Southeast Strategic Regional Coastal Monitoring Programme

BEACH MANAGEMENT PLAN REPORT

Pagham Harbour 2012

BMP 134
September 2013
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Abstract

An analysis of beach changes for the Pagham Harbour Beach Management Plan (BMP) area is presented in this report, covering the period from February 2011 to March 2012, and from the commencement of the Strategic Regional Coastal Monitoring Programme (SRCMP) in March 2003 to March 2012.

The volumes calculated from the surveys show that since February 2011 Church Norton Spit above 0mODN has extended in a northerly direction, accreting by 18,100m$^3$, an average rate of 16,600m$^3$/year. Since March 2003, the Spit has accumulated a total of 173,500m$^3$ of material. The growth of the Spit has fluctuated in speed and direction since 2003.

The Church Norton to Pagham Harbour frontage (formerly named 4dMU2) has in total accreted by 23,300m$^3$ above -1mODN since February 2011, and has seen an overall increase of 31,300m$^3$ of material since March 2003. The accretion has been distributed relatively evenly across the groyned part of the frontage and open beach at Church Norton.

The Pagham Beach frontage (formerly named 4dMU2A) has eroded by 26,800m$^3$ above 0mODN since February 2011. The most significant area of erosion lies in front of the houses on southwest Pagham Beach that lie south of the most southerly rock groyne. This area has been subject to scour and berm width reduction since 2009, when the outflow from the harbour was narrowed to a single channel in front of the houses. Hot spot analysis shows that this specific area has eroded by 34,600m$^3$ since 2003, with most of this loss (21,000m$^3$) occurring recently, between February 2011 and March 2012. Analysis of the berm width reduction in this area shows that the minimum width is now 29m, a reduction of some 10m since February 2011. This distance however remains greater than Royal Haskoning’s ‘Warning’ width of 20m.

The wave report for July 2011 to June 2012 shows there were only 2 occurrences of the significant wave height ($H_s$) above the threshold of 3.5m. However, the first of these storms, 13 December 2012, recorded the highest waves ($H_s$ of 4.55m) since the buoy was deployed in May 2008.

An analysis method known as ‘Trend Mapping’ has been conducted for the Spit and Pagham Beach area, showing the overall erosional and accretional trends based on all 14 baseline surveys. The map shows a large area of erosional trend on the southern part of the ebb delta and berm face of Pagham Beach particularly focussed in front of the residential properties, consistent with the volumetric findings.

Assessment of critical levels for Pagham Beach show there are currently 2 potential flood pathways at the ‘Warning’ level (5.3mODN), but none at the ‘Action’ (5.1mODN) or ‘Emergency’ (4.9mODN) levels.

1 Introduction

This Beach Management Plan (BMP) report provides a detailed analysis of beach changes and wave and tidal measurements since the commencement of the SRCMP.

This report encompasses Survey Unit 4dSU23 (formerly named 4dMU2 and 4dMU2A) which extends from Church Norton to Pagham. This unit is managed by the Environment Agency (EA) with a ‘hold the line’ policy to protect the wetland and mudflats that have been designated a Site of Special Scientific Interest (SSSI).
The location of the frontage is shown in Figure 1.1 and also includes the nearest wave buoy and tide gauge at Rustington. Also shown are the Church Norton and Pagham Spits, fronting the harbour entrance south side and north side respectively.

Figure 1.1 Location of Pagham Frontage

This report covers the period from February 2011 to February 2012, and from the commencement of the SRCMP in March 2003 to February 2012. The whole of Survey Unit 4dSU23 is modelled for these periods in this report. Further to this, there have been 14 baseline surveys since 2003 and these are included, covering the region labelled ‘survey-to-survey review area’ in Figure 1.2. This area encompasses the whole of Church Norton Spit to allow a focussed analysis of the evolution of the highly mobile sediment in the spit system.

Figure 1.2 Extent of Survey Unit 4dSU23 and Review Area (2008 Aerial Photography)
1.1 Church Norton to Pagham Harbour

The Church Norton to Pagham Harbour frontage is a sheltered east-southeast facing stretch with a relatively shallow lower foreshore due to an extensive offshore sand and shingle bank named ‘Inner Owers’. The beach has wooden groynes from Selsey in the southwest until farmland gives way to the Pagham Harbour saltmarsh and tidal mudflats, where a significantly wide shingle berm begins.

1.2 Pagham Beach

The Pagham Beach frontage is a southeast facing stretch that contains the main harbour channel and the leading tip of Church Norton Spit. Pagham Beach is backed by a row of houses along the northeastern half of the Unit, with four large shore-normal rock groynes to retain shingle.
2 **BMP Design Conditions**

2.1 **Tide Levels**

Tide Levels for the area from the UK Hydrographic Office (UKHO) are given in Table 2.1 below.

<table>
<thead>
<tr>
<th>Tide Level</th>
<th>Tide Height (mODN)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Selsey Bill</td>
</tr>
<tr>
<td></td>
<td>(Formerly 4dMU2)</td>
</tr>
<tr>
<td>MHWS</td>
<td>2.4</td>
</tr>
<tr>
<td>MHW</td>
<td>1.95</td>
</tr>
<tr>
<td>MHWN</td>
<td>1.5</td>
</tr>
<tr>
<td>MSL</td>
<td>0</td>
</tr>
<tr>
<td>MLWN</td>
<td>-1</td>
</tr>
<tr>
<td>MLW</td>
<td>-1.55</td>
</tr>
<tr>
<td>MLWS</td>
<td>-2.1</td>
</tr>
<tr>
<td>Spring Tidal Range (m)</td>
<td>4.5</td>
</tr>
<tr>
<td>Neap Tidal Range (m)</td>
<td>2.5</td>
</tr>
</tbody>
</table>

*Table 2.1. Tide Levels*
2.2 Wave Return Periods and Joint Probability

The recent development of a conceptual model of the Pagham Harbour system by Royal Haskoning\(^1\) has analysed wave return periods and joint probabilities, although the calculated figures are not yet available. However, the Action level identified by Royal Haskoning at 5.1mODN is defined as the 200 year Standard of Protection (SoP) including sea-level rise for the frontage, based on numerical wave modelling conducted by HR Wallingford\(^1\).

2.3 Critical Conditions

The Royal Haskoning study has specified Warning, Action and Emergency conditions for Pagham Beach. The criteria are based on beach berm width and height for the area in front of the houses between the harbour entrance and Pagham Sailing Club building. Table 2.2 below details the conditions.

<table>
<thead>
<tr>
<th>Alarm Level</th>
<th>Berm Width (m)</th>
<th>Berm Height (mODN)</th>
<th>Action Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning</td>
<td>20</td>
<td>5.3</td>
<td>Planning for recycling/recharge works and funding allocation to be undertaken</td>
</tr>
<tr>
<td>Action</td>
<td>15</td>
<td>5.1</td>
<td>200 year SoP. Recycling/recharge works to be undertaken</td>
</tr>
<tr>
<td>Emergency</td>
<td>10</td>
<td>4.9</td>
<td>Recycling/recharge works critical</td>
</tr>
</tbody>
</table>

Table 2.2. Pagham Beach Critical Conditions

Assessment of beach performance against these conditions for all baseline surveys is detailed in Section 12 of this report.

3 Surveys Conducted

All topographic surveys are conducted according to the Environment Agency’s National Specification, summarised in the Explanatory Notes in Annex A.

Numerous different survey methods have been used during the programme for data collection. These include aerial photogrammetry, Lidar and Real Time Kinematic (RTK) GPS surveying. The schedule of surveys completed since the start of the SRCMP is given in Table 3.1 below.

\(^1\) Royal Haskoning, Pagham Harbour Geomorphology (report to the Environment Agency) 2011
<table>
<thead>
<tr>
<th>Date</th>
<th>Coverage</th>
<th>Type</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/03/2003</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>13/07/2003</td>
<td>MU2 and MU2A</td>
<td>Profile</td>
<td>1:5000 Photogrammetry</td>
</tr>
<tr>
<td>23/04/2004</td>
<td>MU2 and MU2A</td>
<td>Profile</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>05/07/2004</td>
<td>MU2</td>
<td>Bathymetric</td>
<td>Single Beam</td>
</tr>
<tr>
<td>06/07/2004</td>
<td>MU2A</td>
<td>Bathymetric</td>
<td>Single Beam</td>
</tr>
<tr>
<td>22/08/2004</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>05/11/2004</td>
<td>MU2</td>
<td>Bathymetric</td>
<td>Single Beam</td>
</tr>
<tr>
<td>27/11/2004</td>
<td>MU2 and MU2A</td>
<td>Profile</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>22/04/2005</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>27/05/2005</td>
<td>MU2 and MU2A</td>
<td>Profile</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>17/09/2005</td>
<td>MU2</td>
<td>Profile</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>19/09/2005</td>
<td>MU2A</td>
<td>Profile</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>27/10/2005</td>
<td>MU2 and MU2A</td>
<td>Profile</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>04/11/2005</td>
<td>MU2A</td>
<td>Profile</td>
<td>1:5000 Photogrammetry</td>
</tr>
<tr>
<td>10/04/2006</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>12/06/2006</td>
<td>MU2 and MU2A</td>
<td>Profile</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>08/09/2006</td>
<td>MU2 and MU2A</td>
<td>Profile</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>10/10/2006</td>
<td>MU2A</td>
<td>Bathymetric</td>
<td>Single Beam</td>
</tr>
<tr>
<td>03/11/2006</td>
<td>MU2</td>
<td>Bathymetric</td>
<td>Single Beam</td>
</tr>
<tr>
<td>08/12/2006</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>Lidar</td>
</tr>
<tr>
<td>02/03/2007</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>1:3000 Photogrammetry</td>
</tr>
<tr>
<td>27/09/2007</td>
<td>MU2</td>
<td>Profile</td>
<td>RTK GPS</td>
</tr>
<tr>
<td>08/10/2007</td>
<td>MU2A</td>
<td>Profile</td>
<td>RTK GPS</td>
</tr>
<tr>
<td>06/01/2008</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>Lidar</td>
</tr>
<tr>
<td>12/03/2008</td>
<td>MU2A</td>
<td>Post Storm Profile</td>
<td>RTK GPS</td>
</tr>
<tr>
<td>02/09/2008</td>
<td>MU2</td>
<td>Profile</td>
<td>RTK GPS</td>
</tr>
<tr>
<td>14/10/2008</td>
<td>MU2A</td>
<td>Profile</td>
<td>RTK GPS</td>
</tr>
<tr>
<td>11/11/2008</td>
<td>MU2A</td>
<td>Post Storm Profile</td>
<td>RTK GPS</td>
</tr>
<tr>
<td>16/12/2008</td>
<td>MU2A</td>
<td>Post Storm Profile</td>
<td>RTK GPS</td>
</tr>
<tr>
<td>31/01/2009</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>Lidar</td>
</tr>
<tr>
<td>24/05/2009</td>
<td>MU2</td>
<td>Profile</td>
<td>RTK GPS</td>
</tr>
<tr>
<td>20/08/2009</td>
<td>MU2A</td>
<td>Profile</td>
<td>RTK GPS</td>
</tr>
<tr>
<td>01/12/2009</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>Lidar</td>
</tr>
<tr>
<td>13/05/2010</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>Lidar</td>
</tr>
<tr>
<td>11/10/2010</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>Lidar</td>
</tr>
<tr>
<td>03/02/2011</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>Lidar</td>
</tr>
<tr>
<td>28/09/2011</td>
<td>MU1 to MU3</td>
<td>Baseline</td>
<td>Lidar</td>
</tr>
<tr>
<td>08/03/2012</td>
<td>MU2 and MU2A</td>
<td>Baseline</td>
<td>Lidar</td>
</tr>
</tbody>
</table>

*Table 3.1. Completed surveys*

The surveys completed on 10 March 2003, 03 February 2011 and 08 March 2012 have been used in this report for comparisons covering MU2 and MU2A, and all 14 of the baseline surveys are included for comparisons covering the review area.
3.1 Panoramic Images of the MU2 Frontage over time

September 2003

August 2011

August 2012
3.2 Panoramic Images of the MU2A Frontage over time

**September 2003**

**August 2011**

**August 2012**
4 Beach Management Operations

The EA have in the past recycled shingle from the Church Norton foreshore to replenish loss from the Spit following winter storms when required. Since 2004 this recycling has not been undertaken due to the rapid accretion of the Spit. However, the changing shape and direction of growth of the Spit has led to some concerns over the potential for erosion along Pagham Beach from the harbour’s strong ebb current, now flowing northeastwards.

As detailed in the 2011 Pagham BMP report, recycling was undertaken in early November 2009, with further material dredged from the English Channel and imported during a second phase of works in March and April 2010. Table 4.1 below summarises the volumes involved.

### Table 4.1. Amounts of material recycling and recharge

<table>
<thead>
<tr>
<th>Date</th>
<th>Amount (m³)</th>
<th>Moved From</th>
<th>Moved To</th>
</tr>
</thead>
<tbody>
<tr>
<td>November 2009</td>
<td>10,000</td>
<td>Church Norton Spit</td>
<td>Pagham Beach, from most eastern rock groyne to 80m east of Pagham Sailing Club</td>
</tr>
<tr>
<td>March/April 2010</td>
<td>18,000</td>
<td>Imported</td>
<td>Pagham Beach, from most eastern rock groyne to 80m east of Pagham Sailing Club</td>
</tr>
<tr>
<td>March/April 2010</td>
<td>2,000</td>
<td>Imported</td>
<td>Pagham Beach, against the western side of the most eastern rock groyne</td>
</tr>
</tbody>
</table>

5 Surveyed Volumes

Figures 5.1 and 5.2 in Annex B present Digital Terrain Models (DTM) of the survey-to-survey review area for all 14 baseline surveys. Figure 5.1 shows a side by side comparison of the DTMs to provide an overview of the large-scale changes, and Figure 5.2 shows each model in closer detail.

Beach material volumes for this frontage are considered in three parts: MU2, Church Norton Spit, and MU2A. This distinction allows the rapid growth of the Spit to be considered independently and alongside the changes to the surrounding system.

5.1 Church Norton Spit Volume

The volume of material above 0mODN constituting Church Norton Spit has been calculated for all 14 baseline surveys. The 0mODN datum has been used as it is the lowest common level reached by all DTMs. Mean Low Water Neaps (-1.25mODN at MU2A) was not achieved sufficiently by the earlier surveys, in particular those performed using Aerial Photogrammetry.

The plan area of the spit considered for volume calculation is defined as the part of the spit that forms a barrier to the direct outflow from the harbour. The northeastward extent of this area is defined by the 0mODN contour generated from the survey data, and as such changes for each survey. The change in plan shape and morphology of the spit are analysed in further detail in Section 9 of this report.
Figure 5.3 gives a schematic illustration of how the spit extent is defined.

![Figure 5.3 Method Used to Define Extent of Pagham Harbour Spit](image)

The calculated volumes of the Spit are given below in Table 5.1, including the average rate of growth from survey to survey.

<table>
<thead>
<tr>
<th>Survey Date</th>
<th>Volume above 0mODN (m$^3$)</th>
<th>Mean rate of growth (m$^3$/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/03/2003</td>
<td>77,800</td>
<td>-</td>
</tr>
<tr>
<td>22/08/2004</td>
<td>73,700</td>
<td>-2,800</td>
</tr>
<tr>
<td>22/04/2005</td>
<td>75,200</td>
<td>2,300</td>
</tr>
<tr>
<td>10/04/2006</td>
<td>108,400</td>
<td>34,400</td>
</tr>
<tr>
<td>08/12/2006</td>
<td>107,500</td>
<td>-1,300</td>
</tr>
<tr>
<td>02/03/2007</td>
<td>163,800</td>
<td>244,500</td>
</tr>
<tr>
<td>06/01/2008</td>
<td>174,800</td>
<td>13,000</td>
</tr>
<tr>
<td>31/01/2009</td>
<td>226,800</td>
<td>48,600</td>
</tr>
<tr>
<td>01/12/2009</td>
<td>236,200</td>
<td>11,300</td>
</tr>
<tr>
<td>13/05/2010</td>
<td>241,900</td>
<td>12,800</td>
</tr>
<tr>
<td>11/10/2010</td>
<td>232,400</td>
<td>-23,000</td>
</tr>
<tr>
<td>03/02/2011</td>
<td>233,200</td>
<td>2,500</td>
</tr>
<tr>
<td>28/09/2011</td>
<td>235,400</td>
<td>3,400</td>
</tr>
<tr>
<td>08/03/2012</td>
<td>251,300</td>
<td>35,900</td>
</tr>
</tbody>
</table>

Table 5.1 Volume of Church Norton Spit to the nearest 100m$^3$

These volumes are graphed below in Figure 5.4, showing the significant accretional trend of the Spit as a solid line in black. However, a linear trend for the growth may not be considered the best fit for the data, as there is only a finite amount of north eastwards growth possible before the spit joins with Pagham Beach. The outwash from the Harbour ebb tide is an opposing force to this, slowing the growth, and so the decelerating trend shown as a dashed red line may be considered a better description of the system over time.
5.2 MU2 Volumes

Digital Terrain Models have been created from the baseline surveys for March 2003, January 2008, January 2009, December 2009 and February 2011 for the MU2 frontage.

To present volumes for these surveys, the amount of material above MLWN (-1mODN) has been calculated for the MU2 frontage, with its eastern boundary defined as the western extent of the barrier part of Church Norton Spit, as shown in blue in Figure 5.5.

As shown in Figure 5.6 below, the MU2 frontage has been divided into 32 discrete areas based on groyne bays or interim profile lines where there are no groynes.
The beach volumes for each of these MU2 areas are given in Table 5.2 below, for all surveys that achieved -1mODN.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MU2.1</td>
<td>5,100</td>
<td>6,100</td>
<td>5,700</td>
<td>5,400</td>
<td>6,200</td>
<td>5,900</td>
<td>6,000</td>
</tr>
<tr>
<td>MU2.2</td>
<td>7,300</td>
<td>8,800</td>
<td>8,400</td>
<td>8,000</td>
<td>8,600</td>
<td>8,400</td>
<td>8,800</td>
</tr>
<tr>
<td>MU2.3</td>
<td>7,400</td>
<td>9,100</td>
<td>8,800</td>
<td>8,400</td>
<td>8,600</td>
<td>8,700</td>
<td>9,000</td>
</tr>
<tr>
<td>MU2.4</td>
<td>8,000</td>
<td>9,100</td>
<td>9,100</td>
<td>8,900</td>
<td>8,600</td>
<td>8,600</td>
<td>9,300</td>
</tr>
<tr>
<td>MU2.5</td>
<td>8,500</td>
<td>9,900</td>
<td>9,700</td>
<td>9,400</td>
<td>8,700</td>
<td>8,800</td>
<td>9,600</td>
</tr>
<tr>
<td>MU2.6</td>
<td>9,300</td>
<td>10,600</td>
<td>10,300</td>
<td>9,900</td>
<td>9,000</td>
<td>9,400</td>
<td>10,200</td>
</tr>
<tr>
<td>MU2.7</td>
<td>11,500</td>
<td>12,600</td>
<td>12,400</td>
<td>11,800</td>
<td>11,100</td>
<td>11,400</td>
<td>12,200</td>
</tr>
<tr>
<td>MU2.8</td>
<td>12,500</td>
<td>13,500</td>
<td>13,400</td>
<td>12,700</td>
<td>12,300</td>
<td>12,100</td>
<td>13,100</td>
</tr>
<tr>
<td>MU2.9</td>
<td>12,400</td>
<td>13,300</td>
<td>13,100</td>
<td>12,500</td>
<td>12,100</td>
<td>12,100</td>
<td>12,800</td>
</tr>
<tr>
<td>MU2.10</td>
<td>10,900</td>
<td>11,900</td>
<td>11,800</td>
<td>11,800</td>
<td>11,000</td>
<td>11,300</td>
<td>12,000</td>
</tr>
<tr>
<td>MU2.11</td>
<td>10,500</td>
<td>11,300</td>
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<td>12,000</td>
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<td>12,600</td>
<td>12,900</td>
</tr>
<tr>
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<td>11,000</td>
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<td>14,100</td>
<td>14,900</td>
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<tr>
<td>MU2.13</td>
<td>69,700</td>
<td>73,700</td>
<td>54,200</td>
<td>53,500</td>
<td>46,700</td>
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</tr>
<tr>
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<td>27,800</td>
</tr>
<tr>
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<tr>
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<td>13,100</td>
<td>12,500</td>
<td>12,400</td>
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<td>8,300</td>
<td>7,800</td>
<td>7,800</td>
</tr>
<tr>
<td>MU2.18</td>
<td>9,900</td>
<td>10,700</td>
<td>10,900</td>
<td>11,100</td>
<td>10,600</td>
<td>9,700</td>
<td>9,900</td>
</tr>
</tbody>
</table>
Table 5.2 MU2 Beach Volumes above -1mODN to the nearest 100m$^3$

The table shows most of the MU2 areas are relatively stable, although MU2.13 (southern Inner Owers) has lost a large amount of material, some 20,000m$^3$ since 2003, with other significant losses in MU2.22 and 23 (northern Inner Owers) of some 22,000m$^3$ in total. The updrift areas immediately south of the harbour entrance, MU2.26 to 29 have accreted, however, gaining some 63,000m$^3$ in total.

The overall MU2 volume totals for each survey are graphed below in Figure 5.7, showing a recent recovery in overall volume following an erosional trend between 2008 and 2011.

![Figure 5.7 Total Volume of MU2 above -1mODN](image-url)
5.3 MU2A Volumes

Given the additional DTMs produced for the survey-to-survey review for the MU2A section of the frontage, volumes of material have been calculated for each of the 14 baseline surveys conducted since the start of the SRCMP. Due to the limited seaward extent of the earlier surveys, the volumes for MU2A are calculated as the amount of material above the 0mODN contour.

In order to exclude the Church Norton Spit from these volumes, the western extent of MU2A for the calculation is defined by the harbour training wall, as shown in blue in Figure 5.8.

![Figure 5.8 Western Extent of MU2A for Volume Calculation](image)

Figure 5.8 Western Extent of MU2A for Volume Calculation

Figure 5.9 below shows the MU2A frontage divided into 16 discrete areas based on groyne bays or interim profile lines where there are no groynes.

![Figure 5.9 MU2A Areas for Volume Calculation](image)

Figure 5.9 MU2A Areas for Volume Calculation

The beach volumes for each of these MU2A areas are given in Table 5.3 below.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
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<tr>
<td>MU2A.1</td>
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<td>11,400</td>
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<td>10,900</td>
<td>10,500</td>
<td>11,500</td>
<td>11,500</td>
<td>11,700</td>
</tr>
<tr>
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<td>37,900</td>
<td>35,700</td>
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<td>35,800</td>
<td>35,500</td>
<td>34,900</td>
<td>35,100</td>
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<td>40,000</td>
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<td>42,800</td>
<td>42,000</td>
<td>42,100</td>
<td>42,200</td>
<td>42,700</td>
</tr>
<tr>
<td>MU2A.6</td>
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<td>44,400</td>
<td>56,700</td>
<td>58,700</td>
<td>54,000</td>
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<td>55,800</td>
<td>55,500</td>
<td>54,500</td>
<td>54,700</td>
<td>54,500</td>
</tr>
<tr>
<td>MU2A.7</td>
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<td>30,800</td>
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<td>29,300</td>
<td>27,900</td>
<td>27,400</td>
<td>26,700</td>
<td>26,500</td>
<td>22,800</td>
</tr>
<tr>
<td>MU2A.12</td>
<td>18,800</td>
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<td>18,900</td>
<td>19,800</td>
<td>19,300</td>
<td>19,800</td>
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<td>18,900</td>
<td>18,500</td>
<td>18,200</td>
<td>17,700</td>
<td>16,300</td>
</tr>
<tr>
<td>MU2A.13</td>
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<td>37,900</td>
<td>39,700</td>
<td>38,200</td>
<td>39,600</td>
<td>38,000</td>
<td>39,100</td>
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<td>38,700</td>
<td>37,600</td>
<td>35,200</td>
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<td>MU2A.14</td>
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<td>48,100</td>
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<td>45,300</td>
<td>44,200</td>
<td>45,100</td>
<td>44,400</td>
<td>44,700</td>
<td>46,000</td>
</tr>
<tr>
<td>MU2A.16</td>
<td>74,900</td>
<td>75,200</td>
<td>73,000</td>
<td>75,200</td>
<td>69,100</td>
<td>67,900</td>
<td>63,700</td>
<td>62,800</td>
<td>61,700</td>
<td>73,600</td>
<td>71,800</td>
<td>71,500</td>
<td>67,600</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>648,100</strong></td>
<td><strong>562,100</strong></td>
<td><strong>616,500</strong></td>
<td><strong>638,000</strong></td>
<td><strong>595,000</strong></td>
<td><strong>604,700</strong></td>
<td><strong>575,800</strong></td>
<td><strong>584,700</strong></td>
<td><strong>573,700</strong></td>
<td><strong>582,800</strong></td>
<td><strong>572,000</strong></td>
<td><strong>575,700</strong></td>
<td><strong>560,500</strong></td>
</tr>
</tbody>
</table>

Table 5.3 MU2A Beach Volumes above 0mODN to the nearest 100m³
These MU2A volume totals are graphed below in Figure 5.10, showing a significant decline in beach volume for MU2A since 2011.

**Figure 5.10 Total Volume of MU2A above 0mODN**

6 Difference Models

Figures 6.1, 6.2 and 6.3 in Annex C present Difference Models of the survey-to-survey review area for all 14 baseline surveys.

Figure 6.1 shows a side by side comparison of the Difference Models to provide an overview of the changes, and Figure 6.2 shows each Difference Model in closer detail. Figure 6.3 presents the Difference Model of the March 2003 to March 2012 surveys.

6.1 Survey-to-Survey Review Area

The Difference Models highlight the rapid growth of the barrier part of Church Norton Spit and the accompanying changes to the ebb tidal delta and surrounding beaches.

Table 6.1 provides commentary on the significant changes within the review area since the start of the SRCMP, including the concurrent volume changes to the Spit.
<table>
<thead>
<tr>
<th>Survey Dates</th>
<th>Church Norton Spit</th>
<th>Significant Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td>To</td>
<td>Change in volume (m³)</td>
</tr>
<tr>
<td>10/03/2003</td>
<td>22/08/2004</td>
<td>-4,100</td>
</tr>
<tr>
<td>22/08/2004</td>
<td>22/04/2005</td>
<td>1,500</td>
</tr>
<tr>
<td>22/04/2005</td>
<td>10/04/2006</td>
<td>33,200</td>
</tr>
<tr>
<td>10/04/2006</td>
<td>08/12/2006</td>
<td>-800</td>
</tr>
<tr>
<td>08/12/2006</td>
<td>02/03/2007</td>
<td>56,200</td>
</tr>
<tr>
<td>02/03/2007</td>
<td>06/01/2008</td>
<td>11,000</td>
</tr>
<tr>
<td>06/01/2008</td>
<td>31/01/2009</td>
<td>52,000</td>
</tr>
<tr>
<td>31/01/2009</td>
<td>01/12/2009</td>
<td>9,400</td>
</tr>
<tr>
<td>01/12/2009</td>
<td>13/05/2010</td>
<td>5,700</td>
</tr>
<tr>
<td>13/05/2010</td>
<td>11/10/2010</td>
<td>-9,500</td>
</tr>
<tr>
<td>11/10/2010</td>
<td>03/02/2011</td>
<td>800</td>
</tr>
<tr>
<td>03/02/2011</td>
<td>28/09/2011</td>
<td>2,200</td>
</tr>
<tr>
<td>28/09/2011</td>
<td>08/03/2012</td>
<td>15,900</td>
</tr>
</tbody>
</table>

Table 6.1 Summary of Review Area changes
6.2 MU2 and MU2A

Figures 6.4 and 6.5 in Annex C present Difference Models of December 2009 to February 2011 and March 2003 to February 2011 respectively for the whole MU2 and MU2A frontage.

The maps include polygons to delineate and highlight the areas of significant accretion or erosion, with the change in volume within the area given on the maps. The polygons are based on areas with significant variation over the long-term, between March 2003 and February 2011, with the same areas used to assess both Difference Models.

Table 6.2 summarises the volume changes for each of these ‘hot-spot’ areas.

<table>
<thead>
<tr>
<th>Area</th>
<th>Volume Change (m$^3$) Feb 2011 to March 2012</th>
<th>Volume Change (m$^3$) March 2003 to March 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Owers (south)</td>
<td>-1,100</td>
<td>-35,200</td>
</tr>
<tr>
<td>Inner Owers (north)</td>
<td>-1,900</td>
<td>-50,600</td>
</tr>
<tr>
<td>Church Norton Beach</td>
<td>12,800</td>
<td>118,200</td>
</tr>
<tr>
<td>Ebb Delta (south of Church Norton Spit)</td>
<td>-8,200</td>
<td>-201,300</td>
</tr>
<tr>
<td>Main Body of Church Norton Spit</td>
<td>15,800</td>
<td>190,000</td>
</tr>
<tr>
<td>Harbour Entrance (south side)</td>
<td>-400</td>
<td>-25,000</td>
</tr>
<tr>
<td>Harbour Entrance (north side)</td>
<td>1,000</td>
<td>-38,800</td>
</tr>
<tr>
<td>Pagham Beach (southwest)</td>
<td>-21,000</td>
<td>-34,600</td>
</tr>
<tr>
<td>Pagham Beach (northeast)</td>
<td>-2,900</td>
<td>-13,500</td>
</tr>
</tbody>
</table>

Table 6.2 MU2 and MU2A Hot Spot area Volumes to the nearest 100m$^3$

7 Profile Change Analysis

The CD containing this report also has the profile charts and summaries of changes in cross-sectional area (CSA) for the MU2 and MU2A beach profiles, based on the baseline and BMP surveys.
The calculation of CSA is based on the area of beach above a Master Profile. Typically the lower boundary of the Master Profile would be set to Mean Low Water Neaps (-1mODN at MU2 and -1.25mODN at MU2A). Where the seaward limits of earlier surveys did not achieve MLWN, the height of the lower boundary has been increased so that the area beneath all survey profiles close and a consistent comparison can be established.

Figure 7.1 shows the locations of two example profiles passing through the Spit, plotted in Figures 7.2 and 7.3 to illustrate the change in cross-sectional shape over time.

Of particular note is the growth of the Spit and later reduction of the southern part of the ebb delta, as labelled on the profile plots.

Figure 7.1 Locations of example profiles
**Figure 7.2 Example profile 4d01401A passing through Pagham Beach and the Spit**

**Figure 7.3 Example profile 4d01402 passing through Pagham Beach and the Spit**
8 Bathymetric Surveys

A detailed multibeam hydrographic survey is currently being undertaken for the entire 4d coastal sub-cell. This work is part of a larger project to produce baseline maps of the bathymetry of the southeast of the UK. The resulting data sets are anticipated to be completed by Spring 2014, for inclusion in the 2014 BMP reports.

9 Changes in MHW Position

Maps showing the changes in Mean High Water position for the review area are given in Figure 9.1 in Annex D. The MHW contours for each survey are shown together to highlight changes, in particular the growth of Church Norton Spit. The lines also illustrate the erosion of southwest Pagham beach and the north side of the harbour entrance.

As outlined in Section 4 of this report, there have been public concerns over the erosion of southwest Pagham Beach, particularly in front of the houses west of the most south westerly rock groyne, following the growth of the Spit and the subsequent realignment of the outflow towards the northeast.

To explore this issue, the average distance from the houses to the Mean High Water (MHW) contour for every survey has been graphed in Figure 9.2 below, showing how the berm width has steadily decreased since 2009.

![Figure 9.2 Reduction in Berm Width Near the Most Westerly Houses in MU2A](image)
In relation to this, Figure 9.3 below shows how a rapid northward growth of the spit during 2009 blocked the ‘Southern Channel’ through the Ebb Delta, concentrating the outflow to a single channel in front of the houses. This also coincided with the beginning of the supposed deceleration of the spit growth (indicated by the red dashed line in Figure 5.4) as the outflowing water has since been able to flush further accumulation with a correspondingly greater force in the remaining ‘Northern Channel’:

![Figure 9.3 Blockage of the ‘Southern Channel’ through the Ebb Delta in 2009](image)

Table 9.1 below shows how both the Spit growth rate and direction of growth have affected the berm width in front of the houses on southwest Pagham Beach.
<table>
<thead>
<tr>
<th>Dates</th>
<th>Spit Growth (m)</th>
<th>Comments on Spit Growth</th>
<th>Average Distance from MHW to Houses (m)</th>
<th>Comments on Berm Erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/03/2003 to 22/08/2004</td>
<td>51</td>
<td>Significant growth to NE</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>22/08/2004 to 22/04/2005</td>
<td>76</td>
<td>Growth to NE</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>22/04/2005 to 10/04/2006</td>
<td>62</td>
<td>Growth to NE</td>
<td>83</td>
<td>Berm width relatively stable as Harbour outflow distributed over between to channels</td>
</tr>
<tr>
<td>10/04/2006 to 08/12/2006</td>
<td>20</td>
<td>Growth to NE</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>08/12/2006 to 02/03/2007</td>
<td>139</td>
<td>Growth to NE</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>02/03/2007 to 08/01/2008</td>
<td>141</td>
<td>Growth to NE</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>06/01/2008 to 31/01/2009</td>
<td>130</td>
<td>Growth to NE</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>31/01/2009 to 01/12/2009</td>
<td>112</td>
<td>Growth to N, southern channel blocked</td>
<td>73</td>
<td>Beginning of significant berm erosion due to blocking of southern channel</td>
</tr>
<tr>
<td>01/12/2009 to 13/05/2010</td>
<td>6</td>
<td>Very little growth</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>13/05/2010 to 11/10/2010</td>
<td>7</td>
<td>Very little growth</td>
<td>70</td>
<td>Concentrated outflow of northern channel preventing growth of spit to north, erosion of berm continues</td>
</tr>
<tr>
<td>11/10/2010 to 03/02/2011</td>
<td>44</td>
<td>Significant growth to N</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>03/02/2011 to 28/09/2011</td>
<td>-43</td>
<td>Previous growth to N eroded</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>28/09/2011 to 08/03/2012</td>
<td>56</td>
<td>Growth to NNE</td>
<td>52</td>
<td>Stable growth direction found (NNE) causing continuing narrowing of northern channel and erosion of berm</td>
</tr>
</tbody>
</table>

Table 9.1 Growth of Spit in relation to narrowing berm width in front of residential properties

10 Wave Climate and Storm Event Performance

A detailed analysis of the wave climate and storm events occurring between July 2011 and June 2012 is presented in Annex E.

The wave report for July 2011 to June 2012 shows there were only 2 occurrences of the significant wave height ($H_s$) above the threshold of 3.5m. However, the first of these storms, 13 December 2012, recorded the highest waves ($H_s$ of 4.55m) since the buoy was deployed in May 2008. No post-storm survey was conducted at Pagham during this reporting year.
11 Additional Analysis - Trend Mapping

The relatively large number of baseline surveys completed at Pagham since the start of the SRCMP has allowed an assessment of the growth of each geographical point of the review area frontage.

Whereas Difference Models show elevation changes between two surveys, trend mapping combines the elevation information from every available survey to reflect the beach change tendencies at every point in a single model, showing the growth of the beach in metres per year. Figure 11.1a below shows the trend map for the Pagham review area based on all 14 baseline surveys since 2003. Figure 11.1b presents the accompanying confidence map, showing which parts of the trend map are the most and least valid as a measure of elevation change. Annex F gives a full explanation of the trend mapping and correlation calculation methodology.

Figure 11.1a Trend Map of Pagham Review Area 2003 to 2012
Figure 11.1a shows a large area of erosional trend on the southern part of the ebb delta and berm face of Pagham Beach particularly focussed in front of the residential properties. Figure 11.1b shows that the confidence values for these areas are relatively high, and so this can be considered a relatively well-defined trend.

12 Assessment of Beach Performance Against Critical Levels

To assess the performance of Pagham Beach against the Warning, Action and Emergency conditions established by the 2011 Royal Haskoning report, the berm width and height have been analysed for the part of Pagham Beach fronted by residential buildings.

The berm width is defined as the distance from the back of beach houses to the beach crest, and the berm height is taken from the height of the March 2012 DTM. To determine the location of the beach crest, a standard deviation map has been created based on the 4 most recent surveys (October 2010, February 2011, September 2011 and March 2012). This map clearly distinguished the stable berm (low standard deviation values ~<0.05m) from the mobile beach face (high standard deviation values ~>0.25m) to allow a simple crest delineation. The cross shore distance from this line to the houses was sampled every 5m for the length of the assessment area to produce minimum, average and maximum values as show in Table 12.1.

<table>
<thead>
<tr>
<th>Survey Date</th>
<th>Berm Width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>03/02/2011</td>
<td>24</td>
</tr>
<tr>
<td>08/03/2012</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 12.1 Berm Width in front of Residential Properties
The table shows the current minimum berm width is 29m, and so is everywhere wider than the 20m Warning level. This minimum is an increase on the 2011 minimum width by some 5m.

The March 2012 berm height compared with the critical levels is shown in Figure 12.1.

Figure 12.1 March 2012 Berm Height Assessment

If the green ridge in the figure is considered a flood barrier, then currently 2 potential pathways can be identified as susceptible to 1:200 year storm waves, at the locations indicated by the blue arrows on the map. The most significant of these pathways lies in front of the houses affected by the major erosion on southwest Pagham Beach, which also coincides with the minimum berm width of 29m.

There are currently no apparent pathways at the Action level (orange) or Emergency level (red).
Figure 12.2 shows the locations of profiles 4d01388 and 4d01388B that pass through or near the potential flood pathways. These profile plots are shown in Figures 12.3 and 12.4 showing the baselines surveys against the critical levels.

![Figure 12.2 Profiles passing through or near potential flood pathways](image)

**Figure 12.2 Profiles passing through or near potential flood pathways**

![Figure 12.3 Berm height compared to critical levels: Profile 4d01388](image)

**Figure 12.3 Berm height compared to critical levels: Profile 4d01388**
Figure 12.4 Berm height compared to critical levels: Profile 4d01388B

The profile plots show the fluctuation of the berm height through time, highlighting in profile 4d01388B the significant narrowing of the berm width, between September 2011 and March 2012 of some 10m.
Annex A

Explanatory Notes
EXPLANATORY NOTES

1. Summary of method of conducting topographic and hydrographic surveys (based on the Environment Agency’s National Specification Sections XIII and XII)

Topographic cross-shore (profile) measurements are made at the intercept of the beach and a hard structure, at all changes of beach slope, at changes in surface sediment and at maximum defined intervals (every 5 metres). At some sites (those with long, low-tide terraces), the maximum interval is relaxed to 10 metres seawards of 50 metres from the beach toe. Each measurement is feature-coded with the sediment type. Profiles are 100-500m apart, depending on management status. The seaward limit is Mean Low Water Neaps.

Topographic baseline (spot height) surveys are carried out annually at Beach Management Plan sites. Cross-shore profiles are measured at 50 m intervals (in the same manner as for beach profiles) with the addition of spot heights at the crest and toe of hard structures, the beach surface surrounding structures, all beach ridge crests, all other changes in slope and sediment changes. All measurements are feature-coded with sediment type. Sufficient data points must be measured to generate a reliable Digital Terrain Model.

Hydrographic surveys are conducted with a single beam echo-sounder, with the position fixing requirement relaxed to DGPS. Soundings are taken along cross-shore profile lines 50m apart and extend 1km offshore. A minimum of 4 shore parallel tie lines are required (including one near each of the landward and seaward boundaries). The landward limit varies slightly across the region, due to the variation in tidal range, but in general is landward of Mean Sea Level, thus providing overlap with the topographic surveys. Tidal control may be by RTK GPS or by correction from tide gauges which are tied to the survey control network.

2. Change in Cross-sectional Area (CSA)

The annual change in cross-sectional area is calculated as the difference in CSA between two surveys, expressed as a percentage change compared to the earlier CSA.

\[
\frac{CSA_1 - CSA_2}{CSA_2} \times 100
\]

Eqn (1)

where \( CSA_1 \) = most recent springtime survey and \( CSA_2 \) = spring survey previous year. Therefore an annual change of \(-14\%\) represents erosion during the last year of \(14\%\) of the area of last year’s survey.

3. Method of derivation of Digital Terrain and difference models

The Digital Terrain Model is created by interpolating the points of a topographic baseline survey collected by using RTK GPS system. The interpolation method used to create the SCOPAC DTMs is specified as Natural Neighbour and is applied in ArcGIS to create a 1 metre resolution grid. The Natural Neighbours interpolation creates a Delauney Triangulation of the input points and selects the closest nodes that form a convex hull around the interpolation point, then weights their values by proportionate area. A Natural Neighbours interpolation combines TIN functionality with the raster interpolation process.
To visualise the resulting grid, the same colour scheme is applied, thus enabling comparison between grids of different geographic origin. The colour bands cover a elevation range between -4 to +12 metres OD with elevations lying between -2 and +5 metres OD are shown in 0.5 metres intervals, the remaining elevation bands shown in 1 metre intervals.

The difference models are created by using a grid calculator within the GIS system. For example the difference model of two baseline surveys is created by subtracting the earlier baseline grid from the most recent baseline grid:

$$Grid_1 - Grid_2$$ \hspace{1cm} Eqn (2)

where $Grid_1 =$ most recent baseline grid and $Grid_2 =$ previous baseline grid. Therefore an annual change of $-14m^2$ represents erosion during the last year of $14m^2$, whilst positive values represent accretion over the period.

Within the SDCG, the Digital Terrain Model is created by interpolating the points of a topographic baseline survey collected using aerial photography and photogrammetry techniques. The interpolation method used to create the SDCG DTMs is specified as Triangular Irregular Network (TIN) and is applied in Vertical Mapper to create a 1 metre resolution grid. The TIN interpolation connects points based on the nearest neighbour relationship (the Delaunay criterion) which states that a circumcircle drawn around any triangle will not enclose the vertices of any other triangle.
Annex B

Digital Terrain Models
Figure 5.1 - Digital Terrain Model Comparison (1 of 3)
Figure 5.1 - Digital Terrain Model Comparison (2 of 3)
Figure 5.2 - Digital Terrain Model (4 of 14)

Elevation (mODN)
- 10 to 12
- 9 to 10
- 8 to 9
- 7 to 8
- 6 to 7
- 5 to 6
- 4.5 to 5
- 4 to 4.5
- 3.5 to 4
- 3 to 3.5
- 2.5 to 3
- 2 to 2.5
- 1.5 to 2
- 1 to 1.5
- 0.5 to 1
- 0 to 0.5
- -0.5 to 0
- -1 to -0.5
- -1.5 to -1
- -2 to -1.5
- -3 to -2
- -4 to -3

April 2006

Pagham Harbour
Figure 5.2 - Digital Terrain Model (5 of 14)
Figure 5.2 - Digital Terrain Model (6 of 14)
Figure 5.2 - Digital Terrain Model (8 of 14)

Pagham Harbour

2008 Aerial Photography

Elevation (mODN)

-10 to -12
-9 to -10
-8 to -9
-7 to -8
-6 to -7
-5 to -6
-4.5 to -5
-4 to -4.5
-3.5 to -4
-3 to -3.5
-2.5 to -3
-2 to -2.5
-1.5 to -2
-1 to -1.5
-0.5 to 0
-0.5 to -1
-1 to -0.5
-1.5 to -1
-2 to -1.5
-3 to -2
-3.5 to -3
-4 to -3.5
-4.5 to -4
-5 to -4.5
-6 to -5
-7 to -6
-8 to -7
-9 to -8
-10 to -9

January 2009
Figure 5.2 - Digital Terrain Model (9 of 14)

Pagham Harbour

2008 Aerial Photography

December 2009

Elevation (mODN)

- 10 to 12
- 9 to 10
- 8 to 9
- 7 to 8
- 6 to 7
- 5 to 6
- 4.5 to 5
- 4 to 4.5
- 3.5 to 4
- 3 to 3.5
- 2.5 to 3
- 2 to 2.5
- 1.5 to 2
- 1 to 1.5
- 0.5 to 1
- 0 to 0.5
- -0.5 to 0
- -1 to -0.5
- -1.5 to -1
- -2 to -1.5
- -3 to -2
- -4 to -3

0 250 500m
2008 Aerial Photography

Figure 5.2 - Digital Terrain Model (10 of 14)
Annex C

Difference Models
Figure 6.1 - Difference Model Comparison (1 of 3) Pangham Harbour

Change in Elevation (m):
- <= -3
- -3 to -0.25
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to -0.25
- -0.25 to 0.25
- 0.25 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- 2.5 to 3
- >= 3

Accretion
- No Change

Erosion
- <= -3
- -3 to -0.25
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to -0.25
- -0.25 to 0.25
- 0.25 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- 2.5 to 3
- >= 3

March 2003 to August 2004
August 2004 to April 2005
April 2005 to April 2006
April 2006 to December 2006
December 2006 to March 2007
March 2007 to January 2008
Figure 6.1 - Difference Model Comparison (2 of 3)
Figure 6.1 - Difference Model Comparison (3 of 3)
Figure 6.2 - Survey to Survey Difference Model (1 of 13) Pagham Harbour

March 2003 to August 2004

Change in Elevation (m)

-3 to -0.25
-1.5 to -1
-1 to -0.25
-0.5 to 0.25
0.5 to 1
1 to 1.5
2 to 2.5
2.5 to 3
-2.5 to -3
-3

Erosion

Accretion

No Change
Figure 6.2 - Survey to Survey Difference Model (2 of 13)
Pagham Harbour

2008 Aerial Photography

August 2004 to April 2005

Change in Elevation (m)

- >= 3
- 2.5 to 3
- 2 to 2.5
- 1.5 to 2
- 1 to 1.5
- 0.5 to 1
- 0.25 to 0.5
- 0.5 to -0.25
- 1 to 0.5
- 1.5 to -1
- 2 to -1.5
- 2.5 to -2
- 3 to -0.25
- <= -3
Figure 6.2 - Survey to Survey Difference Model (4 of 13) Pagham Harbour

2008 Aerial Photography

April 2006 to December 2006

Change in Elevation (m)

- >= 3
- 2.5 to 3
- 2 to 2.5
- 1.5 to 2
- 1 to 1.5
- 0.5 to 1
- 0.25 to 0.5
- -0.25 to 0.25
- -0.5 to -0.25
- -1 to -0.5
- -1.5 to -1
- -2 to -1.5
- -2.5 to -2
- -3 to -0.25
- <= -3

Erosion

Accretion

No Change
Figure 6.2 - Survey to Survey Difference Model (5 of 13)

Pagham Harbour

2008 Aerial Photography

December 2006 to March 2007

Change in Elevation (m)
- <= -3
- -3 to -0.25
- -2 to -1.5
- -1.5 to -1
- -1 to 0.5
- -0.5 to -0.25
- -0.25 to 0.25
- 0.25 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- >= 3

Erosion
- No Change
- Accretion

0 250 500m
Figure 6.2 - Survey to Survey Difference Model (6 of 13) Pagham Harbour

Change in Elevation (m)

- >= 3
- 2.5 to 3
- 2 to 2.5
- 1.5 to 2
- 1 to 1.5
- 0.5 to 1
- 0.25 to 0.5
- -0.25 to 0.25
- -0.5 to -0.25
- -1 to 0.5
- -1.5 to -1
- -2 to -1.5
- -2.5 to -2
- -3 to -0.25
- <= -3

March 2007 to January 2008

2008 Aerial Photography
Change in Elevation (m)

-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to 0.5
-0.5 to 0.25
0.25 to 0.5
0.5 to 1
1 to 1.5
2 to 2.5

Erosion

No Change

Accretion

January 2008 to January 2009

Pagham Harbour

Figure 6.2 - Survey to Survey Difference Model (7 of 13)
Figure 6.2 - Survey to Survey Difference Model (8 of 13) Pagham Harbour

Change in Elevation (m)

-2.5 to -2
<= -3
-3 to -0.25
-2 to -1.5
2.5 to 3

Erosion
1.5 to 2
0.25 to 0.5
0.5 to 1
1 to 1.5
2 to 2.5

Accretion
No Change
0.25 to 0.5
-0.25 to 0.25
-0.5 to -0.25
-1 to 0.5
-1.5 to -1
-2 to -1.5
-2.5 to -2
-3 to -0.25
<= -3

January 2009 to December 2009

2008 Aerial Photography
Figure 6.2 - Survey to Survey Difference Model (9 of 13)

Pagham Harbour

2008 Aerial Photography

December 2009 to May 2010

Change in Elevation (m)

-2.5 to -2
-3 to -0.25
-2 to -1.5
-1.5 to -1
-1 to 0.5
-0.5 to -0.25
-2.5 to -2
-3 to -0.25
<= -3

>= 3
2.5 to 3
2 to 2.5
1.5 to 2
1 to 1.5
0.5 to 1
0.25 to 0.5
No Change

Accretion

Erosion

0 250 500m
Figure 6.2 - Survey to Survey Difference Model (11 of 13)

Pagham Harbour

Change in Elevation (m)

- Erosion:
  - 1.5 to 2
  - 0.25 to 0.5
  - 0.5 to 1
  - -1 to 0.5
  - -1.5 to -1
  - -2 to -1.5
  - -2.5 to -2
  - -3 to -2.5
  - <= -3

- Accretion:
  - 2.5 to 3
  - 1.5 to 2
  - 1 to 1.5
  - 0.5 to 1
  - 0.25 to 0.5
  - -0.5 to -0.25
  - -0.25 to 0.25

- No Change:
  - >= 3
  - 2.5 to 3
  - 2 to 2.5

October 2010 to February 2011
February 2011 to September 2011

Change in Elevation (m)

- >= 3
- 2.5 to 3
- 2 to 2.5
- 1.5 to 2
- 1 to 1.5
- 0.5 to 1
- 0.25 to 0.5
- -0.25 to 0.25
- -0.5 to -0.25
- -1 to 0.5
- -1.5 to -1
- -2 to -1.5
- -2.5 to -2
- -3 to -0.25
- <= -3

Figure 6.2 - Survey to Survey Difference Model (12 of 13)
Figure 6.3 - March 2003 to March 2012 Difference Model
Figure 6.4 (1 of 5) - 4d-MU2 Difference Model and Hotspot Analysis

Change in Elevation (m) between February 2011 and March 2012

-3.767 m

-1,142 m

Inner Owers (south)

Blue = Material Gained
Red = Material Lost

Volume (m³)
-3,767 m³
Figure 6.4 (2 of 5) - 4d-MU2 Difference Model and Hotspot Analysis

Change in Elevation (m) between February 2011 and March 2012

Blue = Material Gained
Red = Material Lost

Volume (m3)
-3,767

Inner Owers (north)
Figure 6.4 (3 of 5) - 4d-MU2 Difference Model and Hotspot Analysis

Change in Elevation (m) between February 2011 and March 2012

-3,767

Volume (m³)

Blue = Material Gained
Red = Material Lost

Ebb Delta (south of Spit)

Church Norton Beach

Harbour Entrance (south side)

(2008 Aerial Photography)
Pagham Beach

Main Body of Church Norton Spit

Accretion

Harbour Entrance (north side)

Harbour Entrance (south side)

Ebb Delta (south of Spit)

Change in Elevation (m) between February 2011 and March 2012

Volume (m³)

Blue = Material Gained
Red = Material Lost

Blue = Material Gained
Red = Material Lost

-3,767

15,831

-8,163

-1,043

-352
Figure 6.4 (5 of 5) - 4d-MU2 & MU2A Difference Model and Hotspot Analysis

Change in Elevation (m) between February 2011 and March 2012

- 2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -2 to -1.5
- -2.5 to -2
- -3 to -0.25
- >= -3
- 2.5 to 3
- 2 to 2.5
- 1.5 to 2
- 1 to 1.5
- 0.5 to 1
- 0.25 to 0.5
- -0.25 to 0.25
- -0.5 to -0.25
- -1 to 0.5
- -1.5 to -1
- -2 to -1.5
- -2.5 to -2
- -3 to -0.25

Erosion

Accretion

Pagham Beach (northeast)

Pagham Beach (southwest)

Volume (m3)

-3,767

-21,014

Blue = Material Gained
Red = Material Lost

(2008 Aerial Photography)
Change in Elevation (m) between March 2003 and March 2012

Volume (m$^3$)

-3,767

Blue = Material Gained
Red = Material Lost

Inner Owers (south)
Figure 6.5 (2 of 5) - 4d-MU2 Difference Model and Hotspot Analysis

Change in Elevation (m) between March 2003 and March 2012

- Erosion:
  - >= 3
  - 2.5 to 3
  - 2 to 2.5
  - 1.5 to 2
  - 1 to 1.5
  - 0.5 to 1
  - 0.25 to 0.5
  - No Change: -0.25 to 0.25
  - -0.5 to -0.25
  - -1 to 0.5
  - -1.5 to -1
  - -2 to -1.5
  - -2.5 to -2
  - -3 to -0.25
  - <= -3

- Accretion:
  - Blue = Material Gained
  - Red = Material Lost

Volume (m3)
-3,767

Inner Owers (north)
Figure 6.5 (3 of 5) - 4d-MU2 Difference Model and Hotspot Analysis

- Ebb Delta (south of Spit)
  - Change in Elevation (m) between March 2003 and March 2012
    - Blue = Material Gained
    - Red = Material Lost

- Volume (m³)
  - -3,767

- Harbour Entrance (south side)
  - -25,060
  - 118,168
  - -201,319

- Change in Elevation (m) between March 2003 and March 2012
  - >= 3
  - 2.5 to 3
  - 2 to 2.5
  - 1.5 to 2
  - 1 to 1.5
  - 0.5 to 1
  - 0.25 to 0.5
  - -0.25 to 0.25
  - -0.5 to -0.25
  - -1 to 0.5
  - -1.5 to -1
  - -2 to -1.5
  - -2.5 to -2
  - -3 to -0.25
  - <= -3
Figure 6.5 (4 of 5) - 4d-MU2 & MU2A Difference Model and Hotspot Analysis

Southeast Strategic Regional Coastal Monitoring Programme

BMP Site Report 2012

Change in Elevation (m) between March 2003 and March 2012

- >= 3
- 2.5 to 3
- 2 to 2.5
- 1.5 to 2
- 1 to 1.5
- 0.5 to 1
- 0.25 to 0.5
- No Change
- -0.25 to 0.25
- -0.5 to -0.25
- -1 to -0.5
- -1.5 to -1
- -2 to -1.5
- -2.5 to -2
- -3 to -2.5
- -3 to -0.25
- <= -3

Red = Material Lost
Blue = Material Gained

Volume (m³)

-3,767

Pagham Beach (southwest) -34,600
Harbour Entrance (north side) -38,796
Harbour Entrance (south side) -25,060
Main Body of Church Norton Spit 189,988
Ebb Delta (south of Spit) -201,319

(2008 Aerial Photography)
Figure 6.5 (5 of 5) - 4d-MU2 & MU2A Difference Model and Hotspot Analysis

Southeast Strategic Regional Coastal Monitoring Programme

Change in Elevation (m) between March 2003 and March 2012

- >= 3
- 2.5 to 3
- 2 to 2.5
- 1.5 to 2
- 1 to 1.5
- 0.5 to 1
- 0.25 to 0.5
- No Change -0.25 to 0.25
- -0.5 to -0.25
- -1 to 0.5
- -1.5 to -1
- -2 to -1.5
- -2.5 to -2
- -3 to -2.5
- <= -3

Pagham Beach (northeast)

Pagham Beach (southwest)

Volume (m³)

-13,456

-34,600

-3,767

Blue = Material Gained
Red = Material Lost

(2008 Aerial Photography)
Annex D

Mean High Water Position
Figure 9.1 (1 of 1) Changes in Mean High Water Position 2003 - 2012

Pagham Harbour

2008 Aerial Photography

Mean High Water Level 1.9mODN
Annex E

Rustington Wave Rider Buoy Report

July 2011 – June 2012
Rustington Waverider Buoy - July 2011 to June 2012

Location
OS: 506333E 93783N
WGS84: Latitude: 50° 44.036’ N  Longitude: 00° 29.677’ W

Water Depth
~10 m CD

Instrument Type
Datawell Directional Waverider Mk III

Data Quality

<table>
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<tr>
<th>Recovery rate (%)</th>
<th>Sample interval</th>
</tr>
</thead>
<tbody>
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<td>95</td>
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</tr>
</tbody>
</table>

Storm Analysis

<table>
<thead>
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<th>Date/Time</th>
<th>H_s (m)</th>
<th>T_p (s)</th>
<th>T_z (s)</th>
<th>Dir. (°)</th>
<th>Water level elevation (OD)</th>
<th>Tidal stage (hours re. HW)</th>
<th>Tidal range (m)</th>
<th>Tidal surge* (m)</th>
<th>Max. surge* (m)</th>
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</thead>
<tbody>
<tr>
<td>13-Dec-2011 00:30</td>
<td>4.55</td>
<td>8.3</td>
<td>6.9</td>
<td>200</td>
<td>2.94</td>
<td>HW</td>
<td>4.7</td>
<td>0.38</td>
<td>0.56</td>
</tr>
<tr>
<td>03-Jan-2012 09:30</td>
<td>3.86</td>
<td>10.0</td>
<td>6.7</td>
<td>218</td>
<td>0.29</td>
<td>HW +4</td>
<td>2.1</td>
<td>0.20</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Table D1: Highest storms during the reporting period, July 2011 to June 2012

A storm is defined using the Peaks-over-Threshold method (Figure D1). Each storm is then examined in detail, and covers the period 16 hours either side of the storm peak, so as to include both the build-up and decay of the storm. This is the procedure recommended by the CIRIA Beach Management Manual (second edition) since it covers the build-up and decay typical of mid-latitudes depression.

The threshold used for Rustington is 3.5m. Originally, the threshold was 3m, which necessarily erred on the low side for the first few years of deployment. The revised value has been determined using extremes analysis of 8 years of measured data (based on 3 hourly values) and the 0.25 year return period is used to identify 4 storms in an average year.

* Tidal information is obtained from the nearest recording tide gauge (the gauge on Arun Platform). The surge shown is the residual at the time of the highest H_s. The maximum tidal surge is the largest positive surge during the storm event.
Summary

This reporting year was relatively quiet in terms of number of storms, concentrated in December and January, but also experienced the highest waves measured since the deployment of the buoy. Apart from some isolated periods of moderate waves, the winter months from mid-January to March were unusually quiet.

![Storms at Rustington from Jul 2011 to Jun 2012](image1)

![Storms at Rustington - all years](image2)

Figure D2: Incidence of storms during reporting period (top) and since deployment (bottom)

Acknowledgements

TASK2000 tidal prediction software was kindly provided by the Permanent Service for Mean Sea Level, Proudman Oceanographic Laboratory.
Monthly time series of $H_s$

Figure D3: Monthly time series of $H_s$ at Rustington. Storm threshold, shown in red, is 3.5 m
**Highest storm**

This was the highest storm since the deployment of the wave buoy in 2003 and waves were breaking at the buoy for several hours during this storm; where breaking waves were clearly present in the measured time series, the parameters have been omitted. Accordingly, there are likely to have been short periods where measured significant wave heights the values shown.

The storm was associated with a deep depression (central pressure 946 hPa), situated to the west of Scotland (Figure D5) and saw a typical rapid rise in significant wave height from 3 to ~4.5m and subsequent decay within 8 hours. There is evidence of some long period swell some 14 hours prior to the storm peak. Wave direction backed from SW to SSW during the hours of highest waves, veering back to SW as the seas reduced below 3m. The main period of high waves spanned High Water, on a spring tide, but tidal surge was quite small (~0.3m).

**Rustington - Storms during Jul 2011 to Jun 2012**

![Graphs showing wave height (Hs), period (Tp), maximum wave height (Hmax), and tidal elevation (OD)](image)

**Figure D4: Highest storm of the reporting period**
Figure D5: Surface Pressure chart on 13 December 2011 at 00:00Z

Figure D6: Surface Pressure chart on 14 December 2011 at 00:00Z
Second highest storm

This storm also resulted from a deep depression (central pressure 968 hPa) off northwest Ireland (Figure D8), but was shorter-lived and with no evidence of a long period swell train. Storm direction remained SW for the duration of the storm, the peak of which occurred around mid-tide on a neap tide.

Rustington - Storms during Jul 2011 to Jun 2012

![Graphs showing storm data](image)

**Figure D7**: Second highest storm of the reporting period
Figure D8: Surface Pressure chart on 03 January 2012 at 00:00Z
Annex F

Trend Mapping Methodology
Trend Mapping Methodology

Trend mapping is intended to summarise the changes in elevation of a frontage through time in a single model. Whilst this aim is also achieved by a simple graph of total volume over time, trend mapping allows the independent consideration of the history and future of any points of interest and sub-regions within the modelled study area.

The ‘least squares’ method is used to establish the linear trend of elevation at each point, then the correlation of the trend is checked using the ‘root mean squared’ deviation of the measured heights from the trend line. A coloured map of trend values is produced, accompanied by a coloured map of correlation values to show which parts of the trend map are the most and least valid in terms of linear correlation.

The ‘root mean squared (RMS) deviation from the trend’ is used as a correlation measure in this methodology instead of the ‘correlation coefficient’ (CC), which is widely used in statistics to test of the strength of the linear dependence between two variables. The primary reason for this is that CC is undefined in cases where the slope of the least squares trend line is zero, as the variance of the elevations will also be zero. The scenario of little or no elevation change occurs commonly in the context of trend mapping of beaches. Using the RMS deviation as a correlation measure avoids this problem as it tests against a predetermined hypothesised linear trend, whereas the CC tests for any non-zero sloped trend.

An outline of the method used to generate the source data for the trend and correlation maps are given below.

1. Establishing the Trend

A closely-spaced grid of points is firstly created to cover the study area, then the elevations for each of the surveys at each of the grid points is determined using GIS software, giving a table such as the following:

<table>
<thead>
<tr>
<th>Easting</th>
<th>Northing</th>
<th>DTM_Oct03</th>
<th>DTM_Mar04</th>
<th>DTM_Nov04</th>
<th>DTM_May05</th>
<th>DTM_Dec05</th>
<th>DTM_Feb06</th>
</tr>
</thead>
<tbody>
<tr>
<td>54677.500</td>
<td>99730.000</td>
<td>5.80563</td>
<td>6.60188</td>
<td>6.84016</td>
<td>5.26998</td>
<td>6.28826</td>
<td>6.17332</td>
</tr>
<tr>
<td>546720.000</td>
<td>99730.000</td>
<td>5.80415</td>
<td>6.50149</td>
<td>6.83863</td>
<td>5.58995</td>
<td>6.55123</td>
<td>6.40362</td>
</tr>
<tr>
<td>546722.500</td>
<td>99730.000</td>
<td>5.98042</td>
<td>6.57740</td>
<td>6.80298</td>
<td>6.10243</td>
<td>6.84985</td>
<td>6.55410</td>
</tr>
<tr>
<td>546727.500</td>
<td>99730.000</td>
<td>6.00075</td>
<td>6.64506</td>
<td>6.77764</td>
<td>6.92933</td>
<td>6.59750</td>
<td>6.75755</td>
</tr>
<tr>
<td>546730.000</td>
<td>99730.000</td>
<td>6.00168</td>
<td>6.58675</td>
<td>6.75843</td>
<td>6.91049</td>
<td>6.61048</td>
<td>6.77374</td>
</tr>
</tbody>
</table>

*These columns are the elevation values from the Survey DTM’s*

For each row (i.e. each point on the beach) the gradient of the least squares trend of the survey dates (x-axis values) and elevations (y-axis values) is calculated. This value is then converted into the appropriate units of ‘metres growth per year’.

2. Establishing Confidence in the Model

To establish confidence in the trend at each beach point, the difference between each of the survey elevations and the height of the trend line is calculated for each row. These differences are then each squared and the mean of the results calculated. The mean
then square-rooted to give the correlation value (the confidence) for the trend at that beach point.

This can be summarised with the following algorithm:

For each Table Row
   For each Survey Elevation
      ‘Squared Deviation from trend line’ = (‘Measured beach height’ – (‘trend’ * ‘survey date’) + ‘Intercept’)^2
   Next survey elevation
   Mean Squared Deviation = Sum of ‘Squared Deviations from trend line’ / No. of Survey Elevations
   RMS Deviation = (Mean Squared Deviation)^0.5
   Next Table Row

The Diagram below shows a table of values calculated as above.

<table>
<thead>
<tr>
<th>Date</th>
<th>Trend Intercept</th>
<th>Deviation from Trend Line</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>04/04</td>
<td>5.26998</td>
<td>6.2606</td>
<td>0.999960314</td>
</tr>
<tr>
<td>05/05</td>
<td>5.65123</td>
<td>6.4510</td>
<td>0.999929351</td>
</tr>
<tr>
<td>05/06</td>
<td>6.10243</td>
<td>6.5410</td>
<td>0.999923275</td>
</tr>
<tr>
<td>06/07</td>
<td>6.5529</td>
<td>6.7558</td>
<td>0.999947267</td>
</tr>
<tr>
<td>07/08</td>
<td>6.91048</td>
<td>7.1704</td>
<td>0.999953275</td>
</tr>
</tbody>
</table>

The confidence values measure the validity of the trend of each point, with zero being a perfect correlation, reflecting a perfectly well-defined trend.

In the above example the correlation values are very large, implying that the validity of each of the corresponding trends are low. This is primarily because the number of surveys (six) is very small. More surveys, over a longer period of time, will generally result in better confidence values.