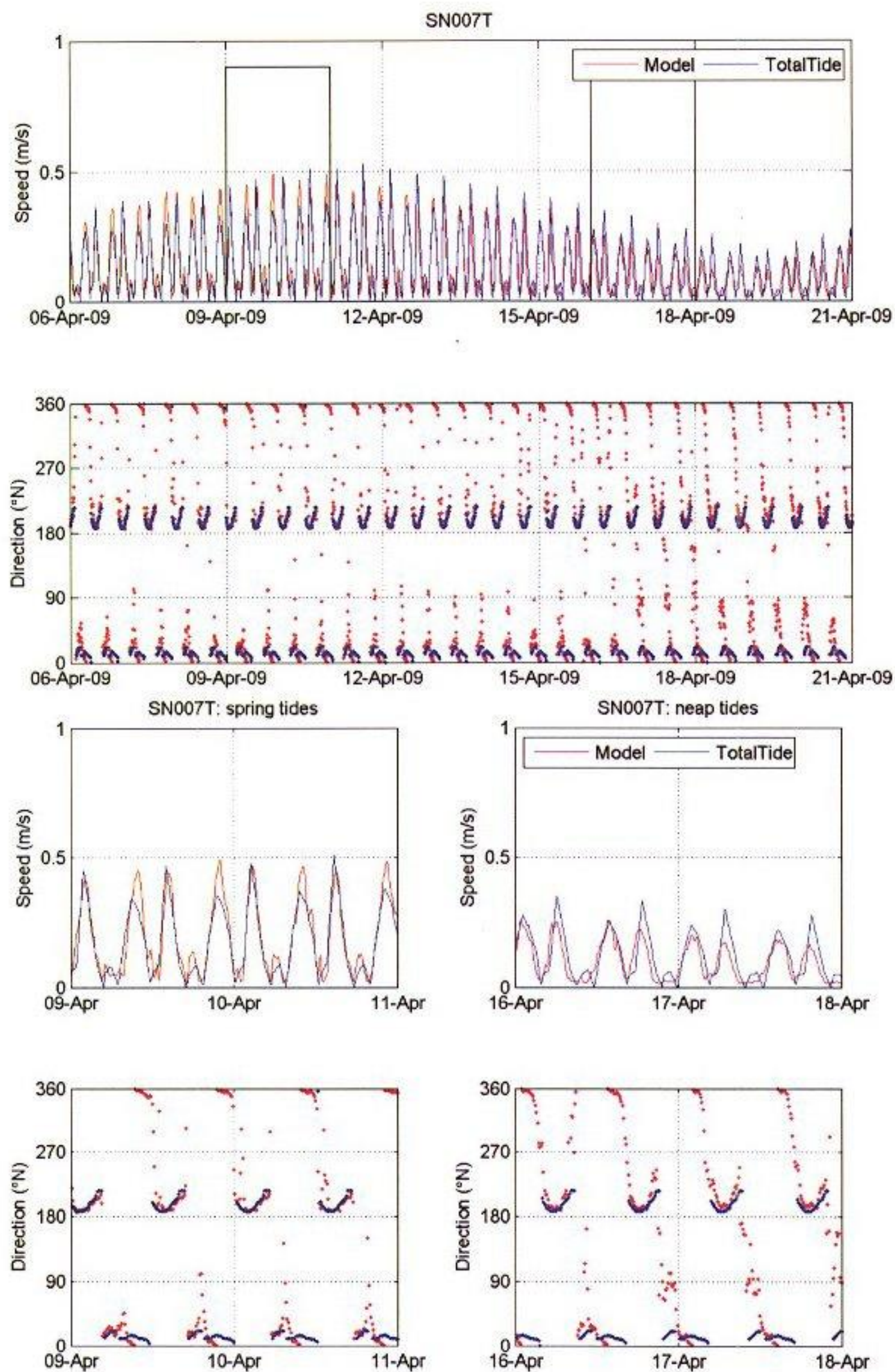


Figure A28. Model validation of flows against TotalTide predictions at SN007T

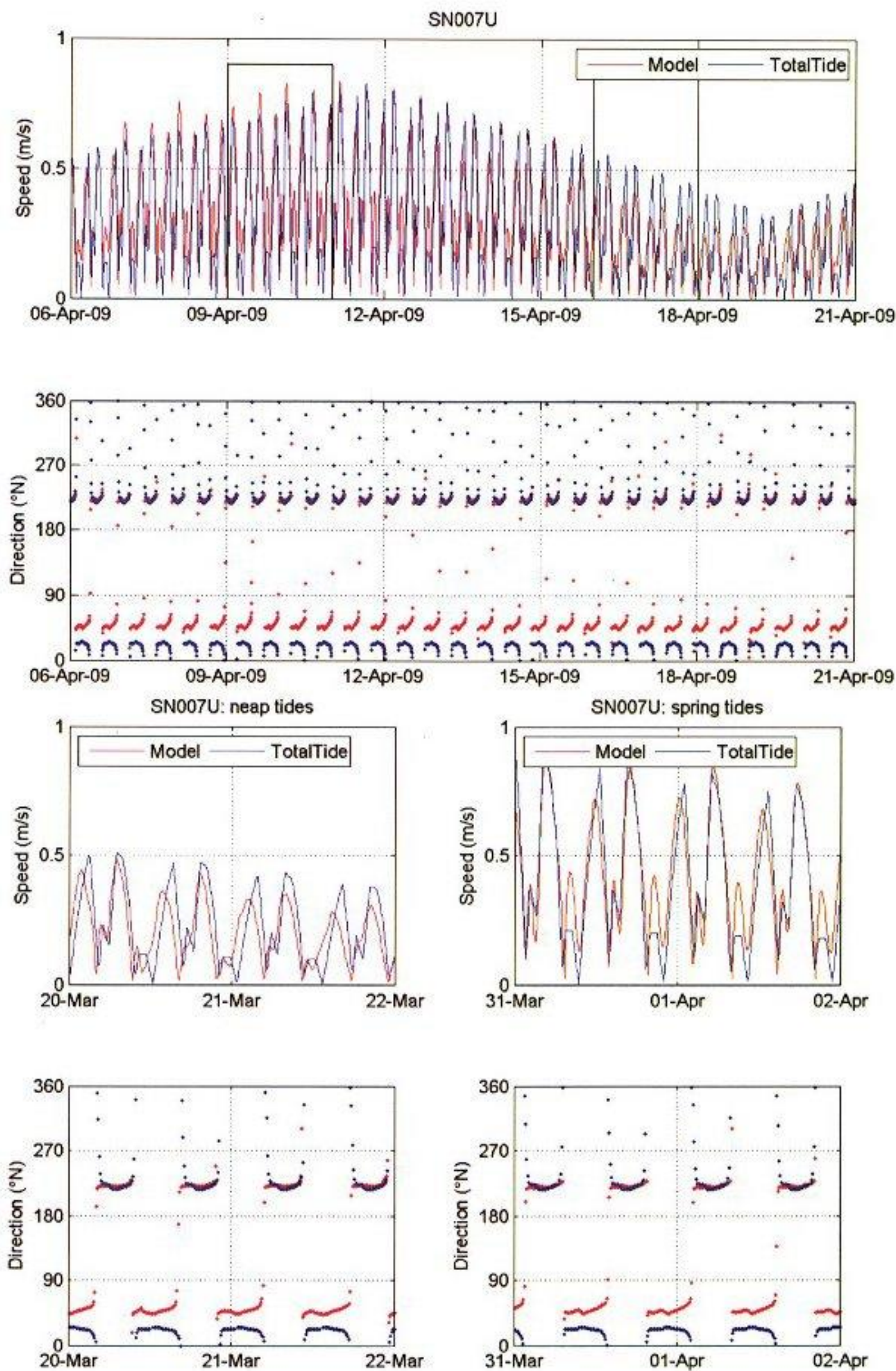


Figure A29. Model validation of flows against TotalTide predictions at SN007U

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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