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Supplementary Environmental Information

Cherry Cobb Sands Compensation Site Interim Report on Detailed Modelling

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Cherry Cobb Sands Compensation Site

Interim report on detailed modelling

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1 INTRODUCTION

1.1 PURPOSE OF REPORT

1.1.1 The Able Marine Energy Park (AMEP) Environmental Statement was submitted to the Infrastructure Planning Commission in December 2011. At the time of the submission, the applicant stated that further detailed modelling of the Compensation Site would be undertaken to understand the likely development of intertidal habitat within the site over time.

1.1.2 This report provides interim findings on the review of assumptions and the results of the detailed modelling carried out to date. The design is not concluded at this stage and the modelling results obtained so far will be used to inform further design development.

1.1.3 The plan layout of this site as presented in the Environmental Statement (Figure 28.1) is shown on Figure 1.

1.1.4 This report firstly builds on the information presented in Annex 32.5 of the Environmental Statement (Sedimentation, Erosion and Saltmarsh Growth). This annex considers observations made at the Paull Holme Strays and other Humber managed realignment sites to provide evidence on how the proposed site at Cherry Cobb Sands might develop. Since submission of the Environmental Statement a PhD thesis (Ref 1) submitted to Hull University has been reviewed and contains additional measurements of conditions at Paull Holme Strays during 2006 and 2007 2.5 to 4 years after it was first breached.

1.1.5 This report also includes the results of further modelling of erosion and accretion at the Cherry Cobb Sands site using the revised assumptions and a revised initial profile for the ground levels within the site immediately prior to breaching of the site. The approach to this modelling is discussed in section 4.1 of Annex 32.4 (Model testing of a 90 ha layout) and briefly summarised in section 3.1 of Annex 32.6 (Assessment of 110 ha layout).

1.2 OBJECTIVES OF THE COMPENSATION SITE MODELLING

1.2.1 The Compensation Site is required to meet five key objectives that are relevant to the geomorphology and modelling of the site. These are

- The site should provide a minimum of 100 ha of intertidal area. The area of the channel cut through the existing saltmarsh (around 2ha) to provide access for tidal waters to the breach is included within this total along with the 'footprint' area of the section of the bank that is removed to create the breach.
- The site should provide the maximum possible area of sustainable mudflat with a target of 82 ha. If this target were to be achieved it would provide double the amount of mudflat lost as a result of the AMEP development on the south bank of the Humber.

- The minimum requirement is that substantially in excess of 41 ha of sustainable mudflat should be created. This area is the anticipated loss of mudflat arising, both directly and indirectly from the AMEP development.
- For the purposes of this assessment, mudflat is assumed to be intertidal areas below 2.5mAOD. Observations at the nearby Paull Holme Strays site reported in Annex 32.5 indicated that once levels within the site accrete to 2.5mAOD, significant saltmarsh growth starts to occur.
- The amount of excavation within the Cherry Cobb Sands Site should approximately balance the amount of fill required to construct the surrounding flood defence embankment. This is to avoid the import of additional fill if excavation is too little or export of fill if the amount excavated is too great.

1.3 ENLARGEMENT OF CHERRY COBB SANDS CREEK

1.3.1 A second objective of the detailed modelling was to attempt to quantify the changes in size of Cherry Cobb Sands Creek that are predicted to occur as a result of the breaching of the Compensation Site. Annex 32.4 section 4.4 and Annex 32.6 section 3.3 both predict an increase in the size of the Cherry Cobb Sands Creek between the breach and the main low tide channel of the Humber because of increased ebb tidal flows. As flows in the section of Cherry Cobb Sands Creek to the north of the breach are expected to reduce following the breach, so it is predicted that the size of this part of the Creek will diminish.

1.3.2 Following submission of the Environmental Statement a request was received from the Marine Management Organisation to quantify the change in creek dimensions. This supported the desire of the Internal Drainage Boards for comfort that the introduction of the Compensation Site would not adversely affect the capacity of their outfalls into Stone Creek.

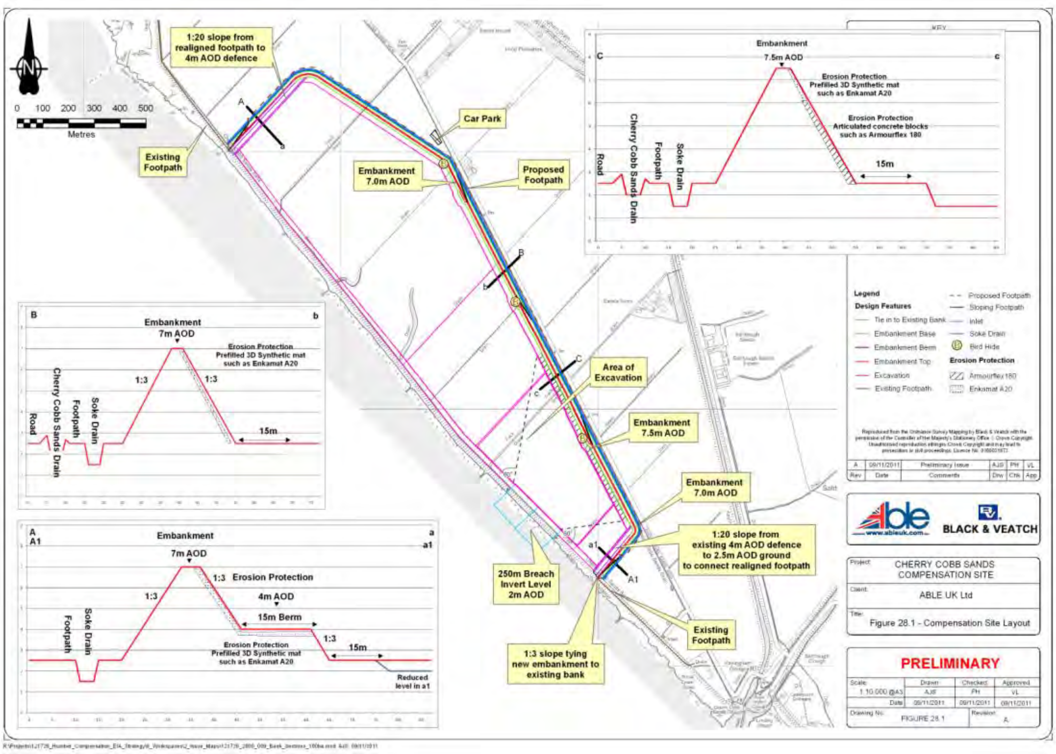


Figure 1 Compensation Site arrangement in Environmental Statement

2 *REVIEW OF INFORMATION FROM PAULL HOLME STRAYS*

2.1 SUMMARY OF INFORMATION FROM ANNEX 32.5

2.1.1 Annexes 32.4 and 32.5 summarise the information used in the preparation of the Environmental Statement from Paull Holme Strays and other operational managed realignment sites in the Humber (Welwick, Chowderness and Alkborough). Since there has been no relevant further information gathered from any of these sites apart from Paull Holme Strays, the information in Annex 32.5 about these sites is not repeated here.

2.1.2 For the studies of accretion and erosion the key information gathered from Paull Holme Strays was the measurements of siltation for the Environment Agency reported by Brown (Ref 2). Accretion after one year is plotted as a function of site level on Figure 2, copied from the results presented on Figure 19 of Annex 32.4. The monitoring was continued for 5 years and the ratio of accretion after five years compared to that after one year is compared in Figure 3, which is copied form Figure 20 of Annex 32.5.

2.1.3 Uncertainty bands are not easy to include in Figures 2 and 3. This is because the actual monitoring of siltation started six months after the site was breached so no formal measurement of initial ground levels was made at the 35 individual sites where siltation was monitored. In order to estimate initial levels, an observed strong correlation between bed level and accretion rate was used to estimate initial level. Sites with similar levels two years after breaching were grouped together and the results extrapolated back to estimate the initial level. The maximum and minimum limits shown on Figure 2 are taken from the range of ground levels included within each group.

2.1.4 In the original assessment no account was taken of the location within Paull Holme Strays of the siltation monitoring sites. Review of the monitoring report (Ref 2) shows that the lowest six sites (those in 2005 with a level below 2.6mAOD) and those on Figure 2 with estimated initial levels of 1.82 or 2.18 mAOD (monitoring sites 2.1, 2.2, 2.3, 3.1, 4.2 & 4.3) were all located around the landward edge of the Paull Holme Strays site at a considerable distance from the breach site. The location of these sites would strongly indicate that it is unlikely that any erosion took place at these sites because velocities close to the edge of the site are always likely to be too low to permit erosion.

2.1.5 It is a feature of the monitoring of this program for monitoring accretion within Paull Holme Strays that the majority of sites whatever their level are close to the landward edge of the site with those some distance from the edge also being a significant distance from the breaches. The site closest to the breach (3.4) is in excess of 200m from the breach.

2.2 *ADDITIONAL MEASUREMENTS AT PAULL HOLME STRAYS*

2.2.1 In addition to the monitoring carried out during the first five years after the breaching of the Paull Holme Strays site, a postgraduate student at the University of Hull also monitored physical conditions at this managed realignment site as part of a PhD study. These observations are reported in the thesis submitted by Clapp (Ref 1). The observations covered a range of sediment and flow properties at the site and were measured during an 18 month period in 2006 and 2007 starting 2.5 years after the site was breached.

2.2.2 A wide range of measurements were undertaken. Those that provide the most significant additional information on the performance of the Paull Holme Strays site include:

- Measurement of accretion and erosion at an additional 31 sites,
- Measurement of the dry density of the settled sediment within the site,
- Measurement of tides and suspended sediment concentrations in the larger breach, and
- Measurements of the shear stress threshold for erosion.

Accretion and erosion measurements by Hull University

2.2.3 The measurements of accretion and erosion reported in chapter 4 of Ref 1 were made in a similar way to those carried out for the Environment Agency. The results were grouped into the same level bands as those chosen by the Environment Agency and the results compared for the period both sets of measurements were carried out. The results are summarised in Table 1 copied form Table 4.6 of Ref 1. The results from the two monitoring programs are very comparable especially within the height bands 2.0 to 2.6 mAOD where mudflat is most likely to be present.

2.2.4 The University monitoring is important in that it adds six points below 2.0 mAOD to the one monitored by the Environment Agency. If the single site in this group where erosion was measured by the University is removed from the analysis, the average accretion at the other sites was 175 mm and very similar to the single site monitored by the Environment Agency.

2.2.5 The low level sites monitored by the University were all within 200m of the breach so monitored an area not monitored by the Environment Agency. Interestingly at the majority of these sites the average accretion was similar to the single site monitored by the Environment Agency which was located on the other side of the managed realignment. The single low level site where erosion was measured by the University was immediately inside the breach where maximum velocities might be expected and erosion most likely to occur.

2.2.6 The other feature of interest in the siltation measurements is that accretion rates are consistently higher in winter months than summer months (Figure 4.4 of Ref 1), a feature also found in the Environment Agency monitoring.

Sediment dry density measurements by Hull University

2.2.7 The University also made numerous measurements of dry sediment density throughout the managed realignment. The results reported in section 6.1 of Ref 1 showed an average dry density of 1050±140 kg/m^3. This sediment dry density did not vary significantly around the site, but did vary seasonally (Table 6.2 of Ref 1) with a density of 1130±160 kg/m^3 in summer and 970±220 kg/m^3 in winter.

2.2.8 These measurements of dry density may be compared with the 500kg/m^3 assumed in Table 4.1 of Annex 32.4 of the Environmental Statement and used in the calculation of accretion and erosion rates. In the light of this evidence of *in-situ* dry densities within a nearby Humber managed realignment site, a dry density of 1050 kg/m^3 will be used in the calculation of erosion and accretion volumes in the detailed design for Cherry Cobb Sands.

Suspended sediment concentration measurements by Hull University

2.2.9 The University monitored suspended sediment concentrations in the main breach on six tides with different high tide levels, measured as water depth above the breach. The results are reported in Chapter 5 of Ref 1 and presented in Table 2, which is based on the individual measurements reported in Appendix 4 of Ref 1. All these measurements were made in the summer months May to September so may not have sampled winter conditions with their higher accretion rates.

2.2.10 Suspended sediment concentrations on the flood tide are generally higher than on the ebb tide in Table 2 which is consistent with the deposition of sediment within the site. These results also show that generally concentrations increase as high tide levels rise, which is consistent with higher velocities on larger tides entraining more sediment. However, neither of these two features applies to all the measurements which may be because of differences in wave activity that can change the amount of sediment in suspension or because measurements of suspended sediment are subject to uncertainty and are often found to vary over short timescales.

2.2.11 The sediment concentrations reported by Hull University are variable, but on large tides are higher than those assumed in section 4.1 of Annex 32.4 of the Environmental Statement. The measured difference in sediment concentration between flood and ebb tides is by contrast smaller than the 250mg/l assumed in the settlement calculations, but as the measurements only reflect summer conditions, they may not be representative of the whole year.

Threshold of erosion measurements by Hull University

2.2.12 Four sediment cores were placed in a laboratory flume to try and measure the threshold for erosion of suspended sediment. The results are discussed in chapter 7 of Ref 1.

2.2.13 For the three sediment cores which had dry densities close to 1000 kg/m^3, there was an increase in the suspended sediment concentration in the water column when the shear stress exceeded 0.63N/m^2. The highest shear stress measured over these cores without any increase in sediment concentration was 0.07N/m^2. This suggests the threshold for erosion of the sediment settled in Paull Holme Strays at a dry density of around 1000 kg/m³ lies between these two values.

2.2.14 The fourth sediment core which had the highest dry density of 1580 kg/m³ did not erode in the flume even when the shear stress in the flume reached 2.75N/m².

Table 1 Comparison of Environment Agency and University siltation measurements (Table 4.6 of Ref 1)

Elevation	University monitoring			Environment Agency monitoring	
	No of points	Average accretion (mm)	Range (mm)	No of points	Average accretion (mm)
<2.0	6	140±137	-34 – 329	1	186
>2.0-2.3	7	112±74	22 – 219	5	125±36
>2.3-2.6	6	81±32	55 – 135	10	95±27
>2.6-3.0	8	13±39	-69 – 41	11	43±45
>3.0-3.5	4	6±5	-1 – 11	8	11±4

± Value represents standard deviation of samples within each group.

Table 2 Measurements of suspended solids concentrations in 2006/7

HW level (m over breach)	Date	Flood tide concentration (mg/l)		Ebb tide concentration (mg/l)		Average difference between flood and ebb tides (mg/l)
		Average	Max	Average	Max	
0.48	11/5/2007	87	99	62	82	25
1.18	19/7/2006	184	271	204	284	-20
1.28	23/5/2006	328	470	214	268	114
1.48	16/8/2006	142	356	86	167	56
1.98	11/9/2007	268	455	202	300	66
2.78	11/9/2006	522	647	334	596	188

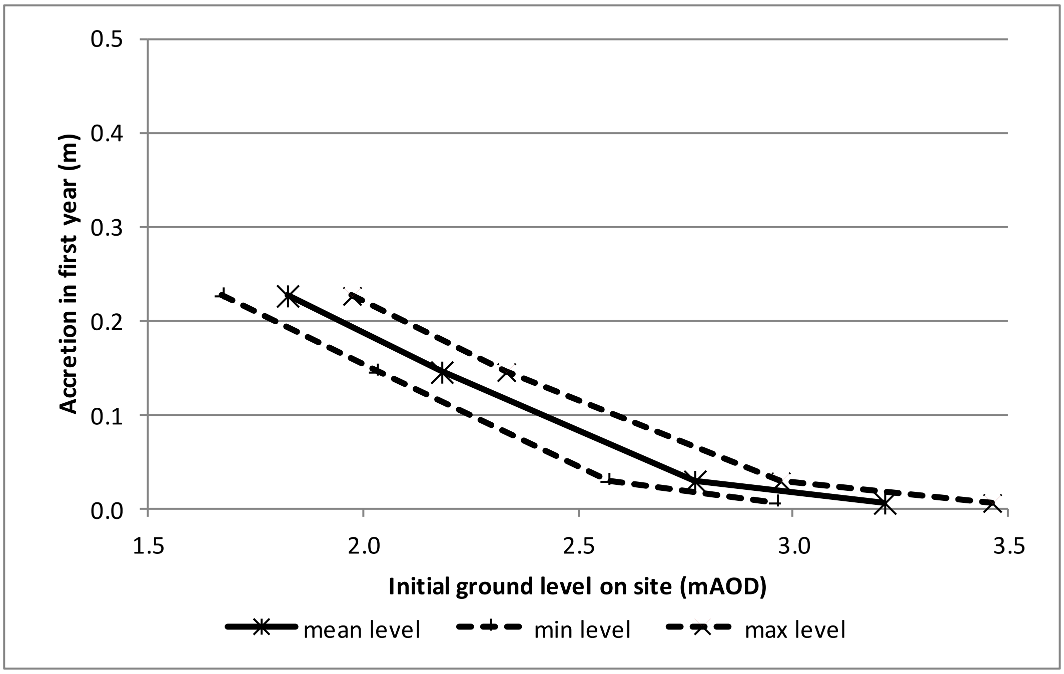


Figure 2 Accretion after one year at Paull Holme Strays

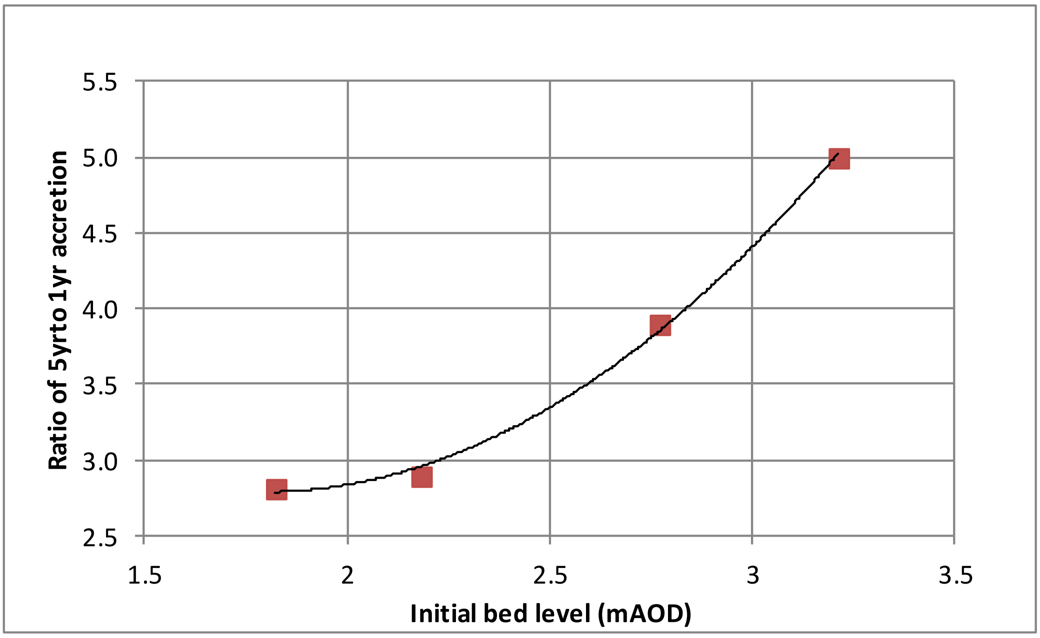


Figure 3   Ratio of accretion over five years to one year at Paull Holme Strays

2.3 PARAMETER VALUES ASSUMED FOR SILTATION MODELLING

2.3.1 In light of the additional information available from the Hull University monitoring, some changes to the assumed parameters use in the siltation modelling have been made in comparison with those adopted in section 4.1 of Annex 32.4 of the Environmental Statement. The parameters used in the original Environmental Assessment are listed in Table 10 of Annex 32.4 are based on the values quoted in Ref 3 (Ormondt and Roelvink, 2004) from the Humber strategy studies. These values are compared with those adopted for this assessment in Table 3. The values highlighted in bold have been changed for this assessment.

Table 3   Comparison of siltation parameters

Parameter	Value in Table 10 of Annex 32.4	Value in this assessment
Critical stress below which sedimentation occurs	0.2 N/m^2	0.2 N/m^2
Critical stress above which erosion occurs	0.5 N/m^2	0.5 N/m^2
Erosion rate constant	0.0001 kg/m^{2}s	0.0001 kg/m^{2}s
Bed density after deposition	500 kg/m^3	**1050 kg/m^3**
Bed density of long term settled sediments	1500 kg/m^3	1500 kg/m^3
Typical sediment concentration in the water column	200 or 300 g/m^3	**360 g/m^3**

2.3.2 The critical erosion stresses for deposition and erosion and the erosion rate constant have not changed as there is no additional information that would support any change. The work by Hull University shows that the critical erosion stress of 0.5 N/m^2 adopted in the Environmental Statement is within the range identified by the measurements at Paull Holme Strays for sediments settled in Paull Holme Strays.

2.3.3 The major change in this assessment is that the (dry) bed density when sediment is deposited in the site has been increased from 500 to 1050 kg/m^3 in light of the evidence from the Hull University monitoring. No change is made to the bed density of long term settled sediments, in this analysis assumed to be those below the existing ground or bathymetry.

2.3.4 The change to the dry density of recently settled sediment has two effects. Firstly, the rate of accretion is approximately halved if the concentration of sediment in the water column remains unchanged, as 1.05 kg/m^2 of suspended sediment are required to raise bed levels by 0.001 m compared with the 0.5 kg/m^2 of sediment required in the original assessment following the assumptions of Annex 32.4. Secondly, the rate of erosion is reduced by a similar factor because erosion of a greater mass of sediment is required to lower bed levels by each 0.001 m in this assessment.

2.3.5 The second change adopted in this assessment is the assumption made about the concentration of suspended sediment available in Cherry Cobb Sands to accrete sediment. Previously a concentration between 200 and 300 g/m^3 was assumed and found to cause accretion that slightly exceeded that measured at Paull Holme Strays in its first year of operation. The variation with level also closely followed the relationship found at Paull Holme Strays and shown in Figure 2.

2.3.6 The change in the assumed settled sediment density discussed above will reduce accretion rates unless the assumed sediment concentration in suspension is increased to give a similar annual accretion. A suspended sediment concentration of 360 mg/l was found to lead to accretion rates in the absence of erosion that closely match the observed settlement rate at Paull Holme Strays in the first year as indicated on Figure 4. The assumption that erosion is not an important consideration at Paull Holme Strays was made because all the low level monitoring sites used by the Environment Agency were on the opposite side of the managed realignment site to the breach so velocities causing erosion are unlikely.

2.3.7 The upper and lower limits for the Paull Holme Strays results shown on Figure 2, can be broadly represented by assuming concentrations in the water column of 420 and 300 mg/l respectively; 60 mg/l above and below the value that represents average settlement rates.

2.3.8 The application of the 360mg/l sediment concentration for the accretion assessment implicitly assumes that this is the reduction in concentration between the flood and ebb tides. The summer measurements by Hull University in Table 2 reported a smaller difference between flood and ebb tide concentration than required to match the observed accretion rates. The differences may well be larger in winter and the observed average difference in concentration may not fully represent the difference in sediment flux. Overall it is considered precautionary to match the observed accretion rate rather than the relatively limited number of measured suspended sediment concentrations in the Paull Holme Strays breach.

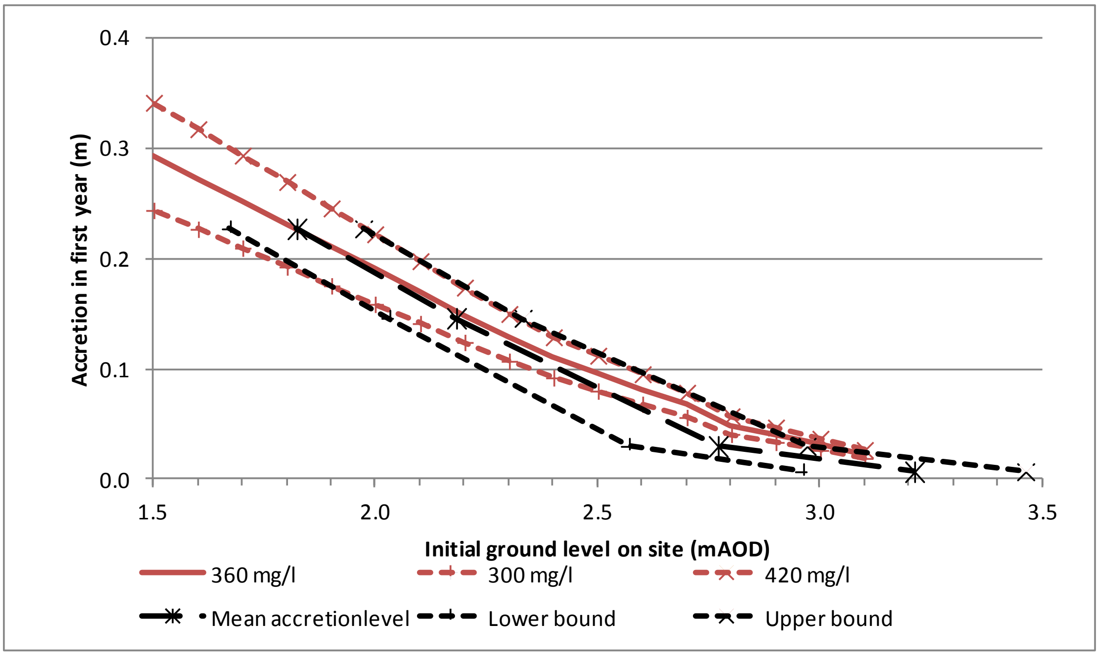


Figure 4 Comparison of assumed accretion with results for Paull Holme Strays

2.4 TIDE LEVELS AND FREQUENCIES

2.4.1 The siltation assessment was based on the same tides as used in the Environmental Assessment and reported in section 1.4 of Annex 32.4. The tidal conditions modelled are indicated in Table 4. The two lowest high water level conditions were not modelled as the inundation of the site is very limited and velocities are likely to be small so erosion is unlikely to be an issue. The contribution of these tides to accretion was included, though it is likely that the suspended sediment concentration will be much lower than normal.

2.4.2 High water levels modelled at Cherry Cobb Sands are slightly higher than those at Immingham by approximately 0.1m as indicated on Table 4. The difference is greatest on spring tides and least on neap tides. These modelled water levels have been used to assess siltation at the Cherry Cobb Sands site.

2.4.3 There are no regular measurements of water levels at the Paull Holme Strays managed realignment site which is about 7 km northwest of the Cherry Cobb Sands site. High water levels in the Humber increase up the estuary with predicted high water levels at King George Dock in east Hull being 0.2 m higher on mean neap tides and 0.3 m higher on mean spring tides than at Immingham (Ref 4). King George Dock is around twice the distance upstream of Immingham as Paull Holme Strays, so it is likely that high tide levels at Paull Holme Strays are 0.1 to 0.15 m higher than those at Immingham. This indicates that high water levels at Paull Holme Strays are probably within 0.1 m of those modelled for Cherry Cobb Sands. For this assessment high water levels at Cherry Cobb Sands and Paull Holme Strays have been assumed to be the same.

Table 4 Model tides used in siltation assessment

Range of HW level (mAOD)	Average frequency of occurrence (%)	Date and HW level of representative tide at Immingham (mAOD)	HW level within Cherry Cobb Sands site (mAOD)
<2.0	15	1.8 (not modelled)	1.85 (estimate)
2.0 – 2.5	26	2.3 (not modelled)	2.36 (estimate)
2.6 - 2 9	23	2.8 (am tide 18/5/10)	2.87
3.0 - 3 3	24	3.1 (am tide 16/5/10)	3.19
3.4 - 3 7	10	3.55 (pm tide 8/9/10)	3.65
3.8 - 4 1	2	3.85 (am tide 9/9/10)	3.96

3 MODELLING OF FIRST SCHEME

3.1 INTRODUCTION

3.1.1 The first scheme that was developed for detailed modelling was based on a single low creek running up the centre of the Cherry Cobb Sands managed realignment site. This scheme provides sufficient fill to construct the surrounding flood banks. Additional fill was excavated from the low area in the centre of the site and placed in a 15m wide berm at 3.0 mAOD all along the inside edge of the new flood defence. This berm will be inundated on all mean spring tides so forms a functional part of the intertidal habitat at a level that will quickly develop into saltmarsh to replace the area lost in formation of the breach.

3.1.2 Tidal water enters the site through a 250 m long breach cut through the existing flood defence bank and fronting saltmarsh with an invert level between 1.8 and 2.0 mAOD.

3.1.3 The plan of the first scheme layout is shown on Figure 5 with colours to highlight the different contour levels within the site. This plan also shows the 14 points where the siltation assessment was carried out. These points were selected to cover the range of conditions anticipated within the site and to help delineate the probable erosion contours. The accretion contours are determined by the depth of inundation over the initial ground level taking account of the number of tides of different height that will inundate the site.

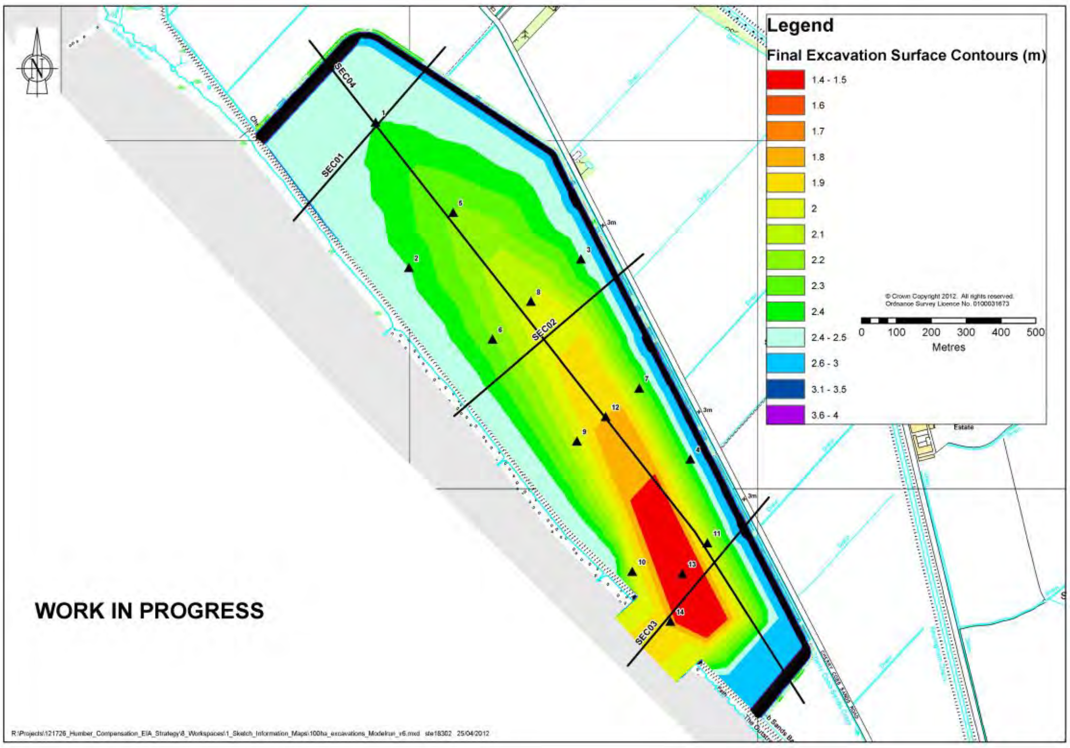


Figure 5 First scheme layout

3.2 STORAGE AND VOLUME CHARACTERISTICS

3.2.1 The surface area and volume characteristics of the first scheme are illustrated in Figure 6. The surface area and volumes include the breach area. The site can store 1.33×10^6 m^3 at 3.5 mAOD within a surface area of 106.3 ha. At 2.5 mAOD the assumed lower limit for saltmarsh creation, the site area is 97.0 ha and there is 10.2 ha below the breach invert level of 1.8 mAOD, giving an area available for mudflat creation of 86.8 ha.

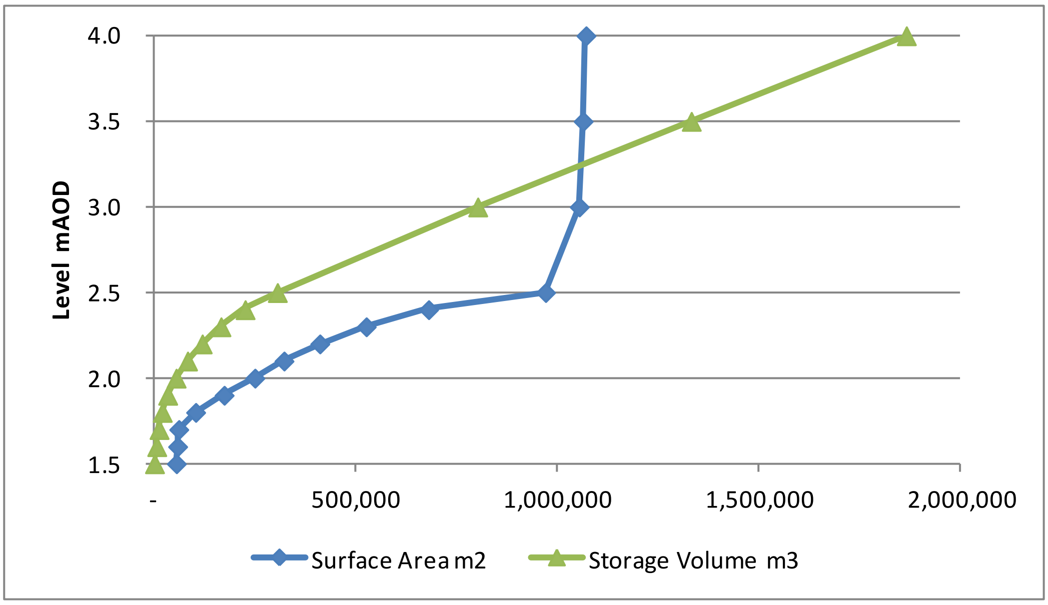


Figure 6 Surface area and volume characteristics of the first scheme

3.3 TIDE CONDITIONS IN THE CHERRY COBB SANDS SITE

Tide levels within the site

3.3.1 The tide levels during the modelled evening high spring tide of 8th September 2010 are illustrated in Figure 7. Tide curves are illustrated for point 1 at the northern end of the site and for point 13 close to the breach and also at Point 16 in Cherry Cobb Sands Creek about 100 m downstream of the breach. The locations of the points within the site are shown on Figure 5, while Point 16 in Cherry Cobb Sands Creek is shown on Figure 23.

3.3.2 The tide rises and falls first in the creek (Point 16) then in the part of the site closest to the breach (Point 13) and finally in the most distant part of the site (Point 1). High water levels are similar within the site and in the creek outside. The flood tide is much shorter than the ebb tide within Cherry Cobb Sands Creek and in the managed realignment site. At low water, the site dries at Point 1 where the bed level is 2.4 mAOD and drains down to 1.89 mAOD at Point 13 just inside the breach which has an invert level of 1.8 mAOD. This illustrates that the drainage of the site is effective.

3.3.3 Within Cherry Cobb Sands Creek the creek almost dries out shortly before the tide floods in again as low water level is very close to the local bed level. For this model test, the size of Cherry Cobb Sands Creek was assumed to be unchanged.

Velocities within the site

3.3.4 Velocities within the site are illustrated for the same high spring tide at Points 1 and 13 and in Cherry Cobb Sands Creek at Point 16 on Figure 8. The time of high tide is also marked to distinguish flood and ebb conditions.

3.3.5 Within Cherry Cobb Sands Creek at Point 16 the ebb tide velocities which peak at 1.3 m/s are much greater and more prolonged than the flood tide velocities which have a maximum of 0.9 m/s.

3.3.6 In the managed realignment site at Point 13 just inside the breach, the flood tide velocities are large, reaching a maximum of 1.4 m/s at this site. The ebb tide is more prolonged and so maximum velocities on the ebb tide are much lower reaching a maximum of 0.7 m/s during the ebb tide. Further away from the breach at Point 1, velocities are much lower on both flood and ebb tides. The maximum velocity on the flood tide reaches 0.7 m/s at Point 1 for a short period, while on the ebb tide the maximum velocity remains below 0.2 m/s.

3.3.7 Velocity patterns across the site on the late flood tide close to the time of maximum velocity are illustrated on Figure 9. Early ebb tide velocities, close to the time of maximum ebb tide velocity are shown on Figure 10 while the whole site is still draining. Both figures show the strong gradient of velocity across the site with the ebb tide velocities being much lower than the flood tide velocities.

Shear stresses within the site

3.3.8 Shear stresses at Cherry Cobb Sands are illustrated on Figure 11 for the same high spring tide at Points 1 and 13 within the Compensation Site. In addition, shear stresses in the centre of the site at Point 8 are also shown (see Figure 5 for location). On this figure, shear stresses within Cherry Cobb Sands Creek at Point 16 are not shown as they are considered in section 6 of this report.

3.3.9 The shear stresses within the compensation site, like velocities, reduce with distance from the breach, with Point 1 having the lowest shear stress and Point 13 the highest. For the majority of the time, shear stress is below the deposition threshold of 0.2 N/m^2 at all the sites (Table 3). Erosion occurs at all sites during the flood tide when shear stress exceeds the erosion threshold of 0.5 N/m^2 (Table 3). Site 13 is the only site of those shown where the shear stress exceeds the erosion threshold on the ebb tide. The longer duration of the high shear stress at site 8 leads to greater erosion of sediment than at site 1 even though the peak shear stress at the two sites is similar.

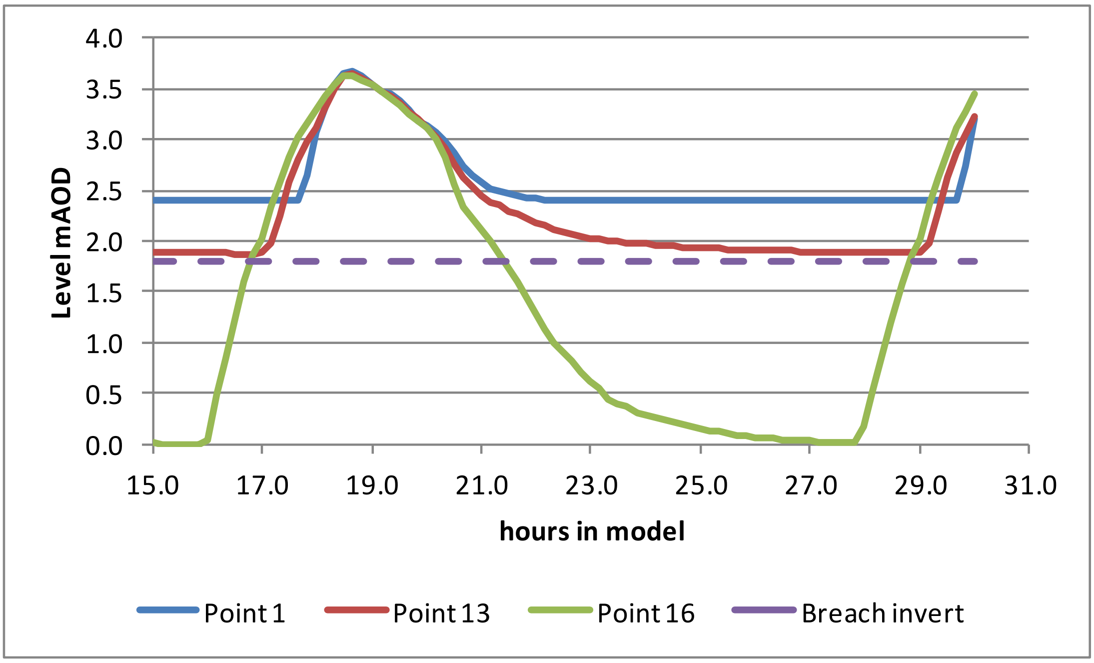


Figure 7 Tide levels in Cherry Cobb Sands on a high spring tide for 1st scheme

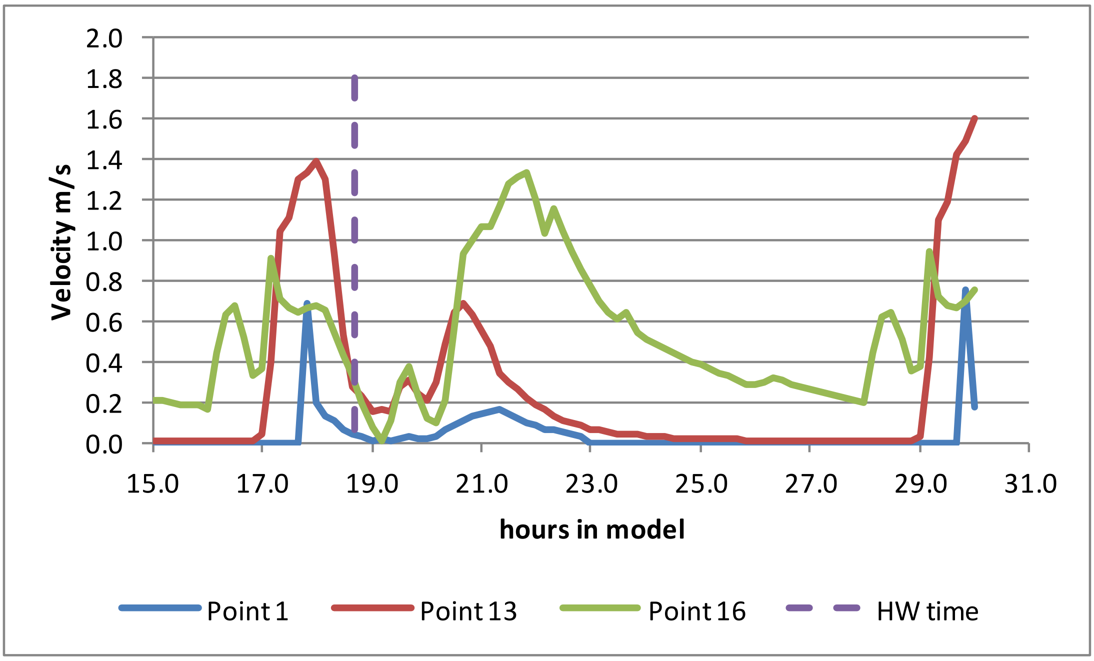


Figure 8 Velocities in Cherry Cobb Sands on a high spring tide for 1st scheme

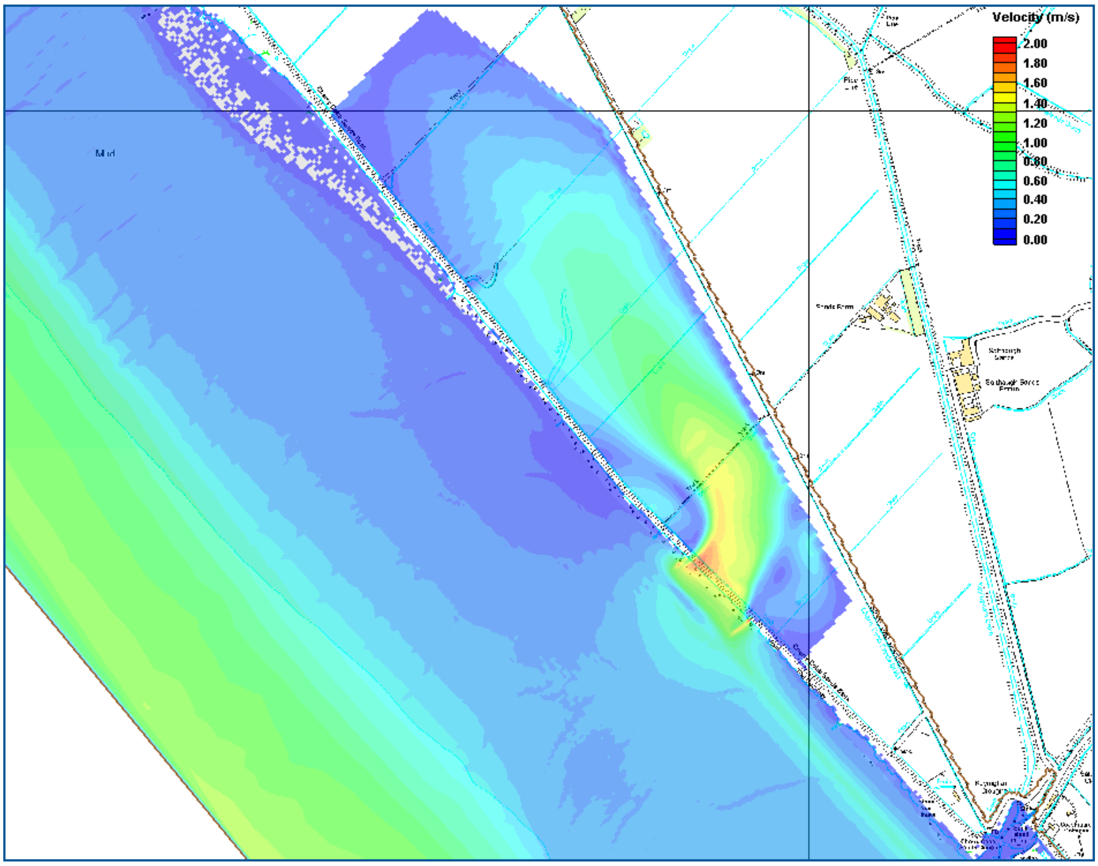


Figure 9   Compensation Site velocity patterns on the late flood tide for 1st scheme

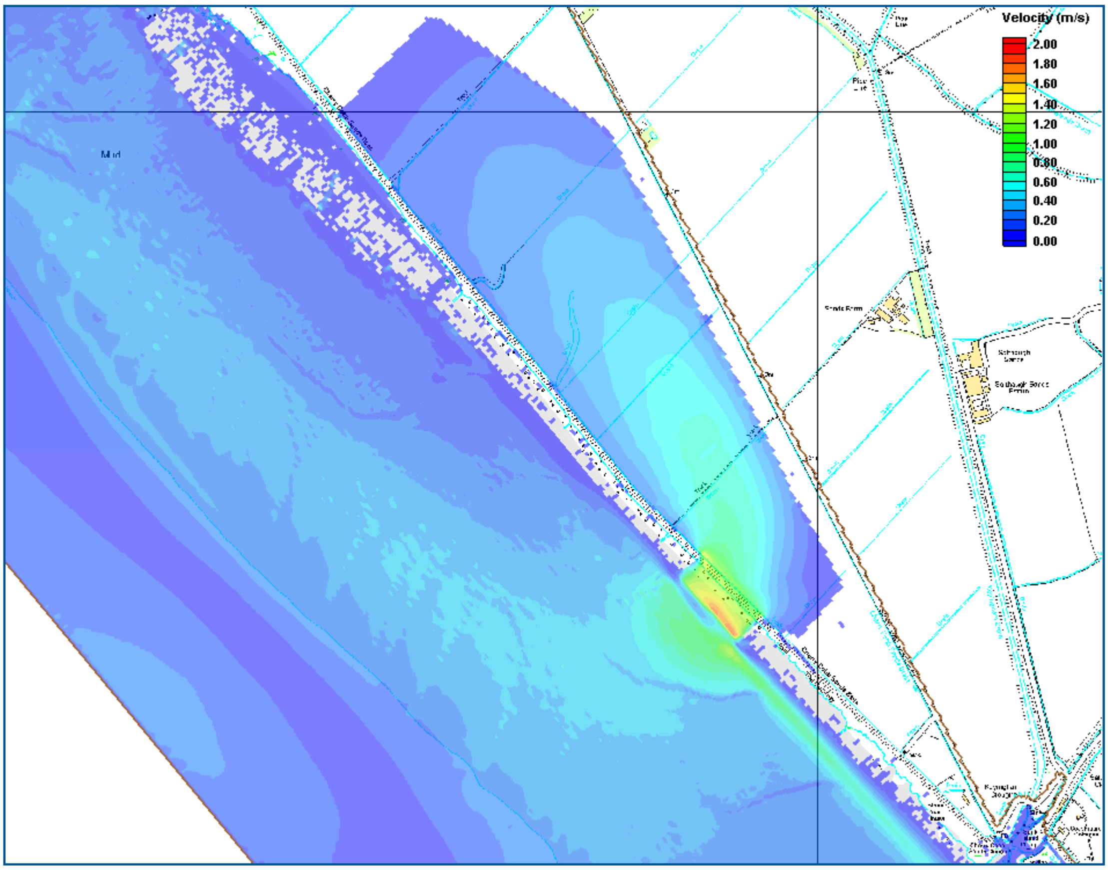


Figure 10   Compensation Site velocity patterns on the early ebb tide for 1st scheme

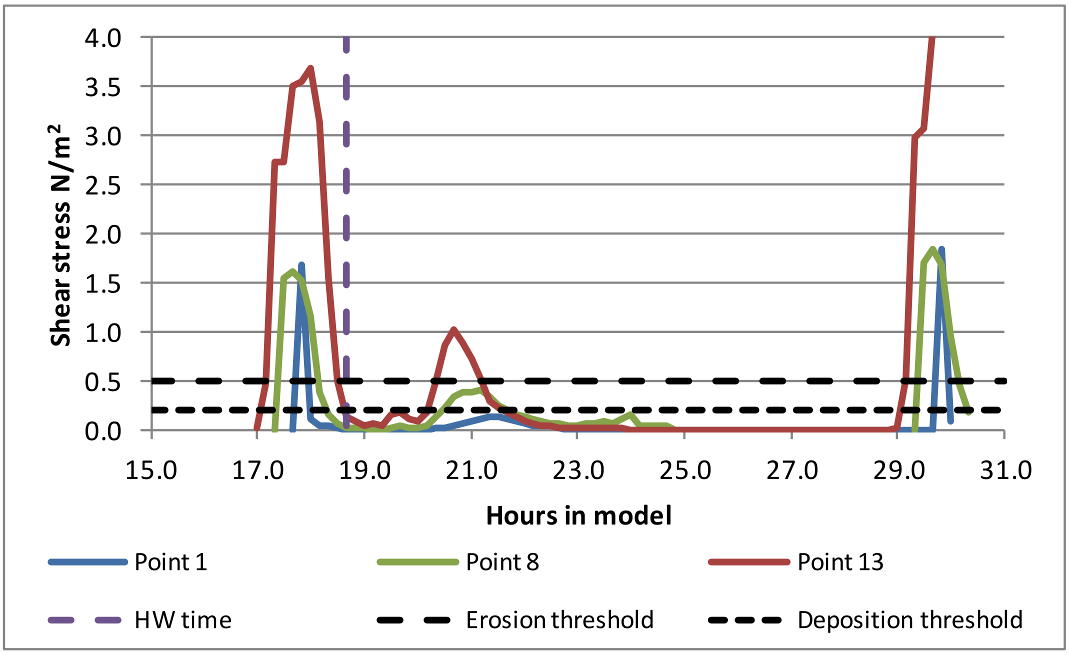


Figure 11 Shear stress in Cherry Cobb Sands on a high spring tide for 1st scheme

3.4 SILTATION AND EROSION ASSESSMENT

Accretion and erosion methodology

3.4.1 A siltation and erosion assessment was carried out at the 14 points shown on Figure 5 to understand the likely evolution of the site after breaching. At each site, it was considered that shear stresses were below the deposition threshold for a sufficient proportion of the time at high tide and during the ebb tide for the whole site to experience similar settlement to that at Paull Holme Strays described on Figure 2.

3.4.2 This accretion would be mitigated by erosion, occurring mainly during the flood tide. This would reduce the total siltation that occurred. Contours of annual siltation were prepared based on the initial ground level at each point in the site. This allowed a surface to be generated of the accretion that might occur within the Compensation Site in the absence of any erosion.

3.4.3 Erosion was estimated by considering the erosion that was predicted at each of the 14 points during the four modelled tides in Table 4, with annual erosion estimated by factoring up the erosion on an individual tide to take account of the number of tides of each range during the year. As in the earlier assessment reported in section 4 of Annex 32.4, the approach of Partheniades to the estimation of erosion was adopted using the factors set out in Table 3. As this erosion was primarily of the recently deposited sediments, the amount of erosion assumed a bed dry density of 1050 kg/m^3 as indicated in Table 3.

3.4.4 At the majority of sites, annual erosion was predicted to be less than deposition so overall the ground level within the compensation site is expected to rise. At a few points near the breach (Points 11, 13 and 14) the annual erosion was predicted to exceed deposition and so erosion of the site is anticipated at these locations. At these sites, the overall erosion was assessed assuming that firstly all the accreted sediments were eroded and that the remaining erosion was of existing bed sediments that had a dry density of 1500 kg/m^3 as indicated in Table 3.

3.4.5 The erosion estimates at each of the assessment points were plotted and contours of equal erosion drawn. These contours were subtracted from the anticipated accretion surface to determine the predicted ground level within the Compensation Site at the end of the first year. The resulting changes in bed level since breaching were multiplied by a factor of three to predict conditions after five years.

3.4.6 The factor of three used to convert the change after one year to the change after five years was determined by considering the ratio of accretion after five years to accretion after one year experienced at Paull Holme Strays and shown as Figure 3. This factor takes account of two processes, firstly that as ground level rise, inundation will be slightly less frequent and shallower, so the rate of accretion will decrease even if other circumstances do not change. In addition, the extra weight of freshly deposited sediment and the gradual expulsion of water from previously accreted sediments will result in compaction of the sediment and gradually reduce their level. Both these factors are included in the ratio derived for Paull Holme Strays.

3.4.7 Where initial ground levels are below 2.2 mAOD, the ratio between accretion after five years and after one year should be less than 3.0, while for areas where initial ground levels are greater than 2.2 mAOD this ratio should be greater than 3.0. As the prime interest in the Compensation Site is in those areas remaining below 2.5 mAOD, it was considered that a factor of 3.0 was a reasonable compromise for this purpose, noting that initially there were no areas within the site where levels initially exceeded 2.5 mAOD except for the 15 m berm adjacent to the new flood embankment.

Predicted ground surface after five years

3.4.8 The predicted ground surface of the Compensation Site after five years is shown on Figure 12. The surface area of the site, including the breach area after five years is compared with the initial surface area on Figure 13. The changes in area are indicated in Table 5. The accretion of the site significantly reduces the area remaining below 2.5 mAOD from 97 to around 41 ha. There are smaller reductions in area at lower levels down to 2.0 mAOD. The area below 2.0 mAOD is predicted to increase, though this is difficult to predict reliably and will depend on how the flow scours the area around the breach where it turns from flowing across the breach to flowing parallel to the main flood defence.

3.4.9 The 41 ha area predicted to be below 2.5 mAOD is expected to remain as mudflat over the five years, though the 14 ha that is predicted to be below 1.8 mAOD will only act as mudflat if a creek cuts through the breach to allow the ponded area behind the breach to drain. This is expected to happen naturally, but if the breach proves unusually resistant to erosion, it may be necessary to intervene to ensure this low part of the site is able to drain.

3.4.10 Comparison of levels predicted by the contouring software with the 14 points used to develop the contours showed the contours were on average 0.02 m lower than the points with a standard deviation of 0.04m if three points (11, 13 and 14) closest to the breach where erosion was predicted were excluded. The contours in this area were deliberately arranged to underpredict the calculated erosion at these points as erosion as large as initially predicted was judged unlikely to persist for five years as significant accretion over the majority of the site was anticipated which would reduce maximum velocities and shear stresses.

Table 5 Predicted change of first scheme surface area over five years

Level (mAOD)	Area after five years (ha)	Initial area (ha)	Difference (ha)
3.0	100.3	105.4	-5.0
2.5	41.1	97.0	-55.9
2.4	33.8	68.0	-34.2
2.2	25.5	41.0	-15.6
2.0	21.4	24.9	-3.6
1.8	14.0	10.2	3.7

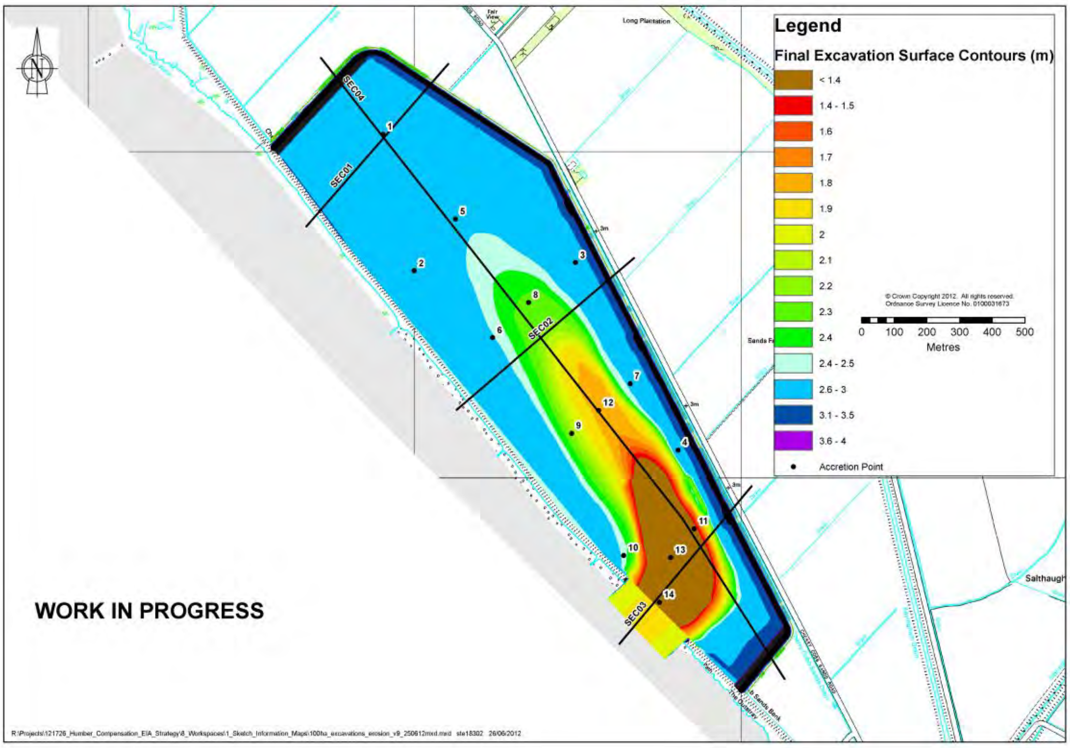


Figure 12 Predicted ground levels for first scheme after five years

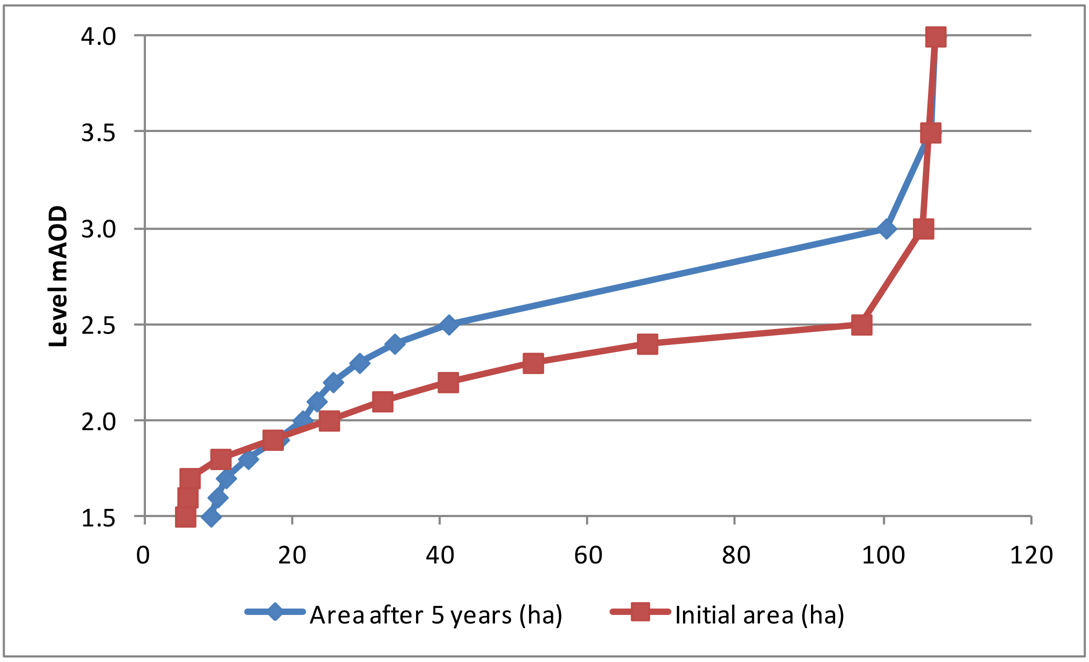


Figure 13 *Surface area of first scheme initially and after five years*

4 MODELLING OF SECOND SCHEME

4.1 INTRODUCTION

4.1.1 The second scheme that was developed for detailed modelling was based on excavating two low creeks within the Cherry Cobb Sands managed realignment site. This scheme was intended to increase the area at low level within the site to reduce the rate of siltation predicted for the first scheme. The additional excavation was placed as a 15 m wide berm at 3.0 mAOD around the inside of the old flood defence embankment. As with the berm around the remainder of the site it will be inundated on all mean spring tides and will form a functional part of the intertidal habitat at a level that will quickly develop into saltmarsh.

4.1.2 Tidal water enters the site through a 250 m long breach cut through the existing flood defence bank and fronting saltmarsh with an invert level between 1.8 and 2.0 mAOD. This breach arrangement is identical to the first scheme.

4.1.3 The opportunity was also taken to reconfigure the shape of the deepest part of the site just inside the breach so that it was better aligned with the flow streamlines as they turn inside the breach and run parallel to the flood defence. The extra material was placed in the area south of the breach which is likely to accrete rapidly.

4.1.4 The plan of the second scheme layout is shown on Figure 14 with colours to highlight the different contour levels within the site. This plan also shows the 21 points where the siltation assessment was carried out. Most of the points were identical to those used for the first scheme, but additional points were identified to try and map the boundary of the more complex shape of the second scheme.

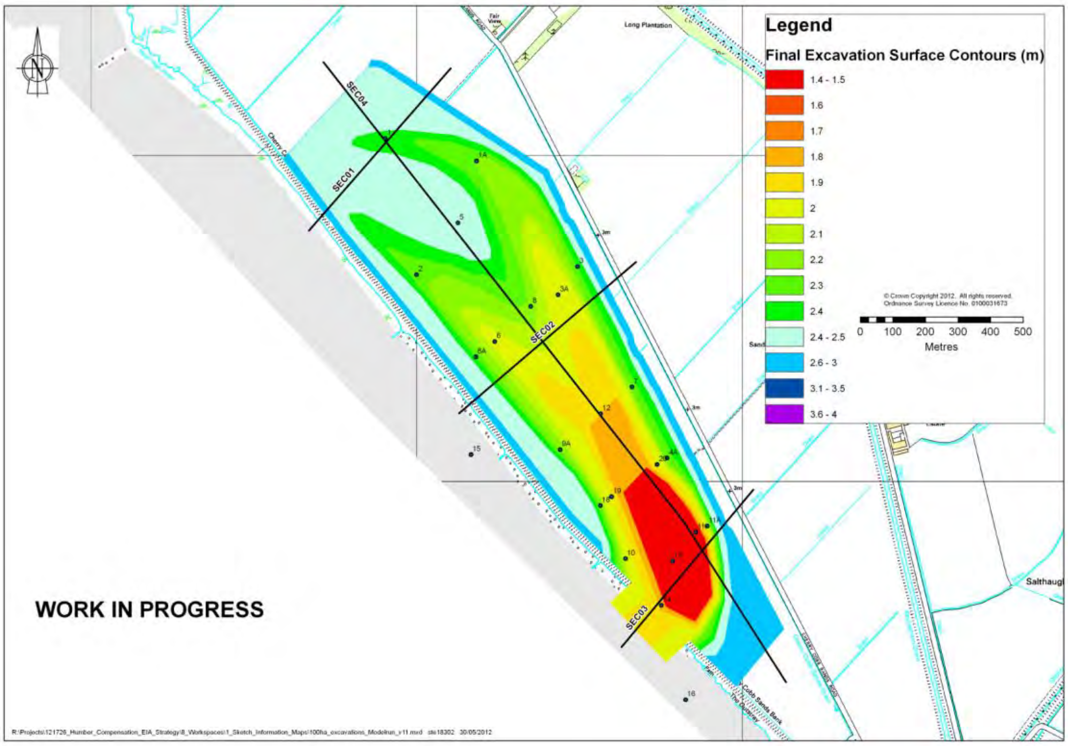


Figure 14 Second scheme layout

4.2 STORAGE AND VOLUME CHARACTERISTICS

4.2.1 The surface area and volume characteristics of the first scheme are illustrated in Figure 15. The surface area and volumes include the breach area. The site can store $1.33x10^6$ m^3 at 3.5 mAOD within a surface area of 106.3 ha. At 2.5 mAOD the assumed lower limit for saltmarsh creation, the site area is 92.1 ha and there are 11.8 ha below the breach invert level of 1.8 mAOD, giving an area available for mudflat creation of 80.3 ha. This second scheme has 5 ha less than the first scheme at 2.5 mAOD, but 5 ha more at a level of 2.0 mAOD.

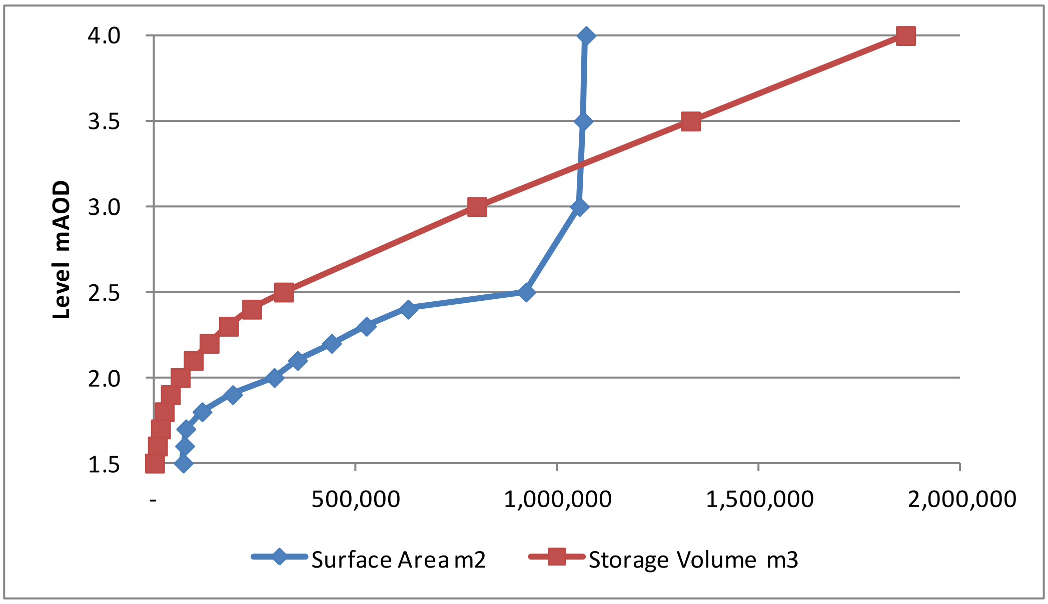


Figure 15 Surface area and volume characteristics of the 2nd scheme

4.3 TIDE CONDITIONS IN THE CHERRY COBB SANDS SITE

Tide levels within the site

4.3.1 The tide levels during the modelled evening high spring tide of 8th September 2010 are illustrated in Figure 16 for the second scheme. Tide curves are illustrated for point 1 at the northern end of the site and for point 13 close to the breach and also at Point 16 in Cherry Cobb Sands Creek about 100 m downstream of the breach. The locations of the points within the site are shown on Figure 14 while Point 16 is shown on Figure 23.

4.3.2 The results are indistinguishable from those for the first scheme in Figure 7.

Velocities within the site

4.3.3 Velocities within the site are illustrated for the same high spring tide at Points 1 and 13 and in Cherry Cobb Sands Creek at Point 16 on Figure 17 for the second scheme. The time of high tide is also marked to distinguish flood and ebb conditions.

4.3.4 Within Cherry Cobb Sands Creek at Point 16 the velocities with the second scheme are very similar to those with the first scheme as the storage characteristics of the two sites are very similar.

4.3.5 In the Compensation Site at Point 13 just inside the breach, the flood tide velocities for the second scheme are similar to the first scheme reaching a maximum of 1.4 m/s. The ebb tide of the second scheme is similar to the first scheme, but maximum velocities on the ebb tide are marginally lower with a maximum of 0.6 m/s. Further away from the breach at Point 1, velocities are similar in both schemes.

4.3.6 Velocity patterns across the site on the late flood tide close to the time of maximum velocity are illustrated for the second scheme on Figure 18. Early ebb tide velocities, close to the time of maximum ebb tide velocity are shown on Figure 19 while the whole site is still draining. Both figures show the areas of largest velocity follow the contours of the bed topography with its two creeks at this time. Apart from this difference arising from the bed topography the contours are similar for the two schemes.

Shear stresses within the site

4.3.7 Shear stresses at Cherry Cobb Sands are illustrated for the second scheme on Figure 20 for the same high spring tide at Points 1, 8 and 13 within the Compensation Site as shown for the first scheme.

4.3.8 The shear stresses within the compensation site like velocities reduce with distance from the breach, with Point 1 having the lowest shear stress and Point 13 the highest. While shear stresses at point 13 are similar for both schemes, those at Point 8 are notably lower in the second scheme. This is because this site is at a slightly higher level between the two creeks for this scheme and so velocities and therefore shear stresses are lower. At Point 1, the peak shear stress in the second scheme is greater than in the first scheme, but is probably of little significance as it is immediately after the site starts to flood.

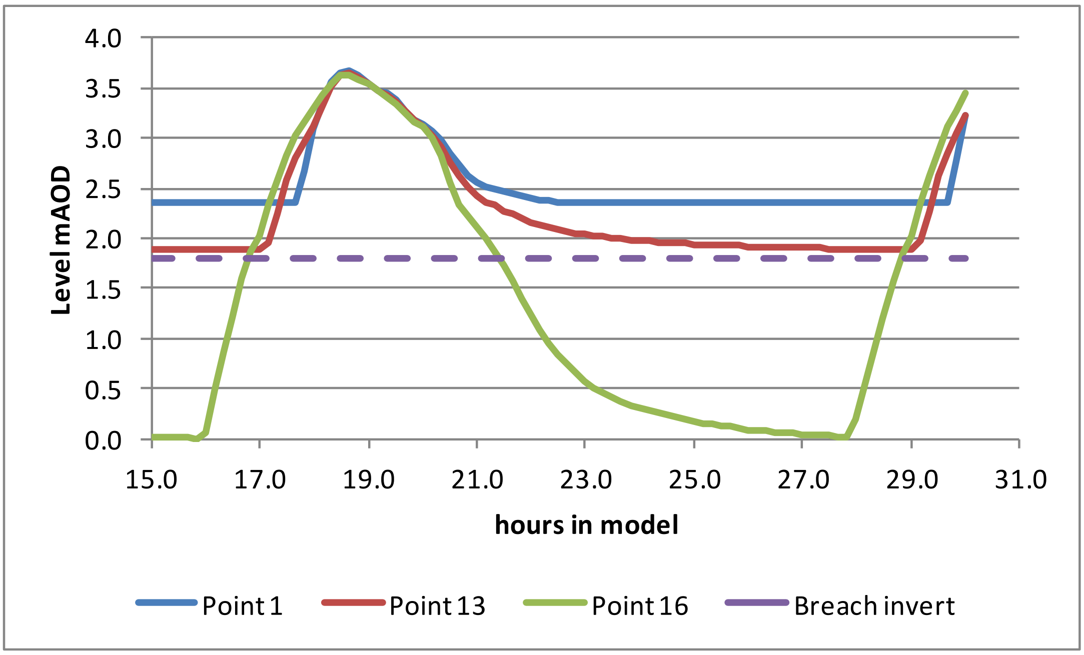


Figure 16 Tide levels in Cherry Cobb Sands on a high spring tide for 2nd scheme

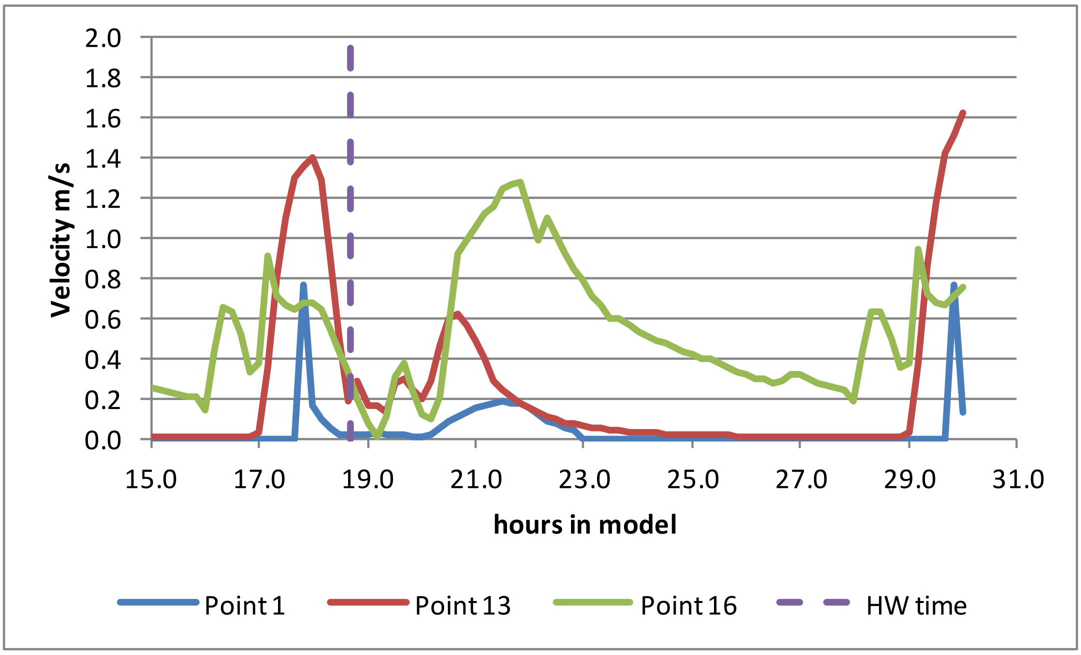


Figure 17 Velocities in Cherry Cobb Sands on a high spring tide for 2nd scheme

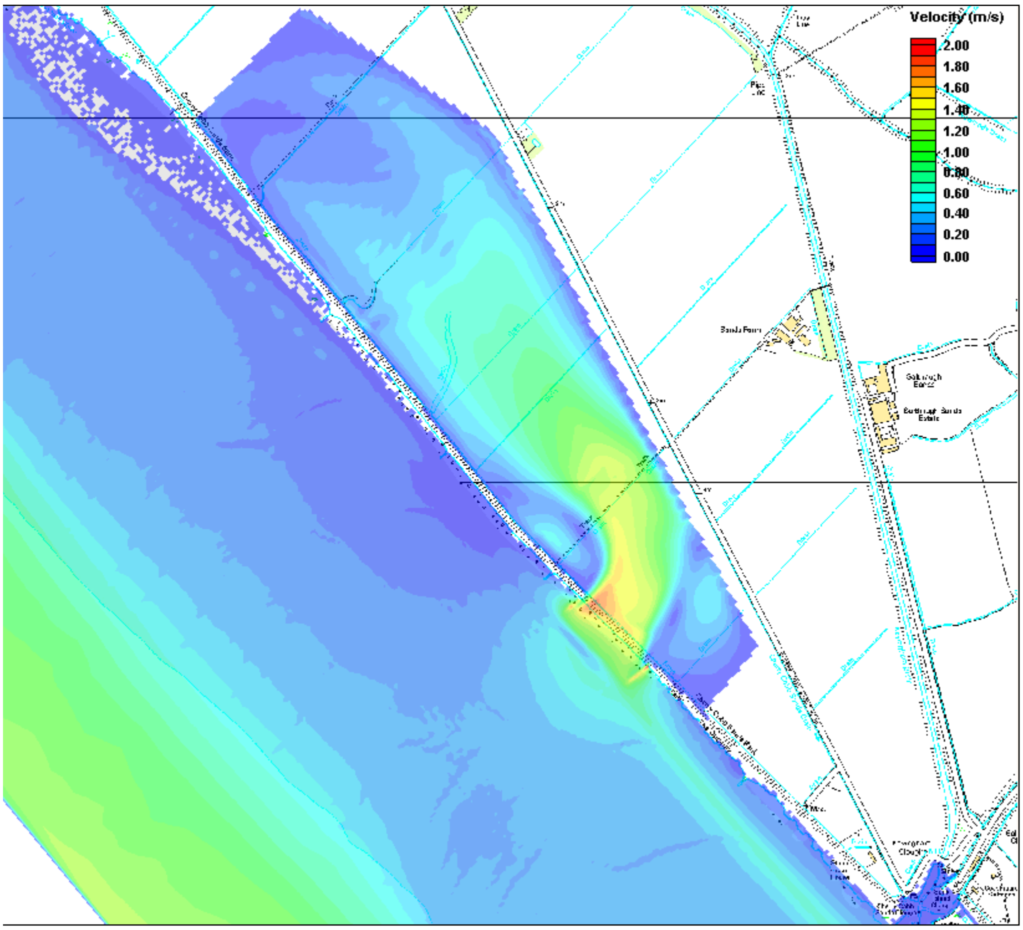


Figure 18 Compensation Site velocity patterns on the late flood tide for 2nd scheme

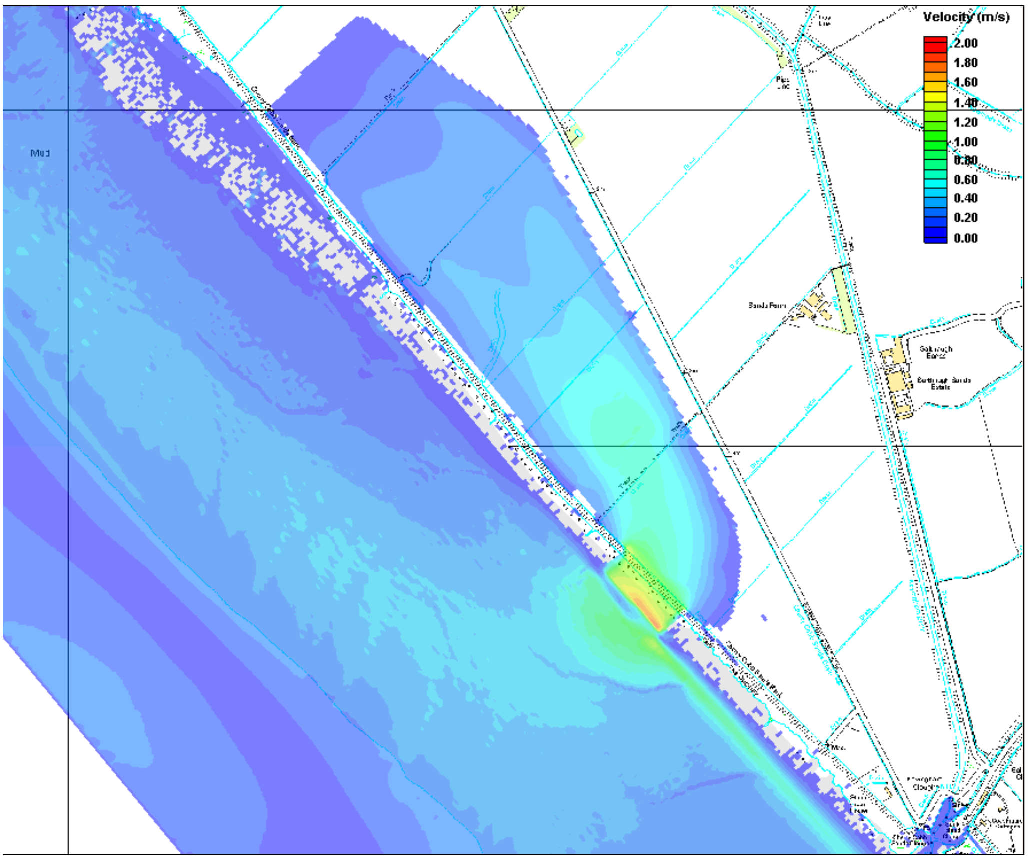


Figure 19 Compensation Site velocity patterns on the early ebb tide for 2nd scheme

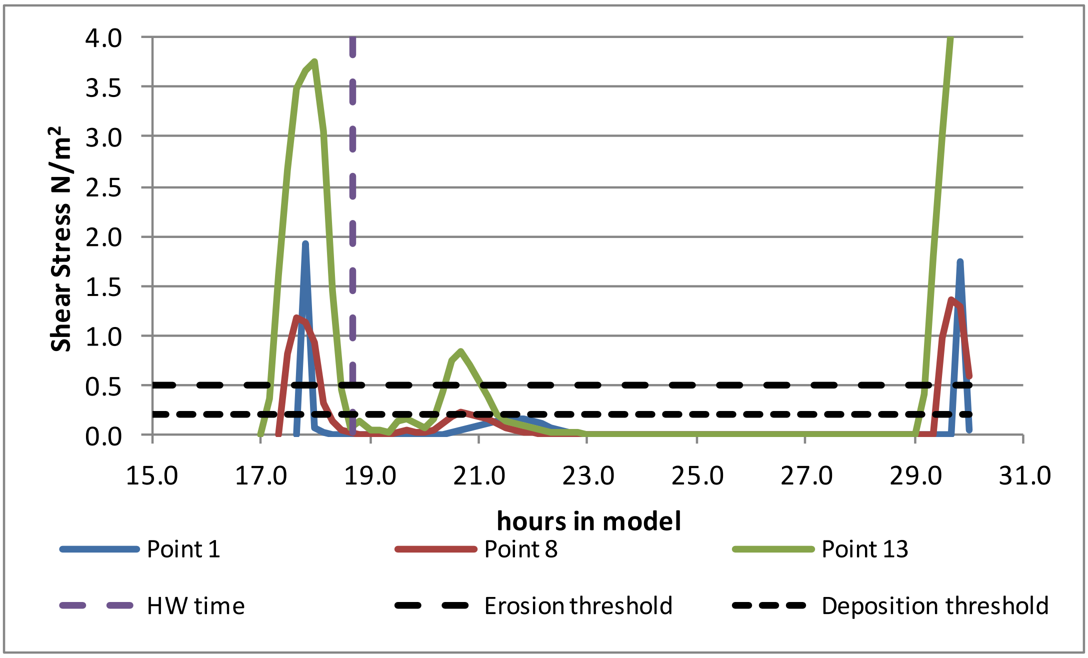


Figure 20 Shear stress in Cherry Cobb Sands on a high spring tide for 2nd scheme

4.4 SILTATION AND EROSION ASSESSMENT

Accretion and erosion methodology

4.4.1 A siltation and erosion assessment was carried out at the 21 points shown on Figure 14 to understand the likely evolution of the site after breaching. The method of analysis was identical to that adopted for the first scheme in section 3.4.

Predicted ground surface after five years

4.4.2 The predicted ground surface of the Compensation Site with the second scheme after five years is shown on Figure 21. The surface area of the site, including the breach area after five years is compared with the initial surface area on Figure 22. The changes in area are indicated in Table 6. The accretion of the site significantly reduces the area remaining below 2.5 mAOD from 92 to around 43 ha. There are smaller reductions in area at lower levels down to below 2.0 mAOD.

4.4.3 The 43 ha area predicted to be below 2.5 mAOD is expected to remain as mudflat over the five years, though the 12 ha that is predicted to be below 1.8 mAOD will only act as mudflat if a creek cuts through the breach to allow the ponded area behind the breach to drain. This is expected to happen naturally, but if the breach proves unusually resistant to erosion, it may be necessary to intervene to ensure this low part of the site is able to drain.

4.4.4 Comparison of the levels predicted at the 21 points considered in developing the prediction of levels after five years with the levels calculated using the contouring package showed an average difference in predicted level of <0.01 m with a standard deviation of 0.09 m if the two points closest to the breach (13 and 14) were excluded from the assessment. This was done for the same reasons as given for the first scheme but knowledge gained from that scheme allowed better estimates of probable conditions at points such as 11 to be made.

Table 6 Predicted change in second scheme surface area over five years

Level (mAOD)	Area after five years (ha)	Initial area (ha)	Difference (ha)
3.0	98.5	105.4	-6.9
2.5	43.3	92.1	-48.8
2.4	33.6	62.9	-29.2
2.2	23.5	43.9	-20.4
2.0	16.1	29.7	-13.6
1.8	10.3	11.8	-1.6

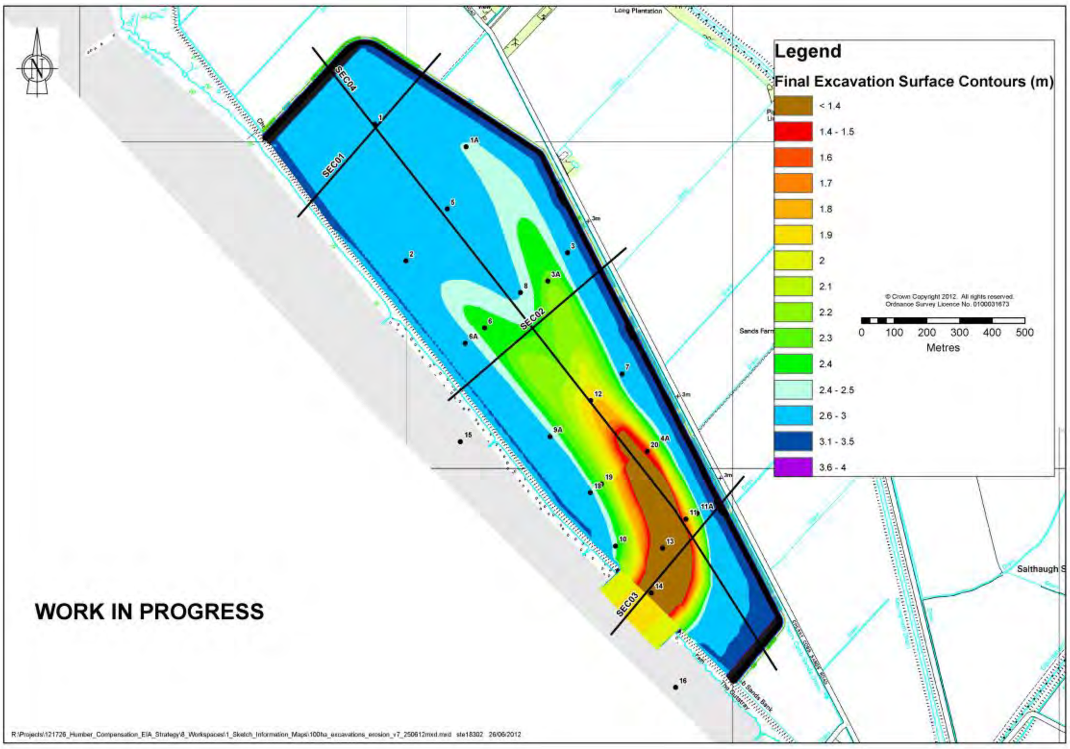


Figure 21 Predicted ground levels for second scheme after five years

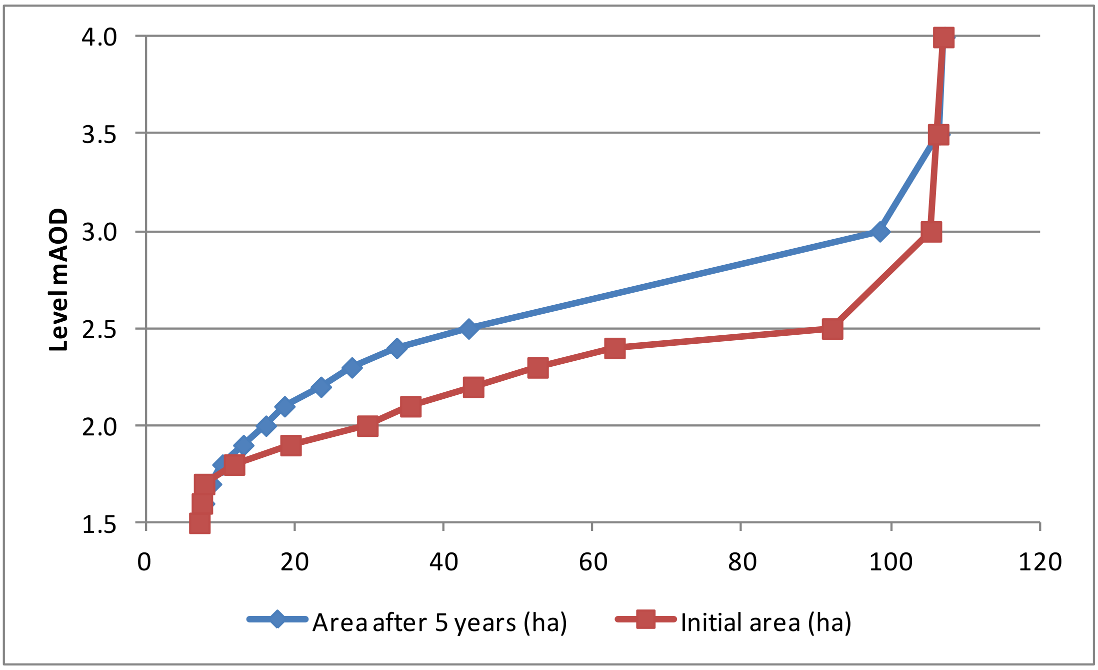


Figure 22 Surface area of second scheme initially and after five years

5 REVIEW OF FIRST AND SECOND SCHEMES

5.1 COMPARISON OF THE TWO SCHEMES

5.1.1 The two schemes perform in a similar manner. Both enclose an area of 106 ha at 3.5 mAOD and contain 1.33x10^6 m^3 of water when filled to this level on a spring tide. The first scheme has an initial surface area of 97 ha below 2.5mAOD while the second scheme has an initial surface area of 92 ha at this level. The initial differences in surface area are indicated in Table 7. At levels of 2.5 and 2.4 mAOD there is 5 ha less area in the second scheme while at a level of around 2.0 mAOD there is 5 ha more area in the second scheme. This would suggest that the second scheme has more accommodation space for siltation before the site accretes above 2.5 mAOD at which saltmarsh is expected to form.

Table 7 Comparison of initial surface areas of the two schemes

Level (mAOD)	First scheme surface area (ha)	Second scheme surface area (ha)	Difference (ha)
3.0	105.4	105.4	0
2.5	97.0	92.1	4.9
2.4	68.0	62.9	5.1
2.2	41.0	43.9	-2.9
2.0	24.9	29.7	-4.8
1.8	10.2	11.8	-1.6

5.1.2 After five years the predicted areas are similar as indicated in Table 8. At levels above 2.2 mAOD the difference in surface area between the two schemes is predicted to be less than 2.5 ha. This is within the uncertainty of the predictions. After five years, the first scheme contains 1.17x10^6 m^3 below 3.5 mAOD while the second scheme contains 1.10x10^6 m^3.

5.1.3 The predictions also suggest that the first scheme may have up to 5 ha additional surface area at around 2.0 mAOD. This is unlikely to be a real effect but arise from the estimates of the shape close to the breach. As indicated in paragraph 4.1.3 the opportunity was taken in the second scheme to improve the shape of the excavation to match the model streamlines and this has led to a slightly narrower channel after five years that may better represent the likely evolution of both schemes.

Table 8 Comparison of the surface areas of the two schemes after five years

Level (mAOD)	**First scheme surface area (ha)**	**Second scheme surface area (ha)**	**Difference (ha)**
3.0	100.3	98.5	1.8
2.5	41.1	43.3	-2.2
2.4	33.8	33.6	0.2
2.2	25.5	23.5	2.0
2.0	21.4	16.1	5.3
1.8	14.0	10.3	3.7

5.2 SENSITIVITY TO ASSUMPTIONS

5.2.1 The predictions after five years are sensitive to the assumptions made about the siltation environment in the Cherry Cobb Sands Compensation Site. Perhaps the most sensitive parameter is the assumed concentration of suspended sediment that settles out each tide within the Compensation Site. For the base case discussed above a change in suspended sediment concentration of 360 mg/l was assumed between incoming and outgoing water to match the mean rates of accretion observed in Figure 4. However, there is some uncertainty in the accretion measured in the site arising from the method of analysis as indicated in Figure 2. This can be modelled by assuming the sediment concentration varies between 300 and 420 mg/l as illustrated in Figure 4. The higher rate of siltation is associated with a difference of 420 mg/l in the incoming and outgoing sediment concentration while the lower rate is associated with the 300mg/l difference in incoming and outgoing concentration.

5.2.2 The observed difference between the incoming and outgoing suspended sediment concentrations was measured in summer conditions at less than 200 mg/l at Paull Holme Strays in the results presented in Table 2. However, these measurements do not take account of the higher concentrations anticipated in winter months when higher siltation rates are observed.

5.2.3 The results from sensitivity tests using higher and lower concentration differences are shown in Table 9. These show that the predicted area of the Compensation Site below particular levels is very sensitive to the assumption made on sediment concentration. A change of ±16.7 percent (60 mg/l in 360 mg/l) in assumed sediment concentration leads to changes in intertidal area after five years that are between ±10 and ±20 percent in the active part of the foreshore between 2.0 and 2.5 mAOD. This sensitivity is unlikely to be reduced as suspended sediment concentrations are inherently variable. These conclusions suggest that it would be prudent to place a ±20 percent uncertainty around these predictions.

Table 9 Results of sensitivity tests on accretion rates

Level (mAOD)	First scheme surface area (ha)			Second scheme surface area (ha)		
	Base case	Change with 300 mg/l	Change with 420 mg/l	Base case	Change with 300 mg/l	Change with 420 mg/l
3.0	100.3	0.5	-0.7	98.5	1.4	-1.7
2.5	41.1	8.4	-5.0	43.3	8.0	-8.0
2.4	33.8	4.7	-3.8	33.6	7.1	-5.4
2.2	25.5	2.9	-1.9	23.5	3.7	-4.8
2.0	21.4	1.7	-1.9	16.1	2.4	-1.9
1.8	14.0	2.9	-2.8	10.3	1.7	-1.7

6 *ENLARGEMENT OF CHERRY COBB SANDS CREEK*

6.1 INTRODUCTION

6.1.1 The Environmental Statement anticipated that the drainage flows from the Compensation Site would lead to erosion of Cherry Cobb Sands Creek and its enlargement over time. This was expected to mitigate for the adverse effects initially anticipated on the land drainage from Stone Creek. This potential enlargement was not quantified in the Environmental Statement. Representations from the Marine Management Organisation and the Internal Drainage Boards have requested that this effect be quantified.

6.1.2 The enlargement of a tidal creek depends on the balance of accretion and erosion due to tidal flows within the creek taking account of other factors such as occurrences of large fluvial flows down the creek following periods of high rainfall and possibly storm wave activity which can increase shear stresses substantially and also increase sediment concentrations which will preferentially settle out in any areas of low velocity.

6.1.3 Experience at Cherry Cobb Sands Creek, according to those responsible for land drainage, is that there is a tendency for sediment to accrete in the creek. Over time this has made drainage more difficult from the outfalls discharging to Stone Creek. In early 2008, following the large summer floods of 2007, the Environment Agency dredged the creek to increase its capacity as reported in Annex 32.1. However, the drainage representatives report the creek has returned to pre-dredge conditions and they are now planning further maintenance of this creek over the next five years to restore its capacity.

6.2 ASSESSMENT METHODOLOGY

6.2.1 The changes to Cherry Cobb Sands Creek are not solely determined by the flows and velocities in the creek immediately after the Compensation Site is breached. As the creek enlarges in response to the increased drainage flows, the larger creek will become a more preferred route for flooding the surrounding areas of Foulholme Sand and also the Compensation Site during the flood tide because of the greater capacity and reduced friction losses associated with the enlarged creek. The creek is also likely to become a more preferred route for drainage from Foulholme Sand and also the Compensation Site during the early part of the ebb tide while Foulholme Sand is still inundated. This is likely to increase ebb flows in the creek as well.

6.2.2 The response of the flows to the enlargement of Cherry Cobb Sands Creek is one factor that makes estimation of its future size uncertain. A second factor is that the enlarged shape of the creek is also uncertain depending on whether the bed or the sides of the creek are less resistant to erosion. The final shape of the creek is thus somewhat uncertain. In this assessment a possible future shape is suggested and then tested in the hydrodynamic model to consider the flows and velocities that arise and see if these produce characteristics that seem likely to be sustainable. The final shape of the creek is likely to have a similar cross section area to that predicted but may well have a different width and depth from that predicted.

6.3 CHANGES TO CHERRY COBB SANDS CREEK

6.3.1 In Annex 32.6 Table 7 of the Environmental Assessment, an assessment of the likely erosion in Cherry Cobb Sands Creek for 90 and 110 ha Compensation Site designs tested in that Annex and Annex 32.4 was made. This table considered three points in the creek that are shown on Figure 23. These results from Annex 32.6 are repeated here in Table 10. These results show the predicted annual accretion or erosion at the three points considered.

Table 10 Predictions of sedimentation in Cherry Cobb Sands Creek (Annex 32.6)

	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 16 100 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

6.3.2 At Point 15 500 m 'upstream' of the breach, annual accretion of around 0.5 m is predicted in comparison with about 0.3 m for the baseline case. 100 m 'downstream' of the breach at Point 16 between the breach and the Cherry Cobb Sands outfall, annual erosion of around 1.3 m is predicted with a breach invert level of 1.8 mAOD as adopted for the detailed design and slightly more if a higher breach invert level is adopted. About 500 m to the south east of Stone Creek at Point 17, annual erosion of around 0.6 m is predicted with a breach invert level of 1.8 mAOD and around 0.8 m annual erosion for a breach invert of 2.0 mAOD.

6.3.3 The dimension of Cherry Cobb Sands Creek increases towards its mouth as illustrated in Table 11 which shows the width, invert level and cross section area below a top level related to the level on Foulholme Sand of the creek at Points 15, 16 and 17 and a fourth location at the southern end of the creek close to its outfall into the Humber and also shown on Figure 23. There is a large reduction in invert level downstream of Stone Creek accompanied by an increase in width and cross section area even though the level of the adjacent part of Foulholme Sand reduces along the length of the creek.

Table 11 Baseline dimensions of Cherry Cobb Sands Creek

Location	**Top level (mAOD)**	**Invert level mAOD**	**Width (m)**	**Cross section area (m^2)**
Point 15	2.06	0.26	30	24.0
Point 16	1.95	-0.16	54	60.6
Point 17	1.04	-1.52	80	114.8
Downstream	1.00	-2.15	149	147.1

6.3.4 The revised creek dimensions tested in the model are set out in Table 12. At Point 15 the invert level has been raised to represent the siltation of Cherry Cobb Sands Creek anticipated north west or upstream of the breach. At this section no change in creek width is considered.

6.3.5 Downstream of the breach erosion and enlargement of the creek is expected. At Point 16 between the breach and Stone Creek, the width of the creek is increased on the west (Foulholme Sand) side by 20 m and its invert level is reduced by 1.8 m. This section has the largest percentage change in creek cross section area and the largest area below the relatively high local level of Foulholme Sand. Enlargement is expected on the west side because the dominant ebb flow from the Compensation Site is directed towards this bank of the creek and so expected to erode it in preference to the east bank.

6.3.6 Downstream of Stone Creek at Point 17 no change in the width of Cherry Cobb Sands creek is anticipated, but the invert level is assumed to drop by around 0.4 m. No change is assumed at the downstram end of the creek. The invert level along the creek has been set to provide a slight fall between the breach and the low water channel.

6.3.7 The existing shape of Cherry Cobb Sands Creek at the four points shown on Figure 23 is compared on Figure 24 with the anticipated changes in the creek as set out in Table 12. The chainage scale is arbitrary, these figures indicate to a consistent scale except for the very wide downstream section how the creek currently increases in size and is expected to do so after the Compensation Site is operational.

Table 12 Predicted future dimensions of Cherry Cobb Sands Creek

Location	Top level (mAOD)	Invert level mAOD	Width (m)	Cross section area (m^2)
Point 15	2.06	0.88	30	17.9
Point 16	1.95	-1.91	74	180.5
Point 17	1.04	-1.91	80	153.3
Downstream	1.00	-2.15	149	147.1

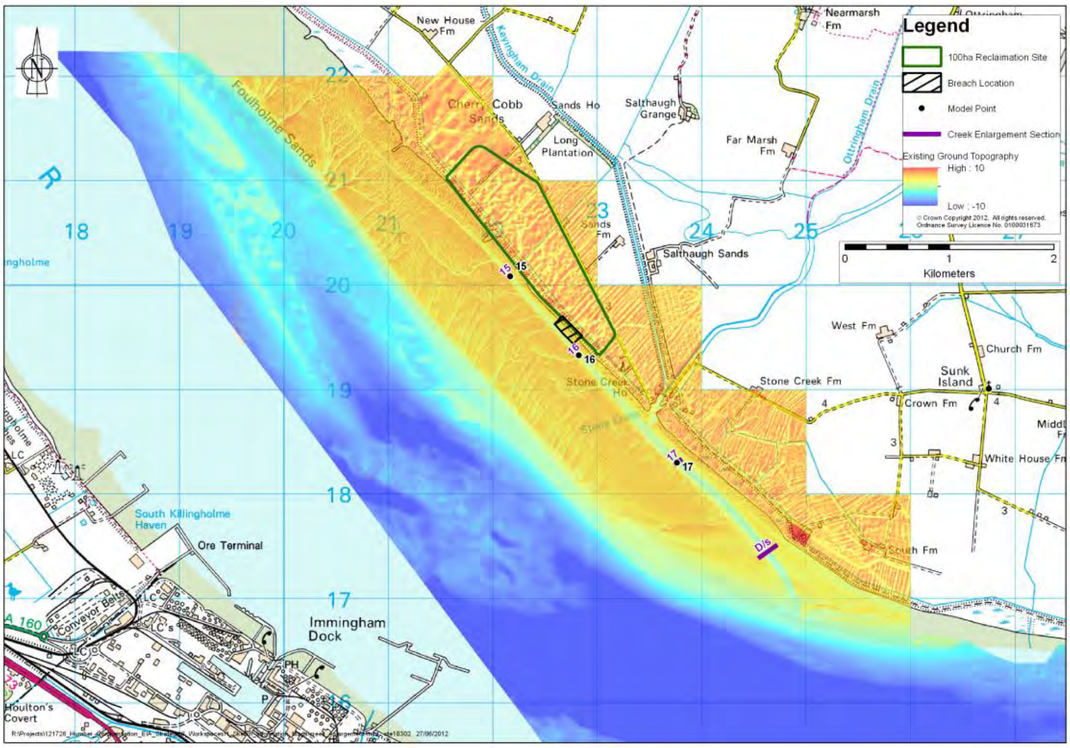
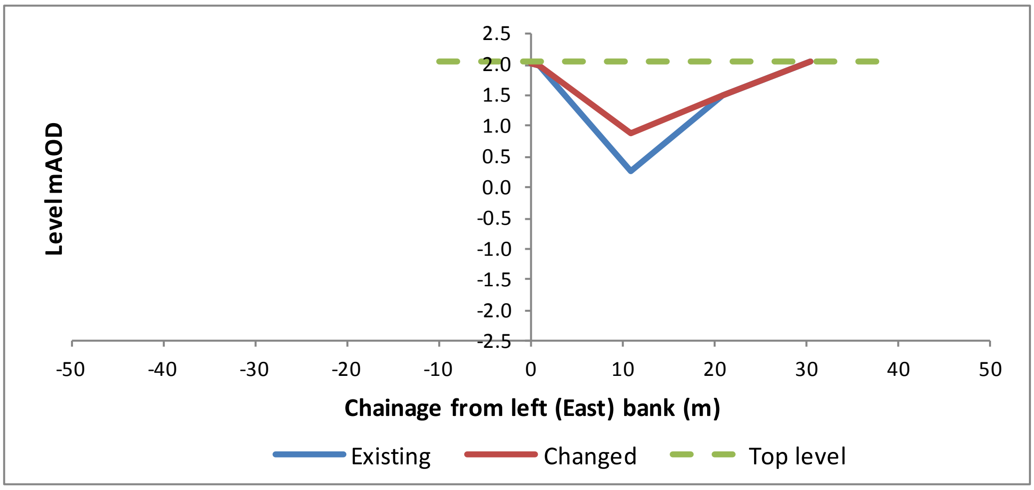
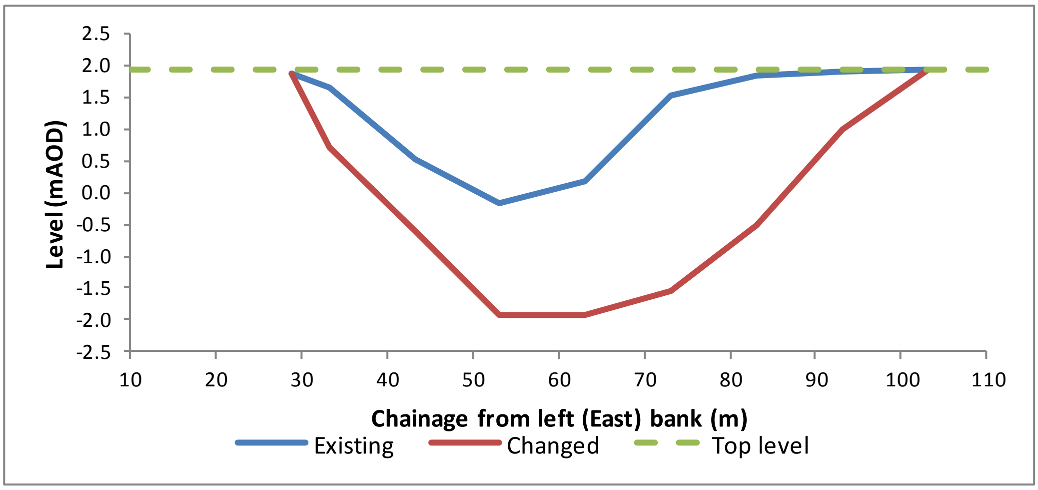


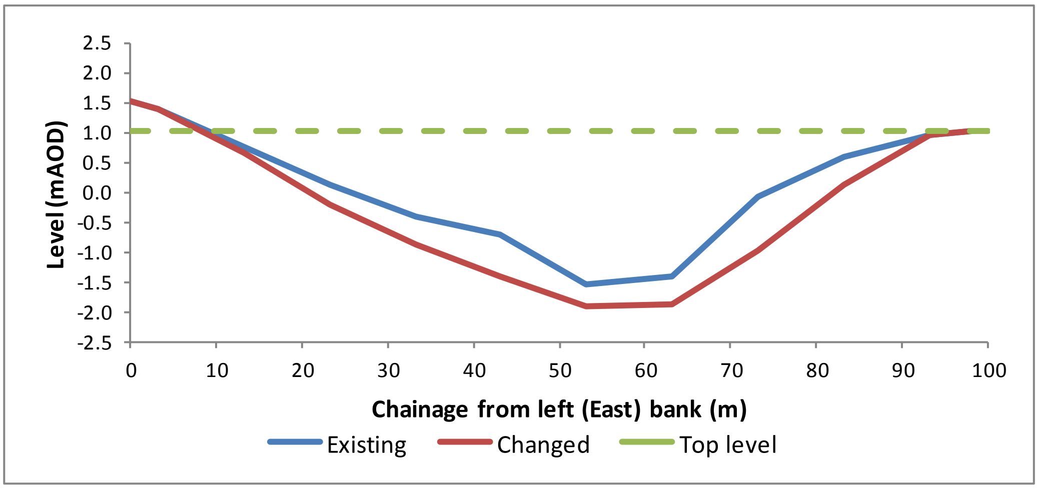
Figure 23 Assessment points within Cherry Cobb Sands Creek



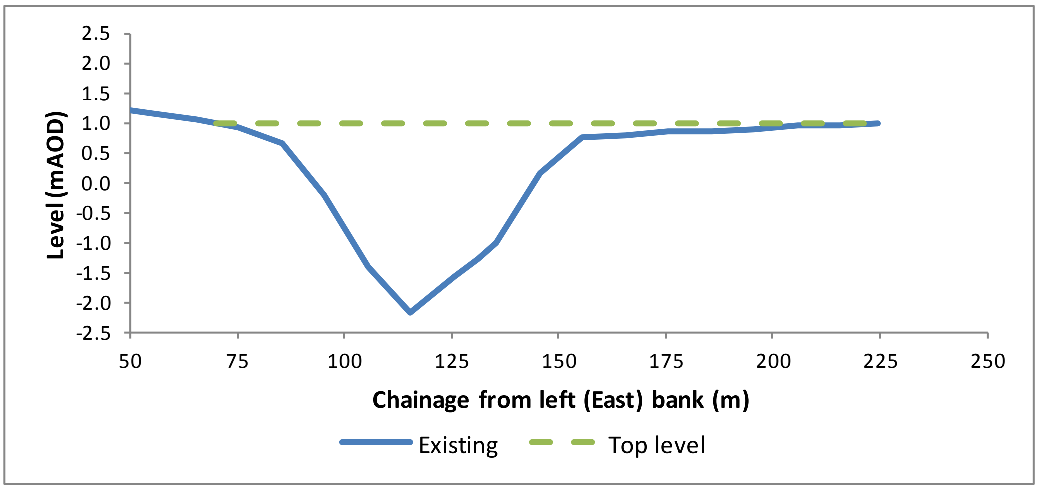
Section 15



Section 16



Section 17



D/s section (note change of chainage scale)

Figure 24 Anticipated changes in Cherry Cobb Sands Creek due to Compensation Site

6.4 Changes to Tides and Velocities in Cherry Cobb Sands Creek

6.4.1 The effects of the changes to the dimensions of Cherry Cobb Sands Creek on tide levels and velocities are shown for Points 15, 16 and 17 in Figure 25. This figure shows existing conditions, the immediate effect of the introduction of the Compensation Site before Cherry Cobb Sands Creek has had time to respond and finally the anticipated conditions after the creek has responded to the changes in flow associated with the discharge from the Compensation Site.

6.4.2 In preparing these figures, model results across the whole cross section of the creek have been used to calculate flows and average velocities using the available flow area in the creek. When the tide is above the banks of the creek, the flow area is based on the same creek dimensions and does not take account of flows across the intertidal areas on either side of the creek.

6.4.3 At Point 15 north west of the breach, the operation of the Compensation Site reduces velocities. The majority of flow in the creek is diverted into the site on the flood tide, and on the ebb tide, the existing drainage is impeded by the outflow through the breach. The ebb tide level drops more slowly as a result of this impedance. The anticipated reduction in cross section at this site combined with the anticipated increase in cross section south east of the breach restores velocities and tide levels in this part of the creek to values similar to those found before the Compensation Site was commissioned.

6.4.4 Between the breach and Stone Creek at Point 16, the largest changes in velocity are anticipated as a result of the operation of the Compensation Site as illustrated on Figure 25. At this Point, the velocities increase markedly on the ebb tide before the creek starts to change and also the fall of the ebb tide is delayed by the larger flow. With the enlargement of the creek, velocities on the ebb tide return to values similar to those experienced in the existing condition, while on the flood tide there remains an increase in velocity as the flooding tide flows up this enlarged channel. It is important to note that flows in this creek are considerably larger than either the existing flows or even after the Compensation Site has been breached. Flood tide flows are predicted to be around three times greater than existing, while ebb tide flows are twice those predicted immediately after the site is commissioned.

6.4.5 At Point 16 the enlargement of the creek prevents the delay in the fall of the ebb tide predicted immediately after the site is commissioned. The lower invert level in the creek leads to much lower water levels in this part of the creek, though there remains some ebb flow in the creek until the tide reverses on the incoming tide.

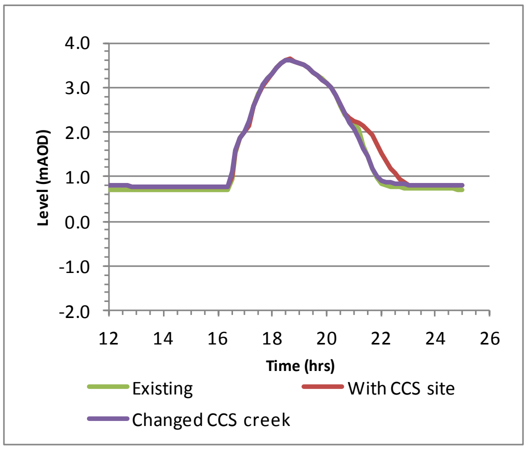
6.4.6 At Point 17, the changes arising from the introduction of the Compensation Site are less pronounced that those upstream of Stone Creek. The enlargement of the creek has the effect of increasing flows on the flood tide with notably larger velocities at this site as indicated on Figure 25. On the ebb tide the assumed enlargement of the creek helps ameliorate the increase in velocity resulting from drainage of the Compensation Site, but does not fully compensate for this change.

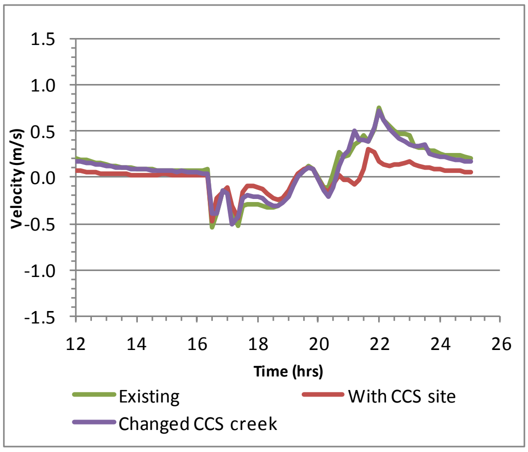
6.4.7 Plots of shear stress for the existing creek and for the changed creek are shown in Figure 26 for Points 16 and 17. Point 15 is not shown because the creek dried out for part of the ebb tide so the comparison is not valid. The maximum shear stress at both sites now occurs on the flood tide and is associated with tide returning up the larger creek. During the ebb tide, shear stresses with the Compensation Site in operation and the enlarged creek are very similar.

6.4.8 Assessment of the likely erosion indicates that with the changes in creek size at Points 15 and 16, as a result of the Compensation Site there may be some further changes to enlarge the creek at Point 16 and reduce it at Point 15, but the changes are smaller as rates having initially changed by an order of magnitude, with the creek dimensions changed, they are now within a factor of three. Further enlargement at Point 17 seems likely because of the high flood flows which keep erosion potential high. These indicative erosion rates are compared for the three sites in Table 13.

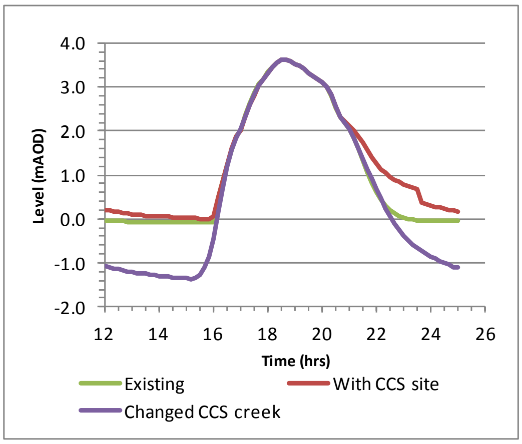
Table 13 Comparison of indicative erosion (no units) at Points 15, 16 and 17

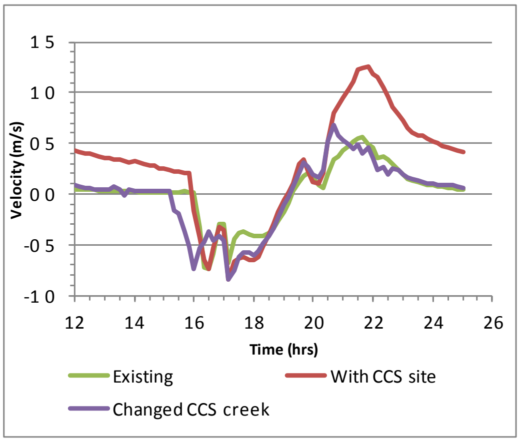
Location	Existing case	With CCS site	Changed CCS Creek
Point 15	0.12	0.01	0.04
Point 16	0.07	0.68	0.18
Point 17	0.17	0.42	0.39



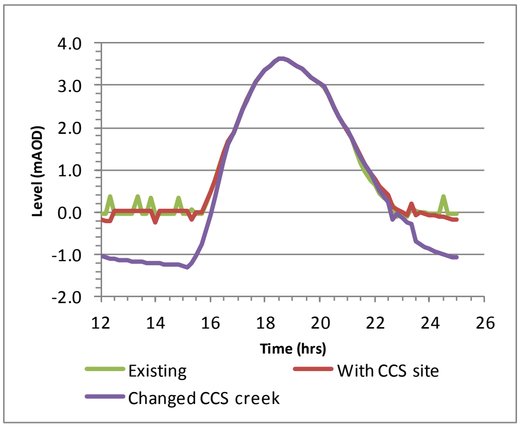


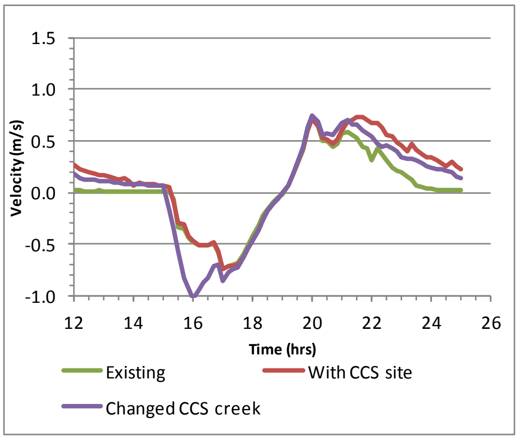
Point 15 tide levels and velocities





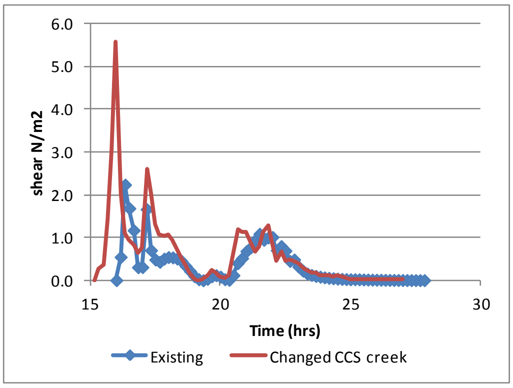
Point 16 tide levels and velocities

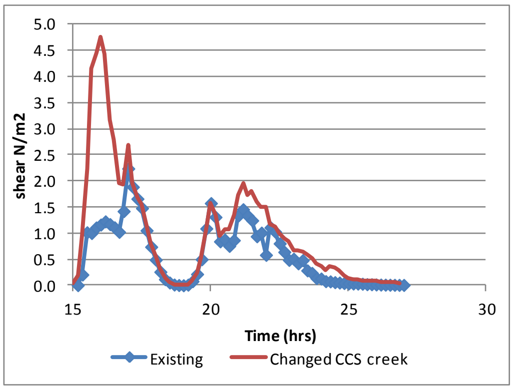




Point 17 tide levels and velocities

Figure 25 Effects on tide levels and velocities in Cherry Cobb Sands Creek





Point 16 Point 17

Figure 26 Predicted shear stress in Cherry Cobb Sands Creek

7 *FUTURE DESIGN DEVELOPMENT*

7.1 *MANAGEMENT INTERVENTIONS TO ENHANCE MUDFLAT DEVELOPMENT*

Introduction

7.1.1 One of the key issues in the development of the Cherry Cobb Sands managed realignment site is the siltation that is expected to occur. Once levels exceed a critical threshold, saltmarsh is likely to develop within the space of a few years. This is the experience gained from the monitoring of the nearby Paull Holme Strays managed realignment site during its first five years of operation (Ref 2).

7.1.2 With this background, management measures that can delay or prevent the development of saltmarsh have been considered to identify methods of providing the required sustainable mudflat habitat. Natural England has expressed a clear preference that 'natural methods' be employed to prevent saltmarsh growth with minimal need for external management intervention in the natural evolution of the intertidal habitat on the site.

7.1.3 A range of management methods have been considered including those that modify the initial design to limit saltmarsh growth along with those that would require significant subsequent management intervention that are less favoured by Natural England.

7.1.4 The methods identified have been drawn from a variety of sources that either evaluate methods of eradicating invasive saltmarsh species such as *Spartina anglica* or *phragmites* or by identifying the opposites of those conditions and methods that are favourable for saltmarsh growth. The methods identified fall into four categories:

- Physical modification of site characteristics to reduce the likelihood of saltmarsh growth;
- Physical management intervention in the site to control saltmarsh growth;
- Use of chemicals to eradicate saltmarsh; and
- Use of biological controls on saltmarsh growth.

7.1.5 The first group of methods modify site design to make conditions less favourable for saltmarsh growth and would generally be those favoured by Natural England. The remaining three methods use management interventions to modify the natural evolution of the site to limit or prevent saltmarsh growth. These latter methods are not favoured by Natural England.

Physical modification of site characteristics

7.1.6 The approaches that physically modify the conditions on site to limit saltmarsh growth include:

- Changing the elevation of the site so that it is inundated more frequently as saltmarsh plants will not survive if flooded too frequently;

- Changing the slope of the site to limit site drainage as standing water prevents plants establishing;
- Increasing the site exposure to waves or tidal prism as strong currents or high wave energy prevent plants establishing;
- Change the pattern of inundation to reduce accretion rates;
- Use of geotextiles can also prevent plants establishing, but as it would also prevent birds feeding in the mudflat it has been discounted.

7.1.7 The first method of modifying ground levels has been adopted, along with the third method of attempting to increase exposure to strong currents. However, siltation raises levels as illustrated in sections 3 to 6 and so this approach has a limited life in an area subject to accretion. One other by-product of accretion within a managed realignment site is that accretion reduces tidal prism and so over time tidal currents will reduce as the volume of water required to fill the site each tide also reduces.

7.1.8 This leaves three remaining methods that have not been considered so far at Cherry Cobb Sands. These are to limit site drainage and so encourage standing water to remain on the site, change the inundation pattern to reduce inundation or to increase the exposure to strong waves.

7.1.9 The most favoured method of increasing the exposure of a site to strong waves is to remove the whole of the original sea defence bank rather than making a short breach as proposed at Cherry Cobb Sands. This approach was adopted at the Chowderness managed realignment site in the Humber and it has been reported anecdotally that this has slowed the rate of saltmarsh establishment at this site. The removal of the original flood embankment at Chowderness would have been particularly effective in promoting wave exposure as that site is exposed to a long westerly fetch across the upper Humber Estuary towards Whitton Ness.

7.1.10 At the Welwick managed realignment site the original flood defence was removed, but the fronting saltmarsh was left in place except at two breach locations where it was removed. Unfortunately the saltmarsh is at a high level so will usually prevent significant wave energy passing over and into the site. The results of monitoring at this site are not publically available but there is no anecdotal indication that saltmarsh development has been retarded at this site.

7.1.11 The conditions at Cherry Cobb Sands are somewhat similar to those at Welwick in that a bank of saltmarsh at high level separates the managed realignment site from the mudflats further offshore. A potentially important difference is that the Welwick site is exposed to a long southerly fetch across Spurn Bight to Tetney Haven while the exposure at Cherry Cobb Sands is limited to a relatively short fetch across the estuary to Immingham. The habitat damage caused by the removal of a significant area of fronting saltmarsh at Cherry Cobb Sands and the limited fetch that could potentially be opened up by so doing makes removal of all the existing flood defence and fronting saltmarsh less likely to be effective at this site.

7.1.12 The remaining untried methods are to limit site drainage and make the site less attractive for saltmarsh plants to establish and to limit accretion rates to prolong the period before ground levels rise to levels that promote saltmarsh growth. Both these methods might be implemented through a Regulated Tidal Exchange (RTE) approach that limits the depth of inundation each tide and hence the rate of accretion. The slope of such a site could also be made as flat as possible to delay drainage and so encourage areas of standing water.

7.1.13 This approach should be further investigated to identify how much the rate of accretion can be reduced, noting that apart from the immediate locations of inlets and outfalls, erosion of previously deposited sediment is unlikely. Limiting site slopes to limit drainage could also be attempted both within an open site and within a RTE area, though it would be important to ensure that anoxic conditions did not develop. Evidence of the likely effectiveness of poor drainage on saltmarsh establishment and the ecological value of mudflat that evolves in such circumstances should also be sought to understand the habitat benefits of delaying saltmarsh growth, given that accretion of ground levels is likely to be an ongoing process however the site is managed because of the sediment concentration in the estuary waters.

Physical management interventions

7.1.14 Physical management intervention in a site once it is established to limit or prevent saltmarsh growth is limited to:

- ploughing,
- physically removing the plants or
- mowing or cutting down the saltmarsh.

7.1.15 Physical removal of plants is unlikely to be practical on a large site and cutting will not affect the roots which will remain in the soil and may prevent the growth of the benthic invertebrate fauna that is an important component of the habitat value of mudflat. Ploughing would turn in the plants and roots but also greatly modify the habitat for benthic invertebrates so limit their diversity. Ploughing or any physical method of control would need to be regularly repeated as the saltmarsh seeds would still be present in the water column and able to germinate if conditions are otherwise favourable.

Chemical and biological management interventions

7.1.16 Chemical control using herbicides or biological control of saltmarsh have been discounted as being inappropriate adjacent to a Natura 2000 site.

7.2 FURTHER DETAILED DESIGN OF COMPENSATION SITE

7.2.1 The detailed design of the Cherry Cobb Sands Compensation Site discussed in this report has shown that accretion of sediment within the site is a major factor that is likely to significantly reduce the area of mudflat present within the site during the first decade after breaching. The rates of accretion that might be experienced have been calibrated against experience at the nearby Paull Holme Strays.

7.2.2 The comparison with Paul Holme Strays has identified that uncertainties in the assumptions on the amount of sediment available to cause accretion within the site would have a significant effect on the rate at which mudflat rises to levels at which conversion to saltmarsh is likely.

7.2.3 The results reported here suggest that an initial area of over 90 ha at Cherry Cobb Sands below a level of 2.5 mAOD is likely to be approximately halved over a five year period.

7.2.4 Alternative approaches to developing the site are therefore being considered to ensure mudflat habitats persist for longer. These approaches will consider partitioning the site into several compartments that could be shallow flooded with tidal water through the existing flood banks and then drained back through the banks or into the main part of the managed realignment site.

7.2.5 As indicated in section 7.1, development of one or more Regulated Tidal Exchange areas within the Cherry Cobb Sands site is being considered as a potential way forward. Likely siltation rates within such an area will be considered along with appropriate additional methods of managing the site to limit or prevent saltmarsh growth. These include limiting ground slope within the site to limit drainage and so restrict saltmarsh growth but at the same time ensuring the mudflat that is generated is able to provide suitable ecological function as a mudflat.

8 REFERENCES

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