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Coastal flood boundary conditions for UK mainland and islands

Project: SC060064/TR5: Practical guidance swell waves

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or by telephoning 08708 506506.

Author(s):
Alastair McMillan
David Worth
Dr Alice Johnson
Professor Jonathan Tawn
Dr Keming Hu

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Research Contractor:
Royal Haskoning
Rightwell House
Bretton
Peterborough, PE3 8DW
Tel: 01733 334455
Email: info@royalhaskoning.com

Environment Agency's Project Manager:
Stefan Laeger, Evidence Directorate

Collaborator(s):
Professor Jonathan Tawn

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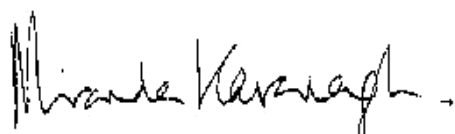
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Miranda Kavanagh
Director of Evidence

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The lead consultant of this project was Royal Haskoning, led by Alastair McMillan. The following members of the project team contributed to the work as follows:

| | | |
|--|---|--|
| Alastair McMillan | - | Extreme analysis of waves and reporting |
| Dr Alice Johnson | - | Development of statistical procedures, extreme analysis of waves and reporting |
| David Worth | - | Extreme analysis of waves and reporting |
| Dr Emma Eastoe | - | Development of statistical procedures |
| Professor Jonathan Tawn extreme | - | Development of statistical procedures, analysis of waves and reporting |
| Dr Keming Hu | - | Analysis of extreme wave conditions and reporting |
| Professor Robert Nicholls (University of Southampton) | - | Peer review |

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1. Introduction

Successful risk-based flood and coastal erosion risk management requires the best available information on coastal flood boundary conditions, such as sea levels and swell waves. Current information is not consistent around the country and is becoming out of date.

In April 2008, the Environment Agency took on the strategic overview of coasts in England, giving it an overarching role in the management of the English coastline.

This practical guidance was created for the Environment Agency R&D project S060064 *Coastal flood boundary conditions for UK mainland and islands*. The aim of this project was to develop and apply improved methods to update these important datasets, using a longer data record.

The aims of the project were to:

- Provide a consistent set of swell wave extremes around the coasts of England, Wales and Scotland.
- Offer best practice guidance on how to use this new dataset.

This document provides practical guidance on how to view the findings from the swell wave studies, described in a separate document (SC060064/TR3, *Technical report on swell wave conditions*). The detailed results are given in GIS format and can be obtained from the Environment Agency. The swell information given in the technical report updates the HR Wallingford report SR409, *Swell and bi-modal wave climate around the coast of England and Wales*¹ and provides, at the time of writing, the best information on a national level.

The work was conducted by a project team led by Royal Haskoning in collaboration with Professor Jonathan Tawn.

The Environment Agency Project Executive was Angela Scott; the Environment Agency's Business User was Tim Hunt and the Environment Agency Project Manager was Stefan Laeger.

The Project Director for Royal Haskoning was Fola Ogunyoye; their Project Manager was Alastair McMillan.

The project was supported by the Scottish Environment Protection Agency (SEPA) and the Scottish Executive.

2. Coverage

This project has produced swell wave parameters for a continuous chainage of points around the coast of England, Scotland and Wales.

Additional island chainages are included for the following locations:

- Shetland Isles
- Inner Hebrides
- West Coast of the Isle of Man
- Bristol Channel

Figure 2.1 and **Figure 2.2** show the main coastal chainages and the additional island chainages for these locations. These figures can be found at the end of this report.

Note 1

Extreme swell wave heights are considered accurate to one decimal place

Extreme swell wave heights provided by this project can be considered accurate to one decimal place. Two decimal places have been provided to differentiate between nodes on the chainage. This does not infer greater accuracy and the user should be mindful of this when selecting a node for an extreme swell wave height.

Note 2

Definition of annual exceedance probability

Annual exceedance probabilities (AEP) describe the likelihood of being exceeded in any given year. AEPs can also be expressed as chance. For instance, an AEP of one per cent has a chance of being exceeded of one in 100 in any given year. In coastal design this often termed 'return period'.

Note 3

How to obtain the data

The data produced by this project can be obtained for *Environment Agency statutory purposes* under license via the Environment Agency Customer Contact Centre (www.environment-agency.gov.uk/contactus).

3. What is swell?

Through observation of waves, a number of features can be easily measured. These are summarised over a time interval by the following statistics:

- Wave height – here taken as the significant wave height (H_s).
- Wave period – here taken as the zero crossing wave period (T_z).
- Wave direction – here taken as the mean wave direction (degrees N).

Waves can take the form of two types: wind waves and swell waves. A standard interpretation of these waves is that wind waves are generated by local winds, while swell waves are generated over a larger region and are due to decay of wind wave events .

The relevance of swell waves to coastal flood risk and the design of coastal structures arise from their wave period, which is longer than for wind waves. Associated with the longer period is an increase in the power of the waves. Thus swell waves can be very damaging to coastal structures. Their long wave period also means that wave run-up and wave overtopping will be much greater than for wind waves of equivalent wave height.

It is recommended that the consequence of swell waves is taken into account alongside consideration of the (more common) wind wave conditions. It will normally be adequate to evaluate the two cases (swell waves/wind waves) separately. Joint probability scenarios can treat the occurrence of swell as having no, or low, correlation to the occurrence of wind waves.

It is important for practitioners to know the direction associated with swell. For this reason, we have split the swell wave return period into direction sectors at sixty degree intervals, as shown in **Figure 3.1**.

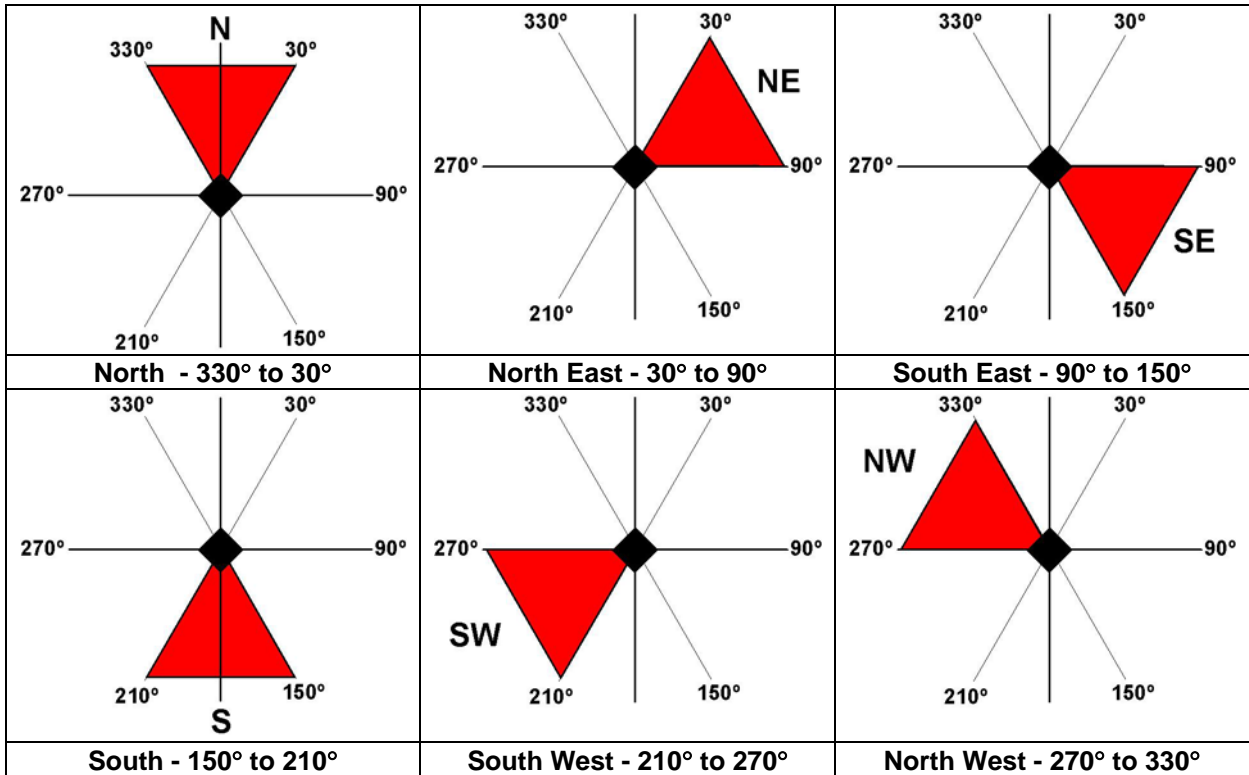


Figure 3.1 – Directional sectors

4. Summary of outputs

This project has produced swell wave parameters for a continuous chainage of points around the coast of England, Scotland and Wales. The swell wave results were obtained by statistical analysis of Met Office hindcast modelled offshore wave data.

Key outputs from the project are summarised in **Table 4.1**:

Table 4.1 – Swell wave Shapefile description

| Shapefile reference | Description |
|---------------------|---|
| CFB_Swell_Wave.shp | <ul style="list-style-type: none">• Metadata (Section 5.2).• References to files showing swell wave heights of annual probability with annual exceedance probability ranging from 100 to 0.1 per cent (average return period one in one year to one in 1,000 years) related to six sectors of wave direction and references.• References to files showing a relationship between swell wave height and the corresponding wave period.• References to files containing confidence intervals associated with the swell wave heights. |

The above parameters are given at points along a chainage line around the UK coast. The points are set broadly along a contour line of 50-m water depth, though in the shallower waters of the North Sea a approximate contour line of 20-m water depth is used.

5. GIS format

5.1 Introduction

Our results are supplied in a GIS format which the practitioner can use with standard software. This section describes the format of Shapefiles and the associated results file.

We have supplied the GIS Shapefiles together with files which contain the results in a separate folder. The Shapefile references these files which contain the results, therefore the folder and Shapefile must remain in same relative paths.

Table 5.1 describes the metadata within the Shapefile, CFB_Swell_Wave.shp

Table 5.1 – Swell wave Shapefile metadata

| Metadata | Description |
|-------------------------------------|---|
| Easting | X-Coordinate of output point in metres referenced to British National Grid |
| Northing | Y-Coordinate of output point in metres referenced to British National Grid |
| Chainage Reference 1 | Chainage the output points refer to Main/Shetland/Hebrides/Isle of Man/Bristol Channel. Chainage originates at Newlyn, Cornwall |
| Chainage Reference 2 | Regional chainages the output points on the main chainage refer to North, North East, South East, South, South West, West, North West |
| Chainage | Chainage position in kilometres |
| File reference | Reference to Met Office point used for the analysis |
| Swell wave height results file | This is a link to the location of a .csv file which displays the swell wave heights (in metres) for a given return period related to the six sectors of wave direction. The name of the file reflects the Met Office data point for which the method was applied. |
| Swell wave period probability table | This is a link to the location of a .csv file which displays wave period bands for a given wave height band, in terms of a probability. The name of the file reflects the Met Office data point to which the method was applied. |
| Confidence interval file | This is a link to the location of a .csv file which displays the swell wave confidence intervals for a given return period related to the six sectors of wave direction. The name of the file reflects the Met Office data point to which the method was applied. |

5.2 Swell wave heights

The results files are referenced to Met Office data points to which the method was applied. The results files are in a comma separated format which can be viewed in a standard spreadsheet application.

Although wave heights are quoted to two decimal places they should not be treated as accurate to that apparent degree of precision. Wave heights should be considered accurate to one decimal place.

Table 5.2 provides an example of how the results files for swell wave height appear, for an example output point north of the Shetland Islands.

The direction refers to the six sectors of wave direction as described in Section 3. Swell wave heights (in metres) of annual exceedance probability ranging from 100 to 0.1 per cent (average return period one in one year to one in 1,000 years), as listed below, are given for each of these six sectors.

- 1, 5, 10, 20, 25, 50, 75, 100, 150, 200, 250, 300, 500, 1,000 years

For some sites, N/A, meaning not applicable, will appear as a value. This means there was insufficient data to carry out meaningful analysis. It implies that swell from that direction is not a common occurrence so may not be particularly significant for many design or assessment purposes.

Table 5.2 – Return period significant swell wave heights per direction sector for output point GL0133

| DIRECTIONS | T1 | T2 | T5 | T10 | T20 | T25 | T50 | T75 | T100 | T150 | T200 | T250 | T300 | T500 | T1000 |
|-------------------|-----------|-----------|-----------|------------|------------|------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|
| NORTH | 5.29 | 5.59 | 5.95 | 6.2 | 6.43 | 6.50 | 6.7 | 6.82 | 6.89 | 7.00 | 7.07 | 7.12 | 7.16 | 7.28 | 7.42 |
| NORTHEAST | 4.19 | 4.54 | 4.94 | 5.21 | 5.45 | 5.52 | 5.72 | 5.83 | 5.91 | 6.01 | 6.07 | 6.12 | 6.16 | 6.26 | 6.39 |
| SOUTHEAST | 4.89 | 5.19 | 5.53 | 5.76 | 5.95 | 6.01 | 6.17 | 6.26 | 6.32 | 6.39 | 6.44 | 6.48 | 6.51 | 6.59 | 6.68 |
| SOUTH | 3.95 | 4.19 | 4.42 | 4.54 | 4.64 | 4.66 | 4.72 | 4.75 | 4.77 | 4.79 | 4.81 | 4.82 | 4.82 | 4.84 | 4.86 |
| SOUTHWEST | 5.18 | 5.38 | 5.6 | 5.74 | 5.85 | 5.89 | 5.98 | 6.02 | 6.05 | 6.09 | 6.12 | 6.13 | 6.15 | 6.19 | 6.23 |
| NORTHWEST | 5.56 | 5.77 | 5.98 | 6.12 | 6.22 | 6.25 | 6.34 | 6.38 | 6.41 | 6.44 | 6.46 | 6.48 | 6.49 | 6.52 | 6.56 |

5.3 Swell wave period

The results files are referenced to Met Office data points to which the method was applied. The results files are in a comma separated format which can be viewed in a standard spreadsheet application.

For any swell wave there will be a wave period associated with the significant wave height. We have provided a table showing wave period occurrence probability for a range of wave heights. The results were generated by analysis of Met Office model data. The model data, covering only eight years record, does not contain all possible combinations of swell wave height and period. In these situations the tables show N/A for wave period. For practical purposes, we recommend using the highest probability wave height from lower return periods.

Swell wave periods (in seconds) are separated into the following bandings:

| | | | | | |
|--------------|-------|--------|--------|--------|------------------|
| Less than 8s | 8-10s | 10-12s | 12-14s | 14-16s | Greater than 16s |
|--------------|-------|--------|--------|--------|------------------|

Significant wave heights (in metres) of swell are separated into the following bandings:

| | | | | | | | | |
|--------------|------|------|------|------|------|------|------|-----------------|
| Less than 1m | 1-2m | 2-3m | 3-4m | 4-5m | 5-6m | 6-7m | 7-8m | Greater than 9m |
|--------------|------|------|------|------|------|------|------|-----------------|

A probability (expressed to two decimal places) of a wave period being associated with a significant wave height is provided.

Table 5.3 provides an example of how the results files for swell wave period appear, for an example output point north of the Shetland Islands.

Table 5.3 – Probability table (two decimal places) of a wave period for a given significant swell wave height - GL0133

| | Tz <8s | Tz 8-10s | Tz 10-12s | Tz 12-14s | Tz 14-16s | Tz >16s |
|------|--------|----------|-----------|-----------|-----------|---------|
| <1m | 0.29 | 0.18 | 0.16 | 0.15 | 0.14 | 0.08 |
| 1-2m | 0.40 | 0.24 | 0.17 | 0.11 | 0.06 | 0.01 |
| 2-3m | 0.28 | 0.31 | 0.24 | 0.11 | 0.04 | 0.01 |
| 3-4m | 0.09 | 0.45 | 0.30 | 0.12 | 0.03 | N/A |
| 4-5m | N/A | 0.45 | 0.32 | 0.19 | 0.04 | N/A |
| 5-6m | N/A | 0.20 | 0.56 | 0.22 | 0.02 | N/A |
| 6-7m | N/A | N/A | 0.71 | 0.14 | 0.14 | N/A |
| 7-8m | N/A | N/A | N/A | N/A | N/A | N/A |
| >8m | N/A | N/A | N/A | N/A | N/A | N/A |

5.4 Confidence intervals

Statistical analysis was carried out on Met Office model data to provide confidence intervals associated with swell wave height values. These can be added or subtracted to the swell wave height values to make allowances for uncertainty. Please note that confidence intervals provide uncertainty information for swell wave heights only.

The results files are referenced to Met Office data points to which the method was applied. The results files are in a comma separated format which can be viewed in a standard spreadsheet application. **Table 5.4** provides an example of how the results files for swell wave confidence intervals appear, for an example output point north of Shetland.

The direction refers to the six sectors of wave direction as described in Section 3. Swell wave confidence intervals (in metres) of annual exceedance probability ranging from 100 to 0.1 per cent (return period one to 1,000 years, listed below) are given for each of the six sectors.

- 1, 5, 10, 20, 25, 50, 75, 100, 150, 200, 250, 300, 500, 1,000 years

Table 5.4 – Confidence intervals for swell wave heights for output point GL0133

| DIRECTIONS | T1 | T2 | T5 | T10 | T20 | T25 | T50 | T75 | T100 | T150 | T200 | T250 | T300 | T500 | T1000 |
|-------------------|-----------|-----------|-----------|------------|------------|------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|
| NORTH | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| NORTHEAST | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 |
| SOUTHEAST | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| SOUTH | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| SOUTHWEST | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| NORTHWEST | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |

6. What are these results to be used for?

6.1 Introduction

The outputs of this project provide improved information on offshore swell wave parameters around the coast. This information is needed to support successful risk-based flood and coastal erosion risk management. It can inform a wide range of decisions, including those listed below:

- coastal design
- flood forecasting
- flood risk mapping
- spatial planning.

6.2 Which swell wave shall I use?

This project has produced swell wave heights for offshore points along a continuous chainage around the coastline of England, Scotland and Wales. In many cases the practitioner requires wave information for a coastal site. The outputs of this project cannot be used directly at a coastal site. Instead, the wave conditions have to be modified to account for the effects of shallower water as the waves move from offshore to nearshore. This section describes how the results of this project can be used by the practitioner to identify the worst case swell wave conditions for a given coastal site.

Swell wave direction

Firstly, the user has to choose the swell wave direction. A useful indicator of worst case swell directions is the fetch to which the coastal site is exposed to. The coastal site may be susceptible to swell waves from more than one direction. In making the choice, be mindful of possible shielding to the site by headlands, islands or areas of shallow water.

Choosing the output point

Once a direction(s) has been selected, an output point should be selected to find the offshore swell wave conditions pertinent to the site and the wave directions to which it is vulnerable. It may be appropriate to look at results from more than one output point, especially if the site is exposed over a wide range of directions.

Finding the resultant swell wave conditions

The swell wave parameters are linked to their respective output point and can be seen through use of GIS and spreadsheet software.

Comment

The practitioner needs to be mindful that the worst case swell conditions may not necessarily be caused by the offshore swell condition perpendicular to a coastal site. Waves will often change direction when moving from deeper water (offshore) to shallow water (nearshore). There are three main processes which causes this to happen:

- Refraction – The wave front may bend due to differential wave speed arising from different water depths along the front, notably if the wave front approaches the coastline from a non-perpendicular angle.
- Diffraction – Bending of the wave front due to obstructions, for example if the waves encounter an offshore breakwater or small island.
- Reflection – Waves that encounter a surface can abruptly change direction without much loss of energy, such as if the wave encounters a vertical sea wall.

These processes will depend on the bathymetry between the offshore point and coastal site. Bathymetry information can be obtained from Admiralty Charts, for example. These will inform the user of changes in depth which can lead to refraction of the waves; the charts will also identify obstructions. Bathymetry data is also commercially available in digital form.

Although not normally necessary, selection of relevant output point(s) can be assisted by construction of wave rays. This process involves developing wave rays extending from the coastal site to the offshore swell chainage line. Bathymetry of the sea area is needed. The wave rays require the practitioner to first choose a wave period. A number of wave periods should be tested to identify the influence of period on the wave directions from which the site is vulnerable.

6.3 Wave transformation

The swell wave parameters provided are for offshore points. In order to determine respective conditions at the coastline, wave transformation is needed.

Wave transformation involves the transfer of an offshore wave in deeper water, that is the offshore swell waves identified by this project, into shallower water in the nearshore zone. The standard approach for this is to use a numerical model. There are a number of numerical models which can be used to transform offshore waves. These models require the input of the offshore wave conditions as a boundary condition. In addition a water level and bathymetric information is required. More detailed bathymetry should be used where available to improve reliability of results. The transformation numerical models simulate the physical processes involved, including refraction and diffraction; some also model wave reflection.

The offshore wave conditions from a range of directions and output points can be tested using the transformation model. Through conducting a range of tests, this method determines the worst case swell wave in terms of wave height and wave period in the nearshore area and therefore at a specific coastal site.

6.4 Limitations

This project used eight years of data for the swell wave analysis, therefore estimates of extreme swell wave parameters for lower annual exceedence probabilities (higher return periods) will be limited. The user should be mindful of uncertainties and adopt a precautionary approach, as set out in the worked example (Section 7). Use of Met Office data covering a longer time period would provide more robust results. Further data with which to undertake additional analysis is available from the Met Office.

6.5 Analysis of wind waves

As described in Section 3, there are two general classifications of wave: swell wave and wind wave. Both need to be considered when assessing wave conditions at a coastal site.

Met Office swell and wind wave data were compared to identify dependence between them. Correlation between the two needs to be accounted for to produce a joint occurrence of swell and wind waves. Swell wave heights were compared to wind wave heights to determine any correlation between them and therefore dependence at the same point in time. At the eight test sites there was no, or very little, correlation between swell wave heights and wind-sea heights; therefore we conclude that the two are independent and can be assessed on this basis.

Hindcast model wind wave data for points around the coast of England, Scotland and Wales can be obtained from the Met Office. A range of directions should be considered for wind-generated waves. The statistical analysis carried out to produce swell parameters for this project would be applicable to Met Office wind wave data.

7. Worked example

The following steps should be carried out when determining extreme swell wave conditions:

1. Identify possible direction sectors for which the coastal site may be susceptible
2. Identify output points
3. Identify the corresponding results for the output point
4. Determine the worst case swell wave condition in terms of direction sector and wave height
5. Choose an appropriate corresponding wave period
 - a) Selection of wave period for a corresponding swell wave height
 - b) Selection of longer wave period
 - c) Selection of worst case swell condition
6. Consider allowance for uncertainty
7. Chosen swell wave condition

This worked example shows how a practitioner can use the data to select output points relevant to obtain swell information for a coastal site. We have used an example at Worthing, on the south coast of England, for illustrative purposes. The key aspects of this site can be seen in **Figure 7.1**.



Figure 7.1 – Worthing location map

1. Identify possible directional sectors for which the coastal site may be susceptible

This can be done by simply referring to a map of your site. Consider the possible fetches over which the waves can develop. It is also useful to obtain a bathymetric chart of the sea bed for the study site, available from the UK Hydrographic Office. Be mindful that the geography of the coastline (depth changes and obstructions, man made and naturally occurring) can influence the wave propagation onshore. In this example we consider the following:

- Swell from the south west sector along the English Channel and originating in the Atlantic Ocean.
- Swell from the southern sector across the English Channel.

2. Identify output points

Open the CFB_Swell_Wave.shp Shapefile in a standard GIS software package. **Figure 7.1** shows how this will appear. Use licensed mapping, if possible, to aid the process.

Identify the chainage on which the output point lies from the following options:

- Main
- Shetland
- Hebrides
- Isle of Man
- Bristol Channel.

In this example we will select a point directly offshore from Worthing. Since the coastline around Worthing has no significant changes in direction, use of a single output point should be sufficient.

The chainage reference of the point can be found by using the Identifier tool (from the GIS software) and clicking on the chosen output point, as shown in **Figure 7.2**. The output points at Worthing are on the Main chainage. The selected point is at chainage 4582 km. The reference Met Office model point used for the analysis is GL2607.

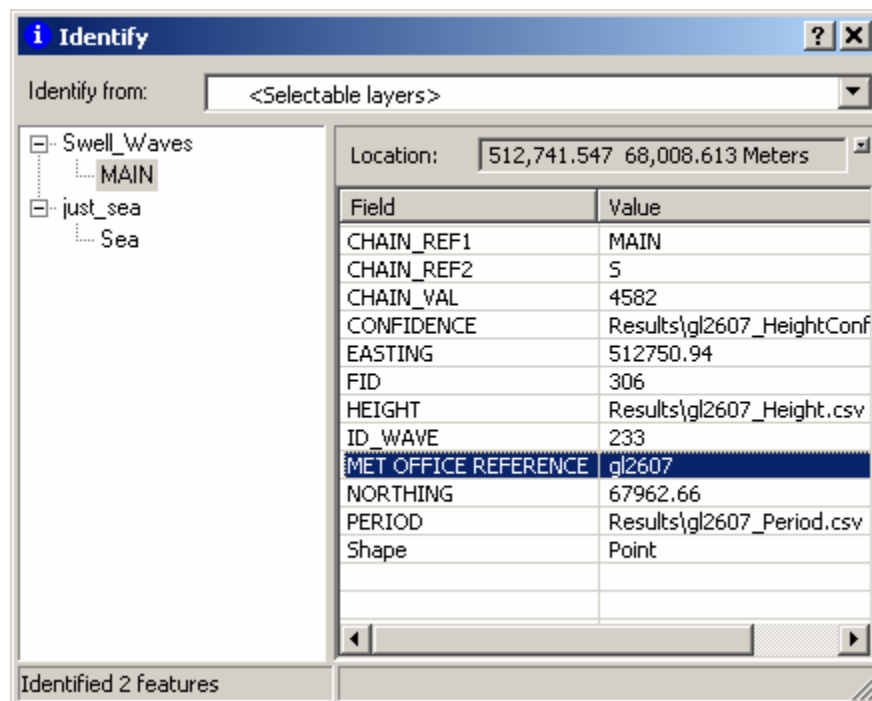


Figure 7.2 Swell wave Shapefile metadata

3. Identify the corresponding results for the output point

Again using the Identifier tool in the GIS software, select the swell wave height results file, swell wave period probability table and the confidence interval file for the chosen output point, as shown in **Figure 7.3**. These files are named according to the Met Office files used for the analysis and are contained in the results folder accompanying the Shapefile.

Chainage 4582km – Met Office data point GL2607

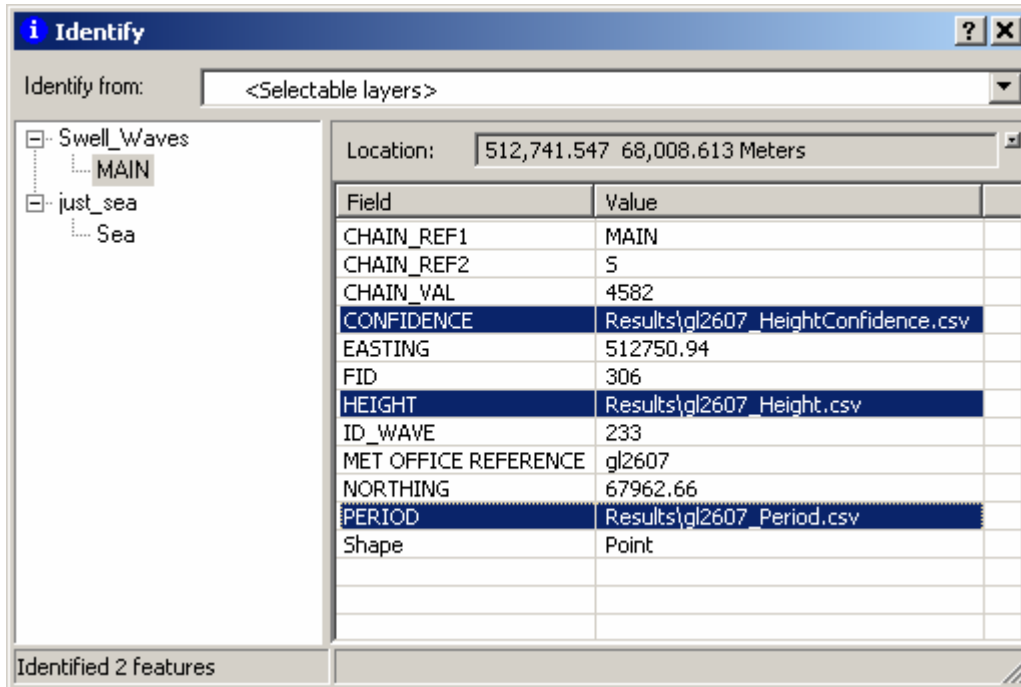


Figure 7.3 Results files for selected output points

4. Determine the worst case swell wave condition in terms of direction sector and wave height

Open the swell wave height results file (gl2607_height.csv) in a standard spreadsheet application. In this example we will use the 100-year return period significant wave height as the target condition. **Table 7.1** presents these results.

Table 7.1 – Example 100-year swell wave heights (gl2607_Height.csv)

| Direction Sector | T100 |
|------------------|------|
| North | N/A |
| North East | N/A |
| South East | N/A |
| South | 3.29 |
| South West | 2.97 |
| North West | 2.47 |

Thus, the worst case scenario is with swell waves from the southern sector. In Step 1 our hypothesis was for swell that can potentially occur from the south or south west. One may still consider both direction sectors; this depends on the requirements of the study.

Whilst there may be some swell from the north west at the offshore model data point used for reference, there can be no waves from this direction at the Worthing coastline. Results for this directional sector can therefore be ignored.

5. Choose an appropriate corresponding wave period

Open the swell wave period probability table (gl2607_Period.csv) in a standard spreadsheet application, as shown in **Table 7.2**.

Table 7.2 – Example wave period probability table (g2607_period.csv)

| | | Wave period | | | | | |
|-------------|------|-------------|----------|-----------|-----------|-----------|---------|
| | | Tz <8s | Tz 8-10s | Tz 10-12s | Tz 13-14s | Tz 14-16s | Tz >16s |
| Wave height | <1m | 0.63 | 0.19 | 0.10 | 0.07 | 0.01 | N/A |
| | 1-2m | 0.74 | 0.22 | 0.04 | N/A | N/A | N/A |
| | 2-3m | 0.66 | 0.34 | N/A | N/A | N/A | N/A |
| | 3-4m | N/A | N/A | N/A | N/A | N/A | N/A |
| | 4-5m | N/A | N/A | N/A | N/A | N/A | N/A |
| | 5-6m | N/A | N/A | N/A | N/A | N/A | N/A |
| | 6-7m | N/A | N/A | N/A | N/A | N/A | N/A |
| | 7-8m | N/A | N/A | N/A | N/A | N/A | N/A |
| | >8m | N/A | N/A | N/A | N/A | N/A | N/A |

The wave period bandings for each range of wave heights are based on the Met Office data only. Thus, there will be instances where a wave period is not given. In these cases we recommend using the highest probability wave period from the next lower wave height banding.

a) Selection of wave period for a corresponding swell wave height

For our example we have a swell wave height in the 3-4 m banding. No wave period is shown in the table for the 3-4 m banding, so we select the highest period from the next lower wave height band. This is the 2-3 m banding for which the greatest probability is for waves of period less than eight seconds. Being precautionary, we therefore select eight seconds as our wave period for the 3.29 m swell wave height from the south.

b) Selection of longer wave period

Due to the limited data record used for the analysis, we also recommend consideration of longer wave periods. For practical purposes, these should be considered when the probability of a wave period banding for a given swell wave height banding is greater than five per cent. In this example, there is a probability of 34 per cent that a 2-3 m swell wave height may occur for a wave period of 8-10 seconds. Likewise there is a 10 per cent probability that a swell wave height less than one metre will occur for a 10-12 seconds wave. Similarly there is a seven per cent probability that a wave height less than one metre will occur for a 13-14 seconds wave period. Being precautionary, we will select the highest wave period using this process. Therefore we will also consider a swell wave height of 0.9 m with a wave period of 14 seconds.

c) Selection of worst case swell condition

Mindful of our precautionary approach, and the importance of wave period when considering swell, we also recommend identifying the worst case scenario swell wave condition from the swell wave period table. In this instance there is probability of one per cent of a swell wave height less than one metre occurring with a corresponding wave

period between 14 and 16 seconds. Thus, a swell wave condition of a 0.9 m swell wave height with a wave period of 16 seconds should be considered. If there is evidence, perhaps from wave buoy data, of a wave period of greater than 16 seconds occurring at the site, one should instead use this to represent the 'worst case' swell wave condition.

6. Consider allowance for uncertainty

We have provided confidence intervals for a given swell wave height annual exceedance probability per direction sector. This was achieved using a statistical process to derive uncertainty information. These intervals provide a range above and below the swell wave height given in the tables.

Open the confidence interval file (gl2607_HeightConfidence.csv) in a standard spreadsheet application.

Ensure the confidence intervals are selected for the swell wave height in Step 4, in terms of direction sector and annual exceedance probability. Therefore select the confidence intervals for the T100 return period (one per cent annual exceedance probability) for the south and south west sectors. **Table 7.3** shows confidence intervals for the 100-year return period (one per cent annual exceedance probability) per direction sector.

Table 7.3 – Confidence intervals for one per cent annual exceedance probability (100-year return period)

| Direction sector | T100 |
|------------------|------|
| North | N/A |
| North East | N/A |
| South East | N/A |
| South | 1.0 |
| South West | 0.3 |
| North West | 0.2 |

7. Chosen swell wave condition

Table 7.4 shows the swell wave conditions to be considered from this example. The wave heights are rounded off to one decimal place. We have considered swell from the southern direction sector for illustration purposes. We may also consider swell from the south west, as identified in the hypothesis at Step 1.

Table 7.4 – Chosen swell wave conditions

| Scenario | Swell wave height (m) | Confidence interval (+/- m) | Wave period (s) |
|----------|-----------------------|-----------------------------|-----------------|
| a) | 3.3 | 1.0 | 8 |
| b) | 0.9 | - | 14 |
| c) | 0.9 | - | 16 |

Note that confidence intervals are only valid for the annual exceedance probability and direction sector which corresponds to the swell wave height identified in Step 4. Therefore the confidence interval of 1.0 for a one per cent annual exceedance probability (100-year return period) can only be applied to Scenario a).



Key: Chainage Reference

- Main
- Bristol Channel
- Hebrides
- Isle of Man
- Shetland

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Title:
Swell Wave Chainages

Project:
SC060064: Development and
Dissemination of Coastal and
Estuary Extremes

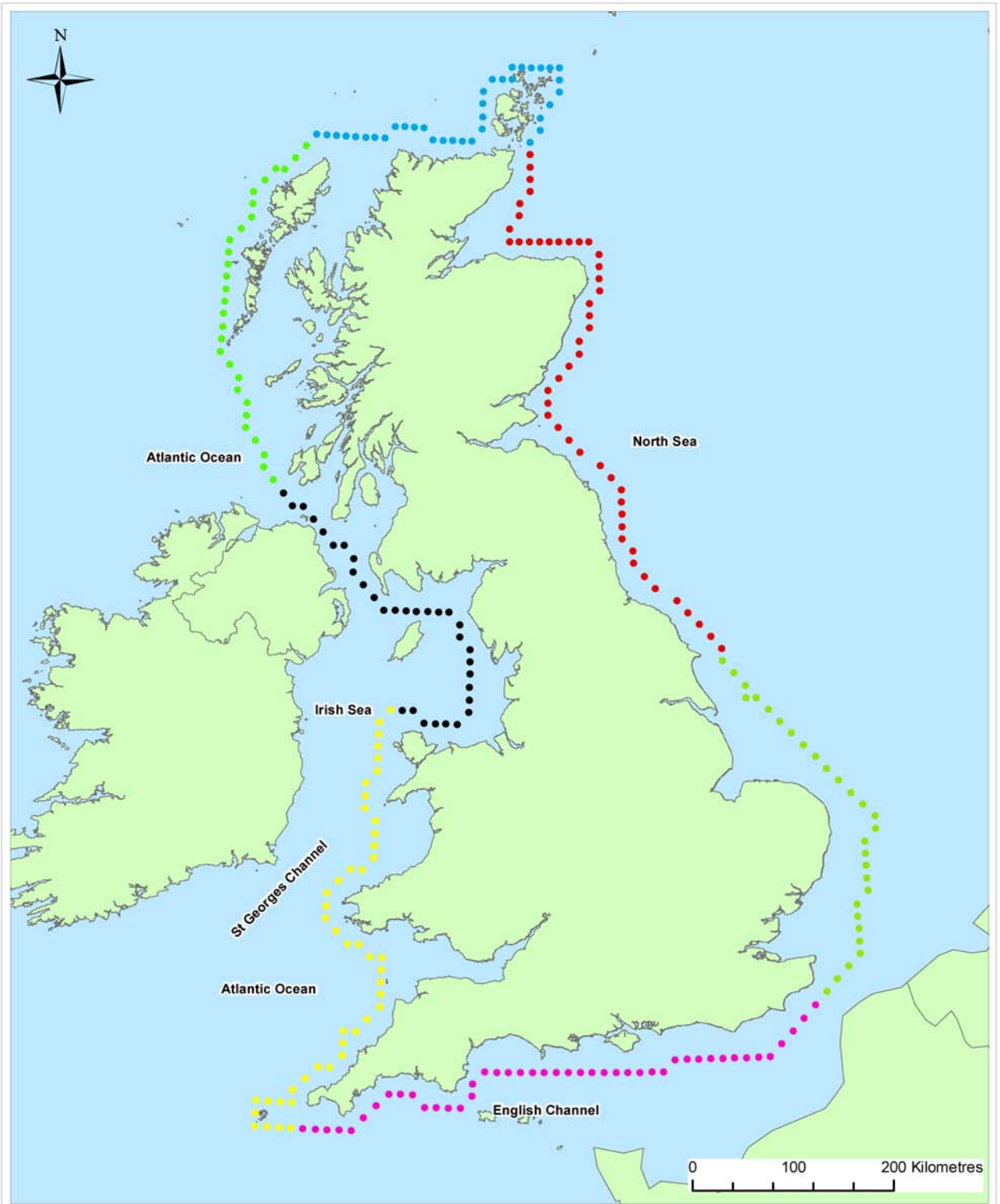
Client:
Environment Agency

Date:
2010

Scale @A4:
1:5,500,000

Figure:
2.1





| | | |
|---|---|-------------------------------|
| <p>Key:</p> <p>Regional Chainages</p> <ul style="list-style-type: none"> ● North ● North East ● South East ● South ● South West ● West ● North West <p>Source / Copyright I:\957299\Technical_Data\F12_GIS\Projects\Report_Figures\Extreme_Swell_Wave_Best_Practice_Guidance</p> | <p>Title: Regional Chainages</p> <p>Project: SC060064: Development and Dissemination of Coastal and Estuary Extremes</p> <p>Client: Environment Agency</p> <p>Date: 2010</p> <p>Scale @A4: 1:5,000,000</p> | <p>Figure: 2.2</p> |
|---|---|-------------------------------|

References

1. HAWKES, P.J., BAGENHOLM, C., GOULDBY, B.P. AND EWING, J. 1997.
Swell and bi-modal wave climate around the coast of England and Wales.
HR Wallingford Report No. SR409.

Glossary

| | |
|--|--|
| Annual exceedence probability: | The probability (likelihood) of being exceeded in any given year. |
| Bathymetry: | The study of underwater depth. |
| Chainage | Continuous arbitrary line of output points around the coastline with the zero chainage at Newlyn and continuing clockwise around the UK coastline. |
| GIS | Geographic Information System software. |
| Hindcast data | Data from retrospective forecasting. Inputs for past events are entered into the model to see how well the output matches the known results. |
| Mean wave direction (θ_m) | Spectrally averaged mean direction from which wave energy is coming. |
| Significant wave height (H_s) | Standard wave height measure equal to the average wave height of the highest one-third of the waves. |
| Wind waves | Waves generated by local wind conditions also known as wind-sea waves. |
| Zero crossing wave period (T_z , T_{av}) | Average time interval between similar direction crossings of mean water level for a wave record. |

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Environment Agency
Rio House
Waterside Drive, Aztec West
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Tel: 0870 8506506
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

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