Annex 32.6

Assessment of 110 ha Layout

(Black & Veatch)

Cherry Cobb Sands Compensation Site

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Annex 32.6
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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 110 ha site shown on Figure 1 has been proposed as a Compensation Site. The existing ground levels within this site are approximately 2.5 mAOD. Approximately 300,000 m³ of fill will be removed from within the site to form the surrounding flood defences. The final profile will be agreed with Natural England to maximise the area of sustainable mudflat developed within the site. Ground levels within the site will be profiled within the range 1.5 to 3.5 mAOD, though levels outside this range will develop due to sedimentation within the site.

1.1.2   For the tests described in this report, ground levels are lowered to 1.5 mAOD in the southern portion of the site near the proposed breach. The remainder of the site has been graded between 1.5 and 2.5 mAOD to allow drainage of the site at low tide. Further detailed tests will be carried out to decide the most suitable ground levels for long term maintenance of mudflat habitat.

1.1.3   The final breach arrangement will be agreed with Natural England to maximise the area of sustainable mudflat.   In these studies the breach is shaped as a 250 m cut through the existing flood embankment with its invert profiled into the shape of a shallow Vee. Minimum invert level s of 2.0 and 1.8 mAOD have been adopted for the breach in the tests described in this report. In both cases the edges of the Vee where they meet the flood embankment have been set 0.2 m above the lowest level in 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. A similar breach with an invert level of 2.0 mAOD was used in the tests for the 90 ha site in Annex 32.4.

1.1.4   The breach invert level 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 set above the breach invert level are expected to drain out each tidal cycle, apart from some low lying areas that will not have time to drain during spring low water. These areas will drain out each fortnight during the neap tide periods when there will be much less inundation of the site.

1.1.5   Over the course of time erosion of a creek through the breach is expected. This will allow the whole site to drain at low tide.
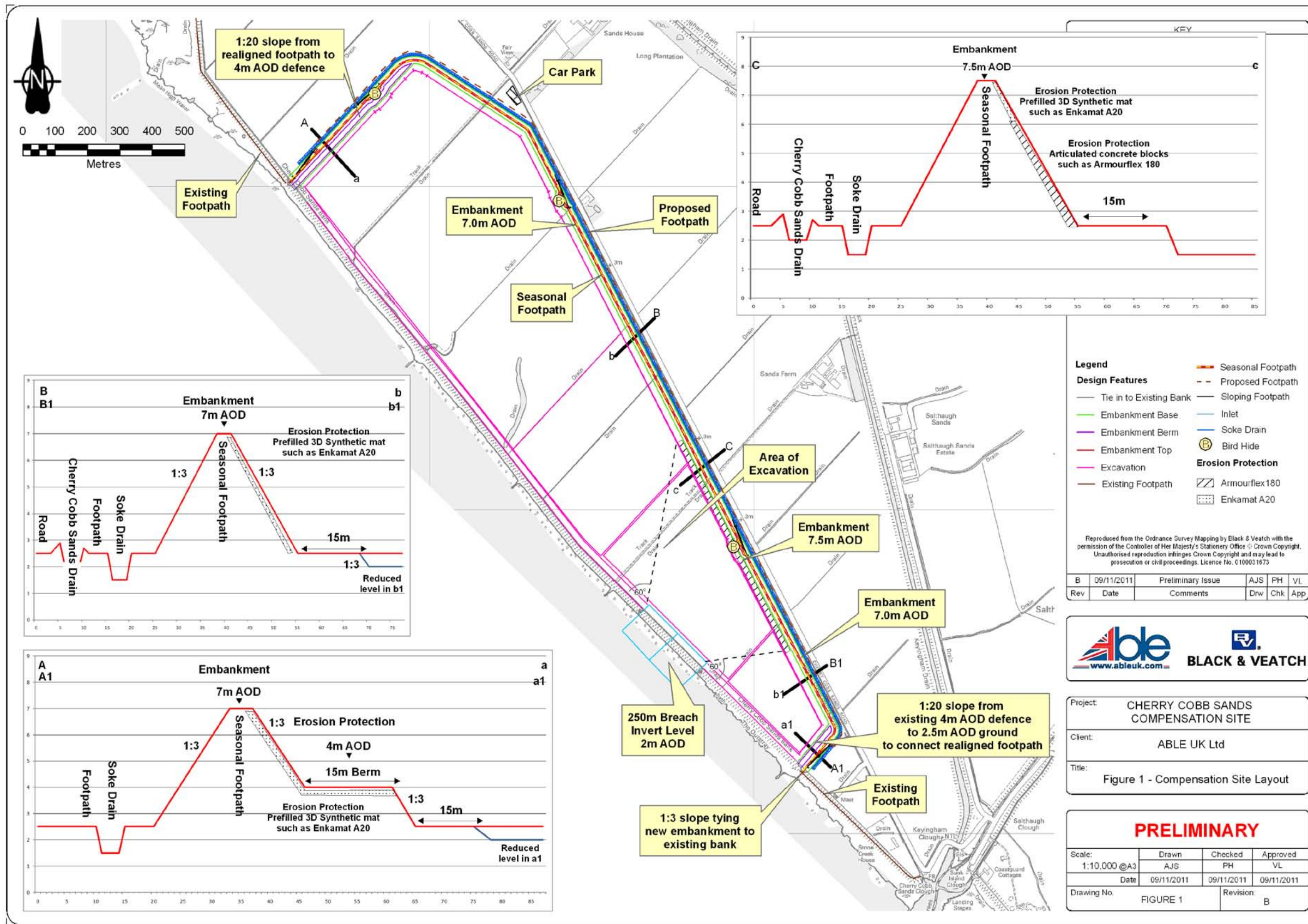
Figure 1   Proposed 110 ha Compensation Site

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.*

1.2.2   Initially it was thought that a 90 ha managed realignment would be sufficient, but Natural England requested a larger site. Unfortunately this decision came too late for full testing of this site to be included within the Environmental Statement. The effects of a 110 ha site have been assessed by extrapolating the results from the model testing of the 90 ha site reported in Annex 32.4, and verifying these using the information available from the additional model tests of the 110 ha site reported in this Annex. Breach invert levels of 1.8 and 2.0 mAOD have been considered.

1.3 FORESHORE TOPOGRAPHY AND MODEL LIMITS

1.3.1   The models described in this Annex for the 110 ha site and Annex 32.4 for the 90 ha site both used the same digital terrain ground model (DTM) described in Annex 34.4 and 34.2. The breach in the flood defences for the110 ha Compensation Site is at the same location and of the same length as the one for the 90 ha site in Annex 32.4.

1.3.2   The flows over the foreshore of Foul Holme Sand and down Cherry Cobb Sands Creek, including the flows through the breach into the Cherry Cobb Sands Compensation Site are largely dominated by the topography of the foreshore and breach. The size of the Compensation Site affects the volume of water flowing through the breach and the range of the tide affects the flows over the foreshore and through the breach.

1.3.3   The boundaries of the model on the Humber foreshore used in this Annex for the 110ha site and the 90 ha site in Annex 32.4 respectively were the same and are shown on Figure 2. Within the Compensation Site itself, the 110 ha model enclosed 20 ha more within the area exposed to tidal inundation than the 90 ha model.
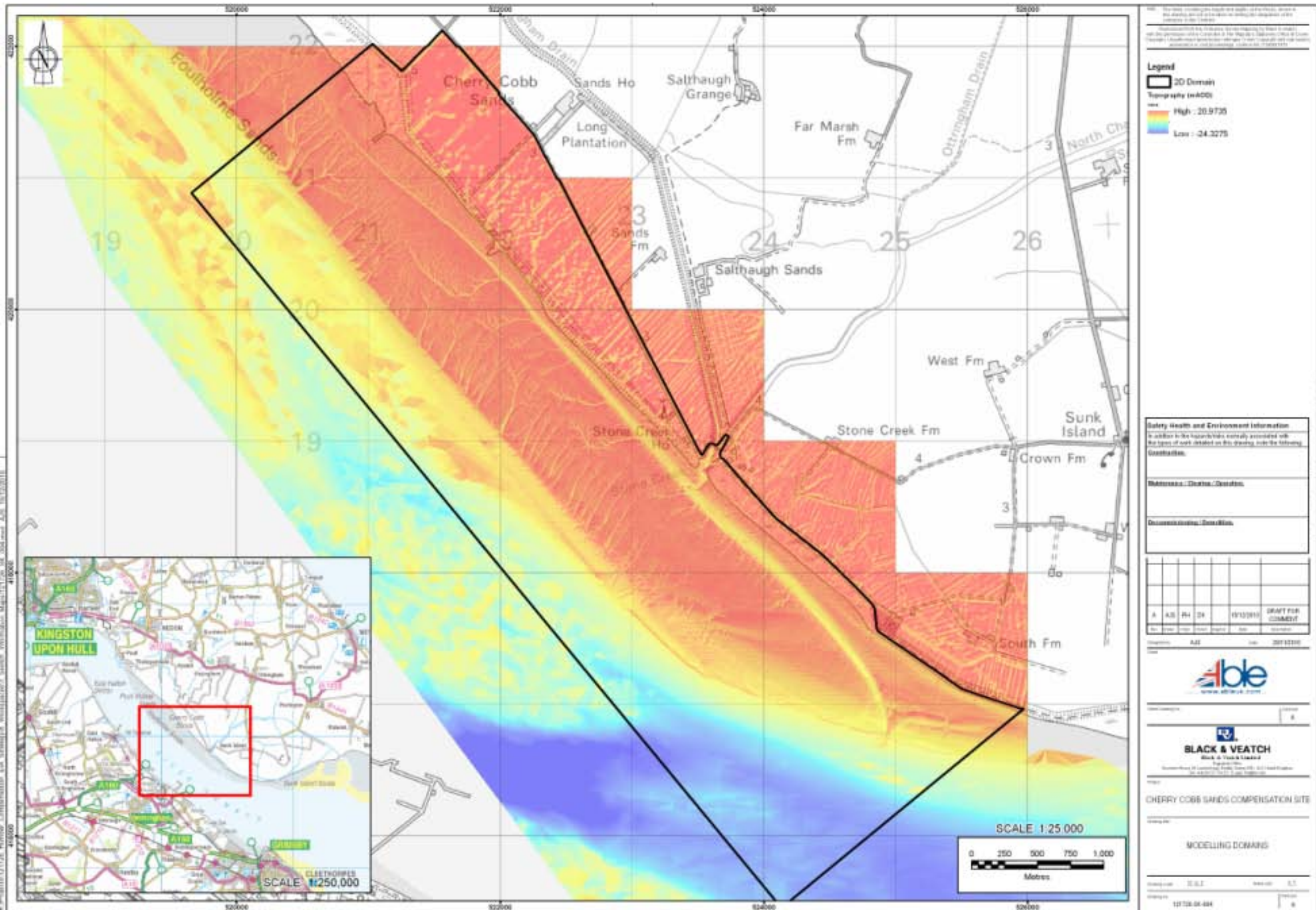
Figure 2   Foreshore topography and model boundaries near Cherry Cobb Sands

1.4   *TIDAL BOUNDARY CONDITIONS*

1.4.1   The set up of the hydraulic model, the derivation of its boundary conditions and the verification of the model are described in Annex 32.2.

1.4.2   For the modelling of the 90 ha site in Annex 32.4, four tides from 2010 were used as reported in Table 1. For the modelling of the 110 ha site only Tides 1 and 2 with high water levels of 3.96 and 3.64 mAOD at Stone Creek were tested.

Table 1   Comparison of tidal conditions at Stone Creek (Point 21)

Tide type	Average frequency of occurrence %		Tide levels in Stone Creek mAOD			
			High water levels		Low water levels	
			Baseline	With scheme	Baseline	With Scheme
Tide 1	1.4.3	2	3.96	3.96	0.25	0.35
Tide 2	1.4.4	10	3.63	3.64	0.25	0.35
Tide 3	1.4.5	24	3.17	3.15	0.25	0.35
Tide 4	1.4.6	23	2.86	2.84	0.24	0.34

2.1   I*NTRODUCTION*

2.1.1   In the tests of the 110 ha Compensation Site, the same comparison
               Points and long sections as used for the 90 ha Compensation Site and
               shown in Figure 3 have been adopted. The points used in the 110 ha
               site are at exactly the same coordinates as those shown in Figure 3 for
               the 90 ha site. The main difference between the two sites is in the
               location of the realigned flood defence at the northern part of the site
               to the north of Point 10

2.1.2   Flows through the breach will increase by approximately 22 % as a
               result of the increased area of the Compensation Site. Within the site
               this increase in flows through the breach will lead to increased flows
               within the site, especially near to the breach. The effect these
               increases in flows will have on velocities and hence sedimentation
               patterns will be subject to further detailed studies to determine the
               most sustainable arrangement for mudflat creation.

Figure 3   Sections and points where velocity and level extracted

MODEL TIDE LEVELS

2.2.1   The model tests for the 110 ha site considered tides at the 21 points
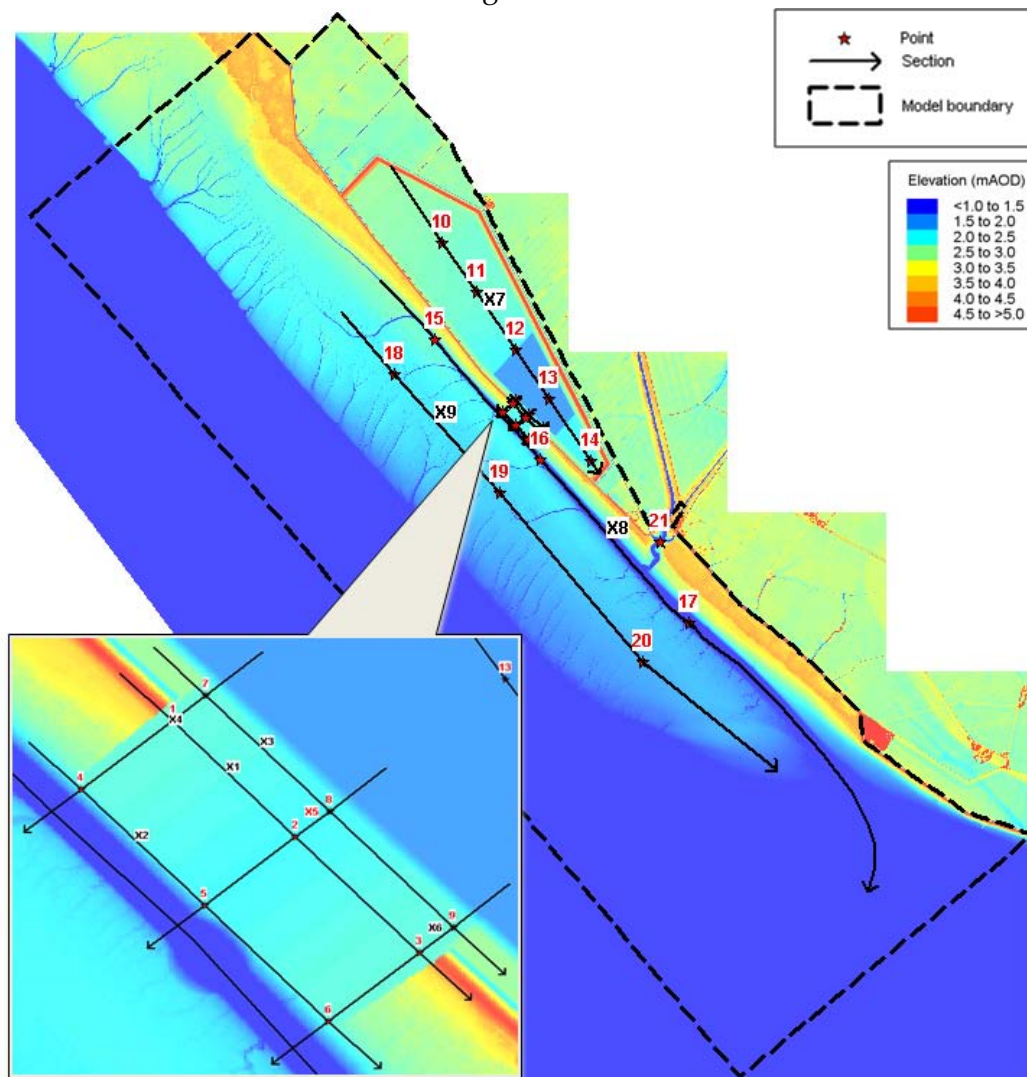   identified on Figure 3. At the three key comparison sites within the
          estuary and the habitat creation site listed on Table 2, differences
          between the high water levels predicted for the 90 ha and 110 ha sites
          on Tide 2 were no more than 0.01 m. The model predictions suggest
          that changing the invert level of the breach from 2.0 to 1.8 mAOD has
          less than 0.01 m effect on high water levels.

Table 2   Comparison of high tide levels for 90 and 110 ha Compensation Sites

High Tide mAOD (1730 on 8/9/10)	Baseline	90 ha site	110 ha site	110 ha site
Breach invert level mAOD	-	2.0	1.8	2.0
Stone Creek (Point 21)	3.63	3.64	3.64	3.64
Foul Holme Sand North (Point 18)	3.62	3.63	3.63	3.63
Inside site north end (Point 10)	-	3.70	3.71	3.70

2.2.2   Within the Compensation Site the predicted high water levels at the
          north end (Point 10) are approximately 0.06 m higher than at Stone
          Creek. 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 around
          0.05 m across the Compensation Site.

2.2.3   Predicted tide levels with the 110 ha Compensation Site for Tide 2 on
          the evening of 8th Sept 2010 are shown in Figure 4.   The predicted
          tide with a 90 ha site is shown as a dotted line at Point 13 within the
          Compensation Site. Elsewhere the levels are very similar to those
          with a 110 ha site. The effect of changing the breach invert level from
          2.0 to 1.8 mAOD is clearly seen at Point 13 inside the Compensation
          Site in an area where ground levels are 1.5 mAOD. With a breach
          invert level of 2.0 mAOD the predicted low tide level within the
          Compensation Site is 2.13 mAOD for both the 90 and 110 ha site. The
          predicted low water level at Point 13 with a breach invert of 1.8
          mAOD reduces to 1.90 mAOD.

Low tide at Stone Creek

2.2.4   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 predicted minimum water level during the low
          tide period are compared in Table 3 for the 90 and 110 ha
          Compensation Sites for the large spring tide in the late evening of 8th
          Sept 2010 .

2.2.5   Table 3 shows that changing the size of the Compensation Site from
          90 to 110 ha does not change the low water level at Stone Creek

which remains 0.10 m above the baseline case. The 110 ha site does, however, slightly reduce the time when water levels are below 0.5 mAOD because of the larger discharge passing down Stone Creek. The 110 ha site leads to a 30 minute reduction in the time water levels are below 0.5 mAOD on Tide 2 compared with the baseline. Changing the invert level of the breach from 1.8 to 2.0 mAOD has no effect on low tide conditions at Stone Creek.

2.2.6   Annex 32.4 Table 4 shows that the duration of the low tide period at Stone Creek is shorter on Tide 2 than for any of the other tides modelled previously. On this basis the average duration of the low tide period at Stone Creek has been taken as 6 hours 40 minutes. The reduction associated with introduction of the Compensation Site is expected to be 20 to 30 minutes based on the previous findings.

Table 3   Duration and level of low water at Stone Creek

Low Tide at 0030 on 9/9/10	Baseline	90 ha site	110 ha site	110 ha site
Breach invert level mAOD	-	2.0	1.8	2.0
Low water level mAOD	0.25	0.35	0.35	0.35
Duration (hours) of levels < 0.5 mAOD	6.17	5.83	5.67	5.67
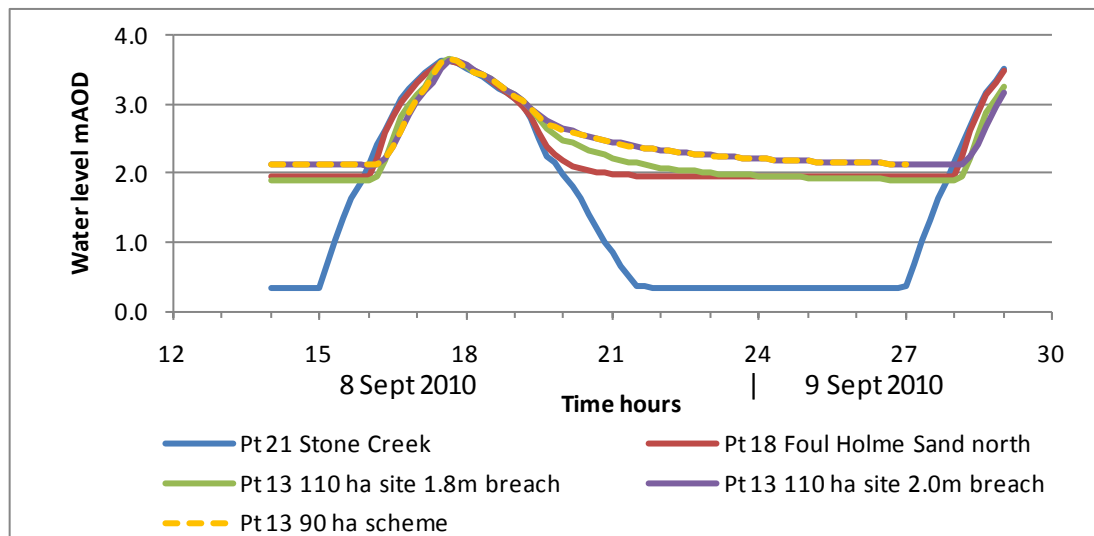
Figure 4   Comparison of Model tide levels for 90 and 110 ha Compensation Sites

2.3   BREACH VELOCITIES

2.3.1   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.

2.3.2   For the 110 ha Compensation Site considered in this Annex, two breaches were tested with different invert levels in the centre of the breach: one with an invert level of 1.8 mAOD and the other with an invert level of 2.0 mAOD. Both breaches had invert levels at the sides

of the breach 0.2 m higher than in the centre to form the flat-vee profile. The 90 ha Compensation Site tested in Annex 32.4 had the same design of breach with an invert level of 2.0 mAOD. Predicted velocities in the centre of the breach for the evening tide on 8th Sept 2010 are shown on Figure 5.

2.3.3   The average breach velocities with the 110 ha Compensation Site with a 2.0 mAOD breach invert have a very similar time history to those for the 90 ha site which had the same breach invert level. The average velocity during the flood and ebb portions of the tide are around 20% greater for the 110 ha site than for the 90 ha site as reported in Table 4.

2.3.4   Table 4 also shows that reducing the breach invert from 2.0 to 1.8 mAOD decreases the average velocity on the flood and ebb portions of the tide by 8% because of the greater depth of water through the breach. Figure 5 shows that with the 1.8m AOD breach the peak flood tide velocity occurs about 20 minutes earlier.

2.3.5   Maximum predicted velocities on the line of the breach are reported in Table 4 and shown on Figure 5. The maximum velocities within the breach channel are predicted on the centreline of the breach inside the Compensation Site. These maximum velocities, which are noted in Table 4 were predicted for the highest tide (Tide 1 on Table 1).

2.3.6   Increasing the area of the Compensation Site from 90 to 110 ha increases the maximum velocity within the breach channel, though because velocities are only output at 10 minute intervals the maximum within the model may have been missed. There is evidence that the maximum velocity will reduce slightly if the breach invert level is reduced from 2.0 to 1.8 mAOD because of the greater depth of water available.

Table 4   Predicted velocities in the centre of the breach

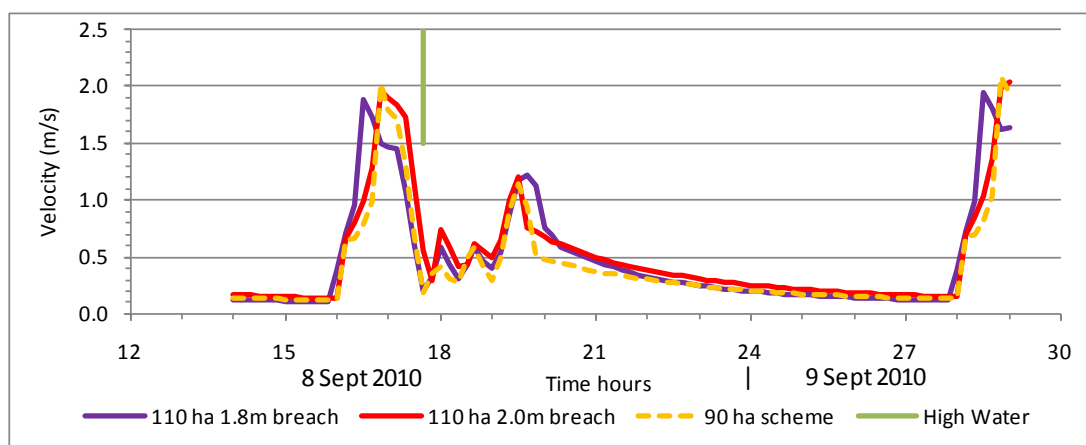| Date and approx HW time (1730 on 8/9/10)	Compensation site area			Tidal duration (hrs)
	90 ha	110 ha	110 ha	
Breach invert level	2.0	1.8	2.0	
Average flood tide velocity (m/s)	0.99	1.09	1.18	1.83
Average ebb tide velocity (m/s)	0.30	0.35	0.38	10.33
Max velocity on breach centreline (m/s)	2.0	1.9	2.0	
Max velocity in breach channel on Tide 1 (m/s)	2.4	2.3	2.6	

Figure 5   Comparison of predicted velocity profiles in the centre of the breach

2.4   VELOCITIES IN AND AROUND THE COMPENSATION SITE

Flood tide velocity pattern

2.4.1   The predicted velocity pattern on Tide 2 close to the time of maximum flood tide velocity, at 1700 on 8th Sept 2010 are illustrated in Figure 6a for the 90 ha site, Figure 6b for the 110 ha site with a 1.8 mAOD breach invert and in Figure 6c for the110 ha site with a 2.0 mAOD breach invert. The lower velocities through the breach for the 110 ha site with the 1.8 mAOD breach are the most obvious difference between the velocity patterns. This is because the velocity through the breach with a 1.8 mAOD invert was at its peak around 20 minutes earlier than with the 2.0 mAOD invert as noted in Figure 5.

2.4.2   The maximum velocities are slightly larger within the 110 ha Compensation Site than those predicted within the 90 ha site, though this is not evident in Figure 6. On the foreshore over Foul Holme Sand the velocity distribution and magnitude seems little affected by the changes in Compensation Site area or breach invert level.

Ebb tide velocity pattern

2.4.3   The predicted velocity pattern on Tide 2 close to the time of peak ebb velocities over Foul Holme Sand at 1930 on 8th Sept 2010 with the 90 and 110 ha Compensation Sites are illustrated in Figure 7. The pattern at 2200 on 8th Sept 2010 is illustrated in Figure 8.

2.4.4   At 1930, Figure 7a and c show that the velocity pattern over the foreshore is very similar for the 90 and 110 ha site with 2.0 mAOD breach invert. With the lower   1.8 mAOD breach in Figure 7b, the velocity through the breach is lower because of the greater depth of water, but the band of slightly raised velocity over Foul Holme Sand is wider, suggesting more flow goes over the sand bank at this time with the lower breach invert.

2.4.5   When Foul Holme Sand has dried at 2200 as in Figure 8, all the flow from the Compensation Site is directed into Cherry Cobb Sands Creek. The velocities with the 110 ha site through the breach in Figure 8b and c are greater than with the 90 ha site in Figure 8a. The velocities in Cherry Cobb Sands Creek with the 2.0 mAOD breach in Figure 8c seem rather greater than those shown at this time in Figure 8b for the 1.8 mAOD breach.

2.4.6   Figure 7 and Figure 8 both suggest that the highest ebb velocities within the Compensation Site are for the 110 ha site with a 1.8 mAOD breach.   For Figure 8a and c where the breach invert level remains unchanged at 2.0 mAOD, the 110 ha site leads to an increase in ebb velocities throughout the Compensation Site compared with the 90 ha site.
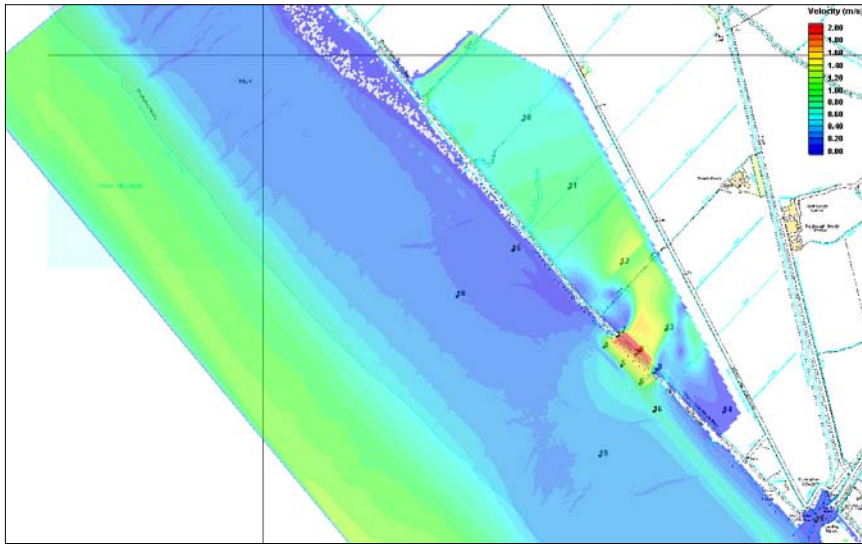
a) With 90 ha Compensation Site and 2.0 mAOD breach invert
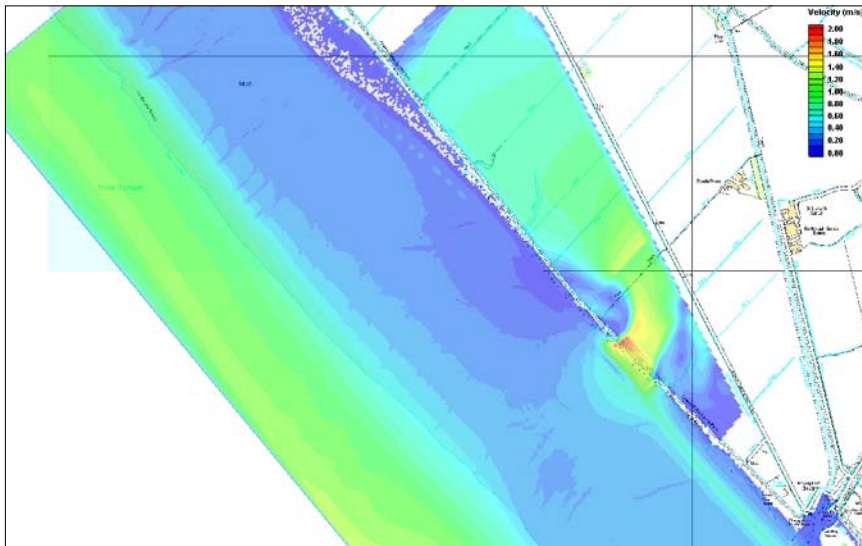
b) With 110 ha Compensation Site and 1.8 mAOD breach invert
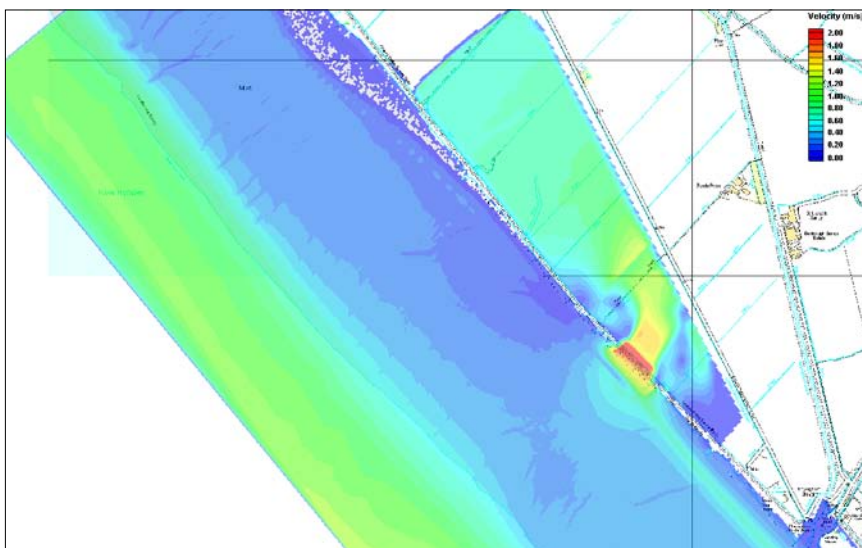
c) With 110 ha Compensation Site and 2.0 mAOD breach invert

Figure 6   Flood tide velocities at 1700 on 8th Sept 2010

a)   With 90 ha Compensation Site and 2.0 mAOD breach invert

b)   With 110 ha Compensation Site and 1.8 mAOD breach invert

c)   With 110 ha Compensation Site and 2.0 mAOD breach invert

Figure 7   Ebb tide velocities at 1930 on 8th Sept 2010

a) With 90 ha Compensation Site and 2.0 mAOD breach invert

b) With 110 ha Compensation Site and 1.8 mAOD breach invert

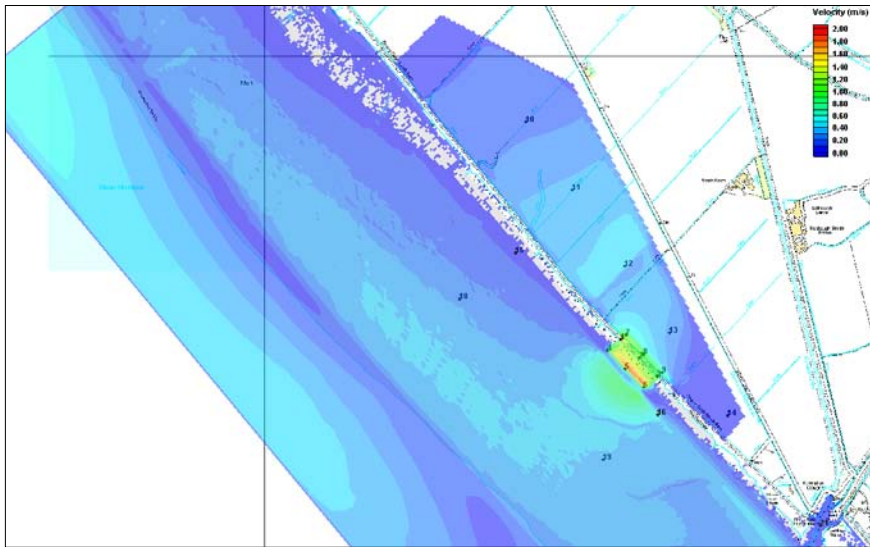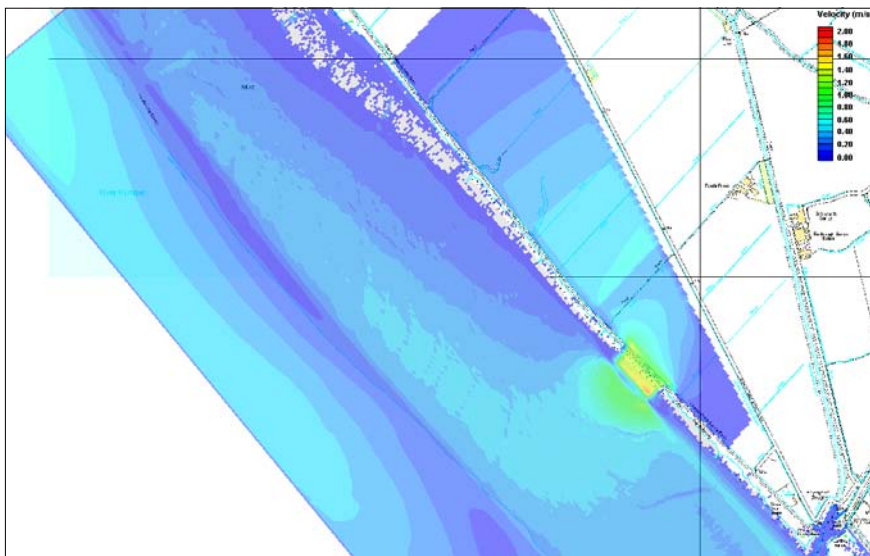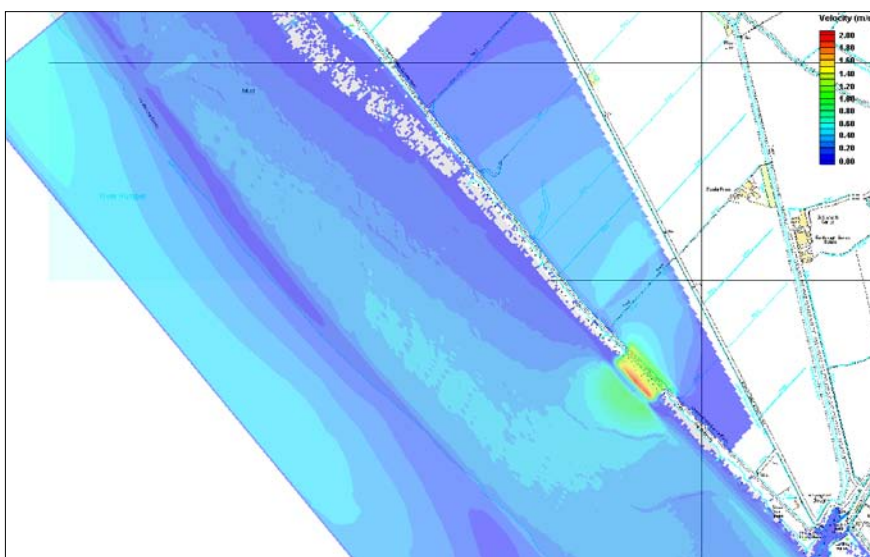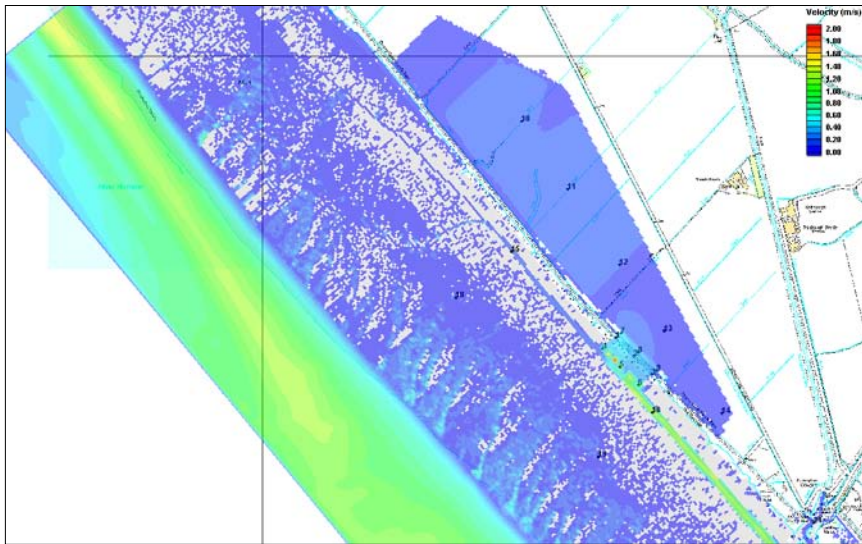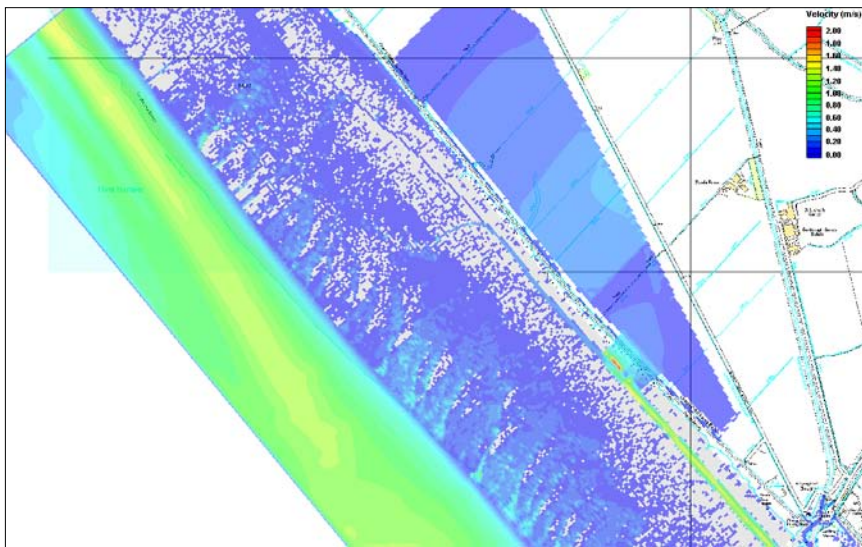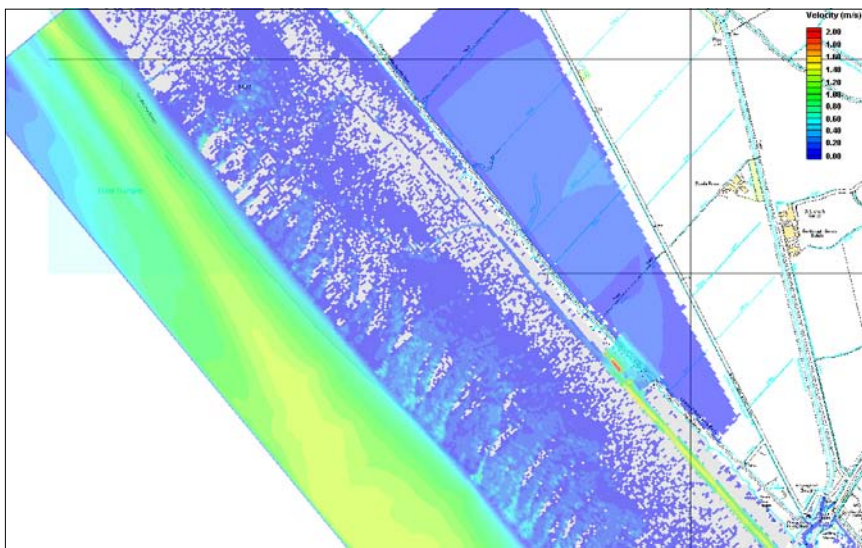c) With 110 ha Compensation Site and 2.0 mAOD breach invert

Figure 8   Ebb tide velocities at 2100 on 8th Sept 2010

2.5.1   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.

2.5.2   Maximum velocities predicted at the three points in Cherry Cobb Sands Creek (Points 15-17) and Point 21 in Stone Creek on the flood and ebb tide are set out in Table 5 for the baseline and with the 90 or 110 ha Compensation Sites. In the case of the 110 ha Compensation Site breach invert levels of 1.8 and 2.0 mAOD are also compared. Velocities in Stone Creek are much lower than at any of the three points 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, with any Compensation Site velocities at Point 16 just south of the breach are larger than those at Points 15 north of the breach or at Point 17 south of Stone Creek.

2.5.3   The predicted maximum velocities in Cherry Cobb sands Creek with a 110 ha Compensation Site are greater than with a 90 ha site at Point 16 100 m south of the breach on both flood and ebb tides. At Point 15 north of the breach and Point 17 south of Stone Creek, changing the size of the Compensation Site from 90 to 110 ha is predicted to have a relatively small effect. Reducing the breach invert level from 2.0 to 1.8 mAOD is predicted to increase maximum velocities on the flood tide at Point 16 just south of the breach, suggesting some increase in inflow to the Compensation Site with the lower breach. The level of the breach seems to have little effect on the maximum ebb tide velocity. At Point 17, south of Stone Creek, the lower breach level is predicted to cause a small reduction in maximum ebb velocity.

2.5.4   The predicted maximum velocity along Cherry Cobb Sands Creek during the flood and ebb of the large spring tide on the evening of 8th Sept 2010 are shown on Figure 9. The maximum velocities predicted with a 90 ha Compensation Site are shown as a dotted line while those predicted for the 110 ha site with breach levels of 1.8 and 2.0 mAOD are shown as solid lines. The maximum velocity on this tide with the 90 ha site is 1.4 m/s, while for the 110 ha site the maximum velocity is 1.5 m/s. Reducing the level of the breach from 2.0 to 1.8 mAOD is predicted to cause a minor reduction in maximum velocity.

2.5.5   Comparisons of the predicted velocity profiles through this tide at three points in the creek are shown in Figure 10. The three parts of the figure compare velocities at Point 15 upstream or north of the

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breach and at Points 16 and 17 downstream of the breach. The dotted line shows the predicted velocity profile with the 90 ha site and 2.0 mAOD breach invert while the solid lines show the predicted profiles with a 110 ha site and breach invert levels of either 1.8 or 2.0 mAOD.

2.5.6　　In all cases the differences between the predicted velocity profiles for the 90 and 110 ha Compensation Sites are very much smaller than their difference from the baseline. At Points 16 and 17 south of the breach site, the ebb tide velocities with the 110 ha site are slightly greater throughout the ebb tide for the 2.0 mAOD breach than for the 90 ha site. For the 1.8 mAOD breach, ebb tide velocities in Cherry Cobb Sands Creek recede from the maximum velocity more rapidly than with the 2.0 mAOD breach.

2.5.7　　On the flood tide at all sites and on the ebb tide at Point 15 velocity profiles for the 90 ha and 110 ha sites are very similar in Cherry Cobb Sands Creek.

2.5.8　　Predicted velocities in Stone Creek at Point 21 are compared for the 90 and 110 ha Compensation Sites in Figure 11. The predicted effects of the change in size of the Compensation Site or level of the breach are very small at Point 21.

Table 5　　Predicted maximum velocities in Cherry Cobb Sands Creek

| Date and approx HW time (1730 on 8/9/10)	Baseline	90 ha site	110 ha site	110 ha site
Breach invert level (mAOD)	-	2.0	1.8	2.0
Location	Flood tide maximum velocity m/s			
Point 15 500 m north of breach	0.53	0.54	0.56	0.52
Point 16 100 m south of breach	0.75	0.79	0.92	0.80
Point 17 500 m south of Stone Creek	0.93	0.92	0.92	0.92
Point 21 within Stone Creek	0.08	0.08	0.07	0.07
Location	Ebb tide maximum velocity m/s			
Point 15 500 m north of breach	0.74	0.24	0.24	0.23
Point 16 100 m south of breach	0.55	1.33	1.42	1.44
Point 17 500 m south of Stone Creek	0.81	1.04	0.99	1.12
Point 21 within Stone Creek	0.10	0.06	0.06	0.06
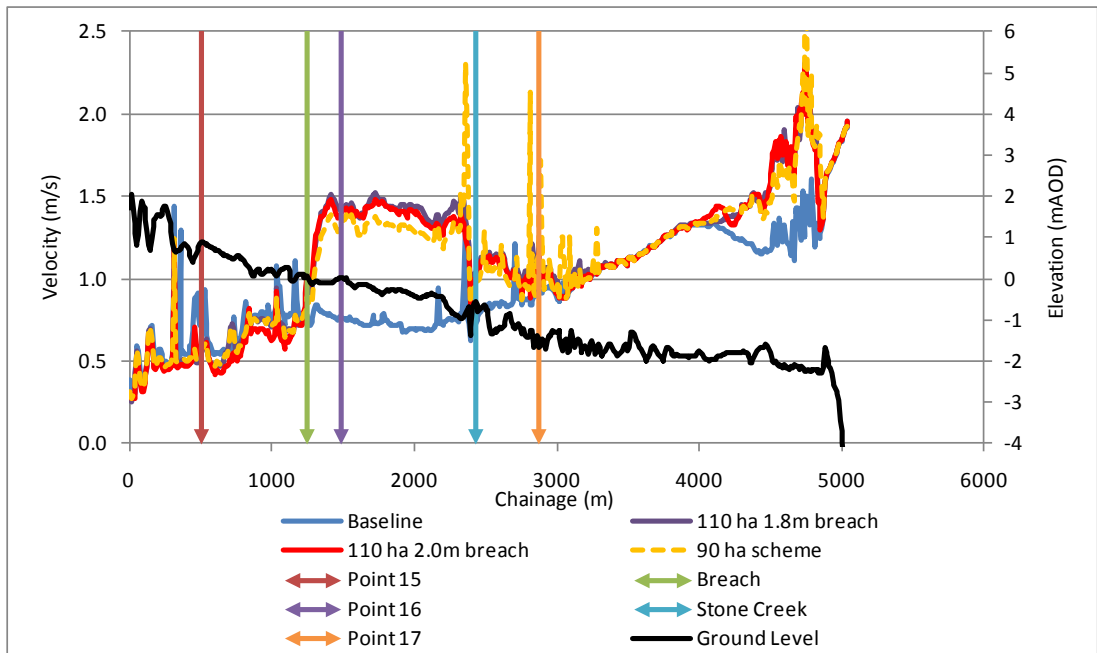
Figure 9   *Maximum predicted velocities in Cherry Cobb Sands Creek 8th Sept 2010*
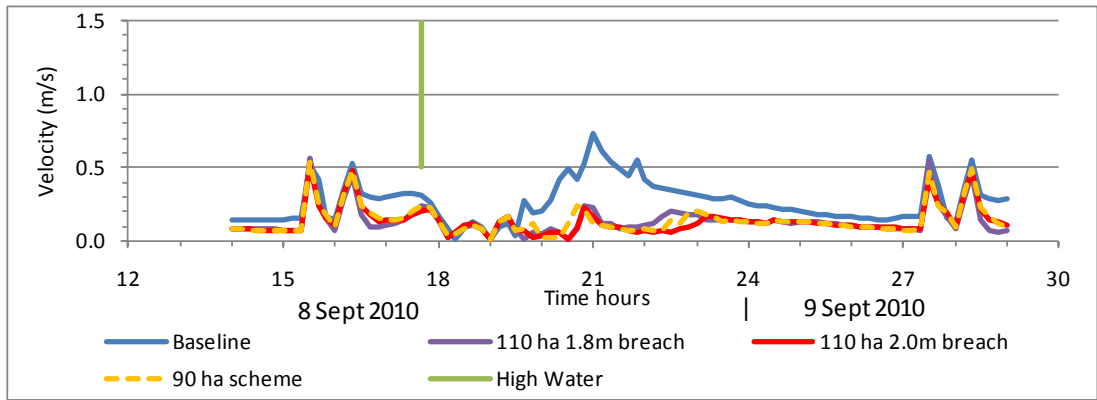
a) Point 15 500 m north of breach
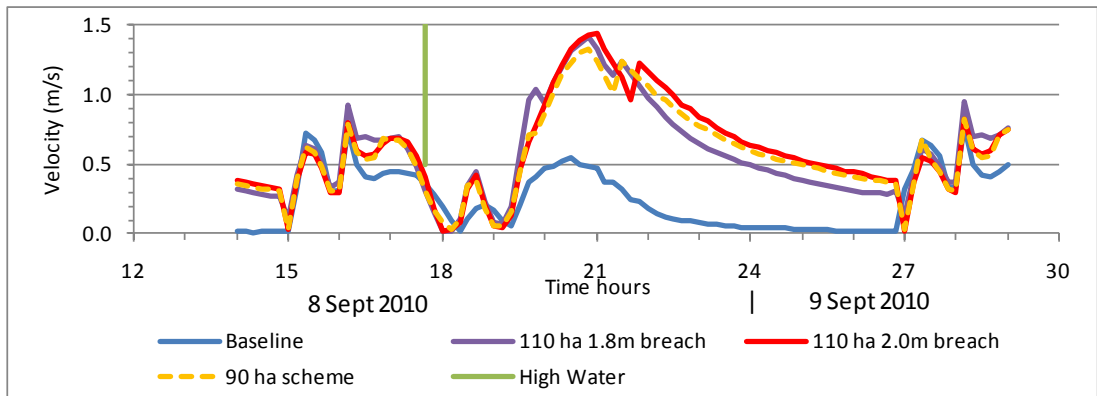
b) Point 16 100 m south of breach
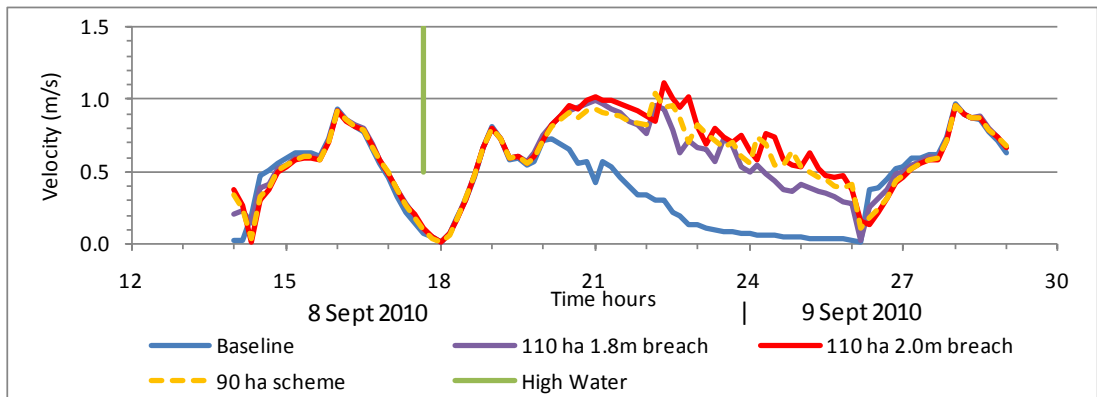
c)   Point 17 500 m south of Stone Creek

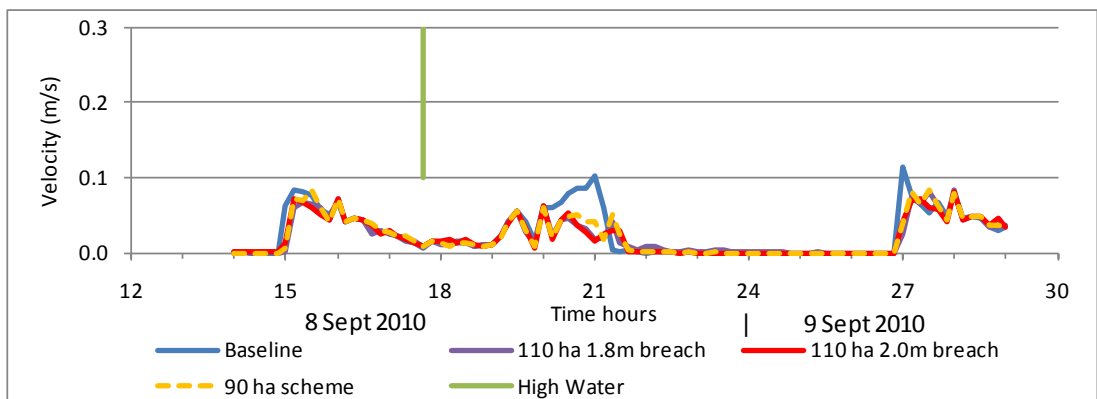*Figure 10   Comparison of predicted velocities in Cherry Cobb Sands Creek*

Figure 11   Comparison of predicted velocities in Stone Creek

2.6 *VELOCITIES OVER FOUL HOLME SAND*

2.6.1   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.

2.6.2   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 for the 90 and 110 ha Compensation Sites are shown on Table 6 where they may be compared with the maximum predicted baseline velocities.

2.6.3   On the flood tide predicted maximum velocities across Foul Holme Sand are similar in the baseline case to those with any of the Compensation Sites tested. At Point 18 north of the Breach and at Point 20 south of Stone Creek the predicted maximum ebb tide velocity in the baseline case is similar to those with the 90 or 110 ha Compensation Sites. For Points 18 and 20 and for the flood tide at Point 19 the presence of the Compensation Site is having a very small effect.

2.6.4   At Point 19, 100 m south of the breach, Table 6 shows that the 110 ha Compensation Site causes a slight increase in predicted maximum ebb tide velocity if the breach remains at 2.0 mAOD. However, if the breach invert is lowered to 1.8 mAOD there is a 7% increase in maximum ebb tide velocity compared with the maximum ebb tide velocity for the 110 ha site with a 2.0 m AOD breach invert. This indicates the sensitivity of maximum ebb tide velocities over Foul Holme Sand just south of the breach to the breach invert level.

Table 6   Predicted maximum velocities over Foul Holme Sand

Date and approx HW time (1730 on 8/9/10)	Baseline	90 ha site	110 ha site	110 ha site
Breach invert level (mAOD)	-	2.0	1.8	2.0
Location	Flood tide maximum velocity m/s			
Point 18 500m north of breach	0.48	0.47	0.47	0.47
Point 19 100m south of breach	0.36	0.36	0.36	0.36
Point 20 500m south of Stone Creek	0.41	0.42	0.43	0.42
Location	Ebb tide maximum velocity m/s			
Point 18 500 m north of breach	0.26	0.27	0.28	0.27
Point 19 100 m south of breach	0.25	0.37	0.41	0.38
Point 20 500m south of Stone Creek	0.60	0.60	0.60	0.60

2.6.5   A comparison of the predicted velocity profiles over the top of Foul Holme Sand on the evening tide of 8th Sept 2010 is shown in Figure 12 for Points 18, 19 and 20. The predicted velocity profile for the 90 ha Compensation Site is shown by a dotted line, while the predicted profiles for the 110 ha site are shown as solid lines.

2.6.6   At Point 18, 500 m north of the breach, Figure 12a shows there are small changes in predicted velocities as result of the Compensation Site tide. The predicted maximum velocity at the time of first inundation on the flood tide is unaffected by the presence of the Compensation Site. The size of the Compensation Site and the level of the breach do not affect predicted velocities at this location.

2.6.7   Predicted velocities at Point 19 on the top of Foul Holme Sand are increased during both flood and ebb tides as indicated in Figure 12b due to the presence of the Compensation Site. If the breach invert remains at 2.0 mAOD, the velocities with the 90 and 110 ha Compensation Sites are very similar. If the breach invert is lowered to 1.8 mAOD, there are some small predicted velocity increases though these do not exceed 0.05 m/s.

2.6.8   Velocities at Point 20, 500 m south of Stone Creek, are hardly affected by the presence of the Compensation Site as Figure 12c shows. There are no noticeable differences caused by the area or breach invert level of the site.
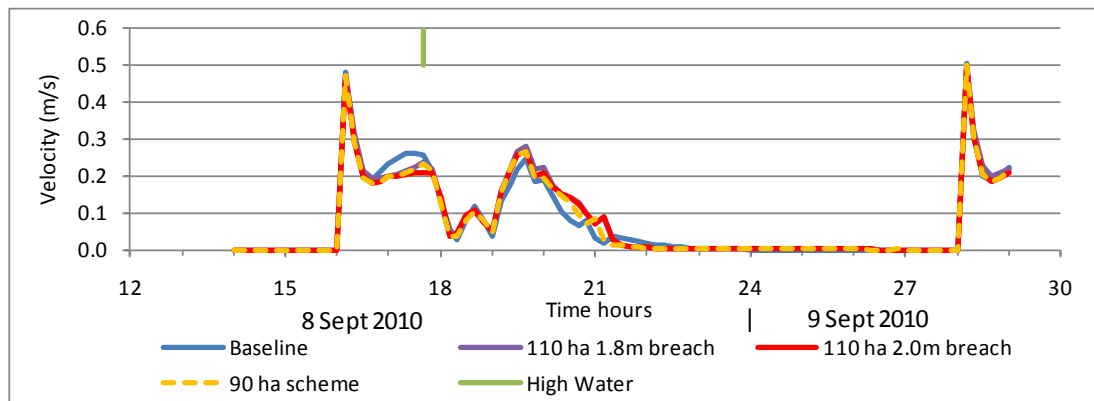
a)   Point 18 500 m north of breach

b)   Point 19 100 m south of breach

c) Point 20 500 m south of Stone Creek
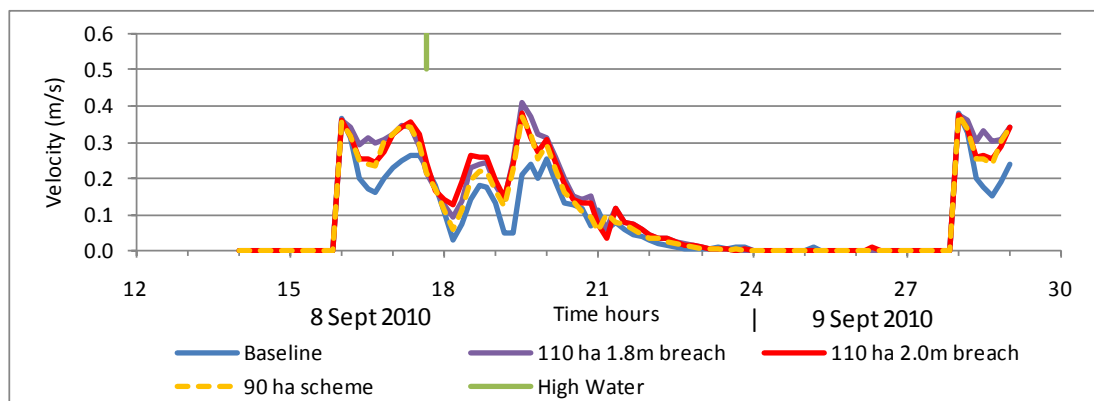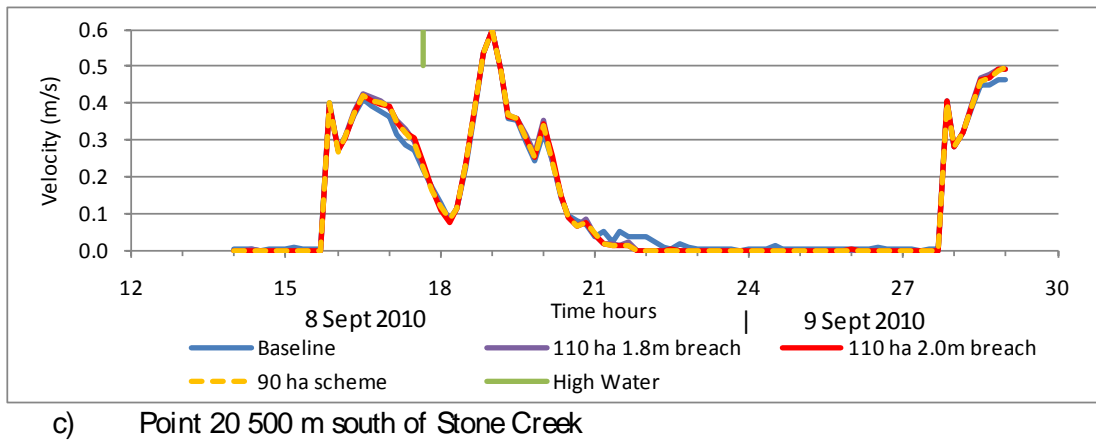
Figure 12   Comparison of predicted velocities over Foul Holme Sand

2.6.9   A profile of the predicted maximum velocities along Section 9 on the top of Foul Holme Sand shown on Figure 3 is shown for the high spring tide on 8th Sept 2010 in Figure 13. The predicted maximum velocity on this profile for the 90 ha Compensation Site is shown dotted while those for the two breach invert levels modelled for the 110 ha Compensation Site are shown as solid lines. The predicted maximum velocities for the baseline are very similar to those predicted with any of the Compensation Sites that have been tested.

2.6.10   There are minor increases in predicted velocity immediately to the south of the breach in the vicinity of Point 19, as shown on Figure 12b and in more detail in Table 6 as a result of the Compensation Site.
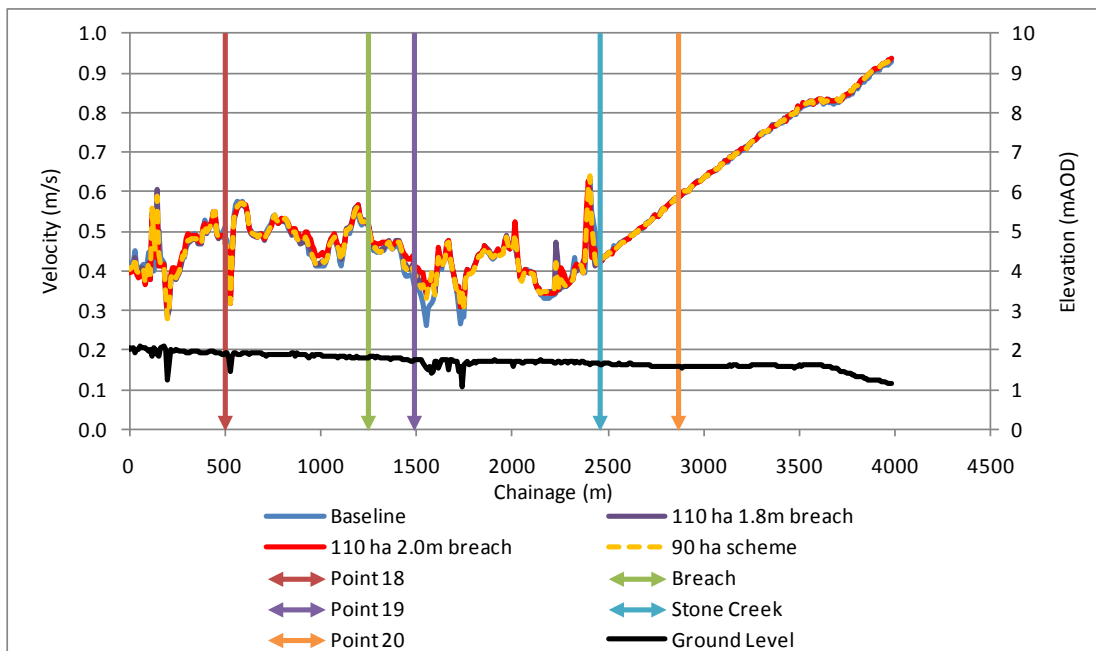
Figure 13   Predicted maximum velocities on top of Foul Holme Sand 8th Sept 2010

3 SEDIMENTATION ASSESSMENT

3.1 INTRODUCTION

3.1.1 The sedimentation parameters utilised in Annex 32.4 for the assessment of the 90 ha habitat creation site have been applied to the 110 ha site in this section and compared with the results for the 90 ha site. However, the 110 ha Compensation Site has only been tested for Tides 1 and 2 in Table 1 with baseline high water levels of 3.96 and 3.63 mAOD at Stone Creek compared with the four tides that were tested for the 90 ha site in Annex 32.4.

3.1.2 The assessment of accretion rates in areas where that is the dominant process is not affected by the smaller number of tides modelled. The annual accretion predicted in the absence of erosion, uses the method adopted for the 90 ha site which is based on the frequency of occurrence of tides in an average year, the depth of water at high tide at the location for each of these tides and the assumed concentration of sediment in suspension.

3.1.3 An average concentration of 300 g/m^3 of sediment in suspension has been assumed based on the experience of sedimentation at Paull Holme Strays described in Annex 32.5 as interpreted in Annex 32.4 to verify the sedimentation methodology.

3.1.4 Predictions of erosion associated with the 110 ha Compensation Site are based on Tides 1 and 2 of Table 1 which together have a predicted occurrence of 12 % of the time. The rates of erosion from this pair of tides, weighted for their frequency of occurrence has been compared with those for all four tides weighted for their frequency of occurrence. This showed that erosion during Tides 1 and 2 was on average 48% of the total, though the standard deviation was considerable at 24%.

3.1.5 For this assessment of the 110 ha sites, the erosion calculated during Tides 1 and 2 at each Point has been weighted for their frequency of occurrence. This estimate has then been adjusted to account for the proportion of the total predicted erosion that was predicted at the same Point for Tides 1 and 2 in Annex 32.4 when considering the effects of the 90 ha site. In this way the results from the two tides modelled for the 110 ha Compensation Site are comparable with the predictions made in Annex 32.4 for the 90 ha site. Assessments have been made for breach invert levels of 1.8 and 2.0 mAOD to identify how sensitive the sedimentation predictions are to the breach invert level.

3.2   *SEDIMENTATION WITHIN THE COMPENSATION SITE*

3.2.1   No assessment of sedimentation has been undertaken for the 110 ha Compensation Site. This will be done as part of the site development studies that seek to maximise the long term development of mudflat to meet the agreed compensation requirements. The ground profile assumed for the 110 ha site described in this Annex is the same at the southern end of the site as adopted for the 90 ha site and described in Annex 32.4. At the northern end of the site the ground levels were modified slightly because of the larger area of the site.

3.2.2   The anticipated sedimentation of the 110 ha site considered in these test is therefore likely to be very similar to that reported in Annex 32.4. The major difference will arise because of the 20 % larger inflow to the site reported in Table 4 and the increased velocities on the ebb tide within the site noted in Figure 7 and Figure 8. These increased velocities will lead to a smaller increase in ground levels in those parts of the site that are likely to have accreted to a level close to 2.5 mAOD after five years. A preliminary assessment of the ground levels within the site after five years is shown on Figure 14.

The KEY/Legend panel contains:

KEY

Legend

- Flood Embankment
- Esitmated Ground Level (mACD) after 5 Years of Sedimentation
  - < 2.5 - Mudflat
  - 2.5 - 2.6 - Developing Saltmarsh
  - > 2.6 Saltmarsh

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A	22/09/2011	Preliminary Issue	DLG	LVI	VL
Rev	Date	Comments	Drw	Chk	App

Project: CHERRY COBB SANDS COMPENSATION SITE

Client: ABLE UK Ltd

Figure 14 Possible ground levels in 110ha compensation site after 5 years

PRELIMINARY

Scale:		Drawn	Checked	Approved
1:10,000 @A3		DLG	LVI	VL
	Date	22/09/2011	22/09/2011	22/09/2011
Drawing No. 121726-2000-007			Revision:	A

R:\Projects\121726_Humber_Compensation_EIA_Strategy\8_Workspaces\2_Issue_Maps\121726_2000_007_Sedimentation_V2_Fig3.mxd gar65001 22/09/2011

Figure 14   Possible ground levels in the 110 ha Compensation Site after five years

3.3 SEDIMENTATION IN CHERRY COBB SANDS CREEK

3.3.1 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 2.5. Upstream of the breach at Point 15 there is a reduction in velocity on the ebb tide as a result of the breach.

3.3.2 Table 7 compares the predicted sedimentation in Cherry Cobb Sands Creek in the baseline case and for the 90 and 110 ha Compensation Site considering breach invert levels of 1.8 and 2.0 mAOD for the 110 ha site.

3.3.3 In the baseline case, accretion is predicted at all locations considered in the creek, with greater accretion at Points 16 and 17 either side of the Stone Creek confluence. The predicted tendency for Cherry Cobb Sands Creek to accrete in the baseline case is in accordance with experience as discussed in Annex 32.4 Section 4.4.

3.3.4 The effect of the Compensation Site on sedimentation in Cherry Cobb Sands Creek is indicated in Table 7. North of the breach, at Point 15, the size and breach invert level of the Compensation Site has little effect on the predicted accretion of Cherry Cobb Sands Creek which is predicted to rise compared to the baseline. At Point 16, south of the Compensation Site, the predicted annual erosion increases from 1.4 to 1.6 m if the site area increases from 90 to 110 ha and the invert level of the breach remains at 2.0 mAOD, while at Point 17 it increases from 0.75 to 0.9 m.

3.3.5 With the larger Compensation Site, the predicted annual erosion is sensitive to the invert level of the breach as Table 7 indicates. If the breach invert reduces from 2.0 to 1.8 mAOD there is a 0.3 m reduction in predicted annual erosion in Cherry Cobb Sands Creek south of the breach at Points 16 and 17. This predicted reduction in erosion rate is the result of the reduction in ebb tide velocities in Figure 10b and c noted for the 1.8 mAOD breach case.

Table 7   Predictions of sedimentation in Cherry Cobb Sands Creek

	Baseline	90 ha site	110 ha site	110 ha site
Breach invert level (mAOD)	-	2.0	1.8	2.0
Location	Prediction of change after one year (m)			
Point 15 500 m north of breach	0.27	0.55	0.54	0.54
Point 16 500 m south of breach	0.69	-1.4	-1.3	-1. 6
Point 17 500 m south of Stone Creek	0.62	-0.75	-0.63	-0.89

Note: Positive values represent accretion; negative values erosion

3.4 SEDIMENTATION IN STONE CREEK

3.4.1   The velocities in Stone Creek are low as indicated in Section 2.5. At Point 21 in this creek, shear stress is always <0.2 N/m² on all tides in the baseline tests and in all the tests with operational Compensation Sites. 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.

3.4.2   As accretion occurs at all times with or without the scheme, it is unlikely that the size or breach invert level 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.

3.4.3   The predicted increase in low water levels immediately following the introduction of the Compensation Site does not change as the site area changes from 90 to 110 ha and as the breach invert level changes from 1.8 to 2.0 mAOD. However, the increase in the size of the Compensation Site from 90 to 110 ha is associated with a 10 minute reduction (Table 3) in the time that water levels in the creek are below 0.5 mAOD.

3.4.4   These predicted changes to water levels in Stone Creek are initial changes before the effect of the anticipated enlargement and deepening of Cherry Cobb Sands Creek predicted in Section 3.2 takes place. Once this deepening has occurred, 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. When this happens, risk of additional accretion within Stone Creek discussed will recede.

3.4.5   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.

3.5.1   The velocities over Foul Holme Sand are generally low as indicated in Sections 2.6. Annual erosion has been calculated for Points 18, 19 and 20 on Figure 3 on the top of Foul Holme Sand using the method set out in Annex 32.4 section 4.1 and adjusted as described in Section 3.1. 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.

3.5.2   The predicted sedimentation results for the three points on Foul Holme Sand are presented in Table 8. They show that increasing the size of the Compensation Site from 90 to 110 ha slightly reduces the percentage of time that accretion is predicted (predicted shear stress <0.2 N/m^2) at Point 19 and to a lesser extent at Point 20. North of the breach at Point 18, increasing the size of the Compensation Site causes minor change in the predicted percentage of the time that accretion will occur.

3.5.3   Reducing the breach invert level from 2.0 to 1.8 mAOD reduces the predicted time that accretion will occur at Point 19 just south of the breach, but has a very small effect at Points 18 and 20 further away.

3.5.4   The predicted annual erosion at Points 18, 19 and 20 on Foul Holme Sand hardly changes as a result of the increase in Compensation site area from 90 to 110 ha or of the change in breach invert level form 2.0 to 1.8 mAOD.

3.5.5   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 wave activity is 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.

3.5.6   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 for sites of 90 or 110 ha area for breach invert levels of 2.0 and 1.8 mAOD. There is a possibility that the rates of accretion on Foul Holme Sand near to the breach might be marginally lower with the 110 ha Compensation Site compared with the 90 ha site because of the small reduction in the time when accretion due to tidal currents is predicted at Point 19. Reducing the breach invert level from 2.0 to 1.8 mAOD is predicted to cause an additional small reduction in the percentage of time that accretion occurs at Point 19. However, as accretion is predicted for more than 80% of time with no predicted tidal erosion, the increased risk of a creek forming in this area as a result of any of the tested Compensation Sites remains low.

Table 8   Predicted annual sedimentation over Foul Holme Sand

	Baseline	90 ha site	110 ha site	110 ha site
Breach invert level (mAOD)	-	2.0	1.8	2.0
Location	Percent of time with accretion			
Point 18 500 m north of breach	95.5	93.6	95.7	95.7
Point 19 500 m south of breach	93.6	89.1	83.5	86.0
Point 20 500 m south of Stone Creek	78.3	77.0	75.8	76.0
	Annual erosion estimate (m)			
Point 18 500 m north of breach	0.006	0.006	0.006	0.006
Point 19 500 m south of breach	0.000	0.000	0.000	0.000
Point 20 500 m south of Stone Creek	0.038	0.038	0.039	0.038

4   *CONCLUSIONS*

Tide levels

4.1.1   Increasing the area of the Compensation Site from 90 to 110 ha and varying the breach invert level between 1.8 and 2.0 mAOD is predicted to have a minimal effect on tide levels within the Humber Estuary or within the Compensation Site.

Effects on the breach and Compensation Site

4.1.2   The maximum velocities through the breach are generally found in the centre where ground levels are 0.2 m lower. Increasing the size of the Compensation Site from 90 to 110 ha increases the average velocities during flood and ebb tides by around 20%. If the breach level is reduced from 2.0 to 1.8 mAOD the average velocities through the breach reduce by 8% because of the greater depth of water. Because the site starts to flood a little earlier on the rising tide the peak velocity through the breach occurs about 20 minutes earlier.

4.1.3   Creeks formed inside and outside the breach channel are expected to propagate back towards the original flood defence line and eventually will cut through this line probably close to its centre.

4.1.4   A preliminary assessment of ground levels after five years within the 110 ha Compensation Site has been made based on the predictions for the 90 ha site considered in Annex 32.4. This assessment will be refined in further studies to agree with Natural England the most appropriate initial ground profile to maximise the area of mudflat that can be provided in the long term within the Compensation Site.

Effects on Cherry Cobb Sands Creek

4.1.5   Velocities in Cherry Cobb Sands Creek between the breach site and Stone Creek on the flood tide are increased slightly by the presence of the Compensation Site. The predicted velocity increases marginally if the size of the Compensation Site increases to 110 ha provided a 2.0 mAOD breach invert is maintained. Reducing the breach invert to 1.8 mAOD is associated with a larger increase in velocity.

4.1.6   The presence of the Compensation Site will lead to a substantial increase in ebb tide velocities within Cherry Cobb Sands Creek downstream of the breach and past Stone Creek. These predicted velocities are around 0.1 m/s greater with the 110 ha site than with the 90 ha site if a breach invert of 2.0 mAOD is maintained. Reducing the breach invert to 1.8 mAOD is predicted to cause a small reduction in ebb tide velocities compared with a 2.0 mAOD breach.

4.1.7   Erosion of Cherry Cobb Sands Creek south of the breach will be quite rapid and the rate is predicted to increase if the Compensation Site is increased from 90 to 110 ha with a 2.0 mAOD breach invert. If the breach invert is reduced to 1.8 mAOD a small reduction in the rate of erosion of Cherry Cobb Sands Creek is anticipated. The final equilibrium bed level in Cherry Cobb Sands Creek would also be expected to be slightly higher if the breach invert level is lower.

4.1.8   Accretion in Cherry Cobb Sands Creek upstream of the breach is predicted, but is unlikely to be affected by increasing the area of the Compensation Site to 110 ha or changing the breach invert from 2.0 to 1.8 mAOD.

4.1.9   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

4.1.10   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.

4.1.11   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. This change is predicted for Compensation Site areas of 90 to 110 ha and breach invert levels of 1.8 to 2.0 mAOD. The presence of the Compensation Site is predicted to reduce the 6 hours 10 minute duration of low water levels below 0.5 mAOD. This time is predicted to reduce by 20 minutes with a 90 ha site and by 30 minutes with a 110 ha site. The reduction is not predicted to vary if the breach level changes from 2.0 to 1.8 mAOD.

4.1.12   The 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 erosion predicted in this creek as a result of the Compensation Site.

4.1.13   The Stone Creek inlet is predicted to continue to be an area of sediment accretion after the Compensation Site is introduced as it is at present.

Effects on Foul Holme Sand

4.1.14   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.

4.1.15   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.

4.1.16   Increasing the size of the Compensation Site from 90 to 110 ha is predicted to slightly increase this risk as does a reduction in breach invert level from 2.0 to 1.8 mAOD. Even with an area of 110 ha and a breach invert of 1.8 mAOD, the risk remains low as tidal currents are not sufficient to cause erosion and velocities are low enough to allow sediment accretion for more than 80% of the time in the absence of wave activity in the area most affected by the breach.