Southeast Strategic Regional Coastal Monitoring Programme

BEACH MANAGEMENT PLAN REPORT

Pagham Harbour 2010

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<table>
<thead>
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<tbody>
<tr>
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</tbody>
</table>
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1 Introduction

This Beach Management Plan Report provides a detailed analysis of beach changes and wave and tidal measurements since the commencement of the Strategic Regional Coastal Monitoring Programme (SRCMP).

This report encompasses Management Units MU2 and MU2A which extend from Church Norton to Pagham. These units are managed by the Environment Agency and include the Pagham Harbour frontage. A ‘hold the line’ policy has been adopted in both units in order to protect the wetland and mudflats in the hinterland that have been designated a Site of Special Scientific Interest (SSSI).

As part of the SRCMP the beach has been surveyed three times a year between 2003 and 2006 using aerial survey techniques. The surveys comprised biannual profile surveys and a complete beach plan survey every year. In 2003, the autumn aerial survey was not completed due to limited flight windows with favourable tides during daylight hours. Between 2007 and 2009, the autumn profile surveys were undertaken by the SDCG Survey Team with the spring profile and baseline survey completed by Lidar due to constraints associated with nesting birds. Since 2010, all surveys of Pagham Harbour have been completed by Lidar to minimise intrusion to the SSSI site. In addition to this, bathymetric surveys of the adjacent seabed were conducted in 2004 and 2006, and were reported on in the 2008 Pagham Beach Management Plan Report.

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](image)

On an annual basis and if required, the Environment Agency recycle shingle from the foreshore to replenish any loss from the Church Norton Spit following winter storms. This is typically done over an 8 week period between January and March. The Environment Agency has not undertaken any shingle recycling at Church Norton within the last 6 years due to beach stability and the rapid accretion of the Spit. However, the complex and highly dynamical character of the sediment drift regime has led to
concerns over the potential for the erosion of Pagham Beach from the harbour’s strong ebb current.

In 2008 Arun District Council commissioned Royal Haskoning to undertake an investigation of the system and the causes of coastal erosion along the Pagham frontage. This included a Geomorphological Assessment and a detailed Environmental Scoping Report on the feasibility of moving shingle from the distal end of Church Norton Spit to Pagham Beach, taking into account the environmental sensitivity of the site\(^1\). These works were carried out during this reporting year and form part of the discussion in this report.

Following the Royal Haskoning investigation, the Environment Agency are undertaking a project to create a detailed conceptual model of the harbour hydrodynamics and sediment regime\(^2\). The work has incorporated SRCMP data and analysis, and to complement the ongoing investigation, this report has been extended to form a review of the survey to survey changes at the site from the commencement of the programme to present, in addition to presenting the changes during this reporting year from January 2009 to December 2009, and the period from the baseline in March 2003 to December 2009.

The inclusion of additional modelling in this report aims to reflect an increased understanding of the system due to these investigations, and more specifically to illustrate the dramatic growth of the Church Norton Spit, and how the presence of the feature has impacted coastal processes on Pagham beach to the east.

Figure 1.2 shows the extents of Management Units 2 and 2A, and shows the area of Church Norton Spit and Pagham beach covered in the survey to survey review.

\(\text{Figure 1.2 Extent of Management Units and Review Area (2008 aerial photography)}\)

\(^1\) Royal Haskoning, Pagham Coastal Defence Study 2009  
\(^2\) Environment Agency, Pagham Harbour Geomorphological Model Study 2011
1.1 MU2 - Church Norton to Pagham Harbour

The Church Norton to Pagham Harbour frontage is a relatively 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 the point farmland gives way to the Pagham Harbour saltmarsh and tidal mudflats, where a significantly wide shingle berm begins.

![Image: Figure 1.3 Looking north from Church Norton towards Pagham Harbour Entrance](31 January 2007)

1.2 MU2A - Pagham Harbour to Pagham

The Pagham Harbour to Pagham frontage is a southeast facing stretch that contains the main harbour channel and the leading tip of Church Norton Spit. The 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.

Following a review of MU boundaries within Coastal Cell 4d during 2010 to consistently align the Units, the northeastern extent of MU2A is now delineated by the most northeasterly of the rock groynes. This boundary replaces the previous eastern extent at Pagham Sailing Club.

However, the area used for the survey-to-survey review model extends to the previous MU2A extent at Pagham Sailing Club to highlight differences in this area due to erosion and placement of material during beach recycling.
Figure 1.4  Westward view along the MU2A frontage after a storm, looking towards the Pagham Harbour Entrance

2  Tidal Conditions

Tide Levels for MU2 & MU2A from the UK Hydrographic Office (UKHO) are given in Table 2.1 below.

<table>
<thead>
<tr>
<th>Tide Level</th>
<th>MU2</th>
<th>MU2A</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHWS</td>
<td>2.4</td>
<td>2.55</td>
</tr>
<tr>
<td>MHW</td>
<td>1.95</td>
<td>1.9</td>
</tr>
<tr>
<td>MHWN</td>
<td>1.5</td>
<td>1.25</td>
</tr>
<tr>
<td>MSL</td>
<td>0</td>
<td>-0.5</td>
</tr>
<tr>
<td>MLWN</td>
<td>-1</td>
<td>-1.25</td>
</tr>
<tr>
<td>MLW</td>
<td>-1.55</td>
<td>-1.9</td>
</tr>
<tr>
<td>MLWS</td>
<td>-2.1</td>
<td>-2.55</td>
</tr>
<tr>
<td>Spring Tidal Range (m)</td>
<td>4.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Neap Tidal Range (m)</td>
<td>2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table 2.1. Tide Levels
3 Surveys

All topographic and bathymetric 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.

<table>
<thead>
<tr>
<th>MU2 Profile</th>
<th>Baseline</th>
<th>Bathymetric</th>
<th>MU2A Profile</th>
<th>Baseline</th>
<th>Bathymetric</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/03/2003³</td>
<td></td>
<td></td>
<td>10/03/2003³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13/07/2003⁴</td>
<td></td>
<td></td>
<td>13/07/2003⁴</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23/04/2004⁴</td>
<td></td>
<td></td>
<td>23/04/2004⁴</td>
<td></td>
<td></td>
</tr>
<tr>
<td>05/07/2004</td>
<td></td>
<td></td>
<td>06/07/2004</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22/08/2004³</td>
<td>22/08/2004³</td>
<td>22/08/2004³</td>
<td>05/11/2004</td>
<td></td>
</tr>
<tr>
<td>27/11/2004⁴</td>
<td></td>
<td></td>
<td>22/04/2005³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27/05/2005³</td>
<td></td>
<td></td>
<td>27/05/2005³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17/09/2005³</td>
<td></td>
<td></td>
<td>19/09/2005³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27/10/2005³</td>
<td></td>
<td></td>
<td>27/10/2005³</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>04/11/2005⁴</td>
<td></td>
<td>10/04/2006³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12/06/2006²</td>
<td></td>
<td></td>
<td>12/06/2006²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>08/09/2006³</td>
<td></td>
<td></td>
<td>08/09/2006³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/11/2006</td>
<td></td>
<td></td>
<td>10/10/2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>08/12/2006⁵</td>
<td></td>
<td></td>
<td>08/12/2006⁵</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/03/2007³</td>
<td></td>
<td></td>
<td>02/03/2007³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>06/01/2008⁵</td>
<td></td>
<td></td>
<td>06/01/2008⁵</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12/03/2008⁶</td>
<td></td>
<td></td>
<td>14/10/2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/09/2008</td>
<td></td>
<td></td>
<td>11/11/2008⁸</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16/12/2008⁶</td>
<td></td>
<td>31/01/2009⁵</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31/01/2009⁵</td>
<td></td>
<td></td>
<td>31/01/2009⁵</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24/05/2009</td>
<td></td>
<td></td>
<td>20/08/2009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/12/2009⁶</td>
<td></td>
<td></td>
<td>01/12/2009⁶</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13/05/2010⁵</td>
<td></td>
<td></td>
<td>13/05/2010⁵</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/10/2010⁵</td>
<td></td>
<td></td>
<td>11/10/2010⁵</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.1. Completed surveys

The surveys completed on 10 March 2003, 31 January 2009 and 01 December 2009 have been used for the BMP comparisons in this report, and all of the baseline surveys are included in the survey to survey review.

³ EA ABMS Survey – photogrammetry at a scale of 1:3000
⁴ EA ABMS Survey – photogrammetry at a scale of 1:5000
⁵ Survey undertaken using Lidar
⁶ Post Storm Survey undertaken using RTK GPS
4 Surveyed Volumes

Figures 4.1 and 4.2 in Annex C present Digital Terrain Models (DTM) of the survey to survey review area for all 11 baseline surveys.

Figure 4.1 shows a side by side comparison of the DTMs to provide an overview of the large-scale changes, and Figure 4.2 shows each model in closer detail.

4.1 Church Norton Spit

The volume of material above 0mODN constituting Church Norton Spit has been calculated for all eleven 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 Pagham Harbour) was not achieved sufficiently by the earlier surveys, in particular those performed using Aerial Photogrammetry.

Two volumes for each survey have been calculated, the first with a westward extent defined by the point at which the beach (berm) crest diverges to form the promontory, so includes ‘the whole spit’. The second is defined as the part of the spit that forms a barrier to the direct outflow from the harbour. The eastward extent of both of these areas is defined by the 0mODN contour generated from the survey data.

Volumes for both methods are given in order to assess which represents the more appropriate boundary for the western extent of Church Norton Spit.

![Figure 4.3 Methods used to define extent of Pagham Harbour Spit](image)

The calculated volumes are shown below in Table 4.1, including the average rate of growth from survey to survey.

Average rates of growth shown in blue are rates of accretion, while negative values represent average rates of erosion, and are shown in red.
<table>
<thead>
<tr>
<th>Survey Date</th>
<th>Spit From Westward Crest Divergence</th>
<th>Barrier Part Of Spit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volume above 0mODN (m³)</td>
<td>Mean rate of growth (m³/year)</td>
</tr>
<tr>
<td>10/03/2003</td>
<td>326,766</td>
<td>-</td>
</tr>
<tr>
<td>22/08/2004</td>
<td>324,946</td>
<td>-1,252</td>
</tr>
<tr>
<td>22/04/2005</td>
<td>332,374</td>
<td>11,164</td>
</tr>
<tr>
<td>10/04/2006</td>
<td>375,050</td>
<td>44,156</td>
</tr>
<tr>
<td>08/12/2006</td>
<td>368,011</td>
<td>-10,622</td>
</tr>
<tr>
<td>02/03/2007</td>
<td>429,623</td>
<td>267,895</td>
</tr>
<tr>
<td>06/01/2008</td>
<td>441,416</td>
<td>13,894</td>
</tr>
<tr>
<td>31/01/2009</td>
<td>503,726</td>
<td>58,206</td>
</tr>
<tr>
<td>01/12/2009</td>
<td>512,125</td>
<td>10,090</td>
</tr>
<tr>
<td>13/05/2010</td>
<td>518,093</td>
<td>13,375</td>
</tr>
</tbody>
</table>

Table 4.1 Volume of Church Norton Spit

These volumes are graphed below in Figure 4.4.

Figure 4.4 Volume of Church Norton Spit

The graph shows the significant accretional trend of the spit, and illustrates that as the difference between the volumes produced by the two methods remains relatively constant, the barrier part of the spit is providing the significant volume growth.
4.2 MU2 and MU2A

Digital Terrain Models have been created from the baseline and repeat baseline surveys for March 2003, January 2009 and December 2009 respectively for the whole MU2 and MU2A 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 4.5.

![Figure 4.5 Eastern extent of MU2 for volume calculation](image)

As shown in Figure 4.6 below, the MU2 frontage has been divided into 32 discrete areas based on groyne bays or interim profile lines where there are no groynes.

![Figure 4.6 MU2 Areas for volume calculation](image)
The beach volumes for each of these MU2 areas are given in Table 4.2 below.

<table>
<thead>
<tr>
<th>Area No.</th>
<th>Volume (m$^3$) above -1mODN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline March 2003</td>
</tr>
<tr>
<td>MU2.1</td>
<td>5,129</td>
</tr>
<tr>
<td>MU2.2</td>
<td>7,343</td>
</tr>
<tr>
<td>MU2.3</td>
<td>7,357</td>
</tr>
<tr>
<td>MU2.4</td>
<td>7,993</td>
</tr>
<tr>
<td>MU2.5</td>
<td>8,525</td>
</tr>
<tr>
<td>MU2.6</td>
<td>9,333</td>
</tr>
<tr>
<td>MU2.7</td>
<td>11,541</td>
</tr>
<tr>
<td>MU2.8</td>
<td>12,495</td>
</tr>
<tr>
<td>MU2.9</td>
<td>12,412</td>
</tr>
<tr>
<td>MU2.10</td>
<td>10,946</td>
</tr>
<tr>
<td>MU2.11</td>
<td>10,463</td>
</tr>
<tr>
<td>MU2.12</td>
<td>12,473</td>
</tr>
<tr>
<td>MU2.13</td>
<td>69,625</td>
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<td>MU2.14</td>
<td>26,942</td>
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<tr>
<td>MU2.15</td>
<td>10,105</td>
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<tr>
<td>MU2.16</td>
<td>13,490</td>
</tr>
<tr>
<td>MU2.17</td>
<td>7,456</td>
</tr>
<tr>
<td>MU2.18</td>
<td>9,924</td>
</tr>
<tr>
<td>MU2.19</td>
<td>26,817</td>
</tr>
<tr>
<td>MU2.20</td>
<td>31,005</td>
</tr>
<tr>
<td>MU2.21</td>
<td>57,376</td>
</tr>
<tr>
<td>MU2.22</td>
<td>111,464</td>
</tr>
<tr>
<td>MU2.23</td>
<td>119,238</td>
</tr>
<tr>
<td>MU2.24</td>
<td>108,557</td>
</tr>
<tr>
<td>MU2.25</td>
<td>62,890</td>
</tr>
<tr>
<td>MU2.26</td>
<td>30,387</td>
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<tr>
<td>MU2.27</td>
<td>40,784</td>
</tr>
<tr>
<td>MU2.28</td>
<td>39,020</td>
</tr>
<tr>
<td>MU2.29</td>
<td>63,521</td>
</tr>
<tr>
<td>MU2.30</td>
<td>69,426</td>
</tr>
<tr>
<td>MU2.31</td>
<td>79,013</td>
</tr>
<tr>
<td>MU2.32</td>
<td>27,353</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1,120,401</strong></td>
</tr>
</tbody>
</table>

*Table 4.2 MU2 Beach Volumes above -1mODN*

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 11 baseline surveys conducted since the start of the SRCMP. Due to the limited seaward extent of the earlier surveys, the volumes are taken from 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 4.7.

*Figure 4.7 Western extent of MU2A for volume calculation*

Figure 4.8 below shows the MU2A frontage divided into 16 discrete areas based on groyne bays or interim profile lines where there are no groynes.

*Figure 4.8 MU2A Areas for volume calculation*

The beach volumes for each of these MU2A areas are given in Table 4.3 below.
## Table 4.3 MU2A Beach Volumes above 0mODN

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MU2A.1</td>
<td>10,931</td>
<td>9,443</td>
<td>10,487</td>
<td>11,424</td>
<td>10,631</td>
<td>11,100</td>
<td>10,727</td>
<td>11,123</td>
<td>11,062</td>
<td>10,868</td>
<td>10,548</td>
</tr>
<tr>
<td>MU2A.4</td>
<td>52,289</td>
<td>48,307</td>
<td>45,318</td>
<td>44,201</td>
<td>40,009</td>
<td>41,250</td>
<td>39,914</td>
<td>41,120</td>
<td>40,604</td>
<td>40,438</td>
<td>39,832</td>
</tr>
<tr>
<td>MU2A.5</td>
<td>54,729</td>
<td>43,321</td>
<td>45,167</td>
<td>45,868</td>
<td>42,077</td>
<td>43,393</td>
<td>41,960</td>
<td>43,441</td>
<td>42,813</td>
<td>42,806</td>
<td>41,975</td>
</tr>
<tr>
<td>MU2A.6</td>
<td>66,158</td>
<td>44,392</td>
<td>56,693</td>
<td>58,685</td>
<td>53,979</td>
<td>55,340</td>
<td>53,260</td>
<td>56,248</td>
<td>55,847</td>
<td>55,494</td>
<td>54,549</td>
</tr>
<tr>
<td>MU2A.7</td>
<td>46,940</td>
<td>33,511</td>
<td>45,679</td>
<td>46,905</td>
<td>43,774</td>
<td>44,007</td>
<td>42,305</td>
<td>43,362</td>
<td>43,753</td>
<td>44,055</td>
<td>43,495</td>
</tr>
<tr>
<td>MU2A.8</td>
<td>40,208</td>
<td>26,393</td>
<td>42,074</td>
<td>44,132</td>
<td>41,258</td>
<td>41,501</td>
<td>39,599</td>
<td>39,046</td>
<td>38,703</td>
<td>38,178</td>
<td>37,592</td>
</tr>
<tr>
<td>MU2A.9</td>
<td>36,802</td>
<td>20,476</td>
<td>39,208</td>
<td>42,511</td>
<td>39,521</td>
<td>40,153</td>
<td>37,886</td>
<td>36,839</td>
<td>34,603</td>
<td>33,089</td>
<td>32,486</td>
</tr>
<tr>
<td>MU2A.10</td>
<td>17,908</td>
<td>17,731</td>
<td>18,788</td>
<td>20,219</td>
<td>19,180</td>
<td>19,391</td>
<td>18,298</td>
<td>17,876</td>
<td>16,386</td>
<td>15,953</td>
<td>15,628</td>
</tr>
<tr>
<td>MU2A.11</td>
<td>29,288</td>
<td>29,397</td>
<td>29,814</td>
<td>31,159</td>
<td>30,571</td>
<td>30,832</td>
<td>29,073</td>
<td>29,272</td>
<td>27,949</td>
<td>27,423</td>
<td>26,705</td>
</tr>
<tr>
<td>MU2A.12</td>
<td>18,809</td>
<td>18,762</td>
<td>18,915</td>
<td>19,810</td>
<td>19,272</td>
<td>19,771</td>
<td>18,708</td>
<td>18,970</td>
<td>18,894</td>
<td>18,489</td>
<td>18,180</td>
</tr>
<tr>
<td>MU2A.13</td>
<td>38,655</td>
<td>37,890</td>
<td>37,856</td>
<td>39,673</td>
<td>38,247</td>
<td>39,562</td>
<td>38,020</td>
<td>39,149</td>
<td>38,763</td>
<td>39,818</td>
<td>38,917</td>
</tr>
<tr>
<td>MU2A.14</td>
<td>37,813</td>
<td>36,498</td>
<td>35,654</td>
<td>37,165</td>
<td>35,031</td>
<td>35,925</td>
<td>33,331</td>
<td>34,631</td>
<td>33,539</td>
<td>33,217</td>
<td>32,837</td>
</tr>
<tr>
<td>MU2A.15</td>
<td>50,250</td>
<td>50,093</td>
<td>48,778</td>
<td>51,328</td>
<td>48,141</td>
<td>48,069</td>
<td>45,148</td>
<td>45,297</td>
<td>44,231</td>
<td>45,123</td>
<td>44,352</td>
</tr>
<tr>
<td>MU2A.16</td>
<td>74,855</td>
<td>75,238</td>
<td>72,955</td>
<td>75,244</td>
<td>69,106</td>
<td>67,916</td>
<td>63,672</td>
<td>62,766</td>
<td>61,727</td>
<td>73,577</td>
<td>71,793</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>648,125</strong></td>
<td><strong>562,137</strong></td>
<td><strong>616,453</strong></td>
<td><strong>637,996</strong></td>
<td><strong>595,023</strong></td>
<td><strong>604,653</strong></td>
<td><strong>575,755</strong></td>
<td><strong>584,669</strong></td>
<td><strong>573,654</strong></td>
<td><strong>582,753</strong></td>
<td><strong>572,007</strong></td>
</tr>
</tbody>
</table>
4.3 Panoramic Images of the MU2 Frontage over time

**September 2003**

**August 2009**

**August 2010**
4.4 Panoramic Images of the MU2A Frontage over time

**September 2003**

**August 2009**

**August 2010**
5 Difference Models

Figures 5.1, 5.2 and 5.3 in Annex D present difference models of the survey to survey review area for all 11 baseline surveys.

Figure 5.1 shows a side by side comparison of the difference models to provide an overview of the changes, and Figure 5.2 shows each difference model in closer detail. Figure 5.3 presents the difference model of the March 2003 to October 2010 surveys.

5.1 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 5.1 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>Barrier Part Of Spit</th>
<th>Mean rate of growth (m³/year)</th>
<th>Significant Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td>To</td>
<td>Change in volume (m³)</td>
<td></td>
</tr>
<tr>
<td>10/03/2003</td>
<td>22/08/2004</td>
<td>-4,121</td>
<td>Widespread erosion to ebb delta, southwest Pagham beach and the south side of the harbour entrance. Accretion to the southern side of Church Norton Spit and central section of Pagham beach.</td>
</tr>
<tr>
<td>22/08/2004</td>
<td>22/04/2005</td>
<td>1,515</td>
<td>Similar pattern of erosion and accretion, although erosion less severe. Growth of Church Norton Spit directed to the northeast.</td>
</tr>
<tr>
<td>22/04/2005</td>
<td>10/04/2006</td>
<td>33,208</td>
<td>Further extension of the spit to the northeast, with widespread accretion on the ebb delta.</td>
</tr>
<tr>
<td>10/04/2006</td>
<td>08/12/2006</td>
<td>-835</td>
<td>Small extension of the spit to the northeast, with widespread erosion on the ebb delta and Pagham beach.</td>
</tr>
<tr>
<td>08/12/2006</td>
<td>02/03/2007</td>
<td>56,222</td>
<td>Very large and significant extension of the spit to the northeast, with a leading ridge of accumulation on the ebb delta.</td>
</tr>
<tr>
<td>02/03/2007</td>
<td>06/01/2008</td>
<td>11,042</td>
<td>Further significant growth of the spit, with erosion to the part of the ebb delta lying south of the spit, and the south side of the harbour entrance.</td>
</tr>
<tr>
<td>06/01/2008</td>
<td>31/01/2009</td>
<td>51,998</td>
<td>Similar pattern of erosion and accretion, with a significant widening of the leading edge of the spit.</td>
</tr>
<tr>
<td>31/01/2009</td>
<td>01/12/2009</td>
<td>9,396</td>
<td>Extension of the spit directed due north, with erosion to the central section of Pagham beach and the southern side of the spit.</td>
</tr>
<tr>
<td>01/12/2009</td>
<td>13/05/2010</td>
<td>5,696</td>
<td>Extension of the spit to the northeast, with further erosion to the southern part of the ebb delta. Significant accretion to Pagham beach east of the most easterly rock groyne.</td>
</tr>
<tr>
<td>13/05/2010</td>
<td>11/10/2010</td>
<td>-9,517</td>
<td>Very little significant change to spit and the southwest section of Pagham beach. Long and narrow line of erosion to the seaward side of the spit.</td>
</tr>
</tbody>
</table>

Table 5.1 Commentary on Review Area changes
5.2 MU2 and MU2A

Figures 5.4 and 5.5 in Annex D present difference models of January 2009 to December 2009 and March 2003 to December 2009 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 December 2009, with the same areas used to assess both difference models.

Of particular note are the six areas of long-term erosion shown in Figure 5.5. Table 5.2 provides commentary on these areas, suggesting a possible cause for the loss of material in each case. These causes relate to the conceptual model of the overall sediment regime for Pagham Harbour, which is discussed in detail in Section 9 below.

<table>
<thead>
<tr>
<th>Area Description</th>
<th>Volume Loss (m$^3$) March 2003 to December 2009</th>
<th>Possible Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Owers (south)</td>
<td>-25,486</td>
<td>Onshore drift towards Church Norton Spit</td>
</tr>
<tr>
<td>Inner Owers (north)</td>
<td>-36,735</td>
<td>Onshore drift towards Church Norton Spit</td>
</tr>
<tr>
<td>Ebb Delta (south of Church Norton Spit)</td>
<td>-72,648</td>
<td>Scour due to wave reflection against Church Norton Spit</td>
</tr>
<tr>
<td>Harbour Entrance (south side)</td>
<td>-18,681</td>
<td>Scour due to ebb tidal current</td>
</tr>
<tr>
<td>Pagham Beach (southwest)</td>
<td>-48,845</td>
<td>Scour due to the deflection of the ebb tidal current direction from east to northeast</td>
</tr>
<tr>
<td>Pagham Beach (far east)</td>
<td>-28,315</td>
<td>Longshore drift, towards northeast and/or southwest depending on the location of a possible divergent drift divide</td>
</tr>
</tbody>
</table>

Table 5.2 Commentary on long-term erosional areas

6 Profile Change Analysis

The CD accompanying this report contains 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.

Previous Beach Management Plan reports have contained colour coded maps of the profiles to illustrate the changes. However, as the cross sections are derived from the
digital terrain models, they essentially represent only arbitrary samples of the more complete data set, and therefore cannot add to the analysis as the DTMs in Annex C and the difference models in Annex D cover the same periods.

7 Wave Climate and Storm Event Performance

A detailed analysis of the wave climate and storm events occurring between July 2009 and June 2010 is presented in Annex E.

The reporting period was a relatively quiet year for storms with only three occurrences of the significant wave height ($H_s$) above the threshold of 3.5m, all taking place between mid and late November 2009. However, this stormy period was significant for many sites along the south coast including Boscombe, Milford, Hayling Island and Pevensey Bay. In Coastal Cell 4d, the southwest facing section of Seaford beach was considered particularly exposed, and a post-storm survey was conducted on 8 December 2009 following the final event.

Although no post-storm survey was conducted at Pagham during this reporting year, the Autumn Lidar survey was flown on 1 December 2009, immediately after the stormy November period. Furthermore, the first of two phases of recycling works were undertaken before the storms at the start of November 2009.

The performance of the beach can be assessed from the difference model of January 2009 to December 2009 (Figure 5.4), and the quantities of placed material remaining after the storms, discussed below.

8 Beach Recycling Works

In early November 2009, approximately 10,000m$^3$ of beach material was moved from the distal end of Church Norton Spit and placed on Pagham beach between the most eastern rock groyne to 80m east of Pagham Sailing Club.

For second phase of the operation, a further approximately 20,000m$^3$ of material was imported and placed along the same stretch between March and April 2010. Approximately 2,000m$^3$ of this imported material was placed against the western side of the most eastern rock groyne and the remaining 18,000m$^3$ was placed from the most eastern rock groyne to 80m east of Pagham Sailing Club.

8.1 Phase One

Figure 8.1 below shows the extraction and deposition areas for the first phase of the works, showing volumes from the January 2009 to December 2009 difference model for each area. This model has been extended further to the east to encompass the entire deposition area, some 80m of which lies beyond the MU2A eastern extent.

The figure shows that as a result of erosion from January to December 2009, largely weighted by the November storms, the deposition area experienced a net loss of 11,629m$^3$, of which 10,000m$^3$ was the material placed during the Phase One works.
Figure 8.1 Phase One: Extraction and Deposition Areas

The extraction area experienced a net gain of 3,336 m$^3$, due to the accretion of the Church Norton Spit, although 10,000 m$^3$ was removed. The figure also highlights that the growth of the tip of the spit between January and December 2009 was in a northerly direction, deflected from the previous northeasterly direction.

Since December 2009 the direction of growth has returned to the northeast (Table 5.1).

8.2 Phase Two

Figure 8.2 shows the two deposition areas for the second phase of the works, showing volumes from the December 2009 to May 2010 difference model for each area. This model has also been extended further to the east to encompass the additional 80m that lies beyond the MU2A eastern extent.

The figure shows that Deposition Area A, from the most eastern rock groyne to 80m east of Pagham Sailing Club, retained all deposited material and experienced a net gain of 1,619 m$^3$ over the period.
Deposition Area B experienced erosion, with a net change of -1,792m$^3$. Material loss in this area was focused below the berm crest on the beach face.

**Figure 8.2 Phase Two: Recharge Deposition Areas**

9 Sediment Drift Regime

9.1 Sediment Transport
The location, orientation and dynamic nature of the Pagham Harbour system has resulted in a complex sediment drift regime. Figure 9.1 below shows the East Head to Pagham sediment transport map produced by the 2004 SCOPAC study of the south coast.

The map shows that the general longshore drift direction for the MU2 and MU2A area is towards the northeast. Southwest of a divergent drift divide located some 600-800m northeast of Pagham Harbour entrance, the direction of drift is reversed and is towards the harbour entrance. Northeast of the drift divide the drift direction is again towards the northeast.
The geomorphological assessment undertaken by Royal Haskoning in 2009 identified the major influencing features of the system\(^7\). A summary of these key features is given below.

- The tidal pattern is typically asymmetrical with a shorter ebb phase than the flood, resulting in a dominant ebb current of 1.0 to 1.5 metres per second in the harbour channel. This has led to the formation of the ebb tidal delta as material at the harbour entrance is flushed seaward.
- The shore parallel currents along the frontage, although not trivial, are less significant than the ebb current and range between 0.5 to 0.75 metres per second.
- The drift divergence is caused by wave refraction due to the ebb delta and orientation of the coastline with respect to the dominant wave directions from the southwest, south and southeast.

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\(^7\) Royal Haskoning, Pagham Coastal Defence Study 2009
- Drift convergence occurs where southwesterly drift meets the northeasterly ebb current.
- The major sources of sediment input include offshore and nearshore banks such as Inner Owers, the Mixon Shoal and Kirk Arrow Spit, as well as longshore drift.

Adding to these features, the difference models (Figures 5.1 to 5.5) indicate that a relatively consistent line of scour occurs to the ebb delta on the seaward side of the spit. This is assumed to be caused by reflected wave erosion as the spit forms a barrier preventing replenishment to this part of the delta by the flushing ebb tidal current.

To illustrate the main features of the system, Figure 9.2 presents a schematic interpretation of sediment drift regime.

![Figure 9.2 Schematic interpretation of the Pagham Harbour sediment drift regime](image-url)
The locations of the drift divergence and drift convergence both fluctuate and both depend upon the extent of the influence of the ebb current and the presence of the ebb delta. This demonstrates the complexity of the system as the ebb current feeds the ebb delta which itself generates the wave refraction, creating southwesterly drift that in turn opposes the ebb current.

With such a feedback mechanism, it could be envisaged that the continued northeastward growth of the spit could increase the influence of the ebb tide current so that the location of the drift convergence moves further to the northeast. If the gap between the divergence and convergence decreases without an accompanying extension of the ebb delta, the drift divergence could cease altogether so that the longshore drift direction would be uniquely to the northeast. This would inevitably affect the stability of the ebb delta due to a lack of material supplied longshore and subsequently the stability of the Church Norton Spit, eventually increasing the likelihood of breach and the formation of a new and straighter south or southeast facing channel.

9.2 Sediment Budget

In order to account for the movement of material into and out of the system, combined DTMs have been created encompassing the whole study area of MU2 and MU2A, for each of the March 2003, January 2009, December 2009, May 2010 and October 2010 surveys.

These surveys all achieved a seaward extent of -1mODN along the entire frontage and as such this datum has been used to calculate volumes for the entire system. It should be noted then that the ‘entire system’ refers only to material above this datum, so that potentially extensive amounts of material in the ebb delta, lower foreshore of beaches, nearshore banks (e.g. Inner Owers) and material entrained in the harbour itself are effectively ‘out of the system’.

The volumes are given Table 9.1, showing the change in volume between each survey and the average rate of growth.

<table>
<thead>
<tr>
<th>Survey Date</th>
<th>Volume (m$^3$) above -1mODN</th>
<th>Change in volume (m$^3$)</th>
<th>Mean rate of growth (m$^3$/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/03/2003</td>
<td>2,213,112</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>31/01/2009</td>
<td>2,318,534</td>
<td>105,422</td>
<td>17,876</td>
</tr>
<tr>
<td>01/12/2009</td>
<td>2,299,821</td>
<td>-18,713</td>
<td>-22,483</td>
</tr>
<tr>
<td>13/05/2010</td>
<td>2,301,835</td>
<td>2,014</td>
<td>4,513</td>
</tr>
<tr>
<td>11/10/2010</td>
<td>2,258,446</td>
<td>-43,389</td>
<td>-104,950</td>
</tr>
</tbody>
</table>

Table 9.1 Volumes of MU2 and MU2A above -1mODN

To discuss the changes in volume to the system as a whole, the mechanisms of sediment input and output and their magnitude should be considered:
**Sediment Inputs**

- Onshore Drift – from offshore and nearshore banks (e.g. Inner Owers), from beach foreshore material (below -1mODN) and from ebb delta (below -1mODN).
- Longshore Drift – from Selsey (MU1).
- Harbour Input – landward sediment transported into system by ebb tide.

**Sediment Outputs**

- Offshore Drift – movement of material to beach foreshore (below -1mODN) and to ebb delta (below -1mODN).
- Longshore Drift – out of system to the northeast (MU3) and to the ebb delta (below -1mODN).
- Harbour Output – sediment transported into harbour by flood tide.

The influence of each of these mechanisms is difficult to establish purely from topographic considerations, with changes occurring rapidly and on the margins of surveyed areas. It is anticipated that one of the outcomes of the ongoing Environment Agency study of the system\(^8\) will be an improved knowledge of the amounts of material supplied by and removed by each of these mechanisms. As such, discussion here is currently limited to the changes to the system as a whole above the -1mODN datum.

Table 9.1 shows that although the system has increased in size considerably since March 2003, the overall amount of material appears to have possibly started a downward trend, with a very high current rate of negative growth (erosion). Figure 9.3 shows a graph of the volumes to illustrate these changes over time.

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\(^8\) Environment Agency, Pagham Harbour Geomorphological Model Study 2011
It is suggested that a major factor of the apparent trend is the erosion of material in the southern part of the ebb delta, where the Church Norton Spit prevents renourishment by the ebb current.

10 Conclusions

The Pagham Harbour frontage continues to be a highly mobile beach with many influences, including complex tide, current and wave interactions that all affect the health of the beach protecting the SSSI wetlands and mudflats behind.

The most recent changes to the frontage suggest that material is being lost from the Inner Owers nearshore bank, the ebb delta and Pagham Beach (Figure 5.4). Although some 230,000m$^3$ of material is encapsulated in the barrier part of Church Norton Spit (Table 4.1), there is evidence that the body of the spit is thinning due to erosion along its seaward side (Figure 5.1, Table 5.1). It is suggested that this is related to erosion on the southern part of the ebb delta, where the spit itself prevents the ebb current from depositing replenishing material.

The longer term changes are characterised by general spit accretion, coupled with continued erosion at Inner Owers, the ebb delta, Pagham Beach and the south edge of the harbour entrance as material is redistributed within the system via a complex sediment drift regime (Figure 5.3). Although the MU2 and MU2A system (above -1mODN) as a whole had increased in volume by some 105,000m$^3$ between March 2003 and January 2009, the total volume has since dropped by some 60,000m$^3$ suggesting the beginning of a downward trend in the total material volume (Table 9.1, Figure 9.3). However, as much of the material stored in the ebb delta and nearshore banks is below -1mODN, it is possible that at least some of the material considered lost is retained in the system below this level. However, one of the outcomes of the ongoing Environment Agency study of the system is likely to be an improved knowledge of the magnitude of sediment inputs and outputs to the system, which will allow a more detailed assessment of the stability of the transport regime.

The recycling and renourishment works undertaken during November 2009 and March to April 2010 have certainly provided benefit to the system, with the imported material from Phase Two of the operations still in place (Figures 5.1 and 8.2). Although there were losses to the recycled material placed in Phase One, the placement of material before the November storms was timely and served to protect the vulnerable residential stretch at the eastern extent of MU2A.
References


Website

www1: http://stream.port.ac.uk/environment/scopac5/epag/index.htm
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.

\[
\text{Eqn (1)} \quad \frac{\text{CSA}_1 - \text{CSA}_2}{\text{CSA}_2} \times 100
\]

where \( \text{CSA}_1 \) = most recent springtime survey and \( \text{CSA}_2 \) = 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:

$$\text{Grid}_1 - \text{Grid}_2$$

Eqn (2)

where \( \text{Grid}_1 \) = most recent baseline grid and \( \text{Grid}_2 \) = previous baseline grid. Therefore an annual change of \(-14\text{m}\) represents erosion during the last year of \(14\text{m}\), 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

Glossary
Glossary

Data Application

This section aims to provide guidance on the accuracy and limitations of the Strategic Regional Coastal Monitoring Programme data, in order to inform its use and application. It must be appreciated that the accuracies of each measurement system must be taken into account when drawing conclusions from the data, particularly when interpreting difference models.

Topographic survey data

Topographic data points collected with RTK GPS can be considered accurate to ±0.03m for the baseline (spot height) surveys, which are used to generate both DTM's and difference models. Accordingly, differences of ±0.06m can generally be considered as ‘real’, whilst smaller changes may be an artefact of the measuring system, and should be considered as ‘no change’. In practice, Regional Monitoring Programme analysis considers only differences in excess of ±0.25m, as indicative of genuinely measurable change. Smaller changes may also be present but these are filtered from the analysis to provide clarity. Nevertheless, even where detailed analysis of difference models suggests that the changes are real, the user should approach the results as indicative, unless reinforced over time or with other information.

LIDAR data

LIDAR (‘Light Detection and Ranging’) is an aeroplane-mounted optical remote sensing technology. Modelling using LIDAR as the source the data set is less precise than RTK GPS. Each LIDAR cell value has a plan position representative of a 1m² grid (pre-2007 data is 2m² resolution). Changes with positional accuracy of better than 1-2m, therefore, cannot be observed. Profiles across steep slopes may suggest that the changes ‘bounce’ back and forth. This is an artefact of the accuracy of the source data. LIDAR is particularly ineffective at identifying sharp edges or steep slopes e.g. seawalls and cliffs where an affect known as ‘shadowing’ can occur. Despite these limitations in accuracy, the changes will indicate an overview of change, but to a lower precision than the RTK data. Users should compare the differences with the adjacent topographic profiles to confirm how representative lidar difference models are of real change.

Ortho-photography

All ortho-photography since 2002 uses a common ground control network, but care must be taken when comparing results with earlier photography. It is not unknown for instances of swimming pools to have ‘moved’ up to 2m, due to a different control network.
**Coastal Terms**

**Beach Backstop**
This maybe defined as a seawall, promenade or any other structure at the back of a beach. If no backstop structure exists, for the purposes of master profile analysis this is the perceived landward boundary of any given active beach.

**Coastal Process Cell**
The coast of the UK has been divided into a series of Major Coastal Cells, many with sub-cells. These sub-cells represent a practical subdivision of the coastline into lengths that follow sediment cell principles while enabling suitably sized groups to be formed to consider coastal defence issues at the strategic level. This provides the necessary framework for Operating Authorities to prepare Shoreline Management Plans (SMP’s).

**Coastal Process Cells of Southeast UK**

**Cross-Sectional Area**
The cross-sectional area is the area between the survey profile and the master profile.

**Management Unit**
A Management Unit is a length of shoreline with coherent characteristics in terms of natural coastal processes, land use and coastal defence.

**Master Profile**
The Master Profile is the boundary or datum, which any given profile is measured against. Each profile has a unique Master Profile, with a lower boundary of Mean Low Water Neaps (MLWN), which allows only the active beach cross-section of each survey to be measured and compared against other surveys.

**Mean High Water Contour**
The Mean High Water (MHW) contour is the line at which the beach intersects the average High Water elevation for a particular region. This implies that beach erosion (and subsequent encroachment of the sea) can be highlighted as a landward shift of the MHW contour. As shown below, the amount by which the MHW position will shift for a given change in volume is directly related to the steepness of beach.
Specifically, loss of material on a low gradient (gently sloping) beach will result in a more significant landward movement of the MHW position than the same volume loss on a steeper beach:

**Beach steepness affecting shift in Mean High Water Position**

Similarly, cases where erosion itself has caused beach steepening would be reflected in the narrowing of the distance between the MHW and Mean Low Water (MLW) contours over the same time period. Thus, the changing shape of the beach can be inferred from the changing contour positions.

**Beach steepening**

**Profile**

A profile is cross-section through a beach; normal to the shoreline, where repeatable topographic, hydrographic and LIDAR surveys can be undertaken in order for changes in beach level to be observed. In the 4d coastal sub cell, nearly 1500 profiles 1km in length exist at an average longshore spacing of 50m. Different types of profiles are surveyed at different times - interim profiles (those spaced at 200m) are surveyed in every survey, with baseline profiles (those spaced at 50m) surveyed only when a Beach Management Plan or repeat baseline survey is undertaken.

*Note: Profile lines displayed in the Profile Change Summary maps are intended to indicate Profile locations and may be longer or shorter than the actual width of frontage covered.*
South Downs Coastal Group

The former Coastal Group that was concerned with matters relating to the frontage between Beachy Head and Selsey Bill, or coastal sub-cell 4d. The SDCG has now been amalgamated with the South-East Coastal Group, and now covers coastal cell 4 between the Thames Estuary and Selsey Bill.

All Coastal Groups are made up of Local Authority, County Council and other coastal stakeholders. For further information about the South Downs and South East Coastal Groups, please visit [http://www.sdcg.org.uk/] and [http://www.se-coastalgroup.org.uk/]
Annex C

Digital Terrain Models
Southeast Strategic Regional Coastal Monitoring Programme

Figure 4.1 - Digital Terrain Model Comparison (1 of 2)

Pagham Harbour

March 2003

August 2004

April 2005

April 2006

December 2006

March 2007

Elevation

0 to 0.5

1 to 1.5

2 to 2.5

3 to 3.5

4 to 4.5

5 to 6

7 to 7.5

8 to 8.5

9 to 9.5

10 to 12

Southeast Strategic Regional Coastal Monitoring Programme

BMP Site Report 2010
Figure 4.1 - Digital Terrain Model Comparison (2 of 2)
Figure 4.2 - Digital Terrain Model (4 of 11)

Pagham Harbour

2008 Aerial Photography

April 2006
Figure 4.2 - Digital Terrain Model (5 of 11)

Pagham Harbour

2008 Aerial Photography

December 2006

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

January 2009

Figure 4.2 - Digital Terrain Model (8 of 11)
Figure 4.2 - Digital Terrain Model (9 of 11)

Pagham Harbour

December 2009
Figure 4.2 - Digital Terrain Model (10 of 11)

Pagham Harbour

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

May 2010

2008 Aerial Photography
Figure 4.2 - Digital Terrain Model (11 of 11)
Annex D

Difference Models
Figure 5.1 - Difference Model Comparison (1 of 2)
Figure 5.1 - Difference Model Comparison (2 of 2)

Pagham Harbour

Southeast Strategic Regional Coastal Monitoring Programme

BMP Site Report 2010
Figure 5.2 - Survey to Survey Difference Model (1 of 10)

Pagham Harbour

2008 Aerial Photography

March 2003 to August 2004

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 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 5.2 - Survey to Survey Difference Model (2 of 10)

Pagham Harbour

2008 Aerial Photography

August 2004 to April 2005

Change in Elevation (m)

-0.5 to 0.25
-1.5 to -1
-1 to 0.5
-0.25 to 0.25

1.5 to 2
0.5 to 1
No Change
-0.25 to -0.5
0.25 to 0.5
-0.5 to -0.25

2.5 to 3
2 to 2.5
1.5 to 2
1 to 1.5
0.5 to 1

Erosion

Accretion

No Change
Figure 5.2 - Survey to Survey Difference Model (3 of 10)

Pagham Harbour

2008 Aerial Photography

Change in Elevation (m)

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

Erosion

1.5 to 20
0.25 to 0.5
0.5 to 1
1 to 1.5
2 to 2.5

Accretion

No Change

April 2005
to
April 2006

0 250 500m
Figure 5.2 - Survey to Survey Difference Model (4 of 10)

Pagham Harbour

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
Figure 5.2 - Survey to Survey Difference Model (5 of 10)

Pagham Harbour

2008 Aerial Photography

Change in Elevation (m)

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

December 2006 to March 2007
Figure 5.2 - Survey to Survey Difference Model (7 of 10)

2008 Aerial Photography

Pagham Harbour

2008 Aerial Photography

Change in Elevation (m)

-0.5 to -0.25
-1.5 to -1
-1 to 0.5
-0.25 to 0.25
Erosion

1.5 to 2
0.25 to 0.5
0.5 to 1
1 to 1.5
Accretion

No Change

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

-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 2008 to January 2009
Figure 5.2 - Survey to Survey Difference Model (3 of 10)

Pagham Harbour

Change in Elevation (m)

- No Change
- Erosion
- Accretion

- <= -3
- -3 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

January 2009 to December 2009

2008 Aerial Photography
Figure 5.2 - Survey to Survey Difference Model (10 of 10)

Pagham Harbour

Change in Elevation (m)

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

May 2010 to October 2010

2008 Aerial Photography
Figure 5.3 - March 2003 to October 2010 Difference Model

Pagham Harbour

2008 Aerial Photography

March 2003 to October 2010

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 5.4 (1 of 5) - 4d-MU2 Difference Model and Hotspot Analysis

Change in Elevation (m) between January 2009 and December 2009

Accretion

-3.767

Blue = Material Gained
Red = Material Lost

Volume (m3)

0 150 300m

0 150 300m

(2008 Aerial Photography)
Figure 5.4 (2 of 5) - 4d-MU2 Difference Model and Hotspot Analysis

Change in Elevation (m) between January 2009 and December 2009

-4.366

Volume (m3)
-3,767

Blue = Material Gained
Red = Material Lost

(2008 Aerial Photography)
Southeast Strategic Regional Coastal Monitoring Programme

Figure 5.4 (3 of 5) - 4d-MU2 Difference Model and Hotspot Analysis

Change in Elevation (m) between January 2009 and December 2009

-3.767

Volume (m³)

Blue = Material Gained
Red = Material Lost

Accretion
-3.0 to -0.25
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

Erosion

-3,767

Volume (m³)

Blue = Material Gained
Red = Material Lost

Accretion
-3.0 to -0.25
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

Erosion
Southeast Strategic Regional Coastal Monitoring Programme

BMP Site Report 2010

Change in Elevation (m) between January 2009 and December 2009

-3 to -0.25
-0.25 to 0.25
-1 to 0.5
-1.5 to -1
-2 to -1.5
-2.5 to -2
-3 to -0.25
-3,767
-1,451
-416
13,255
-1,451
3,767

Volume (m³)

Blue = Material Gained
Red = Material Lost

Figure 5.4 (4 of 5) - 4d-MU2 & MU2A Difference Model and Hotspot Analysis
Church Norton to Pagham
Southeast Strategic Regional Coastal Monitoring Programme

BMP Site Report 2010

Figure 5.4 (5 of 5) - 4d-MU2 & MU2A Difference Model and Hotspot Analysis

Change in Elevation (m) between January 2009 and December 2009:

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

- Accretion:
  - 0.5 to 1
  - 2.5 to 3

- No Change:
  - 3 to 0.5

Volume (m³):
- Blue = Material Gained
- Red = Material Lost

-3,981

-3,767

-416

Volume (m³):
-3,767

Blue = Material Gained
Red = Material Lost
Southeast Strategic Regional Coastal Monitoring Programme

BMP Site Report 2010

Change in Elevation (m) between March 2003 and December 2009

- Volume (m³)
  -36,735

Blue = Material Gained
Red = Material Lost

Figure 5.5 (1 of 5) - 4d-MU2 Difference Model and Hotspot Analysis

(2008 Aerial Photography)
Figure 5.5 (2 of 5) - 4d-MU2 Difference Model and Hotspot Analysis

Change in Elevation (m) between March 2003 and December 2009

-36.735

Volume (m³)

Blue = Material Gained
Red = Material Lost

0 150 300m

(2008 Aerial Photography)
Figure 5.5 (3 of 5) - 4d-MU2 Difference Model and Hotspot Analysis

Change in Elevation (m) between March 2003 and December 2009

- >= 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

Volume (m3)
- -36,735

Blue = Material Gained
Red = Material Lost

(2008 Aerial Photography)
Figure 5.5 (4 of 5) - 4d-MU2 & MU2A Difference Model and Hotspot Analysis

Volume (m³)
-48,845

Blue = Material Gained
Red = Material Lost

Erosion
150
-0.5 to -0.25
-36,735

Accretion
150
300m
300m

Change in Elevation (m) between March 2003 and December 2009

-18,681

(2008 Aerial Photography)

172,576

-72,648

94,243

-48,845

-36,735

Volume (m³)
Southeast Strategic Regional Coastal Monitoring Programme

Figure 5.5 (5 of 5) - 4d-MU2 & MU2A Difference Model and Hotspot Analysis

Change in Elevation (m) between March 2003 and December 2009

- >= 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

Erosion

Volume (m³)

Blue = Material Gained
Red = Material Lost

-36,735

-28,315

Volume (m³)

-36,735

-28,315

Blue = Material Gained
Red = Material Lost

(2008 Aerial Photography)
Annex E

Rustington Wave Rider Buoy Report
July 2009 – June 2010
Rustington Waverider Buoy - July 2009 to June 2010

Location
OS: 506331E  93784N
WGS84: Latitude: 50°44.0365’N   Longitude: 00°29.6765’W

Water Depth
~9.9m CD

Instrument Type
Datawell Directional WaveRider Buoy Mk III

Data Quality

<table>
<thead>
<tr>
<th>C1(%)</th>
<th>Sample interval</th>
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<td>30 minutes</td>
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</table>

Storm Analysis

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<tr>
<th>Date/Time</th>
<th>Hs (m)</th>
<th>Tp (s)</th>
<th>Tz (s)</th>
<th>Dir. (º)</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>
</tr>
</thead>
<tbody>
<tr>
<td>14-Nov-2009 13:00</td>
<td>3.91</td>
<td>9.1</td>
<td>6.7</td>
<td>208</td>
<td>-0.11</td>
<td>HW +4</td>
<td>4.5</td>
<td>0.56</td>
<td>0.62</td>
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<tr>
<td>23-Nov-2009 13:30</td>
<td>3.72</td>
<td>10.0</td>
<td>6.5</td>
<td>214</td>
<td>1.93</td>
<td>HW -1</td>
<td>3.2</td>
<td>0.54</td>
<td>0.63</td>
</tr>
<tr>
<td>25-Nov-2009 04:00</td>
<td>3.61</td>
<td>8.3</td>
<td>6.2</td>
<td>212</td>
<td>1.66</td>
<td>HW</td>
<td>2.6</td>
<td>0.15</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Table F1  Storms during the reporting period, July 2009 to June 2010

A storm is defined using the Peaks-over-Threshold method (Figure F1). Each storm is then examined in detail, encompassing 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 since it covers the build-up and decay typical of a mid-latitudes depression.

Originally the threshold for this site was set at 3m, since the measurements only spanned 5 years and, therefore, erred on the low side. Now the record length has exceeded 5 years the threshold has been revised to identify 3 or 4 storms in an average year. The new threshold used at Rustington is 3.5m.

Figure F2 shows the monthly time series of Hs, with the threshold shown in red. The occurrence of storm waves in the current reporting period is also compared with similar storm waves in previous years in Figure F3. Subsequent figures show a

* Tidal information is obtained from the nearest recording tide gauge (the Pressure Transducer at Arun Platform). The surge shown is the residual at the time of the highest Hs. The maximum tidal surge is the largest positive surge during the storm event.
time series of the wave conditions for each of the storms listed in Table F1, together with the tidal conditions at the nearest tide gauge. Each graph is centred around the highest $H_s$ of the individual storm.

Summary

This reporting year was relatively quiet but with a lengthy period of storm activity between mid and late November. The highest event was recorded on 14 November 2009 peaking at 3.91m $H_s$. This particular storm was significant for many sites along the south coast including at Boscombe, Milford, Hayling Island and Pevensey Bay.

Acknowledgements

TASK2000 tidal prediction software was kindly provided by the Permanent Service for Mean Sea Level (PSMSL), Proudman Oceanographic Laboratory.
Figure F2  Monthly time series of $H_s$ at Rustington. Storm threshold, shown in red, is 3.5m.
Figure F3  Incidence of storms during (a) reporting period and (b) since deployment
This storm was characterised by an extended period of waves exceeding 3m Hs, followed by a rapid decrease 4 hours after the peak of the storm. The storm was generated by a particularly deep, complex, slow-moving depression (969hPa) centred in the North Atlantic (see Figures F5 and F6), producing strong, south westerly winds over much of southern Britain.

There was some evidence of the storm being followed by long period swell with Tp increasing to 12 seconds for a short period. During the storm build up wave approach was form the south but changing to SSW at the storm peak. The peak of the storm did not occur around High Water, although surge levels were high reaching a maximum of 0.62m.
Figure F5: Surface pressure chart at 00:00Z 13 November 2009

Figure F6: Surface pressure chart at 00:00Z 14 November 2009
Figure F7  Second highest storm of reporting period

This was a short lived storm resulting from a particularly deep North Atlantic depression (954 hPa) which generated a long period swell from the south west propagating up the Channel coast (see Figure F8). $T_p$ remained consistently around 10s both prior to and following the peak of the storm. Wave height peaked at 3.72m $H_s$ and occurred close to High Water. This was also accompanied by a positive surge of $\sim$0.6m which lasted for $\sim$24 hours.
Figure F8: Surface pressure chart at 00:00Z 22 November 2009.
Figure F9  Third highest storm of reporting period

This particular storm was characterised by a short peak in wave height due to shallow water effects, where the wave height is increased because of the additional water depth around high tide. $H_s$ remained over 2m for at least 16 hours before and after the storm peak. The maximum $H_s$ of 3.61m coincided with High Water but with a negligible tidal surge of 0.15m. Wave approach was generally from the SW.