East Lane Bawdsey

Cliff recession study

Waveney District Council

26 July 2011

Halcrow

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Document history

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This document has been issued and amended as follows:

Version	Date	Description	Created by	Verified by	Approved by
1.0	26/07/11	Draft	Paul Fish	Roger Moore	Roger Moore
1.1	19/08/11	Final with client comments	Paul Fish	Roger Moore	Roger Moore

Contents

1 Scope of work

This report has been produced at the request of Waveney District Council to investigate the coastline at East Lane, Bawdsey. This stretch of coastline has a long history of coast protection, yet residents' observations suggest that in recent years, the cliffs have begun to erode at a faster rate and through a different mechanism.

Halcrow's proposal and scope of work comprised three tasks:

- Task 1: A review of relevant data including consultants' reports, aerial photos, beach survey data and geological records. These data will be used to develop an understanding of the context, nature and pattern of coastal cliff development over a timescale of the past 100 years and covering the adjacent coastline. The primary aim of this task is to understand external factors that affect the beach and cliff recession process, such as waves, sediment supply, sediment transport and the impacts of coastal management.
- Task 2: A site visit to document the geology and geomorphology of the cliffs and adjacent shoreline. The cliffs will be characterised to record the location and geometry of failures, presence of seepages and drainage, and the degree of undercutting or protection at the cliff base. The primary aim of this work will be to document the 'pre-disposing' factors that control the cliff recession mechanisms and basal undercutting.
- Task 3: Draw all available evidence together in a brief report to explain historical, contemporary and future potential behaviour of the cliffs at East Lane, Bawdsey. The report will make recommendations where there may be benefit in conducting further work on site, e.g. to conduct site investigation landward of the cliffs, to model the likely maximum extent of cliff recession and shoreline change, or to provide guidance for cliff management and engineering measures to control cliff instability and erosion.

This report documents the findings of these three tasks.

1.1 Client supplied data

Information received and used in this study are summarised in Table 1.1. Task 1 comprised a thorough review of this information to place the site in its regional context and to document evidence of coastal change over recent years. Spatial data were entered to a geographical information system (GIS) to allow analysis.

Table 1.1. Sources of data.

Data	Details	Source
Vertical aerial photos	Data from 1992, 1994, 1997, 2001, 2005, 2006, 2007, 2008, 2009, 2010. Note that 1994 and 1997 data are identical! Coverage from Orford Ness to Deben Estuary	Environment Agency
LiDAR	2m resolution data from 1999 and 2008 covering 1 sq km of coastline at East Lane	Environment Agency
Beach profile data	Survey data covering a series of beach profiles from 1992 to 2010. Information has been entered to SANDS for analysis	Environment Agency
Geological map	1:50,000 paper map indicating bedrock and drift geology of the cliffs and hinterland	British Geological Survey
Ordnance Survey mapping	1:5,000 Mastermap data of the site	Ordnance Survey
Site photos	Various photos of the site highlighting changes in the cliffs during 2010	Various
Environmental Statement	East Lane coast protection, Royal Haskoning and Halcrow December 2005	Waveney District Council
Environmental Appraisal report	East Lane coast protection, Royal Haskoning November 2006	Waveney District Council
Project Appraisal Report	East Lane coast protection PAR, Royal Haskoning August 2006	Waveney District Council
Offshore 'fish tail' breakwater design options	Drawings showing four design options and predicted bay morphologies. Option 2 was constructed.	Waveney District Council

2 Data review

2.1 Geology

The bedrock geology of the study coastline comprises London Clay overlain by Red Crag (a shelly sand). Both formations comprise characteristically weak or 'soft rocks' that are prone to rapid erosion. South of the headland at East Lane, the London Clay crops out on the shore platform. The cliffs comprise up to 2 to 3 metres of London Clay that is overlain by a further 1 to 2 metres of Red Crag upon which a sandy soil c. 0.5 m thick has developed.

The London Clay and Red Crag formations are dominated by clay to sand sized materials, and with the exception of a very thin and discontinuous flint gravel bed at the contact between the two formations, there is very limited supply of coarse beach building material. This means as the cliffs erode the majority of material is transported away and a very small proportion remains in the beach.

The hinterland region has an extensive cover of gravel-rich drift sediments, comprising pre-glacial river gravels (Kesgrave Sands and Gravels), glacial meltwater gravels. These materials form slightly elevated plateaux on which the surrounding villages have been built some distance back from the coast.

The land immediately behind the study frontage, between East Lane headland and the Martello, is flat and lies at an elevation of c. 10m OD. The hinterland to the north and south of the study areas dips away and is formed in reclaimed mudflats and saltmarshes that lie at an elevation near to 0m OD. Key features are shown on Figure 2.1.

2.2 Coastal development

Like much of the east coast of England, the coastline is a relatively recent feature, having been formed by sea-levels rising since the last glacial maximum. Sea-levels in this area reached near present elevations about 3,000 years ago and have rapidly eroded the weak sediments to form cliffs and beaches. Eroded fine-grained sediment was transported to the North Sea where it formed an extensive series of offshore banks, while coarser sediment remained stored in the nearshore zone to form nesses, spits and beaches. The broad morphology of the coast at this time was determined by the elevation of the London Clay, which is relatively more resistant to erosion than the overlying Red Crag. Headlands are formed where the London Clay crops out above ordnance datum, while shallow bays are formed where the weaker crags are exposed at sea level. This general pattern remains today, but is masked by land reclamation and coastal defences.

Natural coastal evolution in this low-lying region allowed formation of salt marshes and mudflats at the margins of estuaries and on the coastal frontage. Most of these marshes were reclaimed in the 16th and 17th centuries, creating the low-lying fertile land to the north and south of Bawdsey village and the land fringing the estuaries of the Ore, Butley and Deben.

In more recent times, the need to protect low-lying agricultural land and properties from the effects of flooding and erosion has led to extensive coastal engineering. Low-lying land north of Bawdsey is protected by a flood embankment, while the cliffs forming the headland at East Lane and the area immediately to the south are protected by hard defences of various type and age. The protection afforded by coastal defences has caused the headland to become increasingly more pronounced over time.

Figure 2.1. Key features of the study coastline and hinterland

2.3 Contemporary regime

East Lane, Bawdsey forms a headland on the East Anglian coast between Hollesley Bay in the north, which is dominated by the massive Orford Ness spit, and the convex coastline to the south that is characterised by the Deben estuary. Bawdsey also forms a significant 'node' on the coast, north of which the coastline trends 25 to 205 degrees and south of which it trends 40 – 220 degrees.

The tide levels for the region increase in a southwards direction and are summarised in Table 2.1. Storm surges are excluded from these data and may typically be 2m above astronomical levels. A joint probability analysis for extreme water levels, combining the effects of surges and high tides, is presented in the Environmental Statement and summarised in Table 2.2.

Table 2.1 Tidal conditions

	Tidal levels (mOD Newlyn)			
	MHWS	MHWN	MLWN	MLWS
Orford Haven	1.54	0.94	-0.66	-1.26
Bawdsey	1.63	1.03	-1.47	-1.47
Woodbridge Haven	1.77	0.97	-1.43	-1.43

Table 2.2 Extreme water levels

Return period	Open coast*(mODN)	Alde/Ore estuary (mODN)
1 year	2.86	2.25
5 years	3.09	-
10 years	3.37	2.63
20 years	3.51	-
25 years	3.58	-
50 years	3.71	-
100 years	3.91	30.2

**based on an average of data from North Weir Point at the mouth of the Alde and Felixstowe Ferry.*

Numerical modelling suggests that inshore waves rarely exceed 2m and that tidal currents are aligned parallel to the coastline and have a typical velocity of around 1.0m/s.

The sediment drift rate of the coastline from Orford Ness to Langard Point, Felixstowe, is high (c. 140,000 cubic metres/year) with transport typically to the southwest, driven by prevailing wave conditions. Drift reversal, with sediment transport to the northeast, is possible under different wave directions. Exact volumes of sediment transported in each direction are uncertain. Sediment originates from Orford Ness, but supply is episodic with temporary storage in gravel bars at the mouth of the Ore.

Sediment transport predominantly occurs along the steep face of the beach immediately fronting the shore and little transport occurs over the shallower nearshore area. This is due to the combined effects of relative large size of beach sediment (gravel), weak current velocities and low wave heights.

These effects mean the defences at East Lane inhibit sediment transport to the south, with gravel accumulating on the beaches to the north and gravel starvation and ablation on the beaches to the south of East Lane.

2.4 History of coastal defences

For at least 70 years the shoreline at East Lane has been protected with hard defences. As noted already, the presence of these defences has had a significant impact on the shape and function of the shoreline at East Lane, creating a promontory that has become more pronounced over time. The defences have affected the coastal processes north and south of East Lane and have led to intermittent beach narrowing, steepening and loss (in front of the seawall at East Lane).

The aerial photography flown since 1992 has been interpreted to determine the recent history of engineering and coastal response (Table 2.3).

2.5 History of beach changes

Beaches in the vicinity of East Lane have been analysed using three sources of information:

- EA beach profile data collected annually since 1992 monitoring the change in beach elevation through time
- Aerial photograph analysis that shows changes in the position of the beach toe, and the width of the shore platform
- LiDAR data that shows the elevation of a 1 sq km section of beach in 1999 and 2008. The data is from the beach south of the Martello tower.

2.5.1 Shore profiles

Data were analysed for ten shore profiles that cover the coastline from Orford Ness to Bawdsey Manor. Observations are summarised in Table 2.5 and a map slhowing the locations of profiles is provided in Figure 2.2.

In summary, the data indicate that to the north of the East Lane headland the beaches are healthy and have generally experienced growth or stable conditions. The beach crest height in this area is c. 4.4m OD at a similar elevation to peak storm surges. At the headland itself, the small beach present in 1992 has now been eroded. South of the headland, beaches covering the next 1km of coastline have been subject to erosion and shoreline retreat. Beyond this point, beaches have remained healthy and stable. In all stable beaches, the crest elevation is c. 4.4m OD

Table 2.3. History of coastal defences and their impacts since 1992, as observed from aerial photographs

Year	East Lane headland	Bay south of East Lane to Martello tower
1992	N-S trending block work revetment with a sloping apron protects the gun emplacement and extends at least 150m north of the headland, where it appears to be buried by beach gravel. The southern part of the structure angles back to the shore where degraded rock armour protection continues for a further 100m.	Evidence of outflanking, leading to the installation of the short section of rock armour visible in the photo. A healthy beach is visible that is held in place by a series of timber groynes that appear to be in a poor condition.
1994/97	Block revetment is degraded and its northern extent appears to be covered by gravel. It also appears that the sloping apron is covered with gravel, and that beach accumulation reaches the southern corner of the structure	Total loss of rock armour and extensive damage to groynes. There appear to be occasional small pockets of erosion visible along the cliffs towards the Martello.
2001	Dramatic loss of the beach exposing the block work that was visible in 1992. At least 280m of this structure and its fronting apron is now visible to the north of the East Lane promontory. A 40m section of block work in the middle of the structure appears to have been eroded and the void has been filled with boulders. Much of the apron of the structure is covered by degraded rock armour that appears to have been placed in two phases using dark grey and pale brown-coloured boulders.	Rock armour now continues from the headland in to the bay to limit outflanking and stop erosion of the car park area. Further south, the back of the beach is protected by rock armour that is of variable width. In the centre of the bay rock armour is narrow and cliff recession has occurred. At the Martello tower and houses the rock armour is wider and has been constructed over a former WW2 observation hut. Cliff recession immediately south of this rock armour has led to the loss of the pill box, which now sits on the foreshore. Groynes are still visible south of the headland, but are highly degraded. Despite this, there is a healthy beach throughout this area.
2005	Continued loss of beach fronting the blockwork, and 300m can now be seen exposed. Rock armour on blockwork is unchanged.	Rock armour now continues along whole frontage to Martello and ends with a curved structure intended to limit outflanking. There is no beach fronting this block work. Outflanking of the Martello is evident and c. 30m erosion has occurred since 2001 at the head of a new bay. Outflanking and bay formation appears associated with significant beach loss, and only a narrow, 10m wide beach is present. Beach loss is also apparent in the intertidal zone where the shore platform has been exposed c.250 m south of the Martello Tower rock armour, revealing the London Clay.
2006	No change since 2005	Failure of 100m rock armour between the houses and the headland leading to cliff recession of up to 8m. The curved structure at the end of the rock armour has failed and outflanking of the Martello tower has continued, with a further 10m of recession occurring. Continued loss of beach means the London Clay platform now extends c 400m south of the Martello.

Year	East Lane headland	Bay south of East Lane to Martello tower
2007	Extensive repairs to the rock armour fronting the revetment/apron with only 40m of the northern revetment now exposed. Armour has been placed at the end of the apron to stop undercutting. Significant retreat of the beach fronting the northern part of these defences since 2006.	Repair of 100m of damaged rock armour by infilling the eroded void with more rock armour. However, these repairs appear ineffective as further cliff recession has occurred behind the armour. The curved end structure of the defences has been patched and boulders placed into the eroded void. Outflanking of Martello has stopped and a small 25m wide beach is present in the bay. The London Clay platform is still exposed over c. 400m of coastline.
2008	Ongoing, but limited erosion of the beach to the north of these defences with exposure of buried groynes and undercutting of the end of revetment/apron	No change visible in defences or outflanking, but beach erosion continues, with a larger area of London Clay platform exposed.
2009	Ongoing retreat of beach from the northern margin of the defences with c. 20m beach retreat observed. This has lead to exposure of rock armour intended protect the margin of the engineering that was installed in 2007.	Doubling of the width of rock armour fronting the Martello tower and houses and construction of a sheet pile structure behind the armour to protect the area north of the houses from erosion. Photograph is taken during construction works. Modification of armour at south of the Martello to build breakwater structure. Boulders placed at cliff toe used in subsequent construction. Boulders also dumped in two piles on the shore platform, which appears to have been excavated to allow barges to get close to the coastline for unloading.
2010	Addition of 80m of rock armour at back of beach north of the old revetment/apron. Growth of beach to re-cover N section of apron.	Completion of rock armour defences, with small in-fill improvements between Martello and WW2 gun, and completion of the 'fish tail' structure at the end of the rock armour (Option 2 of the 4 proposed by Royal Haskoning). Significant erosion of the cliffs (20m) fronting the area of the shore platform excavated during construction in 2009.

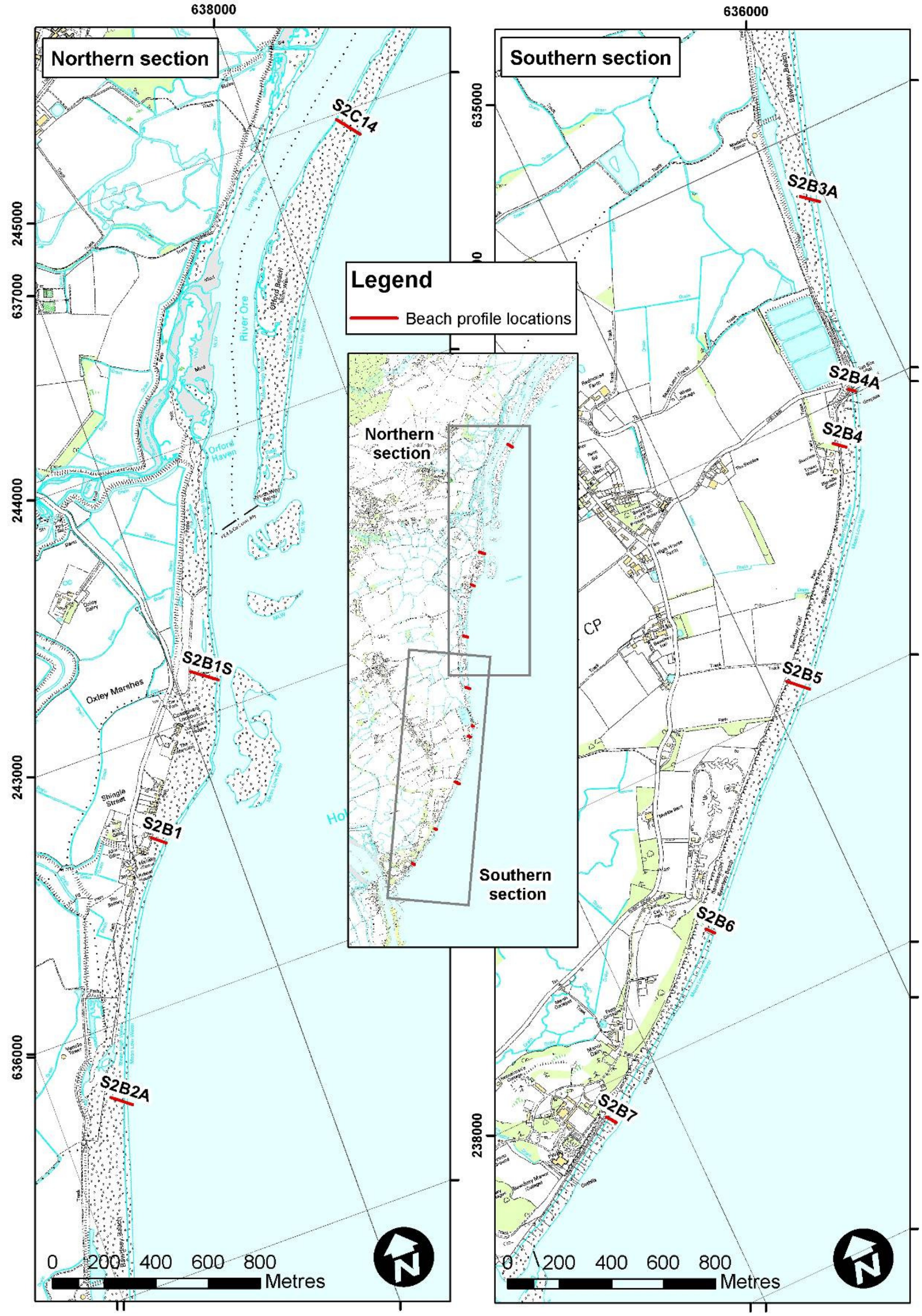

Figure 2.2. Location of shore profiles. Ordnance Survey data reproduced with permission. Waveney District Council licence number 100019684.

Table 2.5. Evidence of beach change from shore profiles.

Profile	Location	Observations
S2C14	North of river Ore mouth	This profile characterises the southern section of the Orford Beach spit. Since August 1991, the landward side of the spit has changed little in position or elevation. The seaward side has experienced significant accretion since 1992, with a c. 15m advance while maintaining crest elevation at c. 4.2 to 4.6m OD. This data indicates a gradual net accretion of sediment that is probably derived from Orford Ness.
S2B1S	South of the Ore mouth	The beach profile data indicate that the beach fronting Oxley Marshes has oscillated dramatically since 1991. Beach profiles in 1992 and 2011 are very similar, but the profile from 2003 is markedly different, and indicates the beach was c. 30m further seaward at this time. Despite these changes in beach face position, the elevation of the beach crest has remained at 4.4 to 4.6mOD. This data indicates dynamic equilibrium, with episodic inputs of sediment that are rapidly transported south. The beach has little net change over time. The episodic inputs are associated with transport of material from the spit to the coastline via gravels bars in the estuary mouth.
S2B1	Shingle Street	A pattern of beach growth is indicated by the beach profile data since 1991 where c. 70m advance of the beach face has occurred in 18 years. The beach morphology and gradient have remained constant over this time. The beach profile data from 2009 suggests the beach extended c. 10m further seaward than its current position, indicating episodic erosion and transfer of sediment south. Since 1992, the beach crest elevation has remained at c. 4.4m OD. This data indicates net growth, with occasional periods where sediment is transported south.
S2B2A	North Bawdsey Beach	The profiles show some fluctuation in the beach since 1992. Between 1992 and 1998 the beach face retreated by c.15m, resulting in a reduction of elevation of up to c. 2m along the profile. However, between 1998 and 2011 this pattern was reversed, with extension of the beach by up to 10m and a typical increase in elevation by c.1m. Over this time, the elevation of the beach crest has remained at c. 4.2 to 4.4m OD. This data indicates dynamic equilibrium, with fluctuation in beach profiles in response to storms or sediment pulses moving down the coast.
S2B3A	South Bawdsey Beach	The beach profile data shows that this section of beach has been consistently eroding over the last 20 years, with almost 40m retreat of the beach face since 1992. Beach crest elevation has also experienced a net reduction from 4.9m OD in 1992 to 4.4m in 2011. This data indicates an eroding beach. The fate of the sediment is unclear.
S2B4A	East Lane headland	The beach profile data cover the engineered headland and highlight the loss of the small, low elevation, beach that covered the defence apron between surveys in August 1992 and August 1995. This data indicates loss of the beach since 1992.
S2B4	Near Martello Tower	Beach profile data was first collected from this location in 2003 in response to concerns about outflanking. The beach profile data reflects changes in the coastal defences in this area and suggests that between 2003 and 2008 the beach retreated by up to c.15m. This data indicates loss of the beach since 2003.
S2B5	North Bawdsey cliff	The beach profile data indicates that c.30m of the beach face retreat has occurred since 1991, but that the cliffs have not changed. The back of the beach has also remained largely unchanged and a beach crest elevation of c. 4.4m has been maintained. This data indicates that the beach face has consistently retreated since 1991, but that sufficient material remains in the beach to afford protection to the cliffs.

Profile	Location	Observations
S2B6	South Bawdsey Cliff	A comparison of profiles from 1992 and 2011 indicates there has been very little net change in the position or size of the beach at this location. Profiles show some variation, in relation to beach ridges moving along the shore face, but the beach crest elevation has remained at c. 4.2m OD. The data indicates the beach has experienced no net change since 1991.
S2B7	Bawdsey Manor	The pattern of change is similar to that seen as S2B6. There has been limited erosion of the beach face since 1991 and the elevation of the beach crest has been maintained at c. 4.2m OD. The data indicates the beach has experienced no net change since 1991.

2.5.2 Aerial photograph evidence

The position of the beach toe was assessed using the aerial photography that shows the gradual emergence of the London Clay shore platform as beaches south of the East Lane headland have been eroded. The assessment was undertaken by measuring the position of the beach toe/shore platform interface in eight shore-normal transect lines (Figure 2.3). The majority of the photographs were taken at MLW, meaning this feature is clearly visible. No data was recorded if the feature was not visible. No assessment of the accuracy of the orthophotographs has been undertaken. Based on a visual assessment only, it is assumed features positions are accurate to +/-20cm.

The results are shown in Figure 2.4 which illustrates the cumulative recession of the beach toe and exposure of the shore platform in each of the photographs. It is assumed that the 1994/1997 image represents 1997. Key observations are as follows:

- All transects show dramatic retreat of the beach in the area affected by accelerated erosion between 1992 and 2010. Net beach retreat ranges from 36m to 106m. The maximum loss is immediately south of the outflanking structure at profile 2 and the magnitude of loss decreases towards the south.
- All transect lines show limited change in the beach toe position between 1992 and 2001. This is a time when there was limited rock armour along the Martello tower frontage
- Dramatic retreat of the beach occurred in all transects between 2001 and 2005, where up to 70 m of beach retreat occurred to reveal the underlying London Clay shore platform. Full rock armour was placed along the whole frontage in 2001 and an end structure to limit outflanking was added in 2005.
- Small fluctuation in beach toe position between 2005 and 2009 with an overall net increase in width in transects (2, 3, 4, 5).
- Second phase of dramatic retreat in most transects between 2009 and 2010, with a further retreat of up to 30m of beach.
- The pattern of beach retreat and exposure of the shore platform is most marked in the northern transects that lie within the recently eroded bay (transects 1-4). However, the southern profiles, which lie beyond the area currently experiencing erosion and bay formation, have also experienced marked retreat.

Figure 2.3. Location of coastal transects. Note the bay is present between profiles 1 and 4, but the London Clay shore platform extends between profiles 1 to 8.

2.5.3 LiDAR evidence

Two epochs of LiDAR data were provided by the Environment Agency. These data were flown in 1999 and 2008 and record beach elevations at a resolution of 2m (ie a spot height is provided for every 2x2m area on the ground). The accuracy of the data are ±25cm in 1999 and ±15cm in 2008. These two surveys are shown in Figure 2.5. The LiDAR data can be processed using GIS to calculate the pattern and magnitude of beach change for the nine years between 1999 and 2008. This involves subtracting one survey from another to calculate the change.

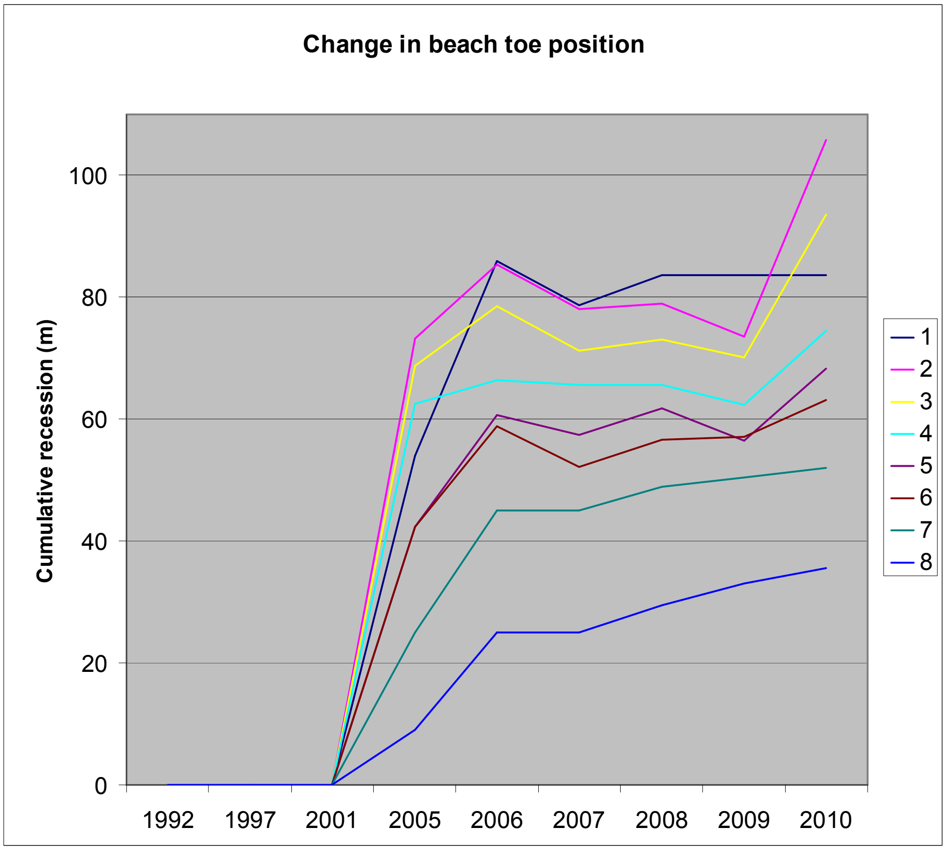

Figure 2.4. Location of the beach toe.

Due to the accuracies of the data, any change calculated to be less than 40cm is unreliable. The changes in beach elevation are shown in Figure 2.6, which highlights the following observations:

- Up to 4m lowering of the beach in the vicinity of the bay due to loss of beach sediment between 1999 and 2008
- Up to 9m lowering in the hinterland of the bay due to cliff erosion and removal of sediment
- Up to 4m lowering of the beaches south of the bay due to erosion of the beach face

These observations corroborate the evidence from aerial photographs and beach profiles.

Halcrow

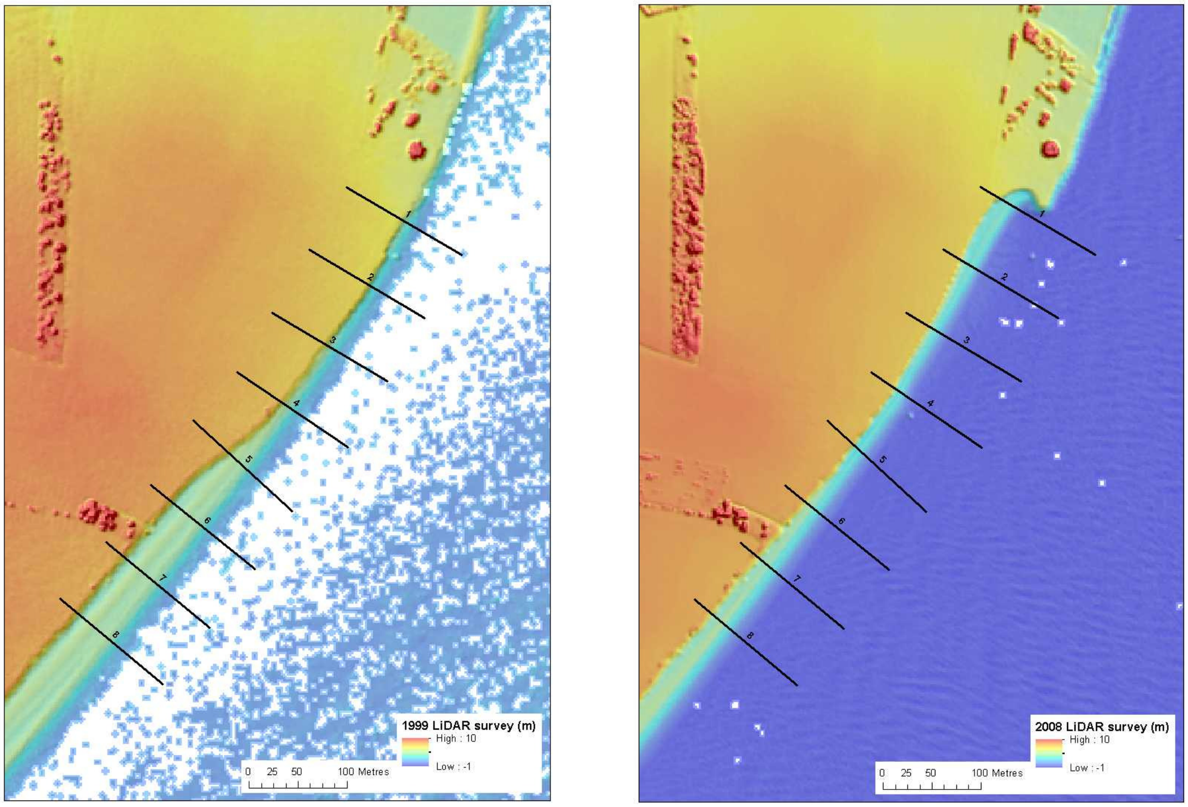

Figure 2.5. LiDAR surveys undertaken in 1999 (±25cm) and 2008 (±15cm).

2.6 History of cliff recession

According to the PAR, long-term erosion rates for the period 1850/1890 to 1960/1970 determined from historical Ordnance Survey maps are as follows

- North of East Lane (for Low Water Mark) 0.0 to 0.5m/yr
- East Lane (for Low Water Mark) up to 0.5 to 1.0m/yr
- East Lane (for Mean High Water Mark) approx 1.5m/yr
- South of East Lane (for Low Water Mark) 1.0-2.0m/yr

The shoreline at East Lane shows coastal steepening over this same period (associated with mapped MLW and MHW lines becoming closer together). The headland has been near constant since 1970, which is consistent with the shoreline being 'held' by coastal defences.

A more detailed assessment of cliff recession has been undertaken using the aerial photography that dates from 1992 to 2010. The methodology follows that used for the beach toe analysis and uses the same eight shore profiles to measure feature position change through time (Figure 2.3). Results are summarised in Figure 2.7 and 2.8 that highlight cliff top position and the calculated cliff recession rates since 1992.

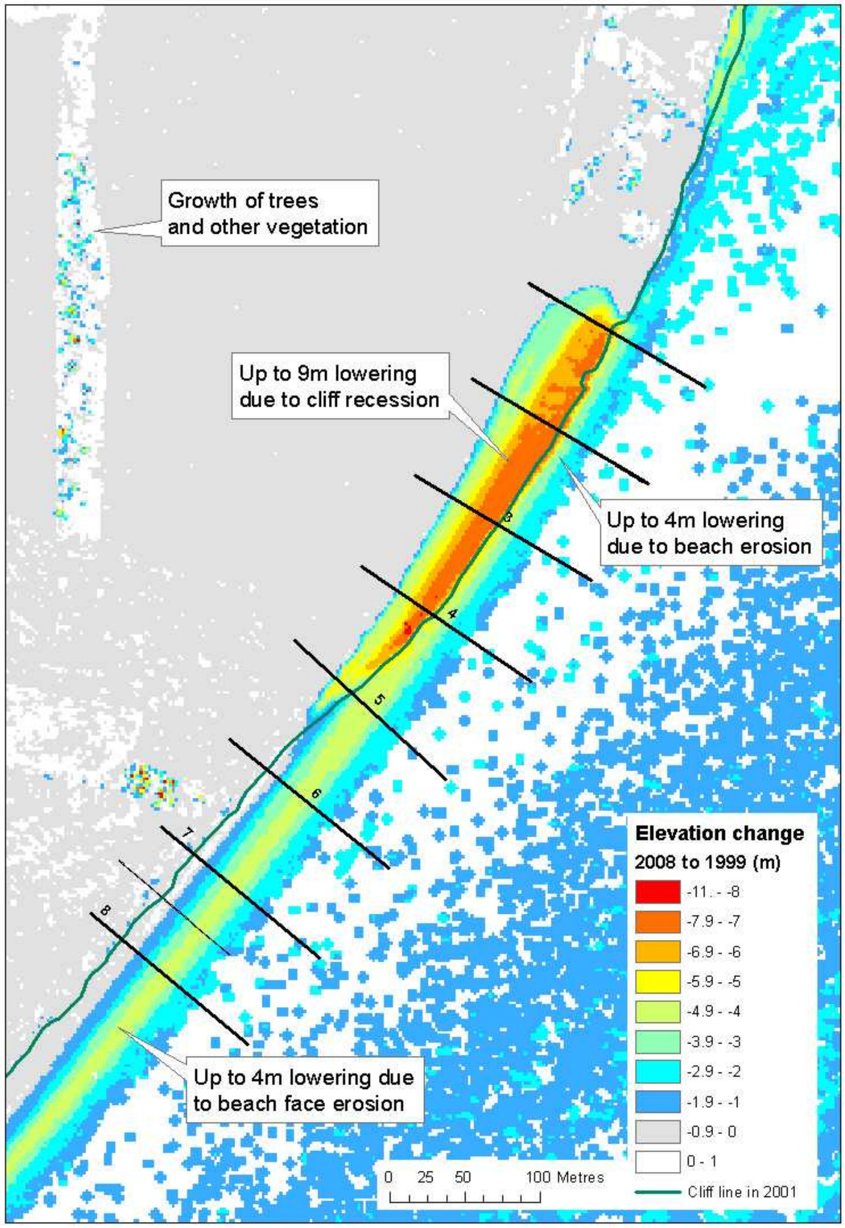

Figure 2.6. Difference in elevation between 1999 and 2008 LiDAR surveys

The figures show the following:

- Very limited erosion between 1992 and 1997, when aerial photography shows the cliffs were stable and well-vegetated.
- The northern-most profile (1) shows a high rate of erosion from 1997 onwards. In 1997 to 2001 the average recession is c. 4m/yr and this rises to almost 8m/yr during 2005 to 2006.

- Profiles 2, 3, 4 show erosion from 1997 to 2001, with rates of under 2m/yr. Erosion in these profiles accelerates from 2001 and reaches a peak rate of c. 15m/yr in 2005 to 2006.
- All profiles record limited erosion between 2006 and 2009, with rates of change under 1m/yr.
- Northernmost profiles (2, 3) record a second phase or erosion between 2009 and 2010 when erosion rates again exceeded 15m/yr. (NB at this time profile 1 is protected by the rock armour end structure)
- Between 1992 and 2010, northernmost profiles (1, 2, 3) show average recession rates of 3 to 4m/yr, which is significantly more than the historical long term average of 1 to 2m/yr. Over the same time period, central profiles (4, 5) show recession rates of c. 1 to 2m/yr. Southern profiles (6, 7, 8) have changed little between 1992 and 2010, and show a long-term recession rate of under 0.5m/yr.

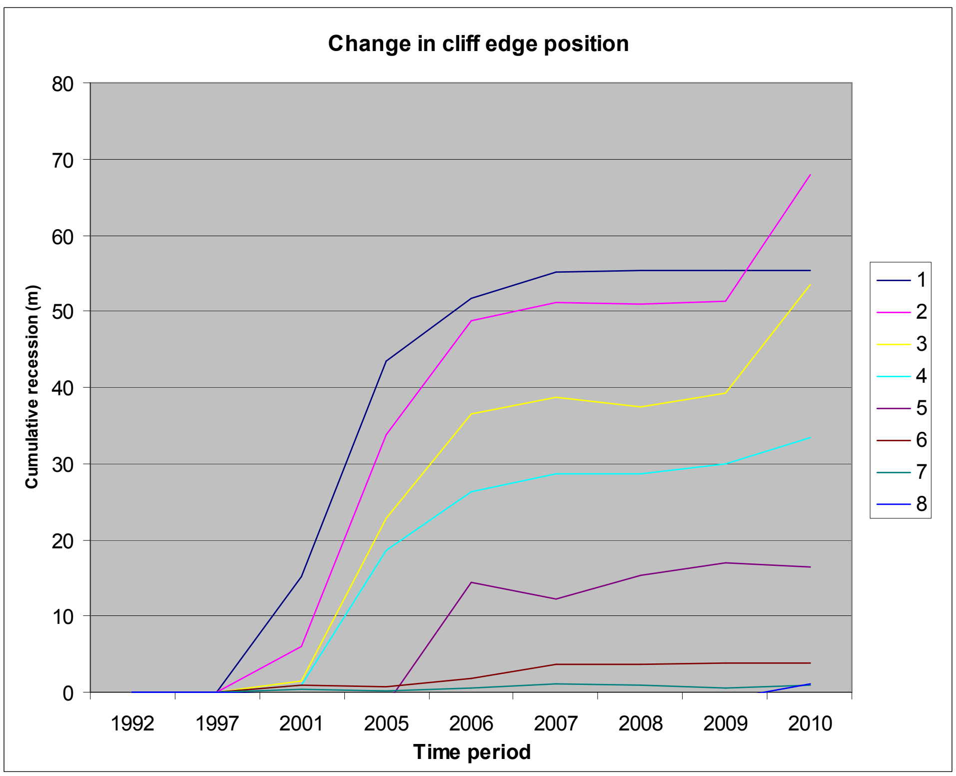

Figure 2.7. Location of the cliff top south of East Lane since 1992.

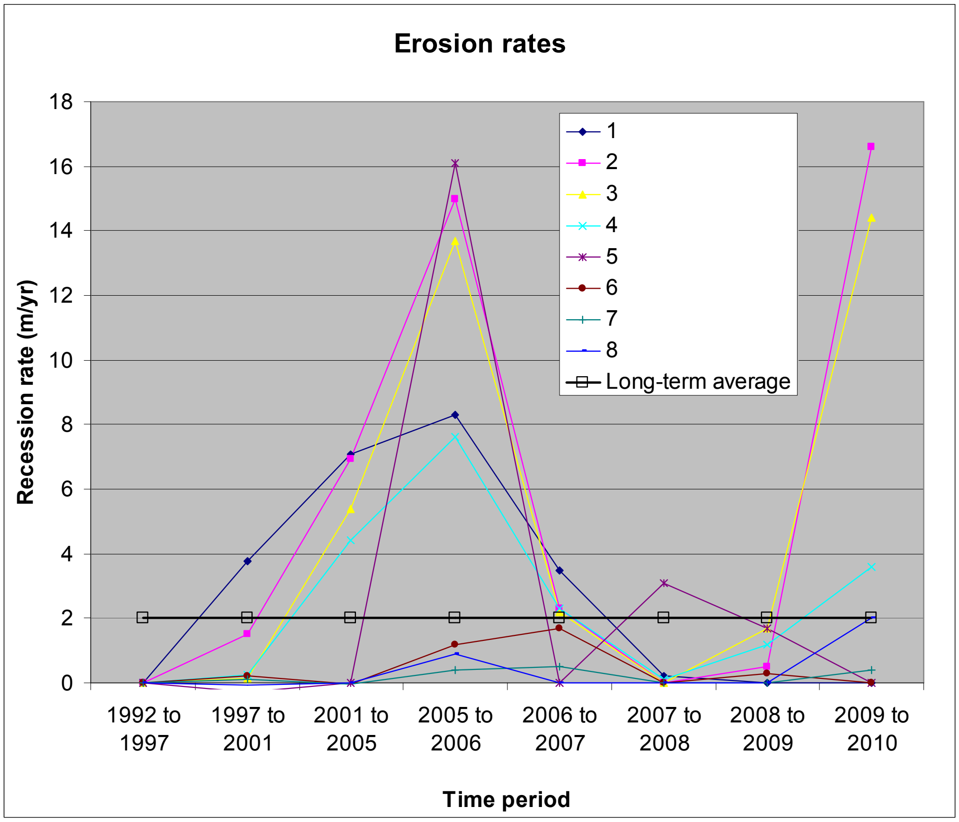

Figure 2.8. Cliff recession rates south of East Lane. Long-term average (1850/90 to 1960/70) is highlighted

3 Site inspection

3.1 Summary of activities

A site inspection was undertaken by Paul Fish and Roger Moore on Monday 11 July 2011. Work involved a walkover of the coastline up to 2km north and south of the East Lane headland; inspection of cliff materials, coastal defence structures and landslides; and a brief site meeting with a representative of the local council (Mr Block).

The weather during the visit was clear and dry. Low tide was at 14.27 hrs meaning the whole intertidal zone could be inspected during the site visit.

3.2 Site observations

Healthy beach immediately north of East Lane

Hollesley Bay, healthy beach looking north. Note saline lagoon formed between beach ridges and coastal flood embankment. The different alignment of the beach and the embankment suggest significant beach progradation.

Coastal defences north of East Lane. The wall and apron were observed in the 1992 aerial photos. Note rock armour in foreground to limit outflanking. Aerial photos show this material is occasionally covered by gravel.

Undercutting of the apron has occurred behind the pill box.

Rock armour of the East Lane headland

Defences on the south side of the East Lane headland. Note rock armour covering toe of revetment apron

Sheet piles installed in 2009 following overtopping of rock armour and cliff recession.

Continuous rock armour to Martello tower.

Rock armour end structure, bay formed behind the armour and thin and narrow beach. Tide line shows deeply-indented London Clay shore platform.

Detail of beach formed in the new bay. Note all grey coloured pebbles are rounded pieces of weak London Clay. Much rarer brown pebbles are flint

Recently eroded cliff in the bay. Basal grey-brown material is London Clay. Orange-brown material towards the top is Red Crag in which a thin pale brown soil has developed. Note in tact drainage pipe exposed by cliff recession.

Detail of small landslide within the bay, between profiles 1 and 2. The Red Crag has remained as an intact block and slumped as the underlying London Clay has been extruded and eroded by wave action.

Geological contact between the London Clay and the overlying Red Crag. The photo highlights the thin and discontinuous pebble bed. This bed is the only supply of beach-building material in the cliffs. All other material is transported to the intertidal zone or offshore.

Overview of the bay showing landsliding and cliff erosion, wide exposure of London Clay shore platform and very thin and narrow beach

Recent landslide south of the bay near profile 5 in an area with a marginally healthier beach. Note the beach is still relatively narrow with the clay platform exposed beyond the beach toe

Recently eroded cliffs in location south of the bay between profiles 6 and 7. Note marginally more healthy beach

Cliffs and beaches south of the bay, between profiles 7 and 8. Note relatively healthy beach and well-vegetated cliffs with evidence for basal trimming by storm waves. Note step up in maximum beach elevation seen in the distance.

Cliffs and beaches south of profile 8. Note width of upper beach platform that afford protection to the cliffs which are themselves highly degraded and well-vegetated.

The site observations highlight the following:

- Healthy beaches in Hollesley Bay north of East Lane headland, with evidence for progradation allowing a saline lagoon to form behind the beach ridges. The northern part of the East Lane defences show evidence of outflanking and exposure of rock armour. The beach in this region shows evidence of ongoing erosion.
- Coastal defences fronting East Lane are in a poor state of repair and have numerous patch-repairs. At low tide there is no beach visible and the shoreline is formed of steeply angled rock armour.

- Coastal defences south of East Lane are in a better state of repair having been more recently installed. At low tide there is no beach visible in this location, and the shoreline is again formed of steeply angled rock armour.
- The coastal defences end with a low breakwater designed to limit outflanking by encouraging formation of a stable bay within which a protective beach will accrete. A bay has formed, but the beach is very limited and composed of weak pebbles of clay that are rapidly eroded. Bay formation has been achieved through erosion of the soft London Clay and Red Crag cliffs and episodic landsliding. Landslides were seen to be associated with water seepage from the cliffs that saturates the clay, causing it to fail and remove support to the overlying crag. The whole bay is fronted by a shore platform formed of soft clay that is deeply indented, reflecting the curve of the cliffline.
- South of the bay, the beach is marginally wider and thicker, but an extensive shore platform formed of soft clay is exposed beneath. The cliffs are active, with evidence for fresh erosion and localised landsliding.
- Further south, the beach increases in width and thickness, and only a small area of shore platform is exposed. Cliffs are degraded and generally well vegetated, but are undercut due to toe erosion
- Southwards, beyond the area of active cliffs, the beaches are considerably wider and have a higher elevation. The shore platform is not exposed at low tide. Cliffs are highly degraded and well vegetated with no evidence for toe erosion.

4 Synthesis of evidence and recommendations

4.1 Causes of erosion

The evidence made available for this assessment by Waveney District Council and the Environment Agency has been reviewed and combined with site observations to determine the likely causes and mechanisms for the recent accelerated erosion south of East Lane, Bawdsey.

The data highlight that the coastline has a long history of coastal engineering of various type, extent and age, that has been in place in some form since at least WW2, and which has undoubtedly had an adverse impact on the natural shape of the coastline and coastal sediment transport processes. Coastal defences have afforded flood protection to adjacent low-lying land and erosion protection to properties and heritage assets. However, the engineering on the East Lane headland has also impeded along-shore sediment transport, causing a build-up of sediment up-drift, and sediment starvation down-drift. This has resulted in the complete loss of the beach that once existing fronting the defences and depletion of the beaches south of the Martello. The effect of beach depletion is evident in the data for a distance of c. 1km south of the headland.

Coast protection measures (specifically the rock armour) have also had a history of outflanking and causing accelerated erosion on adjacent coastlines. The 1992 aerial photograph, taken when only the East Lane headland was defended, highlights outflanking and erosion of the area immediately south (in the vicinity of the current car park). Outflanking and accelerated erosion rapidly occurred south of the Martello following installation of rock armour in 2001 and a new phase of accelerated erosion occurred in 2010 following construction of the offshore 'fishtail' breakwater.

This most recent phase of accelerated erosion also appears to have been promoted by the localised erosion or excavation of the London Clay shore platform in 2009. This area already had a severely depleted beach, and the lowering of the shore platform has allowed waves to break closer to the shore and directly undercut the base of the cliffs. The cause of the localised lowering or excavation of the shore platform is not certain, but the photographic evidence shows that it occurred during the phase of coastal engineering works in 2009. The evidence is compelling and it appears that the shore platform was excavated to allow barges carrying rock armour to land close to the beach. The excavation does not appear to have been reinstated after the construction works.

The current phase of accelerated erosion is therefore considered to be a response to the coastal engineering and construction works. Similar responses can be seen in the data archive. Based on this assessment, the specific pre-conditions and activities summarised below provide explanation of the accelerated erosion and apparent change in cliff behaviour south of East Lane:

- Long-term (1940s to present) – the coastal defences at Bawdsey have prevented the southerly transport of beach sediment leading to the starvation and depletion of the beaches to the south of the East Lane headland. The natural cliff protection afforded by a natural healthy beach has therefore been progressively lost.

- Medium-term (1990s to present) – outflanking and accelerated cliff erosion of the coast protection measures has become more pronounced due to the exposure of the cliffs, and as the coast re-adjusts to form an equilibrium stable bay shape. The cliffs, which no longer have any protection in the form of a healthy beach, are unable to resist forces of wave undercutting and erosion
- Short-term (2009 to present) - accelerated cliff recession and landsliding has occurred due to rapid erosion or excavation of the shore platform, allowing waves to break closer to the shoreline and base of cliffs. The already active cliffs are now more exposed to the impacts of waves and hydrodynamic forces resulting in higher rates of cliff undercutting, erosion and landslides.

This pattern is illustrated in Figure 4.1 which highlights the relationship between cliff and beach erosion and phases of major coastal engineering. Only four profiles are shown for clarity. Profile 2 lies in the centre of the eroded bay, profile 4 is immediately south of the bay in an area of recently reactivated cliff and profiles 6 and 8 are south of the area currently affected by erosion, where cliffs are inactive.

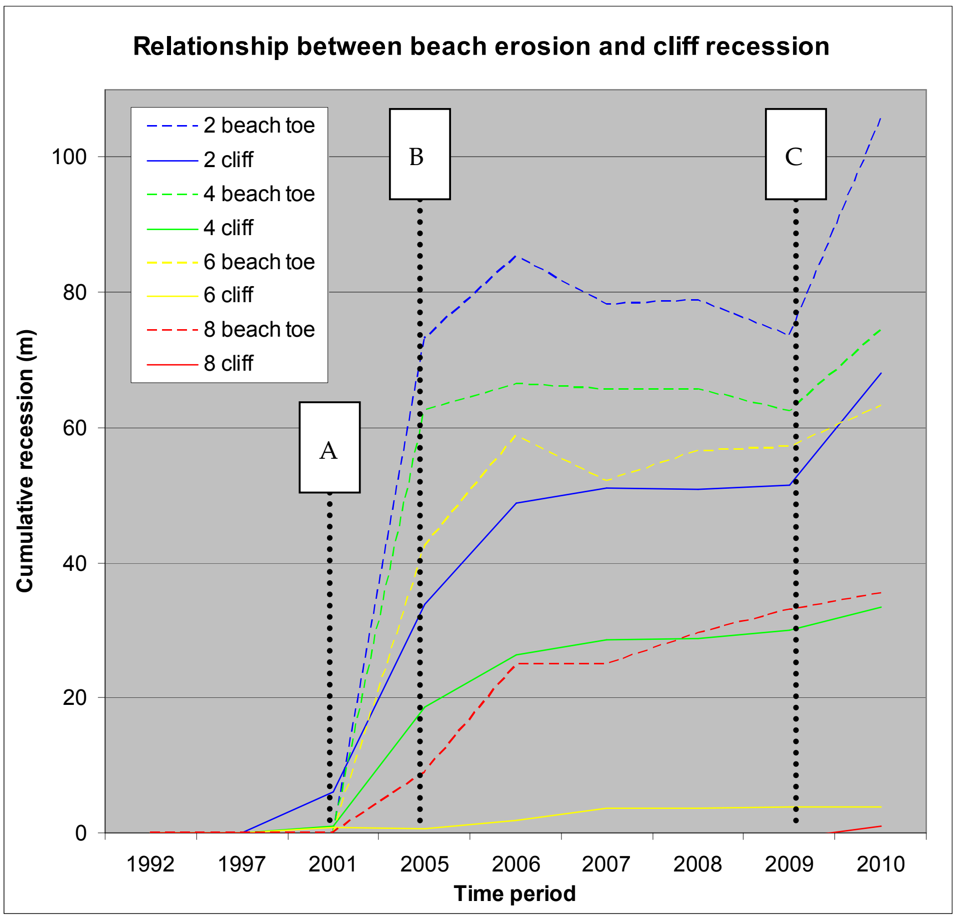

Figure 4.1. Relationship between cliff recession, beach erosion and coastal engineering. Note. Dotted lines indicate phases of engineering: A, rock armour extended to front Martello; B, outflanking measures installed; C, offshore breakwater installed and shore platform excavated

The figure highlights:

- rapid beach loss in all profiles following extension of the rock armour fronting the Martello Tower that was closely followed by cliff recession in the two northern-most transects
- installation of outflanking measures in 2005 appear to have reduced the significant cliff recession rate, but had a more limited impact on reducing beach loss
- installation of the offshore breakwater in 2009 triggered a new phase of accelerated beach loss and cliff recession that was most marked in the north.

4.2 Future scenarios

The pattern of coastal response to engineering is clearly evident in the coastal monitoring data. Beach erosion is intimately linked to cliff recession and both can be associated with phases of engineering, as has been highlighted in Figure 4.1. The differences between individual profiles shown in this figure reveal that erosion is most marked in the north, in the area directly affected by the coastal defences and engineering works. However, beach loss and associated cliff recession are also evident in profiles further south, which are unlikely to be directly influenced by the recent coastal engineering. For example, the beach toes in profiles 6 and 8 have been eroding continuously since 1992, albeit at a lower rate to other profiles. By contrast, the cliff in profile 6 has experienced slight erosion, but the cliffs at profile 8 have been unaffected.

The explanation for these observations is underpinned by the notion that healthy beaches provide sustainable cliff protection. The beaches south of East Lane are starved due to their sediment supply being cut-off from the north, but crucially they are still subjected to the longshore drift of sediment to the south. This means the store of beach sediment is gradually being depleted in a north to south direction, exposing the foreshore and cliffs to wave attack and allowing rapid erosion. If this process continues unchecked, the beaches will continue to be eroded in a southwards direction, leading to progressive exposure of the foreshore and cliffs to waves and hydrodynamic forces, resulting in rapid erosion and cliff recession.

Placing a timescale on these events is beyond the scope of this study, but it is likely that continued southwards beach loss and reactivation of cliffs will occur annually as the coastline responds to sediment starvation and realigns in response to engineering.

4.3 Recommendations for future management

The accelerated cliff erosion and landslides near East Lane, Bawdsey, are thought to be a response to coastal defences and engineering activities, the most recent of which was construction of an offshore breakwater. This structure was designed to create a stable bay protected by a healthy beach. The success of this scheme is currently unclear, as only a limited beach has formed due to the limited supply of sediment, and because cliff erosion has accelerated in response to lowering of the shore platform.

A visual comparison of the predicted stable bay shape for the constructed 'Option 2' design and the 2010 aerial photograph shows the actual bay is 5 to 10m deeper that predicted for typical waves that approach the coast at 113°. The area affected is immediately fronting the part of the foreshore platform that has suffered lowering. The additional erosion is likely to relate to the limited supply of sediment, which has now allowed beach sediments to accumulate, and because of accelerated cliff erosion in response to lowering of the shore platform.

A possible solution to reduce the rate of cliff recession would be to re-establish a healthy beach in the bay through artificial beach feeding. This assumes that the original rock armour 'fish tail' design is correct and that sediment in the bay will not be transported south or offshore. A review of the assumptions underpinning these designs has not been undertaken and is beyond the scope of this assessment.

Consideration might also be given to reconstruction of the foreshore where localised erosion or excavation has occurred since 2009. Reinstatement and raising the level of the shore platform to the same elevation as *in situ* adjacent platforms might take the form of a rockfill mattress of the order of several metres thickness. Clearly the mattress will need to be properly designed to withstand the wave breaking forces and foundation conditions. The reinstated shore platform will reduce wave impact on the beach and cliffs, thereby reducing the high rates of erosion, landslides and cliff recession experienced in recent years.

Active cliff recession and landslides were observed where land drainage was evident in the cliffs. All of the landslides observed are associated with water seepages. Therefore, it is recommended that land drainage is directed away from the cliffs where possible. A deep c. 2m cut-off drain could be installed parallel to the cliff-top to intercept existing land drainage and divert surface water and shallow groundwater away from the cliffs.

Passage of agricultural vehicles close to the cliff edge may have a very marginal effect on cliff stability and erosion due to dynamic loading and vibration. Primarily for safety reasons, it is recommended that vehicles stay 10m away from the cliff edge to mitigate the risk associated with sudden cliff collapse and cliff recession.