Coastal Morphology Report

RP001/S/2007
January 2007
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Geomorphological analysis of East Lane Bawdsey

1. Beach level - profile analysis

The Strategic & Development Planning (Shoreline Management Group) in Anglia have biannual topographic surveys from 1991 at 1 km intervals along the Anglian coast. Nine of these profiles were analysed covering the area from the tip of Orford Ness to the left bank of the River Deben (figure 1 a-c). Summer survey data dating from to 1991 - 2006 was used, with the exception of S2B4A, which was not surveyed after 2002. Profiles were plotted and analysed in MATLAB and SANDS software.

The topographic surveys along transect lines gives an indication of changes and trends of beach level elevation along various sections of the beach profile. It is used to determine whether the beach is losing or accumulating material over a period of years. As of winter 2007, two new profile lines will be surveyed running either side of East Lane Bawdsey and can be utilised in future monitoring programmes.

Beach level - profile analysis results

S2C14
The profile records show a continued accretion trend, there are however unexplained fluctuations in beach levels around 1995. This is the most southerly profile on Orford Ness, although the profile does not cross the tip of the Ness, which is thought to be thinning and would be the most likely point from where sediment would leave the Ness. The tip of the Ness will be considered later in studies of aerial photography (figure 5).

S2B1S
This profile runs across the northern extent of Shingle Street. From 1992 to 1999 the area has been steadily accreting. In 2000 the beach level is seen to drop back to 1991 levels. There is further erosion the following year before the accretion trend starts again, large increases in level are witnessed in 2002-2003. However in 2006 the beach levels have once again returned to levels very similar to 1991. There is an apparent pattern of sediment accumulation for 6-8 years and then a return to a base level. These observations are supported by the aerial photography analysis. However the aerials show that the profile line is not representative of the Shingle Street area to the south, which has accumulated a lot more sediment by 2006 than in 1991.

S2B1
The profile is located on the southern extent of Shingle Street, the data shows a large increase in beach elevation levels. It seems likely this material is coming from the accumulation of shingle to the north, reflected in the S2B1S profile. From 1992 – 1995 the south of Shingle Street has been accreting at the same time as the north. In 1996-1997 there was some small erosion. In 1998 the upper section of the beach is seen to erode or redistribute to the lower section of the beach which has accreted. 1999 is stable with very little change to levels. In 2000, the year of the dramatic erosion in the north, S2B1 is seen to be accreting. However it is not until the next years summer survey in 2001 and again in 2002 that there is significant accretion shown at this profile. Accretion then continues to 2006 similar to the site above. In 2006 accretion is shown when S2B1S erodes dramatically for the second time, if sediment is shifting to the south along the beach, it would be expected to be reflected in the 2007 – 2008 surveys.

S2B2
Located in the bay between Shingle Street and East Lane Bawdsey the beach levels are shown to be stable. There is a roll back of the ridge crest from 1991 to 2006, with the ridge also
flattening to some extent. The transect surveys show slight annual variation in erosion and accretion amounts, but longer term the beach remains stable. The sediment balance here suggests any movement of sediment from Shingle Street does not reach this far.

**S2B3A**
S2B3A is located at the southern end of the bay and just north of the point of East Lane Bawdsey. This profile shows a high amount of erosion within the time span being considered, and a large reduction in the height of the beach. The erosion trend is the result of stable years and slight erosion on others, gradually leading to the now depleted beach levels compared to 1991. It might be possible that the beach is thinning at this point as the north bay readjusts to a more concave shape between Bawdsey and the Alde/Ore. It may also be that a sediment supplies from the south is being denied to the area and the beach is becoming more sheltered by the artificial hard point of East Lane.

**S2B4A & S2B4**
The survey results of S2B4A shows the profile of the constructed defences at East Lane Bawdsey. From 1991 - 2002 there is no change in the profile, other than the disappearance of the beach at the toe of the wall.
Profile S2B4 was later surveyed alongside S2B4A, replacing this transect, the new profile also runs along the rock defences.

**S2B5**
Immediately south of the hardpoint the profile history shows there has been nearly a 20 m erosion of the foreshore. However the profiles up to 2006 do not show any change in the cliff position. Slight erosion is seen annually, with no supply of sediment to compensate this loss, the beach levels continue to lower.

**S2B6**
The transect in the southern bay shows no change in levels. The beach remains very stable with a slight amount of erosion in 2005 and a slight amount of accretion in 2006.

**S2B7**
This profile is located north of the River Deben, it is most likely that material will leave the coastline here, to feed the shoal system offshore of the mouth called The Knolls, or alternatively be received from the river. The beach is affected by the distorted wave climate and diffracted easterly waves as a result of the presence of The Knolls. From the topographic surveys results, overall the beach here is stable, the data shows a very slight erosion trend. The beach remained stable until 1999 where there is some erosion at an elevation of 1-2 m, yet accretion lower down the beach. In 2000 there is a slight reduction in height and in 2001-2002 the lower section of the beach continues to erode very slightly. However in 2003-2004 this is countered by accretion, then again with accretion in 2006 balancing the erosion in 2005. It is unlikely that the hard point at East Lane Bawdsey has much influence on the morphology of this area, other than potentially limiting a sediment supply.
2. Beach level - foreshore change parameter analysis

The aim of the calculation of a foreshore change parameter (FCP) score through this analysis is to gain some indication of the evolution trend of the beach. The foreshore is defined as the beach between the Mean High Water Neap (MHWN) mark and the Mean Low Water Neap (MLWN). The analysis identifies whether the beach is retreating or advancing horizontally along these two levels. It also shows whether the beach is flattening or steepening in gradient between these two points. A foreshore change parameter score is then assigned based on these criteria. It is generally considered that a healthy beach in the region will be a stable beach or a beach advancing at both the MHWN and MLWN marks and flattening in gradient. Beach steepening is associated with erosion and a regressive beach (CCO, 2006).

The same topographic surveys from 1991 - 2006 used in section 1 were used in this analysis. Using only summer surveys means similar 'summer conditions' are compared and prevents changes caused by winter storms biasing results. Water levels are taken from Proudman Oceanographic Laboratory’s POLTIP software with one year of tidal data to give a mean water mark value. The analysis was carried out in SANDS and Microsoft Office Excel. In some years the surveys do not reach the MLWN mark, for these profiles trends were calculated with fewer years of data. An anomaly measurement in 1997 at low water levels on the S2B1S transect was identified, although this did not affect the profile trend the outlier was removed in calculation of the foreshore change parameter. Anomalies were also identified in profile S2B4A, this transect however runs through the rock defences at East Lane Bawdsey and changes in the profile can be attributed to maintenance works and additional rock armour.

Classification of the foreshore change parameter score is assigned according to table 7 in the appendix. A cut-off was used to identify ‘no rotation’ in the beach profile based on the mean movement trend and relative divergence of MHWN and MLWN. A threshold was used to identify ‘no movement’ and was calculated on the amount of movement of along the MHWN and MLWN levels. The 15 year data set only covers short term trends, however with ongoing monitoring these data will become more valuable in the future analysis of the area. The score system is derived from predefined thresholds and was limited to a small foreshore area due to the extent to the surveyors coverage.

Beach level - foreshore change parameter analysis results

<table>
<thead>
<tr>
<th>Profile No.</th>
<th>MHWN (m/yr)</th>
<th>MSL (m/yr)</th>
<th>MLWN (m/yr)</th>
<th>FCP score</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2C14</td>
<td>0.6905</td>
<td>0.6762</td>
<td>0.7325</td>
<td>+ 5</td>
</tr>
<tr>
<td>S2B1S</td>
<td>0.7744</td>
<td>0.9038</td>
<td>-0.909</td>
<td>+ 2</td>
</tr>
<tr>
<td>S2B1</td>
<td>4.8406</td>
<td>4.7911</td>
<td>4.847</td>
<td>+ 5</td>
</tr>
<tr>
<td>S2B2</td>
<td>-0.2453</td>
<td>-0.0969</td>
<td>0.0527</td>
<td>- 2</td>
</tr>
<tr>
<td>S2B3A</td>
<td>-1.737</td>
<td>-1.9541</td>
<td>-2.0558</td>
<td>- 6</td>
</tr>
<tr>
<td>S2B4A</td>
<td>-0.2135</td>
<td>-0.0974</td>
<td>-1.589</td>
<td>- 4</td>
</tr>
<tr>
<td>S2B5</td>
<td>-1.6308</td>
<td>-1.5569</td>
<td>-1.3852</td>
<td>- 4</td>
</tr>
<tr>
<td>S2B6</td>
<td>-0.718</td>
<td>-0.0376</td>
<td>0.0167</td>
<td>- 3</td>
</tr>
<tr>
<td>S2B7</td>
<td>-0.2511</td>
<td>-0.2682</td>
<td>0.02083</td>
<td>- 5</td>
</tr>
</tbody>
</table>

Table 1: Analysis by water level and foreshore change parameter score
Figure 1 a): Orford Ness to Shingle Street, profiles are accreting.
Figure 1 b): East Lane Bawdsey and the bay to the north are experiencing an erosion trend. Trends in the profile S2B4A are affected by the engineering works and rock armour installed at the site.
Figure 1 c): South of East Lane, on the approach to the River Deben. (Note arrows are correctly orientated along the survey bearings and are the length of the topographic profile with bathymetry carried out by the Shoreline Management Group.)
3. Beach area - aerial photography analysis

The Strategic & Development Planning (Shoreline Management Group) in Anglia have flown aerial surveys of this stretch of coast since 1991. For the initial analysis alternate years of photographs were used starting from 1991, until the last four years (2003-2006). This was a time consideration and it was thought to be a sufficient temporal spacing to identify changes in sediment patterns. It was necessary to georectify early photographs in ArcGIS 9.1 based on control points in the more recent orthorectified sets processed and captured by Blom Aerofilms (Blom, 2007).

The analysis concentrated on two areas, The Knolls and Shingle Street. The aim of the analysis was to complement the topographic studies by viewing the coverage and area of sediment and to identify the movement and littoral drift of sediment, namely shingle. Of particular interest was to investigate whether the accumulated bulge of shingle at Shingle Street migrates from the north to the south or vice-versa, how much have the Knolls grown in size, what shape do they form, and how far do they extend? The Shingle Street area was defined by the footpath and the extent of the residential and vegetation development (defined in 1991 photography), and between the transects of S2B1S and S2B1. This ensured a consistent area with only variation in the seaward growth of the beach being measured. The Knolls were defined as offshore shoals completely detached from the coastline.

The analysis only looks at the plan view of the coastline and the outline area within these defined boundaries. It identifies the horizontal spread of sediment and does not consider the vertical accumulation, this is measured from the topographic surveys and possibly LiDAR surveys in the future. The analysis is subject to errors in the GIS methodology, the ortho processing and the known associated flight and camera errors associated with aerial photography. These errors however are not considered to be significant to the results.

Beach area – aerial photography analysis results

The Knolls
The constant wave and tidal interaction has shaped the ebb-tidal delta of The Knolls into a long elongated system of accumulated sand and shingle banks. From 1991 to 2006 The Knolls system has drifted south along Felixstowe Ferry and slightly to the west, with the southern extent curving round to the southwest. The offshore shoals have moved downdrift of the inlet, becoming detached from the Bawdsey foreland in 1991. By 2006 the most northern level is almost in line with the Martello Tower E at Felixstowe Ferry. The Deben flows south along with The Knolls but also cuts channels through the shoals out into the North Sea keeping the banks separated. The main alternate channel is seen to be at its widest in 1999, and nearly closed in 1995. The deviated channels through The Knolls may act like hydraulic groynes holding up the banks to the north from progressing south and even serve to disperse the sediment. This appears to be happening in 1991 to 1999, although the northern most bank has grown in size again in 2001. It is these channels that flow out towards the southeast and create the tails in the banks.

It seems that the River Deben is the most dominant force shaping the Knolls, however this influence is reduced as the system progresses south. The river appears to keep The Knolls away from the Felixstowe coast and the banks themselves have a straight edge maintained by the flow, this is clearly seen in the 2006 images. The peak spring tidal discharge of the river exceeds 2000 m³ s⁻¹ (Burningham & French, 2006). However in 2001 the most southern detached bank of the Knolls is situated where river plume along the Felixstowe coast has become weak, here the southwesterly waves seem to become the dominant factor. Over successive years up to 2005 this bank has been pushed towards, and onto the beach at the Martello Tower marked 'F'. Despite the annual variation in area (table 2), the shape of The
Knolls has developed into a straight edged, elongated single shoal. This shape is the result of a gradual adjustment to the west into the flow of the Deben and through wave impact on the southern extent. This adjustment suggests northeast/southeast wave directions have the most influence, but these are not sufficient enough to push the Knolls onto the coast against the flow of the Deben. The Knolls would be sheltered from southwesterly waves by the protruding Felixstowe coast, and it does not seem likely that the sediment from The Knolls is moving north onto the Bawdssey coastline. The Knolls appear to have a greater sediment input than they do output, this may account for some of the erosion identified in the topographic studies of the Bawdssey southern bay.

The Haskoning, 2005[1] and Burningham & French, 2006 refer to a ten to thirty year cycle of The Knolls. This pattern follows a pattern of a period of growth that extends parallel with the west bank then continues in a perpendicular direction following the coast round. The Knolls are then breached, most likely in storm conditions, this reportedly occurred in 2001 (Haskoning, 2005[1]). The river creates channels flowing directly into the North Sea. The southern section of the Knolls no longer has the flow holding it away from the coast and a temporary natural breakwater eventually joins the shore and distributes sediment both southerly and into the Deben.

The Haskoning, 2005[1] report supports the aerial photography analysis in this section, especially regarding the transportation of sediment from the north to the south through The Knolls system. However the photography (figure 2) shows The Knolls system already had a fragmented distribution at the time of the reported breach in 2001. This may be the old breach channel but will still serve to allow access through The Knolls and result in a weaker main flow southward. The shape of the Knolls also appears to curve away from the coast in 1991, 1999 and 2006 due to pressure from the Deben. It is only the most southern, detached banks that are pushed by waves westerly onto Felixstowe. The fragmented section that joined the coast at Martello Tower F in 2005 is shown to form more of a spit protruding south rather than an evenly distributed breakwater. This structure remains mostly unchanged in 2006 and the sediment is likely to join the coast and migrate south and not back into the Deben as it is already too far along the coast. The photography shows the current situation that the single shoal extent is already level with Martello Tower F, according to the cyclical pattern another breach would be expected soon, only six years after the last.

Shingle Street

Shingle Street has experienced a steady growth in area, and an assumed increase in sediment volume from 1991 to 1999 (figure 3). In 2001 Shingle Street experienced a jump in area size from pre-2000 values to 13.9 Ha. This may have exceeded a critical point and have been too much sediment to be sustained and held. The shingle at this time extended into the river plume, and was most likely carved off, by either the ebb tide or by the waves that appear to curve round Orford Ness in flood tides. By 2004 the area has decreased to 10.6 Ha, from this time until present Shingle Street continues to steadily grow once again. The influence of waves is also highlighted by the salt water lagoon on Shingle Street that appears in 2001 and 2003, which is probably caused by wave overtopping.

The growth at Shingle Street correlates with the continued growth of Orford Ness (shown in profile S2C14). It seems more likely that material feeding Shingle Street is coming from the spit rather than the nearshore banks. However it is not clear whether the origin of the sediment is the tip of the ness, or from the spit within the River Alde/Ore. The predominantly southerly transport direction, and the complex wave and current system around the river mouth prevents this sediment from rejoining the ness. Disruption to the tidal flow and incoming waves are also affected by the bathymetric channels and the shoals south of North Weir Point.
Figure 2: Times series of The Knolls from 1991 – 2006 based on aerial photography

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Figure 3: Times series of Shingle Street from 1991 – 2006 based on aerial photography

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Figure 4. Overlay of aerial photograph survey of The Knolls showing migration of the system south and around coast at Felixstowe.
<table>
<thead>
<tr>
<th>Year</th>
<th>Knolls Area (Ha)</th>
<th>Difference</th>
<th>Shingle Street Area (Ha)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>9.764</td>
<td>7.049</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>5.461</td>
<td>4.3</td>
<td>7.195</td>
<td>0.1</td>
</tr>
<tr>
<td>1995</td>
<td>9.696</td>
<td>4.2</td>
<td>7.568</td>
<td>0.4</td>
</tr>
<tr>
<td>1997</td>
<td>8.061</td>
<td>1.6</td>
<td>8.093</td>
<td>0.5</td>
</tr>
<tr>
<td>1999</td>
<td>4.495</td>
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</tr>
<tr>
<td>2001</td>
<td>6.308</td>
<td>1.8</td>
<td>13.947</td>
<td>5.8</td>
</tr>
<tr>
<td>2003</td>
<td>5.618</td>
<td>0.7</td>
<td>12.919</td>
<td>1.0</td>
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<tr>
<td>2004</td>
<td>8.028</td>
<td>2.4</td>
<td>10.642</td>
<td>2.3</td>
</tr>
<tr>
<td>2005</td>
<td>4.989</td>
<td>3.0</td>
<td>11.403</td>
<td>0.7</td>
</tr>
<tr>
<td>2006</td>
<td>7.016</td>
<td>2.0</td>
<td>11.311</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Table 2: Erosion (red) / Accretion (green) pattern based on differences in area (Ha) from 1991 – 2006 measured at Shingle Street and Knolls area using aerial photography.

Orford Ness

Figure 5: Changes in ness determined from nadir aerial photography. By 2006 the ness is more elongated than in 1992. © Environment Agency copyright and/or database rights 2007. All rights reserved.

Comparison of the tip of Orford Ness beyond the S2C14 profile in 1992 and 2006 clearly shows that there has been significant build up in the length of the ness. The ness has become more established with saltmarsh species and has thinned slightly. The accumulating tip of the ness is not yet vegetated, but has remained stable over the fourteen years.
Figure 6: Erosion and morphology of the bays north and south of East Lane in 1992 (purple) and 2006 (red). The top of the beach follows the vegetation line, cliffs and structures. The low water line is assumed to be the water edge in photography, and rock armour line. The left image shows a consistent back line with a set back of the low water level. South of the defences at East Lane the impact of the rock armour in front of Martello tower D is clear, shortening the length of the beach and narrowing the width. There is no longer a beach present between the tower and the military installation at East Lane.
4. Sediment transport

This analysis has shown the variability in sediment accumulation/loss for the three areas above. These are the significant points of the coast around East Lane Bawdsey where sediment is accumulating and where sediment will be moving to and from. East Lane is at the centre of any sediment transfers between Orford Ness, Shingle Street and The Knolls. The hard point is undoubtedly affecting the littoral drift and this impact will only become more enhanced as the land either side moves back around the promontory. The Suffolk CHaMP report (Haskoning, 2002) calls Orford Ness a terminal sediment feature and major sediment source of 'primary control status'. East Lane Bawdsey is stated as being an anchor point retaining the north bay and again is a primary control. While The Knolls are a sediment sink and anchor point. Clearly these areas are key to this stretch of coast and the hard point will be of increasing influence if maintained. The above sections in this study can not define the sediment budget, or what the lag time on the processes that appear in the analysis are, or even whether the sediment in the north is reaching the Deben and The Knolls. Expanding on this analysis with future monitoring may help explain the sediment pathways.

The upper reaches of the Deben are mostly muddy, however accumulations of shell and gravel deposits exist (Burningham & French, 2006). The 2006 colour aerial photography (figure 7) shows that sediment is clearly suspended in the sea, close to the shore. This sediment may originate from the spit or be coming from offshore banks or off the bed. The photograph shows suspended sediment at the East Lane Bawdsey and even south of the hard point. Suspended sediment like this would be very fine material but neither the less is an indication that at the least a weak supply is reaching or is active on the southern beach. The suspended sediment can be seen washed up to the rock armour and presumable will move south, as it is unable to settle at East Lane. It also suggests that if there was a beach present at East Lane there would be a supply to feed it. The tide in the photography is known to be on the ebb and therefore material is potentially available for littoral drift. What can not be determined from the photograph is what the sediment is, its size or its destination.

Offshore banks
The offshore bed is a mix of mud, fine sand and broken shell. There are outcrops of London Clay and channels covered with fine sediment (HR Wallingford, 2002; Burningham & French, 2006). The depth of closure and the 10 m depth contour are in close proximity to the coast from Slaughden and along the study area. At this point offshore elongated banks and channels follow the tidal stream orientated from the southwest to northeast. Whiting Bank, Bawdsey Bank and Shipwash lie 3, 7 and 12 km offshore, respectively. Each having a minimum crest depth 1 m or less below the lowest astronomical tide. The Cutler is a small nearshore bank 3 km long situated just offshore of Bawdsey cliff (figure 14). The banks themselves are comprised of crushed shells and sand and can be eliminated as a shingle supply to the beach. The Southern North Sea Sediment Transport Study however links the material of The Cutler bank to Bawdsey Cliff (HR Wallingford, 2002). The sand banks are also significant as they can act to dampen waves and importantly the effect of storm waves. This would impact on littoral drift rates and the influence of the Alde/Ore.

The Environment Agency, National Marine Monitoring Team carried out a sediment survey following the approximate line and bearing of the topographic profiles identified in this study, only mud, sand and London Clay was identified. This makes progression of shingle from bank to bank or offshore unlikely. A further sediment survey and tracer study would however be worth considering in future monitoring programmes to clarify the link of the shoreline and the banks.

Tidal forcing
The tidal stream flows south along the coast preceding high water at Dover when the tide is moving into the North Sea from the Channel and to the north after high water at Dover.
Futurecoast, 2002 reports that modelling by the Halcrow Group identifies residual tidal currents as directed north along this stretch of coast. The Southern North Sea Sediment Transport Study SANDFLOW model shows on a spring tide the net tidal residual sediment (0.1 mm) flux is up to 100 kg/m/tide in a northerly direction. Coarser 2 mm gravel is only transported within approximately 20 km of the shore, this is again in a northerly direction. With surge and wind waves the net tidal residual sediment flux is in a southerly direction. The amount of 0.1 mm sand transported is between 1000-10000+ kg/m/tide and 2 mm gravel about 10 - 1000 kg/m/tide. Studies have also identified the possibility of a convergence of currents at the apex of the ness that may be fast enough to move shingle. However these currents are not regarded as capable of moving shingle around Bawdsey. HR Wallingford, 2002 states that Orford Ness becomes nearly 100% shingle, the report states that it is believed sand leaves the coast here, and shingle material continues south from the ness. It also states the predicted longshore transport rates at Bawdsey Manor were southwest and that material does successfully cross the mouth of the Deben. This is supported by the downdrift erosion witnessed at East Lane Bawdsey (figure 13). Posford, 2000[1] modelling estimates the southerly potential transport of shingle to be 83,000 m³ just north of East Lane and 140,000 m³ from East Lane to the Deben.

The general conclusion is that there is a high south sediment drift rate (Futurecoast, 2002). Studies however are not in total agreement of net longshore transport here. Waves and surges and a current lack of understanding of the local banks and bathymetry make estimating sediment transport with confidence difficult.

The residual tidal stream is a link between the beach and the bank system. Literature included in the Futurecoast project includes field measurements and modelling that show sediment is transported offshore to the sand banks. The theory is that material moves from one bank to the next, and when the beach is depleted the banks are at their largest and vice versa. However this contradicts the evidence from the National Marine Monitoring Team's survey data.

The topographic profiles and the aerial photography analysis of Shingle Street both support a southerly movement of sediment along the north Bawdsey bay. Halcrow, 1988 states the migration of the ness south is evidenced by truncated beach ridges along its northern side. These ridges are still present in August 2007. It also states the position of the ness correlates well with flood dominant residual channels in the nearshore, likely to drive the ness south. Halcrow, 2001 states south of the apex of the ness transport is southerly all year round. Between Lowestoft and Harwich Halcrow, 1997 predicts a southerly transport in winter and northerly reversal in the summer.

The sand and gravel material on the ness and the north Bawdsey bay originates from the north and the cliffs of Norfolk and Suffolk. The offshore contribution is not clear, but appears an unlikely supply of shingle material. A monitoring programme at the site could identify the amount of sediment that is able to reach and supply the southern bay and The Knolls, and determine how much material is lost offshore. An erosion analysis could also determine the rate of erosion of the Bawdsey cliffs. According to Pontee, 2005 two thirds of all this sediment stays in the beach system, it also reported that southern sediment moves offshore (Halcrow, 2001; Pontee 2005) where the sand banks are present. At this initial stage of analysis and supported by existing literature, it is surmised that sediment circulation is dominated by the transport of coarser material south as littoral drift, and finer sediment is circulated more offshore.
Figure 7: Suspended sediment shown in 2006 aerial photography. The blue arrows show the wave direction, the tide is in ebb at the time of the photograph. Suspended sediment must be very fine but can be seen around the East Lane hardpoint. Wave refraction can also be seen on the hardpoint. The promontory is exposed to high wave energy and is arguably not sustainability.
5. Wave Analysis

A Valeport 730D wave, tide and current monitor (identified as VP2) was deployed 0.6 km from East Lane Bawdsey by the Shoreline Management Group for the duration; 20 August 2003 - 20 August 2004. However in this period data was lost between 14 - 22 October 2003 and 29 March - 28 April 2004. From the start to 16 November 2003 the wave directionality was incorrect (Haskoning, 2005[2]), this data has been removed from the relevant analysis and the wave rose in figure 10. Analysis of this data was carried out in MATLAB from the data logged and quality checked by Gardline Environmental.

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (m LAT)</th>
<th>National Grid</th>
<th>WGS84</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Easting</td>
<td>Northing</td>
</tr>
<tr>
<td>VP2</td>
<td>4.19</td>
<td>636243.866</td>
<td>239628.624</td>
</tr>
</tbody>
</table>

Table 3. Valeport wave recorder location (Haskoning, 2005[2])

Storminess
If future monitoring were to be planned for a twenty-year period at the site of Bawdsey, analysis of storminess, wave heights and frequency would be a long term check on wave climate and climate change. In this study a storm is defined using the Peaks-over-Threshold method. An arbitrary number is used here, however in further analysis this study and past records can serve as a basis for future storm threshold values. The Channel Coastal Observatory suggests 5 years of data to produce a realistic value, with 3 or 4 storms a year being witnessed. Pontee, 2005 and Halcrow, 1988 report 1 in 100-year significant storm wave heights in the area as being between 2 and 4 m. One of the theories tested, based on post storm observations, is that the wave direction in storm periods is the opposite to calm/average conditions.

Wave analysis results
Wave climate is the primary indicator of sediment transport and cause of littoral drift. Waves measured by the Valeport instrument in 2003 show a dominant easterly rather than north-easterly direction as expected and referred to in HR Wallingford, 2002.

Figure 8: Aerial photograph of The Knolls in 1991. The dark blue arrow shows the wave direction. The Deben on the left of The Knolls is seen to be sheltered, a front can also be seen as the river flows through a channel in The Knolls, causing the bank to tail out.
Figure 9: previous page, Significant wave heights Aug 2003 – Aug 2004, the red line denotes the storm threshold.

Figure 10: Location of the wave recorder ‘VP2’ and wave rose showing the number of waves and directions.
Significant wave heights ($H_s$)
The significant wave height monthly means are shown in table 6 of the appendix. The instrument recorded an annual mean of 0.3 m. This is consistent with the Halcrow, 1988 study, which stated annual wave heights in this stretch as 0.2 - 0.3m between 1978 -1986. Pontee, 2005 suggests $H_s$ more recently are higher, ranging from 0.4 - 0.5m. The report also gives mean annual wave periods as approximately 6 s⁻¹.

Futurecoast, 2002 reports that the dominant waves direction is from the north-northeast to southeast along the line of maximum fetch in the North Sea for long swell waves. The Suffolk CHaMP authored by Haskoning, 2002 states for this coast the net wave energy direction is from the east, comprising principal components from the northeast and southwest. Burningham & French, 2006 state offshore wave heights averaging 0.96 m, with 50% coming from the northwest and 30% having a southwest modal direction. The data used in this study was recorded from January to December 2003. The CEFAS West Gabbard Buoy used is located approximately 45 km from East Lane, considerably further offshore than the Valeport recorder, (CEFAS, 2007). The local bathymetry moving offshore comprises of an area of tidal sandbanks many of which are exposed at low tide, however a small scour hollow to the east of the Inner Gabbard Sandbank has an approximate 60 m water depth. The inner and outer Gabbard sandbanks are situated 33 and 41 km offshore, respectively (Futurecoast, 2002). Conditions at the two instruments would be expected to be different with much of the waves being dampened by the sandbanks situated between them.

Maximum wave heights ($H_{max}$)
The winter period saw the most significant storms of high residual water levels and associated increase in wave heights. Five $H_{max}$ waves were recorded to have reached over 3 m in the year.

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<th>$T_z$ (s)</th>
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Table 4: Storm events, based on $H_s$, wave values recorded and the date they occurred

The effects of storms are significant and cause the rapid movement of shingle material on the low-lying coast. The 1 in 50 storm surge is predicted to be 1.5 m and extreme surges reaching up to 2 m (Futurecoast, 2002). In addition low pressure positive surges of 1 m can occur several times each year (Futurecoast, 2002; Pontee, 2005).

Three storm events were identified in the year (table 4) based on the highest significant wave heights experienced in the recorded time period. The highest waves were then identified, all of which were consistent with the dominant easterly wave directions. It is possible that larger storm events are required to see a change in the wave direction and therefore sediment transport direction. These results support reports such as Haskoning, 2002 and a general sediment drift to the south but with sections of the coast being in relative equilibrium. Halcrow, 1988 reports wave energy decreases towards the south and the littoral potential, although variable also predominantly southerly. The mean annual alongshore wave energy varies from 0-500 kN s⁻¹ and 500-1000 kN s⁻¹ across the study area. This drift is consistent with the formation and long term stability of The Knolls. Drift reversals are shown to be evident in the sand entrapment in groynes. The report also lists the on/offshore mean annual wave energy as 3000-6000 kN s⁻¹.
Figure 11: Mean direction with the three largest $H_{\text{max}}$ waves identified in red. All three 'storm' waves are close to 90 angle of approach.

Figure 12: shows that the largest waves ($H_{\text{max}}$) in this period did exceed the storm threshold on a number of occasions. The direction of the top three waves was all from the east despite the longest fetch being from the northeast.
Summary and conclusions
The above study and consideration of current monitoring data, has provided us with some idea of the processes occurring between Shingle Street and the River Deben.

East Lane Bawdsey
The hardpoint and rock defences at East Lane Bawdsey have reshaped the beach from a long straight stretch into two separated bays (figures 6 & 7). This has implications for transport of sediment along the coast. Aeolian transport of sediment will have stopped, and as the hardpoint becomes more prominent littoral drift may, if not already, cease to bring sediment to the southern bay. As well as impacting nearshore littoral drift, approaching waves at this point are being refracted as the bays develop. This has lead to erosion of the exposed south-orientated cliff at Martello tower D shown in figure 13.

Figure 13: Cliff erosion and rock amour. View looking northeast just south of Martello tower D at East Lane Bawdsey

An erosion trend at East Lane is illustrated in figure 6 and the topographic surveys of transect S2B3A located just to the north. This does not support the theory that the hardpoint is causing a build up of material in the southern section of the bay. Sediment is leaving the beach here, and for now it is surmised that there exists a path for sediment to rejoin the bay at a distance to the south of East Lane. The new Environment Agency profile S2B3B will help to analyse this in future. The accelerated rates of erosion just north of the promontory and immediately to the south appear to be due to a combination of sediment starvation and localised excessive current/eddy generation due to the effects of the promontory such as wave diffraction. Plumes of sediment are visible in the photography particularly in the nearshore and immediate vicinity of the promontory.

East Lane itself, due to the construction of a military installation in 1925, has become a seaward promontory, clearly shown in historic aerial photography. This hardpoint has prevented the natural rollback of the beach that has occurred on either side. The defences and the structures have led to coastal squeeze and increased wave reflection that have caused a total removal of the beach material. The promontory now separates the beach and is subject to high-energy wave impact, this is not sustainable without continued maintenance.

The current Environment Agency works have a design life of 10 -20 years. A continuation of this management strategy will lead to the area becoming more pronounced and a barrier to southerly transport of beach material. It will also enhance the refraction of waves on approach to the coast and be subject to erosion on the unprotected sides of the hardpoint (figure 13). To remove the defences or withdraw from maintenance would slowly erode and realign the beach and coastline. It is believed the single bay would return to a wider beach with a gentle curve.
There would most likely be a redistribution of shingle to fill in the beach area that now no longer exists, however it is not considered that the accumulated bulge of material at Shingle Street would disappear. There are however a number of cliff top properties, including Martello tower D already at risk, these would be sacrificed if the hardpoint was not maintained.

Wave analysis
The southerly progression of the shingle spit of Orford Ness, and its straight nature, which shows no signs of curving back onto the shore from aerial photography (figure 5), lead to the presumption of northeasterly waves. This is also supported by previous research reports based on offshore and wave analysis further north. However the Valeport instrument located at Bawdsey Cliff recorded mostly easterly waves. It may be that the channel bathymetry at the mouth of the River Alde/Ore prevents the spit from recurving despite the easterly waves, or that the wave direction does not become more easterly until further down the coast at Bawdsey. Detailed modelling and wave transformation to detail the local influence of the sandbanks and bathymetry could at a cost determine localised northerly transport if in existence. It could also identify transport around East Lane and at the two river mouths.

Sediment transport
At this initial stage it is concluded that sediment circulation is dominated by the transport of coarser material south as littoral drift and finer sediment is moved more offshore. The tidal influence is reflected in the on/offshore movement, while the wave climate influences the littoral drift more. The wave analysis carried out showed a more easterly rather than north easterly direction referred to in literature such as HR Wallingford, 2002.

The study area is comprised of sand and mostly gravel beaches from Orford Ness to the River Deben. This is backed by low cliffs (10 – 20 metres high) comprised of pre-glacial crag deposits (mainly sand and gravel). The hard engineering structures present have inevitably prevented the coast from self-regulating sediment supplies and influenced the coastal system. Although groynes are in place within the study area, the cliffs are actively eroding. South of the Deben beach levels are very low. (Halcrow, 1988).

The significance of the ebb tidal delta of the Deben is visible in The Knolls, however its contribution to changes at East Lane Bawdsey is negligible. However the observations of The Knolls continued growth up to 2006 may be a concern. As the Knolls cycle through periods of growth and dispersion it will affect the level of material being drawn in via the Deben (Burningham & French, 2006). The Knolls sediment supply from the Bawdsey coast may not be balanced and replenished by a northerly supply in the longer term due to the effects of East Lane.

Observations of the tip of Orford Ness shows the continued growth parallel to the shore and therefore continuing to direct the Alde/Ore flow along with it. Shingle Street has shown overall growth and adjustment of sediment from the north to the southern end. It is thought Shingle Street is being maintained by a number of localised processes in the currents around the Alde/Ore and the sediment supply from the Ness. It accretes and erodes dependent on the sediment supply and these localised processes. Presently it appears to be moving south slightly as when an erosion trend is witnessed at its northern side, an accretion trend is witnessed in the south. This trend can be confirmed, if it becomes more visible or alternatively can be dismissed with future monitoring and data. It is expected that the river will continue to carve sediment off Shingle Street and limit its growth. Growth may also be reduced or halted if the supply of sediment from the Ness is interrupted due to a breach or similar. The link between the Ness and Shingle Street appears to be more significant than between Shingle Street and East Lane. However it is likely that the promontory is supporting the growth of Shingle Street by preventing a southerly migration of sediment.
From the mid-section of the southern bay to the mouth of the Deben, the beach profiles show little overall change suggesting that this bay is a fairly closed sediment compartment. It is unlikely that much sediment is transported around the promontory from the north and equally unlikely any sediment is transported across the mouth of the Deben north to the foreland. While the promontory is in place the coast from Shingle Street to the Deben is developing and behaving as two almost independent bays.

Figure 14: Estimation of some of the sediment paths in the study area. The yellow arrows denote finer sediment, mostly being transported on/offshore. The orange arrows represent coarser shingle sediment moving in southerly alongshore direction. Coming off the ness and feeding into The Knolls, Bawdsey may interrupt this pathway, there are also areas of stability where there may be no movement of sediment. Pathways may also change under storm or variable conditions.

Considerations for the future
It is hoped that this study has highlighted aspects of the geomorphology of Bawdsey that are of interest or not fully understood and therefore can be targeted in a monitoring programme. There are further considerations that will impact on the area that also need to be accommodated in future studies. The Environment Agency's predicted or allowed sea level rise for East Anglia is 4.8mm y⁻¹. The driving forces in the area are water levels and wave action, which are influenced by sea level rise. A higher sea level will mean more erosion and therefore more sediment transport. This could lead to affects such as an extension to Orford Ness. Climate change also brings many unknown factors. For example increased storminess is expected and will cause more large scale shifts in shingle and ridge heights that are quick to respond to such events. Changes in wave climate will vary the alongshore and offshore/onshore transport of the area. Increased sea level will alter the tidal prism of the Alde/Ore and the Deben, this may also be caused by managed realignment and management works. There is the impact from future human development and adaptation of the coast.
through future Flood Risk Management policy and the Shoreline Management Plan. There is also the risk of a breach in the Ness which could lead to flooding of low-lying land, change the course of the Alde/Ore and affect the sediment supply to the south. An obvious point is at Slaughden, yet there are several locations on the Ness such around Stony Ditch point that are not defended and seem more likely to breach.

Monitoring Recommendations

From 2011 the Environment Agency, Shoreline Management Group will most likely adopt a more risk based monitoring programme. East Lane Bawdsey is certainly a dynamic 'hotspot' and is a politically sensitive area making it an area of significance and interest for monitoring. Until 2010 the group will continue to survey the area, with topographic and bathymetric surveys of the area as part of the Anglian Coastal Monitoring Programme Phase VII. This monitoring will also include aerial photography and maintenance of offshore Waverider buoys. The Acoustic wave and current meters (AWACs), including one at Bawdsey Cliff will be maintained until 2009, when they will be removed and modelled data with wave transform calculations will be made from the offshore buoys. In 2011, phase VIII will commence and standard strategic monitoring of aerial photography, and profiles will continue, including the two new topographic surveys at East Lane which started in 2007. Therefore there will be some degree of monitoring of this area in the future by the Shoreline Management Group. It is the opinion of this report that no additional monitoring is required to identify the effect of the promontory at East Lane. However for a full understanding of the geomorphology, sediment paths and the extent of the impact caused by the promontory, a more intense monitoring scheme, combined with modelling and wind data in addition to the existing work would ideally be required. This would especially apply in areas that locally differ from the net southerly sediment movement.

Some of the questions that would be sought to be answered by a specific monitoring programme in the area would be: what is the influence of the sandbars in distorting incoming waves and as a sediment sink? Is there evidence of climate change in sea level rise and storminess? What affect would sea level rise and a different wave climate have? Analysis of these data would hope to find definitive answers to; wave directions, sediment transport and associate processes through a synergistic use of data sets. For example relating beach shingle levels with wave heights, and identifying a correlation with increased wave heights with direction and shingle movement. Storm waves deposit shingle creating a crest out of the reach of non storm waves therefore observations of accretion above the MHWM may be relatable to storm events and be an indicator of storminess.

Reactive monitoring could follow storm events but also involve surveys of calm/control conditions. A programme like this could provide continuous data recording instead of just spot samples. There are AWACs located at Bawdsey Cliff, Felixstowe and Orford Ness providing continuous wave data until early 2009. There is also the potential opportunity to use mobile camera systems to record the beach elevations and morphology for continuous periods of time. With current spot sampling it is impossible to relate the quick response of a mobile material like shingle to wave heights. It is also not possible to make linear trends based on annual data. The data will need to be collected for an uninterrupted number of years, either in monthly blocks or continuously in that time. These data will then support the existing data sets that date back to 1991, which have been used in this report.
References:


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CEFAS, 2004: WaveNet http://map.cefasdirect.co.uk/wavenetmapping/advanced.asp

Futurecoast, 2002: Futurecoast CD. Produced by Halcrow Group Ltd for Defra, Swindon, UK.


http://www.sns2.org


Appendix Notes:

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Table 5: General erosion/accretion trend
- E = erosion  e = slight erosion
- A = accretion a = slight accretion
- = stable/no change

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Table 6: Hs monthly means recorded by VP2 at Bawdsey cliff site
### Glossary:

A selected glossary of terms that appear in this report.

**Beach profile & topographic survey**
Cross-section of a beach. The EA Shoreline Management Group topographic profiles are usually spaced 1 km apart, they run perpendicular to the shoreline and are surveyed every summer and winter. The profile extends from a permanent marker on the backshore to low water. Beach surveys are undertaken using land survey techniques or Global Positioning System (GPS). Along each profile, points are measured at 20 m intervals and at all breaks of slope, and any changes in geology, sediment type and/or habitat type, these are described on each profile.

**Coastal squeeze**
The narrowing of beach width or intertidal zone due to the position of barriers (such as sea walls) on the backshore preventing natural landward migration of the habitat/sediment.

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Table 7: Beach profile classification - Foreshore Change Parameter (CCO, 2006)
**Groyne**
A coastal defence structure placed perpendicular to the shoreline, designed to limit longshore sediment transport.

**MATLAB**
A high-level programming language and matrix based technical computing environment, with functions and 'toolboxes' for algorithm development, data analysis and visualisation and numeric computation developed by MathWorks.

**Ness**
A seaward promontory of sand or shingle, Orford Ness contains mostly shingle material which is highly mobile. The ness has curved to run south alongshore and thus redirecting the River Alde/Ore.

**SANDS (Shoreline and Nearshore Data System)**
SANDS is a database facility to store monitoring data that also comprises an analysis suite developed by the Halcrow Group.

**Sediment transport & net drift**
The movement of particulate matter by the forces of currents, waves and wind (aeolian). Net drift is the numerical aggregating of sediment movement over a period of time. It is used as an indicator of overall sediment movement along a coastal frontage. It does not provide information on the level of movement under any specific condition. For example a southerly net drift may be assigned due to storm activity moving significant amounts of sediment south, even if daily calm conditions may see a northerly transport.

**Significant wave height (Hs)**
Defined as the average height (from wave crest to trough) of the highest of one third of the waves at a point, in a given sea state for a period of time.

**Tidal currents & tidal stream**
The alternating horizontal movement of water associated with the rise and recession of the tide caused by tidal forces.

**Wave diffraction**
The phenomenon by which waves spread and distort due to interaction with obstacles and strong currents.

**Wave reflection**
The processes whereby waves impact on a solid surfaces and bounce back. Depending on the angle of approach reflected waves can interfere with the next set of incoming waves.

**Wave refraction**
The process by which shallow water waves 'bend' due to friction caused by bottom contours. For example as a wave enters a bay, where the water is slowed by friction the wave can alter direction depending on the orientation of the bottom contours, this gives the bending affect called refraction as the waves spread out. Waves approaching a promontory such as East Lane bend as the first contour is encountered, the converging waves then hit a smaller targeted area and erosion it.

**Wave period (Tp)**
The period of a wave is defined as the period of time it takes a wave (two successive crests or troughs) to pass a given point.

**Zero-crossing (Tz)**
This is the average or mean wave period.
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