Technical Annex 1
Coastal Conditions

Contents Amendment Record
This report has been issued and amended as follows:

<table>
<thead>
<tr>
<th>Issue</th>
<th>Revision</th>
<th>Description</th>
<th>Date</th>
<th>Signed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>Draft</td>
<td>19 June 03</td>
<td>LSBanyard</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>Final</td>
<td>31 Jan 04</td>
<td>LSBanyard</td>
</tr>
</tbody>
</table>
Contents

1 Wave Modelling 1
   1.1 Offshore Wave Conditions 1
   1.2 Inshore (Coastal) Wave Conditions 2
   1.3 Harbour Wave Conditions 4

2 Water Levels 7
   2.1 Data Sources 7
   2.2 Tidal cycles under typical spring and neap conditions 7
   2.3 Extreme water levels - previous analysis 9
   2.4 Tidal cycles under severe conditions 10
   2.5 New Statistical Analysis 14

3 Joint Probability of Extreme Waves and Water Levels 20

Figures

1.1 Location of data and wave modelling grids
1.2 Offshore Wave Directions from UK Met Office European Waters Wave Model
1.3 Extreme Wave Heights in Poole Harbour
1.4 Comparison of Extreme Wind Predictions in Poole Harbour

2.1 Locations of water level data sources
2.2 Tidal curves – 23 December 2001 (typical neap tide)
2.3 Tidal curves – 30 December 2001 (typical spring tide)
2.4 Existing Predictions of Extreme Water Level
2.5 Tidal curves – 19 November 1996
2.6 Tidal curves – 10 February 1997
2.7 Tidal curves – 26 September 1999
2.8 Tidal curves – 28 September 2000
2.9 Tidal curves – 12 December 2000
2.10 Tidal curves – 2 January 2001
2.11 Tidal curves – 10 March 2001
2.12 New Predictions of Extreme Water Level
2.13 Collation of Predictions of Extreme Water Level
2.14 Comparison of South West Region Extreme Water Level predictions with previous estimates

2.15 Recommended Extreme Water Level Conditions

3.1 Location of joint probability assessments
1 Wave Modelling

1.1 Offshore Wave Conditions

Additional offshore wave data was obtained from the United Kingdom Meteorological Office (Met Office) to supplement data previously bought for the Shoreline Management Plan (SMP). The location of the offshore point was 50.50°N 1.66°W (reference point BP11), situated in 33m of water (Figure 1.1). Data from the period 12/11/1987 – 10/4/1989 was previously missing from the data set provided, but following discussions, this data was received from the Met Office. The complete data set covers the period 15/10/1986 to 31/12/2001. The format of the data used in the modelling was a timeseries of significant wave height, wave period and direction extracted from the European Waters Wave Model at 3 hour intervals.

On receipt of the data, checks were carried out which included plotting the wave direction against time for the full data period. It was identified that the model data shows a distinct shift in wave direction in May 1990. Prior to this time the predominant direction was 270°N-310°N, whereas afterwards the predominant wave direction changed to 210°N-250°N (Figure 1.2). This is not considered to be a natural change and the predominant wave direction after 1990 is considered to be typical of the location.

Through discussion with the Met Office, it was identified that this change was due to an amendment in the treatment of the boundary conditions of the model. As a result, only the wave data set from January 1991 to December 2001 (11 years) was used in modelling work carried out for this strategy. This still provides a reasonably long set of data on which to base forward planning of coast defences.

Whilst the apparent error prior to 1990 causes some residual doubt as to the validity of the model after this time, the data remains the most highly verified and validated data set available. Additional confidence can be drawn from the representation of wave directions in March – November 1995, when observations from the Coastal Group confirmed that there was a period of a few months when the predominant wave direction veered from 210°N-250°N to 300-100°N (through 000°N). In particular, the advantage of using Met Office data, compared to wave conditions that are hindcast directly from wind conditions and fetch lengths within the English Channel is that the Met Office model includes the
simulation of long period swell conditions. Whilst such conditions may be less important for the prediction of extreme wave conditions, they have a far greater influence on long-term sediment transport. Given the expectation that much of the study frontage will rely on beach control to provide coast defence, this is an important factor in selecting the input data to the wave models.

1.2 Inshore (Coastal) Wave Conditions

The offshore wave conditions were transformed from the offshore location towards the shoreline using Halcrow’s regional wave model MWAVE. The model bathymetry was constructed using:

- data from Admiralty Charts
- bathymetric survey data collected by University of Southampton for Bournemouth Borough Council for a series of beach profiles extending some 450m offshore from the seawall at 33 locations between Branksome Dene and Hengisbury Head
- bathymetric surveys of the Swash Channel and surrounding areas carried out by Poole Harbour Commissioners
- bathymetry survey data collected by Poole Harbour Commissioners for New Forest District Council, under a sub-contract agreement with Halcrow on behalf of Purbeck District Council for a series of beach profiles extending 200m offshore from the seawall at Swanage.

The model grid spacing was 100m x 100m allowing extraction of data from any point within the Poole Bay area (Figure 1.1).

Data in the form of a time series has been extracted at the 10mCD contour at locations off Durlston Bay, Swash Channel and Southbourne to allow calculation and comparison of the joint probability of extreme wave conditions and water levels.

The calculation of extreme wave conditions was carried out by sorting the data into 0.01m data bins and completing a frequency analysis. Based on the frequency analysis, extrapolations of extreme conditions between the 1:1 and 1:200 year return period were made using the Gumbel and Weibull distributions (Table 1.1).
<table>
<thead>
<tr>
<th>Return Period (Years)</th>
<th>Weibull (m)</th>
<th>Gumbel (m)</th>
<th>Average Significant Wave Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10mCD - Durlston Bay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.9</td>
<td>3.7</td>
<td>3.8</td>
</tr>
<tr>
<td>2</td>
<td>4.2</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>5</td>
<td>4.8</td>
<td>4.5</td>
<td>4.6</td>
</tr>
<tr>
<td>10</td>
<td>5.1</td>
<td>4.9</td>
<td>5.0</td>
</tr>
<tr>
<td>20</td>
<td>5.5</td>
<td>5.2</td>
<td>5.3</td>
</tr>
<tr>
<td>50</td>
<td>6.1</td>
<td>5.6</td>
<td>5.8</td>
</tr>
<tr>
<td>100</td>
<td>6.5</td>
<td>6.0</td>
<td>6.2</td>
</tr>
<tr>
<td>200</td>
<td>6.9</td>
<td>6.3</td>
<td>6.6</td>
</tr>
<tr>
<td>10mCD – Swash Channel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.2</td>
<td>2.9</td>
<td>3.0</td>
</tr>
<tr>
<td>2</td>
<td>3.5</td>
<td>3.2</td>
<td>3.3</td>
</tr>
<tr>
<td>5</td>
<td>3.9</td>
<td>3.4</td>
<td>3.6</td>
</tr>
<tr>
<td>10</td>
<td>4.1</td>
<td>3.8</td>
<td>3.9</td>
</tr>
<tr>
<td>20</td>
<td>4.4</td>
<td>4.1</td>
<td>4.2</td>
</tr>
<tr>
<td>50</td>
<td>4.8</td>
<td>4.3</td>
<td>4.5</td>
</tr>
<tr>
<td>100</td>
<td>5.0</td>
<td>4.7</td>
<td>4.8</td>
</tr>
<tr>
<td>200</td>
<td>5.3</td>
<td>5.0</td>
<td>5.1</td>
</tr>
<tr>
<td>10mCD – Southbourne</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.5</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>2</td>
<td>4.9</td>
<td>4.7</td>
<td>4.8</td>
</tr>
<tr>
<td>5</td>
<td>5.4</td>
<td>5.2</td>
<td>5.3</td>
</tr>
<tr>
<td>10</td>
<td>5.7</td>
<td>5.6</td>
<td>5.6</td>
</tr>
<tr>
<td>20</td>
<td>6.1</td>
<td>5.9</td>
<td>6.0</td>
</tr>
<tr>
<td>50</td>
<td>6.7</td>
<td>6.4</td>
<td>6.5</td>
</tr>
<tr>
<td>100</td>
<td>7.1</td>
<td>6.7</td>
<td>6.9</td>
</tr>
<tr>
<td>200</td>
<td>7.5</td>
<td>7.1</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Table 1.1 Marginal extreme wave conditions
1.3 Harbour Wave Conditions

1.3.1 Previous analysis

Predictions of wave conditions within Poole Harbour have been presented in the Shoreline Management Plan. These were based on work by HR Wallingford (1995), which was extended by Halcrow for the SMP to include locations off Brownsea Island and the south of the Harbour.

The wave hindcasting carried out previously was based on wind data recorded at Hurn (Bournemouth Airport) and was calibrated against several days of wave data recorded in the Harbour. A longer data set from Poole Harbour was not available at the time. The wind climate that was derived was presented in Table 2.40 of HR Wallingford (1995) and reproduced in the SMP Volume 2, Table 3.14. Waves were hindcast to 13 locations in total, annotated A to M, which are shown in Figure 1.3.

1.3.2 New analysis

As noted in the SMP, wind data is also recorded by Poole Harbour Commissioners (PHC) at the Harbour Office. Timeseries data from July 1995 to January 2001 (5.5 years) was provided to Halcrow by PHC.

<table>
<thead>
<tr>
<th>Direction Sector</th>
<th>Wind Conditions Adjusted from Bournemouth Airport</th>
<th>Wind Conditions from Poole Harbour Commissioners</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1:1 year (m/s)</td>
<td>1:100 year (m/s)</td>
</tr>
<tr>
<td>345 - 015</td>
<td>15.1</td>
<td>20.1</td>
</tr>
<tr>
<td>015 - 045</td>
<td>13.6</td>
<td>17.7</td>
</tr>
<tr>
<td>045 - 075</td>
<td>11.0</td>
<td>14.6</td>
</tr>
<tr>
<td>075 - 105</td>
<td>11.4</td>
<td>15.5</td>
</tr>
<tr>
<td>105 - 135</td>
<td>15.8</td>
<td>21.4</td>
</tr>
<tr>
<td>135 - 165</td>
<td>17.7</td>
<td>23.9</td>
</tr>
<tr>
<td>165 - 195</td>
<td>23.3</td>
<td>31.3</td>
</tr>
<tr>
<td>195 - 225</td>
<td>23.5</td>
<td>29.9</td>
</tr>
<tr>
<td>225 - 255</td>
<td>22.3</td>
<td>28.6</td>
</tr>
<tr>
<td>255 - 285</td>
<td>21.0</td>
<td>28.3</td>
</tr>
<tr>
<td>285 - 315</td>
<td>17.1</td>
<td>22.5</td>
</tr>
<tr>
<td>315 - 345</td>
<td>16.1</td>
<td>23.3</td>
</tr>
</tbody>
</table>

*Table 1.2 Extreme Wind Conditions*
The extreme wind conditions were calculated using Weibull and Gumbel extreme distributions and the average values of the two analyses are presented in Table 1.2, together with the extremes previously derived from the Bournemouth Airport data. The two sets of predictions are shown graphically in Figure 1.4.

The comparison shows that the maximum and minimum wind speeds are consistent between the two data sets. For example, the 1:1 year return period, the peak wind speed is 24m/s in the Bournemouth Airport (adjusted) data, compared to 23m/s in the Poole Harbour data. There is a difference in the direction of the peak wind speed, however, with the maximum being from the south using the Bournemouth Airport (adjusted) prediction, whereas the maximum direction predicted from the Poole Terminal data is from the south-west. It is considered that the maximum wind speed is more likely to be from the south-west for two reasons: (1) that the prevailing wind direction in the UK is from the south-west and (2) that the land to the south-west of the harbour is flatter and at lower elevation in the valley of the River Frome, compared to the land to the south, which rises to 100-200m over the Purbeck Hills of the Isle of Purbeck.

On balance, it is considered that the Poole Terminal now provides the more reliable data set from which to make future predictions. The existing predictions of extreme wave conditions, based on the previous wind data are, however unlikely to change significantly. To confirm this, wave prediction carried out by HR Wallingford (1995) which were contained in the SMP as Points A and B were...
repeated using the Poole Terminal wind data. The predictions were close, being within \( H_s = 0.01 \text{m} \) for Point A and within \( H_s = 0.17 \text{m} \) for Point B (Table 1.3).

An additional prediction point (Point N) was added at a location off Ham Common, between the existing points at Rockley (Point A) and Hamworthy (Point B). The additional information on the wave conditions at this location was required in order to analyse beach sediment movement and improve the understanding of the longest stretch of beach within the Harbour. The timeseries of wave data from Points A, B and N were used to calculate potential longshore transport rates, and the results are described in Technical Annex 6.

<table>
<thead>
<tr>
<th></th>
<th>Point A</th>
<th>Point N</th>
<th>Point B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1</td>
<td>0.50</td>
<td>0.51</td>
<td>1.01</td>
</tr>
<tr>
<td>1:2</td>
<td>0.53</td>
<td>0.54</td>
<td>1.07</td>
</tr>
<tr>
<td>1:5</td>
<td>0.56</td>
<td>0.57</td>
<td>1.16</td>
</tr>
<tr>
<td>1:10</td>
<td>0.59</td>
<td>0.60</td>
<td>1.22</td>
</tr>
<tr>
<td>1:20</td>
<td>0.61</td>
<td>0.62</td>
<td>1.28</td>
</tr>
<tr>
<td>1:50</td>
<td>0.64</td>
<td>0.65</td>
<td>1.36</td>
</tr>
<tr>
<td>1:100</td>
<td>0.67</td>
<td>0.67</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Table 1.3 Comparison of Extreme Wave Conditions
2 Water Levels

2.1 Data Sources

Water level data has been acquired from electronic gauges, recording timeseries data, at four locations as shown in Figure 2.1, namely:

- **Bournemouth** from British Oceanographic Data Centre from 20 June 1996 to 30 April 2002 sampled at 15 minute intervals
- **Poole Harbour Entrance** from Poole Harbour Commissioners 10 January 1991 to 17 January 2002 sampled at 10 minute intervals
- **Poole Terminal** from Poole Harbour Commissioners 1 July 1997 to 17 January 2002 from sampled at 10 minute intervals
- **Wareham** from the Environment Agency from 25 February 1996 to 31 December 2001 sampled at 10 minute intervals

In addition, records of river flows at **East Stoke**, which is on the River Frome, above the influence of the tide, were provided by the EA, in order to check the fluvial influence on the water level conditions at Wareham.

The data from all of the water level gauges was imported into SANDS for storage and analysis. The length of simultaneous data set at all 4 locations is 4.5 years.

2.2 Tidal cycles under typical spring and neap conditions

Comparison of the tidal curves at these 4 locations allows an assessment of the effect of the Harbour estuary on the hydrodynamics of the tide. In particular, it allows identification of the degree to which the tidal curve is typical of the open sea, or is typical of estuary conditions showing some degree of attenuation of the low water.

From the Admiralty Tide Table, it was found that the tides occurring on 23 December 2001 and 30 December 2001 were representative of Mean Spring and Mean Neap tidal cycles. The tidal curves recorded at each of the 4 locations on these two dates were plotted (Figures 2.2 & 2.3), together with the river flows at East Stoke. The flows rates of 2-3m³/s are typical of day-to-day river conditions at this location.
(a) Bournemouth, Poole Harbour and Poole Terminal
The high water levels at Bournemouth, Poole Harbour Entrance, Poole Terminal and Wareham are within 100mm at all 4 locations. The shapes of the tidal curves are similar - all 4 have a double high tide, with a second peak some 4-5 hours after the main peak level. The timings of the tide vary between each location, with possibly 10-30 mins delay from Bournemouth to Poole Harbour Entrance and typically 5-10 mins delay from Poole Harbour Entrance to Poole Terminal.

The comparison shows that, under typical spring and neap conditions, the tidal curves within the Harbour up to Poole Terminal are not greatly affected by the constriction at the Harbour entrance. There is no attenuation of the low tide (ie there is no reduction in the level down to which the water level reaches during the low tide which might otherwise indicate an inability of the Harbour entrance to discharge the full ebb tidal volume prior to the onset of the subsequent tidal flood). By inference, this finding applies to other locations east of Poole Terminal along the urban/suburban Poole frontage within the Harbour. The Harbour up to Poole Terminal may be considered to act as an enclosed sea under typical spring and neap tide conditions, rather than as an estuary.

(b) Wareham
The rising tide at Wareham is around 30-60 mins later than at Poole Harbour Entrance, but the falling tide is delayed considerably. The first high tide has a minor double peak and the second high tide is higher (by some 200mm) than at Bournemouth, Poole Entrance and Poole Terminal. Under the spring tide condition, the low tide is attenuated and does not reach the low water level that occurs downstream. This is assumed to be due to the shape of the Wareham Channel and River Frome which is progressively narrower from seaward to landward and also due to the water contained in the Outer Harbour (downstream of the Wareham Channel – from Hamworthy to the Harbour Entrance) which is restricting the ebb tide current. At Wareham the channel is considered to act hydrodynamically as an estuary. By inference, there is a point between Wareham and Poole Terminal where this attenuation is no longer affective. From consideration of the shape of the Harbour, this is assumed to be at the downstream entrance to the Wareham Channel, since upstream of this point the channel is narrow and typical of an estuary, whereas downstream the Harbour becomes considerably broader.
2.3 Extreme water levels - previous analysis

Various analyses of extreme water levels have been completed by Halcrow, Dixon & Tawn, HR Wallingford and Reading University. A collation of the various analyses up to 1998 are given in the Poole & Christchurch Bay Shoreline Management Plan (Halcrow, 1998), Volume 2.

Previous analysis of extreme water levels includes predictions by HR Wallingford (1995) based on data at Poole Harbour entrance between January 1991 and July 1993. Weibull and Gumbel distributions were fitted to the high water data and values of the extreme water levels were tabulated. The values of extreme water levels were assumed by taking the average of the Weibull and Gumbel predictions (Figure 2.4).

The predictions for the 1:10 year and 1:100 year water levels were 1.60mOD and 1.85mOD respectively. These were discussed with Borough of Poole and it was concluded that the predictions were probably typically 100mm too high, on the basis that the highest water level ever recorded was 1.66mOD in December 1989, with the previous highest being 1.56mOD, some 30 years earlier. It was expected that the reason for the over-estimate was the short length of the data set, being only 2 years.

![Figure 2.4 Existing Predictions of Extreme Water Level](image.png)
An alternative approach to assessing extreme water level conditions, known as the Spatially Revised Joint Probability Method (SRJPM) has been developed by Proudman Oceanographic Laboratory (POL, 1997), based on computer modelling of the surge component around the UK coast. The method is presented in two parts, namely the assessment of the 1:1yr return period condition and the growth curve, which is defined by the model. Using this method, without further assessment of the 1:1 year return period condition, the resulting predictions are considerably higher than those derived from analysis of data from Poole Harbour (Figure 2.4). It is noted in the method, however, that estimates of the 1:1 year return period water level should be used where available, a process that is followed in Section 2.4.

A summary of extreme water level predictions throughout Poole Bay and further afield was compiled in the Shoreline Management Plan (Halcrow, 1998).

2.4 Tidal cycles under severe conditions

The highest water levels within the four data sets were identified individually and are listed in Table 2.1.

Since the length of data set at Poole Entrance is considerably longer than when the previous predictions were made, the 1:1 year conditions at this location can be found from direct inspection of the highest water levels. The length of data set is 9 complete years with 2 years of gaps. The level that is exceeded nine times is 1.40mCD.

From Table 2.1, there were found to be 7 extreme water level events that were recorded at all 4 gauges. The tidal curves for each are shown chronologically in Figures 2.5 to 2.11 inclusive.
<table>
<thead>
<tr>
<th>Date / Time</th>
<th>Bournemouth Water Level</th>
<th>difference from Poole Entrance</th>
<th>Poole Entrance Water Level</th>
<th>difference from Poole Entrance</th>
<th>Poole Terminal Water Level</th>
<th>difference from Poole Entrance</th>
<th>Wareham Water Level</th>
<th>difference from Poole Entrance</th>
</tr>
</thead>
<tbody>
<tr>
<td>28/9/91 10:58</td>
<td>- (1)</td>
<td>-</td>
<td>1.45</td>
<td>-</td>
<td>- (1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>29/8/92 22:01</td>
<td>- (1)</td>
<td>-</td>
<td>1.49</td>
<td>-</td>
<td>- (1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>30/8/92 10:02</td>
<td>- (1)</td>
<td>-</td>
<td>1.46</td>
<td>-</td>
<td>- (1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>24/10/95 21:25</td>
<td>- (1)</td>
<td>-</td>
<td>- (1)</td>
<td>-</td>
<td>1.47</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>24/11/95 09:45</td>
<td>- (1)</td>
<td>-</td>
<td>- (1)</td>
<td>-</td>
<td>1.39</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>23/12/95 09:35</td>
<td>- (1)</td>
<td>-</td>
<td>1.49</td>
<td>-</td>
<td>1.49</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>19/11/96 07:15</td>
<td>1.39</td>
<td>-0.01</td>
<td>1.40</td>
<td>-</td>
<td>1.49</td>
<td>+0.09</td>
<td>1.41</td>
<td>+0.01</td>
</tr>
<tr>
<td>10/2/97 10:55</td>
<td>1.41</td>
<td>-0.03</td>
<td>1.44</td>
<td>-</td>
<td>1.47</td>
<td>+0.03</td>
<td>1.19</td>
<td>-0.25</td>
</tr>
<tr>
<td>7/9/98 21:45</td>
<td>1.32</td>
<td>-</td>
<td>- (1)</td>
<td>-</td>
<td>1.40</td>
<td>-</td>
<td>- (1)</td>
<td>-</td>
</tr>
<tr>
<td>8/9/98 22:35</td>
<td>1.32</td>
<td>-</td>
<td>- (1)</td>
<td>-</td>
<td>1.39</td>
<td>-</td>
<td>- (1)</td>
<td>-</td>
</tr>
<tr>
<td>26/9/99 21:45</td>
<td>1.32</td>
<td>-0.09</td>
<td>1.41</td>
<td>-</td>
<td>1.37</td>
<td>+0.04</td>
<td>1.36</td>
<td>-0.05</td>
</tr>
<tr>
<td>24/10/99 20:35</td>
<td>1.29</td>
<td>-0.14</td>
<td>1.43</td>
<td>-</td>
<td>- (1)</td>
<td>-</td>
<td>1.33</td>
<td>-0.10</td>
</tr>
<tr>
<td>28/9/00 21:25</td>
<td>1.28</td>
<td>-0.05</td>
<td>1.33</td>
<td>-</td>
<td>1.39</td>
<td>+0.06</td>
<td>1.36</td>
<td>+0.03</td>
</tr>
<tr>
<td>12/12/00 22:15</td>
<td>1.41</td>
<td>-0.02</td>
<td>1.43</td>
<td>-</td>
<td>1.41</td>
<td>-0.02</td>
<td>1.39</td>
<td>-0.04</td>
</tr>
<tr>
<td>2/1/01 05:25</td>
<td>1.30</td>
<td>-0.10</td>
<td>1.40</td>
<td>-</td>
<td>1.39</td>
<td>-0.01</td>
<td>1.41</td>
<td>+0.01</td>
</tr>
<tr>
<td>10/3/01 09:25</td>
<td>1.39</td>
<td>-0.02</td>
<td>1.41</td>
<td>-</td>
<td>1.49</td>
<td>+0.08</td>
<td>1.36</td>
<td>-0.05</td>
</tr>
<tr>
<td>average difference</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+0.03</td>
<td>-</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

*Table 2.1 Ranking of Highest Water Levels at Poole Harbour Entrance between 1991 and 2001 (mOD)*

(1) data not recorded or corrupt
To identify the possible influence of river flow on the tidal curve at Wareham, the flow rate records at East Stoke, which is located upstream from Wareham beyond the tidal influence, were provided by the Environment Agency and are plotted against the right-hand axis on these figures. The typical river flow up to $10\text{m}^3/\text{s}$, which occurs on all occasions, other than the tides of 12 December 2000 and 2 January 2001, when there were flows of $15-25\text{m}^3/\text{s}$.

(a) Peak severe tidal levels
When comparing the peak severe water level events at all 4 locations, the difference (with one exception) between the recorded levels was small. The one exception to this occurred on 10 February 1997, when the peak tide level at Wareham was approximately 200mm lower than at the other 3 locations, an occurrence which is not explained.

In general, however, it is reasonable to assume that peak severe tide levels will be typically within ±50mm at all four locations. This difference is small when compared to the uncertainty implicit in the levelling of the gauges with respect to Ordnance Datum and the mechanism of measurement of the water level.

This means that there is no significant attenuation of the peak water level caused by the narrowing of the channel at the Harbour Entrance nor by the narrowing of the Wareham Channel entering the River Frome. It is reasonable, therefore, to use the data set (and the results of extreme water levels analysis) from Poole Entrance to represent the peak extreme water levels in whole study area from Bournemouth to Wareham.

(b) Tidal locking
The 7 sets of tidal curves were compared to try to identify any indication of tidal locking between Bournemouth (open sea) and Wareham (estuarine location). In the discussion, reference is made to the tidal component (being the element of the water level that is driven by astronomical influences) and the surge component (being the element of the water level that is driven by meteorological influences).

(i) Surge conditions combining with spring tides
During spring tides, the peak water level (being a combination of tidal and surge components) is likely to be higher, but the peak is less likely to be prolonged, since the high (astronomical) tide is followed by a correspondingly low (astronomical) tide.
The severe water levels recorded on 10 February 1997, 26 September 1999, 28 September 2000, 12 December 2000 and 10 March 2001 coincided with spring tides. The surge component of the total water level was up to 500mm. The recorded conditions (with the exception of Wareham on 12 December 2000) retain the typical smooth double-high-tide curves with a low tide approaching MLWS. On the 2 January 2001, the water level at Wareham remains 200-500mm higher than at the other three (seaward) locations for a period of more than 12 hours. This was, however, probably due to high river discharge (which are approximately twice the typical discharge that occurred during the other severe tidal events).

The shapes of the tidal curves at each location are similar to the spring tide conditions examined in Section 1.4.2, and do not show any influence of tidal locking between Bournemouth and Wareham.

(ii) Surge conditions combining with neap tides

On 19 November 1996 and 2 January 2001, the neap tide combined with surge conditions of up to 1.1-1.2m (which are the highest surge conditions believed to have been recorded in the 5 years of simultaneous data sets at the 4 locations).

On the 19 November 1996, the shapes of the tidal curves at all 4 locations remain typical of the neap tide conditions. On 12 December 2000, the water level record at Wareham departs considerably from the typical curve. Following the high tide (which is 30mins after the high tide at the Harbour Entrance, the water level at Wareham drops by only 600mm in the preceding 12hours, by which time the next high tide has arrived. This was, however, probably due to high river discharge (which are approximately twice the typical discharge that occurred during the other severe tidal events).

Under neap tide conditions, no indication of tidal locking occurring between Bournemouth and Wareham has been found. It is noted, however, that the low water levels at approximately 10:00 on the 19 November, are only 200-300mm below the predicted level of the previous high tide. This occurs at all 4 locations and so is not a facet of the Poole Harbour estuary, but is rather due to a prolonged surge condition in the English Channel that is causing a condition close to tidal locking throughout the whole of the Poole Bay & Harbour area.
2.5  

**New Statistical Analysis**

At the outset of the strategy studies, the need for further analysis of extreme water levels was identified, as a greater volume of data had been recorded since the previous predictions were made. Much of this analysis was completed by Halcrow.

In the course of discussions with the Environment Agency (EA), it was found that a study of the water levels through the South West Region was proceeding in parallel with the strategy study. This was based on the SRJPM. In addition, a similar study of extreme water levels in the Southern Region of the Environment Agency had considered water levels in Poole, since this is close to the boundary between the two regions. The method used for the Southern Region was the a GEV analysis based on Annual Maxima values.

A meeting was held on 6 September 2002, between EA, Posford Haskoning (consultant for the South West Region extreme water level analysis), Peter Brett Associates and Halcrow to discuss the various methods being used.

The presentation of data in this section, is therefore divided into the following sections:

- Initial analysis of Poole Harbour recorded data
- Further analysis carried out by Halcrow for discussion with EA
- Further analysis carried out by Posford Haskoning for South West Region extreme water level study

2.5.1  

**Initial analysis of Poole Harbour recorded data**

The data from the Poole Entrance and Poole Terminal gauges were examined in fortnightly intervals within SANDS to identify and delete erroneous data, which were obvious from spiky or flat periods of values. The resulting gaps within the data was not of concern for statistical analysis.

Extreme water levels in excess of the 1:1 year level can be extrapolated from the data set using the Weibull and Gumbel distributions. The method selected was to establish the gradient of the extreme water level extrapolation curve and apply this gradient to the 1:1 year water level. This allowed the complete data set of ten minutely data above the mean sea level to be used, without the need to separate the surge component and detect the high water level at each tide, both of which introduce small uncertainties into the prediction.
The resulting predictions are given in Table 2.2, which are plotted in Figure 2.12.
From inspection of the correlation of the distributions to the data, the Weibull method appears to underestimate the values of the highest water levels within the data set whilst the Gumbel method appears to overestimate.

<table>
<thead>
<tr>
<th>Return Period</th>
<th>Weibull (mOD)</th>
<th>Gumbel (mOD)</th>
<th>Average (mOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.40</td>
<td>1.40</td>
<td>1.40</td>
</tr>
<tr>
<td>2</td>
<td>1.44</td>
<td>1.49</td>
<td>1.46</td>
</tr>
<tr>
<td>5</td>
<td>1.49</td>
<td>1.60</td>
<td>1.54</td>
</tr>
<tr>
<td>10</td>
<td>1.53</td>
<td>1.69</td>
<td>1.61</td>
</tr>
<tr>
<td>20</td>
<td>1.56</td>
<td>1.77</td>
<td>1.67</td>
</tr>
<tr>
<td>50</td>
<td>1.61</td>
<td>1.89</td>
<td>1.75</td>
</tr>
<tr>
<td>100</td>
<td>1.64</td>
<td>1.98</td>
<td>1.81</td>
</tr>
<tr>
<td>200</td>
<td>1.66</td>
<td>2.03</td>
<td>1.84</td>
</tr>
</tbody>
</table>

*Table 2.2 Marginal Extreme Water Levels at Poole Harbour Entrance*

*Figure 2.12 New Predictions of Extreme Water Level*

Despite the expectation that a longer data set would produce slightly lower extreme water level predictions, the results remain very close to predictions made
by HR Wallingford based on the two-year data set. This suggests that the period 1991 to 1993 is representative of the longer period 1991 to 2002.

The reasons for the higher than anticipated water level predictions does not, therefore, appear to relate to the duration of the data. It is likely that this is due to the method of extrapolation. The two methods give widely varying results. The Gumbel method indicates that the highest water level recorded of 1.66mOD is exceeded on average once in every 10 years, whilst the Weibull method predicts that this level is exceeded once in every 70 years at Poole Terminal and 200 years at Poole Harbour Entrance. Both methods are generally well respected for the extrapolation of extreme water levels, but it is possible that the complexity of the tides at Poole Harbour, and in particular the occurrence of the double high tide at Poole, will not allow a more accurate prediction. If the average of the two predictions is assumed, the highest water level recorded of 1.66mOD is predicted to be exceeded on average once in every 20 years.

For comparison, the results of the SRJPM were adjusted to the 1:1 year return period level found in Section 2.4. Up to the 1:10 year level, the results are similar to the extrapolations based on recorded data. Beyond this condition, however, the growth of the predicted curve is considerably steeper, such that at the 1:200 year condition, the prediction using SRJPM is some 400-500mm higher than through the results based on recorded data (Figure 2.12).

2.5.2 Further analysis carried out by Halcrow for discussion with EA

In the course of discussions with the EA and in preparation for a meeting between EA, Posford Haskoning, Peter Brett Associates and Halcrow 6 September 2002, further analysis and collation of the result of others was carried out:

- Analysis of annual maxima using GEV method by Jeremy Benn for EA Southern Region was checked and plotted against the existing results
- GEV analysis based on 5 points per year was carried out as a comparative method to those using the full timeseries or peaks over threshold methods

All of the existing results were plotted (Figure 2.13) and the results presented at the meeting. As a result of discussions it was agreed that the use of recorded data from Poole Harbour and Bournemouth should be incorporated into the South West Region Extreme Water Levels study.
Further analysis carried out by Posford Haskoning for South West Region Extreme Water Level study

The final analysis carried out for the South West Region Extreme Water Level study was described in the study report (PDMM, 2003). The method is described as:

The growth factors in POL Report No 112 for the Dorset coast, particularly east from Portland, are less reliable than for elsewhere around the coast of Great Britain. This is acknowledged by POL. The causes are twofold. Firstly there was a shortage of site data available to POL for calibration of their model. Secondly, the model did not have a fine enough grid to properly represent the pertaining complex shallow water/small tidal range conditions in this area.

Improvement on the POL Report No 112 growth factors was therefore obtained by analysing a wide range of tide level data. Using GEV methods, extreme tide levels were calculated for the individual data sites. A graphical spatial analysis, in lieu of the computer based spatial analysis made by POL, was then used to derive a consistent set of extreme tide levels east from Exmouth. At the boundary with the Agency’s Southern Region, the levels co-ordinate with equivalent return period levels adopted by Southern Region.

A summary of the revised extreme water levels for locations within Poole Bay & Harbour are provided in Table 2.3 and the results are compared with the previous analyses in Figure 2.14.
Table 2.3 Marginal Extreme Water Levels from South West

Note: Data from PDMM (2003) - Environment Agency, South West Region, Report of Extreme Tidal Levels

<table>
<thead>
<tr>
<th>RP</th>
<th>Swanage (mOD)</th>
<th>Sandbanks (mOD)</th>
<th>Poole Ro-Ro Terminal (mOD)</th>
<th>Wareham (mOD)</th>
<th>Bournemouth (mOD)</th>
<th>Hengistbury Head (mOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.41</td>
<td>1.39</td>
<td>1.39</td>
<td>1.39</td>
<td>1.38</td>
<td>1.39</td>
</tr>
<tr>
<td>5</td>
<td>1.58</td>
<td>1.46</td>
<td>1.46</td>
<td>1.46</td>
<td>1.46</td>
<td>1.47</td>
</tr>
<tr>
<td>10</td>
<td>1.65</td>
<td>1.63</td>
<td>1.63</td>
<td>1.63</td>
<td>1.63</td>
<td>1.65</td>
</tr>
<tr>
<td>25</td>
<td>1.75</td>
<td>1.73</td>
<td>1.73</td>
<td>1.73</td>
<td>1.73</td>
<td>1.75</td>
</tr>
<tr>
<td>50</td>
<td>1.82</td>
<td>1.80</td>
<td>1.80</td>
<td>1.80</td>
<td>1.81</td>
<td>1.83</td>
</tr>
<tr>
<td>100</td>
<td>1.90</td>
<td>1.88</td>
<td>1.88</td>
<td>1.88</td>
<td>1.88</td>
<td>1.91</td>
</tr>
<tr>
<td>200</td>
<td>1.97</td>
<td>1.95</td>
<td>1.95</td>
<td>1.95</td>
<td>1.96</td>
<td>1.99</td>
</tr>
</tbody>
</table>

Figure 2.14 Comparison of South West Region Extreme Water Level predictions with previous estimates

For comparison, the levels for Sandbanks/Poole Harbour Ro-Ro Terminal have been plotted together with the previous predictions in Figure 2.4. The revised predictions lie close to the predictions by HR Wallingford (subsequently adopted as the design conditions for the Town Quay defences, as described in Section 2.3) and by Halcrow in Section 2.5.1.
The difference between the three sets of results produced through independent analysis by HR Wallingford, Posford and Halcrow is at most 100mm at the 1:200 year return period, which is small when compared with the uncertainties inherent in such predictions. It is recommended therefore, that:

- For future assessments of flood and coast defence, that the extreme water level conditions contained in Table 2.3 and Figure 2.15 be adopted. This will provide consistent approach between the EA at Regional Level with respect to coastal flooding, with strategy and scheme development of flood and coast defence by operating authorities at local level.
- When applying for the recommended increase in sea level rise (Technical Annex 7), by 2053, the frequency of occurrence of extreme water levels will increase by 10 times. For example, the 2003 1:100-year water level will occur in 2053 at a return period of 1:10 years (Figure 2.15)
- There is no particular need to change retrospectively the design standard of the Town Quay flood defences, since the difference at the 1:200 year return period is less than 40mm.

![Figure 2.15 Recommended Extreme Water Level Conditions](image-url)
3 Joint Probability of Extreme Waves and Water Levels

Knowledge of the likelihood of occurrence of extreme wave conditions and extreme water levels is required for design of defences, whether to calculate wave overtopping or stability of hard defences or beach response under storm conditions.

The likelihood of occurrence of both high waves and high water levels depends on factors such as the tendency for funnelling of waves and water levels into bays and estuaries, the astronomical tidal range (since storm surge will be proportionately larger if the tidal range is small), the slope gradient of the bathymetry (since this will influence wave shoaling) and the orientation of the coastline to the predominant (extreme) wave direction.

Analysis of the joint probability of extreme waves and water levels was carried out by comparing timeseries records of both parameters. The analysis provides a frequency analysis of discrete combinations of wave and water level conditions. The frequency analysis is presented in the form of a matrix, on which contours of probability can be plotted for a number of return periods, in this case the 10:1, 1:1 and 1:10 year contours. The curve of the contours can then be used to predict the joint probability for conditions of higher return period, for example the 1:100 year return period. The method is described in greater detail in the Beach Management Manual (CIRIA, 1996).

The analysis was completed at three locations at the 10mCD contour, at Durlston Bay, Swash Channel and Southbourne (Figure 3.1)

The correlation between extreme wave conditions and water levels can be compared at a given return period, by calculating the “correlation factor”. Guidance on expected values of correlation factor for different locations is given in CIRIA, 1996:

“The suggested minimum correlation factor is 2, since any less would be rather risky without more detailed calculations. This would be appropriate where waves and water levels were expected to be independent. Correlation factor 20 represents a modest level of dependency, appropriate if some correlation is expected even if there is no particular evidence for it. Correlation factor 100
represents well-correlated conditions such as one might expect where strong winds moving into a narrowing sea area would produce both high surges and high waves. Example areas of such correlation would be the eastern English Channel and Severn Estuary during westerly storms, and the southern North Sea during northerly storms. The strong correlation factor 500 presents a dependence that would be unusual around the UK. It might be appropriate in an area where a strong correlation between surges and wave heights would be expected, and where the astronomical tide is low.”

For the purpose of comparison, correlation factors for the three locations within Poole Bay are given in Table 3.1. The lowest correlation between waves and water levels occurs at Durlston, with increasing correlation at Southbourne and highest correlation at the seaward entrance to the Swash Channel. These results appear reasonable, given the factors that influence the correlation.

The Durlston site is the most exposed of the three, with no localised funnelling of waves and water levels. Under extreme conditions from the south-west, the influence of winds to build up water levels will be reduced due to sheltering caused by Durlston Head. There is, however, some correlation demonstrated by the analysis, which may be due to the relatively low tidal range.

It is to be expected that the correlation between extreme waves and water levels increases further into Poole Bay, especially as the seabed bathymetry is flatter than at Durlston (typically 1:1000, compared to 1:100), allowing the influence of wave shoaling to increase, particularly towards the entrance to the Swash Channel. The levels of correlation are not particularly high, however, when compared to other parts of the English coast.

<table>
<thead>
<tr>
<th>Location</th>
<th>Correlation Factor at 1:100 year return period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southbourne</td>
<td>17</td>
</tr>
<tr>
<td>Swash Channel Entrance</td>
<td>25</td>
</tr>
<tr>
<td>Durlston</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3.1 Joint Probability of Extreme Wave and Water Levels with Poole Bay
Figure 1.1  Location of data and wave modelling grids

- **Star**: Offshore Wave Data Timeseries - Met Office Wave Model
- **Triangle**: Wave Data Locations
  - (-10m CD contour)
- **Circle**: Water Level Data - Poole Harbour Commissioners

Depth (mCD)
Figure 1.2  Offshore Wave Directions from UK Met Office European Waters Wave Model

Note: Wave conditions from 1997 to 2001 not plotted due to limits in Excel on numbers of data points.
Figure 2.2 Tidal Curves 23 December 2001 (typical neap tide)
Figure 2.3 Tidal Curves 30 December 2001 (typical spring tide)
Figure 2.5 Tidal Curves 19 November 1996
Figure 2.6 Tidal Curves 10 February 1997
Figure 2.7 Tidal Curves 26 September 1999
Figure 2.8 Tidal Curves 28 September 2000
Figure 2.9 Tidal Curves 12 December 2000
Figure 2.10 Tidal Curves 2 January 2001
Figure 2.11 Tidal Curves 10 March 2001
Figure 3.1  Location of joint probability assessments