REPORT

Cocker Tidal Channel and Cockerham Marsh SSSI Restoration Investigation

Task 2b - Modelling

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Abbreviations

2D	Two Dimensional
B	Baseline (model scenario)
BODC	British Oceanographic Data Centre
BS1	Baseline sensitivity #1 (model scenario)
BS2	Baseline sensitivity #2 (model scenario)
CD	Chart Datum
DHI	Danish Hydraulic Institute
EA	Environment Agency
EGA	Expert Geomorphological Assessment
FM	Flexible Mesh
HAT	Highest Astronomical Tide
HD	Hydrodynamic
HTA	Historical Trends Analysis
LAT	Lowest Astronomical Tide
LiDAR	Light Detection and Range
ME	Mean Error
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
OD	Ordnance Datum
RMSE	Root Mean Square Error
SSSI	Site of Special Scientific Interest
Std	Standard Deviation
TCC	Tidal Cocker Channel (model scenario)
UK	United Kingdom
UKHO	United Kingdom Hydrographic Office

Units

km	kilometres
m	metres
m^2	square metres
m^3	cubic metres
mCD	metres Chart Datum
mOD	metres Ordnance Datum
m/s	metres per second
m^3/s	cubic metres per second (or cumecs)
%	percentage

Preamble

The present study forms part of an initiative called ‘Our Future Coast’, which is instigated by the Department for Environment Food and Rural Affairs (Defra), Wyre Council and the Environment Agency.

‘Our Future Coast’ is focused on working with nature to safeguard coastal communities through seventeen projects across the North West of England, from Formby in the south to Millom Marshes in the north.

The ‘Cocker Tidal Channel & Cockerham Marsh SSSI Restoration Investigation’ is one of these projects, being led by Natural England in partnership with Lancashire Wildlife Trust and the Environment Agency.

The ‘Our Future Coast’ programme aims to develop a suite of natural buffer strips to increase coastal resilience of vulnerable hot spots in the North West. Natural coastal buffer strips can provide multiple benefits, including reducing flood risk, reducing coastal erosion, increasing biodiversity and water quality, providing carbon capture and other ecosystem services such as recreation and well-being.

Buffer strips with their rich vegetation, act as natural means of capturing sediment and dissipating wave energy. Buffer strips include developing salt marsh, managed realignment, reclaiming redundant brownfield sites, dune systems, and intertidal lagoons to provide storage of surface water during high tide.

Further information about the programme can be found here:

Our Future Coast | The Flood Hub

1 Introduction

The downstream reach of the River Cocker in Lancashire flows in a north-westerly direction, discharging into southeast Morecambe Bay across the intertidal expanse of Cockerham Sands (**Figure 1-1**). The 1.5 km reach between a sluice gate at Cocker Bridge and Morecambe Bay is tidal, flowing within an artificially straightened channel, which was cut in the 1960s.

The cut Cocker channel joins into a naturally meandering channel (Patty's Farm Creek) at a confluence just seaward of Bank End Farm. Beyond this confluence, the Outer Cocker Channel flows in a meandering manner across intertidal areas of Cockerham Sands.

Prior to the new cut in the 1960s (shown red in **Figure 1-2**), the natural outflow of the River Cocker was a meandering channel across Cockerham Marsh (shown orange in **Figure 1-2**). There is some argument that the new cut has placed increased energy at the confluence (shown as a yellow box in **Figure 1-2**) between the cut River Cocker channel and Patty's Farm Creek (shown blue in **Figure 1-2**), increasing the tendency for this combined outer channel to incise close to the flood embankment near this point.

Morecambe Bay is a highly dynamic environment, and the alignment of channels can change significantly within a short timescale in response to the governing tidal and sedimentary processes, freshwater discharge from rainfall across the catchment, and the effects of winds, waves and surges during storms.

Following a period of notable channel movement towards the north at the confluence of the cut Cocker Channel and Patty's Farm Creek, in 2012 residents alerted the Environment Agency to the loss saltmarsh fronting the flood embankment and raised concerns at that time about potential flood risk to Bank End Farm and Caravan Park and the nearby Bank Houses Caravan Park.

This prompted a Geomorphological Appraisal by the Environment Agency (Swift, 2013) which incorporated Historic Trends Analysis (HTA) of historic maps and datasets as well as Expert Geomorphological Assessment (EGA) informed by observations from a site visit. Recognising the uncertainties associated with the future extent of saltmarsh erosion due to the dynamic nature of the physical environment, the study recommended enhanced monitoring be undertaken, in combination with further assessment of the suitability of options to address the flood risk (whilst allowing the system to respond as naturally as possible to wider environmental forcing) by means of: (i) enhancing protection of the existing channel bank using bio-engineered brushwood mattresses (or similar); (ii) in-channel flow deflectors; and (iii) strengthening of the main flood embankment near Bank End Farm. The study also suggested that options to re-naturalise the tidal channel of the River Cocker could be considered if that too would alleviate erosion and associated flood risk pressure at Bank End Farm.

The present Cocker Tidal Channel and Cockerham Marsh SSSI Restoration Investigation more widely investigates potential for restoration of natural processes, morphology and habitat in this area and how this might provide other benefits to the estuary and the wider catchment, particularly land drainage and flood risk. The study comprises four main tasks, namely:

- Task 1 – Desk-Based Review and Site Visit
- Task 2 – Optioneering, Modelling and Design
- Task 3 – Catchment Nature Based Solutions
- Task 4 – Cockerham Marsh Site of Special Scientific Interest (SSSI)

This report relates to **Task 2b - Modelling**.

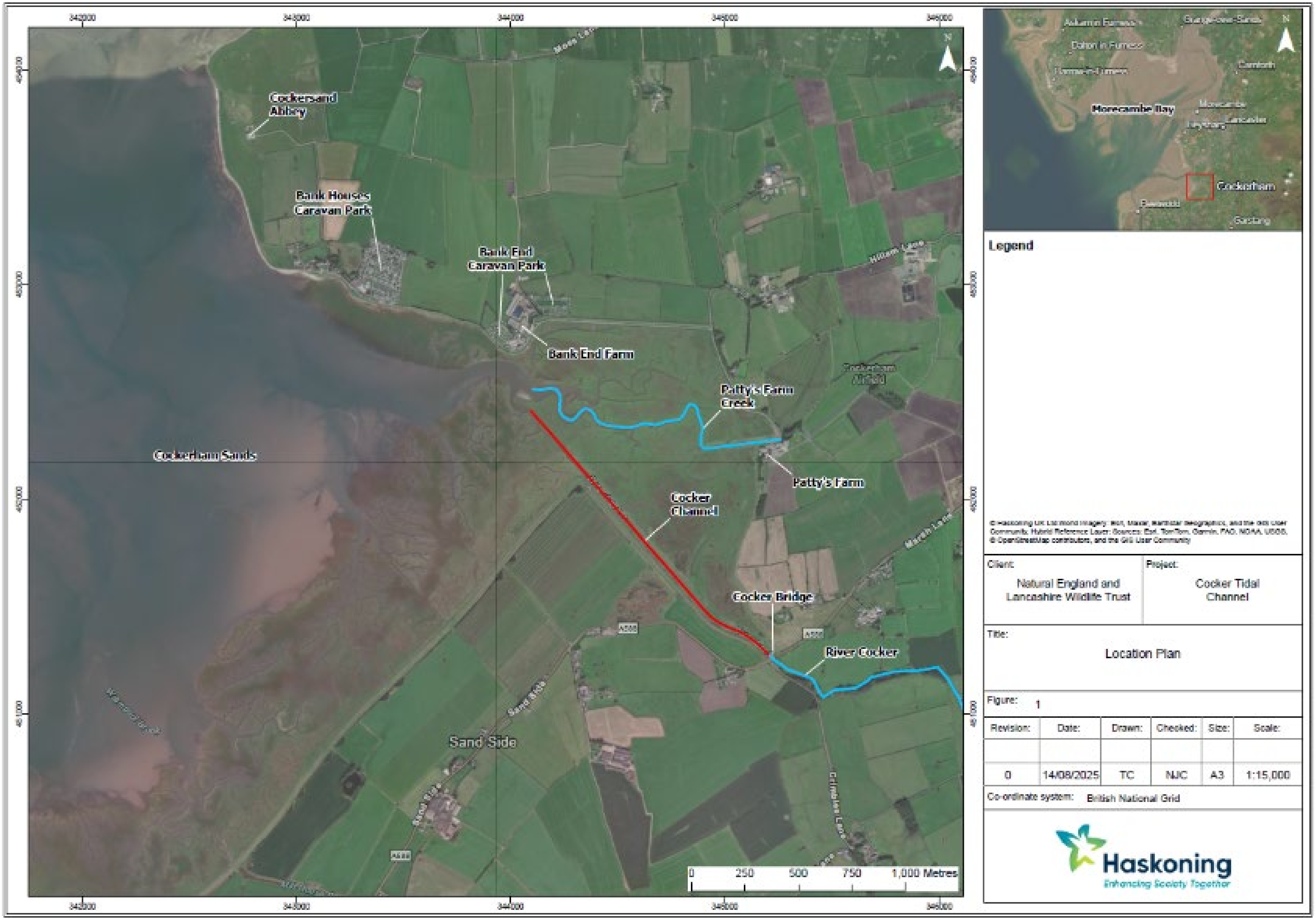


Figure 1-1 Location Plan

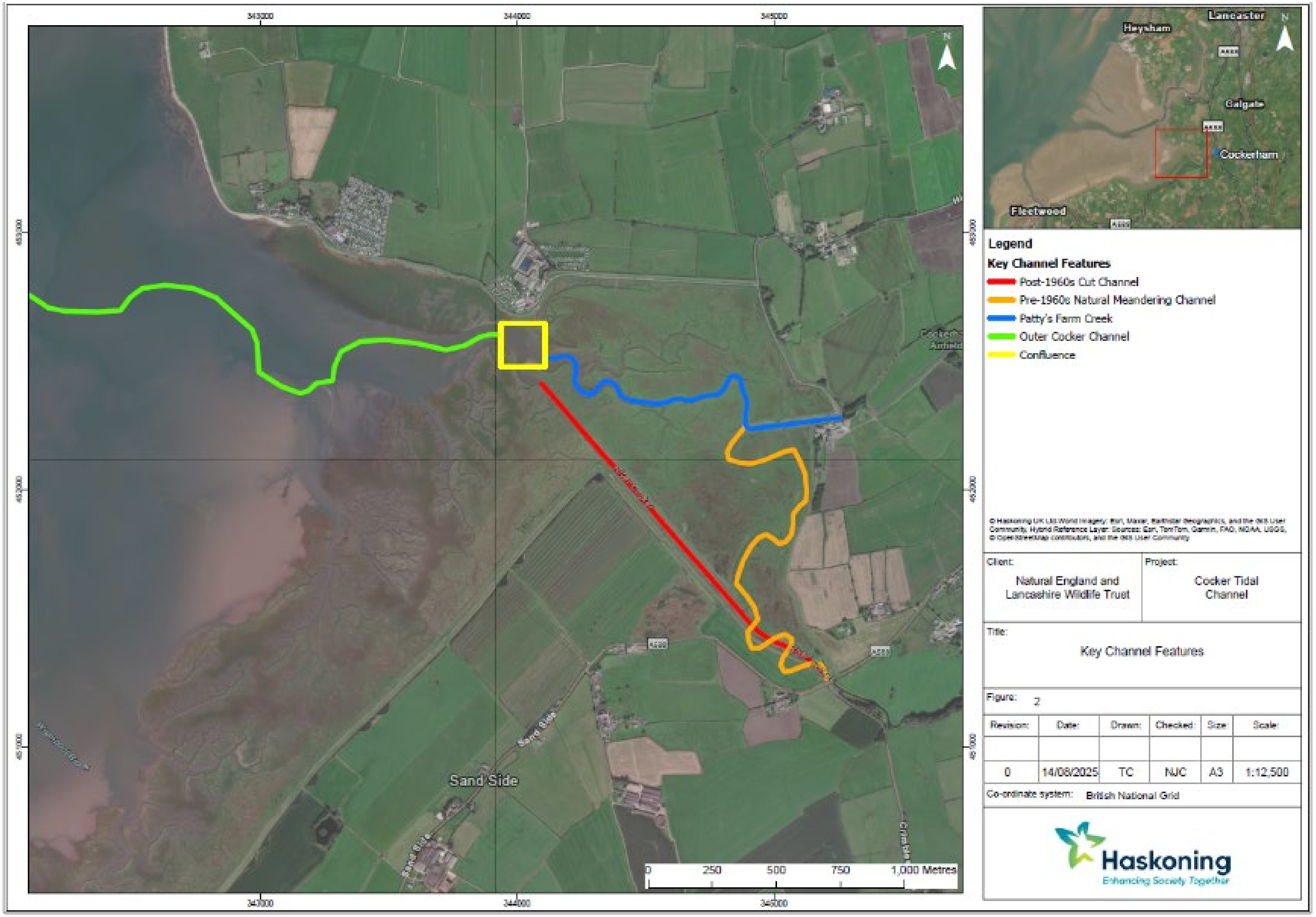


Figure 1-2 Key channel features (after Swift, 2013)

2 Task 2b – Modelling

2.1 Purpose

Numerical modelling has been undertaken to provide simulated hydrodynamic information for the study area to enable a comparison of water levels and tidal currents for both: (i) the baseline conditions; and (ii) the conditions under defined scheme options.

Outputs from the numerical modelling (Task 2b) have informed other Tasks of the study, most notably:

- Task 2a – Optioneering; and
- Task 2c – Design.

2.2 Data Collation

The numerical model has been based on a topography and bathymetry built from the following available datasets:

- **Light Detection and Ranging (LiDAR) Data:** The latest available LiDAR survey data from 2023 were obtained from the Environment Agency covering the whole project area (see **Figure 2-1**).

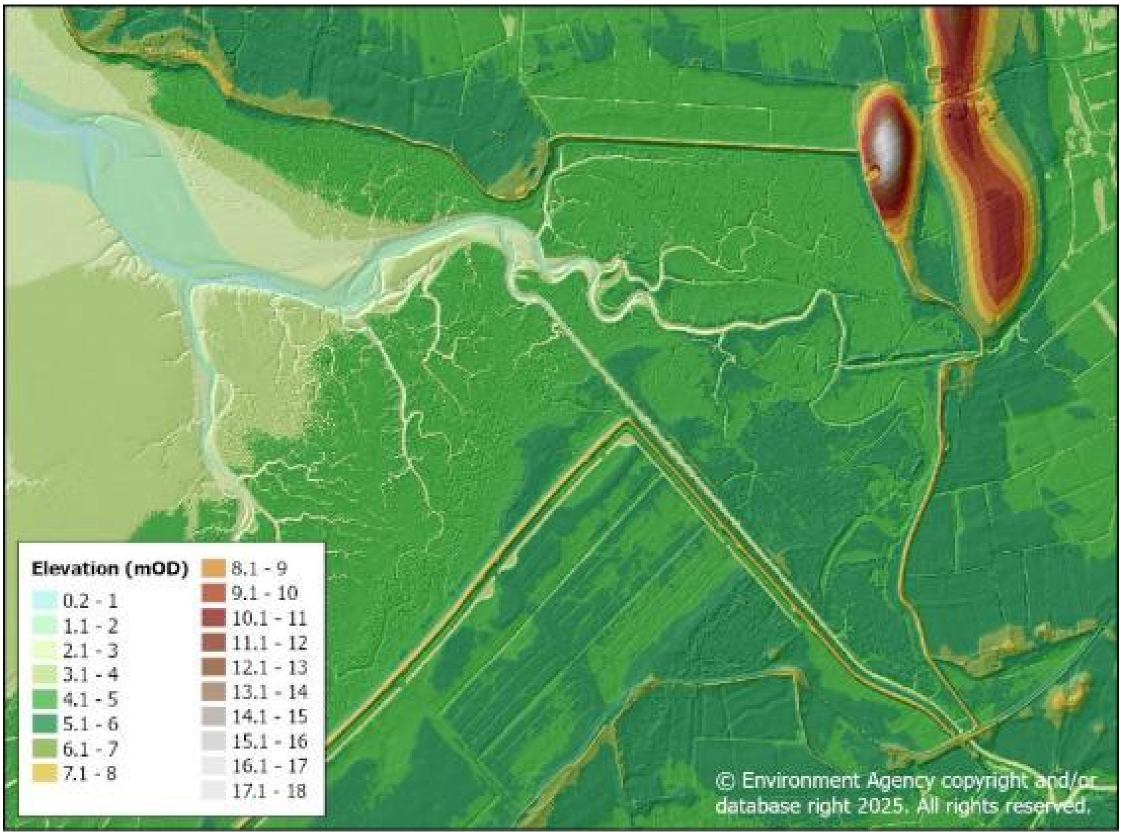


Figure 2-1 Contour plot based on LiDAR data from 2023

- **Bathymetry Data:** The latest available bathymetry survey data were obtained from the following sources, and the data coverage (as well as the hydrodynamic model offshore boundary) is shown in **Figure 2-2**:
    - LiDAR data has been used for mudflat and saltmarsh areas shown as dark brown areas that were not covered by any other bathymetry data
    - United Kingdom Hydrographic Office (UKHO) data sets are shown as light brown areas
    - C-Map data are shown as light brown scatter points

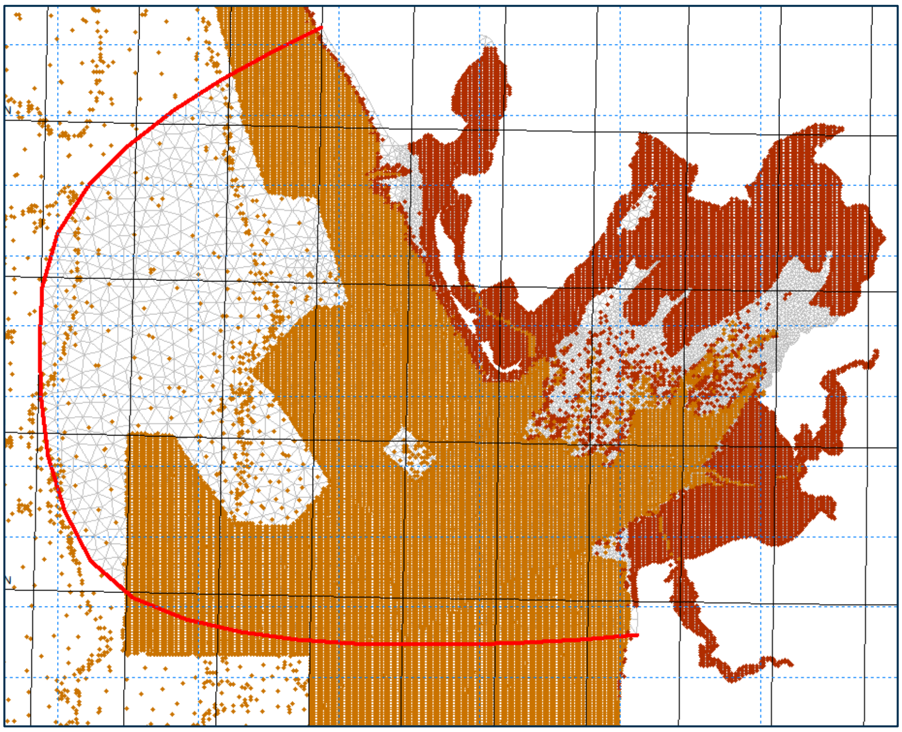


Figure 2-2 Coverage of bathymetry data sets (red line = offshore model boundary)

- **Cocker Channel Long-section Survey:** A long-section survey of the tidal Cocker Channel was surveyed by Survey Operations Limited in March 2013. This covered the channel seaward of the tidal sluice at Cocker Bridge and covered both the new cut and the natural Outer Cocker Channel. Records were provided of the water level, soft bed level and hard bed level, along with a series of accompanying channel section photographs. Whilst it is recognised that this dataset is now potentially out-dated, it has been used as the best available data for the narrow new cut channel. The natural Outer Cocker Channel alignment has changed considerably since 2013, and the survey data was therefore not suitable for use in the model.

The following available datasets have been used as boundary conditions to drive (or verify) the numerical model in respect of hydrodynamic properties:

- **Tidal water levels:** Measured water level data were obtained from the British Oceanographic Data Centre (BODC) at Heysham, whilst astronomical tidal predictions were obtained from the UKHO at both Heysham and Fleetwood.

- **River flow:** The Environment Agency does not have any continuous flow data from the River Cocker but was able to provide ‘spot gauging’ data at Cocker Bridge from surveys in 1979.

3 Numerical Model Set-up

3.1 Model Description

The numerical model for the project is built using the MIKE21-HD software that was developed by the Danish Hydraulic Institute (DHI). The MIKE21-HD software has a proven track record and is widely used in many similar studies worldwide to solve 2D hydrodynamic problems. The 2D model is based on the nonlinear shallow water equations using depth-averaged conditions. The main advantages of this model are:

- The flexible triangular mesh of MIKE21-HD provides accurate boundary fitting for an area with complicated geometry, for example around the Cocker Channel project site within the large Morecambe Bay estuary and Cockerham Sands and Marshes.

- The flexible mesh enables the model to use a coarser grid in the offshore area and the areas further away from proposed development site but a finer mesh in the areas of greatest interest. This approach enables higher computational efficiency whilst still maintaining sufficient accuracy of mesh coverage in areas of greatest interest in the present study.

- The software allows for a triangular mesh covering the wider area to be seamlessly linked into a more refined quadrangular mesh covering the main channels and creeks to better define the flow paths in the model.

3.2 ‘Nested’ Modelling Approach

The study uses a Regional Model of the Irish Sea (described in Section 3.2.1) to generate boundary conditions that drive a ‘nested’ Local Model covering Cockerham Sands (including Bank End Farm, the tidal Cocker Channel and Cockerham Marsh SSSI) (described in Section 3.2.2).

3.2.1 Regional Model

Haskoning has an established 2D Regional Model of the Irish Sea, built using the MIKE21-HD software. This Regional Model covers the whole of the Irish Sea encompassing, on the eastern side, the UK shores from Iona in Scotland to St Ives in the south of England, and the Irish shores on the western side, extending from Portmore in the north to Cork in the south.

Open model boundaries are set to drive the flow conditions in the model. The Regional Model is driven by two open model boundaries, one in the north and the other in the south as shown in **Figure 3-1**.

The model extent and model boundaries for the Regional Model are shown in **Figure 3-1.**

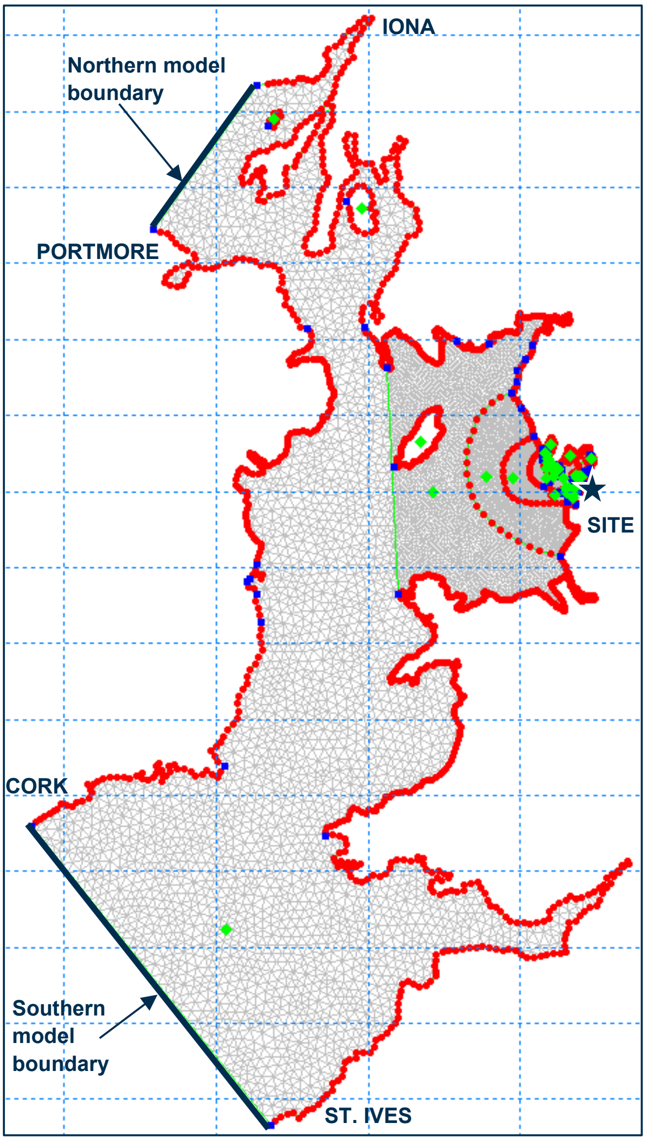


Figure 3-1 Extent of the 2D Irish Sea regional model (black star denotes project site)

The Regional Model has previously been calibrated against both predicted astronomic tidal elevation data and measured tidal elevation data and current data at various standard ports around the Irish Sea. However, for the specific purpose of use in this study, the Regional Model was refined and updated around the study area. The coastline within Cockerham Sands (and especially the tidal Cocker Channel, Patty's Farm Creek and Cockerham Marsh SSSI) was refined to better represent the topography and bathymetry in the study area. The bathymetry data used in the model was updated using the latest available channel long-section survey data for the tidal Cocker Channel and using the 2023 LiDAR data for the 'drying' areas of Cockerham Sands and the entirety of Cockerham Marsh SSSI.

3.2.2 Local Model

The 'nested' Local Model of the study area was also built using MIKE21-HD software. It extends from the Duddon Estuary in the North to Cleveleys in the South and covers the whole of Morecambe Bay and extends offshore to the -30mCD contour. Given this extent, the model fully incorporates the principal areas of interest, including Bank End Farm, the tidal Cocker Channel and Cockerham Marsh SSSI.

The model boundary for the Local Model has been derived from the Regional Model. The Local Model is driven by one open boundary using ‘flather’ conditions which are defined by velocities in x- and y-direction and water level. This is a very efficient model boundary type in terms of downscaling coarse model simulations to local areas.

The boundary at Cocker Bridge was initially set with no flow from the River Cocker, but sensitivity tests were also performed with an appropriate measured constant river flow (1.3 m^3/s) derived from the Environment Agency spot measurements and with a ‘high’ flow of 5.0 m^3/s.

Figure 3-2 shows the extent, bathymetry and offshore model boundary of the Local Model.

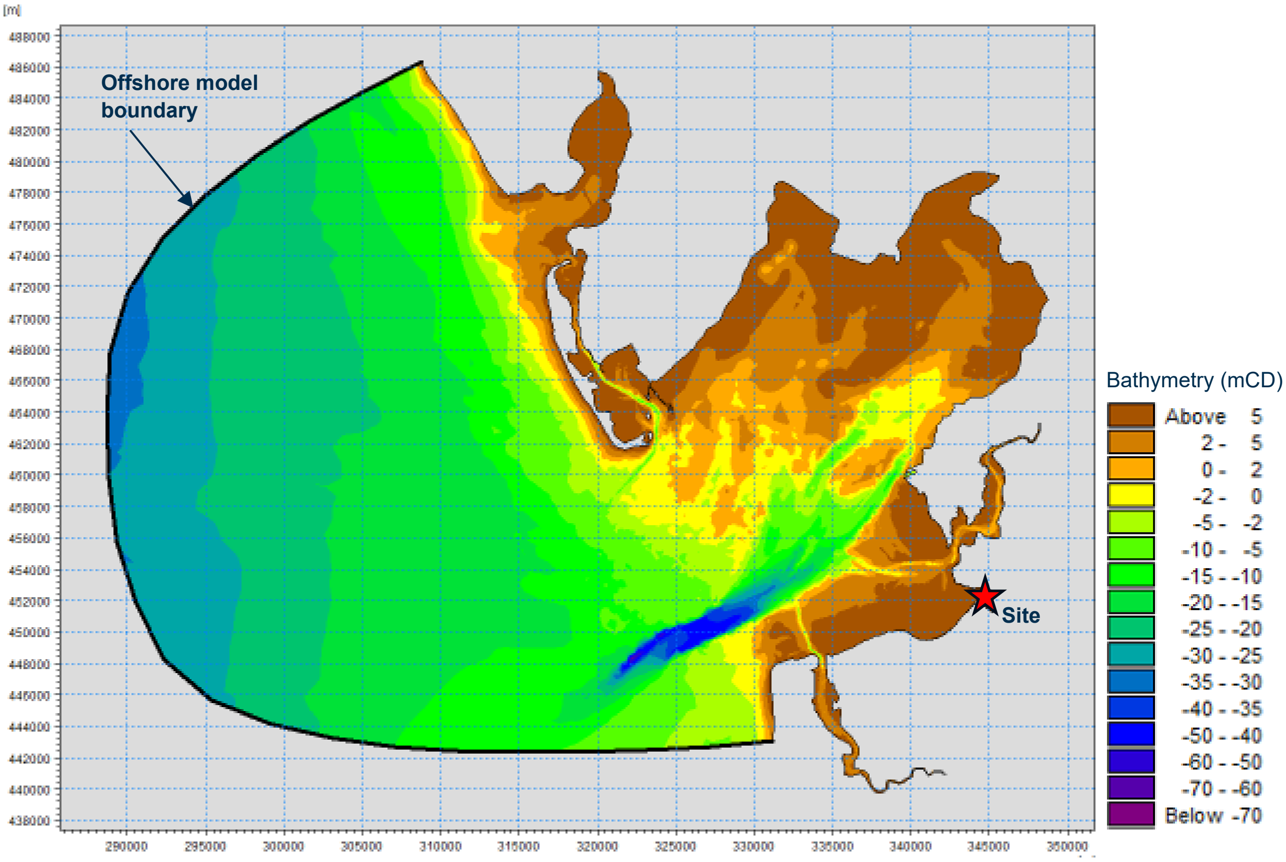


Figure 3-2 Extent, bathymetry and offshore model boundary of the 2D MIKE21-FM-HD local model (red star denotes project site)

3.3 Model Mesh Resolution

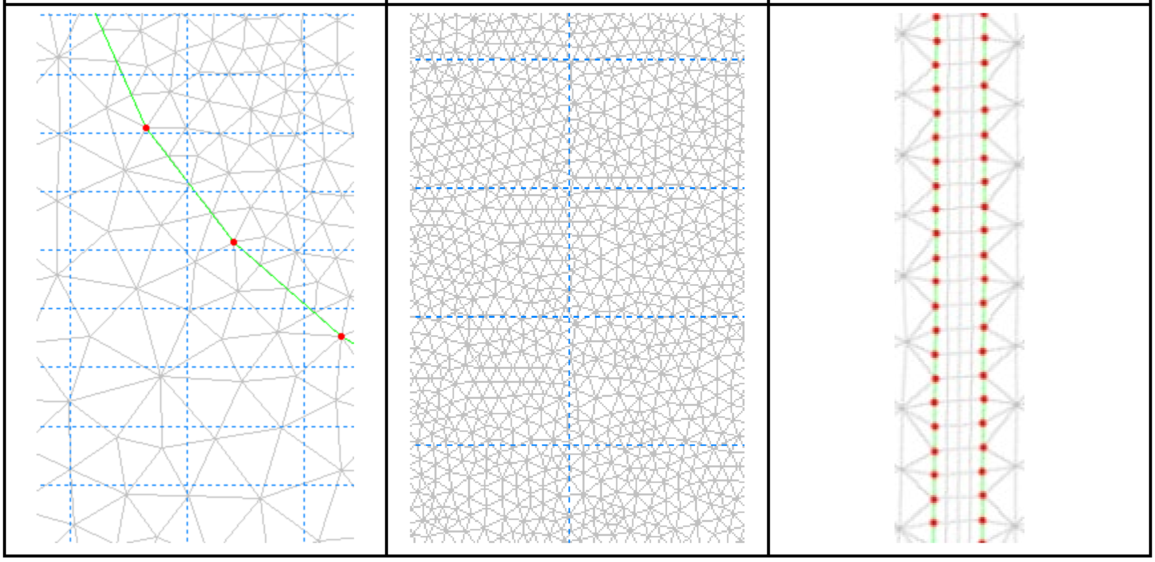
3.3.1 Triangular Mesh

The model domain was divided into areas of different grid resolution as shown in **Figure 3-3**. A triangular mesh was generated between offshore areas up to the Cocker Channel project site with the resolution shown in **Table 3-1**. A quadrangular mesh was generated for the main channel leading into Cockerham Sands and the main creeks flowing into the saltmarsh areas around the project site, including the cut channel, Patty’s Farm creek and the larger creeks within the marsh.

Table 3-1: Mesh Resolution

Mesh Area	Mesh resolution (m^2)	Approx. Max mesh size (m)
Offshore areas	750,000	850
Morecambe Bay	50,000 – 250,000	250 – 500
Mudflat & Marshes	100 – 2,500	10 - 50
Main Channel, Cut Channel and creeks	quadrangular	1.5 x 3

The grid is finest in the area which covers the tidal Cocker Channel to give better definition as this area is of most interest in terms of the hydrodynamic outputs for the restoration investigation. The mesh becomes gradually coarser moving away from the study area to the most offshore areas being the coarsest resolution.



Offshore to Intermediate areas (triangular mesh)	**Intermediate areas** (triangular mesh)	**Cocker Cut Channel** **(**quadrangular mesh)

Figure 3-3: Triangular Mesh Resolution examples

3.3.2 Quadrangular Mesh

Due to the importance of tidal and fluvial flows in the new cut tidal Cocker Channel and the creeks in the adjacent marsh areas, a quadrangular mesh of the cut channel up to the tidal limit and main saltmarsh creek (pre-1960 meandering natural channel **Figure 1-2**) was seamlessly linked into the triangular mesh covering the wider study area. The quadrangular mesh is defined by its mesh size in flow direction as well as in transversal direction to the flow as illustrated in **Figure 3-4**.

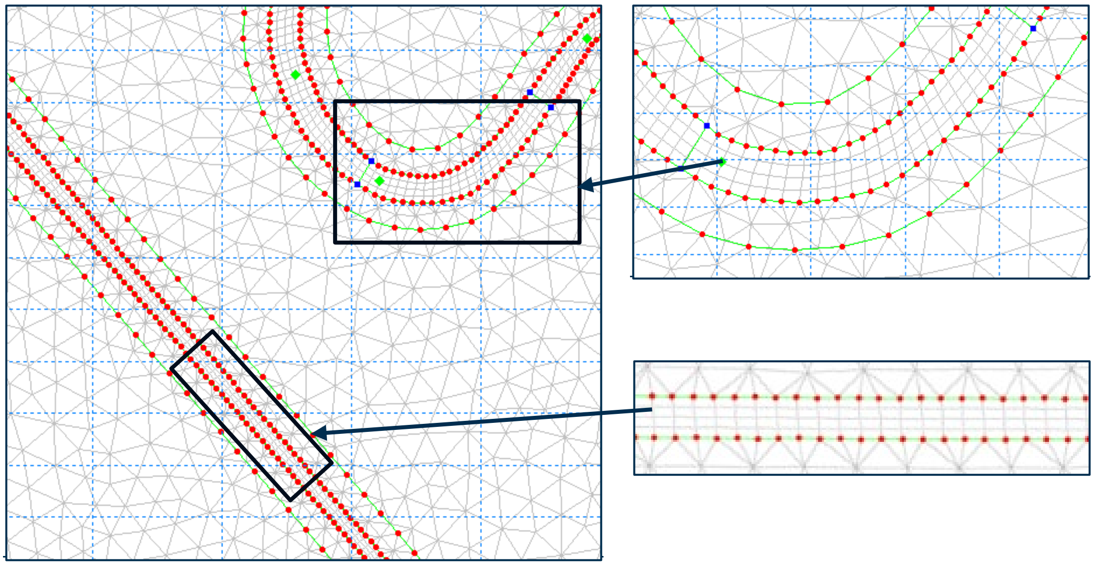


Figure 3-4: Seamless link between triangular and quadrangular mesh of the Cocker Channel

4 Model Verification

This section of the report describes the verification of the MIKE21-HD model used in the study.

4.1 Verification Process

The verification process is required to determine satisfactory performance of the model in respect of hydrodynamic properties. This has been demonstrated by means of comparison of modelled tidal levels at defined stations against predicted astronomical tides and/or measured tidal levels, depending on data availability.

On the open coast, measured tidal data are available from the tide station at Heysham obtained from the BODC. Astronomical tidal predictions were obtained from the UKHO at both Heysham and Fleetwood. Due to this, the process of verification has been to compare the model outputs against measured and/or predicted tidal data from Heysham and Fleetwood for a spring-neap cycle over 14 days in September 2024. This period has been chosen because it coincides with a high equinoctial spring tide.

If the hydrodynamic performance of the model appeared broadly satisfactory, then the set-up would be used as the basis of the model runs in the study. It is important to recognise that any model is an artificial and simplified representation of reality, and in the context of this study, the important aspect is to assess the *relative* change between a baseline condition and a 'with scheme' scenario.

4.2 Verification Runs

The verification runs were undertaken for a period of 13th to 29th September 2024. Data were extracted from the model for the stations of Heysham and Fleetwood and compared against the measured and astronomical predictions from these stations for the same time period.

Output plots shown in **Figure 4-1** for Heysham and **Figure 4-2** for Fleetwood show that the model is simulating astronomical water levels well in September 2024, with good correlation of phasing and amplitude of tidal effect.

There is a slight under-prediction in amplitude of low and high water levels at Fleetwood compared against astronomical predictions, but what is more noticeable is that the measured water levels (where available) differ from both the astronomical predictions and the modelled results, on some occasions by up to around 0.4m, most notably during neap tides, around the 13th and 14th September 2024 and around the 25th and 26th September 2024. This is assumed to have been caused by meteorological surge effects which elevate (or sometimes depress) the measured water level from both the predicted astronomical level and the modelled astronomical level.

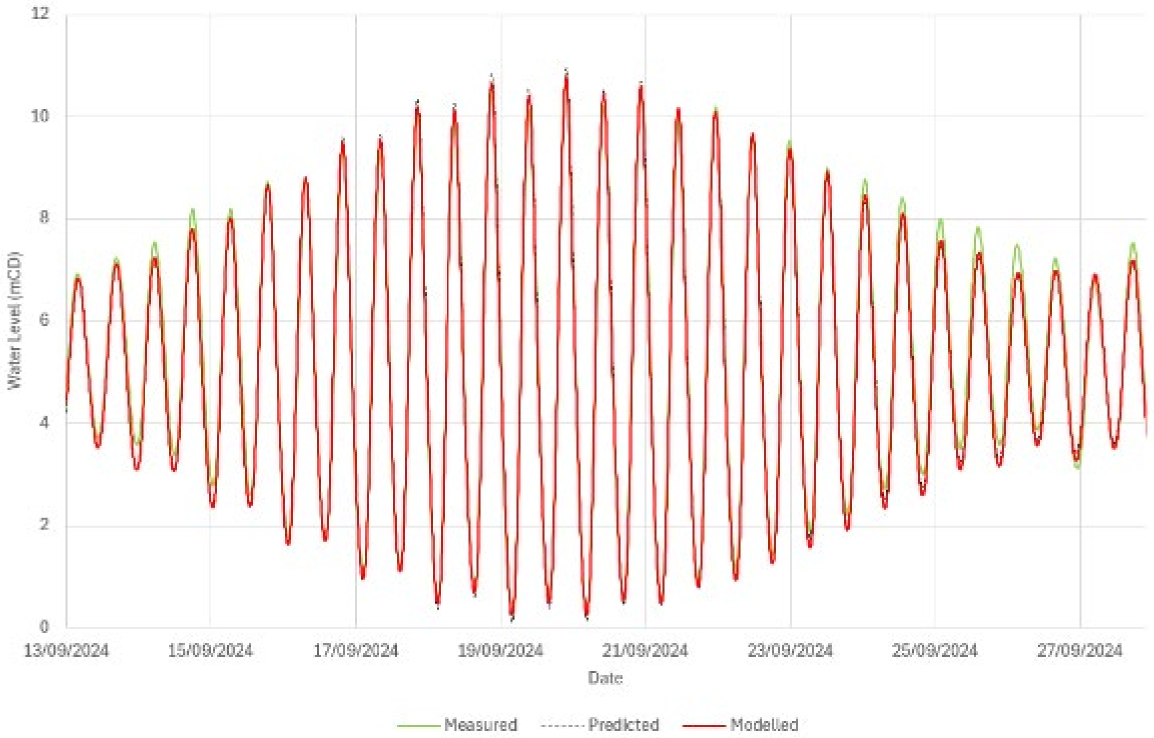


Figure 4-1 Predicted astronomical tide, measured tide and modelled tide at Heysham for Baseline (B) (September 2024)

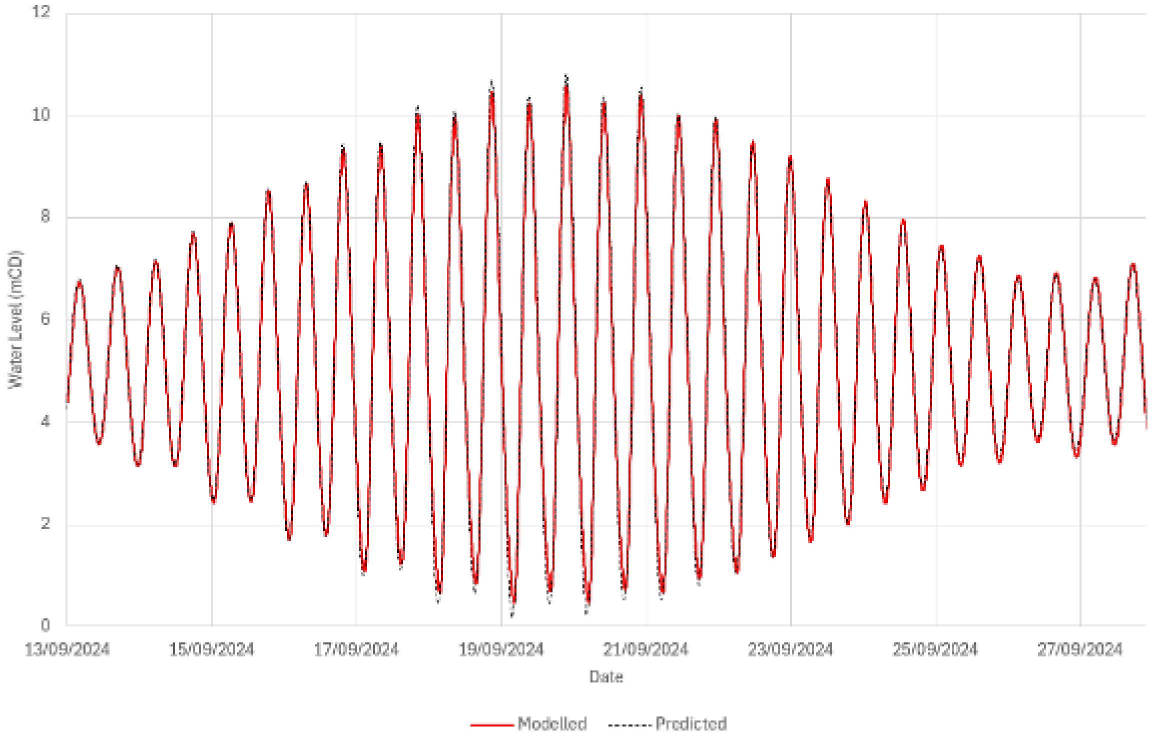


Figure 4-2 Predicted astronomical tide and modelled tide at Fleetwood for Baseline (B) (September 2024)

Table 4-1 shows the statistical parameters used to quantify the model accuracy in water level for the calibration period, namely mean error, root mean square error, standard deviation of residuals and coefficient of determination. The statistical analysis has been carried out by comparing the predicted (or measured) with the modelled water level and the results show that the model achieves a good performance. The RMSE error is 3 - 4% of the observed mean tidal range.

Table 4-1 Model errors in water level for the calibration period

	Mean Error	**Root Mean Square Error (RMSE)**		**Standard deviation of residuals**	**Coefficient of Determination**
Name of station	**ME (m)**	**m**	**%**	**Std (m)**	**R**
Heysham (predicted tides)	0.0581	0.1676	3%	0.1572	0.9963
Heysham (measured tides)	0.1501	0.2561	4%	0.2075	0.9934
Fleetwood (predicted tides)	0.0326	0.188	3%	0.1852	0.9957

Note: *ME: Mean Error; RMSE: Root Mean Square Error; Std: Std. dev of Residuals; R: Coefficient of Determination*

The good overall performance of the model gives confidence to proceed with this model setup for the main model runs for the study.

4.3 Verification Summary

The verification testing has demonstrated the numerical model to be working well in simulating the phasing of tidal effects along the open coast and across Cockerham Sands. The amplitude of high water levels is simulated well, noting that meteorological effects can elevate (or depress) astronomical tides.

5 Model Runs

Section 5.1 gives an introduction to the model simulations that have been performed. Sections 5.2 to Section 5.6 describe each simulation in more detail and present their key findings.

5.1 Introduction

The model was run over a full (14-day) spring-neap cycle in September 2024 for the following scenarios:

- **'Baseline'** (Baseline) – This scenario represents the existing (present day) hydrodynamic conditions, and these have been simulated using the most recently available offshore bathymetry, channel long-section, intertidal topography, and land topography (see **Figure 5-1**). This scenario includes no flow input from the River Cocker.
- **'Baseline Sensitivity' Test 1** (BS1) – As above, but with a constant flow input of 1.3 m^3/s from the River Cocker.
- **'Baseline Sensitivity' Test 2** (BS2) – As above, but with a constant 'high' flow input of 5.0 m^3/s from the River Cocker.
- **'Historic Baseline'** (Historic) – This scenario represents reinstatement of most of the tidal Cocker Channel (except for the most upstream section towards Cocker Bridge which originally flowed south of the current 'new' cut, before heading back north across Cockerham Sands) and infill of the 'new' cut channel tidal Cocker Channel (see **Figure 5-2**) It also broadly represents the 'Tidal Cocker Channel – Option 5 (Full Reinstatement of Original Tidal Cocker Channel and Infill of New Cut)', although this is not considered further as an option within this investigation.
- **'Tidal Cocker Channel – Option 4'** (TCC-4) – This scenario represents reinstatement of most of the tidal Cocker Channel (except for the most upstream section towards Cocker Bridge which originally flowed south of the current 'new' cut, before heading back north across Cockerham Sands) (see **Figure 5-3**).
- **'Cockerham Marsh SSSI – Option 2b'** (SSSI-2b) – This scenario represents a 40m wide breach made in the flood embankment which currently protects Cockerham Marsh against tidal inundation (see **Figure 5-4**).

All model runs cover the same full 14-day spring-neap tidal cycle (incorporating 28 high tides and 28 low tides). This enables the modelled differences between the baselines and the options to be determined over a common time period and range of tidal conditions.

For the purposes of optioneering, the option runs have incorporated a 'typical' river flow through the tidal gates at Cocker Bridge (constant flow input of 1.3 m^3/s) and results have been compared against baseline sensitivity test 1 ('BS1'), which incorporates identical river flow input conditions from the River Cocker.

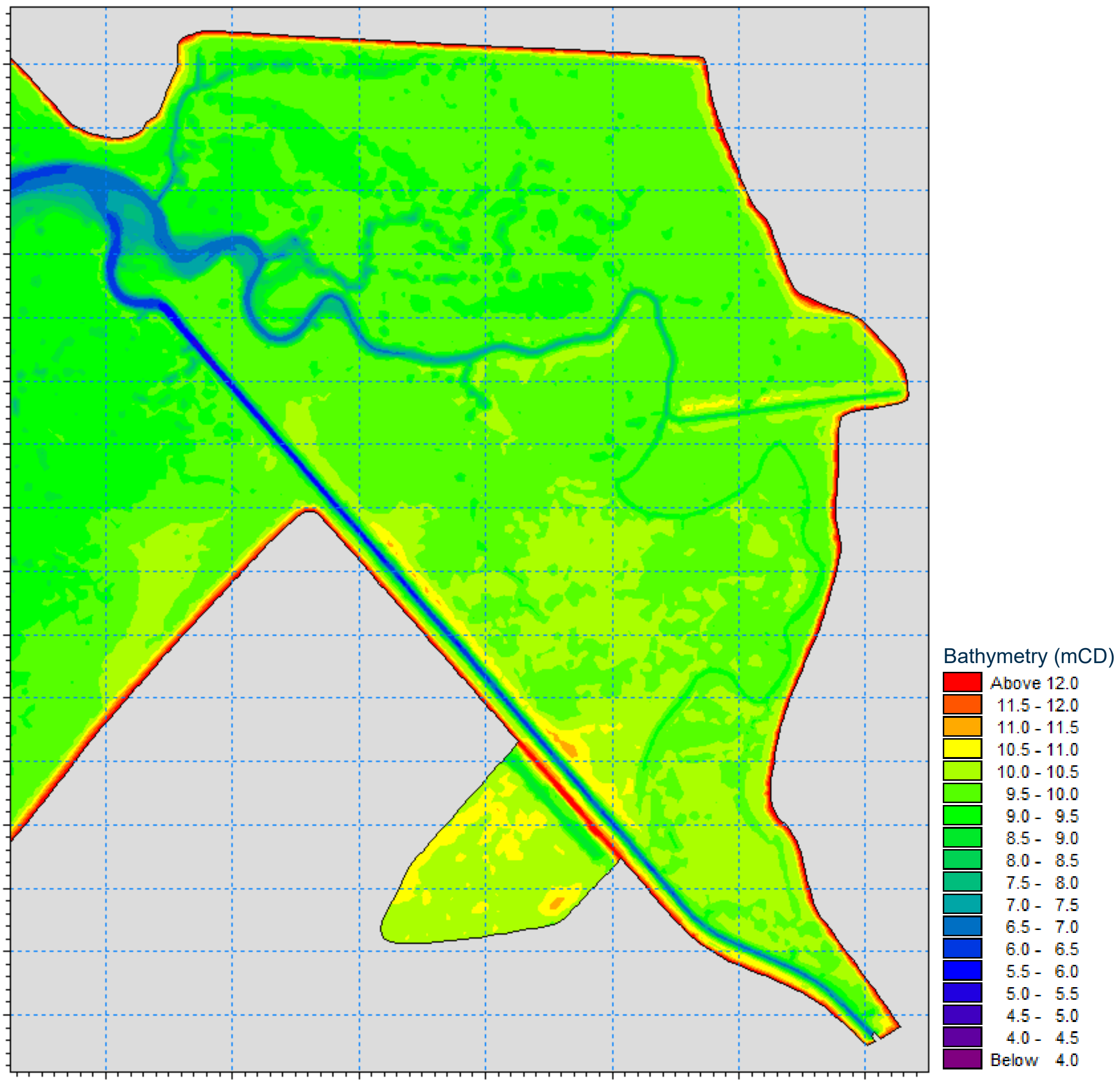


Figure 5-1 'Baseline' model bathymetry

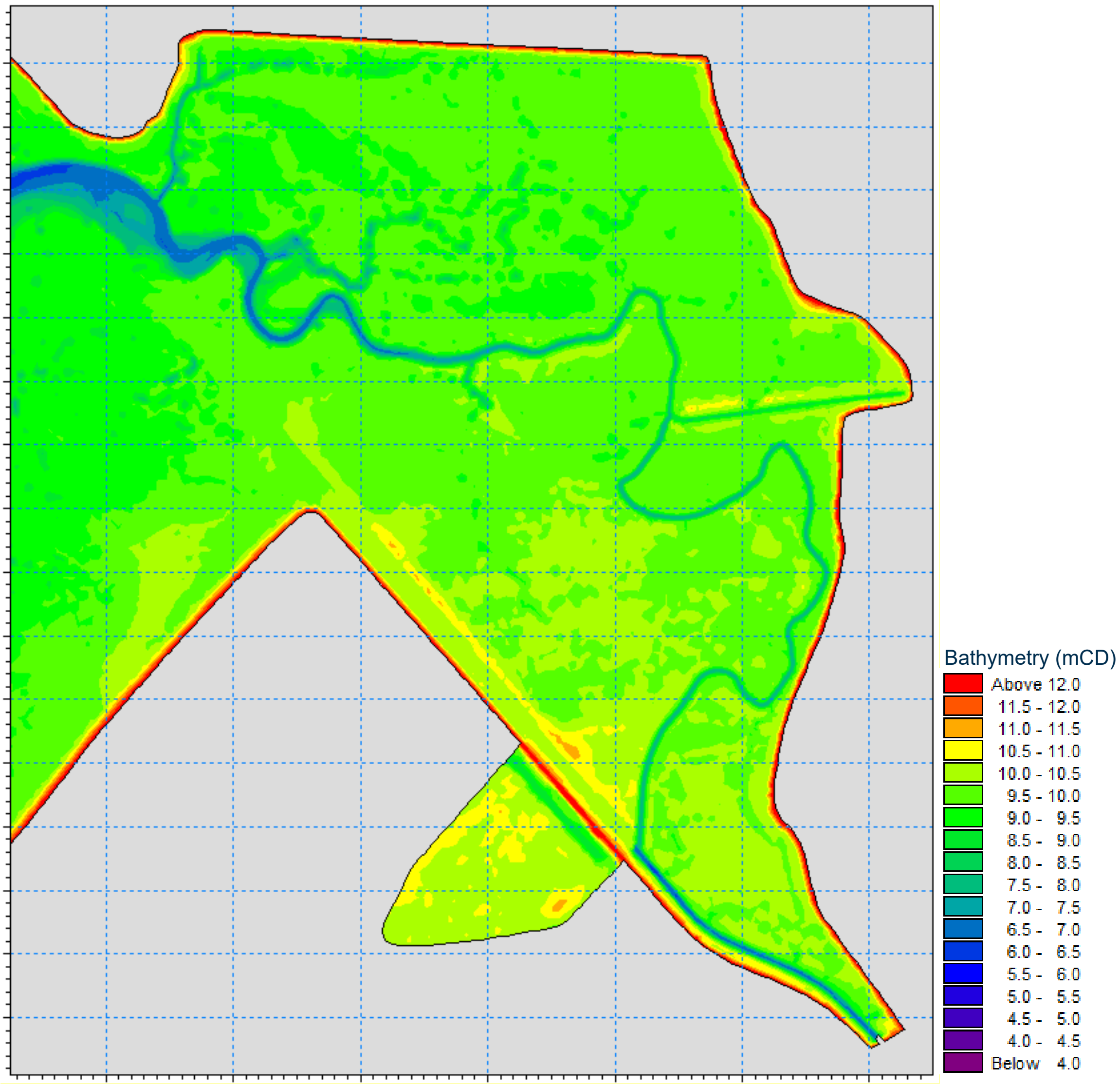


Figure 5-2 'Historic Baseline' - model bathymetry

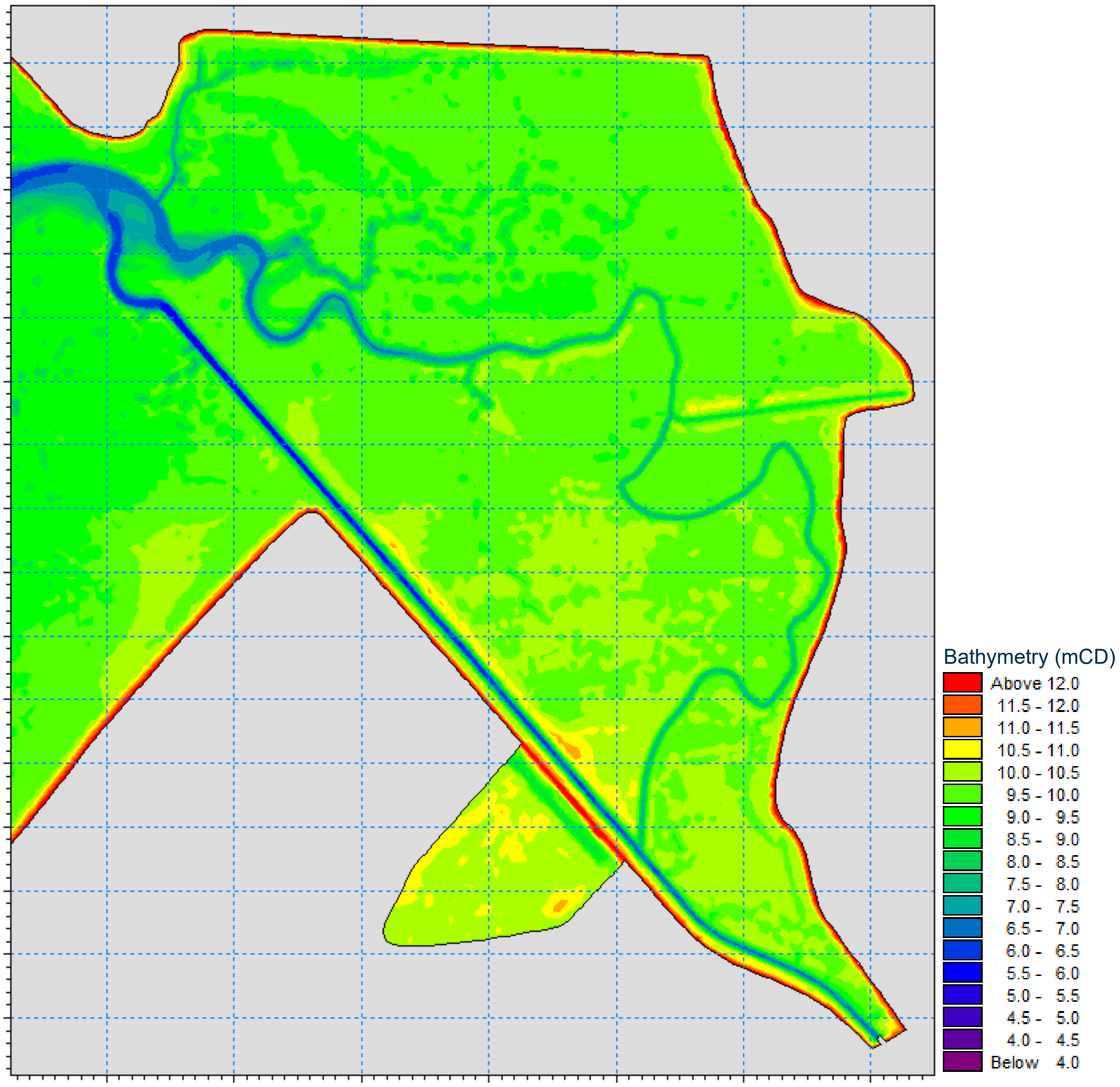


Figure 5-3 'Tidal Cocker Channel - Option 4' model bathymetry

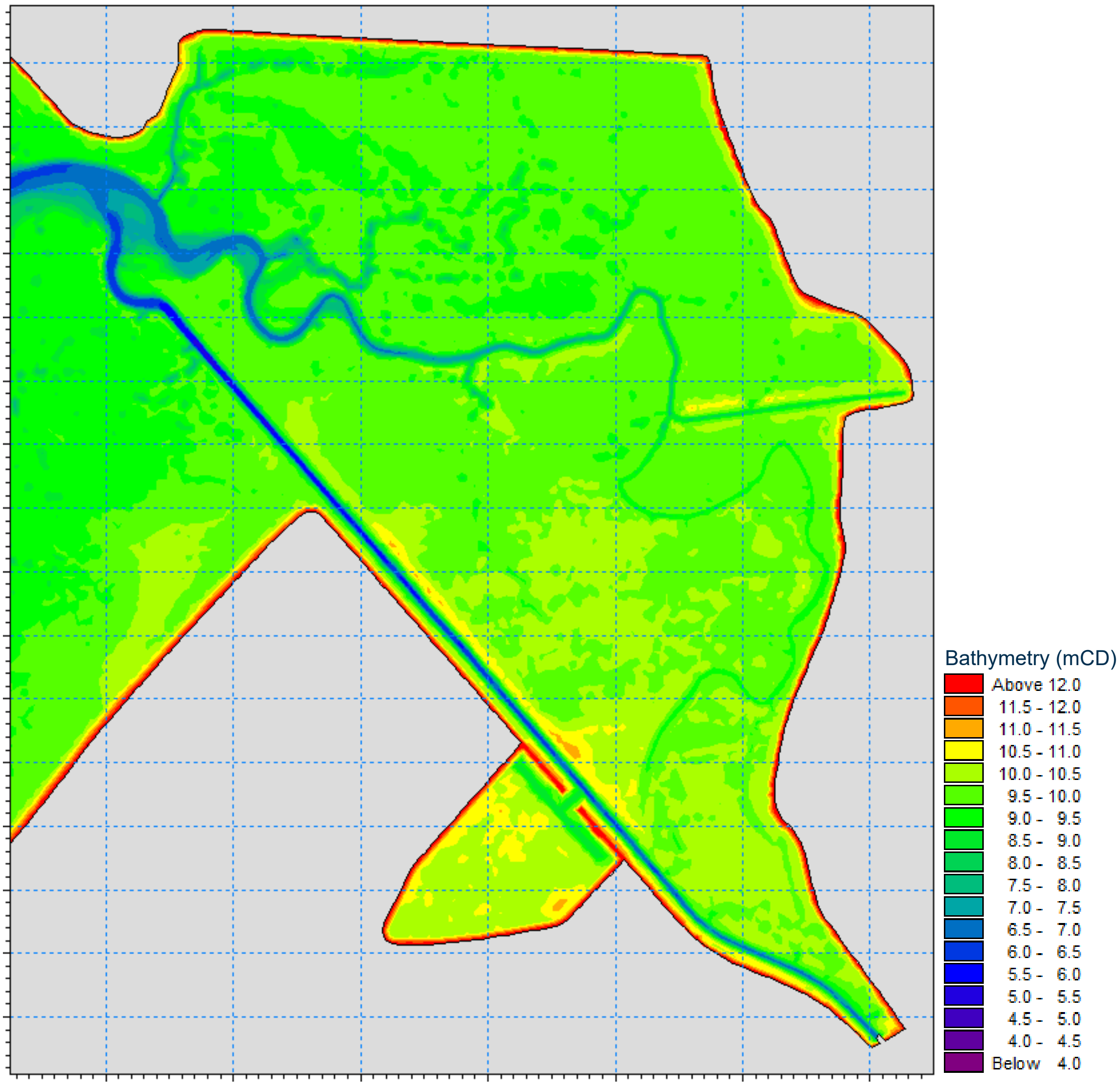


Figure 5-4 'Cockerham Marsh SSSI - Option 2b' model bathymetry

5.2 ‘Baseline’

5.2.1 ‘Baseline’ Description

The ‘Baseline’ can be described as follows:

- The baseline model run covers a full 14-day spring-neap tidal cycle (incorporating 28 high tides and 28 low tides) covering the autumn equinox in September 2024.

- The baseline scenario includes no river flow input through tidal gates from the River Cocker (although this has been considered during subsequent sensitivity testing – see section 5.3).

- The plots below show attained **water level** in metres above Chart Datum (m CD) at various stages through the spring-neap tidal cycle. Each plot is accompanied by a time series graph of water levels through the model run (determined at a point within the confluence of Patty’s Farm Creek and the tidal Cocker Channel – see red dot in **Figure 5-5**), with a vertical bar showing the specific timestep within the spring-neap cycle to which the model output plot relates. [Note: An animation of the changing water levels through the whole simulation period was also produced to aid interpretation.]

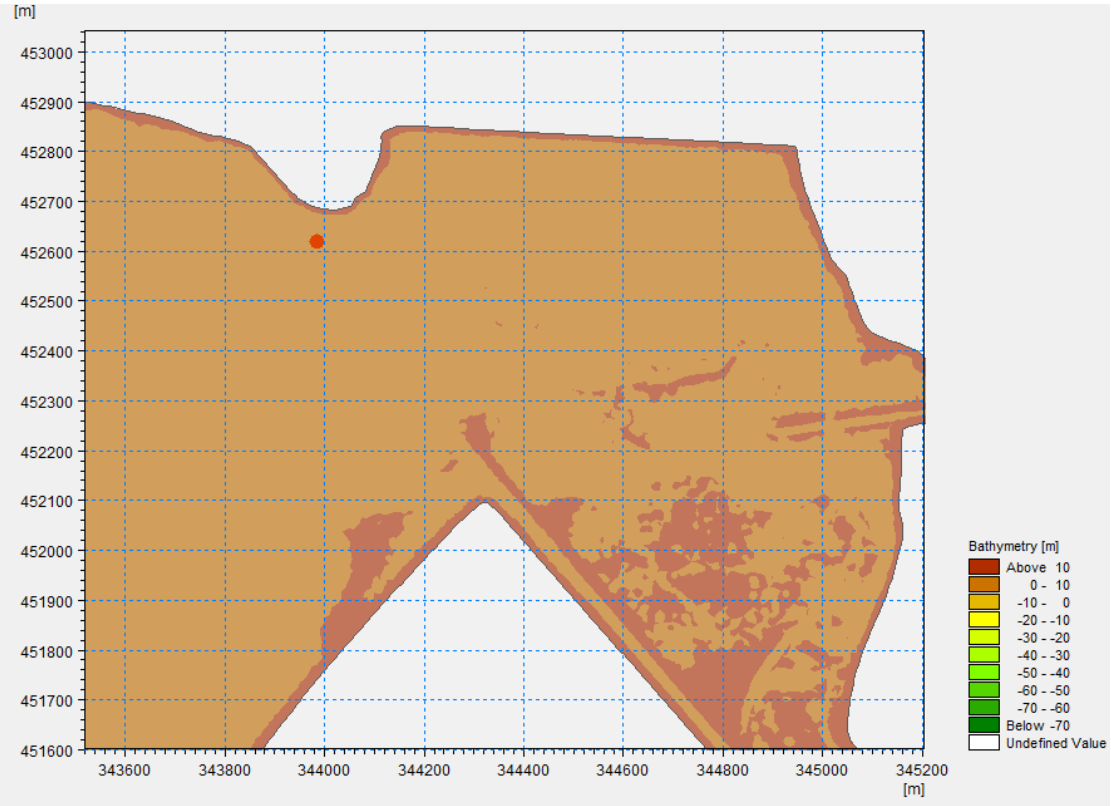


Figure 5-5 Model extraction point (red dot) at the confluence of Patty’s Farm Creek and the tidal Cocker Channel

For context, at nearby Heysham key tidal parameters are shown in **Table 5-1**.

Table 5-1 Tidal parameters at Heysham

Tidal Parameter	**Tidal Level at Heysham**	
	Metres above Ordnance Datum (mOD)	**Metres above Chart Datum (mCD)**
Highest Astronomical Tide (HAT)	5.9	10.8
Mean High Water Springs (MHWS)	4.7	9.6
Mean High Water Neaps (MHWN)	2.5	7.4
Mean Low Water Neaps (MLWN)	-1.8	3.1
Mean Low Water Springs (MLWS)	-3.7	1.2
Lowest Astronomical Tide (HAT)	-4.7	0.2

The simulation commences at low water during the lowest neap tide (starting on 13th September 2024) and runs through to high water on the highest spring tides (peaking on 20th September 2024) before returning to low water during the lowest subsequent neap tides (27th September 2024).

5.2.2 ‘Baseline’ Key Findings

This section describes the key findings of the ‘Baseline’ simulation.

- At high tide 1 (**Figure 5-6**) on the lowest neap at the start of the run, the tide propagates up the Outer Cocker Channel as far as Bank End, but does not spill out across the surrounding inter-tidal areas, nor does it propagate further east onto Cockerham Sands channels and saltmarshes. The tide ebbs during the subsequent low tide, although some water is retained within the main channels.

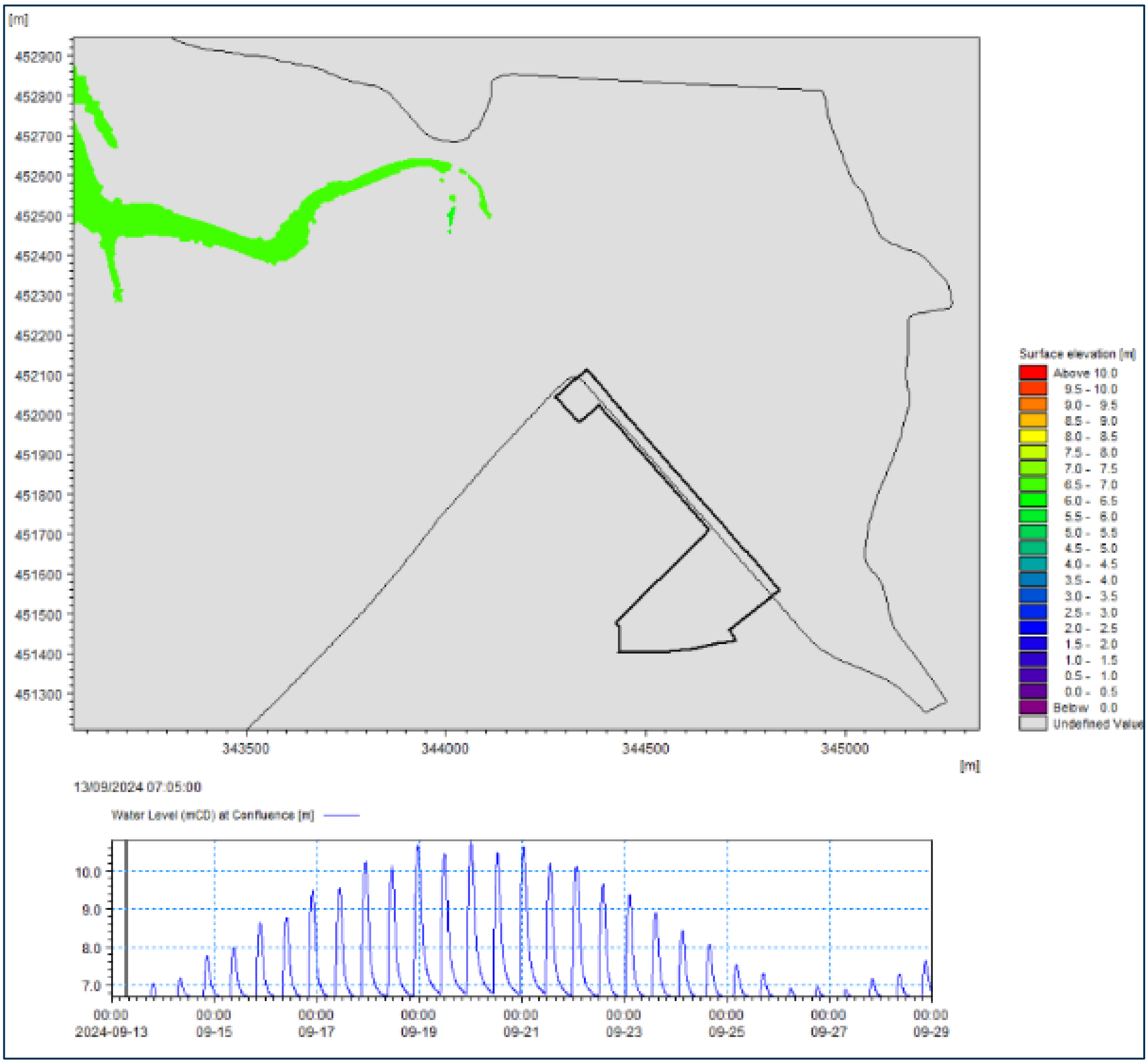


Figure 5-6 Baseline: High water elevation (in metres CD) at high tide 1

- Just after high tide 2 (**Figure 5-7**), the tide propagates further up the ‘new’ cut tidal Cocker Channel, but still the extent of flooding across the surrounding creeks and saltmarshes is limited before the tide ebbs.

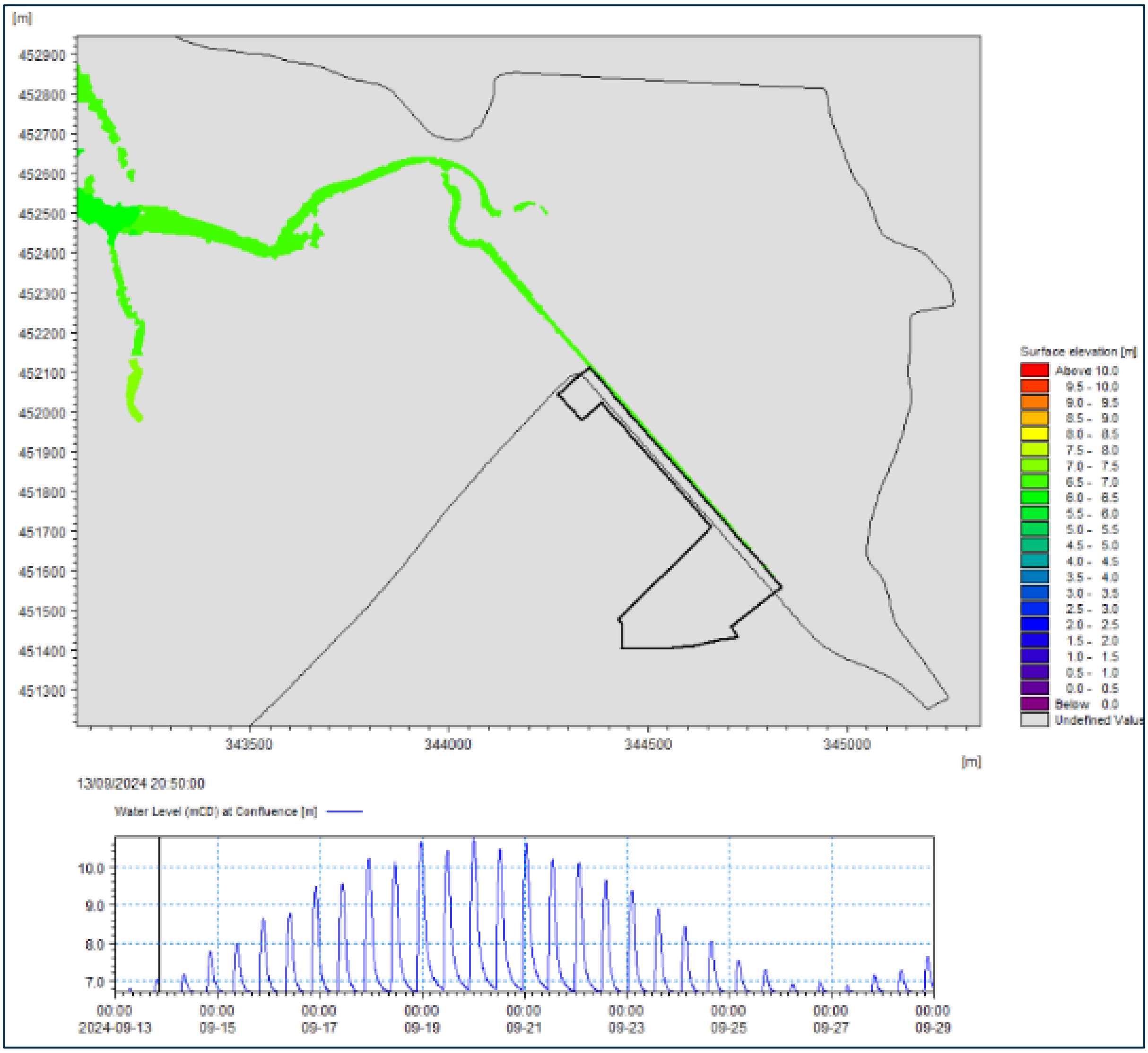


Figure 5-7 Baseline: High water elevation (in metres CD) just after high tide 2

- As would be expected, subsequent high tides progressively increase in attained water level. Initially, the propagation remains largely within the main channels (extending as far upstream within the 'new' cut tidal Cocker Channel as the tidal gates by high tide 4), with the water depths within the channels increasing over successive high tides. (see **Figure 5-8**)

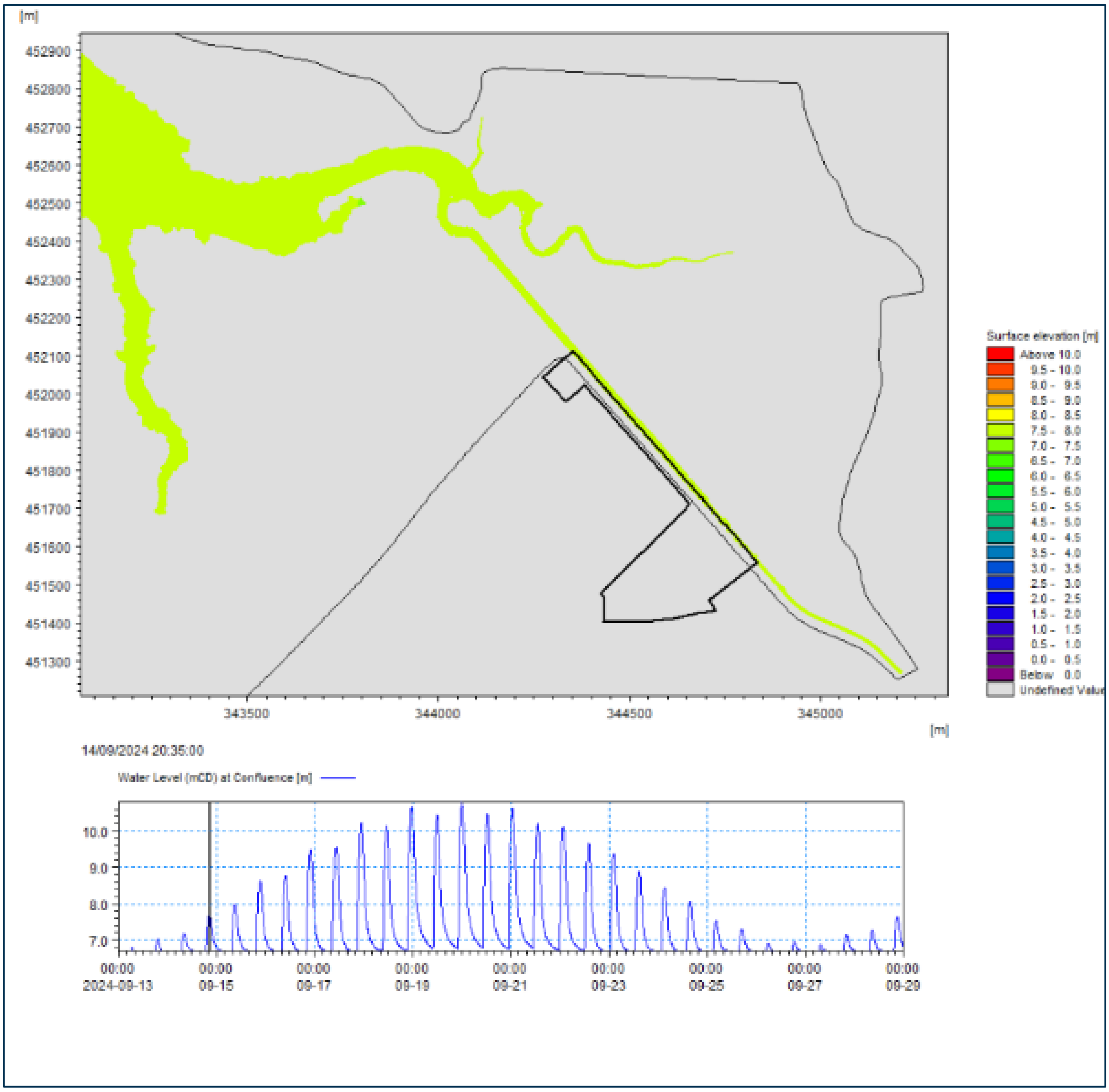


Figure 5-8 Baseline: High water elevation (in metres CD) just after high tide 4

- The outer intertidal areas of Cockerham Sands (i.e. those on the ‘open’ shore adjacent to the Pilling-Cockerham embankment) become progressively inundated such that the mudflat is totally submerged by the time of high tide 8 (**Figure 5-9**). However, the saltmarsh at this location as well as the saltmarsh within the more embayed shore between Bank End Farm and the ‘new’ cut tidal Cocker Channel remains unaffected by tidal processes at this point on the tidal cycle mid-way between lowest neaps and highest springs.

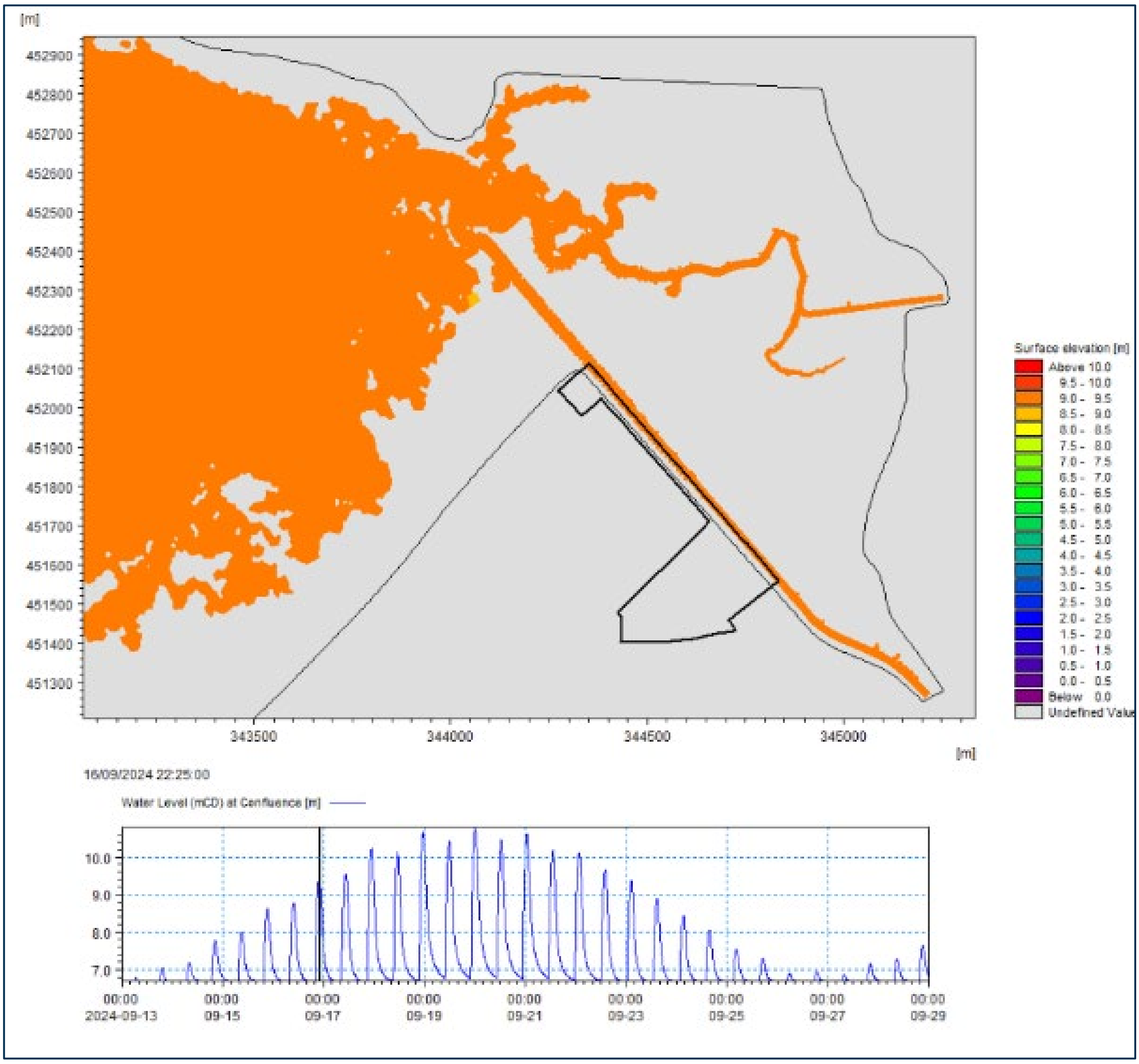


Figure 5-9 Baseline: High water elevation (in metres CD) just after high tide 8

- By the time of high tide 10 (**Figure 5-10**), the saltmarsh along the open shore fronting the Pilling-Cockerham embankment has become submerged at high tide and the tide propagates further inland along the channels and creeks within the embayed section of shore (although much of the saltmarsh here remains uncovered by the tide). Note how tidal flooding of the saltmarsh in the vicinity of Cocker Bridge (the bottom-right of the plot) occurs via tidal propagation up the 'new' cut Cocker Channel, rather than via the original meandering natural Cocker Channel.

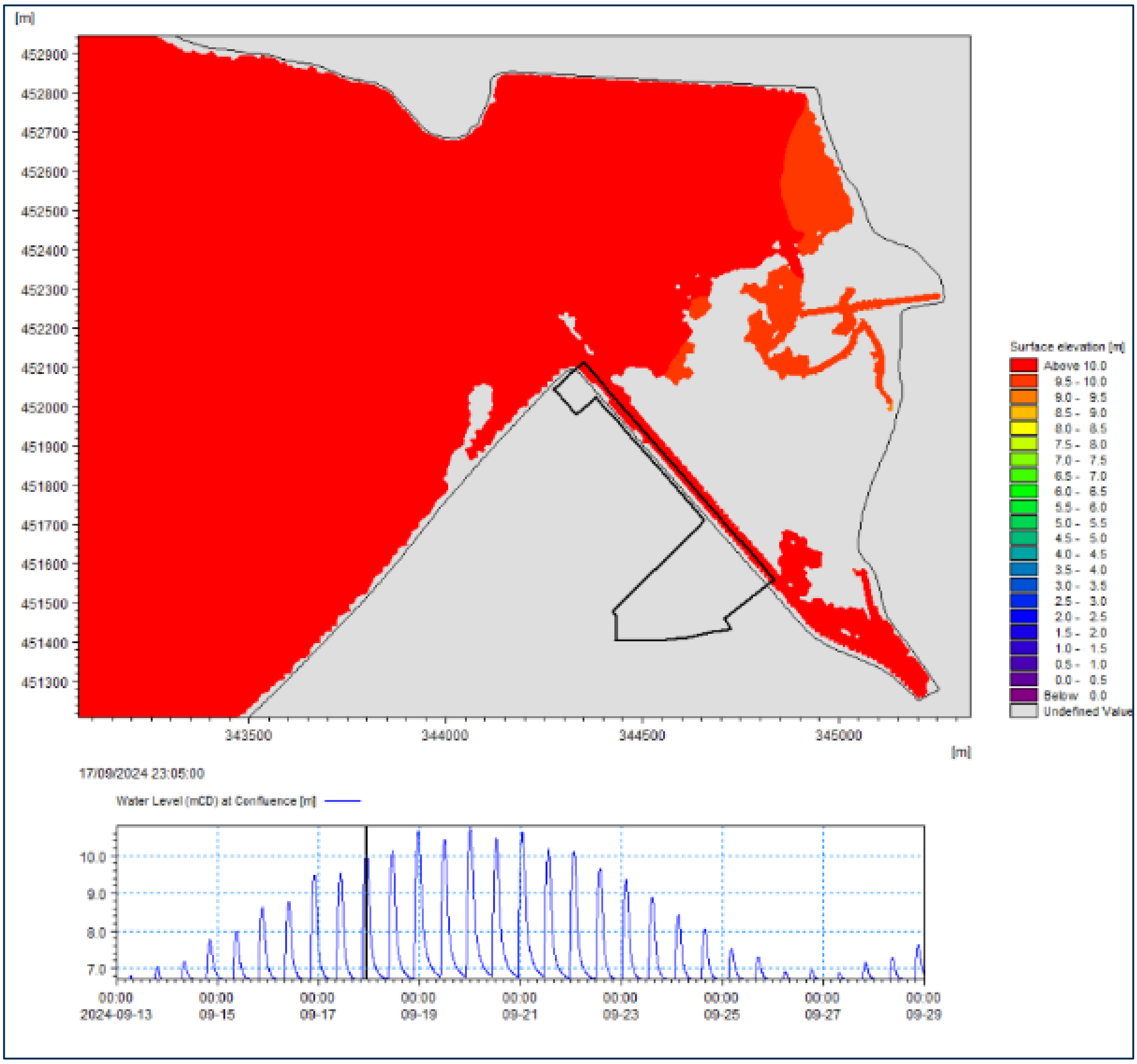


Figure 5-10 Baseline: High water elevation (in metres CD) just after high tide 10

- The saltmarsh within the embayed section of shore first becomes (predominantly) submerged during high tide 12 (**Figure 5-11**). The only exception is a small triangular shaped parcel of land immediately adjacent to Cockerham Marsh SSSI which remains uncovered. When viewing the topography of this area using LiDAR data, it is apparent that this represents a local high spot on the marsh surface (**Figure 5-12**).

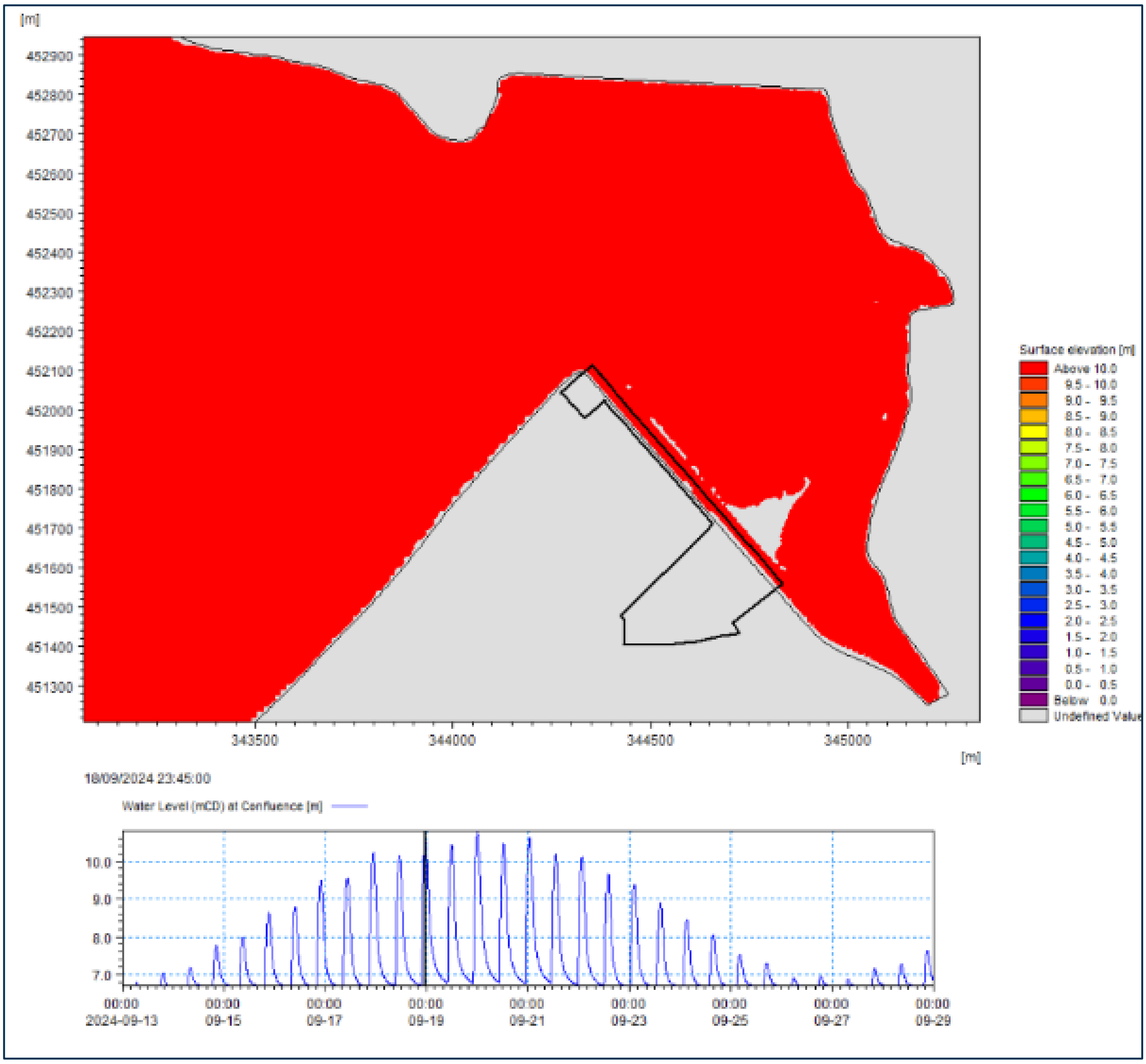


Figure 5-11 Baseline: High water elevation (in metres CD) just after high tide 12

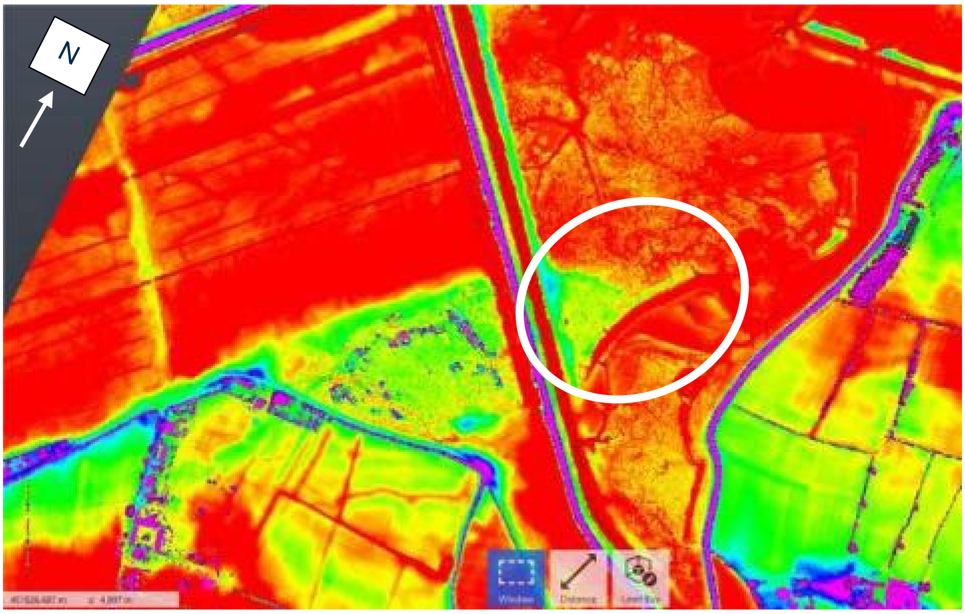


Figure 5-12 Local ‘triangular-shaped’ high spot in marsh surface opposite Cockerham Marsh SSSI

- At the subsequent low water (low water 13, **Figure 5-13**), some tidal water remains on the saltmarsh surface and within the creeks, although this is partly a modelling artefact (the dendritic network of creeks across the marsh surface is not wholly accurately depicted in the model domain).

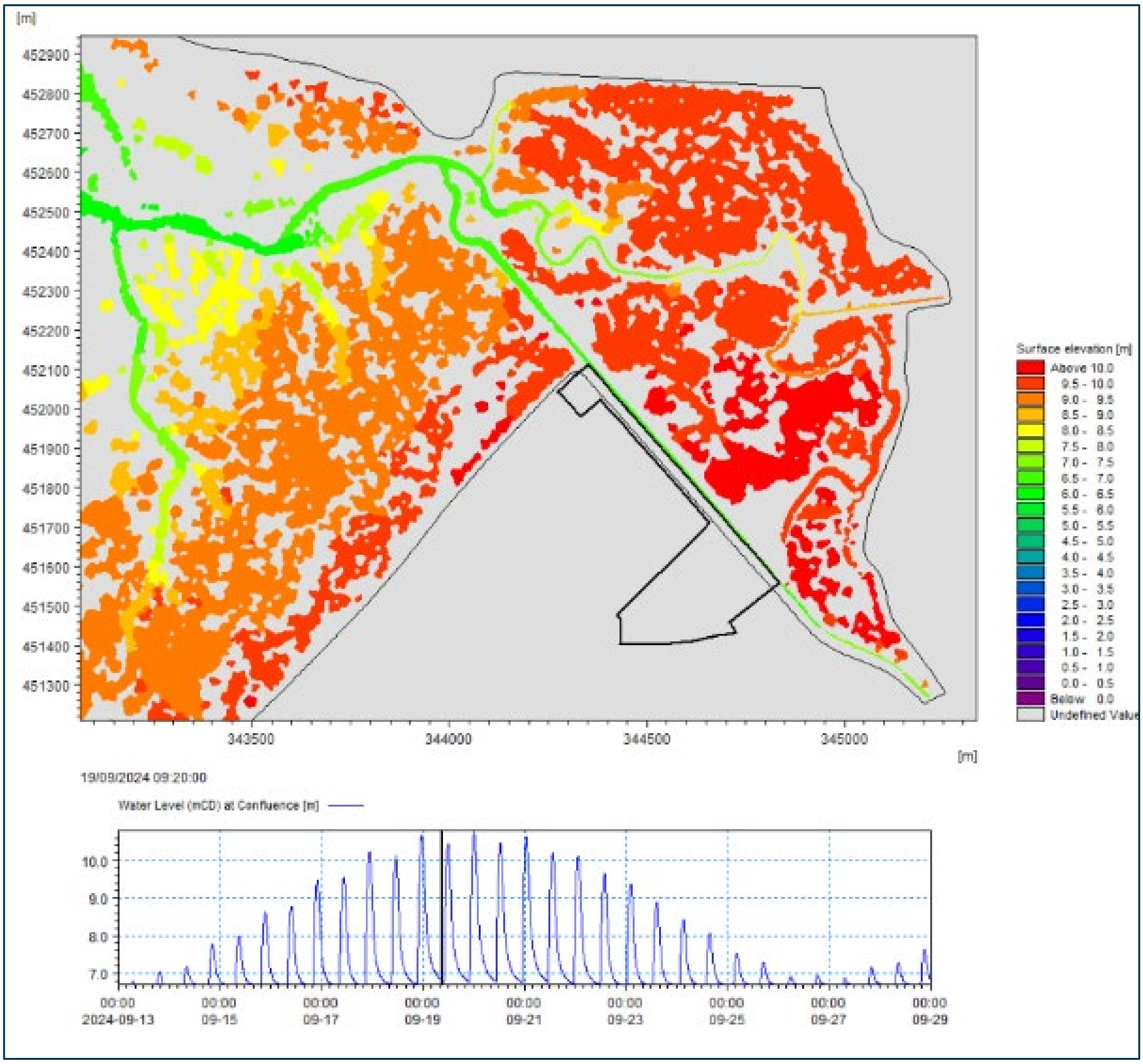


Figure 5-13 Baseline: Low water elevation (in metres CD) at low tide 13

- The highest water levels occur during high tide 14 (**Figure 5-14**). At this time virtually all of the saltmarsh is covered by the high tide, including almost all areas immediately adjacent to Cockerham Marsh SSSI.

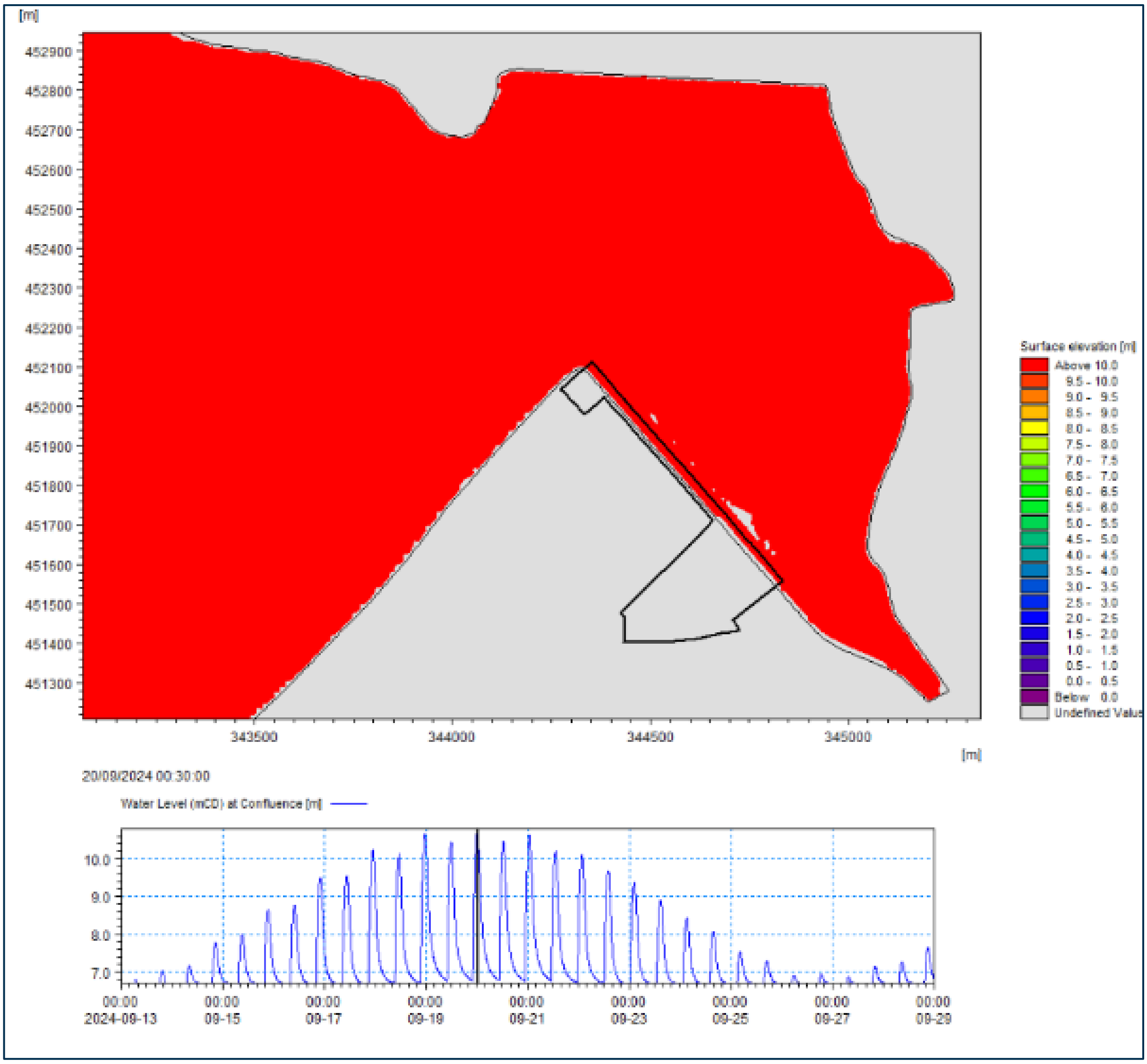


Figure 5-14 Baseline: High water elevation (in metres CD) just after high tide 14

- The small triangular shaped parcel of land immediately adjacent to Cockerham Marsh SSSI becomes covered by tidal waters during this highest spring tide. A timeseries of water level at a point within the centre of this land parcel has been extracted from the model outputs (**Figure 5-15**). This shows the land parcel remains uncovered for most of the simulation period, with only a short period where the very highest spring tide inundates it (**Figure 5-16**). This may, subject to further investigation, may make this land parcel suitable for digging ponds or pools that could potentially become utilised by Natterjack toads. This is discussed further in the Task 2a Optioneering report.

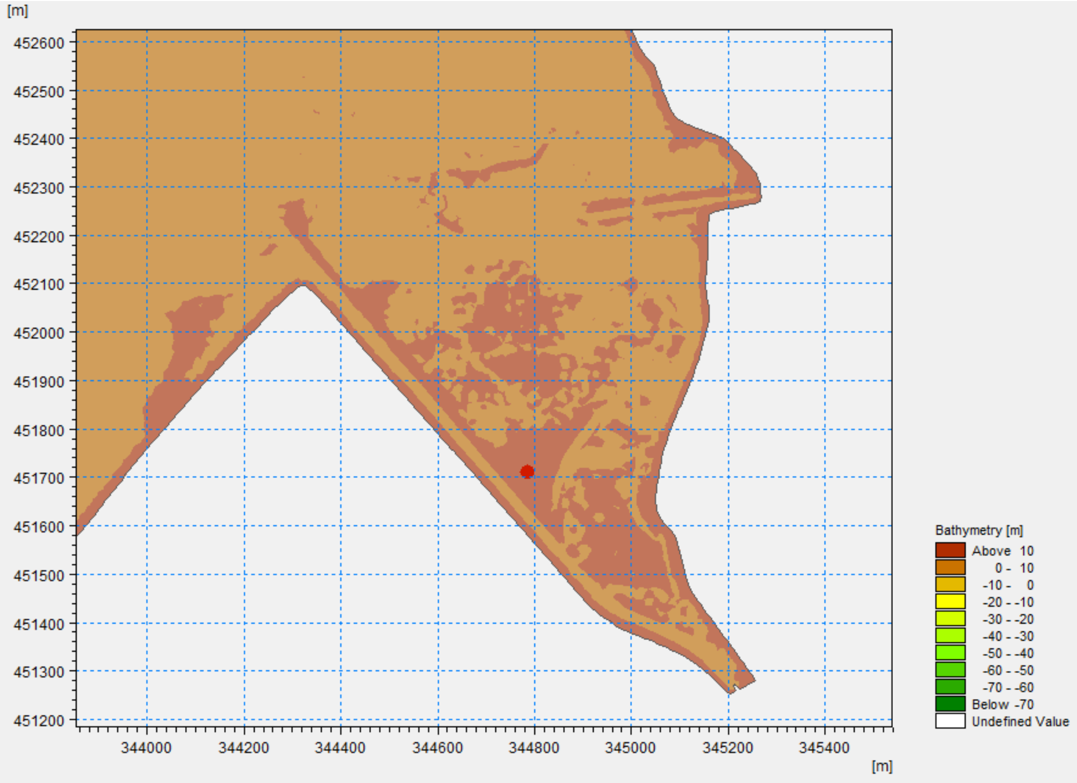


Figure 5-15 Model extraction point (red dot) at the small triangular shaped parcel of land immediately adjacent to Cockerham Marsh

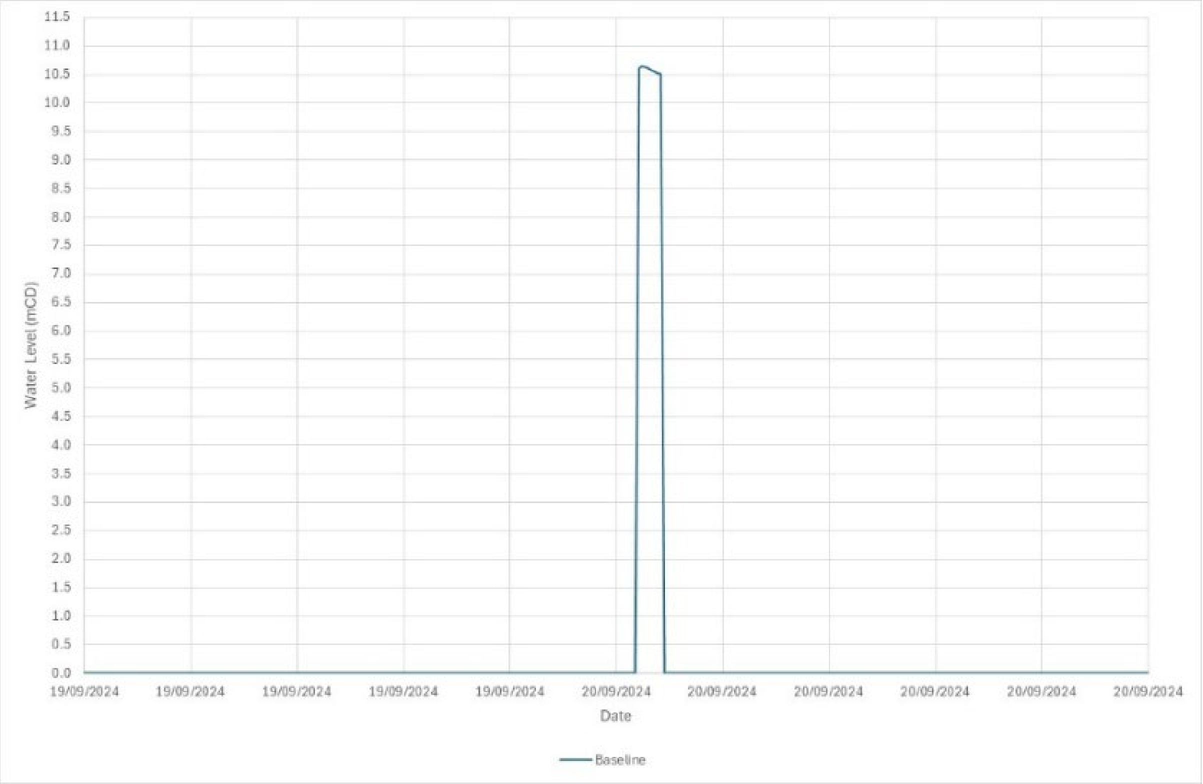


Figure 5-16 Timeseries of water level at the small triangular shaped parcel of land immediately adjacent to Cockerham Marsh

- Following this highest of high water levels during the peak of spring tides, the general patterns described on the ‘climbing’ segment of the neap-spring curve are reversed during the ‘descending’ segment of the spring-neap curve.

- The plots below show current velocities in metres per second (m/s) at the time of peak flood and peak ebb on a spring tide. Each plot is accompanied by a time series graph of water levels through the model run, with a vertical bar showing the specific timestep within the spring-neap cycle to which the model output plot relates. [Note: An animation of the changing current velocities through the whole simulation period was also produced to aid interpretation].

- The peak current velocities occur during the highest spring tide, on the flooding phase before high tide 14 (**Figure 5-17**) and the ebbing phase after high tide 14 (**Figure 5-18**). Within the main channel, these can exceed 1m/s (which has the potential to erode and transport muds) thus contributing to changes in channel alignment.

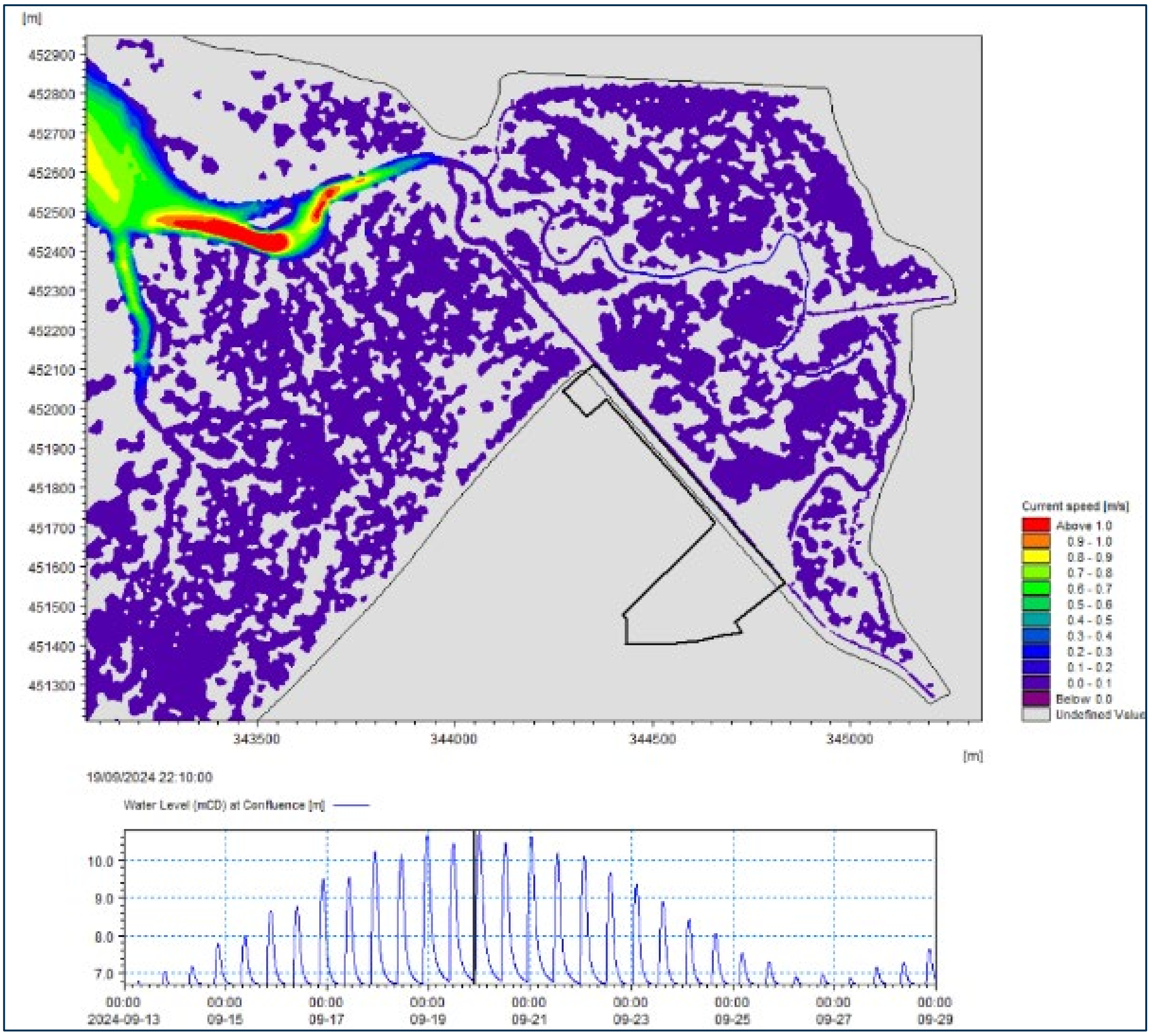


Figure 5-17 Baseline: Peak flood current velocities (in m/s) in the vicinity of Bank End Farm before high tide 14

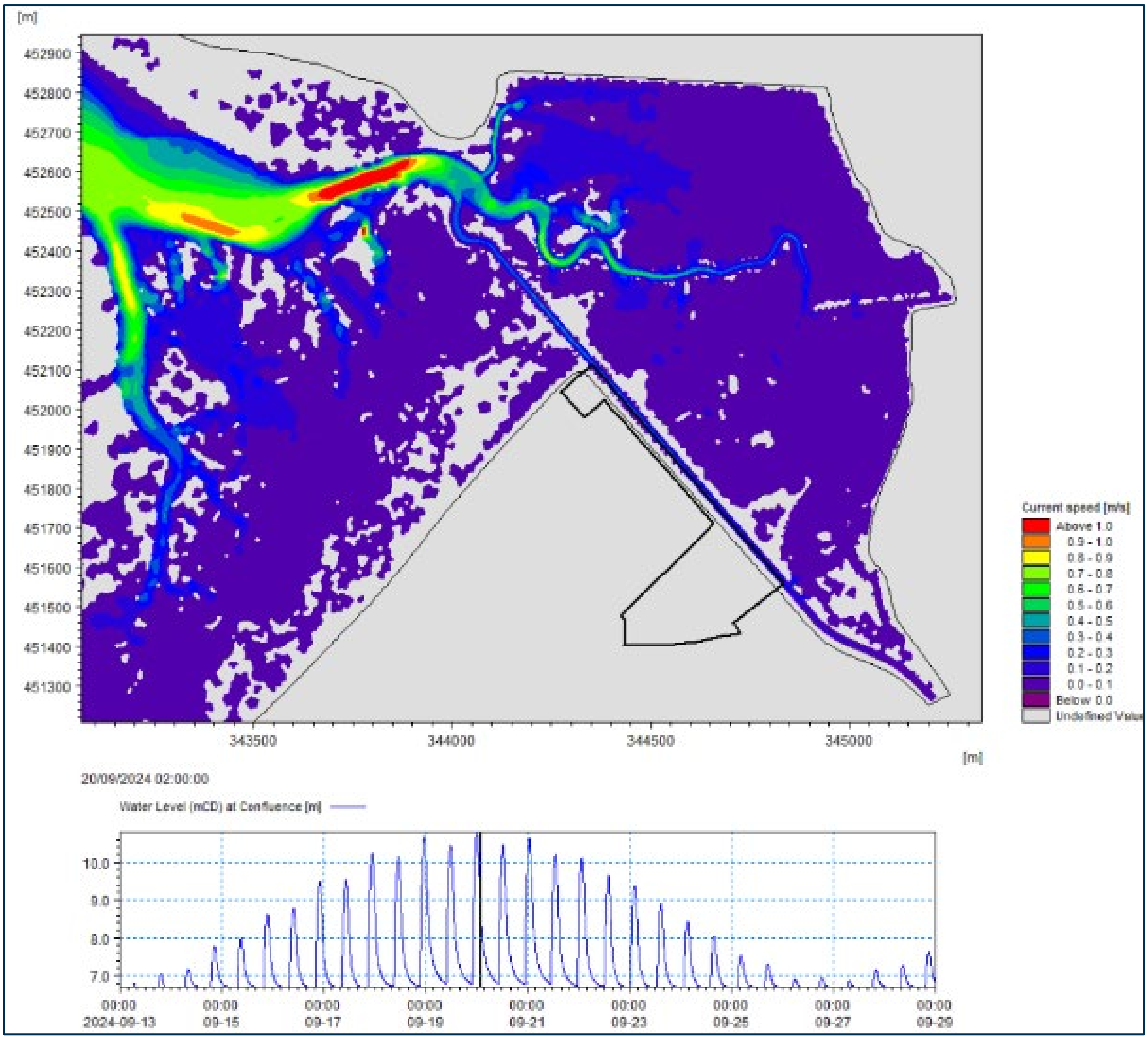


Figure 5-18 Baseline: Peak ebb current velocities (in m/s) in the vicinity of Bank End Farm after high tide 14

- There are times in the tidal cycle when peak currents occur on the flooding tide and other times when they occur on the ebbing tide; however the ebb phase of the tide is longer in duration than the flooding phase (Figure 5-19).

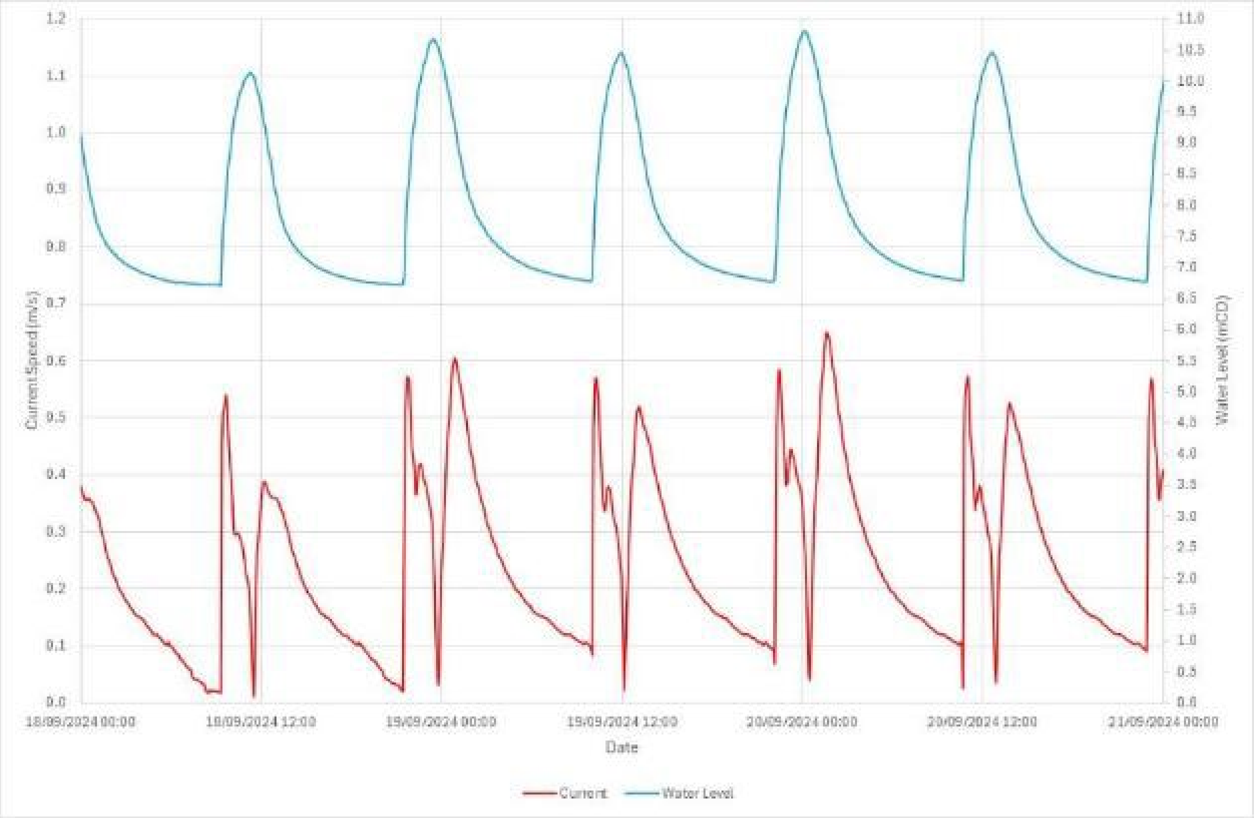


Figure 5-19 Current speed and water level over several flood – ebb phases

5.2.3 ‘Baseline’ Summary

This section summarises the ‘Baseline’ simulation.

- Model results for the baseline option (which includes no flow from the River Cocker) shows that the flooding neap tides propagate up the Outer Cocker Channel and ‘new’ cut tidal Cocker Channel, but do not spill out of these channels across the surrounding inter-tidal areas. After each successive neap high water, the tide ebbs away with some water remaining within the channels.

- Over successive tides, high tides progressively increase in attained water level. Initially, the propagation remains largely within the main channels (extending as far upstream within the ‘new’ cut tidal Cocker Channel as the tidal gates), with the water depths within the channels increasing over successive high tides and areas of Cockerham Sands (seaward of the Pilling-Cockerham embankment) becoming progressively submerged at high water by mid-way between the lowest neap tides and the highest spring tides.

- During higher spring tides, much of Cockerham Sands (seaward of the Pilling-Cockerham embankment) are fully inundated at high water, but large areas of saltmarsh seaward of the Cocker Bridge to Patty’s Farm embankment remain dry until the very highest spring tides.

- There is one particularly notable triangular-shaped area of higher elevation saltmarsh immediately seaward of Cockerham Marsh SSSI which remains dry in all but the single highest spring tide, whereas all other areas of marsh become submerged.

- The above processes are reversed as the tidal cycle moves from peak spring tides back towards neap tides over subsequent days.

- Tidal current velocities are greatest within the Outer Cocker Channel (west of Bank End), dominated by tidal processes. With progression landwards along creeks and channels and across the marsh surface, velocities significantly reduce. The ebb phase of the tidal curve is longer in duration than the flood phase at a point located just offshore from Bank End Farm.

5.3 'Baseline Sensitivity'

5.3.1 'Baseline Sensitivity' Description

The 'Baseline Sensitivity' can be described as follows:

- The baseline sensitivity testing runs cover the same full 14-day spring-neap tidal cycle (incorporating 28 high tides and 28 low tides) as the baseline model runs. The sensitivity tests examine the influence of river flow input through tidal gates from the River Cocker on water levels and current velocities.

- **Sensitivity test 1** incorporates a constant 'typical' river flow from the River Cocker of 1.3 m^3/s. This value is the highest recorded value in the Environment Agency's spot measurements provided for the study. (The minimum recording was 0.007m^3/s and the mean of surveys on six separate dates was 0.28 m^3/s).

- **Sensitivity test 2** incorporates a constant 'high' river flow from the River Cocker of 5.0 m^3/s. (This is an assumed value based on Environment Agency data from channels of a similar size within the county).

- In reality the river flow will not be constant, but the modelling has been used to examine the relative contributions of different elements (tidal flows, river flows) of the system to inform baseline understanding, rather than claiming to be an absolute representation of present-day conditions, which of course are highly variable in nature and multiple in type.

- The plots in section 5.3.2 show attained water level and current velocities for the sensitivity tests in a similar manner to those presented for the baseline case, with certain timesteps selected to demonstrate key findings.

5.3.2 ‘Baseline Sensitivity’ Key Findings

This section describes the key findings of the ‘Baseline sensitivity’ simulation.

- Under sensitivity test 1 (**Figure 5-20**) both the ‘new’ cut section and the outer natural section of the tidal Cocker Channel retain more water throughout the neap tides and at low tide during spring tides compared to the baseline scenario. However, the effect of ‘typical’ (1.3m^3/s) river flow is minor compared to the dominating tidal conditions in terms of water levels.

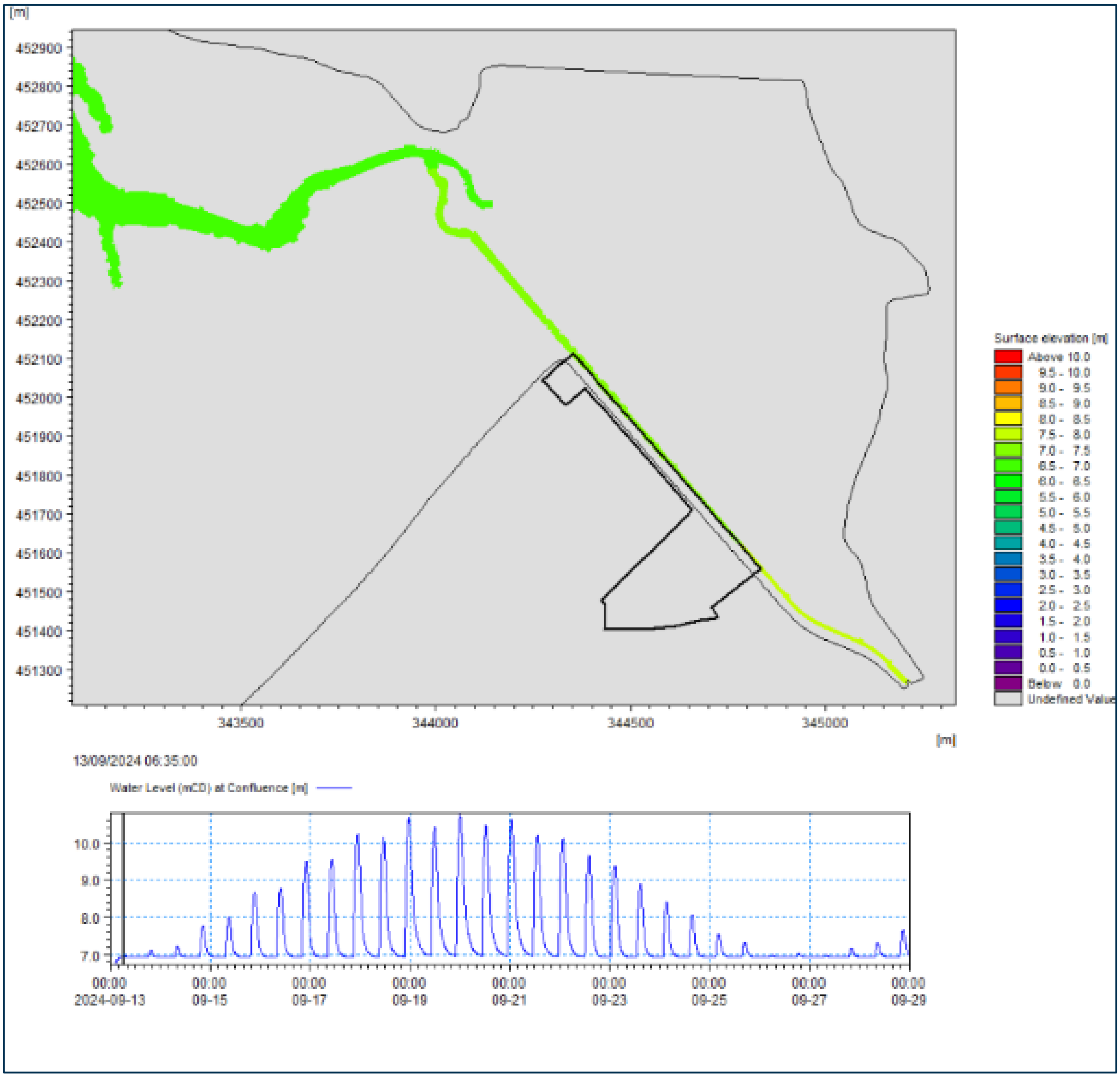


Figure 5-20 Sensitivity test 1: High water elevation (in metres CD) at high tide 1

- The timeseries plot below (**Figure 5-21**) shows the simulated water levels at a point in the model domain within the confluence of Patty's Farm Creek and the tidal Cocker Channel. This shows that the effect of a constant 1.3m^3/s flow from the River Cocker into the model domain does not significantly affect high water levels or tidal phasing (since these processes are dominated by the large-scale tidal effects), but it does elevate water levels at this point during neap tides and at low water during spring tides.

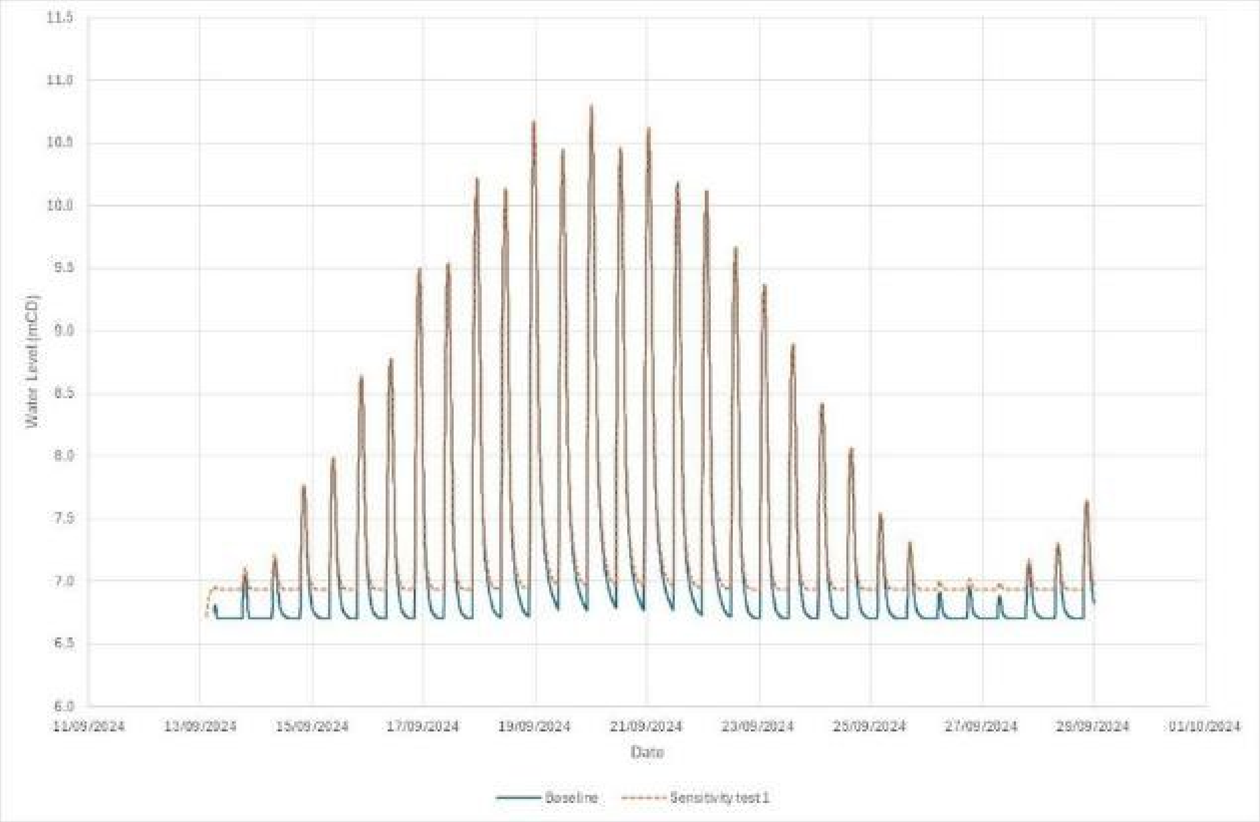


Figure 5-21 Water level comparison between 'Baseline' and 'Sensitivity test 1' at a point within the confluence of Patty's Farm Creek and the tidal Cocker Channel

- Similarly, for current velocities the differences between the baseline scenario and sensitivity test 1 are relatively minor, as shown by the plots of current velocities at the time of peak flood and peak ebb on the highest spring tide, which are similar to the baseline plots previously shown.

- The peak flood currents (**Figure 5-22**) within part of the Outer Cocker Channel are slightly reduced compared to the baseline, whilst the peak ebb currents (**Figure 5-23**) are slightly increased compared to the baseline, but the differences are not deemed significant in magnitude (nor in the location at which they occur, quite far offshore (west) of the Bank End promontory.

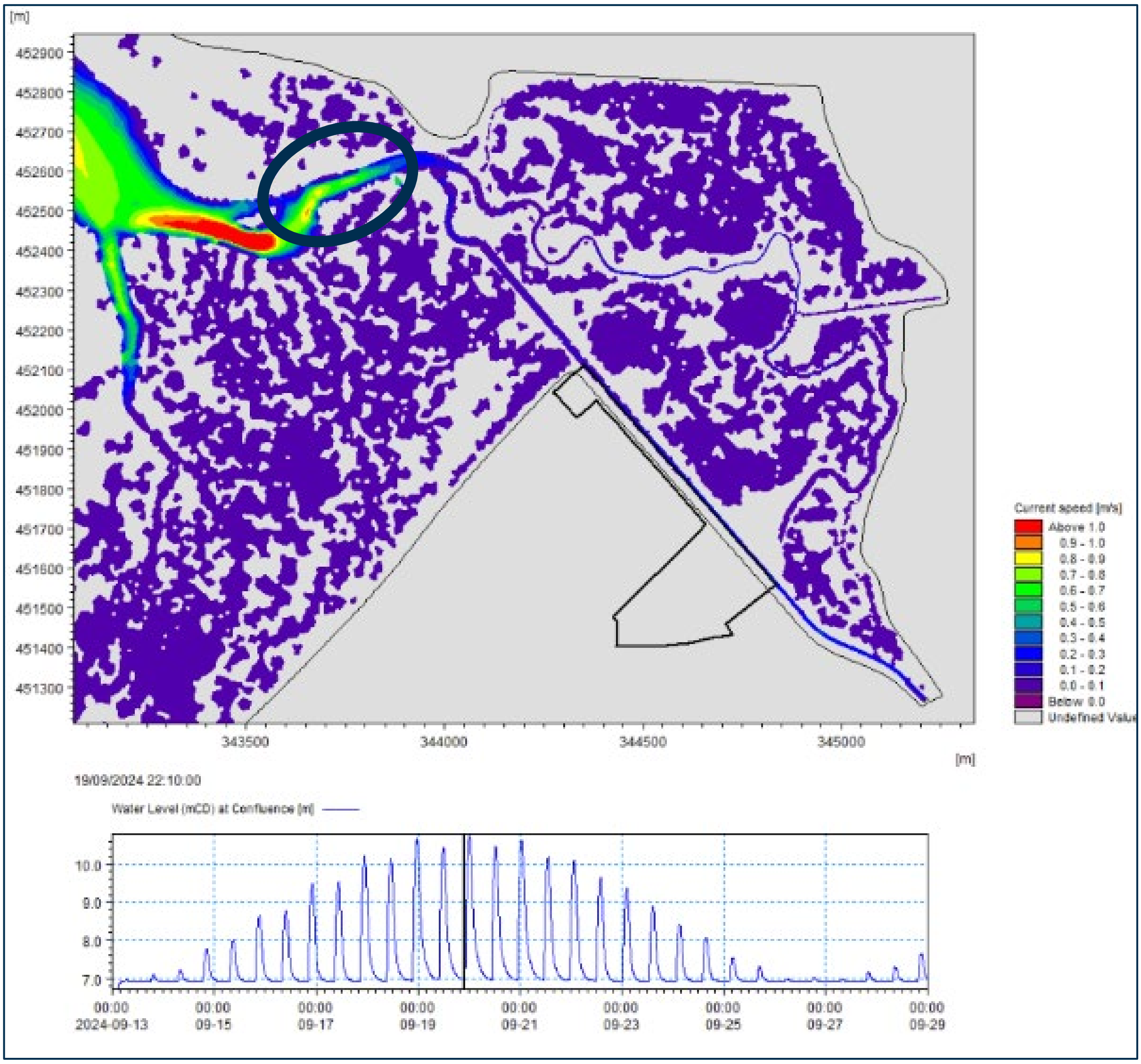


Figure 5-22 Sensitivity test 1: Peak flood current velocities (in m/s) in the vicinity of Bank End Farm before high tide 14

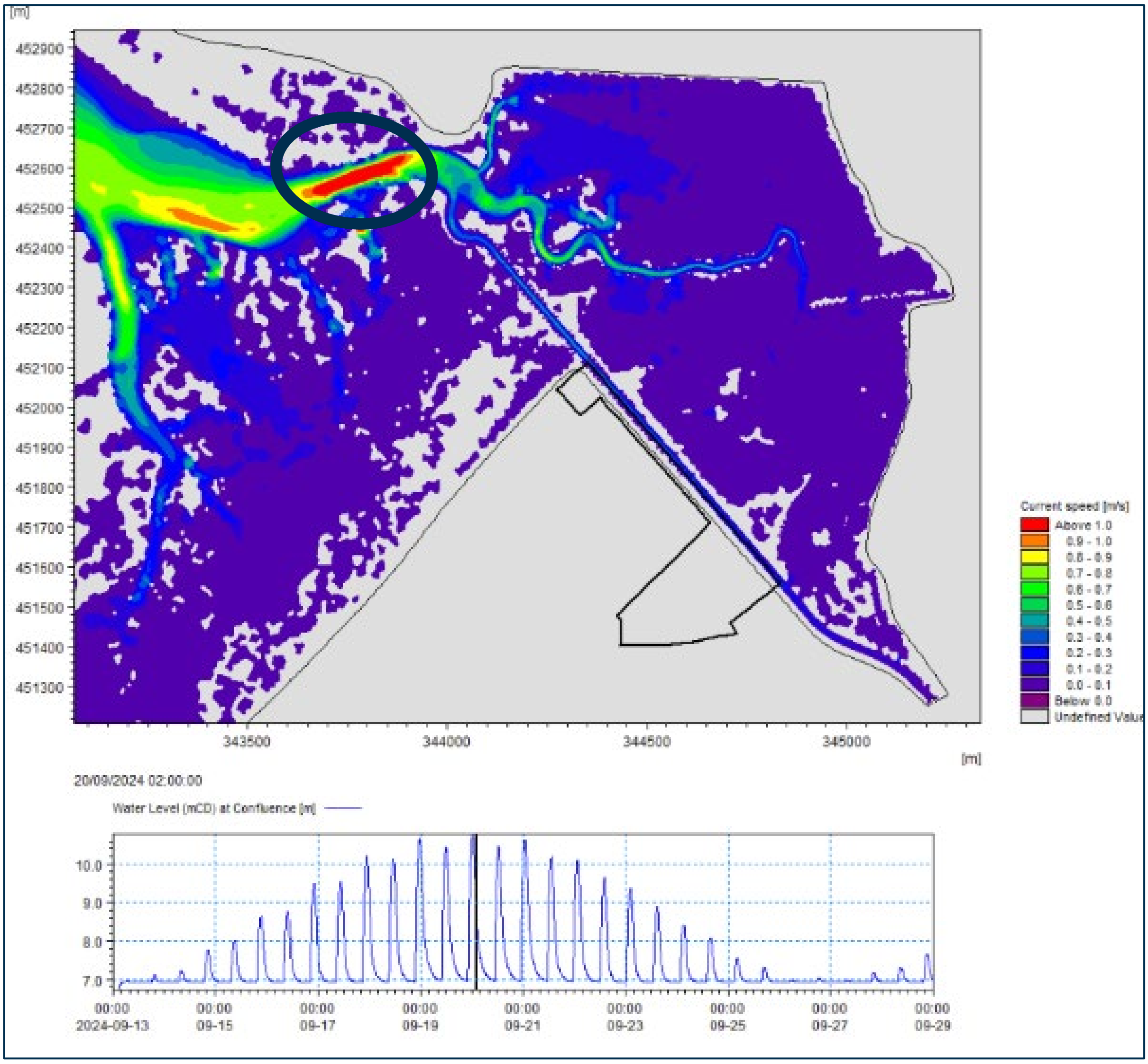


Figure 5-23 Sensitivity test 1: Peak ebb current velocities (in m/s) in the vicinity of Bank End Farm after high tide 14

- Current velocity comparison between ‘Baseline’ and ‘Sensitivity test 1’ (**Figure 5-24**) at a point within the confluence of Patty’s Farm Creek and the tidal Cocker Channel show that current velocities both increase (by up to 0.13m/s compared to the baseline) and decrease (by up to 0.15m/s compared to the baseline), depending on the point within the tidal cycle. Such change is small in magnitude, and values of this magnitude are only observed at points within the tidal cycle where more water is retained within the channel at low water under the sensitivity test, rather than at times of peak flood or ebb flow or at high water, where the magnitude of change is much smaller.

- Although marginal, any increases in current flow may serve to (slightly) ‘hydraulically deflect’ the principal tidal currents within the Outer Cocker Channel more towards Bank End shore, thereby (slightly) increasing erosion tendency along the saltmarsh edge. However, this would suggest that unless there is a persistent increase in river flow from the River Cocker, such effect will reach a limit of exertion, and the tidal currents will continue to dominate.

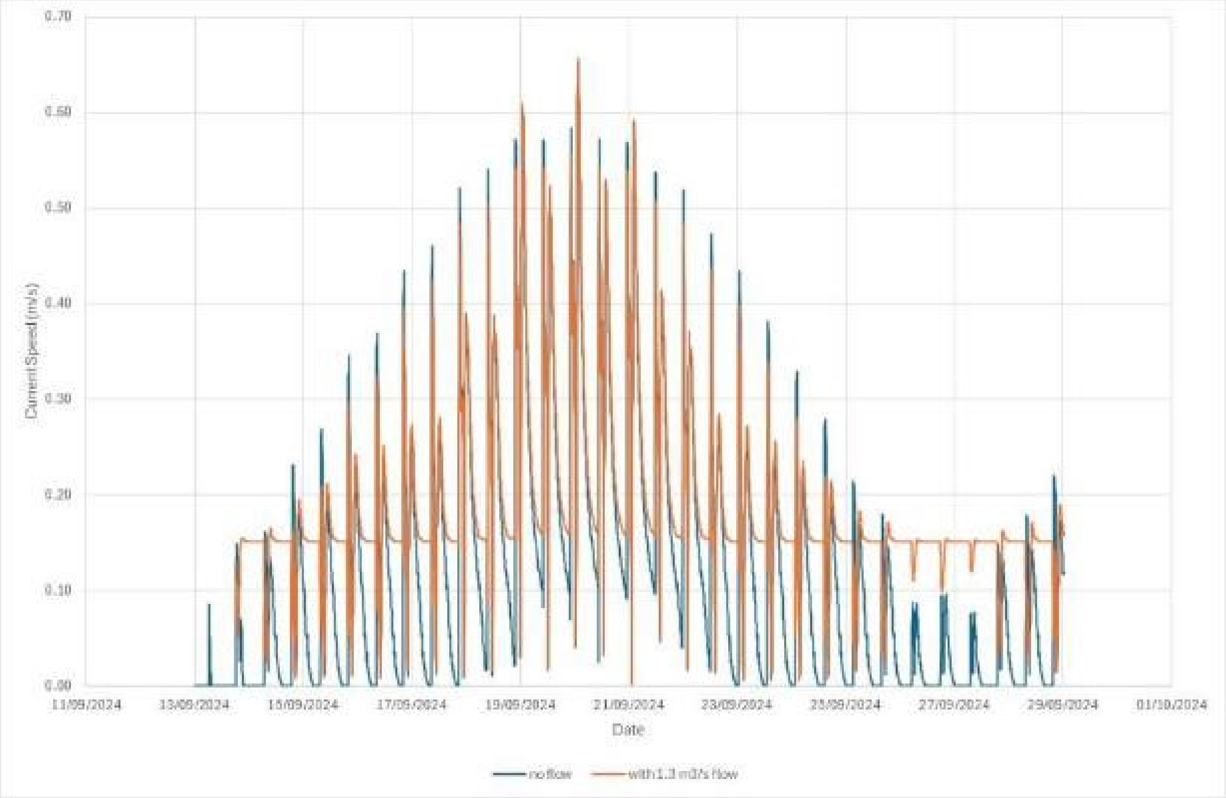


Figure 5-24 Current velocity comparison between ‘Baseline’ and ‘Sensitivity test 1’ at a point within the confluence of Patty’s Farm Creek and the tidal Cocker Channel

- Under sensitivity test 2 (**Figure 5-25**) similar results are observed, albeit to a greater magnitude. Whilst the effect of a constant ‘high’ (5.0m^3/s) river flow from the River Cocker on water levels within the ‘new’ cut channel is greater than under sensitivity test 1, tidal conditions still are the dominating factor within the channel at spring tides. However, the elevated minimum water level retained within the ‘new’ cut tidal Cocker Channel drowns out the tidal effects during neap tides and it is only larger tides towards the spring tide effects that propagate further up-channel. It should be noted that a river flow of this magnitude would not occur in reality as constant input; rather it would be time-limited during and shortly after periods of the heaviest rainfall within the Cocker catchment.

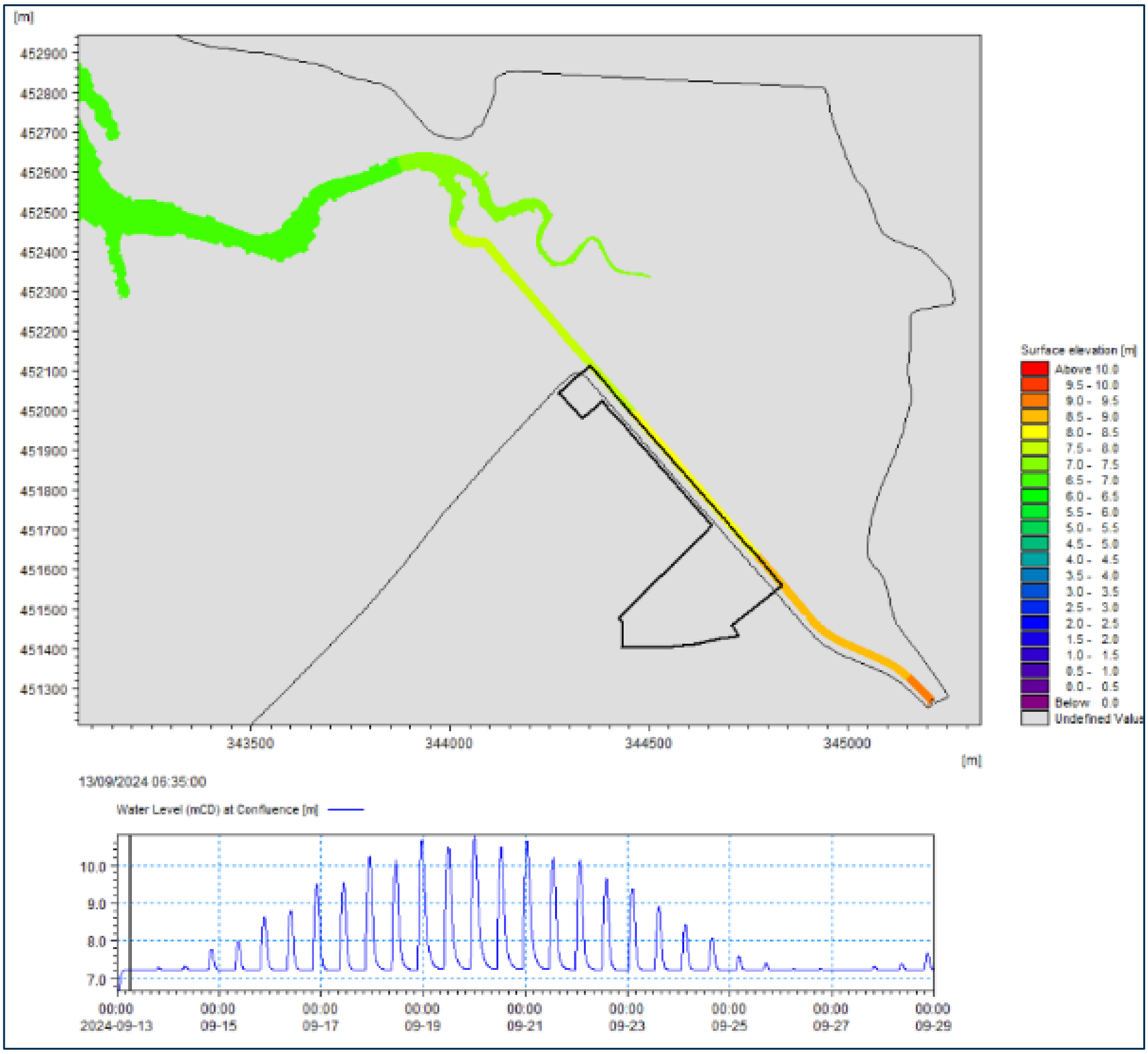


Figure 5-25 Sensitivity test 2: High water elevation (in metres CD) at high tide 1

- The timeseries plot below (**Figure 5-26**) shows the simulated water levels at a point in the model domain within the confluence of Patty’s Farm Creek and the tidal Cocker Channel. This shows that the effect of a constant 5.0m^3/s flow from the River Cocker into the model domain does not affect high water levels or tidal phasing (since these processes are dominated by the large-scale tidal effects), but it does elevate water levels at this point during neap tides and at low water during spring tides.

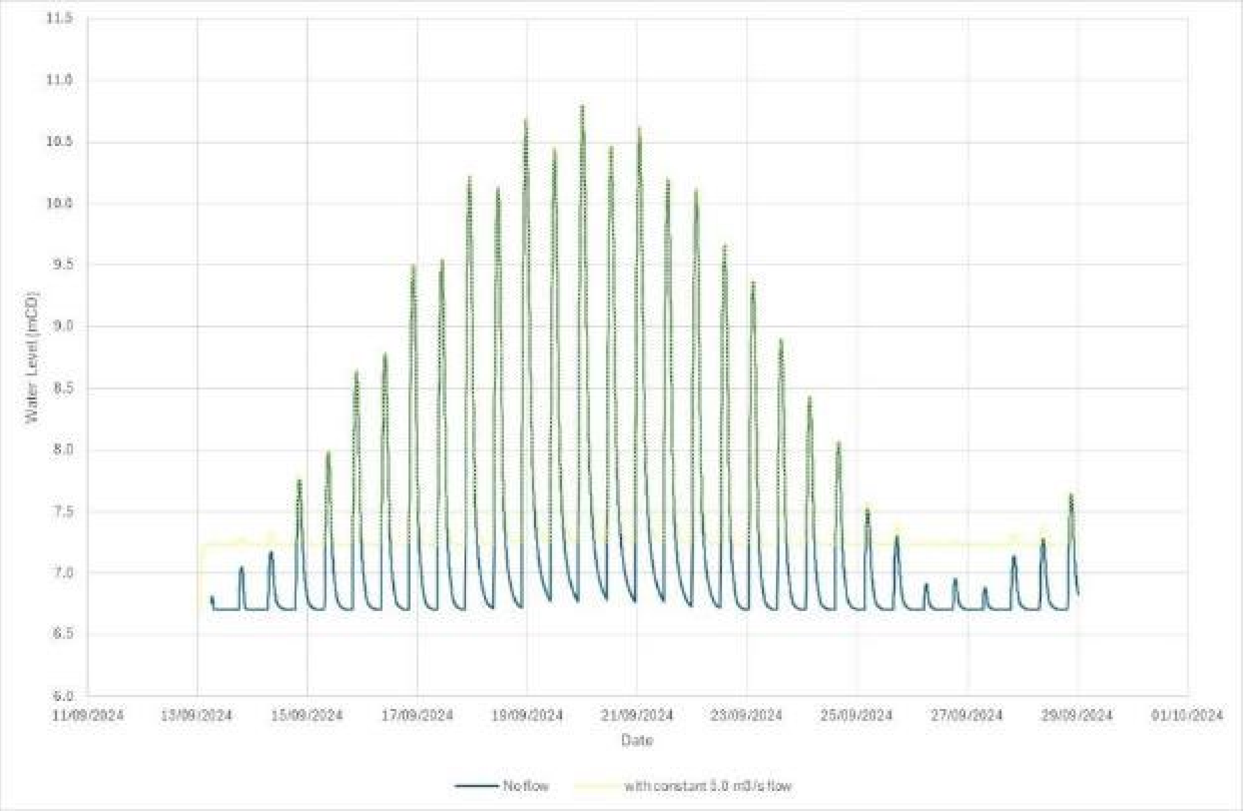


Figure 5-26 Water level comparison between ‘Baseline’ and ‘Sensitivity test 2’ at a point within the confluence of Patty’s Farm Creek and the tidal Cocker Channel

- The changes in peak flood (**Figure 5-27**) and peak ebb (**Figure 5-28**) currents within part of the Outer Cocker Channel are slightly more pronounced for sensitivity test 2 than for sensitivity test 1, but remain relatively insignificant in terms of magnitude.

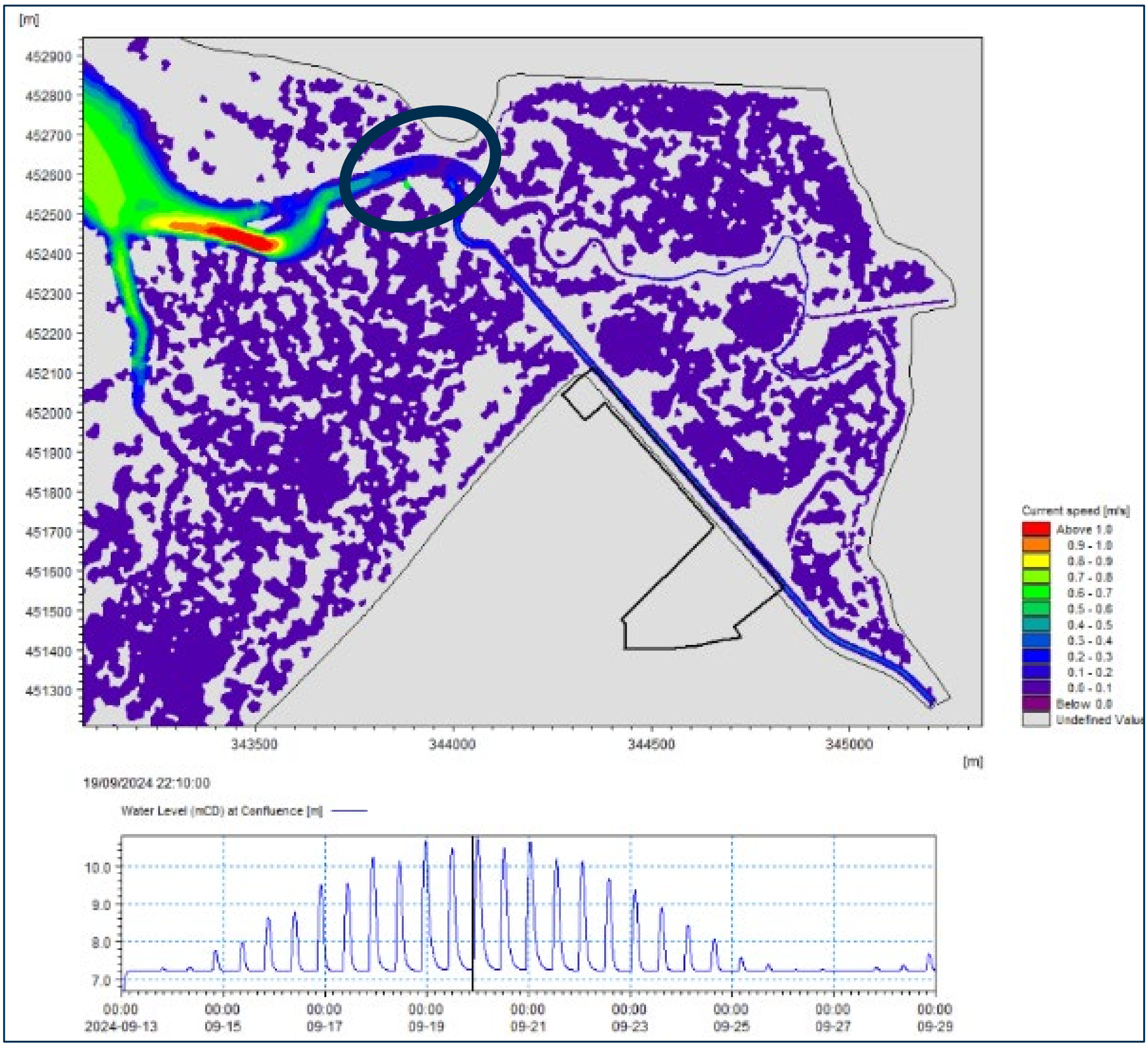


Figure 5-27 Sensitivity test 2: Peak flood current velocities (in m/s) in the vicinity of Bank End Farm after high tide 14

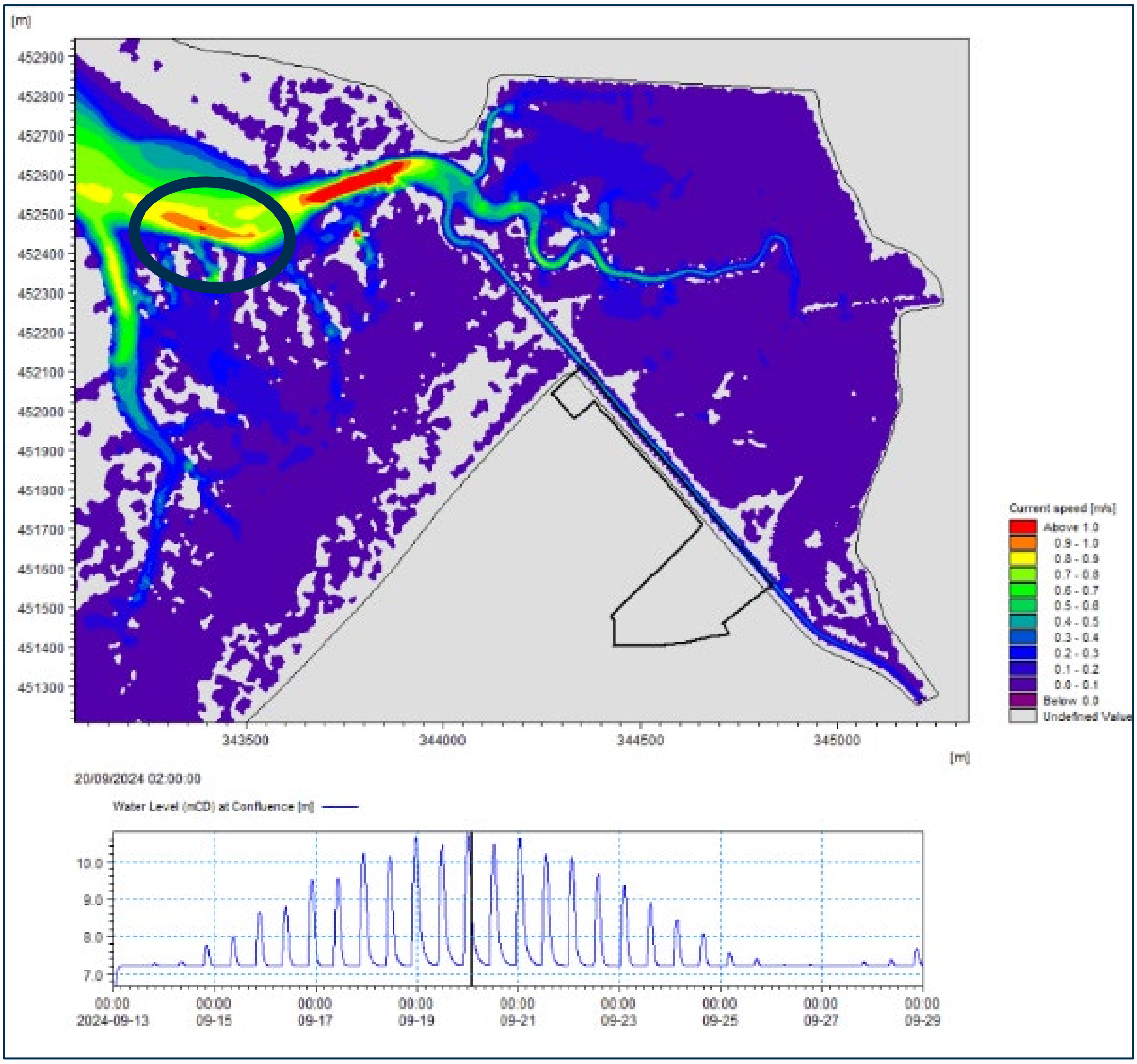


Figure 5-28 Sensitivity test 2: Peak ebb current velocities (in m/s) in the vicinity of Bank End Farm after high tide 14

- Current velocity comparison between ‘Baseline’, ‘Sensitivity test 1’ and ‘Sensitivity test 2’ (**Figure 5-29**) at a point within the confluence of Patty’s Farm Creek and the tidal Cocker Channel show that current velocities both increase (by up to 0.13m/s compared to the baseline) and decrease (by up to 0.15m/s compared to the baseline), depending on the point within the tidal cycle. Such change is small in magnitude, but the increases may serve to (slightly) ‘hydraulically deflect’ the principal tidal currents within the Outer Cocker Channel more towards Bank End shore, thereby (slightly) increasing erosion tendency along the saltmarsh edge. However, this would suggest that unless there is a persistent increase in river flow from the River Cocker, such effect will reach a limit of exertion, and the tidal currents will dominate.

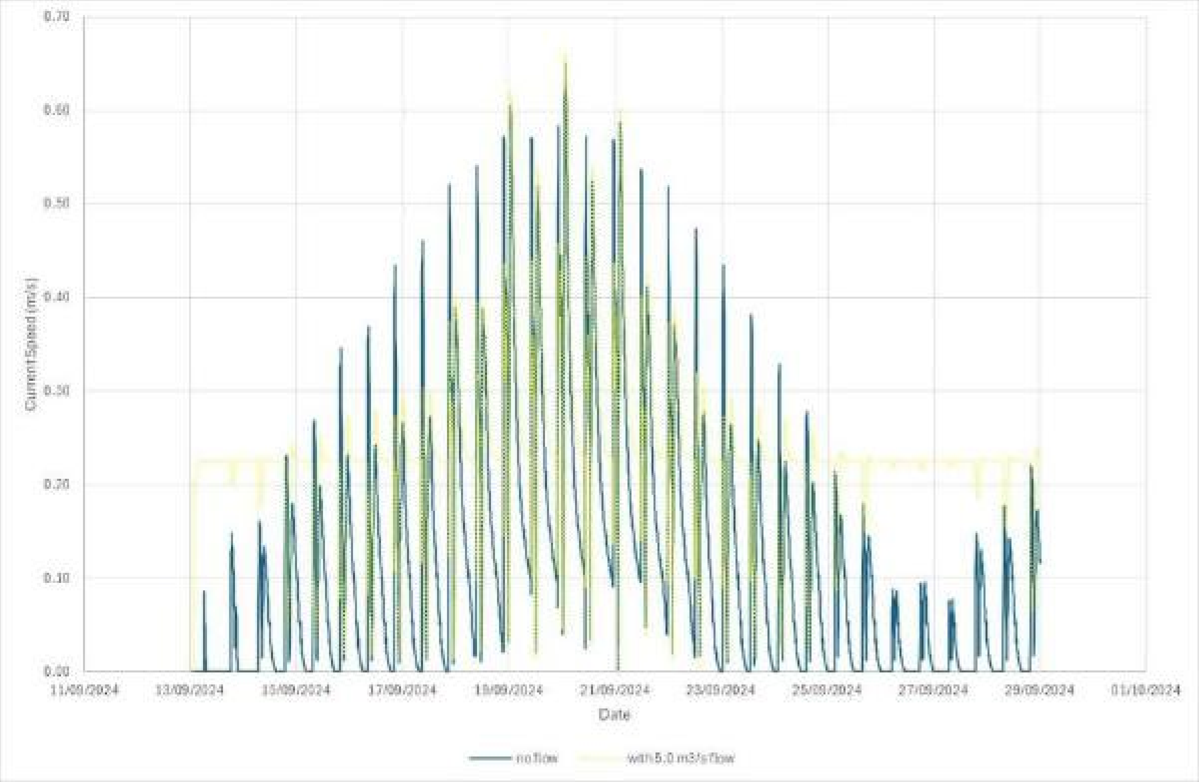


Figure 5-29 Current velocity comparison between ‘Baseline’ and ‘Sensitivity test 2’ at a point within the confluence of Patty’s Farm Creek and the tidal Cocker Channel

5.3.3 ‘Baseline Sensitivity’ Summary

This section summarises the ‘Baseline Sensitivity’ simulations. These incorporate a constant flow from the River Cocker of 1.3m^3/s (baseline sensitivity 1) and 5.0m^3/s (baseline sensitivity 2).

- Model results for the baseline sensitivity option exhibit similar patterns to those described in section 5.2.3 for the ‘baseline’ runs.

- Under both sensitivity tests, the effect of flow from the River Cocker at Cocker Bridge is minimal compared with the governing (landscape-scale) tidal processes, which dominate. There is no measurable change in high water level or tidal phasing, but it does mean that more water is retained within the channels at low water after the tide has ebbed away, as these channels are continuing to be replenished with flow from upstream.

- With river flow input to the model, there is a slight reduction in peak flood currents and a slight increase in peak ebb currents within part of the Outer Cocker Channel compared to the baseline with no river flow, but the differences are not significant in magnitude.

- For the purposes of optioneering, the historic baseline runs in section 5.4 and the option runs in sections 5.5 and 5.6 have been compared against baseline sensitivity test 1 (‘BS1’).

5.4 ‘Historic Baseline’

5.4.1 ‘Historic Baseline’ Description

The ‘Historic Baseline’ can be described as follows:

- In addition to the present-day baseline, it was considered useful to use the established tidal model to also simulate an approximation of the historic baseline conditions that would have existed in the natural tidal Cocker Channel prior to the construction of the ‘new’ cut in the 1960s.

- To make this approximation, the channel cross section of the alignment of the historic tidal Cocker Channel was deepened and widened to mimic a cross section of the natural channel that presently exists just to the north of its confluence with Patty’s Farm Creek. This was applied to the length of channel between the end of the ‘new’ cut section of Patty’s Farm Creek and the ‘new’ tidal Cocker Channel (see **Figure 5-30**). There is a slight step between the invert levels of the mimicked natural tidal Cocker Channel and the ‘new’ cut tidal Cocker Channel at their intersection just downstream of Cocker Bridge, but if this option was progressed to detailed design this would be removed.

- For a short distance immediately downstream of Cocker Bridge, the original historic tidal Cocker Channel meandered south across upper saltmarsh which is now reclaimed as farmland before diverting northwards to the alignment shown on the plan. This short section was not included in the historic baseline and instead the ‘new’ cut tidal Cocker Channel was used in the simulation along this section. In the model, the remaining substantial length of the ‘new’ cut tidal Cocker Channel was infilled so the model interpreted these areas as flat saltmarsh surface.

- Whilst this historic baseline also broadly represents the ‘Tidal Cocker Channel – Option 5 (Full Reinstatement of Original Tidal Cocker Channel and Infill of New Cut)’, that is not considered further as a management option within this investigation and the historic baseline approximation is used purely for purposes of improving understanding of the hydrodynamic processes within the system as they may have been before the ‘new’ cut was constructed in the 1960s. This understanding, in turns, helps contextualise some of the present-day issues that are experienced and processes which operate.

Figure 5-30 Tidal Cocker Channel alignment used in historic baseline run

- The historic baseline modelling run covers the same full 14-day spring-neap tidal cycle (incorporating 28 high tides and 28 low tides) as the baseline modelling runs. This enables the modelled differences between the present-day baseline and the historical baseline to be determined over a common time period and range of tidal conditions.

- The historic baseline runs have incorporated a 'typical' river flow through the tidal gates at Cocker Bridge (constant flow input of 1.3 m^3/s) and results have been compared against baseline sensitivity test 1 ('BS1'), which incorporates identical river flow input conditions from the River Cocker.

- In a similar manner of presentation to the baseline model runs, the plots below show attained **water level** in metres above Chart Datum (m CD) at various stages through the spring-neap tidal cycle.

- As for the baseline runs, the simulation commences at low water during the lowest neap tide (starting on 13th September 2024) and runs through to high water on the highest spring tides (peaking on 20th September 2024) before returning to low water during the lowest subsequent neap tides (27th September 2024).

5.4.2 ‘Historic Baseline’ Key Findings

This section describes the key findings of the ‘Historic Baseline’ simulation.

- Near the start of the model simulation, at high tide 1 (**Figure 5-31**) on the lowest neap tide with a constant input flow from the River Cocker, there is a notable difference in output between the historic baseline and baseline sensitivity test 1 (BS1).

- Historically, the river flow entered the natural tidal channel and discharged into Cockerham Sands along a meandering course, but in the present day it preferentially flows along the ‘new’ cut channel and bypasses the natural channel alignment, even though it remains a distinct feature on the landscape.

- It is also noteworthy that under the same conditions, water is retained in the natural tidal channel (under the historic baseline) to a higher level in its upper reaches than is observed within the ‘new’ cut channel under BS1. The accompanying model animations show that the channel does not fully drain on the ebb before the subsequent flood tide occurs and so natural flow to sea within the reinstated channel is somewhat tide-locked.

- Whilst this may in part be due to the fact that the historic baseline includes no deepening of the natural tidal Cocker Channel seaward of its confluence with the ‘new’ cut section of Patty’s Farm Creek (and so the model may be replicating some ‘artificial’ retainment of flow) it does support the anecdotal evidence that flow conveyance of freshwater away from Cocker Bridge has been markedly improved since the ‘new’ cut was constructed.

- The implication from this is that if the historic alignment was fully reinstated and the ‘new’ cut was infilled, there would be a likely worsening of flood risk upstream in the Cocker catchment due to ‘water locking’ of discharge from Cocker Bridge at its tidal gate.

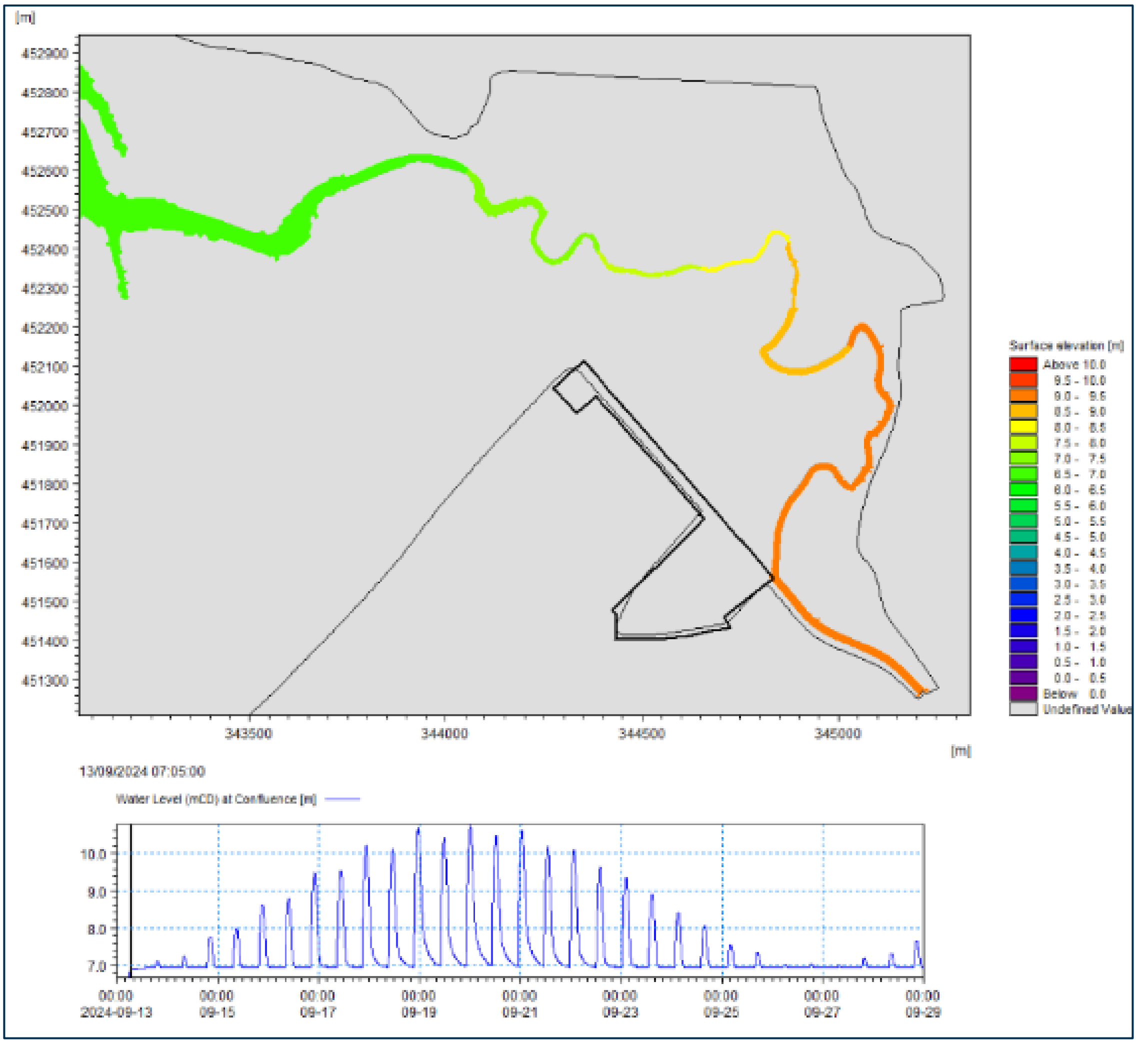


Figure 5-31 Historic baseline: High water elevation (in metres CD) at high tide 1

- The historic baseline shows that subsequent days demonstrate a similar tidal pattern to BS1 across the outer sections of Cockerham Sands, but that the natural tidal Cocker Channel does not necessarily bring tidal water more quickly or in greater capacity to areas of upper saltmarsh in the vicinity of Cockerham Marsh SSSI, Cocker Bridge or Patty's Farm. In fact, the 'new' cut appears to operate somewhat more effectively in this regard by channelling tidal water up its length before this water spills out of channel when it reaches the tidal gates at Cocker Bridge and backflows onto the upper saltmarsh just downstream of this area. In contrast, tidal waters remain in the deeper natural channel under the historic baseline for a longer phase of the tidal cycle. This is exemplified by outputs at the time of high tide 10 (**Figure 5-32**), showing tidal waters remaining within, or in very close proximity to the natural tidal Cocker Channel alignment with little coverage of the upper saltmarsh.

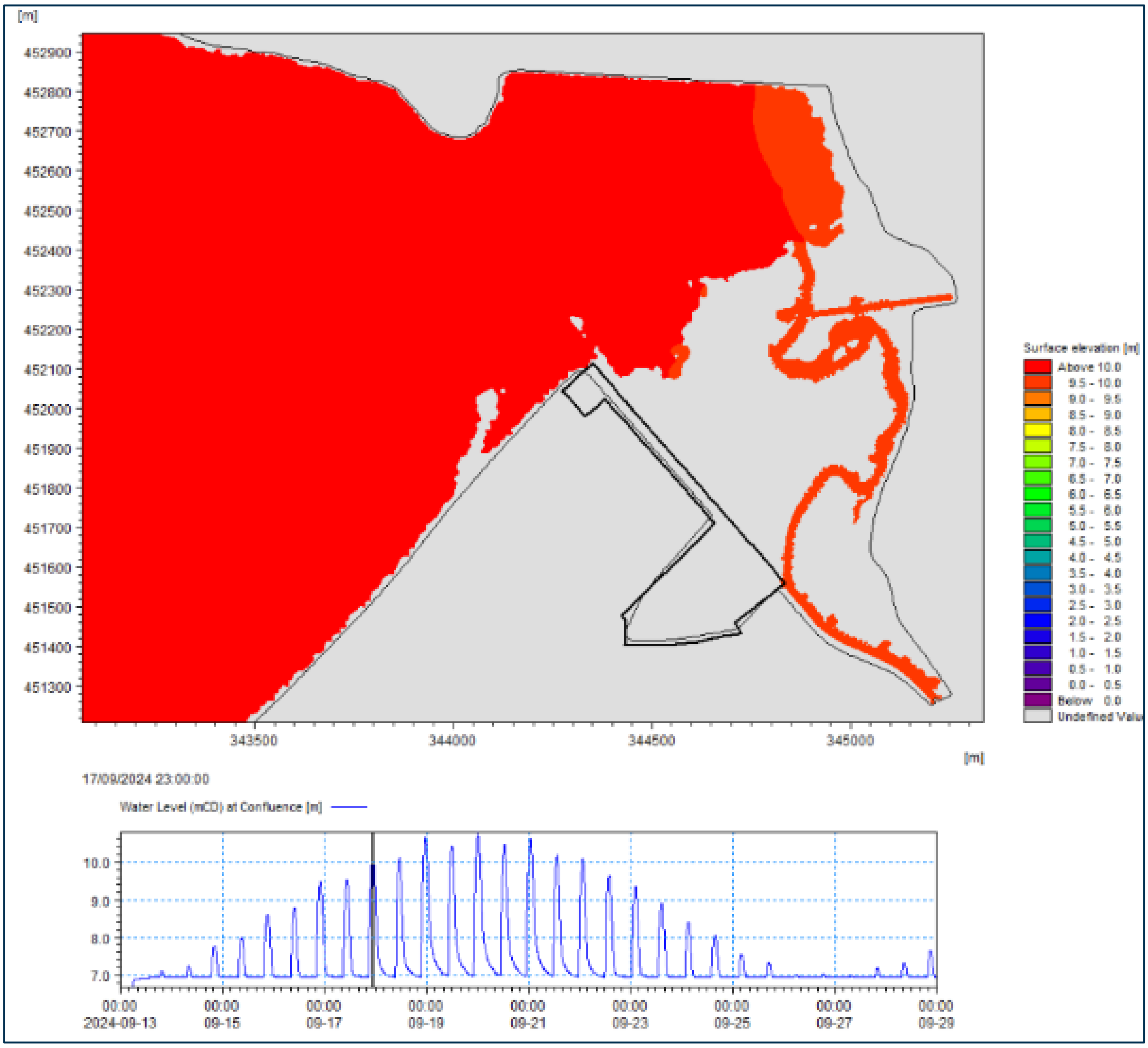


Figure 5-32 Historic baseline: High water elevation (in metres CD) just after high tide 10

- As for BS1, the greatest extent of tidal inundation occurs from the highest spring tide water levels which occur during high tide 14 (**Figure 5-33**). At this time virtually all of the saltmarsh is covered by the high tide, including almost all areas immediately adjacent to Cockerham Marsh SSSI. However, the flooding mainly occurs from progression of the tide from the west across Cockerham Sands as water levels exceed the topographic level of the saltmarsh surface, rather than through overspilling the banks of the natural tidal Cocker Channel.

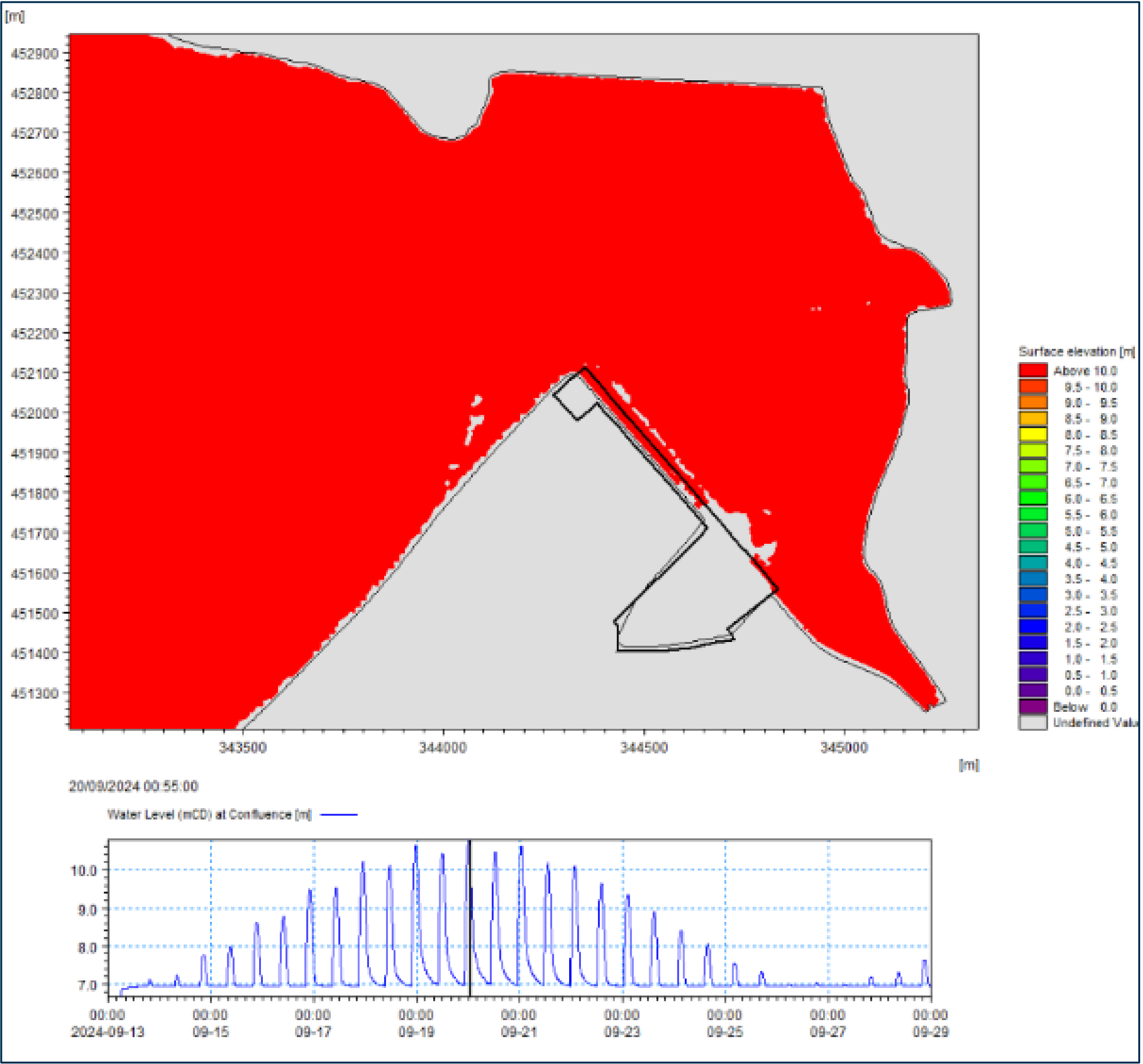


Figure 5-33 Historic baseline: High water elevation (in metres CD) just after high tide 14

- As for BS1, following this highest of high water levels during the peak of spring tides, the general patterns described on the ‘climbing’ segment of the neap-spring curve are reversed during the ‘descending’ segment of the spring-neap curve.

- The plots below show current velocities in metres per second (m/s) at the time of peak flood (**Figure 5-34**) and peak ebb (**Figure 5-35**) on a spring tide. The peak current velocities occur during the highest spring tide, on the flooding phase before high tide 14 and the ebbing phase after high tide 14.

- Results show a minor decrease in the peak flood flows within part of the Outer Cocker Channel for the historic baseline compared to BS1. This is likely to be due to the more slowly draining channel causing a slight ‘hydraulic brake’ on the incoming tide within the channel.

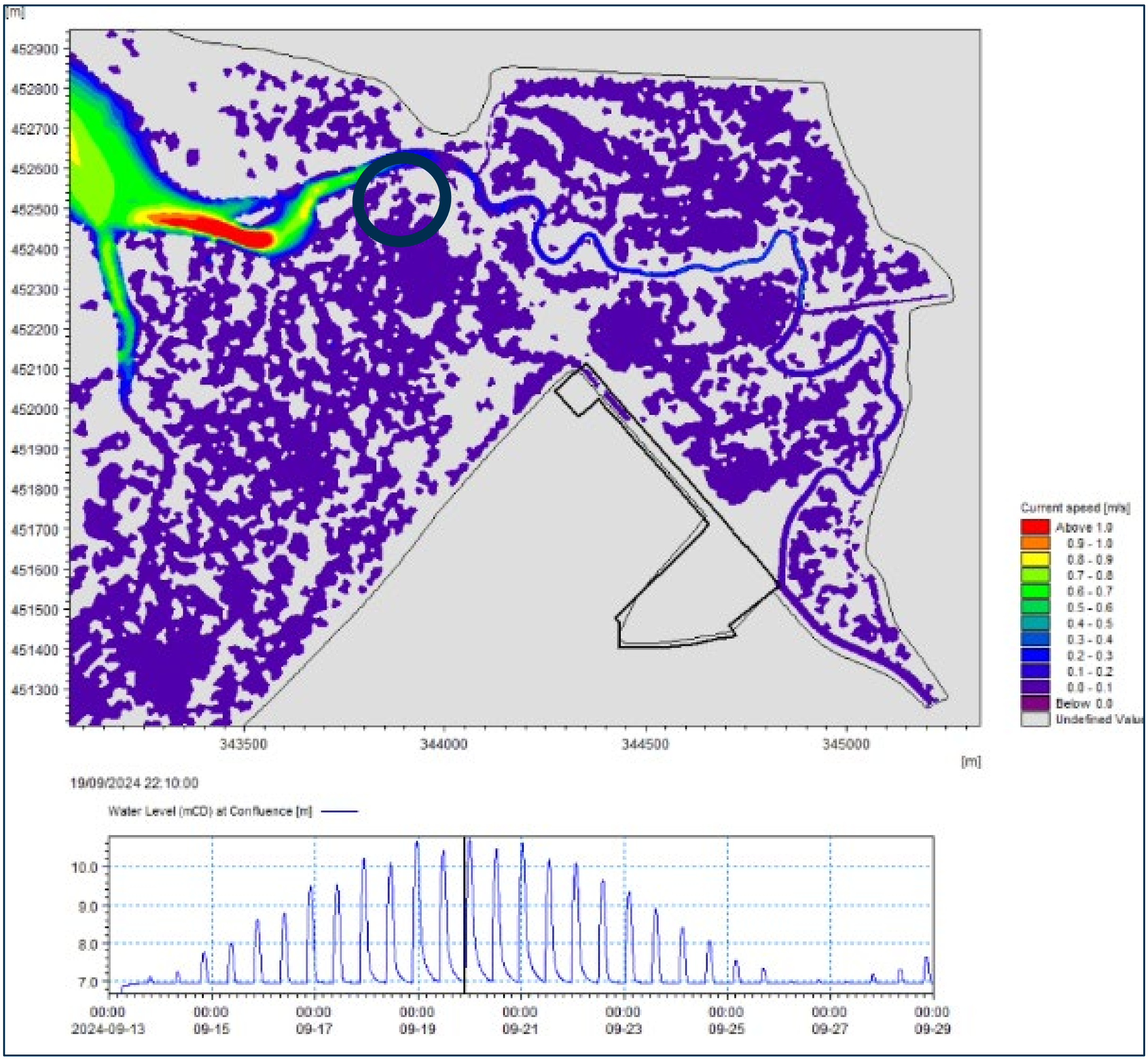


Figure 5-34 Historic baseline: Peak flood current velocities (in m/s) in the vicinity of Bank End Farm before high tide 14

- There is also a minor difference in the peak ebb flows in this vicinity, with the historic baseline showing slightly lower values than BS1. This implies that the previous consideration that construction of the ‘new’ cut has exacerbated ebb flows at this location, prompting the saltmarsh erosion has some veracity, although the magnitude of difference is small and the baseline results suggest that erosion of the saltmarsh at this location is linked more to natural tidal processes (which are governed at a landscape-scale) and have not been significantly exacerbated by construction of the ‘new’ cut. This further implies that efforts to re-naturalise the tidal Cocker Channel would have only modest flood risk benefit to Bank End Farm.

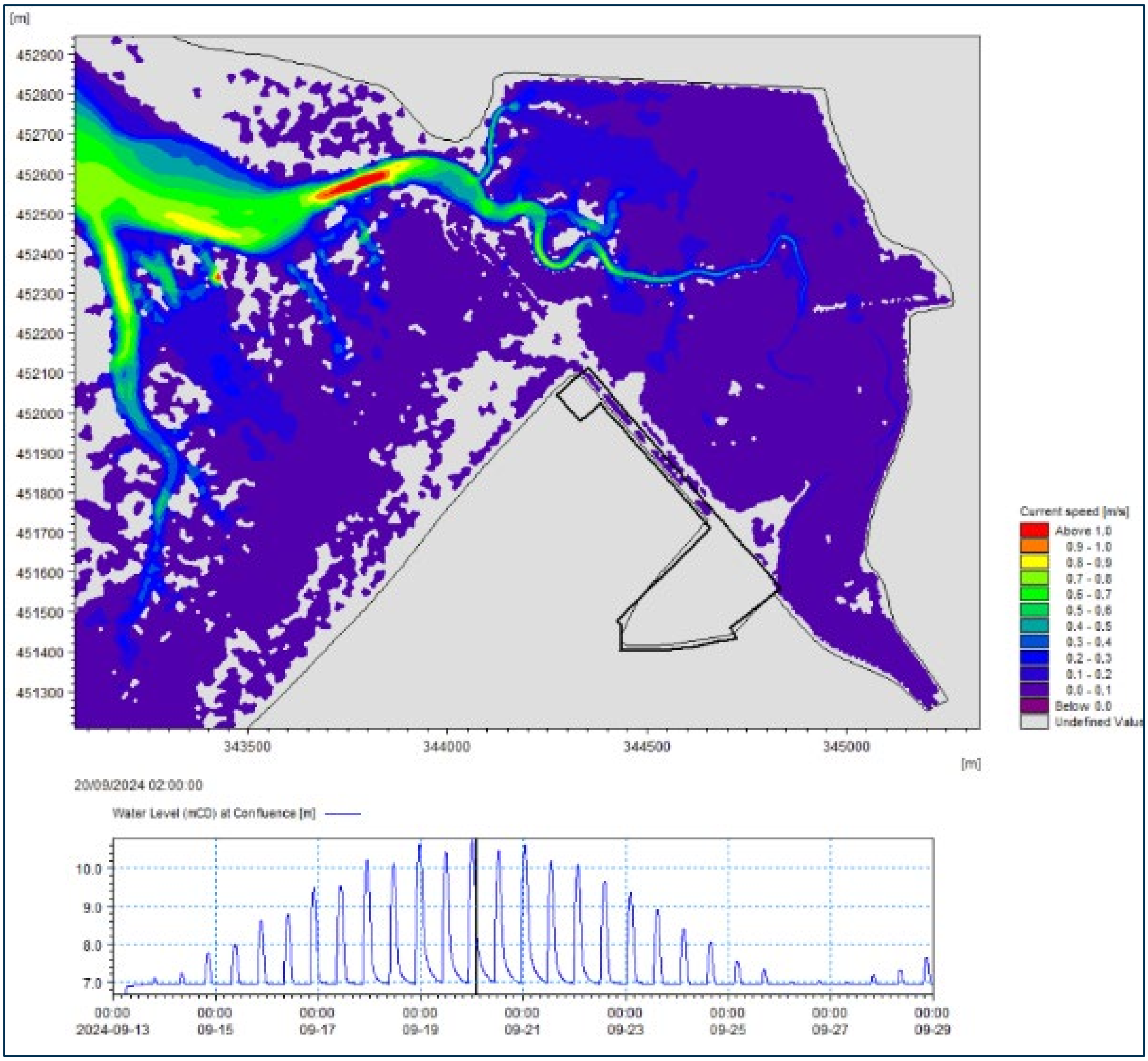


Figure 5-35 Historic baseline: Peak ebb current velocities (in m/s) in the vicinity of Bank End Farm after high tide 14

- A timeseries plot (**Figure 5-36**) produced at a point seaward of Bank End Farm, within the confluence of Patty's Farm Creek and the 'new' cut tidal Cocker Channel, shows the current speeds for BS1 and the historic baseline over spring tides. Also plotted is the water level curve to allow identification of which currents occur during the flood and which during the ebb. Results confirm that currents for the historic baseline are lower when compared to BS1 during the peak phases of tidal currents, but are greater after mid ebb through to low water. This is likely due to the slower ebb caused by the more meandering alignment of the natural tidal Cocker Channel.

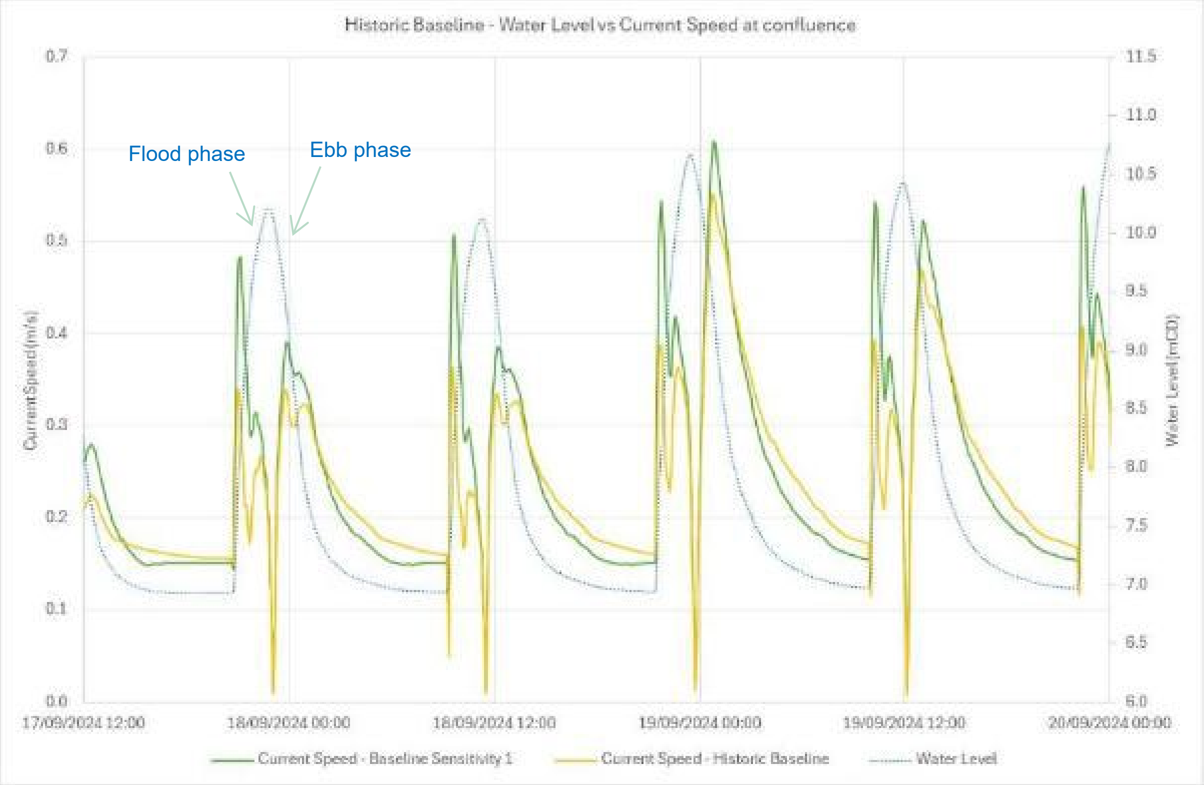


Figure 5-36 Comparison of current speed and water level for 'Baseline sensitivity 1' and 'Historic Baseline' at a point within the confluence of Patty's Farm Creek and the tidal Cocker Channel

5.4.3 ‘Historic Baseline’ Summary

This section summarises the ‘Historic Baseline’ simulation.

- Comparing model outputs from the historic baseline to the present-day BS1 shows useful comparative information regarding the hydraulic function of the natural tidal Cocker Channel and the ‘new’ cut tidal Cocker Channel.

- Historically, it appears that water may have been retained within the natural tidal channel to a higher level in its upper reaches than is observed within the ‘new’ cut channel under present-day arrangements. This is partly because the natural flow to sea of flows from the River Cocker is somewhat tide-locked by the slowly draining, meandering course of the natural channel.

- Flow conveyance of freshwater away from Cocker Bridge is significantly improved in the present-day BS1 compared to the historical baseline, supporting the effectiveness of the ‘new’ cut in reducing flood risk upstream in the Cocker catchment.

- There would be a likely worsening in this regard due to ‘water locking’ of discharge from Cocker Bridge at its tidal gate should the natural tidal channel become fully reinstated, and the existing ‘new’ cut be manually infilled to mimic original natural conditions.

- Furthermore, envisaged benefits from reinstating the natural tidal Cocker Channel in terms of improved hydraulic and ecological functioning do not appear to be fully manifest, as the tide reaches most areas of upper saltmarsh by submergence due to flooding spring tides as they propagate across Cockerham Sands from the west, rather than extensive areas of saltmarsh becoming inundated through overspilling the banks of the reinstated tidal Cocker Channel, which is considerably more localised process.

- One perceived effect of constructing the ‘new’ cut in the 1960s has been an exacerbation of currents during the ebb flows in the vicinity of Bank End Farm, leading to erosion of the fronting saltmarsh. There is a difference in the peak ebb flows in this vicinity between the historic baseline (which shows slightly lower peak values) and BS1 (which shows a slightly localised increase) at certain tidal phases, although the magnitude of difference is small compared to the considerably more dominant currents generated by natural tidal processes. It is therefore considered that efforts to re-naturalise the tidal Cocker Channel would have only modest flood risk benefit to Bank End Farm.

- It should be noted that the above consideration of an historic baseline has been for the purposes of better understanding the historic and present-day natural processes which prevail across Cockerham Sands, and its findings have further supported a decision earlier in the investigation to screen-out an option for full reinstatement of the natural tidal Cocker Channel and infilling of the ‘new’ cut tidal Cocker Channel from further assessment.

5.5 Tidal Cocker Channel – Option 4 ('TCC-4')

5.5.1 'TCC-4' Description

'TCC-4' can be described as follows:

- This scenario represents reinstatement of most of the tidal Cocker Channel (except for the most upstream section towards Cocker Bridge which originally flowed south of the current 'new' cut, before heading back north across Cockerham Sands) (see **Figure 5-37**).

Figure 5-37 Tidal Cocker Channel alignment used in Option TCC-4 run

5.5.2 'TCC-4' Key Findings

This section describes the key findings of the 'TCC-4' simulation.

- Under this option, with the 'new' cut remaining open as the dominant channel, modelling results are identical to BS1 during neap tides and flows do not enter the reinstated reach of the natural tidal Cocker Channel from fluvial or tidal sources.

- The first difference emerges at high tide 4 (**Figure 5-38**) when tidal levels become slightly higher in the 'new' cut, forcing some of the flow from the River Cocker into the reinstated natural channel just after high tide. However, this effect dissipates before the subsequent low water as water levels in the 'new' cut ebb away.

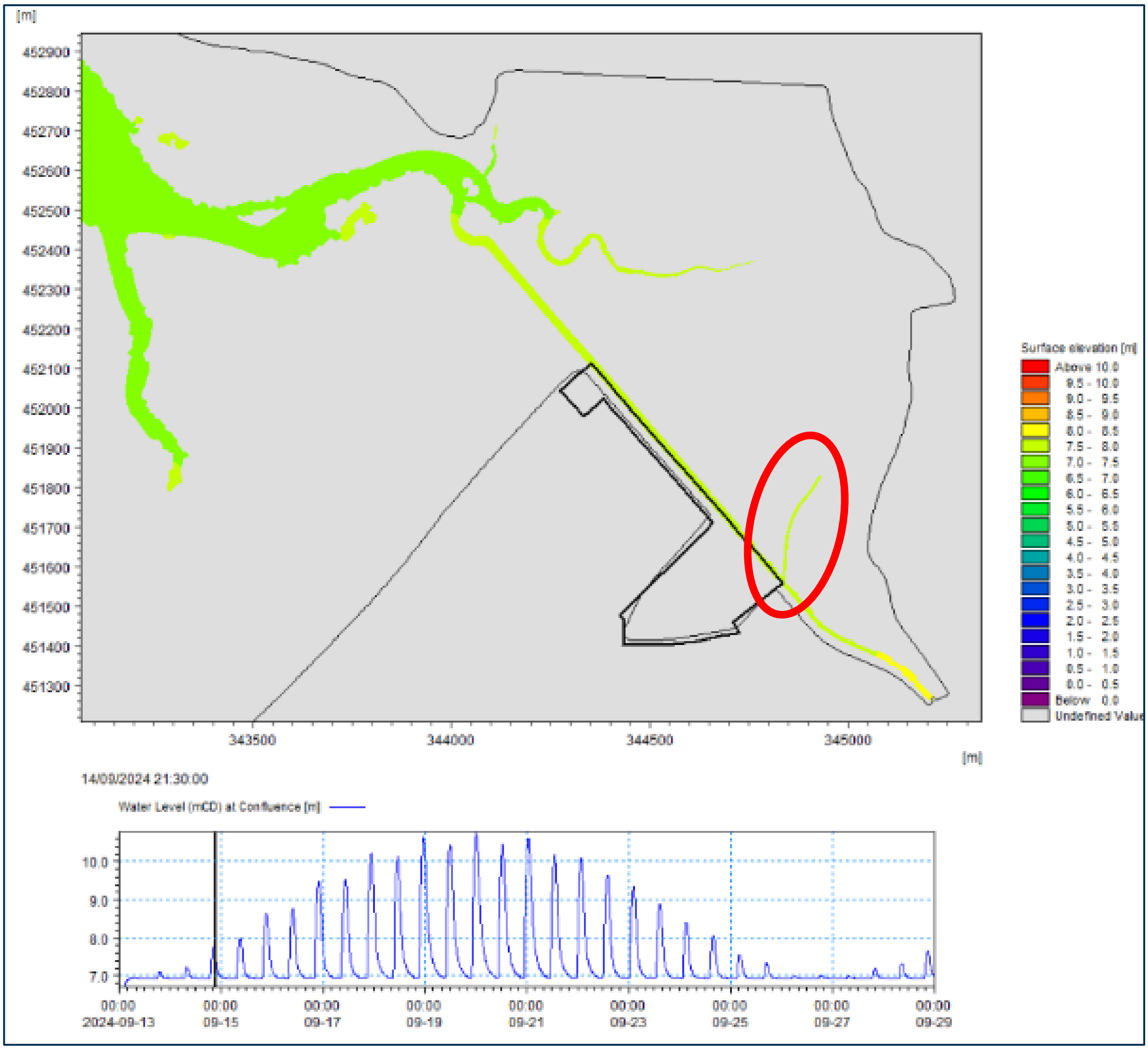


Figure 5-38 Option TCC-4: High water elevation (in metres CD) just after high tide 4

- This process is repeated over subsequent tides, becoming more pronounced with progression from neaps towards springs. High tide 6 (**Figure 5-39**) is the first occurrence in the simulation period where tidal waters fully propagate up the reinstated tidal Cocker Channel. This has the effect of tide-locking flows from the River Cocker, with elevated water levels in the reaches downstream of Cocker Bridge within both the ‘new’ cut and the naturally reinstated channels. However, similar effect occurs to the same magnitude in BS1 from the ‘new’ cut channel alone and so is not exacerbated by the reinstatement of the natural channel

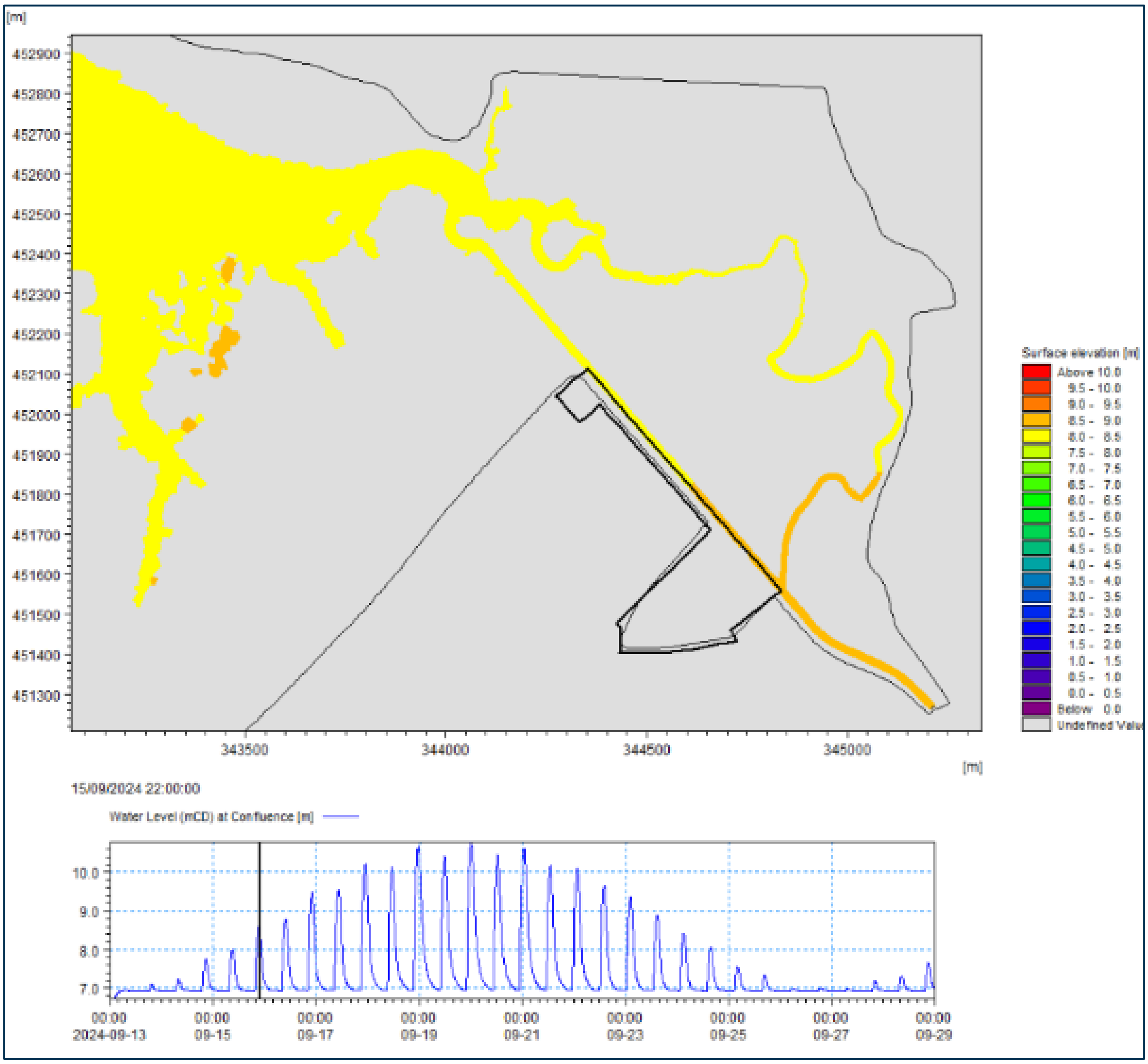


Figure 5-39 Option TCC-4: High water elevation (in metres CD) just after high tide 6

- At around the mid stage of the tidal cycle, around high tide 7 (**Figure 5-40**), tidal flow enters the reinstated natural tidal Cocker Channel from both its seaward end and from the 'new' cut channel.

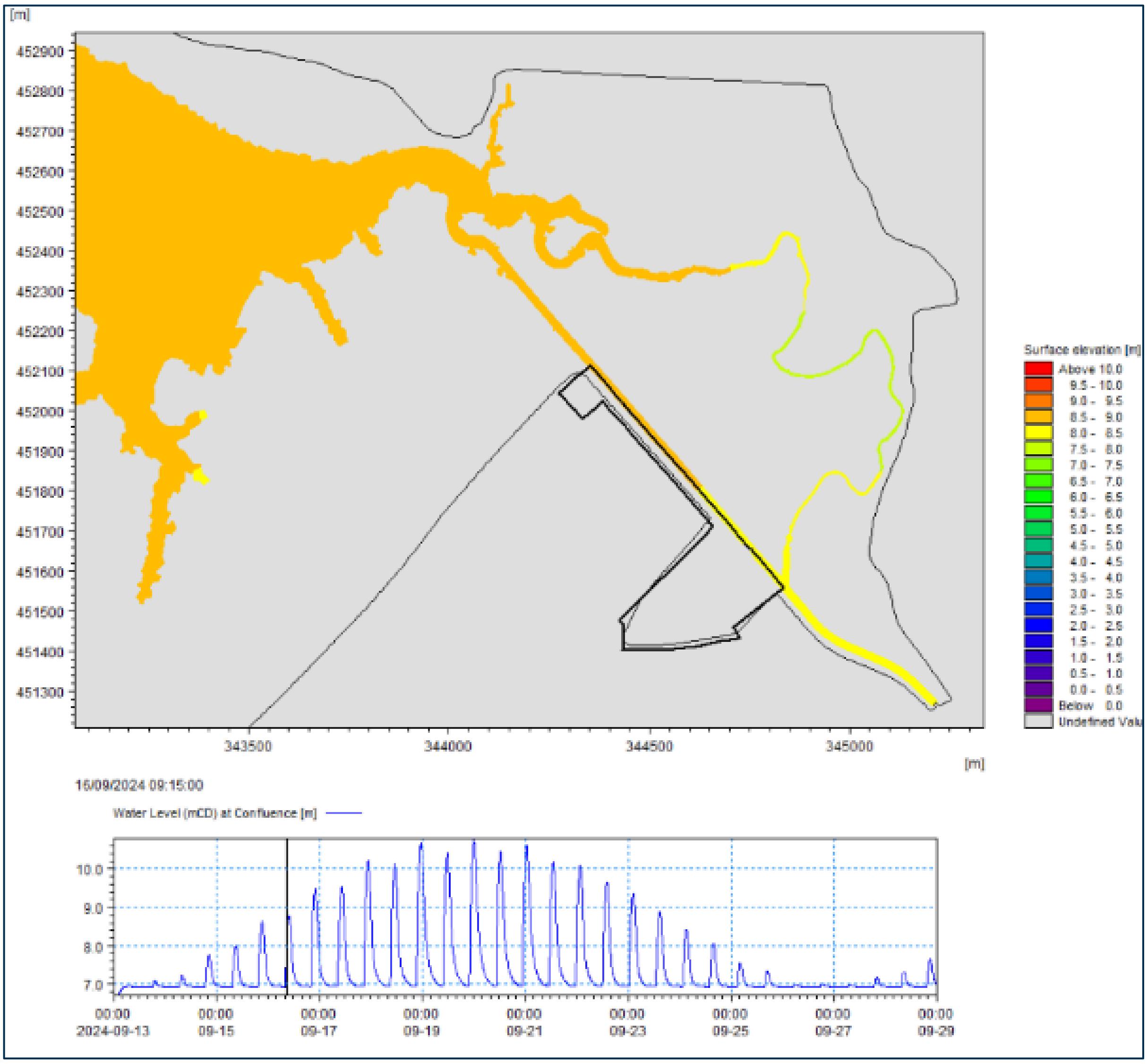


Figure 5-40 Option TCC-4: High water elevation (in metres CD) shortly before high tide 7

- As water levels drop after this high tide (**Figure 5-41**), higher levels are retained in the upstream reach of the reinstated natural channel and the 'new' cut (but again, similar water levels are observed under BS1 for the 'new' cut alone at this tidal stage).

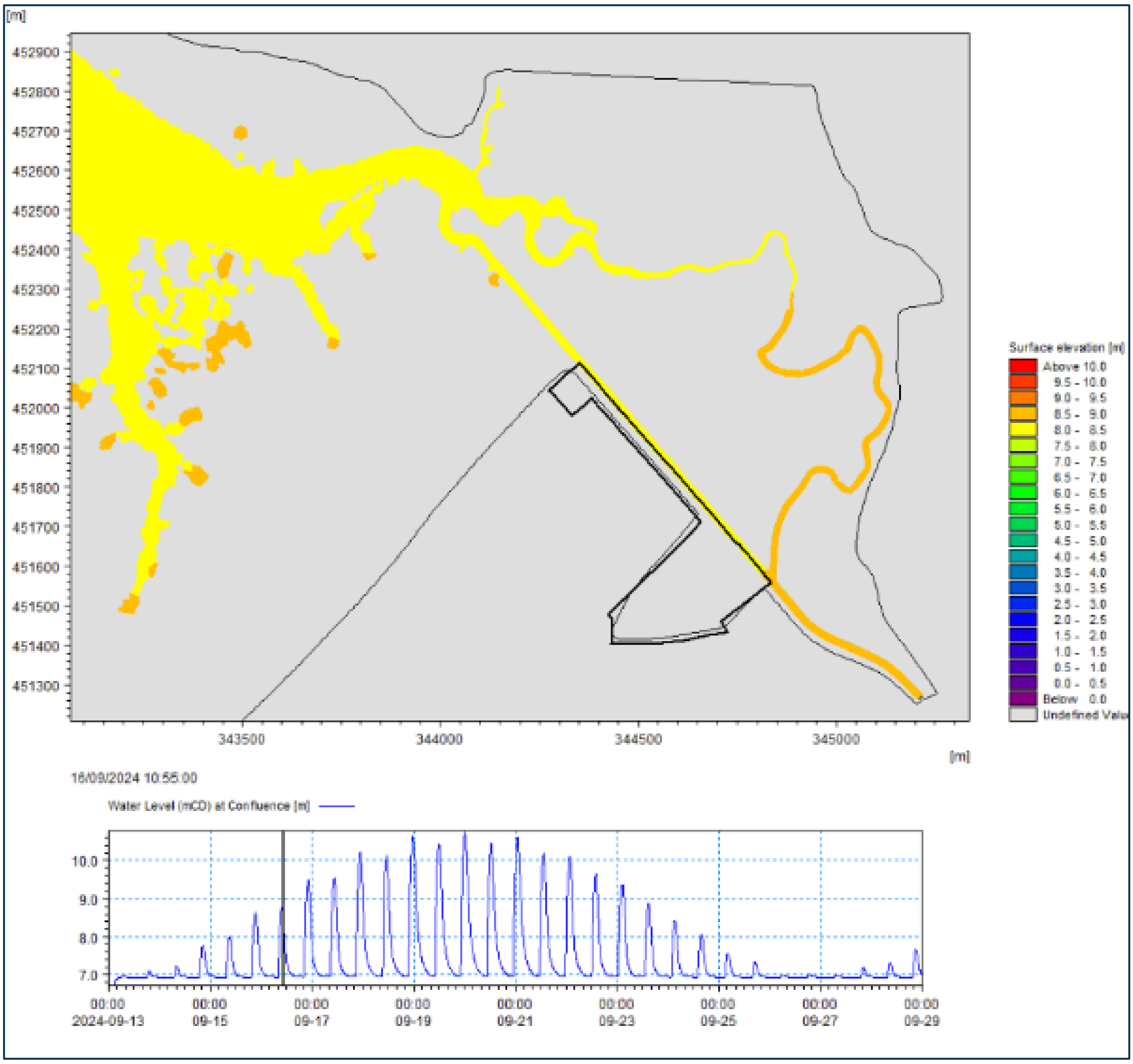


Figure 5-41 Option TCC-4: High water elevation (in metres CD) shortly after high tide 7

- At the upper end of the tidal cycle, towards the largest spring tides, there is only marginal spilling of tidal waters out of the channel onto adjacent upper saltmarsh. The predominant inundation process remains propagation of the tide across the saltmarsh surface from west to east across Cockerham Sands once the threshold elevation of the marsh has been exceeded. (**Figure 5-42**)

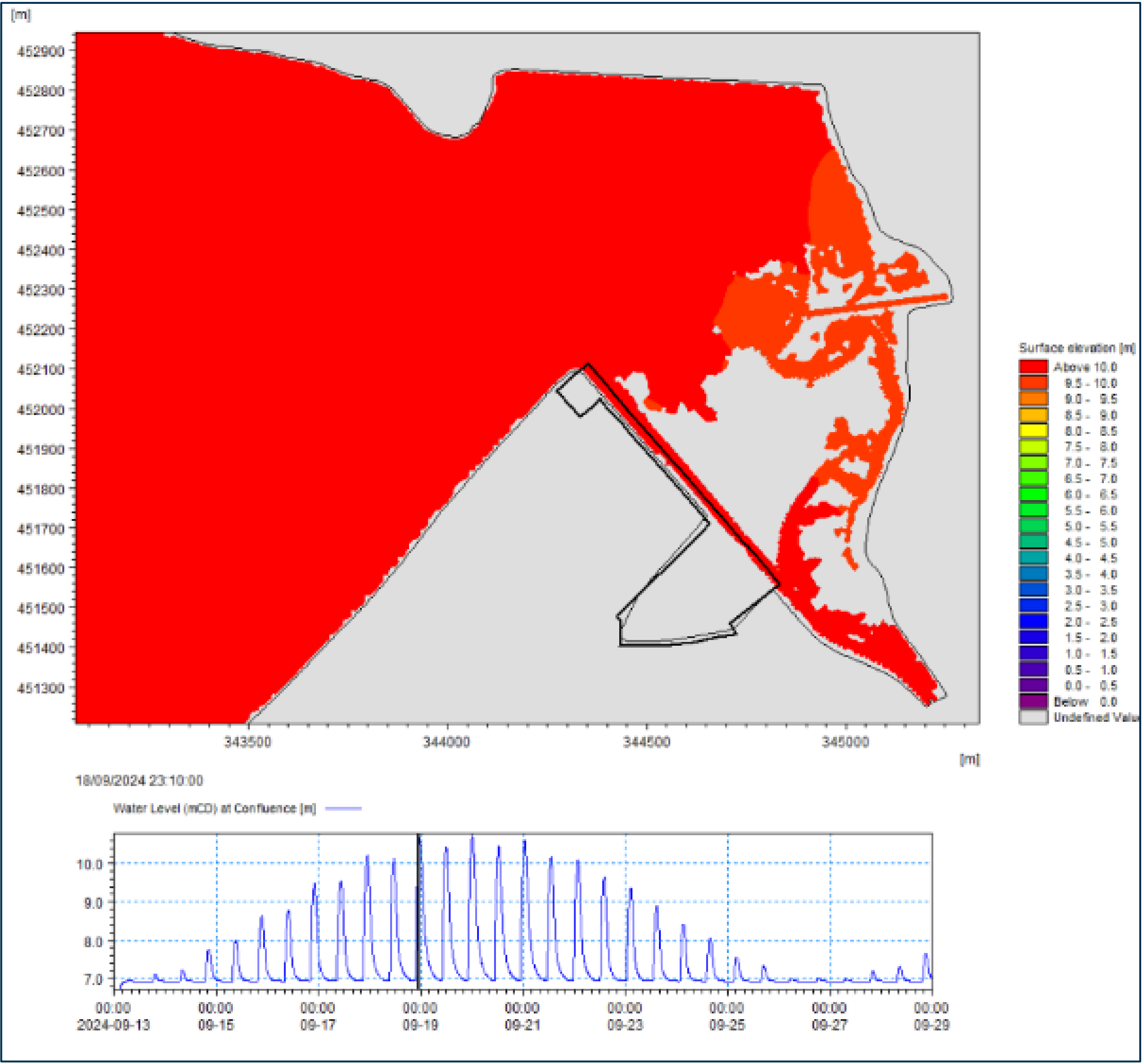


Figure 5-42 Option TCC-4: High water elevation (in metres CD) shortly before high tide 12

- There remains a relatively large area of saltmarsh that is unaffected until the peak water levels occur at high tide on the largest spring tides, at which point it becomes submerged. (**Figure 5-43**)

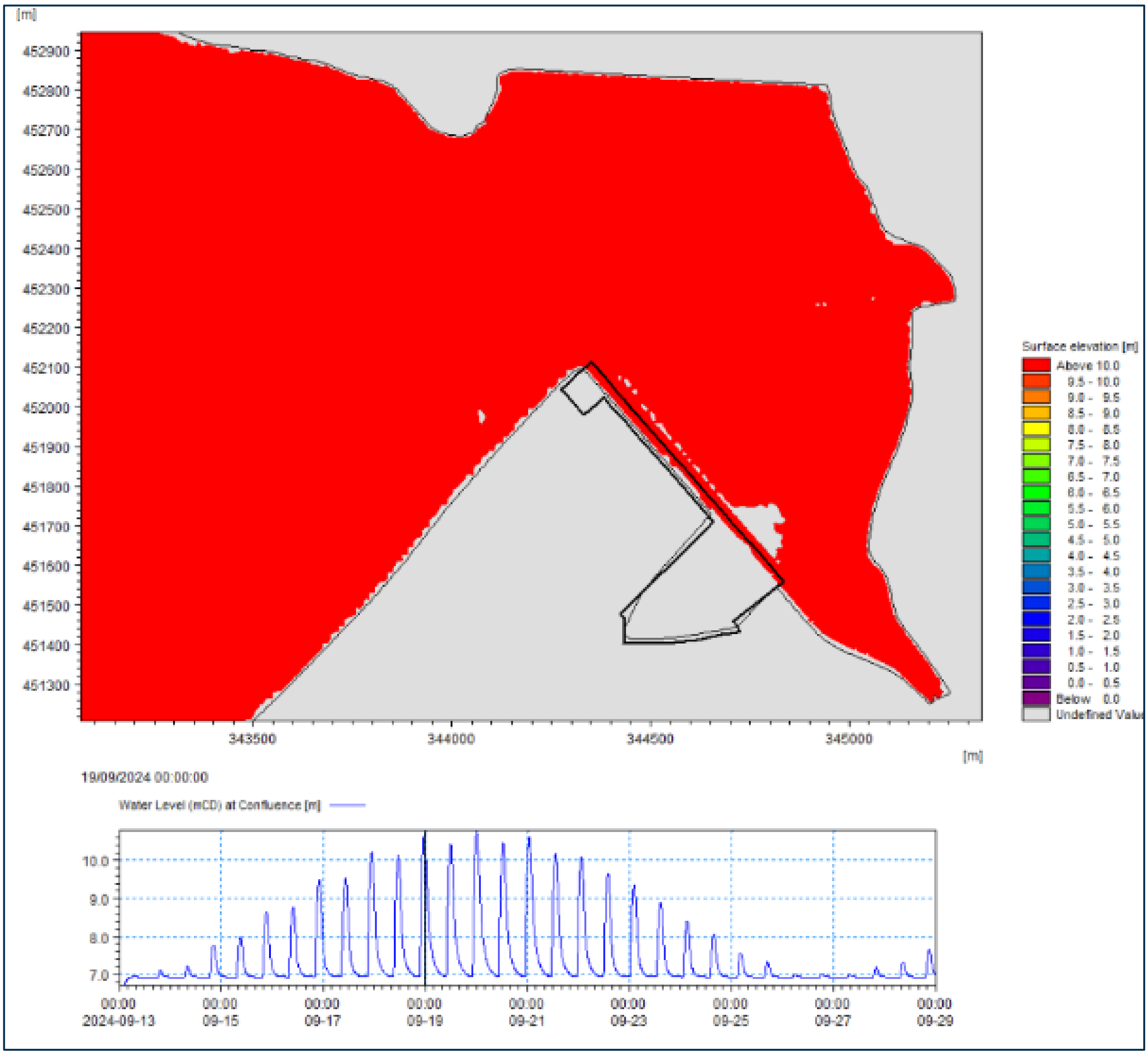


Figure 5-43 Option TCC-4: High water elevation (in metres CD) at high tide 12

- As for BS1, following the highest of high water levels during the peak of spring tides on high tide 14, the general patterns described on the ‘climbing’ segment of the neap-spring curve are reversed during the ‘descending’ segment of the spring-neap curve.

- The plots below show current velocities in metres per second (m/s) at the time of peak flood (**Figure 5-44**) and peak ebb (**Figure 5-45**) on a spring tide. The peak current velocities occur during the highest spring tide, on the flooding phase before high tide 14 and the ebbing phase after high tide 14.

- Results show no appreciable difference in current flows within the vicinity of Bank End Farm on the flooding tide between Option TCC-4 and BS1.

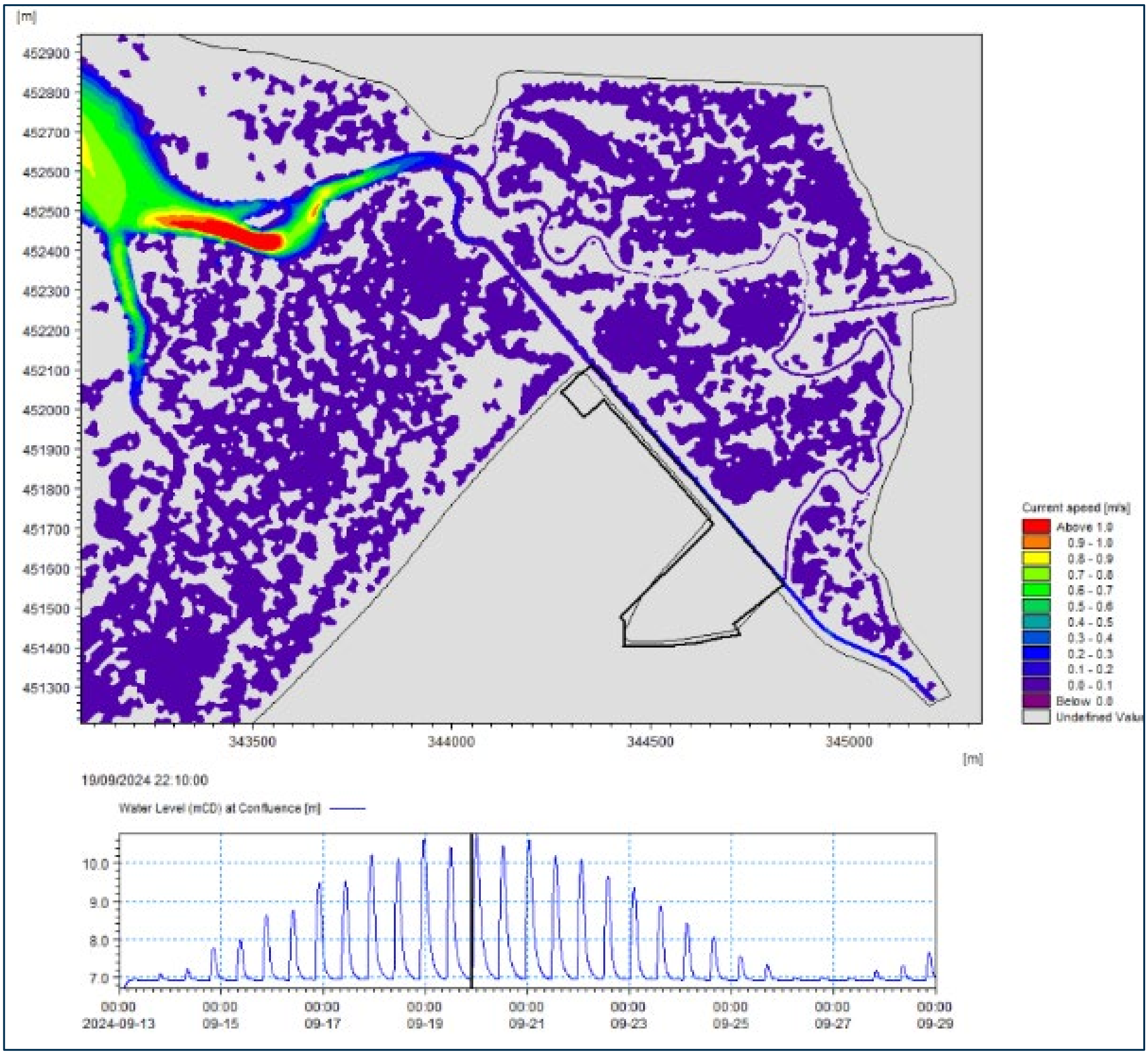


Figure 5-44 Option TCC-4: Peak flood current velocities (in m/s) in the vicinity of Bank End Farm before high tide 14

- There is a difference in the peak ebb flows in the vicinity, with Option TCC-4 showing higher values than BS1. This is likely to be due to some tidal flows being ‘circulated’ from the ‘new’ cut tidal channel through the reinstated natural tidal Cocker Channel to ebb via Patty’s Farm Creek. This appears to strengthen the ebb currents just seaward of Bank End Farm at one part of the tidal cycle, when spring tides are at their greatest (there is no such effect for much of the tidal cycle, especially during neaps).

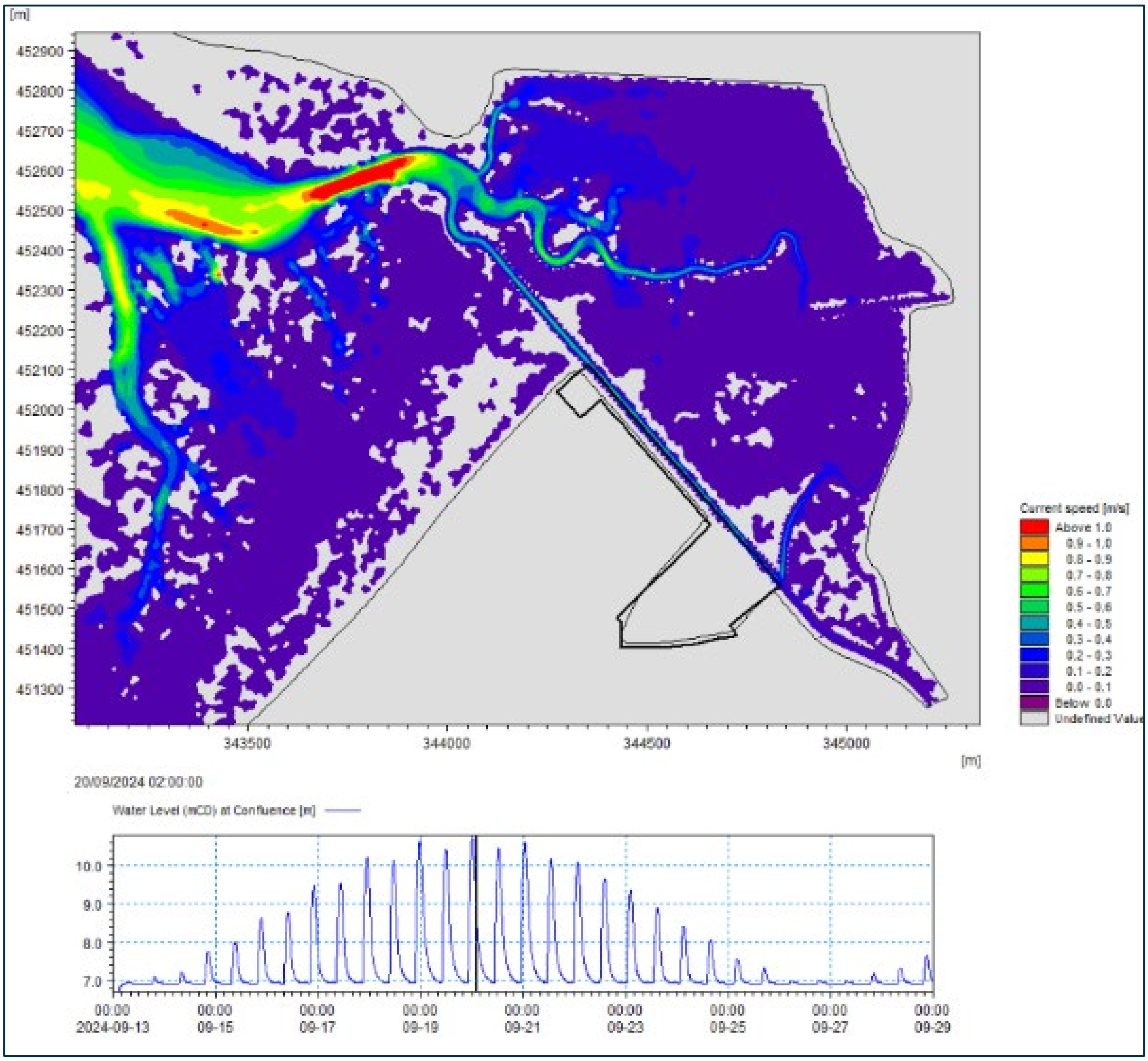


Figure 5-45 Option TCC-4: Peak ebb current velocities (in m/s) in the vicinity of Bank End Farm after high tide 14

- A timeseries plot (Figure 5-46) produced at a point seaward of Bank End Farm, within the confluence of Patty's Farm Creek and the 'new' cut tidal Cocker Channel, shows the current speeds for BS1 and TCC Option 4 over spring tides. Also plotted is the water level curve to allow identification of which currents occur during the flood and which during the ebb. Results confirm that there is no notable change in currents during the flood phase of the tide, but there is an increase in peak currents during all or most of the ebb phase.

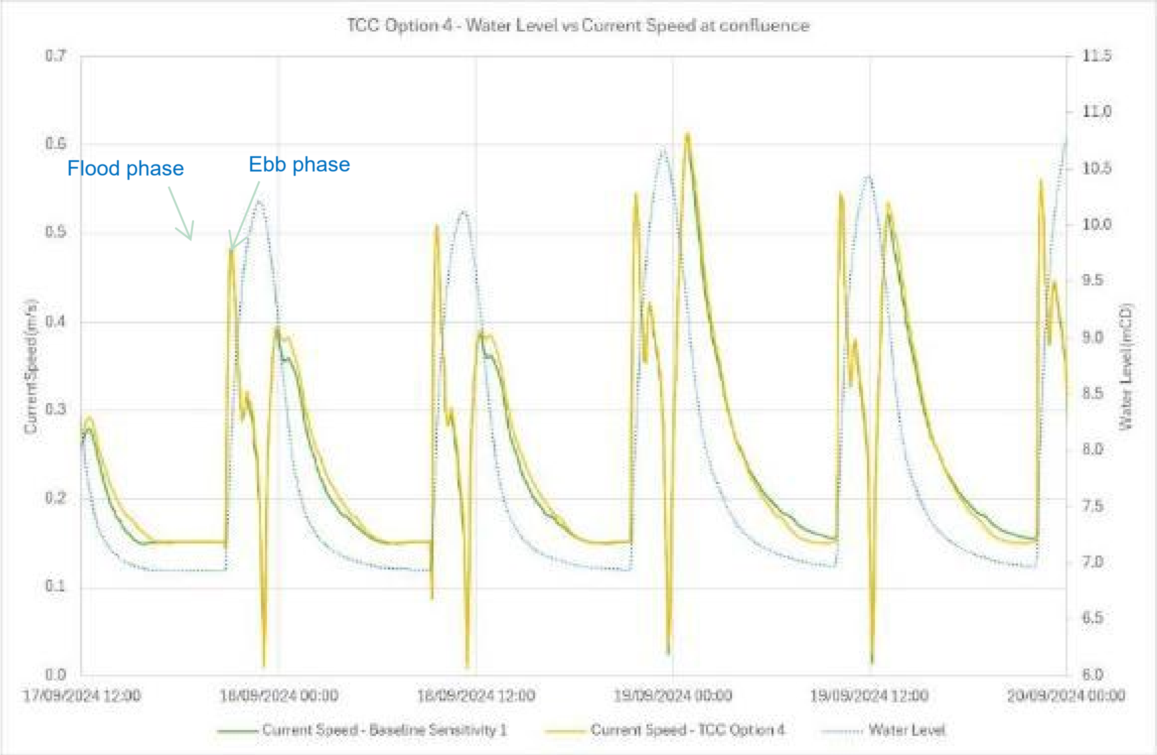


Figure 5-46 Comparison of current speed and water level for 'Baseline sensitivity 1' and 'TCC Option 4' at a point within the confluence of Patty's Farm Creek and the tidal Cocker Channel

5.5.3 'TCC-4' Summary

This section summarises the 'TCC – Option 4' simulation.

- The Tidal Cocker Channel Option 4 involves reinstatement of the natural tidal Cocker Channel whilst also retaining the 'new' cut tidal Cocker Channel.

- Modelling results for this option indicate that whilst this would not worsen the backing-up of waters (and hence would not worsen tide-locking of discharge flow from the River Cocker through Cocker Bridge tidal gates) compared to the present day, there would only localised minor advantages in terms of improved hydraulic connectivity to areas of adjacent upper saltmarsh. This is because the dominant inundation process remains submergence by tides propagating from west to east across Cockerham Sands once the threshold level of the marsh surface has been exceeded by the rising water levels.

- There is potential that by fully reinstating the natural tidal Cocker Channel and retaining the 'new' cut tidal Cocker Channel, there could be some 'circulation' of tidal flows such that when the tidal waters from the largest spring tides ebb away, they do so at higher velocities just seaward of Bank End Farm. In this location there has been a history of saltmarsh loss, and any exacerbation of currents (even temporarily and on only some stages of the tidal cycle) could increase this propensity.

5.6 Cockerham Marsh SSSI – Option 2b ('SSSI-2b')

5.6.1 'SSSI-2b' Description

'SSSI-2b' can be described as follows:

- This scenario represents a 40m wide breach made in the flood embankment which currently protects Cockerham Marsh against tidal inundation (see **Figure 5-47**).

Figure 5-47 Flood embankment and breaching arrangement used in Option SSSI-2b run

- In a similar manner of presentation to the baseline model runs, the plots below show attained **water level** in metres above Chart Datum (m CD) at various stages through the spring-neap tidal cycle.

- As for the baseline runs, the simulation commences at low water during the lowest neap tide (starting on 13th September 2024) and runs through to high water on the highest spring tides (peaking on 20th September 2024) before returning to low water during the lowest subsequent neap tides (27th September 2024).

5.6.2 ‘SSSI-2b’ Key Findings

This section describes the key findings of the ‘SSSI-2b’ simulation.

- Cockerham Marsh SSSI is not affected by tidal inundation during the neap phase of the tidal cycle.
- At high tide around the mid-point of the tidal cycle (starting from high tide 8), there is some tidal flow from the ‘new’ cut tidal Cocker Channel through the breach in the flood embankment into the delph ditch landward of the flood embankment (**Figure 5-48**).

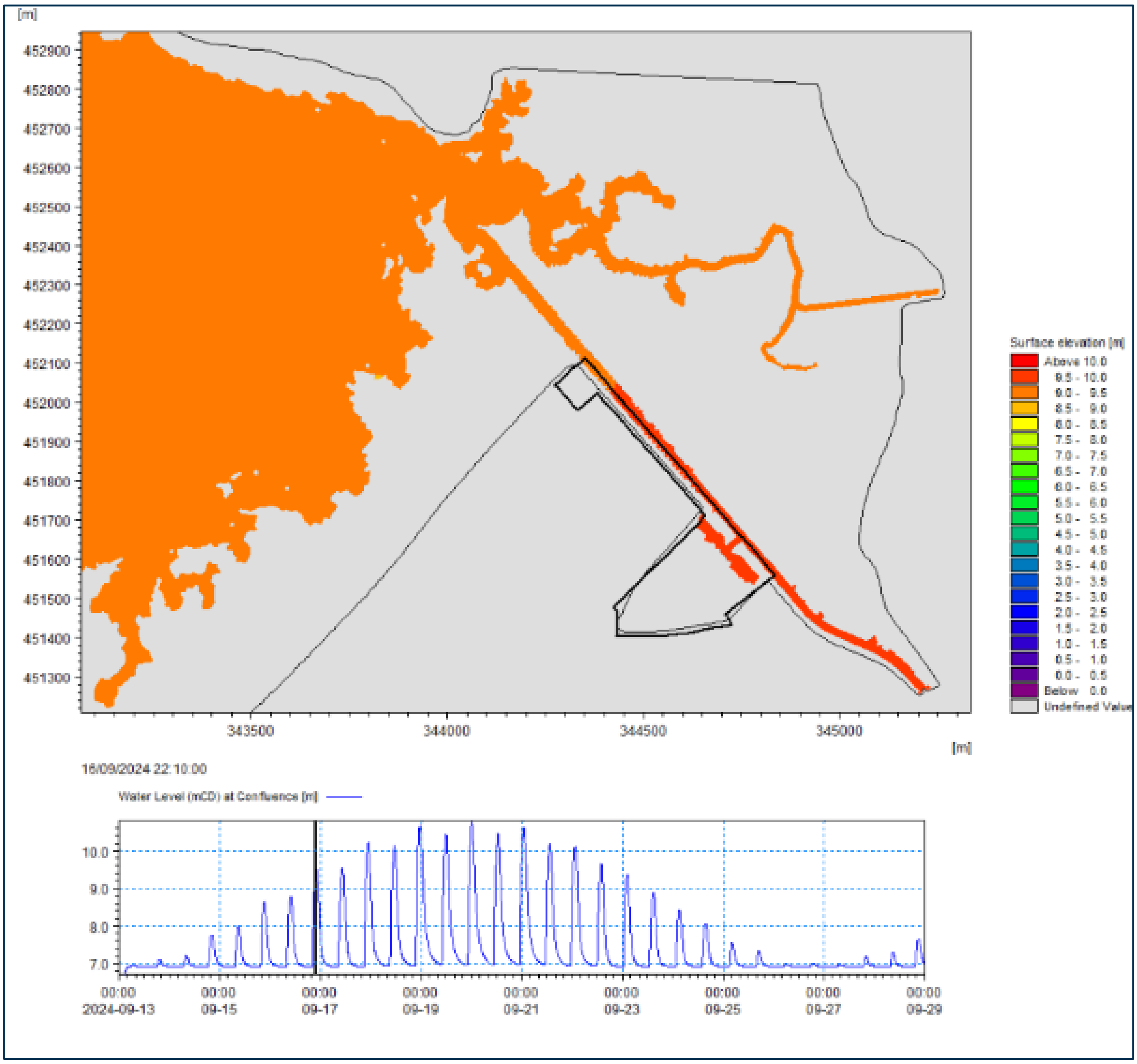


Figure 5-48 Option SSSI-2b: High water elevation (in metres CD) just after high tide 8

- By the time of the subsequent low water, the model indicates some tidal water remaining within the delph ditch (**Figure 5-49**). This pattern is repeated over subsequent successive tides, with tidal water spilling out from the delph ditch over only a narrow margin of land within the SSSI directly adjacent to the ditch.

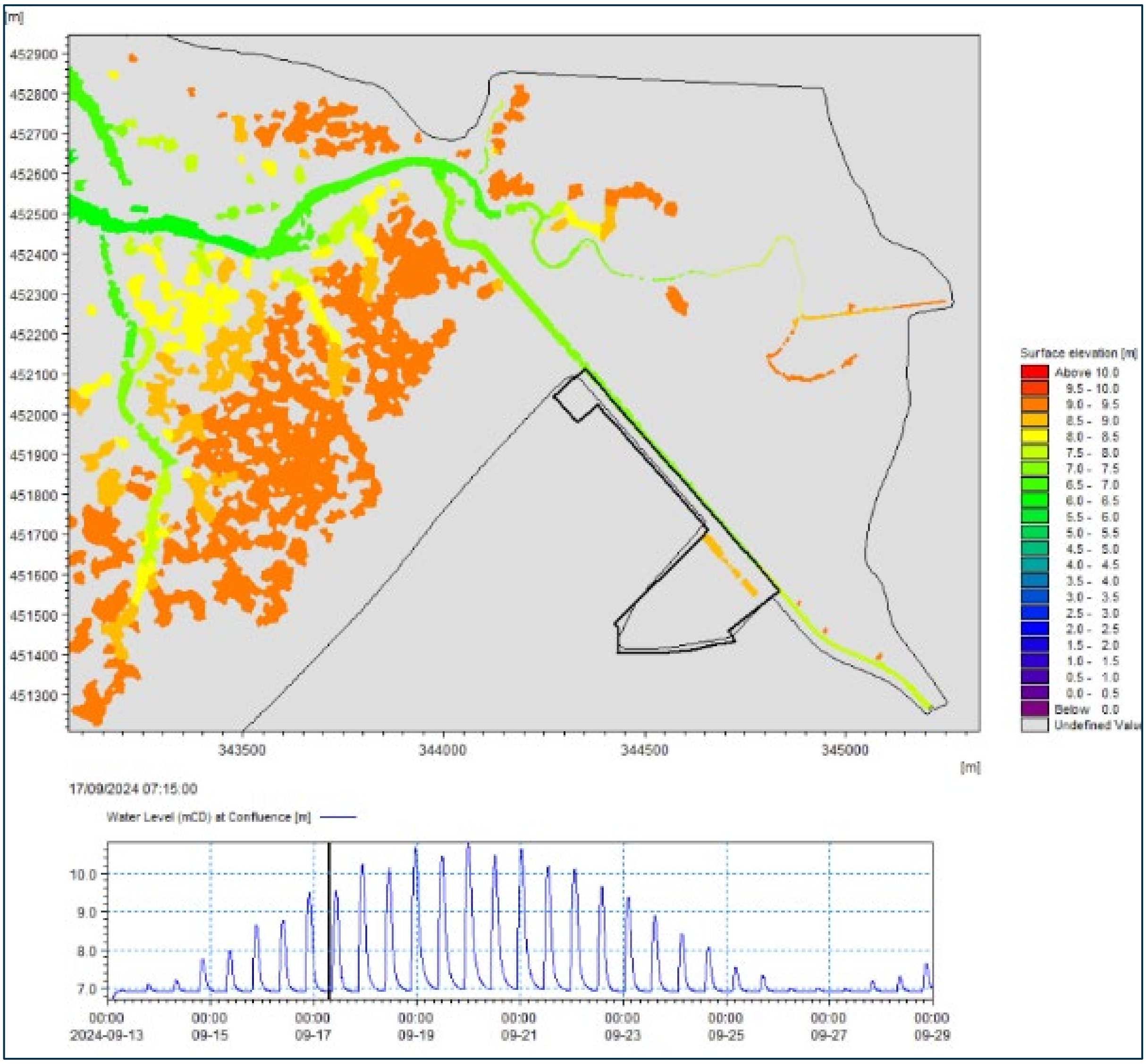


Figure 5-49 Option SSSI-2b: Water elevation (in metres CD) at low tide 9

- The first high tide which causes more significant inundation of the SSSI is high tide 12 (**Figure 5-50**), during which the southeastern parts of the site become affected. This shows the importance of introducing a new (set-back flood embankment to the eastern perimeter of the SSSI if breaching (or a similar option) is to be implemented in order to prevent tidal flooding to agricultural fields to the SSSI's southeast.

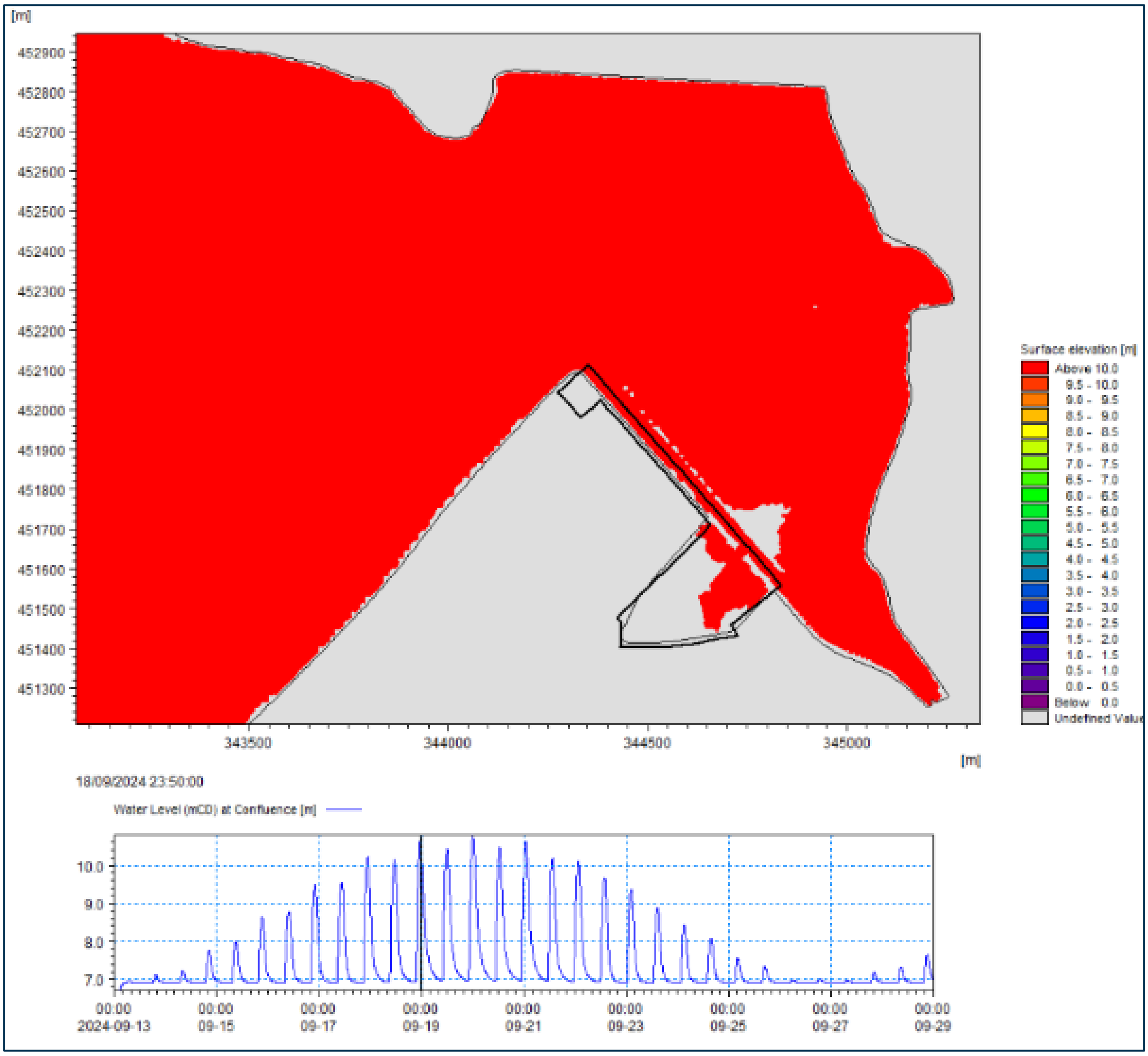


Figure 5-50 Option SSSI-2b: High water elevation (in metres CD) just after high tide 12

- By the time of the subsequent low water, the model indicates some tidal water remaining within the delph ditch and in low areas of the SSSI (**Figure 5-51**).

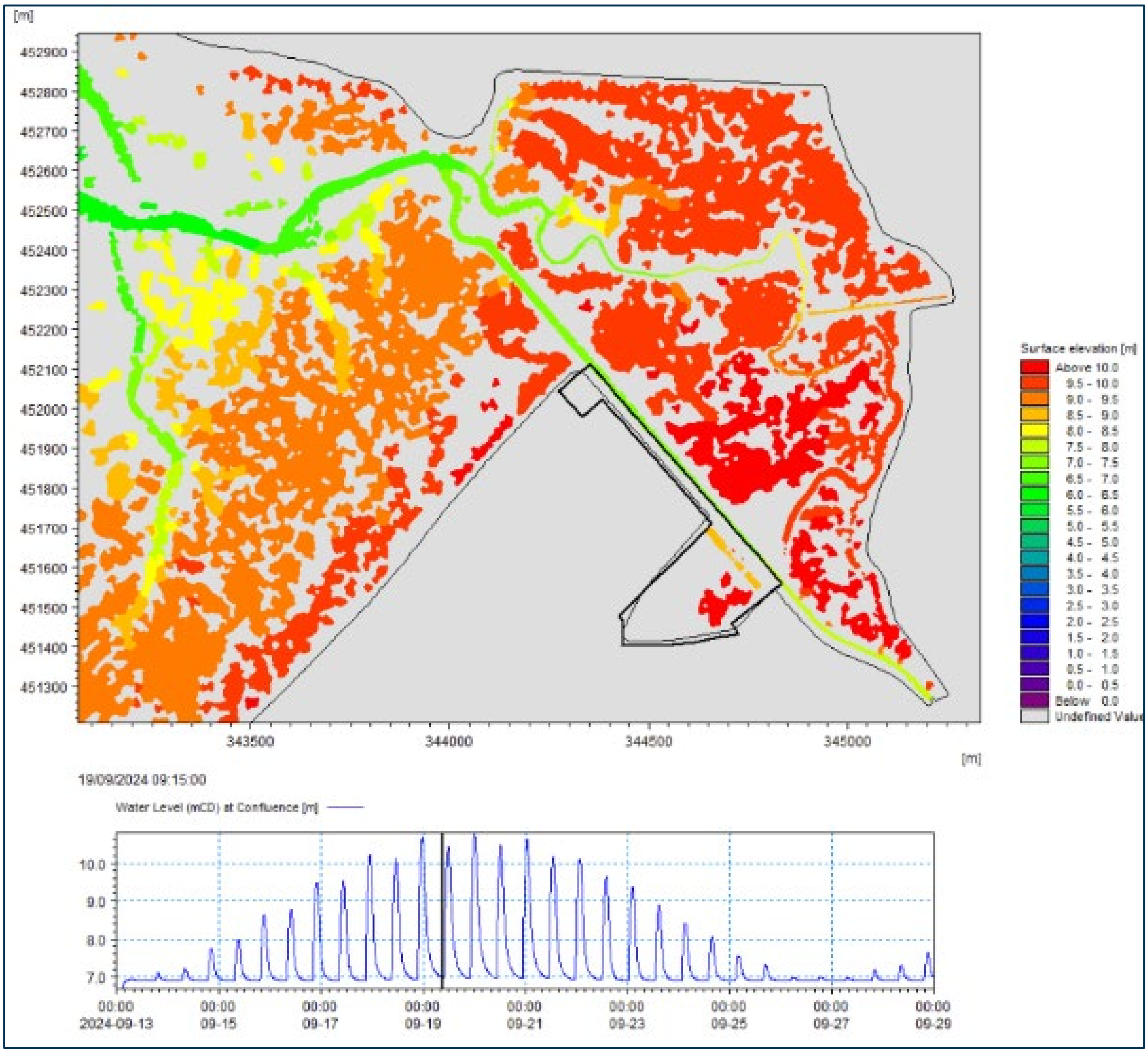


Figure 5-51 Option SSSI-2b: Water elevation (in metres CD) at low tide 13

- This pattern is repeated over subsequent successive days during the peak of the spring tide phase of the cycle, with high tide 14 (the largest modelled high water, **Figure 5-52**) causing the greatest extent of tidal inundation of the SSSI. However, even under this tidal condition, there remains a notable parcel of land towards the eastern side of the SSSI which remains unaffected by tidal water, suggesting that earthworks may locally be required to encourage flow to reach all ponds and pools within the site.

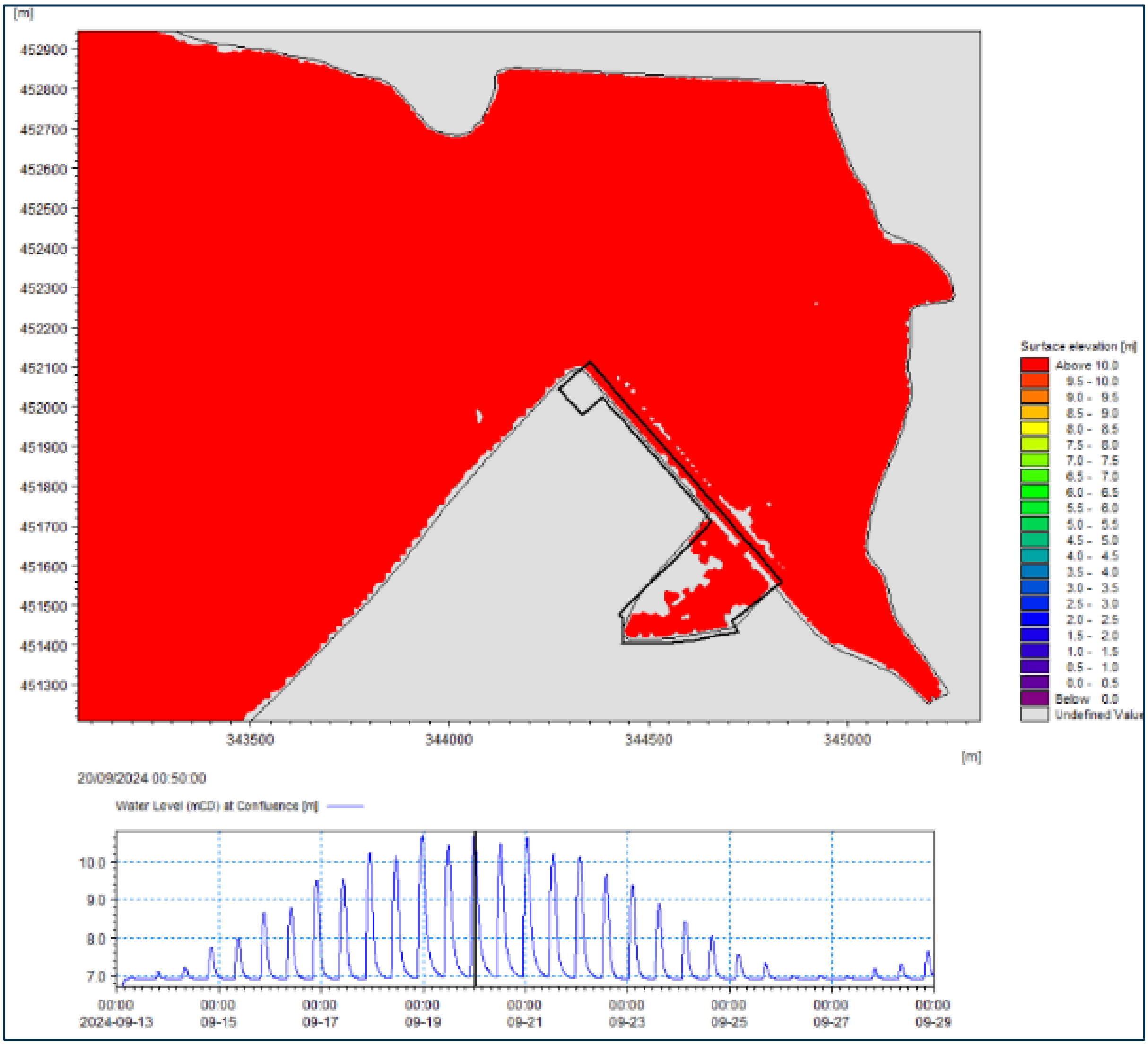


Figure 5-52 Option SSSI-2b: High water elevation (in metres CD) just after high tide 14

- The plots below show current velocities in metres per second (m/s) at the time of peak flooding flow (**Figure 5-53**) through the 40m wide embankment breach and peak ebbing flow (**Figure 5-54**) through the breach on the highest spring tide that was simulated.

- During these tidal phases, the currents through the breach (and across areas immediately adjacent to the breach) are locally increased, but absolute values remain low, suggesting a slow infilling (or draining) of the SSSI through the breach from the tidal Cocker Channel. There is no indication from these model results that there would be adverse effects elsewhere in Cockerham Sands of tidal processes.

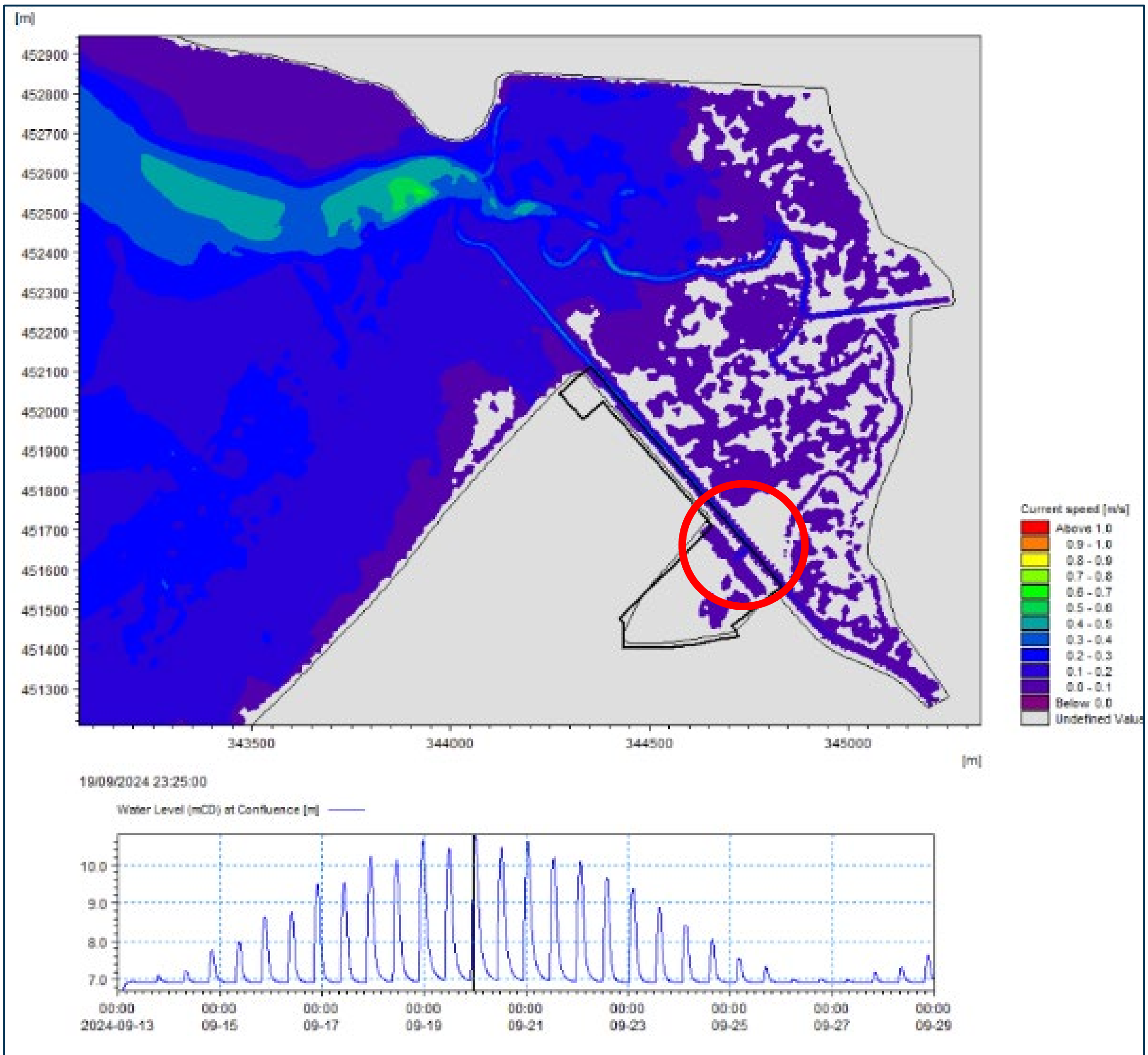


Figure 5-53 Option SSSI-2b: Peak current speed through breach (in m/s) on flood phase of high tide 14

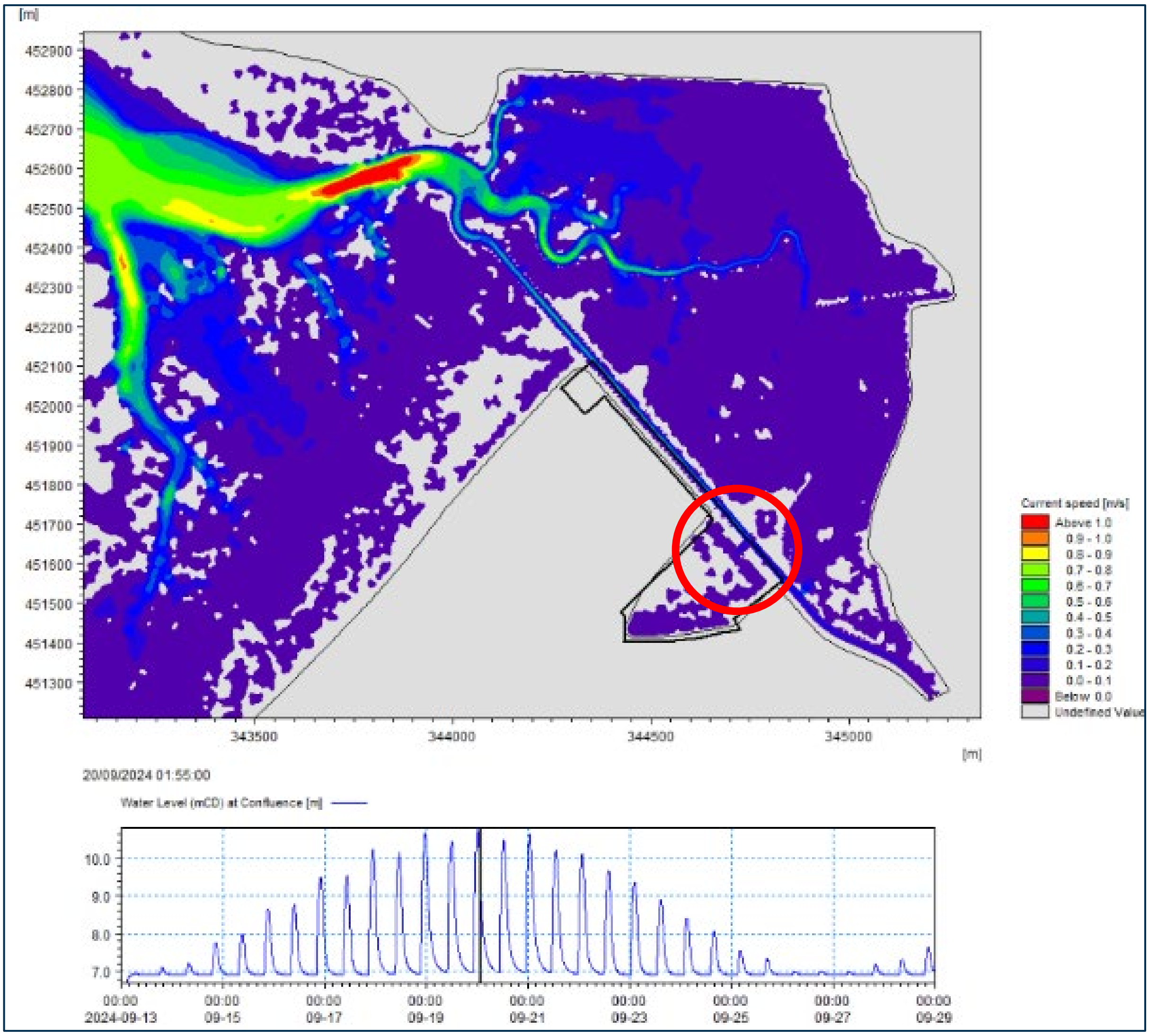


Figure 5-54 Option SSSI-2b: Peak current speed through breach (in m/s) on ebb phase of high tide 14

5.6.3 ‘SSSI-2b’ Summary

This section summarises the ‘SSSI-2b’ simulation.

- Model results for the option of breaching the flood embankment (‘SSSI-2b’) show that tidal flooding would enter through the breach and fill the delph ditch during spring tides (between 16/09/2024 and 23/09/2024 in the modelled simulation period).

- For the earliest and latest days within this time period, inundation would only affect the delph ditch and a very narrow sliver of SSSI land adjacent to the delph ditch (due to overspilling from the ditch).

- During the peak of the spring tides (19/09/2024 – 21/09/2024 in the modelled simulation period), there are five successive high tides that would reach sufficient levels to inundate a greater proportion of the SSSI site.

- However, model results also show that these events do not influence the entirety of the site and so some local earthworks are likely to be required to ensure some tidal connectivity with all pools and ponds.

- Other key findings from the model results are:

    - Notable engineering intervention would be required to exclude tidal flood waters from adjacent land areas beyond the SSSI.
    - Local earthworks would be required to optimise tidal connectivity between pools and ponds on the SSSI.

- It is also inferred that similar results to this SSSI Option 2b could be obtained from other options that reintroduce tidal processes to the site, with the critical determining factors in selection of the preferred option likely being: (i) capital cost; (ii) extent of engineering intervention in the natural landscape setting; (iii) degree of desired management ‘control’ over inundation frequencies; (iv) ongoing maintenance and management requirements.

- In conclusion, the model results show that it is technically feasible to restore occasional tidal processes to ponds and pools within the SSSI for the potential benefit of Natterjack toads.

- However, as described in the accompanying Task 4 (Cockerham Marsh SSSI), this tidal restoration alone is not an absolute determiner of success and ongoing ecological management and maintenance of the SSSI for the benefit of its sole key interest species would still be required.

5.7 Climate Change

Future projections of climate change, and in particular its effects on sea level rise, storm surge, wind speed, wave height, rainfall and river flow, were provided in the Task 1 report.

In summary, the key findings are:

- Mean sea level will be 0.68m - 0.93m higher in 2100 (than a base date of 2018);
- A 1 in 200-year return period storm surge will be 0.68m higher in 2100 (than a base date of 2018).
- Allowances for wind speed should be 10% greater for 2100 (than a base date of 1990).
- Allowances for wave height should be 10% greater for 2100 (than a base date of 1990).
- Allowances for rainfall should be 35% - 50% greater for the 2070s (than a base date of 1990).
- Allowances for river flow should be 49% - 92% greater for the 2080s (than a base date of 1990).

In terms of marine processes (sea level rise, surge, wind and wave), it was originally intended to run the numerical model for a ‘climate change’ scenario, where the water level could be increased at the model boundary to reflect sea level rise and/or storm surge effects. However, through agreement with the Project Steering Group, this run was substituted by an ‘historic baseline’ run which it was felt would be more instructive to the optioneering exercise in Task 2a. However, it would be expected that future increases in sea level rise would lead to increased submergence of the existing intertidal areas as the marks of both low and high water transgress landwards. This would mean that existing lower mudflat areas become permanently submerged at low water, and the mudflat/saltmarsh margin moves landwards. The effect of this transgression upon areas of existing upper saltmarsh/transitional habitat would depend upon the balance between the rate of sea level rise and the rate of sedimentation. If these factors were to balance, then the upper saltmarsh area would retain its position relative to the rising tidal frame. If sedimentation outpaced sea level rise, the upper saltmarsh would become elevated out of the tidal frame and increasing areas would become rank and evolve towards terrestrial vegetation. If sea level rise outpaced sedimentation, the upper saltmarsh would become increasingly inundated and some existing rank vegetation would become upper saltmarsh.

Changes in wind speed and wave height would largely have the effect of generating higher storm-driven currents that would become superimposed upon the baseline tidal currents and could lead to increased erosion of sediments. Once mobilised, these sediments would be transported in suspension until the storm passes and, thereafter, they would become deposited in areas elsewhere within the coastal system, likely largely on the intertidal mudflats and saltmarshes. Such effects could lead to increased tendency for siltation against existing culverts and sluices if deposition occurred towards the head of creeks and drainage channels.

In terms of increased rainfall and its effects on increased river flow, model outputs from the baseline sensitivity tests are useful for inferring probable outcomes on the coastal system. As the dominant processes are tidal, the increased river flow will not cause a highly significant effect on the existing tidal Cocker Channel. Of more importance is the likely increase in flooding of hinterland areas of farmland, from increased rainfall and surface water and from out of bank flows (which in part may become exacerbated by increased tide-locking or siltation at outfalls and sluices).

It is difficult to model predicted effects of climate change comprehensively; usually models may investigate the sensitivity of the system to one aspect (such as river flow or sea level rise) independently of other aspects, with outputs being used to inform management decisions. With this in mind ongoing science, monitoring, forward planning and adaptive management practices are often used to address the challenges of climate change.

6 Conclusions

A modelling study has been undertaken using the MIKE21-HD numerical model to inform the Cocker Tidal Channel and Cockerham Marsh SSSI restoration investigation.

Hydrodynamic information for the study site and wider area has been simulated to enable a comparison of water levels, tidal currents and bed shear stresses for both: (i) the ‘baseline’ (present day) conditions; and (ii) the conditions with defined options considered.

The model has been developed using suitable available survey data from a variety of sources and its mesh has been constructed to provide an optimal balance between computational efficiency and required level of detail, with a finer mesh used near the study area and a coarser mesh used in more remote areas such as the offshore seabed.

The model verification runs (comparing simulated outputs against predicted data) and associated sensitivity tests provided important information on the hydrodynamic conditions within the study area.

The modelling demonstrates the study area to be within a complex hydrodynamic and morphological system, with strong inter-relationships between alignment and depth of tidal channels and the tidal and (to a lesser extent) fluvial processes that prevail. Results from the modelling particularly show the following:

<u>Baseline and Sensitivity</u>:

- Model results for the baseline option (which includes no flow from the River Cocker) and two baseline sensitivity tests (which both include flow from the River Cocker) characterise the tidal propagation within the Outer Cocker Channel, ‘new’ cut tidal Cocker Channel and other main channels, as well as across the saltmarsh surface of Cockerham Sands progressively from neap tides to spring tides.

- During the higher spring tides, much of Cockerham Sands (seaward of the Pilling-Cockerham embankment) becomes fully inundated at high water, but large areas of saltmarsh seaward of the Cocker Bridge to Patty’s Farm embankment remain dry until the very highest spring tides.

- Tidal current velocities are greatest within the Outer Cocker Channel (west of Bank End) and are dominated by tidal processes. With the inclusion of flow from the River Cocker, there is no measurable change in high water level or tidal phasing, but more water is retained within the channels at low water. There is also a slight reduction in peak flood currents and a slight increase in peak ebb currents within part of the Outer Cocker Channel compared to the baseline with no river flow, but the differences are not significant in magnitude.

<u>Historic Baseline</u>:

- Historically, with the original natural meandering channel and no ‘new’ cut present, it appears that water may have been retained within the natural tidal channel to a higher level in its upper reaches and flow conveyance of freshwater away from Cocker Bridge is not as efficient as the present-day baseline with the ‘new’ cut present.

- Envisaged benefits from reinstating the natural tidal Cocker Channel in terms of improved hydraulic and ecological functioning do not appear to be fully manifest, as the tide reaches most areas of upper saltmarsh by submergence due to flooding spring tides as they propagate across Cockerham Sands from the west, rather than extensive areas of saltmarsh becoming inundated through overspilling the banks of the reinstated tidal Cocker Channel, which is considerably more localised process.

- There is a difference in the peak ebb flows in this vicinity between the historic baseline (which shows slightly lower peak values) and the present-day baseline (which shows a slightly localised increase) at certain tidal phases, although the magnitude of difference is small compared to the considerably more dominant currents generated by natural tidal processes. It is therefore considered that efforts to re-naturalise the tidal Cocker Channel would have only modest flood risk benefit to Bank End Farm.

Tidal Cocker Channel Option 4 (Reinstatement of natural tidal Cocker Channel):

- This option would not worsen the backing-up of waters (and hence would not worsen tide-locking of discharge flow from the River Cocker through Cocker Bridge tidal gates) compared to the present day, but there would only localised minor advantages in terms of improved hydraulic connectivity to areas of adjacent upper saltmarsh.

- There is potential that by fully reinstating the natural tidal Cocker Channel and retaining the 'new' cut tidal Cocker Channel, there could be some 'circulation' of tidal flows such that when the tidal waters from the largest spring tides ebb away, they do so at higher velocities just seaward of Bank End Farm. In this location there has been a history of saltmarsh loss, and any exacerbation of currents (even temporarily and on only some stages of the tidal cycle) could increase this propensity.

Cockerham Marsh SSSI Option 2b (Breach in flood embankment):

- When a rising spring tide reaches a suitable threshold level, tidal flooding would enter the SSSI through the breach in the embankment and initially fill the delph ditch and a narrow sliver of SSSI land adjacent to the delph ditch (due to overspilling from the ditch).

- During the peak of the spring tides, there are successive high tides that would reach sufficient levels to inundate a greater proportion of the SSSI site. However, these events would not influence the entirety of the site and so some local earthworks are likely to be required to ensure some tidal connectivity with all pools and ponds. Additionally, notable engineering intervention would be required to exclude tidal flood waters from adjacent land areas beyond the SSSI.

- It is deemed technically feasible to restore occasional tidal processes to ponds and pools within the SSSI for the potential benefit of Natterjack toads. However, this tidal restoration alone is not an absolute determiner of success and ongoing ecological management and maintenance of the SSSI for the benefit of its sole key interest species would still be required.

The numerical modelling undertaken for the project has helped both (i) understand and characterise baseline conditions; and (ii) assess how those conditions may change under different river flows, tidal states, and management options.

These outputs have been used to inform the study's optioneering (Task 2a) stage.