Annex 32.4

Model Testing of a 90 ha Layout

(Black & Veatch)

Cherry Cobb Sands Compensation Site

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Figures 8, 9, 10 and 21 have been produced using Ordnance Survey data.

1 INTRODUCTION

1.1 SITE DESCRIPTION

1.1.1 The Able Marine Energy Park (AMEP) is expected to require a compensatory managed realignment on the north bank of the Humber at Cherry Cobb Sands. The size of the required compensation was not finally agreed at the time of preparing this Annex but the 90 ha site shown on Figure 1 has been tested as a possible Compensation Site. The existing ground levels within this site are approximately 2.5 mAOD. Approximately 300,000 m^3 of fill has been removed from within the site to form the surrounding flood defences. The sections on Figure 1 show the final topography of the site.

1.1.2 The majority of fill for the embankments has been won by lowering ground levels by approximately 1.0 m in the southern portion of the site near the proposed breach where the site investigation showed the soil was likely to be more suitable for reuse as embankment fill than further north. The remainder of the site has been graded between 2.0 and 2.5 mAOD to allow drainage of the site at low tide. The breach is shaped as a shallow 250 m wide Vee with an invert level sloping from 2.2 mAOD on the edges to 2.0 mAOD in the centre of the breach. This is designed to ensure that the last flows draining each ebb tide are focussed into the centre of the breach and so encourage any creek formation to occur in the centre rather than adjacent to one or other ends of the breach.

1.1.3 The assumed layout of the site shown in Figure 1 makes the assumption that all the material excavated below the topsoil layer will be suitable as embankment fill. In practice this may not be the case and the locations of the borrow pits to provide this fill may vary in depth with some 'islands' of unsuitable fill left. Some of these areas might be re-profiled, while others might be left to provide greater variety in the topography of the site. Such decisions will need to be made at the time the fill is selected or rejected as suitable for use in the embankment. These model studies are intended to provide a good indication of how the site is likely to perform hydraulically while accepting that in a site where performance is very sensitive to small variations in level the practical considerations of choosing suitable fill during construction may make lead to minor alterations in its initial behaviour.

1.1.4 The breach invert level of 2.0 mAOD will ensure that those areas where excavation has taken place below this level will initially remain submerged at all states of the tide cycle. The remaining areas are set above 2.0 mAOD are expected to drain out each tidal cycle and those low lying areas that do not have time to drain during spring low water, will drain out each fortnight during the neap tide periods when there will be much less inundation of the site.

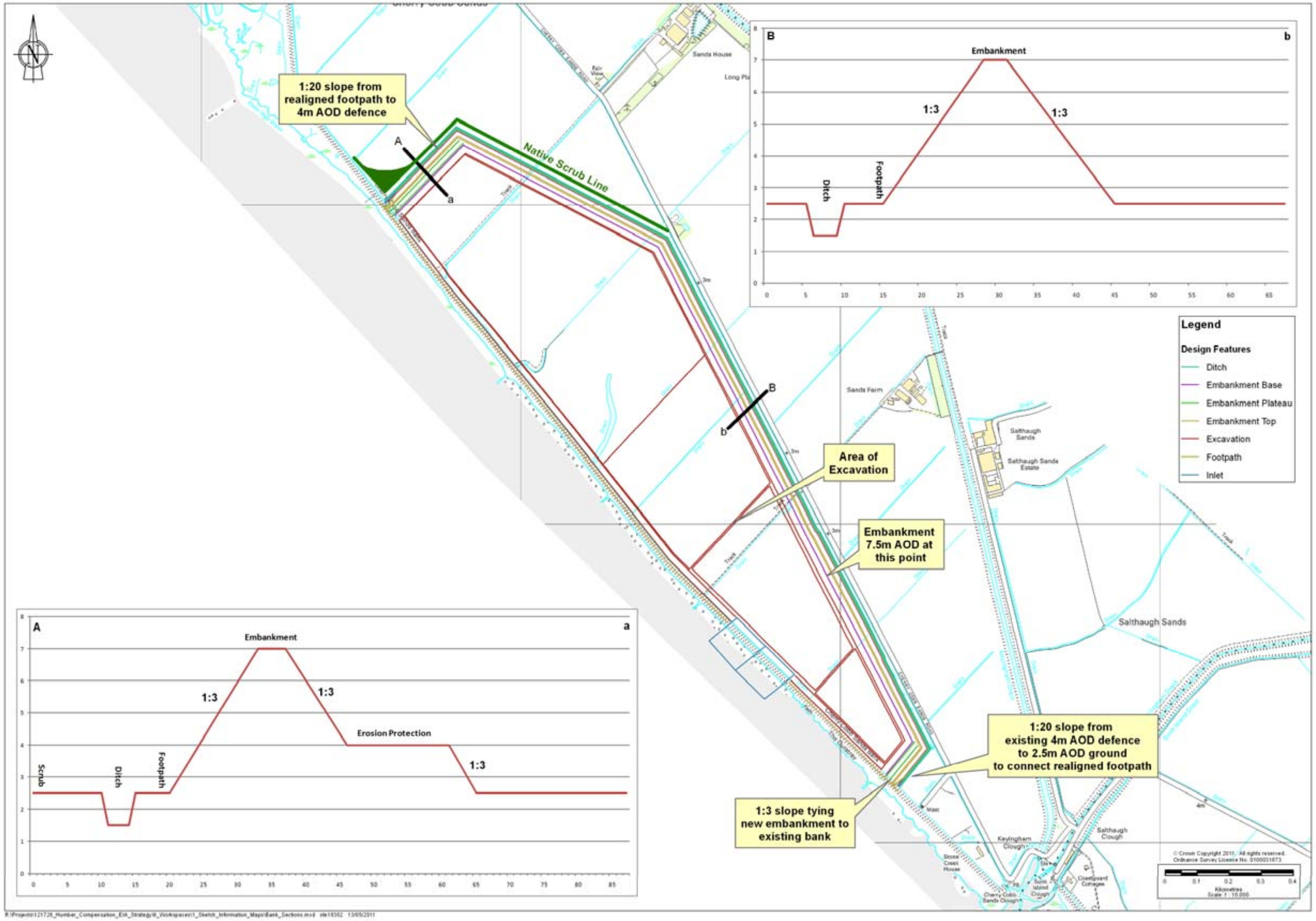


Figure 1 90 ha Compensation Site tested in model

1.2 PREVIOUS MODEL STUDIES

1.2.1 The preferred location invert level and size of the breach was determined from the preliminary studies reported in Annex 32.3. This study concluded: *A 250 m long breach with an invert level of 2 mAOD is recommended situated towards the southern end of the Compensation Site. Removal of some of the saltmarsh fronting the breach site down to 2 mAOD is recommended, with the expectation that all the saltmarsh fronting the breach site will be eroded away fairly rapidly, leading to a direct loss of about 2 ha of saltmarsh.*

1.3 FORESHORE TOPOGRAPHY AND MODEL LIMITS

1.3.1 A digital terrain ground model (DTM) has been set up by combining bathymetry from the 2010 ABP navigation chart, the LiDAR flown in 2007 by the Environment Agency and a 2010 topographic survey of the Compensation Site and adjacent features carried out for Able. The match line between the bathymetry and LiDAR surveys was set at -2 mAOD, where a good match between both surveys was found. There was also no evidence of inconsistency between the levels obtained from the LiDAR survey and those measured in the topographic survey.

1.3.2 The outflow from the Cherry Cobb Sands Compensation Site is expected to flow into a large creek named for this study as "Cherry Cobb Sands Creek" that runs parallel to and about 80 m seaward of the existing flood defences. The topography of the creek and foreshore is shown on Figure 2. Cherry Cobb Sands Creek drains to the south and picks up drainage flowing through the four sluices at Stone Creek and continues parallel to the coast for a further 2 to 2.5 km before turning seaward and entering the low water channel of the Humber. The southernmost part of the creek is believed to be fairly dynamic. Foul Holme Sands separates Cherry Cobb Sands Creek from the main Humber low water channel.

1.3.3 The boundaries of the model are shown on Figure 2. The set up of the hydraulic model and the derivation of its boundary conditions are described in Annex 32.2. For this model testing of the preferred layout the model boundary conditions were taken from the Humber model described in Annex 8.1 and the performance of this detailed model of Foul Holme Sand and the Compensation Site was verified using velocities calculated by the JBA model (JBA, 2011) as no independent measurements of velocity or level were available within the model domain. The results of the verification tests are described in Annex 32.2.

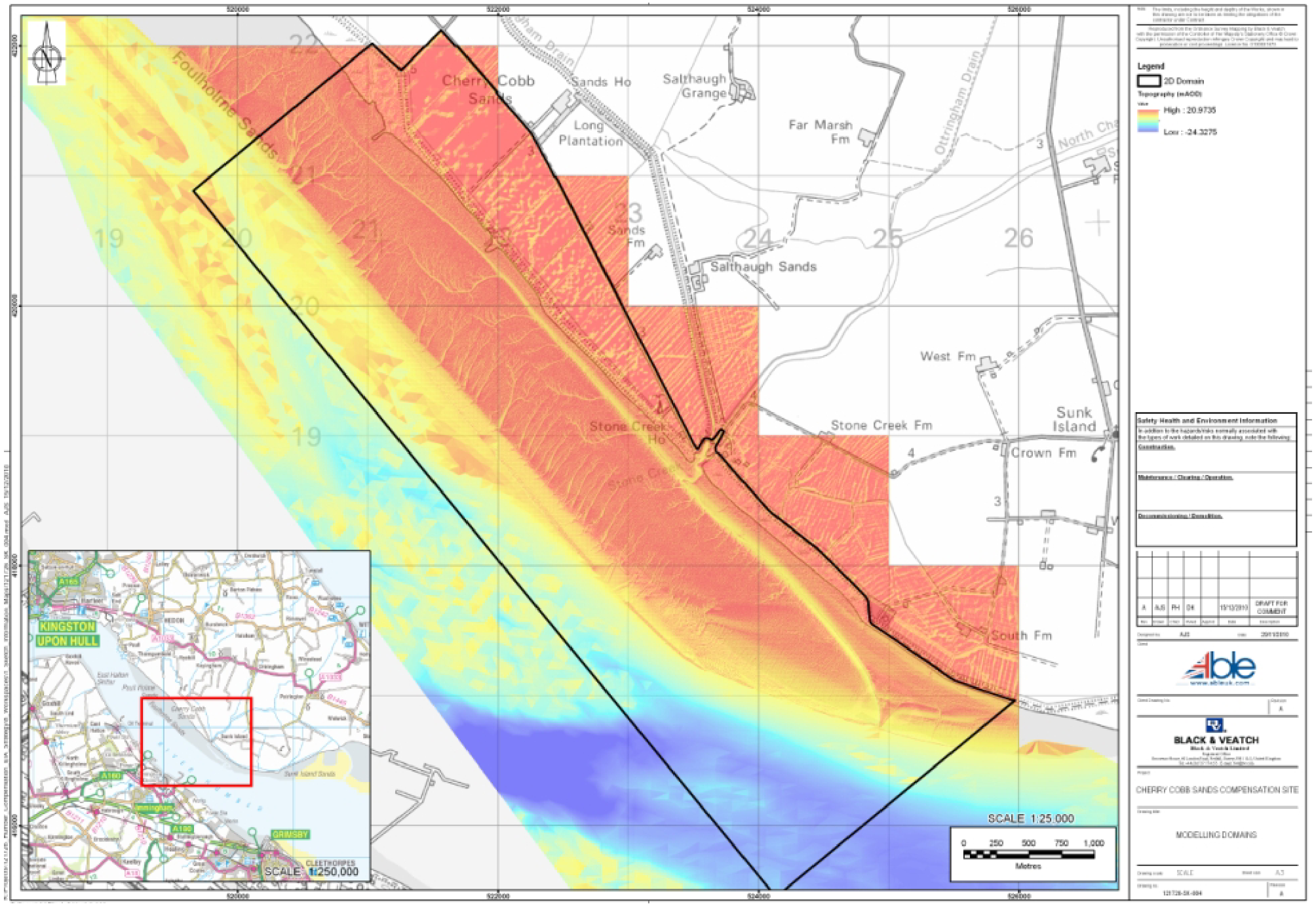


Figure 2 Foreshore topography and model boundaries near Cherry Cobb Sands

1.4 TIDAL BOUNDARY CONDITIONS

1.4.1 Inspection of the tide tables for Immingham (1996 and 2008-2011) has been used to indicate the frequency of exceedance of particular high water levels. As high water levels reduce, the frequency these high water levels are exceeded increases as indicated on Table 1. The variability in the frequency of occurrence from year to year is a natural phenomenon as tide heights vary from year to year in response to the large number of astronomic tide raising forces that determine predicted tide heights.

1.4.2 In addition to the astronomic forces controlling tidal conditions, meteorological conditions cause observed tide heights to differ from those predicted for each day in response to local winds and pressure systems. In practice as meteorological conditions can both raise and reduce tide levels, their overall effect on the frequency of occurrence is fairly small with the important exception of extreme tides which can only occur when extreme meteorological conditions occur in combination with large predicted tides.

1.4.3 The maximum frequency of predicted tides above 2.5 and 3.4 mAOD in these five years occurred in 1996 and the minimum in 2008. This may reflect the effect of the lunar nodal tide that modulates the main lunar component on an 18.6 year cycle. This cycle was at its peak in 1996 and a minimum in 2006. The occurrence of very high tides exceeding for example 3.8 mAOD follows a more complex pattern with the greatest frequency occurring in 2011 and the minimum in 2008.

Table 1 Frequency of occurrence of high tides at Immingham 1996, 2008-2011

Level mAOD	1996	2008	2009	2010	2011	Average (5 years)	Average (3 years)
Percent>2.1	88.3			82.4	83.7		84.8
Percent >2.5	64.0	55.5	56.7	58.6	59.6	58.9	59.4
Percent ≥ 3.0	41.2	32.3		34.8			36.1
Percent ≥ 3.4	15.4	9.6	10.8	11.2	11.9	11.8	12.1
Percent ≥ 3.8	2.5	0.4	1.3	2.6	2.8	1.9	1.8
Percent ≥ 4.0	0.3	0.0		0.7			0.3

1.4.4 The tidal analysis suggests that different classes of tides are likely to affect the Compensation Site in different ways. The frequency that particular tide height classes occur is shown on Table 2. The largest tides, those above 3.8 mAOD, inundate the site most deeply and are likely to be associated with the highest velocities, but as they occur infrequently they probably only have a limited effect on the evolution of the site. Smaller tides with heights between 3.0 and 3.7 mAOD have lower velocities, but with much increased numbers as the height reduces are likely to be more dominant in the evolution of the site. As tide height reduces below 3.0 mAOD, the associated velocities will continue to reduce so these smallest tides, although fairly frequent are unlikely to have a major effect on site evolution.

1.4.5 In order to try and represent the effects of the different tide types, tide heights in Table 2 have been selected to represent the different tidal conditions. The chosen tidal conditions have also been selected from the tides that were used for calibration of the Humber model from May 2010 and for its verification in September 2010 as described in Annex 8.1. The four selected tides area available for assessment of geomorphology, though those with high tide levels of 3.55 mAOD and 3.1 mAOD are used for illustration in this report as these tidal heights represent the more frequently occurring conditions that are likely to dominate the evolution of the Compensation Site and the adjacent foreshore.

Table 2 Frequency of occurrence of each range of high tide level at Immingham

Range of HW level (mAOD)	Average frequency of occurrence (%)	Representative HW level (mAOD)
2.6 - 2.9	23	2.8 (am tide 18/5/10)
3.0 - 3.3	24	3.1 (am tide 16/5/10)
3.4 - 3.7	10	3.55 (pm tide 8/9/10)
3.8 - 4.1	2	3.85 (am tide 9/9/10)

2 *ISSUES FOR THE MODEL TESTING OF THE COMPENSATION SITE*

2.1 *BREACH LOCATION*

2.1.1 The choice of breach arrangement was the primary focus of the earlier model studies reported in Annex 32.3. These recommended that a 250 m breach with an invert level of +2 mAOD was appropriate for the Cherry Cobb Sands Compensation Site. This has been adopted in these model tests as discussed in Section 1.1 with the chosen breach arrangement illustrated on Figure 1.

2.1.2 These model tests consider velocities through the breach, in the section connecting the breach with Cherry Cobb Sands Creek and immediately landward of the breach to gain understanding of the likely stability of the breach.

2.2 *ENLARGEMENT OF CHERRY COBB SANDS CREEK*

2.2.1 The previous model studies reported in Annex 32.3 showed that flows in Cherry Cobb Sands Creek that runs in front of the flood defences increase significantly during ebb tide periods as a result of the drainage of the managed realignment site.

2.2.2 These model studies of the adopted layout are intended to review this finding and give some indication of how the creek might enlarge. An important related issue is to consider if the changes in the regime of Cherry Cobb Sands Creek will have any effect on the evacuation of land drainage through the Stone Creek outfalls. The risk of siltation in Stone Creek as a result of the development was raised in the responses to the Public Consultation on the AMEP proposal as an important concern by the Environment Agency, the Internal Drainage Boards and local residents.

2.3 *VELOCITIES OVER FOUL HOLME SAND*

2.3.1 The presence of the Compensation Site at Cherry Cobb Sands was shown in the preliminary model studies reported in Annex 32.3 to cause a small increase in velocities across Foul Holme Sand. These increases in flow were found to be relatively small and were limited to a short period around high tide when the sand bank is fully covered with water.

2.3.2 If velocities over Foul Holme Sand increase, there is the risk of erosion of the top of the sand bank. Initially scour of the top of the sandbank is likely to be slow, but if it starts to occur and a low way forms across the sand bank, the local increase in water depth will reduce the resistance of this flow path which will increase the flow and velocity in the low way and cause more rapid scour.

2.3.3 How a creek across Foul Holme Sand might develop is very difficult to predict and will depend on the balance between processes that maintain the existing sandbank in its present alignment and shape and the power of the water entering and leaving the managed realignment site to increase the size of any low way.

2.3.4 Within the past 30 years there has been a channel across Foul Holme Sand which aerial photographs and old maps suggest was close to the location of the proposed breach as discussed in Annex 32.1. This annex concluded that there is unlikely to be any constraint in the geology of Foul Holme Sands that would prevent this creek re-forming. However, the presence of such a creek would be within the envelope of natural variability of this foreshore.

2.4 VELOCITIES WITHIN THE COMPENSATION SITE

2.4.1 The preliminary model tests of Annex 32.3 highlighted the presence of high velocities within the Compensation Site for a short period as the site began to fill. The area of high velocity was in an area to the north of the breach and close to the proposed flood embankment where the flow turned to fill the northern part of the site after flowing through the breach. This zone of high velocity was attributed to the shallow water as it began to flood and suggested that erosion within this area was likely.

2.4.2 The flood embankments near the area of high velocity were considered to require protection against erosion caused by these currents. The erosion protection against wave action in these areas is sufficient to protect against current erosion with suitable toe details (Environmental Statement paragraph 28.2.6).

2.4.3 Some excavation of the area where high velocities were previously predicted was required to provide the fill necessary for embankment construction. The base of this excavation was set at around +1.5 mAOD to excavate the full depth of soil that was considered suitable as fill. This is 0.5m lower than assumed in the earlier model studies of Annex 32.3. The presence of the breach invert at +2 mAOD would therefore retain 0.5 m depth of water in this area at low tide giving a greater depth of water in this area as the site started to flood.

2.4.4 The current model studies are required to predict velocities within the Compensation Site. Analysis of these results will help to identify any areas where erosion of the revised ground levels might be anticipated or where siltation rates within the Compensation Site are likely to be significantly slower than experienced in other managed realignment sites in the Humber as discussed in Annex 32.5.

2.5 FAR FIELD EFFECTS OF THE COMPENSATION SITE

2.5.1 The modelling described in this report is restricted to the effects within the Compensation Site and on the adjacent intertidal foreshore of the Humber estuary including Cherry Cobb Sands Creek and Foul Holme Sand. Any more distant effects of the Compensation Site are considered implicitly in the modelling of 'the Project' in Annex 8.1.

3 MODEL RESULTS

3.1 INTRODUCTION

3.1.1 Review of model results was a mixture of visual comparison of the flow field associated with different arrangements, consideration of maximum velocities along long sections or cross sections and review of the time history of velocities and levels at key points on the foreshore or within the site. The locations of the long sections and cross sections and the locations where time histories of velocities and levels have been extracted are shown on Figure 3.

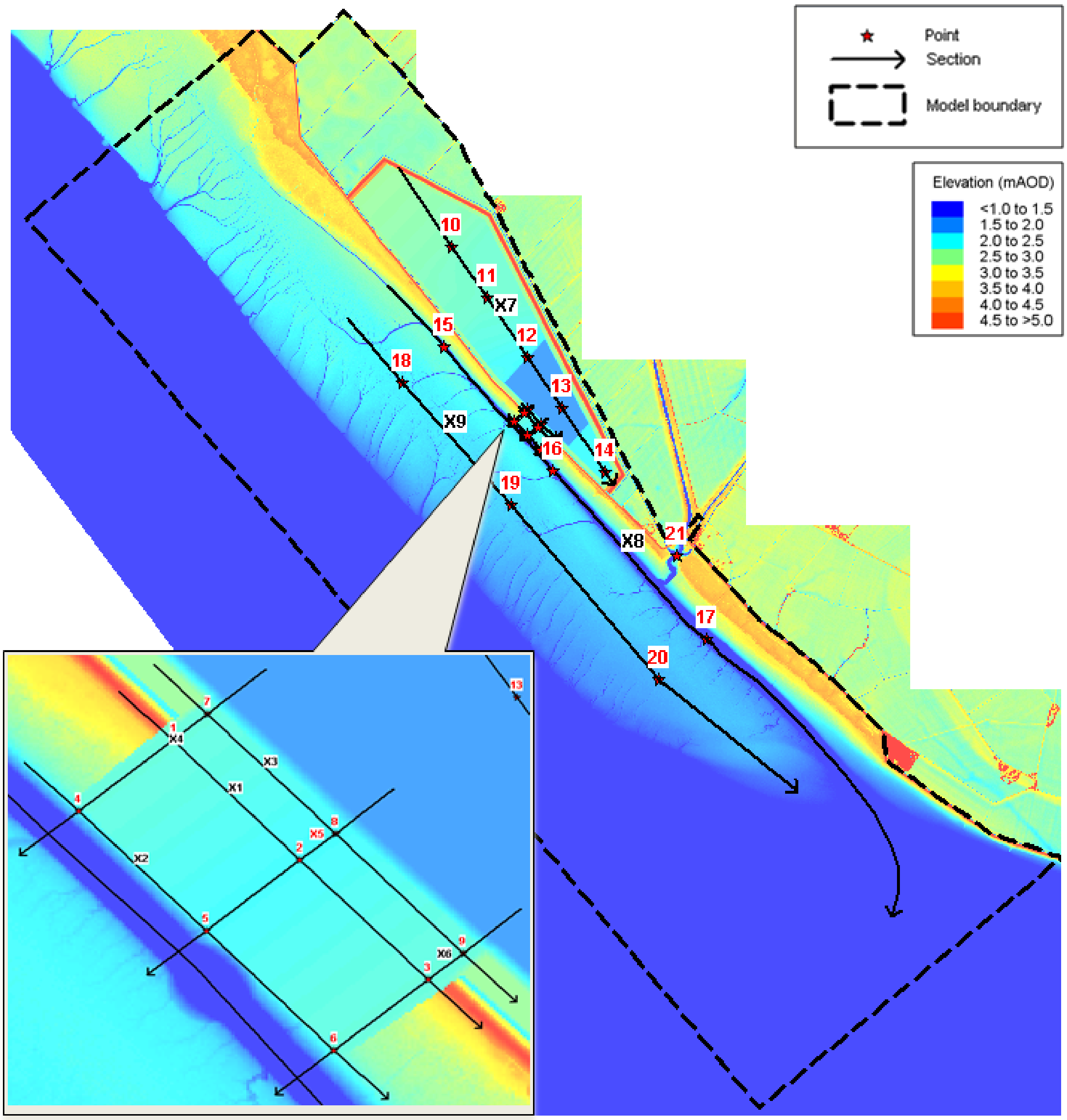


Figure 3 Sections and points where velocity and level extracted

3.2 *MODEL TIDE LEVELS*

High tide levels

3.2.1 The model tests considered the four representative tides of Table 2 at the 21 points identified on Figure 3. At the 10 comparison points within the estuary, differences between the baseline and the with-scheme high water levels could be compared. This showed that with the scheme in place high water levels across the estuary within the model domain are predicted to reduce on average by 0.004 m with a standard deviation of 0.015 m. The standard deviation suggests minor variability in the differences predicted for different tides and locations and tides, but the variability appeared random suggesting it was most probably linked to the 10 minute output frequency of the model than any differences likely to be experienced in practice.

3.2.2 Despite the minor variability in output discussed above, several features are evident from the sample results presented in Table 3 for the baseline and with scheme cases. On the north bank of the estuary covered by the model, high tide levels at Stone Creek and Foul Holme Sand are 0.05 to 0.10 m higher than at Immingham. The difference increases as the height of high water at Immingham rises. There is little evidence of a systematic difference in the high tide level across the model domain in the baseline case. As noted above the effect of the scheme on tide levels within the estuary is small and shows no systematic variation within the estuary.

3.2.3 Within the Compensation Site the predicted high water levels at the north end (Point 10) are consistently higher than in the estuary by 0.045±0.03 m. Levels at other points within the Compensation Site suggest increasing high water levels with distance from the breach site. These results suggest a small amplification in high water levels of up to 0.05 m across the Compensation Site.

Low water levels within the Compensation Site

3.2.4 Predicted high water levels with the Compensation Site on the high spring tide on the evening of 8 September 2010 are shown in Figure 4. The low water levels at each site are determined by the level of the ground at each site. The tide starts to rise approximately 40 minutes later inside the Compensation Site though the time of high water is almost the same. The tide initially falls at the same rate inside and outside, but final drainage of the Compensation Site takes longer.

Table 3 Predicted model high tide levels

Date and approx HW time	0600 9/9/10	1730 8/9/10	0700 16/5/10	0800 18/5/10
Location	**Baseline high water levels mAOD**			
Immingham JBA model (approx)	**3.85**	**3.55**	**3.10**	**2.80**
Stone Creek baseline Pt 21	3.96	3.63	3.17	2.86
Foul Holme Sand North baseline Pt 18	3.94	3.62	3.16	2.86
Location	**With scheme high water levels mAOD**			
Stone Creek with scheme Pt 21	3.96	3.64	3.15	2.84
Foul Holme sand north with scheme Pt 18	3.94	3.63	3.15	2.84
Inside site north end Pt 10	3.98	3.70	3.20	2.87

Low tide at Stone Creek

3.2.5 Drainage through the Stone Creek drainage outfalls is affected by the level and duration of low tide at Stone Creek (Point 21). The predicted duration of the low tide period, when levels were less than 0.5 mAOD, and the minimum water level during the low tide period for the four model tides are reported in Table 4. This shows that with the scheme in operation, low water levels are raised 0.10 m from 0.25 to 0.35 mAOD. The duration of the low water period reduces by 10 or 20 minutes as a result of the scheme, from the baseline average duration of 6 hours 40 minutes.

Table 4 Predicted duration and level of low water at Stone Creek

Date and approx LW time	1300 9/9/10	0030 9/9/10	1400 16/5/10	1500 18/5/10
Location	**Low water level mAOD**			
Stone Creek baseline Pt 21	0.25	0.25	0.25	0.24
Stone Creek with scheme Pt 21	0.35	0.35	0.35	0.34
Location	**Duration (hours) of levels <0.5mAOD**			
Stone Creek baseline Pt 21	6.83	6.17	6.67	7.00
Stone Creek with scheme Pt 21	6.50	5.83	6.50	6.83

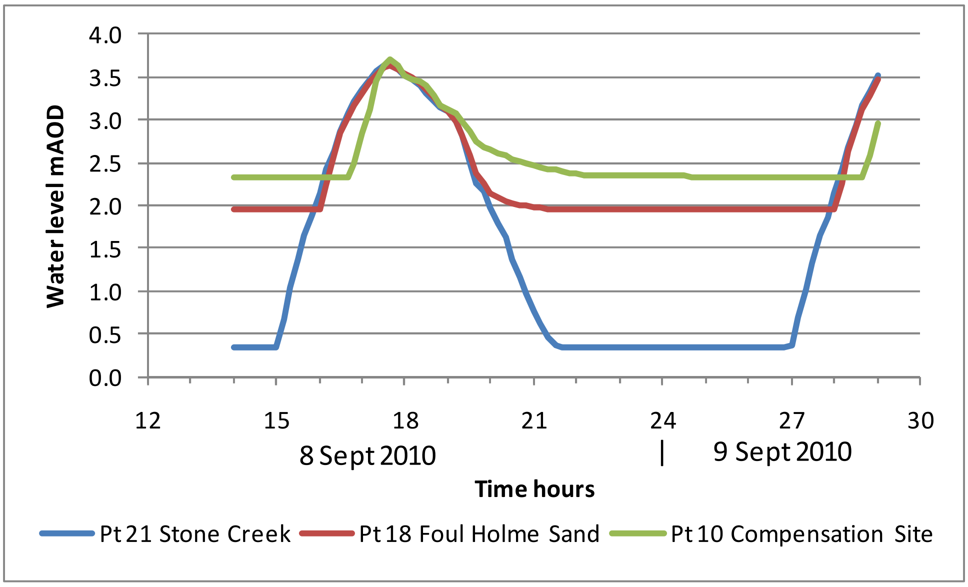


Figure 4 Predicted model tide levels with scheme

3.3 BREACH VELOCITIES

3.3.1 The breach consists of a 250 m wide cut through the existing flood defence and the saltmarsh between the flood defence and Cherry Cobb Sands Creek. The whole area has been included in the hydrodynamic model as a flat-vee profile channel with a crest level of 2.0 mAOD. Levels on either side are set at 2.2 mAOD. Velocities have been extracted at the nine points shown on Figure 3.

Flood tide velocities

3.3.2 Maximum velocities on the flood tide are predicted in the centre of the breach at Point 2. These are included in Table 5. Maximum flood tide velocities on the northern side of the breach are 84 to 98 percent of those in the centre of the breach, while those on the southern side are around 55 to 65 percent of those in the centre. The velocity profiles on the north side of the breach (Point 1) in the centre (Point 2) and on the south side (Point 3) are shown in Figure 5 for the evening tide of 8th September 2010.

3.3.3 A similar pattern is predicted for the breach channel inside the Compensation Site on the flood tide with maximum velocities in the centre, at Point 8 as indicated on Table 5. Velocities at Point 8 are on average around 20 percent higher than at Point 2. There is also greater variation in velocity across the width of the breach as shown on Figure 6, with velocities at Point 7 on the north side being consistently higher than at Point 9 on the south side.

Ebb tide velocities

3.3.4 On the ebb tide, velocities at the breach are less than those encountered on the flood tide as shown on Figure 5, though in all cases the maximum velocity is predicted on the north side of the breach (at Point 1). This pattern is repeated in the breach channel inside the site as shown on Figure 6 with the maximum ebb tide velocities again on the north side at Point 7, though velocities on the north side at Point 7 are only a little greater than at Point 8 in the centre.

3.3.5 A different pattern is found outside the breach. At Points 4, 5 and 6, ebb tide velocities exceed those on the flood tide. The zone of maximum velocity is normally predicted to occur in the middle of the channel at Point 5 where levels are lowest as shown in Figure 7. The 0.2 m lower ground level leads to the long duration of the ebb tide at Point 5. The maximum ebb tide velocities predicted on the south side at Point 6 are on average 92 percent of those predicted in the centre, while those on the north side are on average 55% of those in the centre. The maximum ebb tide velocities predicted in the channel outside the breach line at Point 5 are listed in Table 5 and are on average similar to the maxima predicted in the line of the breach at Point 2.

3.3.6 The maximum predicted velocities throughout the breach channel are generally found in the centre where ground levels are 0.2 m lower. The need for flows to fill the majority of the Compensation Site which is located north of the breach leads to higher velocities on this side of the breach during the flood tide. Similarly the southerly ebb tide in this part of the Humber and especially in Cherry Cobb Sands Creek is the major reason why velocities on the southern side are higher than on the northern side at the western end of the breach channel during the ebb tide.

3.3.7 The highest velocities predicted within the breach channel are found inside the site and as this area has received little consolidation, this is the area where creek erosion is most likely to occur, probably a little to the north of the breach channel centreline. Erosion of the outer end of the breach channel starting where it joins Cherry Cobb Sands Creek is also likely in the southern half of the breach channel. Creeks formed inside and outside are likely to propagate back towards the breach line where the consolidation from the weight of the existing embankment will increase the resistance of the exposed sediments to erosion. Without protection against erosion there is likely to be some erosion of the breach channel starting at both ends and eventually cutting through the line of the breach probably close to its centre.

Table 5 Predicted maximum velocities predicted within the breach channel

Date and approx HW time	0600 9/9/10	1730 8/9/10	0700 16/5/10	0800 18/5/10
Location	**Maximum velocity on the flood tide m/s**			
Point 2 Centre of breach	2.08	2.02	1.56	1.44
Point 8 Breach channel centre inside site	2.37	2.16	2.14	1.69
Location	**Maximum velocity on the ebb tide m/s**			
Point 5 Breach channel centre outside site	1.64	2.00	1.37	1.98

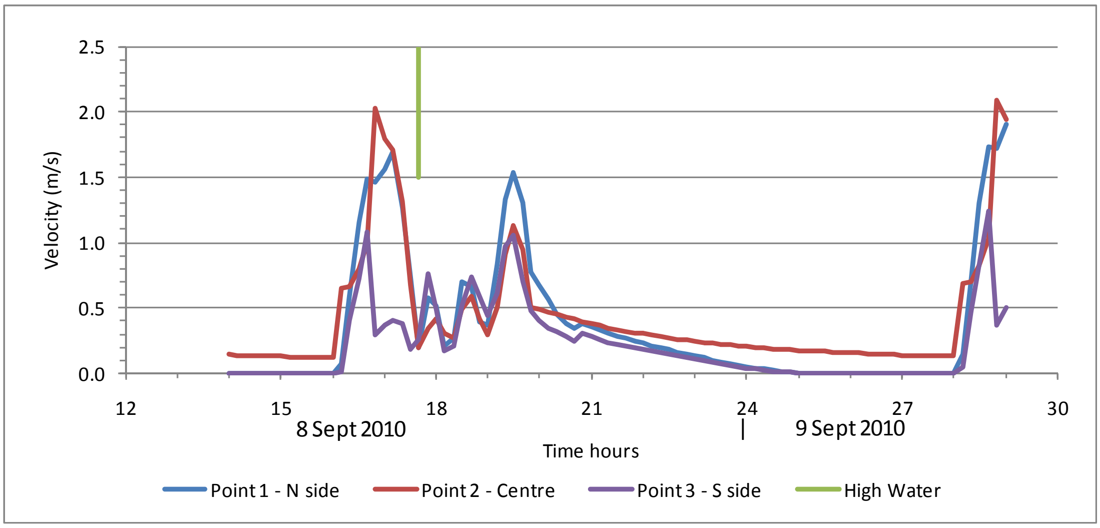


Figure 5 Predicted velocity profiles across the Compensation Site breach

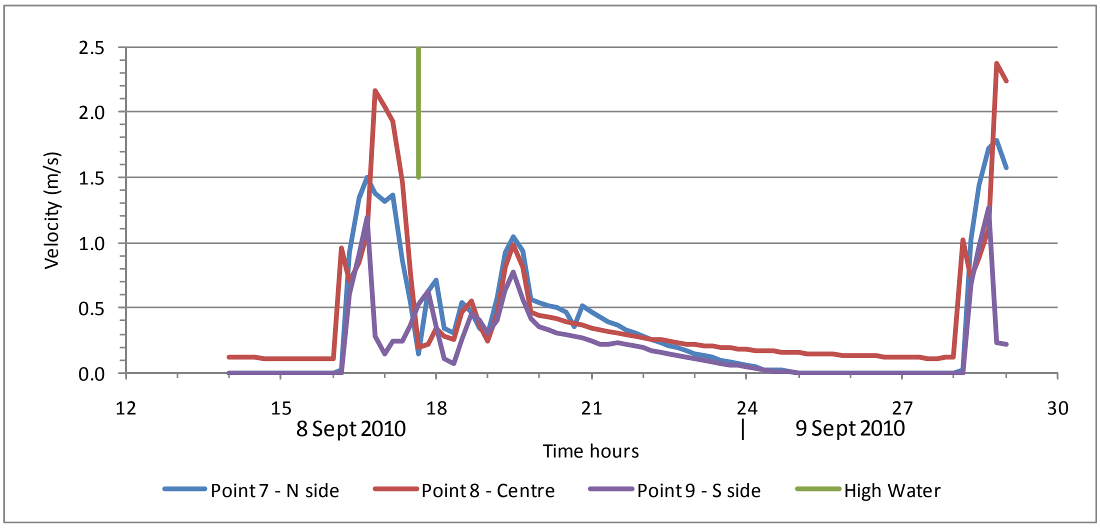


Figure 6 Predicted velocity profiles inside the Compensation Site breach

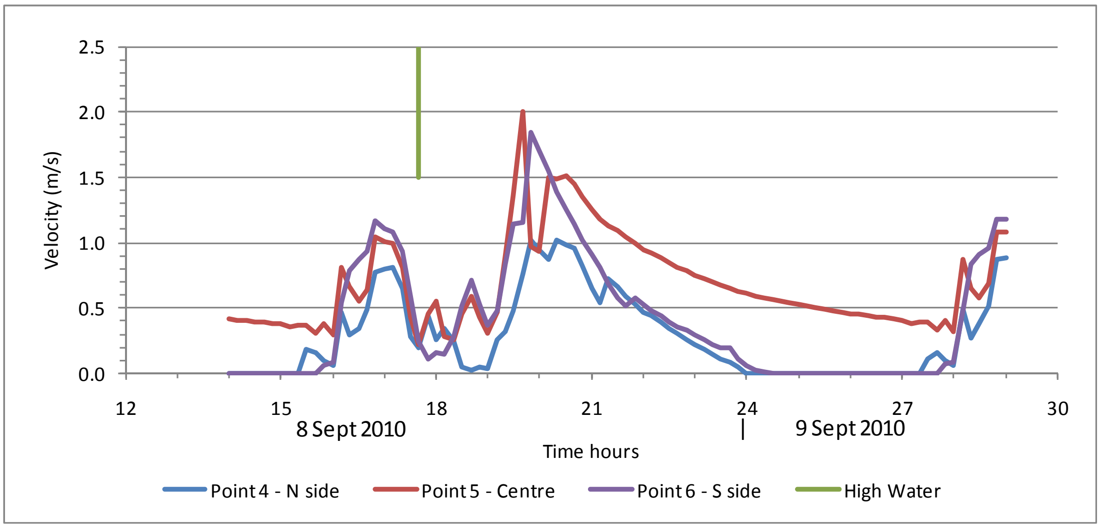


Figure 7 Predicted velocity profiles outside the Compensation Site breach

3.4 VELOCITIES IN AND AROUND THE COMPENSATION SITE

Flood tide velocity pattern

3.4.1 The baseline velocity pattern close to the time of maximum flood tide velocity over Foul Holme Sand is illustrated in Figure 8a for the high spring tide on the evening of 8th September 2010. This may be compared with the velocity pattern at the same time in Figure 8b when the Compensation Site is operational.

3.4.2 These model predictions show that on the flood tide across Foul Holme Sand outside the Compensation Site there is a small increase in velocity to the south of the breach including Point 19 as water flows across the top of the sandbank towards the breach channel. Immediately offshore of the breach channel and across Cherry Cobb Sands Creek there is a local increase in velocity as water accelerates into the breach channel. The high velocities in the centre and northern part of the breach channel inside the existing embankment line are very evident.

3.4.3 North of the breach over an area as far offshore as Point 18 there is a small reduction in velocity across Foul Holme Sand as some of the flow that previously went across this sandbank has been diverted into the Compensation Site through the breach. The reduction is most marked within Cherry Cobb Sands Creek around Point 15.

3.4.4 Within the Compensation Site there is a widespread area of high velocities as the water flooding the site from the breach turns to flood the large northern part of the site. At this time the tide level is rising rapidly within the site as shown for Point 10 on Figure 4.

Ebb tide velocity pattern

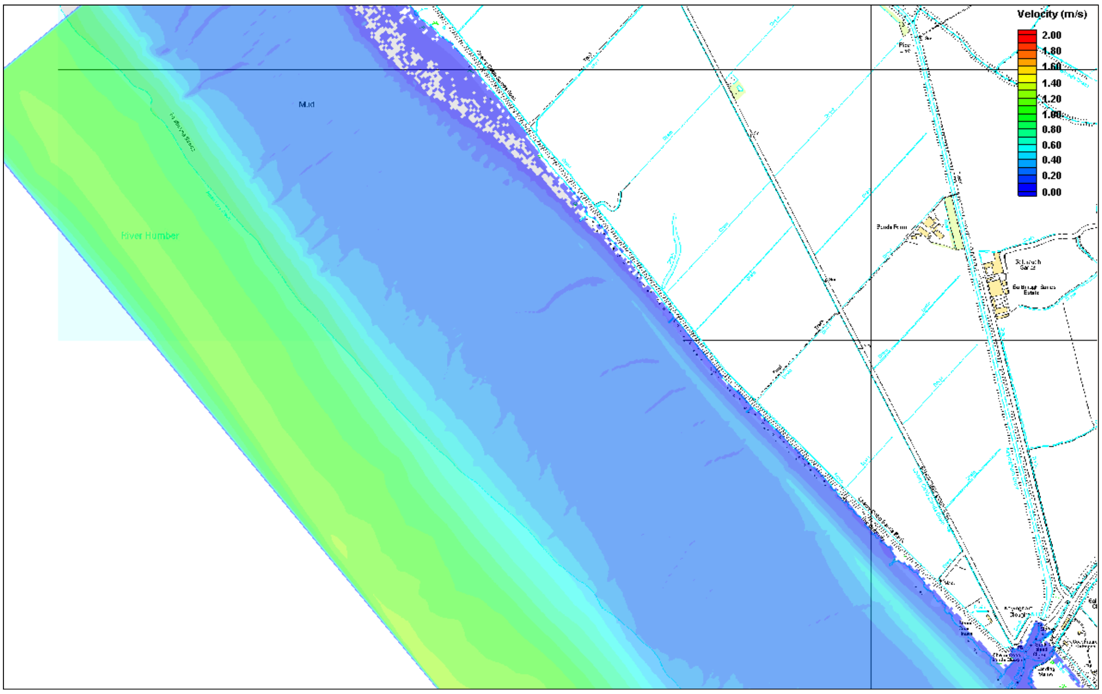
3.4.5 Predicted velocity patterns at 1930 on 8th September 2010 close to the time of peak ebb velocities over Foul Holme Sand are shown in Figure 9. This allows a comparison of baseline velocities in part (a) with those predicted with the Compensation Site in operation in part (b).

3.4.6 Figure 9b shows the high velocities predicted in the centre and southern part of the breach channel outside the existing embankment line. This area of high velocity rapidly disperses as the flow decelerates across Cherry Cobb Sand Creek. However, across the top of Foul Holme Sand there is an area opposite the breach where velocities are increased by around 0.1 m/s compared with areas either side and compared with the baseline in Figure 9a. These higher velocities indicate the potential for a change in the balance of accretion and erosion on top of Foul Holme Sand.

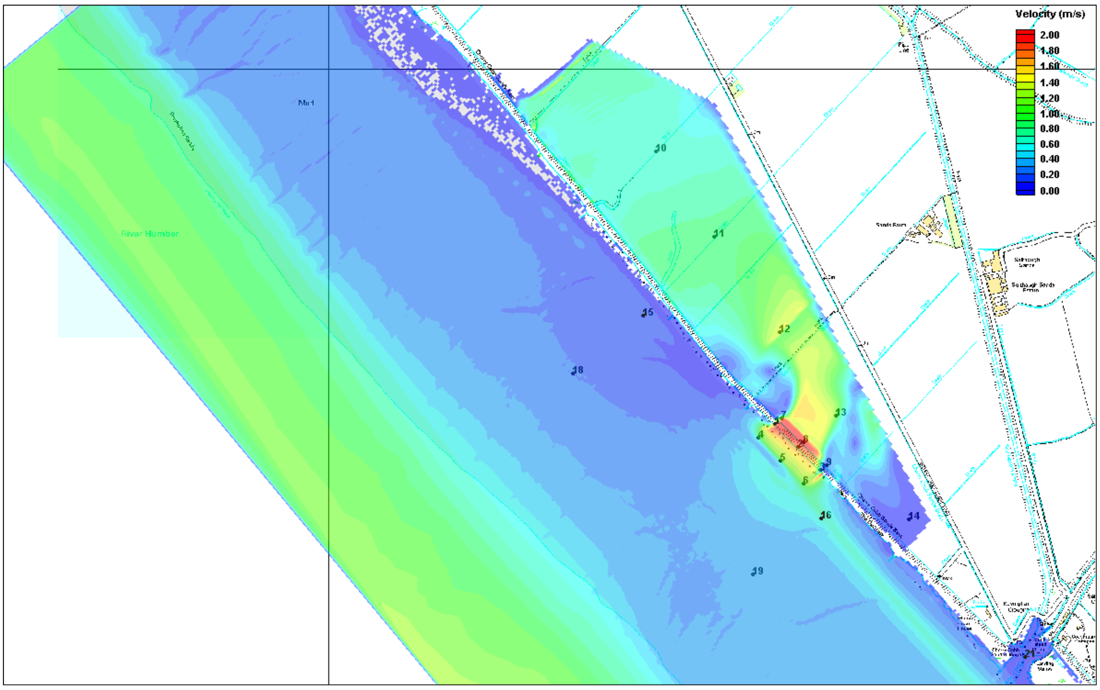
3.4.7 Initially during the ebb tide at 1930, predicted velocities within Cherry Cobb Sands Creek with the Compensation Site in operation are similar to those in the baseline as indicated by comparing the two parts of Figure 9. At this time the creek is playing a relatively minor role in foreshore drainage.

3.4.8 This situation has changed 1.5 hours later at 2100 when the tide has dropped to expose the top of Foul Holme Sand as illustrated by Figure 10. At this time Cherry Cobb Sands Creek forms the major drainage path from the Compensation Site and velocities within this creek are considerably higher than in the baseline case. Elsewhere the reduction in level has allowed most of Foul Holme Sand to dry and so there are no flows across this sandbank.

3.4.9 Predicted ebb tide velocities within the Compensation Site reduce as the time after high water increases.

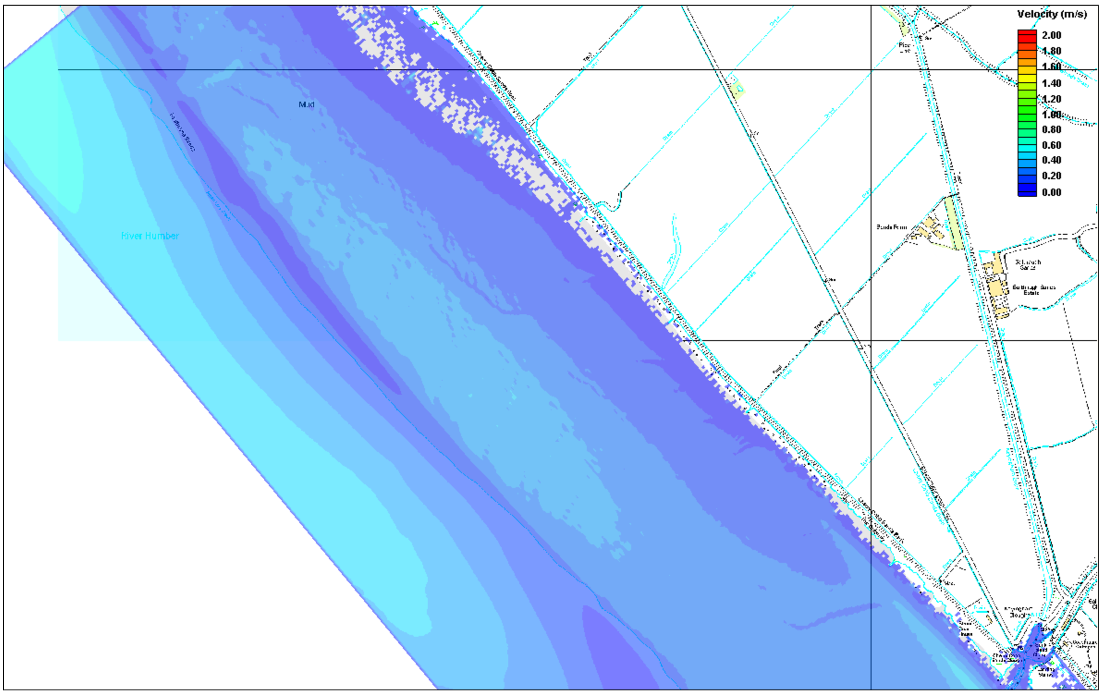


a) Baseline conditions

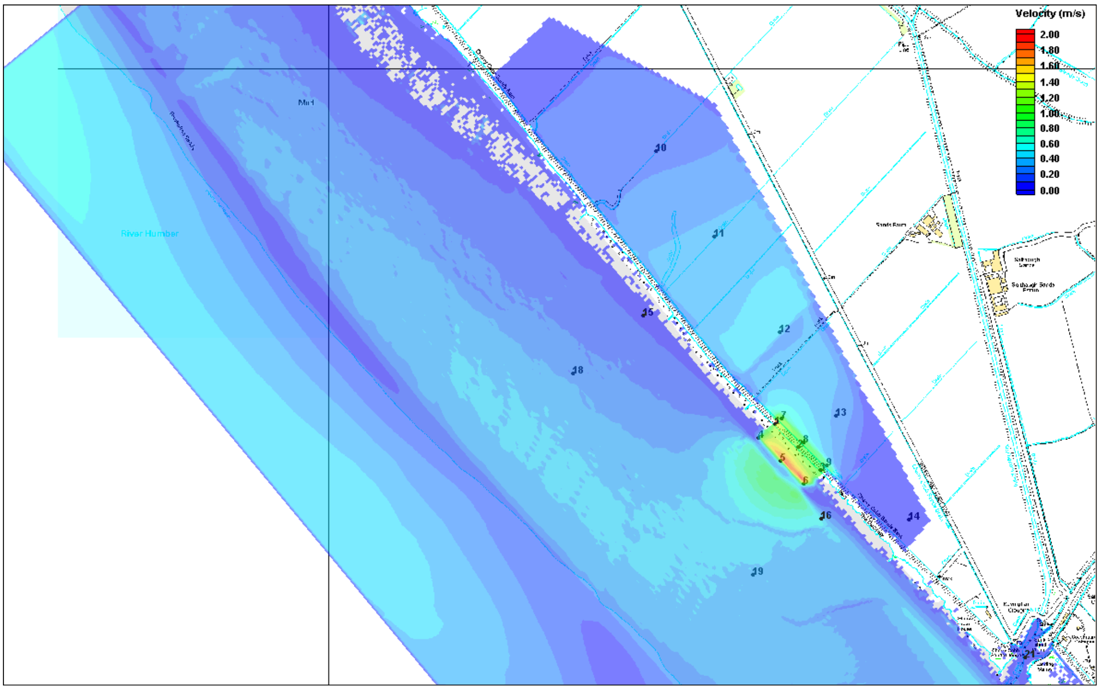


b) With Compensation Site

Figure 8 Predicted flood tide velocities at 1700 on 8th Sept 2010

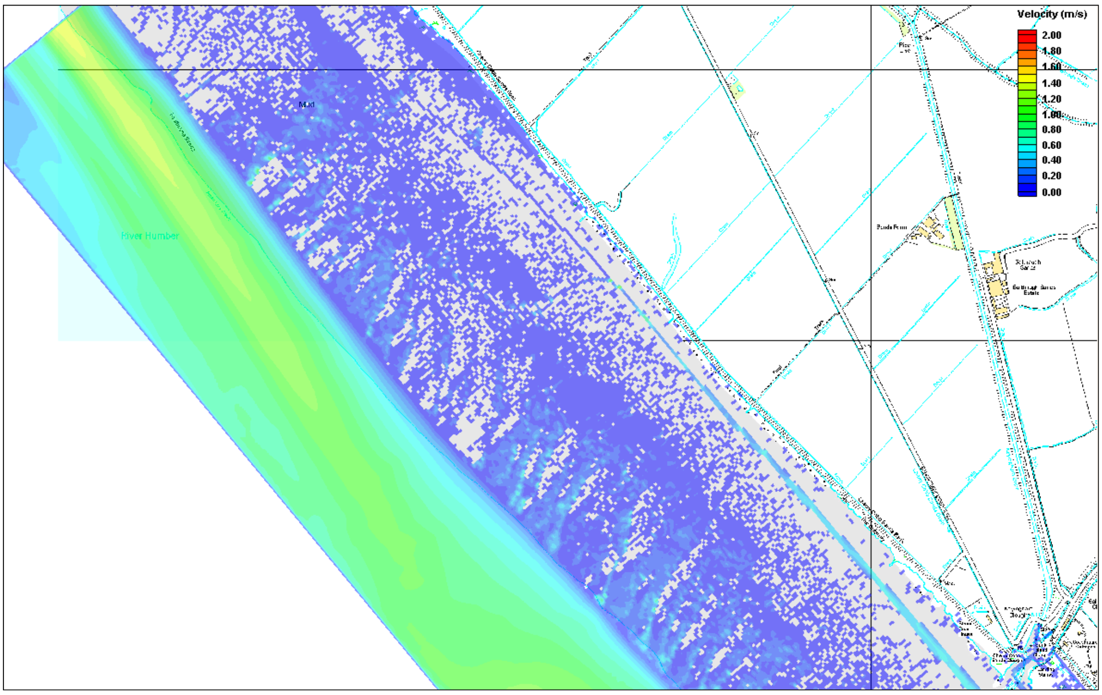


a) Baseline conditions

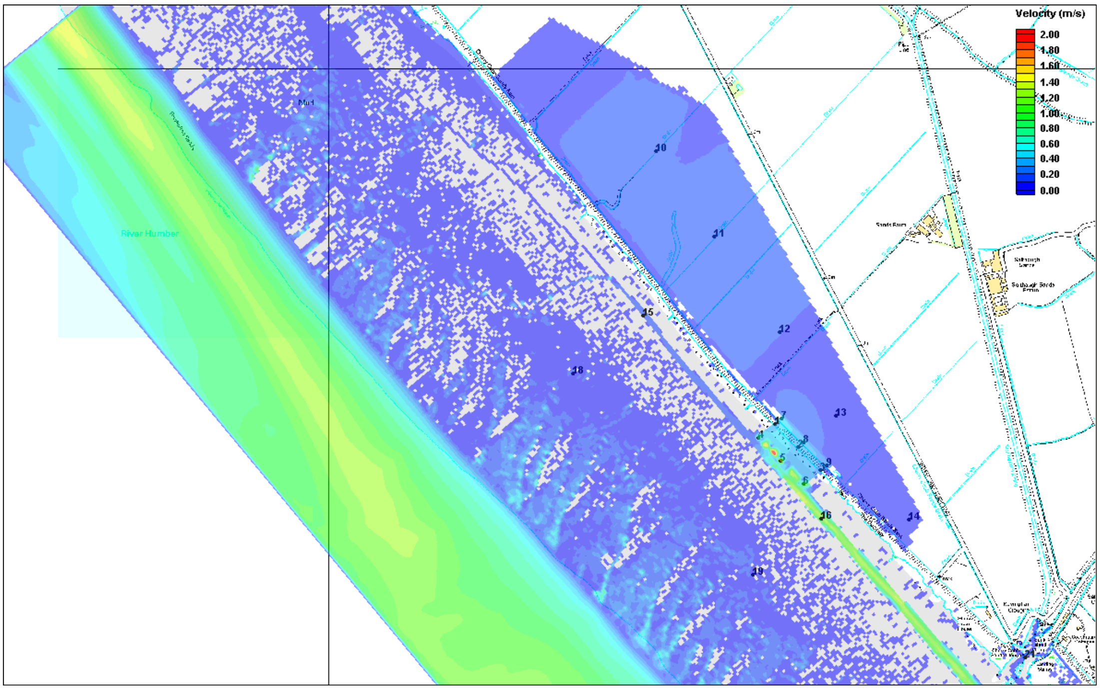


b) With Compensation Site

Figure 9 Predicted ebb tide velocities at 1930 on 8th Sept 2010



a) Baseline conditions



b) With Compensation Site

Figure 10 Predicted ebb tide velocities at 2100 on 8th Sept 2010

3.5 Velocities in Cherry Cobb Sands Creek and Stone Creek

3.5.1 Assessment of flows in Cherry Cobb Sands Creek was made by considering three points and the long section along the creek invert shown on Figure 3. Point 15, located 500 m north of the beach, Point 16 located about 100 m south of the breach and 900 m north of Stone Creek and Point 17 located 500 m south of Stone Creek. In addition flows within Stone Creek upstream of its confluence with Cherry Cobb Sands Creek were considered at Point 21.

3.5.2 Maximum ebb and flood tide baseline velocities predicted at the three points in Cherry Cobb Sands Creek (Points 15-17) and Point 21 in Stone Creek are set out in Table 6. Velocities in Stone Creek are much lower than anywhere in Cherry Cobb Sands Creek. Velocities in Cherry Cobb Sands Creek reduce from south to north towards the head of the creek on the flood tide. On the ebb tide, velocities at Point 17 south of Stone Creek are larger than at the two points north of this outfall.

3.5.3 The maximum predicted velocities in Cherry Cobb sands Creek and Stone Creek with the Compensation Site in operation are shown in Table 7. On the flood tide the predicted maximum velocities everywhere within Cherry Cobb Sands Creek are similar with the Compensation Site as in the baseline. Average maximum velocities reduce by 0.03 m/s with a standard deviation of 0.07 m/s. On the ebb tide the presence of the Compensation Site is predicted to change velocities in Cherry Cobb Sands Creek substantially. Upstream of the breach at Point 15, velocities reduce by 0.2 to 0.5 m/s with the largest reductions occurring on the highest tides. Downstream of the breach at Point 16 there is a large increase in maximum ebb tide velocity of 0.6 to 0.8 m/s, again with the larger increases on the higher tides. Within Stone Creek there are relatively small changes of <0.1 m/s in the already small maximum velocities on both flood and ebb tides.

Table 6 Predicted baseline maximum velocities in Cherry Cobb Sands Creek

Date and approx HW time	0600 9/9/10	1730 8/9/10	0700 16/5/10	0800 18/5/10
Location	**Flood tide maximum velocity m/s**			
Point 15 500 m north of breach	0.57	0.53	0.68	0.40
Point 16 100 m south of breach	0.77	0.75	0.66	0.57
Point 17 500 m south of Stone Creek	0.97	0.93	0.76	0.68
Point 21 within Stone Creek	0.11	0.08	0.07	0.07
Location	**Ebb tide maximum velocity m/s**			
Point 15 500 m north of breach	0.79	0.74	0.65	0.56
Point 16 100 m south of breach	0.60	0.55	0.52	0.50
Point 17 500 m south of Stone Creek	0.85	0.81	0.91	1.20
Point 21 within Stone Creek	0.16	0.10	0.07	0.21

Table 7 Predicted maximum velocities in Cherry Cobb Sands Creek after breaching

Date and approx HW time	0600 9/9/10	1730 8/9/10	0700 16/5/10	0800 18/5/10
Location	**Flood tide maximum velocity m/s**			
Point 15 500 m north of breach	0.49	0.54	0.49	0.32
Point 16 100 m south of breach	0.82	0.79	0.65	0.51
Point 17 500 m south of Stone Creek	0.96	0.92	0.75	0.67
Point 21 within Stone Creek	0.08	0.08	0.09	0.05
Location	**Ebb tide maximum velocity m/s**			
Point 15 500 m north of breach	0.28	0.24	0.25	0.36
Point 16 100 m south of breach	1.35	1.33	1.16	1.19
Point 17 500 m south of Stone Creek	1.05	1.04	0.91	1.15
Point 21 within Stone Creek	0.07	0.06	0.05	0.23

3.5.4 The predicted maximum velocity along Cherry Cobb Sands Creek during the flood and ebb of the large spring tide on the evening of 8th September 2010 are shown on Figure 11. This Figure shows the increase in maximum velocity in the creek between the breach site and Stone Creek when the Compensation Site is in operation. South of Stone Creek, for about 1500 m, the maximum velocity is predicted to not increase with the scheme in operation. In the final 1000 m of Cherry Cobb Sands Creek before it outfalls into the Humber there is a local increase in maximum velocity on the ebb tide. This is likely to increase the dynamic nature of this downstream part of the creek.

3.5.5 Flow profiles through this tide at three points in the creek are shown in Figure 12. The three parts of the figure compare velocities at Point 15 upstream or north of the breach and at Points 16 and 17 downstream of the breach. These figures illustrate how velocities on the flood tide in Cherry Cobb Sands Creek are little affected by the presence of the Compensation Site.

3.5.6 On the ebb tide velocities are reduced upstream of the breach at Point 15. This is presumably the result of flows draining the Compensation Site blocking the flows in Cherry Cobb Sands Creek upstream of the confluence.

3.5.7 Downstream of the breach at Points 16 and 17, there is an increase in the predicted maximum velocity and the duration of high velocities on the ebb tide while drainage of the Compensation Site occurs. At Point 16 just downstream of the breach, the maximum ebb tide velocity is predicted to increase considerably. At Point 17 downstream of Stone Creek the predicted increase in velocity on the ebb tide is much smaller. This arises even though the flow in the creek at the two sites is similar because the size of the creek at Point 17 is larger so the effect of the Compensation Site appears smaller.

3.5.8 Predicted flows in Stone Creek at Point 21 are shown on Figure 13. The presence of the Compensation Site causes small changes in already small velocities.

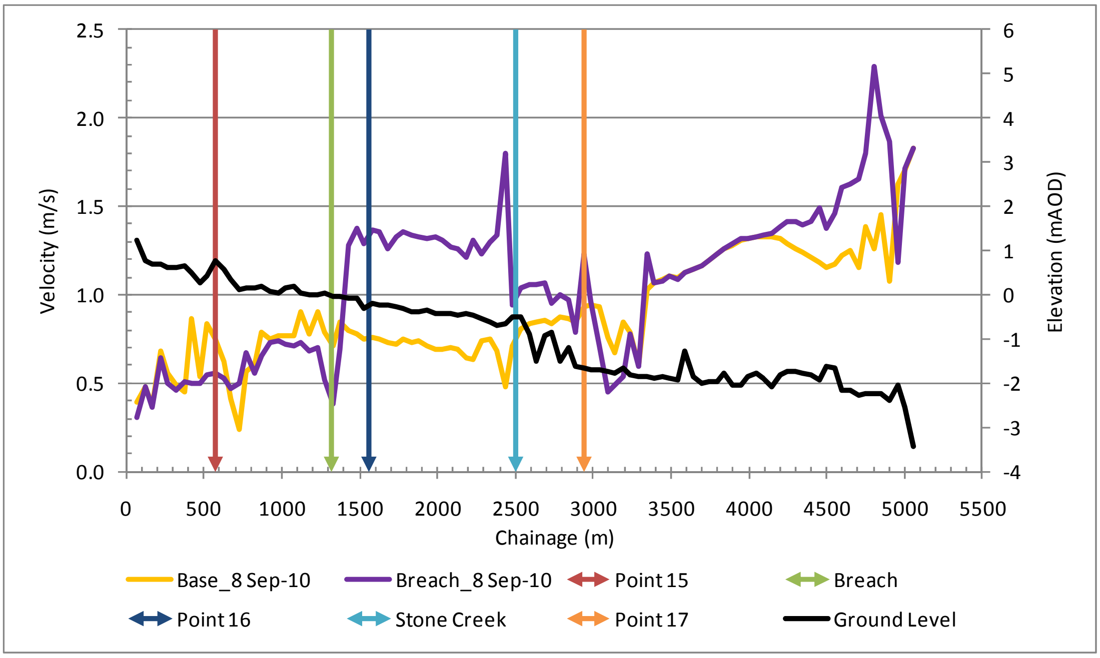
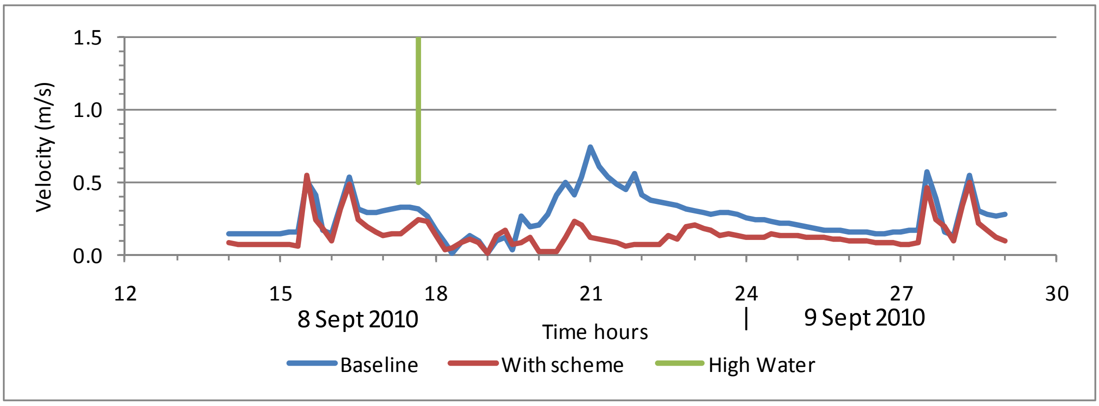
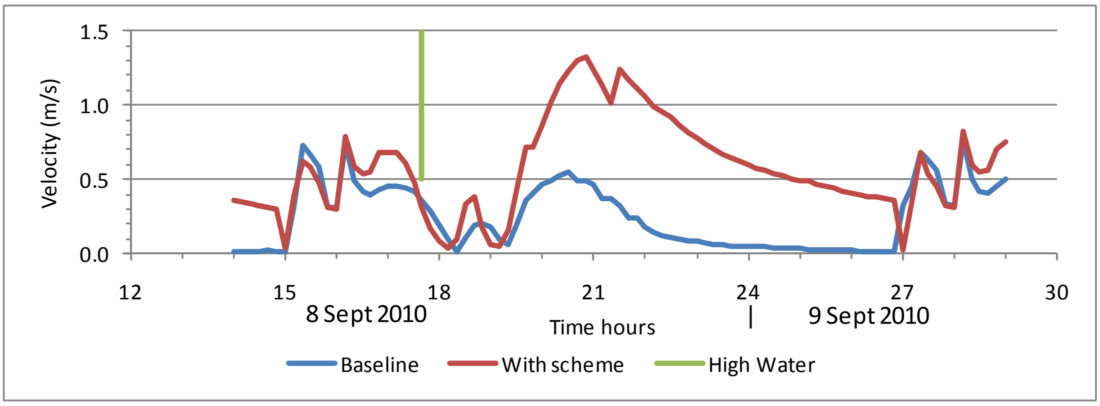


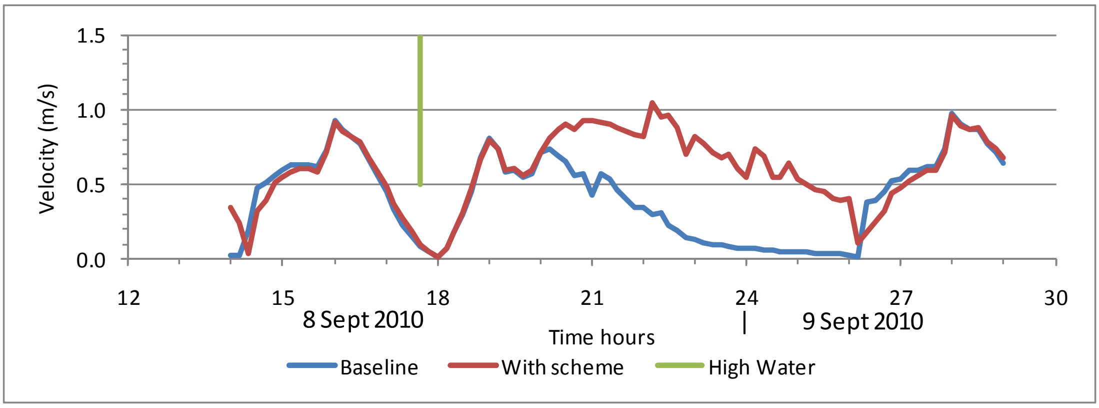
Figure 11 Maximum predicted velocities within Cherry Cobb Sands Creek 8th Sept 2010



a) Point 15 500 m upstream of breach



b) Point 16 100 m downstream of breach



c) Point 17 500 m downstream of Stone Creek

Figure 12 Comparison of predicted velocities in Cherry Cobb Sands Creek

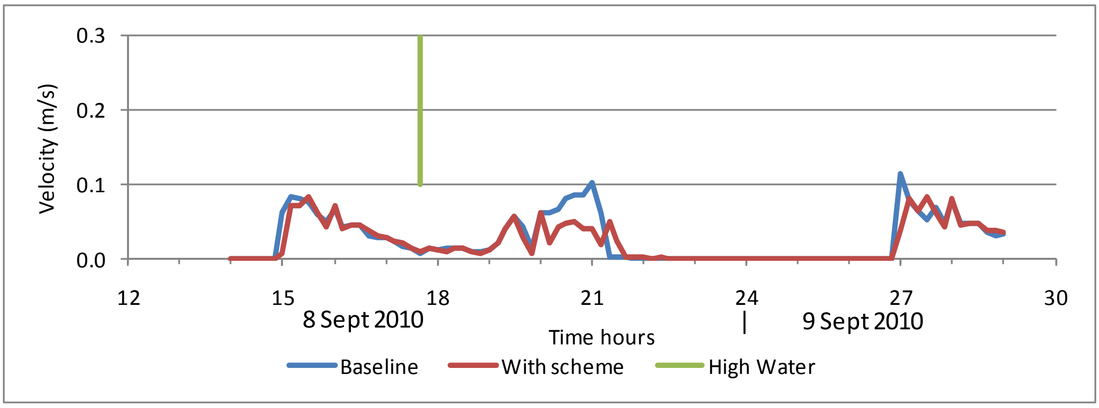


Figure 13 Effect of Compensation Site on velocities in Stone Creek (Point 21)

3.6 VELOCITIES OVER FOUL HOLME SAND

3.6.1 Around high tide, Foul Holme Sand is covered by tidal waters, so some of the water flooding onto and draining out of the Compensation Site can flow across this bank increasing the risk of erosion of the top of the bank.

3.6.2 Velocities on the top of Foul Holme Sand have been measured at Points 18, 19 and 20 shown on Figure 3. The maximum predicted flood and ebb tide velocities at these points during the baseline runs are shown on Table 8. The existing velocities at Points 18 and 19 are predicted to be somewhat higher on the flood tide than the ebb tide, though at Point 20 the most southerly site, ebb tide velocities exceed those on the flood tide. Predicted baseline maximum velocities at Points 18 and 19, north of Stone Creek, are below 0.5 m/s on the ebb and flood of all tides that were modelled, while those at Point 20 are predicted to be up to 0.8 m/s on the ebb tide.

3.6.3 The predicted maximum velocities over Foul Holme Sand with the Compensation Site in operation are shown on Table 9. At Points 18 and 20 some distance north or south of the breach, the predicted maximum velocity on all modelled tides with the Compensation Site in operation are similar to those predicted for the baseline for both the ebb and flood. The average difference is a reduction of <0.01 m/s with a standard deviation of 0.03 m/s suggesting the changes are probably more affected by the stability of the model than representing an actual change in conditions. At Point 19 which is closest to the breach the maximum flood tide velocities are little changed as noted at Points 18 and 20, while on the ebb tide there is an indication on the two higher tides of a small increase in maximum velocity of around 0.1 m/s.

Table 8 Baseline predicted maximum velocities over Foul Holme Sand

Date and approx HW time	0600 9/9/10	1730 8/9/10	0700 16/5/10	0800 18/5/10
Location	**Flood tide maximum velocity m/s**			
Point 18 500 m north of breach	0.50	0.48	0.36	0.34
Point 19 100 m south of breach	0.38	0.36	0.30	0.32
Point 20 500 m south of Stone Creek	0.46	0.41	0.32	0.28
Location	**Ebb tide maximum velocity m/s**			
Point 18 500 m north of breach	0.30	0.26	0.26	0.49
Point 19 100 m south of breach	0.30	0.25	0.22	0.54
Point 20 500 m south of Stone Creek	0.67	0.60	0.58	0.84

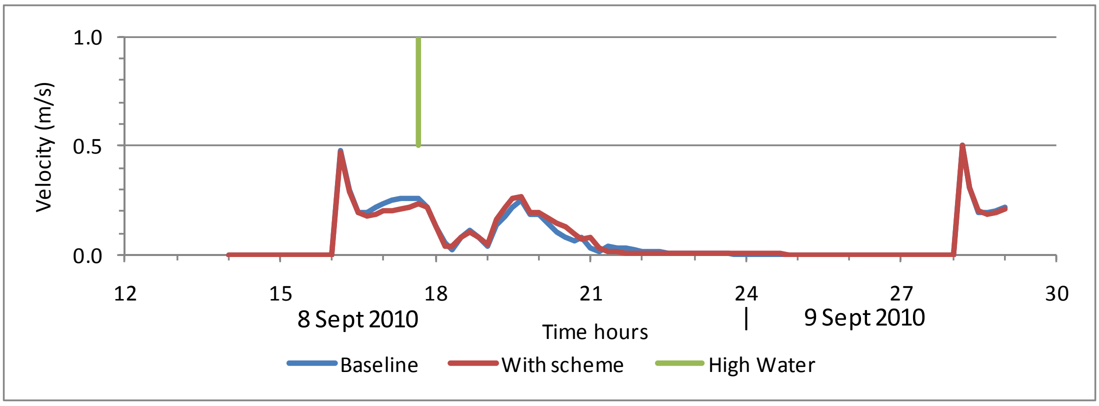
Table 9 Predicted maximum velocity over Foul Holme Sand following breaching

Date and approx HW time	0600 9/9/10	1730 8/9/10	0700 16/5/10	0800 18/5/10
Location	**Flood tide maximum velocity m/s**			
Point 18 500 m north of breach	0.50	0.47	0.36	0.34
Point 19 100 m south of breach	0.37	0.36	0.28	0.30
Point 20 500 m south of Stone Creek	0.50	0.42	0.31	0.30
Location	**Ebb tide maximum velocity m/s**			
Point 18 500 m north of breach	0.28	0.27	0.27	0.41
Point 19 100 m south of breach	0.42	0.37	0.25	0.50
Point 20 500 m south of Stone Creek	0.67	0.60	0.58	0.80

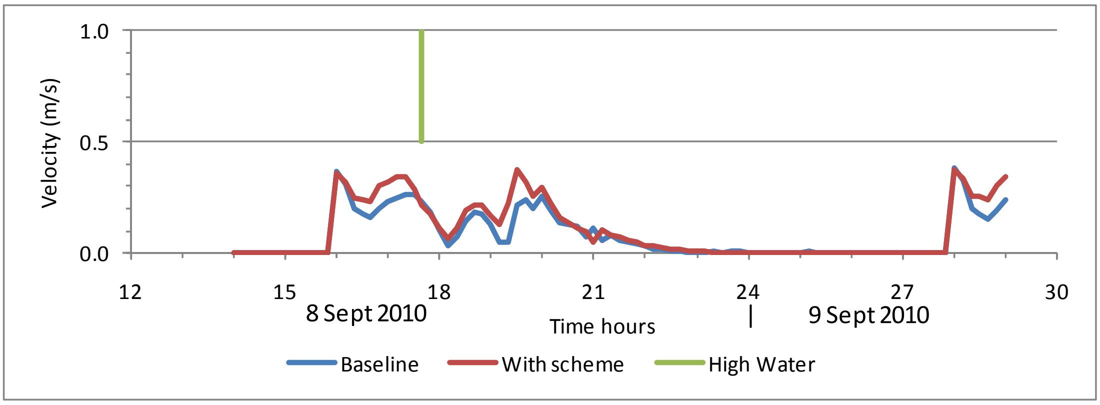
3.6.4 A comparison of the predicted velocity profiles over the top of Foul Holme Sand on the evening tide of 8th September 2010 is shown in Figure 14 for Points 18, 19 and 20. As noted above, conditions at Points 18 and 20 which are some distance away from the breach are little changed as a result of the introduction of the Compensation Site. At Point 19 even though there is a very small reduction in the maximum velocity on the flood tide noted in Table 9, Figure 14 shows that for the majority of the flood tide predicted velocities are up to 0.1 m/s greater with the Compensation Site in operation. This higher velocity contributes to the filling of this site on the flood tide. On the ebb tide, velocities are also higher by a similar amount as the Compensation Site starts to drain.

3.6.5 A profile of the maximum predicted velocities along Section 9 on the top of Foul Holme Sand shown on Figure 3 is shown for the high spring tide on 8th September 2010 in Figure 15. This shows there is almost no difference in the maximum velocity at any point along this section. There are minor reductions in maximum velocity to the north of the breach in the vicinity of Point 18 and minor increases immediately to the south of the breach in the vicinity of Point 19, both as shown on Figure 14 and in more detail in Table 8 and Table 9 which when combined show that there is no change in the part of the tide that the maximum velocity occurs in for Points 18 and 20. However at Point 19, instead of the maximum velocity occurring on the flood tide as in the baseline, the maximum velocities on ebb and flood tides have become fairly similar with a breach in place.

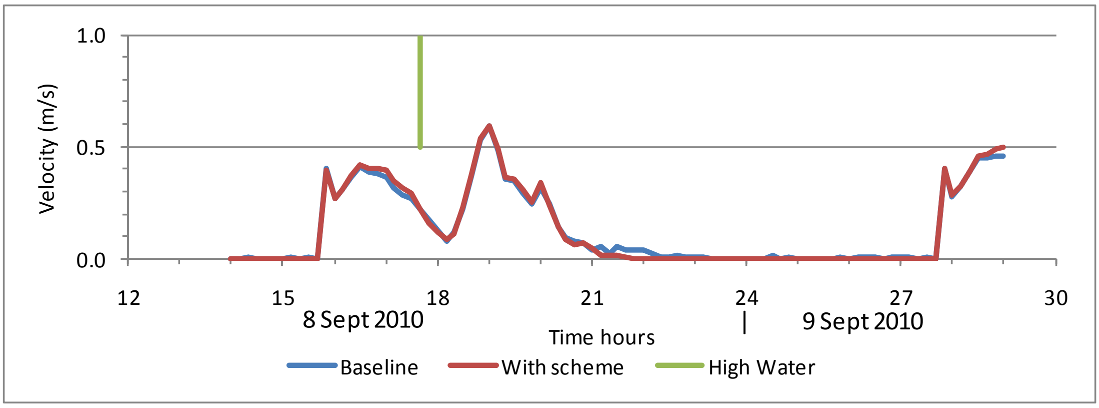
3.6.6 The maximum predicted velocity on the top of Foul Holme Sand downstream of Stone Creek in Figure 15 shows very small changes in maximum velocities all along the profile, despite the evidence in the velocity patterns of flows moving towards the breach on the flood tide in Figure 8b and away from the breach on the ebb tide in Figure 9b. Figure 14b indicates there is an increase in predicted velocity throughout much of the flood and ebb tide even though the peak velocity does not change as Figure 15 shows.



a) Point 18 500 m upstream of breach



b) Point 19 100 m downstream of breach



c) Point 20 500 m downstream of Stone Creek

Figure 14 Comparison of velocities over Foul Holme Sand

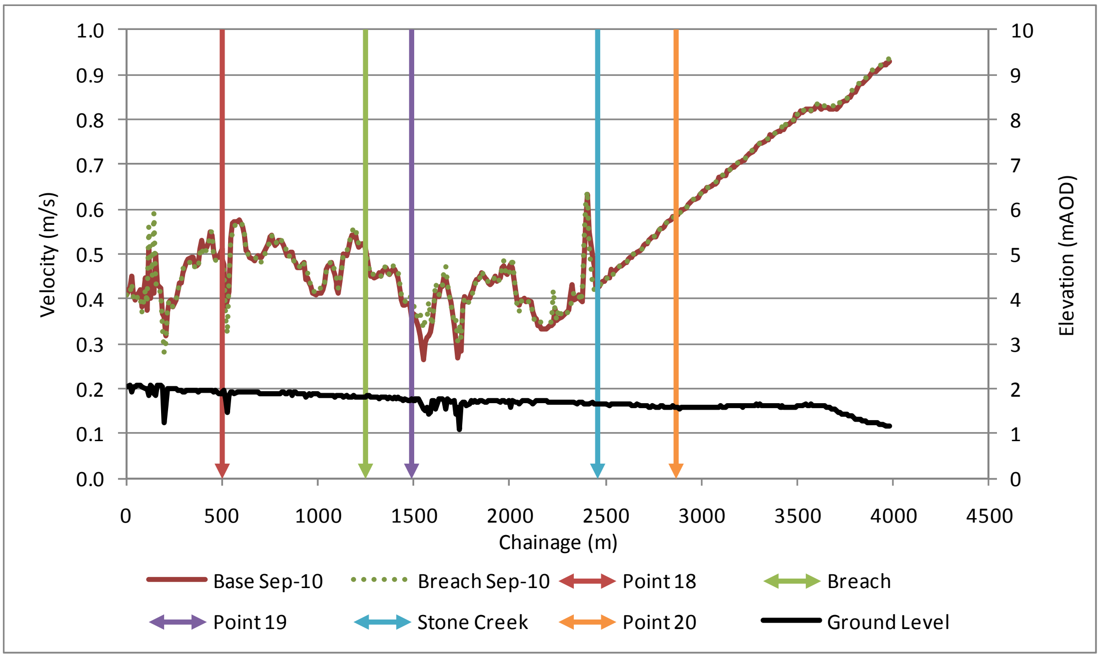


Figure 15 Maximum velocities on top of Foul Holme Sand 8th Sept 2010

3.7 VELOCITIES WITHIN THE COMPENSATION SITE

3.7.1 The predicted maximum velocity along a transect through the middle of the Compensation Site shown on Figure 3 is plotted on Figure 16 for the high spring tide on the evening of 8th September 2010. The velocities at either end of the Compensation Site are low, but there is a section about 1000 m long including Points 11, 12 and 13 where maximum velocities are predicted to exceed 0.8 m/s on this tide.

3.7.2 Velocity profiles during the evening tide of 8th September 2010 at Points 10, 11, 12, 13 and 14, shown on Figure 17, indicate that the maximum velocities at all sites is predicted during the short flood tide period. Velocities at the plotted points are highest at Point 12 near where the ground level rises from 1.5 mAOD to 2.0 mAOD. The plot of maximum velocity on Figure 16 shows that this change in bed level promotes a local rise in maximum velocity. Maximum velocities of 1.1 m/s are also predicted on the flood tide at Point 13 in the area with ground levels of 1.5 mAOD. At Point 11 where ground levels are around 2.3 mAOD, maximum velocities are predicted to reduce to 0.8 m/s.

3.7.3 Maximum velocities experienced throughout the site on the flood tide are predicted to increase with the height of high water as indicated on Figure 18. By contrast peak velocities on the ebb tide are predicted to remain low whatever the height of the tide. Low maximum velocities near the northern boundary at Point 10 and the southern boundary at Point 14 indicate the likelihood of siltation in these areas. However, within the parts of the site typified by Points 11, 12 and 13 where flood tide velocities are higher, these may well limit the rate of siltation that is experienced and lead to some erosion. The local area of high velocity at chainage 100 m is not present for the smaller range tides that have been modelled and should be ignored.

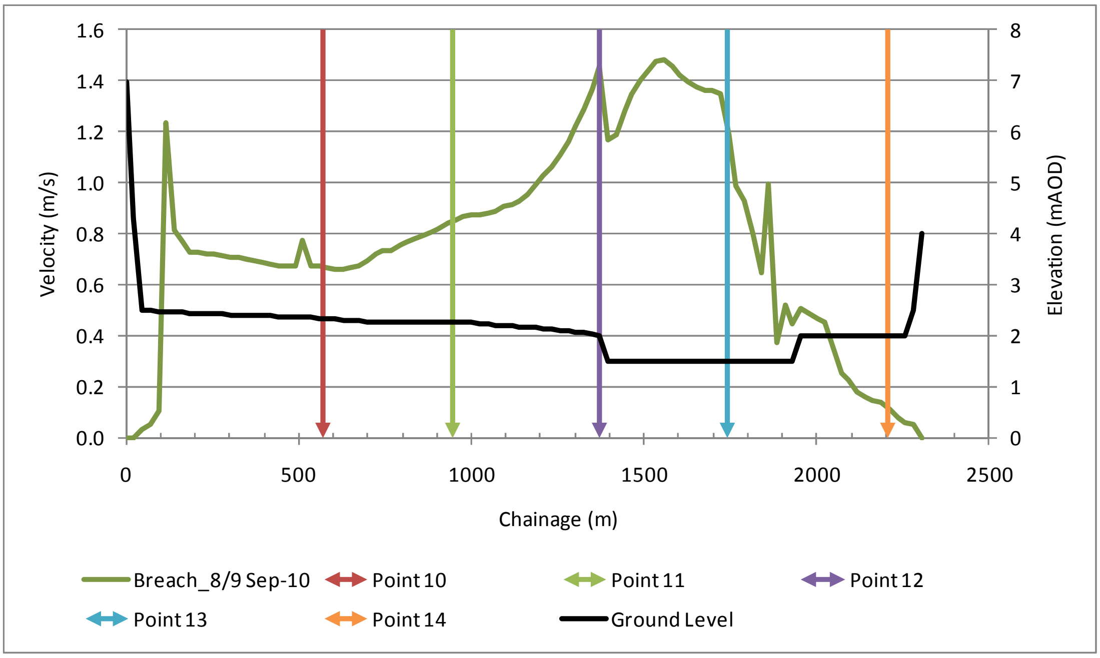


Figure 16 Maximum velocities across the Compensation Site 8th Sept 2010

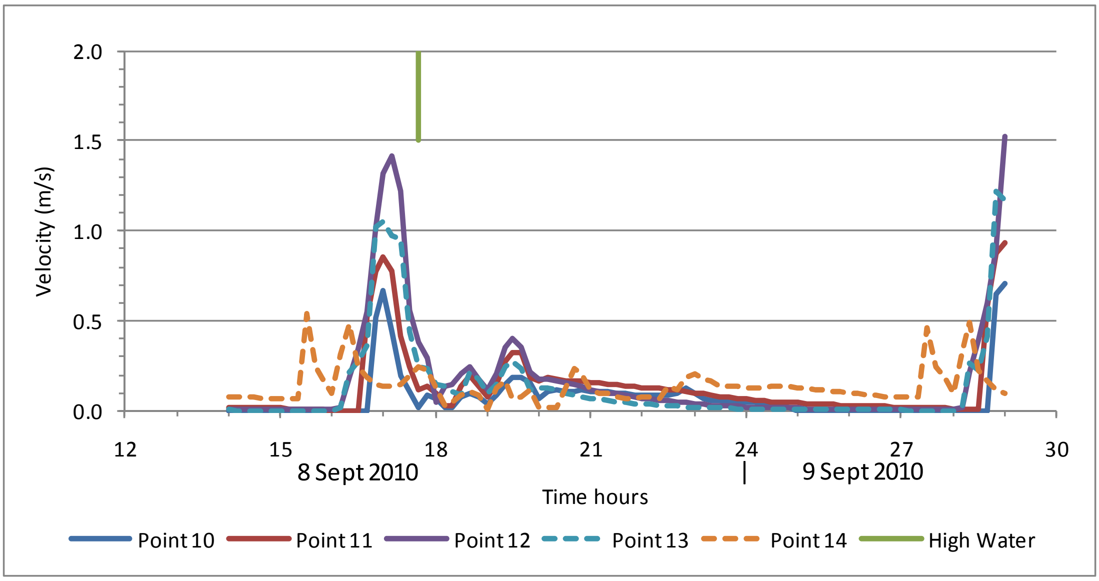


Figure 17 Velocity profile at Points 10 – 14 in Compensation Site

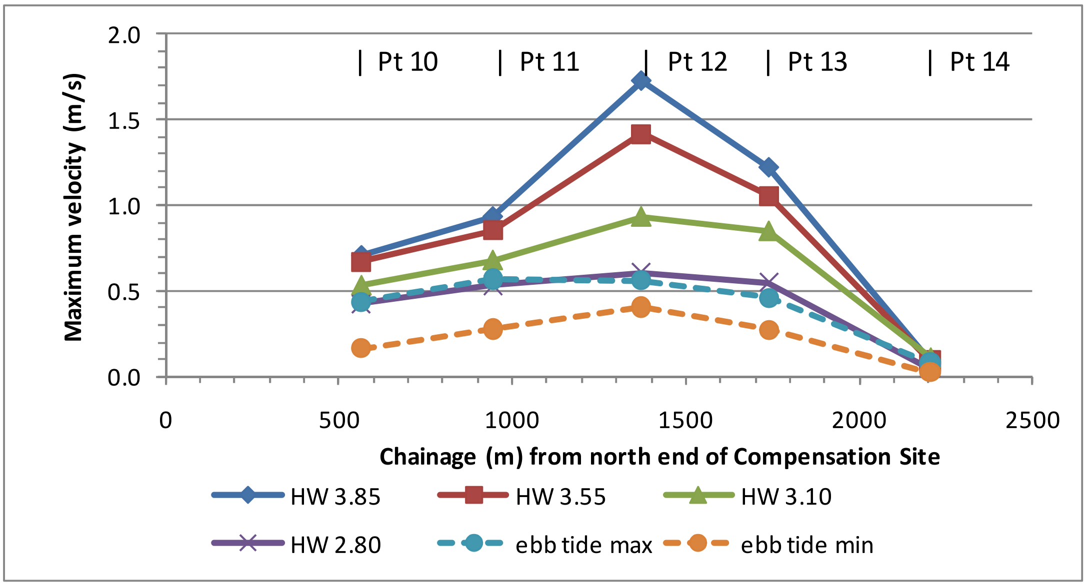


Figure 18 Maximum velocities in the Compensation Site for different tide ranges

4 SEDIMENTATION ASSESSMENT

4.1 EROSION AND ACCRETION PARAMETERS

4.1.1 The balance of accretion and erosion in a tidal estuary is sensitive to the choice of parameters used to calculate these processes. For the Compensation Site we have assumed that the dominant material in suspension and on the surface of the estuary bed is fine material. This is different from the approach in the modelling of the main estuary reported in Annex 8.1 where the models primarily represent sand transport processes. This difference is because the bed of the estuary is sandy while the surface sediments on the intertidal foreshores including those on Foul Holme Sand and within the Compensation Site will be predominantly muddy sediments which behave in a cohesive manner.

4.1.2 Sedimentation processes were calculated for the four tidal conditions modelled and erosion on individual tides was grossed up to an annual value using the tidal frequencies at Immingham in Table 2.

4.1.3 We have used erosion parameters values derived from earlier Humber studies (Van Ormondt & Roelvink, 2004) which adopted the typical parameter values in Table 10 derived from literature and from experience in the Humber. Erosion rates are calculated for the Points shown in Figure 3. Rates of erosion through individual tide cycles were calculated using the Partheniadies approach where the rate of erosion is proportional to the shear stress in excess of the erosion threshold.

4.1.4 The representation of accretion was simplified within the Compensation Site on the assumption that all the sediment in the water column at each survey point was liable to settle out because velocities were below the threshold for accretion for most of the time. The settlement rate was then considered proportional to the assumed suspended sediment concentration in the water column.

4.1.5 The siltation rates measured at Paull Holme Strays are reported in *Annex 32.5 Table 4*. The accretion within the first year at this site is plotted as a function of initial ground level on Figure 19. Accretion rates reduce as ground level increases because of the fewer number of tides inundating the higher ground and the smaller depth of flooding. For Cherry Cobb Sands, the first stage in assessing accretion rates was to predict those that would occur in the absence of any erosion for water column sediment concentrations of 200 g/m^3 and 300 g/m^3. The results plotted on Figure 19 show that the observations at Paull Holme Strays are very similar to the predictions for Cherry Cobb Sands assuming a suspended sediment concentration of 200 g/m^3 and no erosion during the inundation of the site.

4.1.6 If a sediment concentration of 300 g/m^3 is assumed. At Point 14 where no erosion is predicted the model prediction lies on this line in Figure 19. For Point 10 where erosion occurs for a short period on all tides, the prediction lies close to the observed accretion rate at Paull Holme Strays. We have therefore assumed that a sediment concentration of 300 g/m^3 is appropriate for our typical predictions.

Table 10 Sedimentation parameters

Parameter	Value
Critical stress below which sedimentation occurs	0.2 N/m^2
Critical stress above which erosion occurs	0.5 N/m^2
Erosion rate constant	0.0001 kg/m^2s
Bed density after deposition	500 kg/m^3
Bed density of long term settled sediments	1500 kg/m^3
Typical sediment concentration in the water column	200 or 300 g/m^3

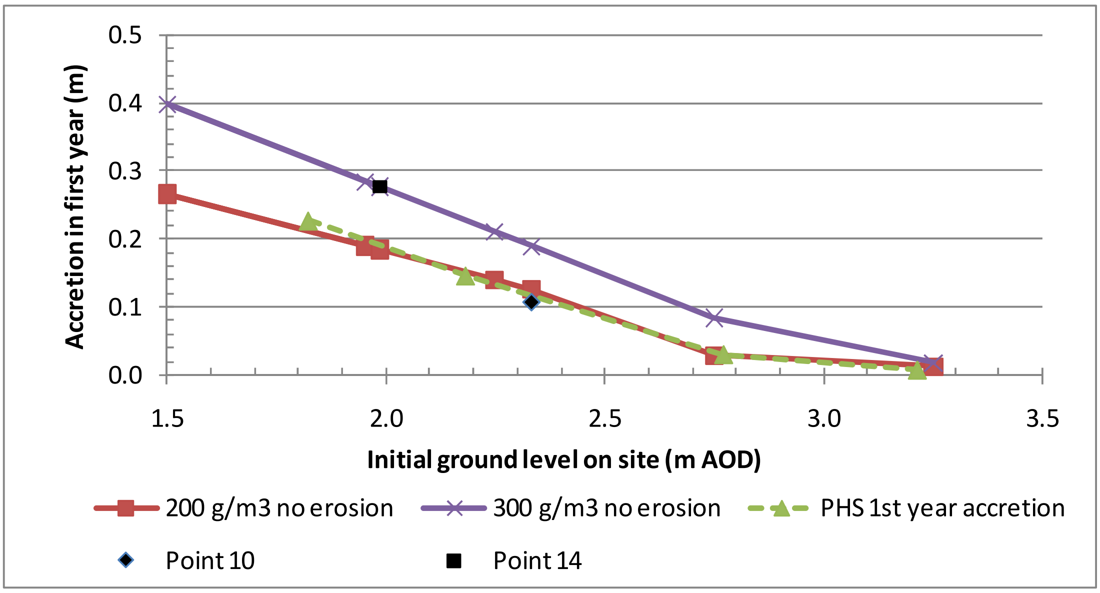


Figure 19 Comparison of observed accretion at Paull Holme Strays with predicted accretion rates at Cherry Cobb Sands

4.2 SEDIMENTATION WITHIN THE COMPENSATION SITE

4.2.1 Accretion and erosion have been calculated for Points 10, 11, 12, 13 and 14 on Figure 3 within the Compensation Site, assuming a suspended sediment concentration of 300 g/m^3 for the typical result. The results are reported in Table 11 for one year and after five years assuming that the ratio of the sedimentation after five years will be around three times that reported after one year on the basis of the observations at Paull Holme Strays for initial ground levels of below 2.5 mAOD presented in Figure 20. Low rates of accretion are associated with 200 g/m^3 sediment concentration and high rates of accretion with 450 g/m^3 suspended sediment concentration.

Table 11 Predictions of sedimentation within the Compensation Site

Point	Ground level mAOD	Predicted change after one year (m)			Predicted change after 5 years (m)		
		Low	Typical	High	Low	Typical	High
10	2.33	0.04	0.11	0.20	0.1	0.3	0.6
11	2.25	-0.03	-0.01	0.07	-0.1	0.0	0.2
12	1.95	-0.07	-0.04	0.01	-0.2	-0.1	0.0
13	1.50	0.00	0.12	0.32	0.0	0.4	1.0
14	1.99	0.18	0.28	0.41	0.6	0.8	1.2

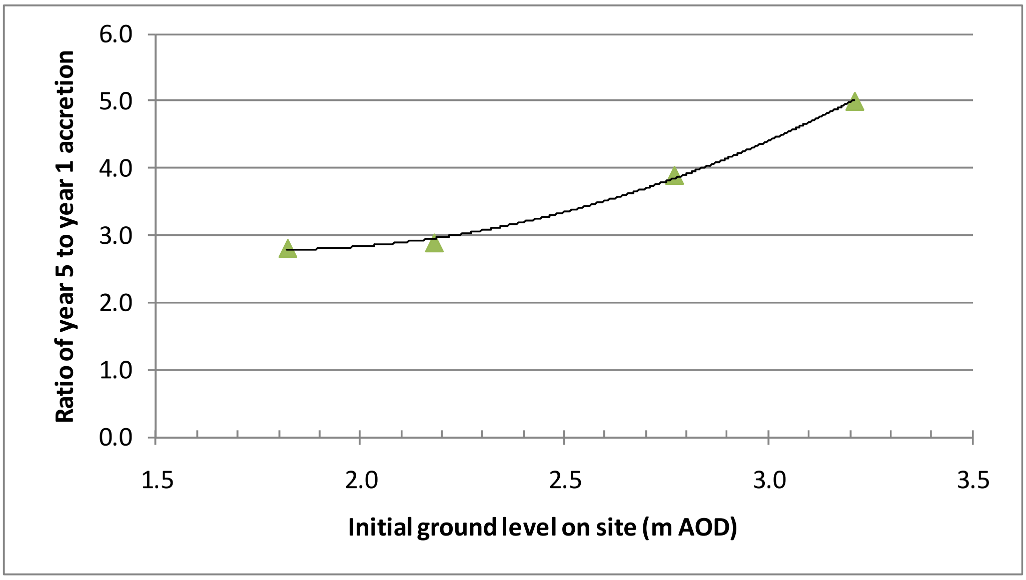


Figure 20 Ratio of accretion over five years to one year at Paull Holme Strays

4.2.2 The 'typical' predicted accretion and erosion at Points 10 to 14 on Table 11 are shown on Figure 19 in comparison with the observations at Paull Holme Strays and predictions in the absence of any erosion. The results for Point 10 lie close to the observations at Paull Holme Strays and implicitly assume that the balance of erosion and accretion at Point 10 would be similar to that experienced at Paull Holme Strays. The results for Point 14 fall on the '300 g/m^3 no erosion' line on Figure 19 since no erosion is predicted at this site because of the low velocities in all tidal conditions. At Points 11, 12 and 13 in areas of higher velocity than Point 10, more erosion is expected, and at Point 12 in particular a small amount of erosion is anticipated for the 'typical' condition.

4.2.3 If the 'low' predictions are considered, the lower suspended sediment concentration of 200 g/m^3 reduces the accretion at all sites and indicates erosion might occur at Points 11 and 12. The low predictions for Point 14 lie on the '200 g/m^3 no erosion' line in Figure 19. The high predictions assume a suspended sediment concentration of 450 g/m^3 which is sufficient to prevent erosion at Points 10 to 14, though erosion might still occur at points between 12 and 13 where Figure 8 indicates flood tide velocities are higher than at the specific points chosen for more detailed analysis.

4.2.4 The 'typical' predictions in Table 11 have been used to estimate contours of sedimentation and erosion within the Compensation Site after five years as shown in Figure 21. These contours also take account of the maximum velocity distribution on the flood tide shown in Figure 8 and on the ebb tide in Figure 9. The contours assume implicitly that measures to protect the breach from erosion as discussed in Section 3.3 have been applied. If the breach is allowed to erode the contours are likely to be fairly similar except in the area closest to the breach channel.

4.2.5 The estimated contours of accretion and erosion after five years have been applied to the original ground levels in Figure 22 to provide estimated ground levels after five years. After five years, around 48.7 ha of the site is anticipated to be above 2.5 mAOD where saltmarsh is expected to start developing. However, an estimated 47.6 ha remains with levels below 2.5 mAOD, including around 2.5 ha within the breach channel. If there is erosion of the breach channel, all this area is likely to remain as mudflat, while if measures to prevent erosion of the breach channel are implemented, the17.2 ha that are predicted to be below 2.0 mAOD would be subtidal as ground levels would be below the breach invert level. In view of the uncertainty inherent in sedimentation predictions, it would be prudent to assume that the contours in Figure 21 probably have an uncertainty of ±50 percent in line with the variability between the high and low predictions in Table 11.

Figure 21 Estimated Compensation Site accretion contours after five years

Figure 22 Estimated Compensation Site ground levels after five years

4.3 *SEDIMENTATION ON FOUL HOLME SAND*

4.3.1 The velocities over Foul Holme Sand are generally low as indicated in Sections 3.4 and 3.6. Predicted annual erosion has been calculated for Points 18, 19 and 20 on Figure 3 on the top of Foul Holme Sand using the method outlined in Section 4.1. In addition the percentage of time that the predicted shear stress was below 0.2 N/m^2, the critical threshold for deposition, was calculated.

4.3.2 The results for the three points on Foul Holme Sand are presented in Table 12. They show that accretion is predicted for more than 90 % of time upstream of Stone Creek (Points 18 and 19) and for about 75% of time south of Stone Creek (Point 20) in the baseline. This is in accord with recent experience of accretion on Foul Holme Sands (Annexes 32.1 and 34.1). The results show a small reduction of 1 to 4 percent of time that accretion can occur with the Compensation Site in place. There is no change in the amount of erosion predicted at any of the points analysed on Foul Holme Sand as a result of the Compensation Site.

4.3.3 These results are based on shear stresses associated with tidal currents alone and make no allowance for the additional shear stress that is present when there is wave activity present. Wave activity is likely to play an important role in the evolution of Foul Holme Sand as it is the major process that is able to promote erosion of the sand bank to balance the accretion that is predicted as a result of tidal currents.

4.3.4 These results suggest that the risk of a creek developing across Foul Holme Sand as a result of the introduction of the Compensation Site is relatively small. There is a possibility that the rates of accretion on Foul Holme Sand might marginally reduce as a result of the Compensation Site because of the small reduction in the time when accretion due to tidal currents may occur. The presence of wave activity for a proportion of the time may alter the present dynamic balance of accretion and erosion on this sandbank slightly towards erosion so marginally increasing the risk that a channel might form across this sandbank.

Table 12 Percentage of time accretion occurs over Foul Holme Sand

	Percent of time with accretion		Annual erosion estimate (m)	
Location	Baseline	With Scheme	Baseline	With Scheme
Point 18	95.5	93.6	0.006	0.006
Point 19	93.6	89.1	0.000	0.000
Point 20	78.3	77.0	0.038	0.038

4.4 *SEDIMENTATION IN CHERRY COBB SANDS CREEK*

4.4.1 The flood tide velocities in Cherry Cobb Sands Creek are little affected by the Compensation Site, but ebb tide velocities in the creek increase downstream of the breach at Points 16 and 17 as indicated in Section 3.5. Upstream of the breach at Point 15 there is a reduction in velocity on the ebb tide as a result of the breach.

4.4.2 Table 13 compares the predicted sedimentation in Cherry Cobb Sands Creek in the baseline case and as a result of the breach that allows the Compensation Site to flood most tides.

4.4.3 In the baseline case, accretion is predicted at all three locations considered in the creek, with greater accretion at Points 16 and 17 either side of the Stone Creek confluence. Siltation of the outfall channel from the Stone Creek land drainage outfalls has been reported by the drainage authorities as affecting the effectiveness of these land drainage outfalls (Annex 32.1 section 2.3). The Lidar survey on which the model bathymetry is based was flown in September 2007, shortly after the large floods of July 2007 were discharged down Cherry Cobb Sands Creek which probably increased the size of this creek (Annex 32.1 section 2.1). With only low land drainage flows assumed at Stone Creek in the model (Annex 32.2), the predicted tendency for Cherry Cobb Sands Creek to accrete in the baseline case is in accordance with experience.

4.4.4 The effect of the Compensation Site on sedimentation in Cherry Cobb Sands Creek is indicated in Table 13. North of the breach, at Point 15, increased accretion within the creek is predicted as a result of the lower ebb tide velocities. By contrast, at Points 16 and 17, downstream of the breach, erosion of the creek by the larger ebb flows is predicted. Erosion of around 1.5m in a year is predicted between the breach and Stone Creek, represented by Point 16. The rate of erosion predicted at Point 17 downstream of the Stone Creek confluence is approximately half that predicted at Point 16.

4.4.5 Comparison of the cross section of Cherry Cobb Sands Creek upstream and downstream of the Stone creek confluence (Annex 32.1, Figure 4) and the lower bed level at Point 17 in Table 13 illustrate how much larger the creek cross section is downstream of the Stone Creek confluence. These two cross sections receive similar ebb tide flows from the Compensation Site, so the reduced rate of erosion in the larger creek cross section downstream of the Stone Creek confluence is expected.

Table 13 Predictions of sedimentation in Cherry Cobb Sands Creek

Point	Ground level mAOD	Baseline prediction of change after one year (m)			Prediction of change after one year with Compensation Site (m)		
		Low	Typical	High	Low	Typical	High
15	0.84	0.08	0.27	0.55	0.36	0.55	0.83
16	0.00	0.43	0.69	1.1		-1.4	
17	-1.49	0.37	0.62	1.0		-0.75	

Note: Positive values represent accretion; negative values erosion

4.5 SEDIMENTATION IN STONE CREEK

4.5.1 The velocities in Stone Creek are low as indicated in Section 3.5. At Point 21 in this creek, shear stress is always <0.2 N/m^2 on all tides in the baseline tests and in the tests with the Compensation Site operational. This indicates that accretion will be continuous with the small freshwater flow that was added to the model through the Stone Creek sluices (*See Annex 32.2).* During these times of low flow, accretion of Stone Creek is expected to occur as has been observed. The large winter flows through these sluices will scour some of the accumulated sediment and the balance of accretion during the summer and erosion in the winter will develop a dynamic equilibrium of sediment levels within Stone Creek.

4.5.2 As accretion occurs at all times with or without the scheme, it is unlikely that the operation of the Compensation Site will have a noticeable effect on sediment levels within Stone Creek provided the suspended sediment concentration in the water column is not changed by the Compensation Site operation. A change in sediment concentration during the flood tide would be particularly important as that is the time when water from Cherry Cobb Sands Creek floods into Stone Creek.

4.5.3 The major effect of the Compensation Site within Cherry Cobb Sands Creek will be during the ebb tide as that is the time when flows and velocities in the creek increase. There is little change predicted in flows during the flood tide so no reason for additional material to be present in suspension as a result of the Compensation Site. In practice, because Cherry Cobb Sands Creek will enlarge because of the greater ebb flows, the velocities on the flood tide are likely to reduce increasing the likelihood of deposition within Cherry Cobb Sands Creek during this phase of the tide. This effect may lead to a small reduction in flood tide suspended concentrations within this creek.

4.5.4 Even though the long term effect of the Compensation Site on Stone Creek siltation is likely to be neutral or possibly beneficial, in the short term there may be greater accretion within Stone Creek while Cherry Cobb Sands Creek adjusts to the increased flows arising from the Compensation Site. The flows that will enlarge the creek are on the ebb tide and the eroded sediment will be carried downstream in the creek towards the Humber low tide channel. Most of the sediment is likely to be deposited here and increase the instability of the Cherry Cobb Sands Creek outfall into the Humber. However, some of the eroded sediment is likely to return up the creek on the following flood tide and a proportion of this returning sediment may well end up in Stone Creek, where it would be likely to be deposited unless freshwater flows were unusually high.

4.5.5 Monitoring of sediment levels within Stone Creek is recommended during the period that Cherry Cobb Sands Creek adjusts to the increased flows arising from the Compensation Site. If the monitoring shows increased sediment levels above those expected on the basis of normal annual variability, remedial action may be justified to ensure no reduction in efficiency of the Stone Creek drainage outfalls.

4.5.6 The small increases in low water levels of 0.1 m and reduction in duration of the low tide period of 10 or 20 minutes reported in Section 3.2 for Stone Creek might have a small adverse impact on water levels within the land drains discharging to Stone Creek at times when flood waters are being evacuated.

4.5.7 These changes to water levels in Stone Creek are predicted without including the effect of the anticipated enlargement and deepening of Cherry Cobb Sands Creek predicted in Section 4.4. Once this deepening has taken place and the associated risk of additional accretion within Stone Creek discussed above has also passed, the low water level within Stone Creek is likely to return to levels similar to or possibly lower than those experienced at present. Similarly the duration of the period with tide levels below 0.5 mAOD seems likely to return to values similar to or possibly longer than those predicted for the baseline conditions.

5 CONCLUSIONS

Tide levels

5.1.1 High and low tide levels in the Humber estuary are predicted to be unaffected by the presence of the Compensation Site. Within the Compensation Site the model predicts that at the northern end, high tide levels could be around 0.05±0.03 m higher than in the estuary.

Effects on Cherry Cobb Sands Creek

5.1.2 Velocities in Cherry Cobb Sands Creek on the flood tide are little affected by the presence of the Compensation Site. This indicates this creek is not an important source of water for filling the Compensation Site on the flood tide.

5.1.3 The Compensation Site will considerably increase velocities and the duration of high velocities in the creek on the ebb tide downstream of the breach and past Stone Creek. This is predicted to lead to erosion in this part of the creek.

5.1.4 Accretion in Cherry Cobb Sands Creek upstream of the breach is predicted to increase after the Compensation Site is introduced.

5.1.5 At the downstream end of Cherry Cobb Sands Creek the velocities in the shallow flows that occur at low tide are quite high. This part of the creek is likely to remain dynamic.

Effects on Stone Creek

5.1.6 The long term effect of the Compensation Site on Stone Creek siltation is likely to be neutral or possibly beneficial. However, in the short term there may be greater accretion within Stone Creek while Cherry Cobb Sands Creek adjusts to the increased flows arising from the Compensation Site.

5.1.7 Within Stone Creek, the presence of the Compensation Site is predicted to initially raise low tide levels by 0.1 m from their present predicted level of 0.25 mAOD and reduce the duration of the period water levels are below 0.5 mAOD by 10 or 20 minutes from the present predicted duration of 6 hours 40 minutes. However, this change in low tide conditions in Stone Creek is anticipated to be temporary until Cherry Cobb Sands Creek has enlarged in response to the predicted increase in velocity associated with the Compensation Site.

Effects on Foul Holme Sand

5.1.8 The velocities over Foul Holme Sand are generally low, and in the absence of wave activity, accretion dominates sedimentation processes on Foul Holme Sand. The operation of the Compensation Site is predicted to make no substantial changes to the conditions encountered on the top of Foul Holme Sand.

5.1.9 The risk of a creek developing across Foul Holme Sand as a result of the operation of the Compensation Site is considered relatively small. There is no change in the amount of erosion predicted at any of the points analysed on Foul Holme Sand as a result of the Compensation Site. Wave activity may alter the present dynamic balance of accretion and erosion on this sandbank slightly towards erosion so marginally increasing the risk that a channel might form across this sandbank.

Effects on the breach and Compensation Site

5.1.10 The maximum velocities throughout the breach channel are generally found in the centre where ground levels are 0.2 m lower. The highest velocities predicted within the breach channel are found inside the site and as this area has received little consolidation, this is the area where creek erosion is most likely to occur, probably to the north of the breach channel centreline. Erosion of the outer end of the breach channel starting where it joins Cherry Cobb Sands Creek is also likely in the southern half of the breach channel.

5.1.11 Creeks formed inside and outside the breach channel are expected to propagate back towards the original flood defence line and eventually cutting through this line probably close to its centre, unless erosion protection is introduced to prevent this.

5.1.12 Within the Compensation Site areas away from the breach site are generally expected to accrete, while erosion is anticipated to occur in areas of high velocity predicted near to and north of the breach. The rate of accretion and the risk of erosion are dependent on assumptions made about the amount of sediment in suspension in the water column. For this assessment typical rates have been estimated based on experience at the nearby managed realignment site at Paull Holme Strays.

5.1.13 Ground levels after five years have been estimated based on typical rates. Around 49 ha are anticipated to be above 2.5 mAOD where saltmarsh is expected to start developing. However, about 48 ha are expected to remain with levels below 2.5 mAOD. As no measures will be taken to prevent erosion of the breach, a creek is likely to form through the breach and all this area is likely to be mudflat.

5.1.14 In view of the uncertainty inherent in sedimentation predictions, it would be prudent to assume that the predicted changes in ground levels probably have an uncertainty of ±50 percent.