# 32 HYDRODYNAMIC AND SEDIMENTARY REGIME

## 32.1 *INTRODUCTION*

32.1.1 This chapter addresses the issue associated with the hydrodynamics and sedimentary regime and details the assessment of potential changes on these aspects which are specific to the Compensation Site. Any changes to the hydrodynamics and sedimentary regime of the Humber Estuary as a result of the AMEP development including distant effects of the development of the Compensation Site as an integral part of the whole Project are covered in *Chapter 8*. *Chapter 8* also includes an assessment of the cumulative and in combination effects of the AMEP development and other developments in the Humber.

32.1.2 Where changes have been predicted to the hydrodynamic and sedimentary regime, this may have an impact on other environmental receptors such as water quality, benthic ecology, fisheries and nature conservation. The significance of these impacts is described in their respective chapters rather than in this chapter.

32.1.3 Within the Compensation Site, the only part of the site that may affect the hydrodynamic and sedimentary regime of the Humber Estuary is the proposed managed realignment at Cherry Cobb Sands. The Old Little Humber Farm site being some distance inland will have no effect on the Humber Estuary and is not considered further in this chapter. Any sedimentation issues arising from the proposed development at Old Little Humber Farm that might affect local watercourses are covered in *Chapter 33* water quality and sediment quality or *Chapter 36* drainage and flood risk.

## 32.2 *LEGISLATION, POLICY AND GUIDANCE*

32.2.1 Legislation, policy and guidance on hydrodynamics and sedimentary regime common to both the AMEP and the Compensation Site are covered in *Chapter 8*. Relevant plans and policies contained within the ERYC Local Plan which are specific to the Compensation Site are summarised below.

***Local Plan Policy***

*Joint Structure Plan for Kingston upon Hull and the East Riding Of Yorkshire*

32.2.2 Policy NAT6 from the Joint Structure Plan for Kingston upon Hull and the East Riding of Yorkshire (Hull City Council & East Riding of Yorkshire Council, 2005) states that:

*'Development in coastal areas should in general, be focused on existing settlements in accordance with the development strategy. Any new development proposed at an undeveloped coastal location, or roll back of existing development, should avoid:*

*(i) the risk from flooding, erosion and landslip, within the lifetime of a building;*

*(ii) areas subject to managed realignment or monitor/review of coastal defence management measures;*

*(iii) a requirement to construct new or to extend or enhance existing coastal protection or flood defences;*

*(iv) significant interference with natural coastal or estuarine processes; and*

*(v) increasing the risk of flooding and coastal erosion, or affecting accretion and deposition of eroded materials on sites elsewhere.'*

*ERYC Holderness District Wide Local Plan*

32.2.3 Policy Env5 of the Holderness District Wide Local Plan (ERYC 1999) states that:
*'The Council will only approve development proposals in the Holderness coastal zone which are not likely during the life expectancy of the development to:*

*(i) lead to a requirement to construct new or to extend or enhance existing coastal protection or flood defences;*

*(ii) interfere significantly with natural coastal or estuarine processes;*

*(iii) increase the risk of flooding and coastal erosion on site or elsewhere;*

*(iv) be affected by the risk of coastal erosion within the developments estimated lifespan;*

*(v) conflict with nature conservation policies of this plan;*

*(vi) preclude reasonably practical options to conserve or enhance important coastal habitats by managed retreat or soft engineering techniques.'*

## *32.3 ASSESSMENT METHODOLOGY AND CRITERIA*

### *Overview*

32.3.1 The methodology for the assessment of impacts of the Compensation Site hydrodynamics and sedimentary regime are consistent with that used in the assessment of the AMEP, as detailed in *Chapter 8*.

### *Modelling and Model Calibration*

32.3.2 A detailed model has been developed to predict flows around Cherry Cobb Sands. This model is driven by boundary conditions derived from the main Humber hydraulic model described in *Annex 8.1*. The set up and calibration of the detailed model of the north bank is described in *Annex 32.2*. This model includes the whole of the Cherry Cobb Sands site, and adjacent foreshore of Foul Holme Sand including the whole length of the drainage creek that fronts Cherry Cobb Sands and receives the land drainage flows from Stone Creek.

### *Construction Phase*

32.3.3 The construction of the majority of the Cherry Cobb Sands site will not have any impacts on the hydrodynamics and sedimentary regime of the estuary since the new embankments will be built behind the existing flood embankments which will remain intact. In the final stages of construction there will be impacts as the foreshore is prepared. The Operational Phase will start as soon as the existing embankment is breached.

### *Operational Phase*

32.3.4 The detailed flow model of Cherry Cobb Sands and the surrounding foreshore has been used to understand the flow patterns and sedimentary regime within Cherry Cobb Sands and over the surrounding foreshore. This model also considers how flows within the local drainage creek and over Foul Holme Sand will change as a result of the flooding and drainage of Cherry Cobb Sands on each tide that is high enough to inundate the site.

*Sensitive Receptors*

32.3.5 There are a number of receptors that may be affected by changes to the hydrodynamic and sedimentary regime during the operational phase of the scheme. These include land drainage and environmental receptors such as intertidal mudflat and saltmarsh habitats.

32.3.6 This Chapter follows the approach set out in *Chapter 8* by describing and where possible quantifying any predicted changes to the hydrodynamic and sedimentary regime of the Humber Estuary arising from the Compensation Site. As these are changes to processes rather than impacts on receptors it is not appropriate to assign significance levels. The implications of the predicted changes to the hydrodynamic and sedimentary regime on various environmental parameters are considered in the relevant chapters, specifically *Chapter 33* water quality and sediment quality, *Chapter 34* aquatic ecology and *Chapter 36* drainage and flood risk.

## *32.4 CONSULTATION*

32.4.1 Consultation on the effects of Cherry Cobb Sands on the hydrodynamic and sedimentary regime has been held as part of the formal statutory and public consultation. The consultee comments received and responses provided relevant to this Chapter are included in *Annex 2.2.* **Error! Reference source not found.**

32.4.2 In addition to the general consultation noted above, meetings with Natural England, RSPB and HINCA (Humber Industry and Nature Conservation Association) have been held to explain and discuss the hydrodynamic and sedimentary issues associated with the design of the Cherry Cobb Sands site.

## *32.5 BASELINE*

***The foreshore at Cherry Cobb Sands***

32.5.1 Cherry Cobb Sands is located to the north of the Stone Creek drainage outfalls. The foreshore bathymetry and the presence of a shore parallel foreshore creek separating the flood embankments from Foul Holme Sand called Cherry Cobb Sands Creek in this assessment is illustrated in *Figure 32.1**Error! Reference source not found.***.

32.5.2 The present foreshore of Cherry Cobb Sands including Foul Holme Sand and Cherry Cobb Sands Creek is described in *Section 2 of Annex*

*32.1*. The tidal flows in this part of the Humber contain high concentrations of suspended sediment as described in *Section 2 of Annex 8.1*. The sediment in suspension is prevented from settling onto the estuary foreshore in areas of high tidal currents or at times when wind and waves are present, but can settle and lead to rapid accretion in areas where tidal currents are low and at times when wave activity is absent.

32.5.3 The saltmarsh survey of the foreshore adjacent to Cherry Cobb Sands found that the entire foreshore between the existing flood embankment and Cherry Cobb Sands Creek was an area of upper and middle saltmarsh (*Annex 34.1*). On Foul Holme Sand some lower saltmarsh plants were found. Natural England, in their condition assessment of this frontage in March 2010, reported that *'Saltmarsh is undergoing a period of expansion and encroachment downshore'* (Natural England, 2010).

32.5.4 The levels on the top of Foul Holme Sands reported from the 2007 LiDAR survey were typically in the range 1.8 – 2.3 mAOD which is generally slightly above 1.9 mAOD, the level of Mean High Water Neap (MHWN) tides at Immingham. These levels are at the lower end of those where colonisation by pioneer saltmarsh might be expected.

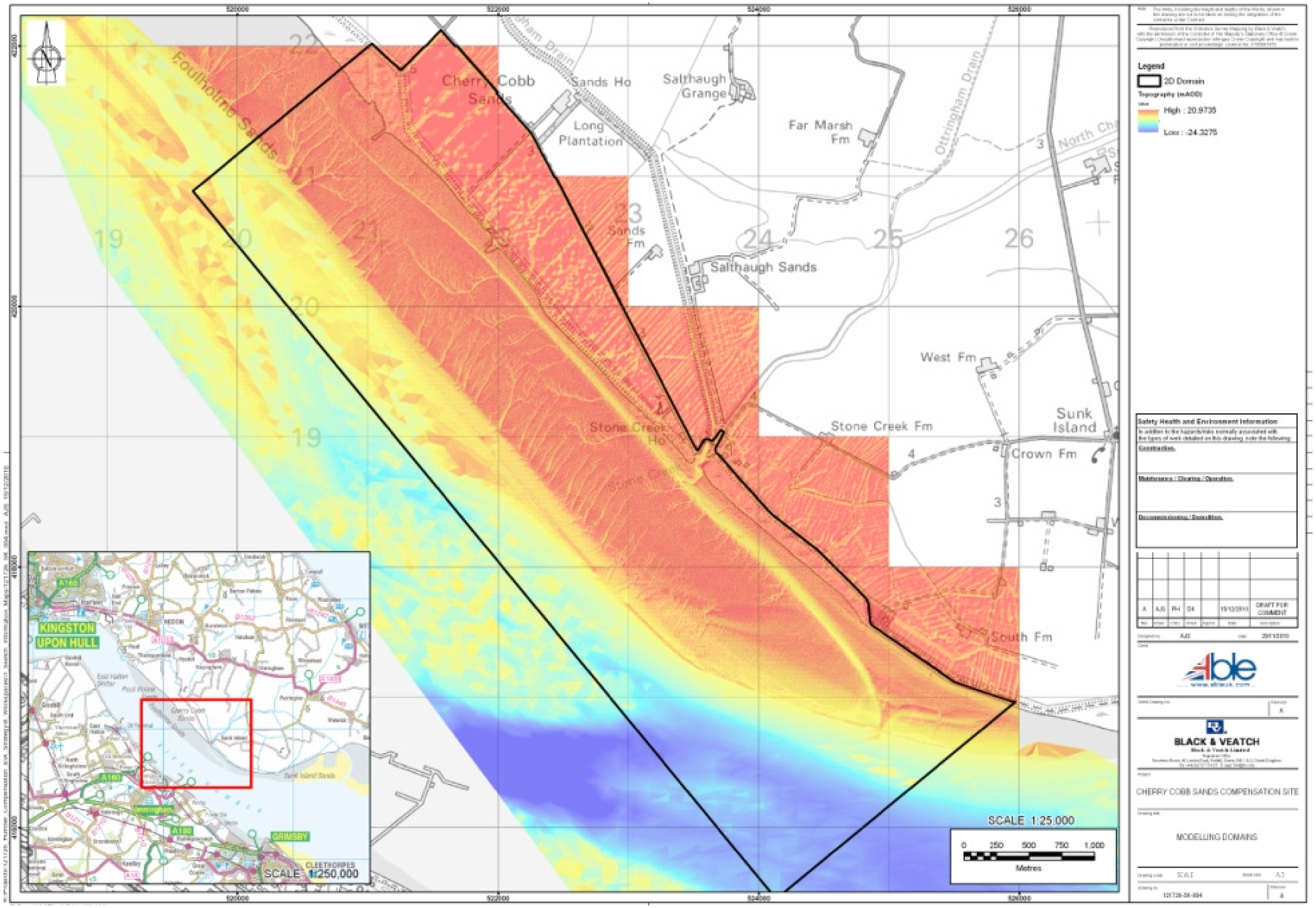


*Figure 32.1 Foreshore topography and model boundaries at Cherry Cobb Sands*

### *The evolution of the Cherry Cobb Sands foreshore*

32.5.5 The present line of the flood embankments at Cherry Cobb Sands was established between 1770 and 1800 and the Stone Creek drainage outfalls were created in the first decade of the 19th century (Shepherd 1966). The changes to Foul Holme Sand and Cherry Cobb Sands Creek over the past 150 years have been reviewed using old Ordnance Survey maps, navigation charts and aerial photographs in *Annex 32.1*. These sources indicate that during the later part of the 19th Century and early 20th Century Foul Holme Sand was a spit separated from the Cherry Cobb Sands foreshore by a channel at low tide. The foreshore of Cherry Cobb Sands at that time was 100 to 400 m wide.

32.5.6 Sometime in the first half of the 20th century the earlier spit merged with the north bank and caused a great increase in foreshore width. This happened after the mapping of 1923 but before the first aerial photographs of the foreshore in 1946. Since then a foreshore parallel creek has been noted on the majority of aerial photographs. These photographs sometimes also show a creek crossing Foul Holme Sand that appears to have moved north along the frontage between 1946 and 1976. In the 1976 aerial photograph and in some large scale mapping from that era the creek across the sandbank was located offshore of the proposed Cherry Cobb Sands breach.

32.5.7 The historic information provided in *Annex 32.1* suggests that the present creek running a short distance offshore of the existing flood embankment may be a relic of the much larger channel present in the 19th and early 20th century. The extension of Cherry Cobb Sands Creek to its current outfall location is a more recent feature associated with the southward and eastward movement of Foul Holme Sands since the 1920s.

### *Siltation at Stone Creek*

32.5.8 Stone Creek is an important tributary of Cherry Cobb Sands Creek which receives land drainage flows from four major land drains, as discussed in *Chapter 36*. The shape of Stone Creek as a small inlet in the existing flood embankment makes it an area where siltation is likely to happen in the absence of special factors because the shape of the inlet shelters it from wave activity and it is in a zone of low tidal currents (*Annex 32.4 Sections 3.5* and *4.5* and *Annex 32.6 Sections 2.5* and *3.4*). The special factor that limits siltation within Stone Creek is the substantial land drainage flow that enters this creek.

32.5.9 The land drainage flows increase ebb tidal currents in Stone Creek especially in winter when run off is greater, and particularly during times of fluvial flood. High ebb tidal currents scour out the silt that accumulates during summer months when land drainage flows are low and of insufficient power to prevent silt accumulating in the creek. This leads to a dynamic equilibrium in Stone Creek with a seasonal cycle of accretion and erosion in response to the seasonal pattern of land drainage flows. There are longer term variations in silt levels in response to dry years when silt levels build up more than normal or wet years when silt levels are lower than normal.

32.5.10 Unfortunately silt takes time to respond to changes in land drainage flow, so a flood that occurs after a long period of low flows is likely to cause water to back up in the drain because of the smaller than normal drainage channel through Stone Creek.

## *32.6 IMPACTS*

32.6.1 This section describes the predicted changes to the hydrodynamic and sedimentary regime as a result of the construction and operation of the managed realignment at Cherry Cobb Sands.

### *Construction Phase*

32.6.2 The Cherry Cobb Sands site will start to have an effect on the hydrodynamic and sedimentary regime in the final stage of construction when saltmarsh fronting the breach site is removed down to the level of the breach (2.0 ± 0.2 mAOD). This will be done to allow tidal waters to reach the existing flood embankments on the majority of tides. The effects of the removal of the saltmarsh on the ecology are considered in *Chapter 34*.

32.6.3 The removal of the saltmarsh fronting the breach site will create an area where foreshore levels are lower that will temporarily experience rapid accretion.

32.6.4 The existing flood embankments will be removed from the 250 m wide breach area during a week when the tides reduce from springs to neaps. The breach will be completed on a suitable neap tide. As the tides start to increase in range again, the site will be flooded on the first tide after the breach is completed that the high water level exceeds the level of the breach. On the first one or two tides, low areas within the site will fill with saline tidal waters. Once this initial filling of the site is complete, water will enter and leave the Cherry Cobb Sands site through the breach and the construction phase will be complete and the operational phase will have started. The effects of the removal of a section of the flood embankment are considered within the Operational Phase.

### *Operational Phase*

*Initial changes outside the Cherry Cobb Sands site*

32.6.5 Once the flood embankment is breached to allow tidal inundation of Cherry Cobb Sands, the flows across Foul Holme Sand and in Cherry Cobb Sands Creek will change. The initial changes are described in *Annexes 32.4* and *32.6*. *Annex 32.4* models the changes associated with a 90 ha intertidal site, while *Annex 32.6* models the effects associated with a 110 ha intertidal site. The effects predicted for these two site sizes are very similar and so the effects arising from the 100 ha Cherry Cobb Sands site that are summarised below have been determined by interpolation between the model results for 90 and 110 ha.

32.6.6 The initial changes to water levels are expected to happen within the first two weeks of operation. These are:

- High tide levels over the foreshore fronting Cherry Cobb Sands and in Stone Creek are predicted to change by no more than 0.02 m. This is within the accuracy of the modelling.
- An increase in low tide levels within Stone Creek is predicted of around 0.1 m above the existing low water level of 0.25 mAOD.
- A reduction by 10 to 30 minutes in the time when tide levels in Stone Creek are below 0.5 mAOD is predicted from the existing average of around 6 hours 40 minutes each tide.

32.6.7 The initial changes to velocities are expected to happen within the first two weeks of operation. These are:

- Predicted maximum velocities of 2.4 to 2.6 m/s through the breach channel as the site floods and drains.
- A predicted maximum ebb velocity on large range tides of 1.3 to 1.5 m/s (an increase of 0.8 to 0.9 m/s) in Cherry Cobb Sands Creek between the breach and the Stone Creek confluence as this creek receives ebb tide flow from the Cherry Cobb Sands site.

- A predicted maximum velocity of 0.37 to 0.41 m/s (an increase of 0.12 to 0.16 m/s) across Foul Holme Sand opposite the breach in the early ebb phase of the larger range tides, while Foul Holme Sand is still inundated.

32.6.8 There are unlikely to be initial changes to siltation happening within the first fortnight of operation but over the first months of operation, the processes of erosion and accretion will start to take effect. These early changes are:

- The velocities in the breach channel will start to form a drainage creek in areas of the breach channel that have not been previously consolidated by the weight of the flood embankment.

- The predicted increased velocities in Cherry Cobb Sands Creek will increase ebb tide suspended sediment concentrations in this creek as these velocities start to enlarge the creek by eroding the creek sides and bed.

- There is a risk that some of the increase in ebb tide suspended sediment concentration in Cherry Cobb Sands Creek finds its way into Stone Creek on the flood tide and leads to increased siltation within Stone Creek.

32.6.9 The predicted increase in velocities across Foul Holme Sand carries with it a possibility of increased erosion of the top of this sandbank. The sediment process analyses in *Annexes 32.4* and *32.6* suggest that because maximum baseline velocities across Foul Holme Sand are a maximum of 0.4 m/s in the affected area, there is no change in the amount of erosion predicted on Foul Holme Sand as a result of the Cherry Cobb Sands site. The present dynamic equilibrium of accretion and erosion on this sandbank may tip slightly towards erosion during periods of wave attack so that the risk that the top of the sandbank will erode and eventually form a creek through Foul Holme Sand as happened in the past will remain small but may marginally increase.

32.6.10 Other rapid changes are:

- Any saltmarsh remaining immediately in front of the breach will start to be eroded by these high velocity flows.

*Short term changes outside the Cherry Cobb Sands site*

32.6.11 Short term changes 1 to 5 years after the Cherry Cobb Sands site is breached are more uncertain than the initial changes and depend on the outworking of the early changes in siltation. These short term effects will also be affected by the tides, surges, floods and storms that occur in this period. The principal short term changes are considered in *Annexes 32.4* and *32.6*.

32.6.12 The changes in water levels and velocities over the first five years are driven by the rapid changes in siltation discussed above:

- High tide levels over the foreshore fronting Cherry Cobb Sands and in Stone Creek are not expected to increase over the first five years.

- The rapid predicted increase of 0.1 m in low tide levels within Stone Creek is expected to reverse over the first five years as the predicted enlargement of Cherry Cobb Sands Creek reduces low water levels within this creek which in turn will lead to lower low tide levels within Stone Creek.

- The duration of the period when water level within Stone Creek are below 0.5 m AOD is expected to slightly increase over the first five years in response to the enlargement of Cherry Cobb Sands Creek. This is expected to substantially reverse the initial reduction in low water period.

32.6.13 There will be changes in the first five years to velocities, but these are harder to predict than the changes to water level. The majority of the initial changes in velocity will persist through the first five years. However, the largest changes in velocity are likely to diminish as the foreshore sediments erode or accrete in response to the initial changes and reduce their effect.

32.6.14 Over the first five years, many of the early siltation effects are expected to mature and rates of change are expected to become slower than at first. The principle changes anticipated in sedimentary regime over the first five years are:

- A creek forms through the breach channel. This creek will take time to erode through the consolidated sediments beneath the flood embankment that was removed, but is expected to be functioning within five years of breaching. This creek will connect the excavated area within the Cherry Cobb Sands site with Cherry Cobb Sands Creek.

- The enlargement of Cherry Cobb Sands Creek downstream of the breach site is expected to be substantially complete within the first five years and the dimensions of this creek are expected to be fairly stable.

- North of the breach, Cherry Cobb Sands Creek is expected to have reduced in size in response to the lower flows in this part of the creek.

- The southernmost part of Cherry Cobb Sands Creek is expected to continue to be dynamic. There may have been some change in the location of the outfall into the Humber or the channel form may have altered. Many of these changes might have happened naturally and it will be very difficult to separate such natural changes from any effects arising from the managed realignment at Cherry Cobb Sands.

- The siltation pattern within Stone Creek is likely to have returned to its baseline pattern of seasonal and annual changes once the new dimensions of Cherry Cobb Sands Creek have stabilised.

- Foul Holme Sand will have continued to evolve in response to tides and waves. Much of this response will be independent of the presence of the Cherry Cobb Sands site and so its influence will be difficult to separate from these natural effects.

*Long term changes outside the Cherry Cobb Sands site*

32.6.15 Predicting changes over periods beyond the first five years on the foreshore outside Cherry Cobb Sands is very uncertain. The effects of climate change and the lunar nodal tidal cycle which modulates tidal forces over an 18.6 year cycle are likely to be the main drivers for change over this foreshore. There is no evidence available to suggest that the changes predicted above have the ability to change the form and function of the Humber Estuary as a whole.

*Initial changes inside the Cherry Cobb Sands site*

32.6.16 The land at Cherry Cobb Sands will be inundated once the site is breached and respond directly to the tidal conditions in the estuary outside. The changes this will cause are predicted in *Annexes 32. 4* and *32.6*. Further more detailed studies of the evolution of the managed realignment at Cherry Cobb Sands are planned. These will, in consultation with Natural England, develop an initial ground profile for Cherry Cobb Sands that will offer the best prospect for long term development of mudflat within the managed realignment site. This is because intertidal mudflat is the prime habitat for which the site is required to provide compensation. In practice this will mean developing a ground profile that minimises the likelihood of accretion and maximises the likelihood of erosion. The objective is to maintain ground levels within the site below 2.5 mAOD since the evidence of *Annex 32.5* suggests this is the threshold above which saltmarsh starts to develop.

32.6.17 The water levels predicted within Cherry Cobb Sands are:

- High tide levels within Cherry Cobb Sands are likely to be very similar to those experienced in the Humber Estuary outside (3.4mAOD is the MHWS level and 1.9 mAOD is the MHWN level at Immingham).

- The modelling predicts that high tide levels in the north end of the site most distant from the breach will be 0.05±0.03 m higher than outside in the estuary.

- Low tide levels will be determined by local ground levels but will not fall below the invert level of the breach. This will leave an area of approximately 15 ha permanently inundated close to the breach where excavation for the embankment has lowered ground levels below this level.

32.6.18 The velocities predicted within the Cherry Cobb Sands site are:

- In the area close to the breach and immediately to the north flood tide velocities of 1.6 to 1.8 m/s are predicted on the largest tides as the tide floods north to inundate the site.

- Further north the maximum flood tide velocities are predicted to reduce gradually to 0.7 to 0.8 m/s on the larger tides as the site widens and the distance to the northern boundary reduces. The proposed refinement of initial ground levels will seek to increase the extent of high velocities within Cherry Cobb Sands to increase the erosive potential of these flows.

- The ebb tide velocities throughout Cherry Cobb Sands are predicted to be below 0.6 m/s as the site gradually drains during the low tide period in the Humber Estuary, though the proposed refinement of initial ground levels is expected to increase ebb tide maximum velocities to encourage more erosion.

32.6.19 Changes to bed levels within Cherry Cobb Sands are unlikely within the first two weeks of operation but over the first months of operation, the processes of erosion and accretion will start to take effect. These early changes are:

- The low velocities at the north end of Cherry Cobb Sands will encourage deposition of suspended sediments which will raise ground levels locally by up to approximately 0.8 m over five years. The 100 ha site has a smaller area south of the breach compared with the 90 and 110 ha sites tested in *Annexes 32.4* and *32.6*. As a result, the area of rapid accretion south of the breach in the 100 ha site will be much reduced.

- In the areas of higher velocity there will be little accretion or erosion and so little change in initial ground levels.

- In the areas of highest velocities close to the breach there is likelihood of erosion since erosion during the high velocities experienced on the flood tide may well outweigh the accretion that is expected during the ebb tide. Local erosion of approximately 0.5 m is anticipated over five years.

32.6.20 During the first five years after breaching, the processes of erosion and accretion in different parts of the site will continue. The changes are subject to considerable uncertainty as described in *Annexes 32.4* and *32.6*. Further consideration of the development of the site over the first five to ten years will be undertaken in consultation with Natural England. A first estimate of typical ground levels after five years is shown in *Figure 28.3*.

32.6.21 The predicted typical ground levels in *Figure 28.3* are slightly lower and show a greater area of mudflat after five years than those shown in *Annex 32.4 Figure 22* and *Annex 32.6 Figure 14*. This is because the reduced site area south of the breach reduces the volume that can be excavated from this area by 14 000 $m^3$. This has been compensated by a small (maximum 0.04 m) reduction in the initial ground levels over much of the site north of the breach which has increased the area remaining below 2.5 mAOD after five years. These results indicate the sensitivity of the results to the ground levels across the site when it is first inundated.

32.6.22 The design does not include erosion protection for the breach so there is the likelihood that within five years, a creek will cut through the breach which will allow the whole of the managed realignment site to drain at low tide. In this circumstance the intertidal area within Cherry Cobb Sands is expected to include more than 50 ha of mudflat with the remainder either developing as saltmarsh or accreting to levels at which saltmarsh is likely to start forming.

32.6.23 During this period, saltmarsh is expected to develop in the higher parts of the site as discussed in *Chapter 34*.

*Long term changes inside the Cherry Cobb Sands site*

32.6.24 Over periods longer than five years, sedimentation within the site is expected to continue but at a much reduced rate. The increasing bed level reduces the frequency and depth of inundation, so reducing the rate of accretion. The increased bed levels reduce the volume of water that floods the site on each tide. In turn this reduces velocities in the incoming flow and so increases the area where accretion dominates and reduces the area where erosion occurs and those areas where velocities are too high to allow settlement.

32.6.25 Over decadal timescales, the effects of climate change will become important raising high tide levels within the site. In a turbid estuary like the Humber the increase in tidal volume over the Cherry Cobb Sands site arising from climate change will allow greater accretion on each tide. It is expected that as a result the long term rate of accretion within the managed realignment will match sea level rise and so bed levels within the site are expected to rise in line with sea level rise.

## *32.7 MITIGATION MEASURES*

### *Construction Phase*

32.7.1 As the construction phase has no impact on hydraulics and sedimentation, no mitigation is proposed.

### *Operational Phase*

32.7.2 The site will be modelled and designed carefully in further consultation with Natural England to encourage erosion within the site away from the flood embankments and reduce the rate of accretion as far as practicable. Protection will be provided to protect the new flood embankment from wave and current erosion as described in *Section*

*28.3*. No other mitigation is proposed for hydraulic and sedimentation effects arising from the operational phase at Cherry Cobb Sands.

## *32.8 CUMULATIVE IMPACTS*

32.8.1 An assessment of the impacts of the Project in combination with other proposed developments within the estuary is discussed in *Chapter 8*. That assessment includes the cumulative effects of the Compensation Site discussed in this chapter with the effects of the AMEP development.