delivering benefits through evidence

Coastal flood boundary conditions for UK mainland and islands

Project: SC060064/TR4: Practical guidance design sea levels

Flood and Coastal Erosion Risk Management Research and Development Programme

The Environment Agency is the leading public body protecting and improving the environment in England and Wales.

It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

This report is the result of research commissioned by the Environment Agency's Evidence Directorate and funded by the joint Environment Agency/Defra Flood and Coastal Erosion Risk Management Research and Development Programme.

Published by:
Environment Agency, Rio House, Waterside Drive,
Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
www.environment-agency.gov.uk

ISBN: 978-1-84911-214-7

This report is printed on Cyclus Print, a 100% recycled stock, which is 100% post consumer waste and is totally chlorine free. Water used is treated and in most cases returned to source in better condition than removed.

Further copies of this report are available from:
The Environment Agency's National Customer Contact Centre by emailing:
enquiries@environment-agency.gov.uk
or by telephoning 08708 506506.

Author(s):
Alastair McMillan
David Worth
Dr Mark Lawless

Dissemination Status:
Publicly available

Keywords:
Extremes, probability, sea levels, surge, tide

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

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

Collaborator(s):
JBA Consulting, National Tidal and Sea Level Facility, Professor Jonathan Tawn

Project Number:
SC060064

Product Code:
SCHO0111BTKK-E-E

Evidence at the Environment Agency

Evidence underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us, helps us to develop tools and techniques to monitor and manage our environment as efficiently and effectively as possible. It also helps us to understand how the environment is changing and to identify what the future pressures may be.

The work of the Environment Agency's Evidence Directorate is a key ingredient in the partnership between research, guidance and operations that enables the Environment Agency to protect and restore our environment.

The Research & Innovation programme focuses on four main areas of activity:

- **Setting the agenda**, by providing the evidence for decisions;
- **Maintaining scientific credibility**, by ensuring that our programmes and projects are fit for purpose and executed according to international standards;
- **Carrying out research**, either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available.

Miranda Kavanagh

Director of Evidence

Acknowledgements

The word described in this report is based on activities by the project team for the Joint Department for Environment, Food and Rural Affairs/Environment Agency research and development project *Coastal flood boundary conditions for UK mainland and islands* (SC060064).

The lead consultant for this project is Royal Haskoning. The following members of the project team contributed to the work as follows:

Royal Haskoning – led by Alastair McMillan and David Worth		Conceptual processes, advice on extreme sea level and surge analyses, verification against recorded levels, adjustment to extreme sea level modelling results, GIS data and reporting
JBA Consulting – led by Mark Lawless	-	Extreme sea level modelling, sea level statistical analysis and analysis of surge curves, reporting
National Tidal and Sea Level Facility – led by Kevin Horsburgh	-	Extreme sea level modelling and reporting
Professor Jonathan Tawn	-	Advice on extreme sea level statistical analyses
Douwe Dillingh (Deltares)	-	Peer review
Professor Robert Nicholls (University of Southampton)	-	Peer review

Contents

List of tables and figures

1 Introduction

Successful risk-based flood and coastal erosion risk management requires the best available information on coastal flood boundary conditions, such as swell waves and sea levels. 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 *Coastal flood boundary conditions for UK mainland and islands*. The aim of this project was to develop and apply improved methods to update these datasets, using a longer data record.

The aims of the project were to:

- Provide a consistent set of extreme sea levels around the coasts of England, Wales and Scotland (replacing advice given in the Proudman Oceanographic Laboratory Report 112)[1].
- Provide a means of generating total storm tide curves for use with the extreme sea levels.
- Offer practical guidance on how to use these new datasets.

This report provides practical guidance on how to view the findings of the extreme sea level and storm tide curve studies. It also explains how to use the results and includes a worked example. Detailed results are given in GIS files accompanying the technical report[2].

The work was conducted by a project team led by Royal Haskoning and including JBA Consulting, Professor Jonathan Tawn, and the National Tidal and Sea Level Facility (NTSLF).

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 sets out extreme sea levels for a continuous chainage of points around the coast of England, Scotland and Wales as shown in **Figures 2.1 to 2.6**. The figures can be found at the end of the main report.

Additional chainages cover the Isle of Arran, the Western Isles, Hebrides, Orkney Islands and the Isle of Wight.

Additional points are included for St Mary's (Isles of Scilly), Port Erin (Isle of Man) and Lerwick (Shetland Islands).

This report also offers advice on appropriate storm surge curves to use and details of where to apply them.

3 Summary of outputs

Key outputs from the project may be summarised as follows:

- Extreme peak sea levels of annual exceedance probability ranging from 100 to 0.01 per cent (average return period one in one year to one in 10,000 years).
- Peak sea level values are given for the full study area coastline at a spacing of about two km. This enables rapid selection of appropriate levels without any need for further interpolation.
- Advice on generating an appropriate total storm tide curve for use with the extreme sea levels. Standard surge tide shapes are given for each part of the coast.

The surge shape should be combined with an astronomical tide to give the total storm tide curve.

Coverage of extreme sea levels extends around the open coast, together with some outer parts of estuaries. Estuary values are not otherwise provided, because of the individual nature of tidal hydraulics in each estuary, making study more appropriate at a local rather than a national level. The boundary between estuaries and the open coast (the inland upstream extent of extreme sea level coverage) is provided in an accompanying Shapefile.

Note 1

Extreme sea levels are considered accurate to one decimal place

Extreme sea levels provided as part of 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 sea level.

Note 2

Extreme sea level values are for still water sea levels only

Extreme sea level values include the effects of storm surge but do not account for any local increase in sea level that may be induced by onshore wave action. Wave set-up, so called, would need to be estimated separately.

Note 3

Definition of annual exceedence 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 4

How to obtain the data

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

4 GIS format

4.1 Introduction

The results are supplied in GIS format which the practitioner can use with standard software. This section describes the format of the Shapefiles.

There are four Shapefiles included with this project, as described in **Table 4.1**.

Table 4.1 Shapefile descriptions

Shapefile reference	Description
CFB_Estuary_Boundaries.shp	Inland estuarine boundaries of the extreme sea levels
CFB_Extreme_Sea_Levels.shp	Extreme sea levels for a range of return periods
CFB_Confidence_Intervals.shp	Confidence intervals providing allowances for uncertainty
CFB_Surge_Shapes.shp	Reference to surge shape appropriate for each Class A gauge site and where to apply it

4.2 Estuary boundaries

Coverage of extreme sea levels extends to the boundary between estuaries and the open coast, but estuary values are not otherwise provided. This Shapefile shows 'cut-off' points at estuaries inland of which the extreme sea levels produced by this project should not be used. Separate studies, using the extreme sea level estimates provided in this project as downstream boundary conditions, should be carried out to derive estuarine extreme sea levels.

4.3 Extreme sea levels

Each point is referenced to its chainage position in kilometres. The chainage forms a line around the UK coast. The zero chainage point is at Newlyn. Extreme sea levels (relative to Ordnance Datum) of annual exceedance probability ranging from 100 to 0.01 per cent (return period one year to 10,000 years), listed below, are given for all points.

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

A GIS Shapefile accompanying this report contains metadata and extreme sea level values for all output points, as described in **Table 4.2**.

Table 4.2 Extreme sea level Shapefile description

Metadata attribute	Description
Chainage	Reference to location on the particular chainage
Return periods	Return period (one to 10,000 years) extreme sea level value
Island	This links the point to a chainage

4.4 Confidence intervals

Extreme sea level confidence intervals for annual exceedance probability ranging from 100 to 0.01 per cent (average return period one year to 10,000 years), listed below, are provided for all sites on the mainland UK chainage.

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

A GIS Shapefile accompanying this report contains metadata and extreme sea level values for all output points, as described in **Table 4.3**.

Table 4.3 Confidence interval Shapefile description

Metadata attribute	Description
Chainage	Reference to location on the particular chainage
Return periods	Return period (one to 10,000 years) confidence interval

4.5 Surge shapes

Guidance is provided on the standard surge shapes to use. These are based on analysis of data from forty Class A gauge sites. Included in this Shapefile is a reference to the respective section of coastline where each surge tide shape can be applied. Each shape is given as a time series of values representing the growth and decline of an extreme storm surge typical to the respective location.

A GIS Shapefile accompanying this report contains metadata for each surge shape, as described in **Table 4.4**.

Table 4.4 Surge shape Shapefile description

Metadata attribute	Description
Profile	Reference to surge shape number in the accompanying spreadsheet
Donor site	Class A gauge where analysis to produce the surge shape was undertaken
Location	Geographic bounds where surge shape applies

In addition to the surge shape Shapefile, an accompanying spreadsheet is provided (Design Surge Shapes.xls) which holds the following information:

Tab 1 (Locations) contains a table referencing the surge shape assigned for each Class A site, as shown in **Table 4.5**. The “Surge Profile” refers to the surge shape values, which can be found in Tab 2 (Donor Surge Shapes). The “Donor Site” is the Class A site at which the surge shape analysis was undertaken. This table also gives advice on where each donor surge shape can be applied. The named sites reference geographic bounds moving clockwise around the coast of the UK.

Tab 2 (Donor Surge Shapes) gives values of the surge shapes for a 99-hour duration at fifteen-minute intervals for each of the surge donor sites.

The remaining worksheets present figures showing the forty surge shapes.

Table 4.5 Surge shapes for Class A sites and geographic frontages to apply the profiles

Surge shape	Donor site	Apply from (clockwise around UK):
1	Wick	John o'Groats to Brora
2	Moray Firth	Brora to Lossiemouth (Moray Firth)
3	Aberdeen	Lossiemouth to Arbroath
4	Leith	Arbroath to North Berwick (incl Firth of Forth and Tay)
5	North Shields	North Berwick to Redcar
6	Whitby	Redcar to Spurn Head
7	Immingham	Spurn Head to Holme-next-the-Sea
8	Cromer	Holme-next-the-Sea to Winterton-on-Sea
9	Lowestoft	Winterton-on-Sea to Aldeburgh
10	Felixstowe	Aldeburgh to Walton-on-the-Naze
11	Sheerness	Walton-on-the-Naze to Margate (incl. Thames Estuary)
12	Dover	Margate to Selsey
13	Portsmouth	Selsey to Milford on Sea (incl. Solent and Isle of Wight)
14	Bournemouth	Milford-on-Sea to Swanage
15	Weymouth	Swanage to Salcombe
16	Devonport	Salcombe to Lizard Point
17	Newlyn	Lizard Point to Hartland Point (Titchberry)
18	St Mary's	Isles of Scilly
19	Ilfracombe	Hartland Point to Minehead
20	Hinkley Point	Minehead to Weston-super-Mare
21	Avonmouth	Weston-super-Mare to Caldicot (Severn)
22	Newport	Caldicot to Llantwit Major
23	Mumbles	Llantwit Major to Tenby
24	Milford Haven	Tenby to St David's Head
25	Fishguard	St David's Head to New Quay (Cei Newydd)
26	Barmouth	New Quay (Cei Newydd) to Aberaeron Bay
27	Holyhead	Aberaeron Bay to Amlwch
28	Llandudno	Amlwch to Point of Ayr
29	Liverpool	Point of Ayr to Fleetwood
30	Heysham	Fleetwood to Haverigg Point (incl. Morecambe Bay, Duddon Estuary)
31	Workington	Haverigg Point to Isle of Withorn (incl. Solway Firth, Wigtown Bay)
32	Port Erin	Isle of Man
33	Portpatrick	Isle of Withorn to Girvan
34	Millport	Girvan to Mull of Kintyre (incl. Arran)
35	Port Ellen	Mull of Kintyre to Oban (incl. Islay, Jura, Colonsay)
36	Tobermory	Oban to Kyle of Lochalsh (incl. Tiree, Coll, Mull, Rhum, Eigg and Skye)
37	Ullapool	Kyle of Lochalsh to Point of Stoer
38	Kinlochbervie	Point of Stoer to John o'Groats
39	Stornoway	Outer Hebrides
40	Lerwick	Orkney Islands, Shetland Islands

5 What are these results to be used for?

5.1 Introduction

In extreme analysis of physical events one is, by definition, often trying to predict an event that has not occurred and indeed may rarely occur. Despite the uncertainties, practitioners require information on extreme sea levels for a number of purposes, including those listed below:

- flood risk mapping
- flood risk assessments
- spatial planning
- coastal design
- flood warning
- port operations.

5.2 Choosing an extreme sea level

This project produced extreme sea levels at a two km resolution around the coast of the UK. For this project, tide data (predicted and observed) was obtained for a number of sites around the UK coast. The method used to determine the return period of total sea level (astronomical tide and surge) was the skew surge joint probability method (SSJPM). Skew surge is the difference between the predicted astronomical high tide and the nearest observed high water, as shown in **Figure 5.1**.

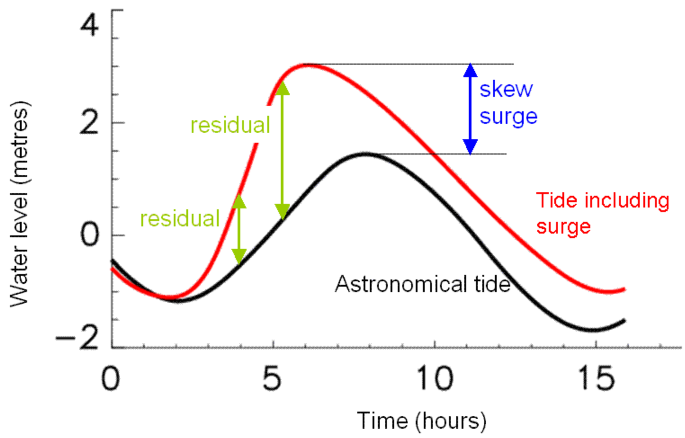


Figure 5.1 Illustration of skew surge

This section describes how a practitioner should select an extreme sea level for a site.

1. <u>Ensure site is within boundaries of this project</u>

This project provides extreme sea levels for all open coast points and some outer estuarine locations. Due to the complex physical processes present, extreme sea levels for most estuarine locations are not included. Please refer to the estuary 'cut-off' lines as indicated by the accompanying Shapefile and shown in **Figures 2.1 to 2.6**. If the site is upstream of the estuary boundary, the extreme sea level cannot be obtained directly from the results of project.

2. Find site

The coastal chainage is presented in a Shapefile (CFB_Extreme_Sea_Level.shp). The chainage is slightly offshore for ease of viewing in mapping software. The chainage points are perpendicular to the site which they represent. Given the complex alignment of the coastline, this coastal chainage is not precise. We recommend picking the closest chainage point to the site of interest in a perpendicular direction from the coast. This should be simply done "by eye" as the accuracy of the sea level values does not warrant any more rigorous selection process.

3. Choose return period sea level

Linked to each chainage point are sixteen peak sea levels which have an annual exceedance probability ranging from 100 to 0.01 per cent (one to 10,000-year return periods). Although levels are given to two decimal places, practitioners should treat them as only accurate to one decimal place. Quotation to two decimal places is made to help users assess the difference between locations.

4. Confidence intervals

This project provides estimates of sea level with annual exceedance probabilities ranging from 100 to 0.01 (one to 10,000-year return periods). The data used to make these estimates is limited to less than 100 years of records, therefore there is a degree of uncertainty associated with the values. Confidence intervals are provided in a separate Shapefile (CFB_Confidence_Intervals.shp), referenced to the same chainage as the sea levels. It is important that the user selects the same output points in the Shapefiles for sea level and associated uncertainty information. Consider these confidence intervals when undertaking sensitivity testing in a study or design.

5.3 Generating design tide curves

Three components are required to generate a design tide curve for any given site. These are discussed in the following sections.

1. Extreme sea level
2. Base astronomical tide curve
3. Surge component

5.3.1 Extreme sea level

Select an extreme sea level for a site, as described in **Section 5.2**.

5.3.2 Base astronomical tide curve

1. Identify standard port

This method of generating a base tide curve involves using Admiralty Tide Tables (ATT). First select the standard port for your site from Part II of the ATT.

2. Choose predicted high tide level between HAT and MHWS

The base astronomical tide should be high enough to represent a larger than 'normal' event but also reach an appropriate level to reflect an event which occurs every year. It is common practice to base a design tidal graph on a spring tide. However, spring tides vary substantially over time due to the influence of the lunar cycle. Therefore we recommend using a level between highest astronomical tide (HAT) and mean high water springs (MHWS).

Select a level between HAT and MHWS for the standard port. Table V contains HAT values for standard and secondary ports. Values of MHWS can be derived from Part II of the ATT.

3. Identify date and time for selected level between HAT and MHWS

Part I of the ATT contains predicted times and levels for high and low tides for a one-year duration. In the tables, find the level between HAT and MHWS for the standard port and its respective date and time. If this level is not contained in the predictions, simply select a lower level ensuring it is higher than MHWS.

4. Choose a base astronomical tidal cycle duration

Choose a duration for the base astronomical tidal cycle to meet your requirements. The date and time of your selected high tide (between HAT and MHWS) should be the centre of the base astronomical tide. We recommend extending the tide curve to two days before the peak and two days after, giving a total duration of approximately 100 hours. This ensures an adequate time for a number of high tides.

5. Identify harmonic constants

The preceding steps identify a base tide event in terms of date, time and peak level. To produce the base astronomical tide curve, one needs to identify harmonic constants. The harmonic constants represent the multiple influences which contribute to an astronomical tide, including: rotation of the Earth, positions of the Moon and the Sun relative to Earth, the moon's altitude above the Earth, and bathymetry. Part III of the ATT contains the six largest harmonic constants for primary and secondary ports, required to generate a base astronomical tide curve. Select the harmonic constants for your site including any seasonal corrections applicable to the dates of the identified base tide event. Use the closest port in the Admiralty Tide Tables if your site is not referenced.

6. Generate base astronomical tide curve using standard software

Software to generate tide curves is readily available. Input the start date and time, the end date and time and the harmonic constants to produce the base tide curve.

Some tide curve generation software has the harmonic constants inbuilt, in which case Step 5 is not necessary.

Note

For Environment Agency projects, flood forecasting teams are able to provide astronomical base tide curves.

Site location and dates of the desired astronomical tide curve prediction will be required when making this request. This information is found by the end of Step 4 above.

5.3.3 Surge component

As mentioned in **Section 3.1** skew surge is the difference between an observed high tide and the nearest predicted high tide, regardless of timing. The surge itself will include the rise in sea level caused by the pertaining low pressure weather system and its associated storm winds. It does not account for local wave set-up which can arise near the coastline. Practitioners will have to allow for this effect separately.

In reality surge shapes are highly variable between different extreme events. However, for practical purposes it is convenient to have a standard surge shape that can be used to generate total design event tide curves in a consistent manner for a particular length of the coast. The surge shape will vary between different sections of the coast.

Select the appropriate surge shape for your site using the GIS data (CFB_Surge_Shape.shp). A summary of surge shapes and their suggested zone of application is given here in **Table 4.3.** In some cases the site may be at the boundary between two surge shapes, for example at Minehead. In this instance we recommend undertaking a sensitivity test using both shapes.

5.3.4 Resultant curve

Use a spreadsheet to combine the three components (target peak sea level, base astronomical tide and surge shape) to produce the resultant tide curve. The time resolution of the tide and surge data in the spreadsheet needs to be the same. In addition, the astronomical tide levels need to be expressed relative to Ordnance Datum, not Chart Datum.

For practical purposes we recommend that the extreme sea level, peak astronomical tide level and peak surge height should occur coincidentally. Therefore, position the surge shape so its peak height is coincident in time with the peak level in the base tide sequence. Scale the surge shape from its unit height of one so the surge height added to the peak of the base tide equals the target peak sea level desired. Adding the scaled surge heights to the base tide levels gives the net design event tide curve. An example is shown in **Section 6.**

It is also acceptable to place the surge peak either before or after the peak of the base astronomical tide. Sensitivity tests for this timing shift can be undertaken depending on the requirements of the study. Ensure the scaling factor is altered to reflect the lower surge shape value now coincident with the peak of the base astronomical tide curve. Be careful that this scaling factor still achieves the desired peak sea level. If this does not occur, adjust the scaling factor by trial and error until the required result is obtained.

5.4 Additional allowances

Future sea level rise estimates are not considered in this project. We recommend using the most up-to-date Department for Environment, Food and Rural Affairs (Defra) guidance to incorporate climate change allowances. The rise in sea level for future scenarios applies to all levels in the resultant tide curve, not just the peak levels.

6 Worked example

The following steps should be carried out when determining a design tide curve:

1. Check study location is outside of estuary boundaries
2. Select an appropriate chainage point for extreme sea levels
3. Select an annual exceedance probability peak sea level
4. Consider allowance for uncertainty
5. Identify base astronomical tide
6. Convert levels to Ordnance Datum
7. Identify surge shape to apply
8. Produce the resultant design tide curve
9. Sensitivity test
10. Apply allowance for climate change

This worked example shows how a practitioner can use the data to select relevant sea level information for a coastal site. We have used an example at Clovelly, North Devon, for illustrative purposes.

1. <u>Check study location is outside of estuary boundaries</u>

Open the CFB_Estuary_Boundaries.shp Shapefile to show the estuary boundaries. If the site is upstream of the estuary boundary, the extreme sea level cannot be obtained directly from the results of project. A location plan for Clovelly is presented in **Figure 6.1**. Clovelly is found on the open coast, and is thus within the coverage of this project.

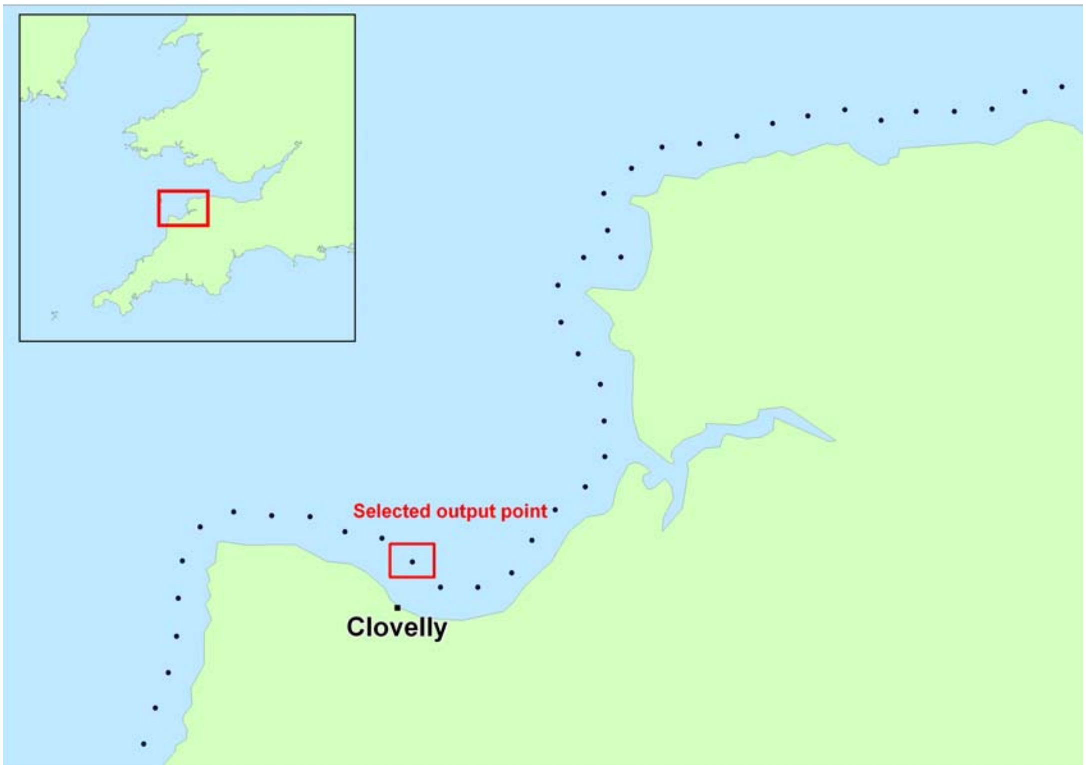


Figure 6.1 Location plan for Clovelly

2. <u>Select an appropriate chainage point for extreme sea levels</u>

Open the CFB_Extreme_Sea_Levels.shp Shapefile in a standard Geographical Information Systems (GIS) programme. If licensed mapping is available, use this to aid the process. Using the location of your site as a guide, simply draw a line perpendicular from the coastline to nearest chainage point. The accuracy of the sea level values does not warrant any more rigorous selection process. The coastal chainage point for this worked example is 208 km, as shown in **Figure 6.1**.

3. <u>Select an annual exceedance probability peak sea level</u>

Again, ensure the CFB_Extreme_Sea_Levels.shp Shapefile is open in a standard GIS programme. Using the identification tool, click on the selected chainage point. This will open a table displaying the chainage in the first row. The other rows are the return periods from one to 10,000 in the left hand column and the corresponding sea level values (in metres relative to Ordnance Datum) in the right hand column. **Figure 6.2** shows how this will appear.

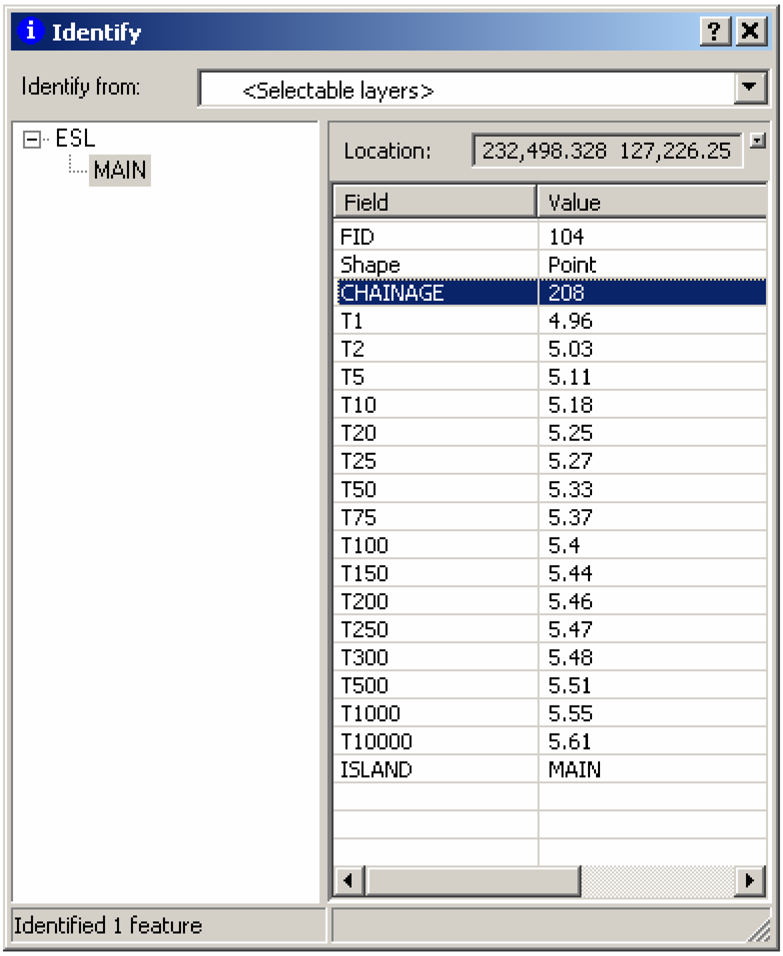


Figure 6.2 CFB_Extreme_Sea_Levels.shp Metadata

Extreme sea levels at this chainage are presented in **Table 6.1**.

Table 6.1 Extreme sea levels for Clovelly

Return period (years)	Ch208km extreme sea levels (mOD)
1	4.96
2	5.03
5	5.11
10	5.18
20	5.25
25	5.27
50	5.33
75	5.37
100	5.40
150	5.44
200	5.46
250	5.47
300	5.48
500	5.51
1,000	5.55
10,000	5.61

For this example, we will assume the one in 200 year (0.5 per cent annual exceedence probability) level is the target peak for the intended analysis. This level is 5.46 mOD.

4. Consider allowance for uncertainty

At this point, decide whether the study requires a consideration of uncertainty. Select (using the Identification tool) the same chainage point as the sea level values from the confidence intervals Shapefile (CFB_Confidence_Intervals.shp) to determine the uncertainty information. **Figure 6.3** shows how this will appear.

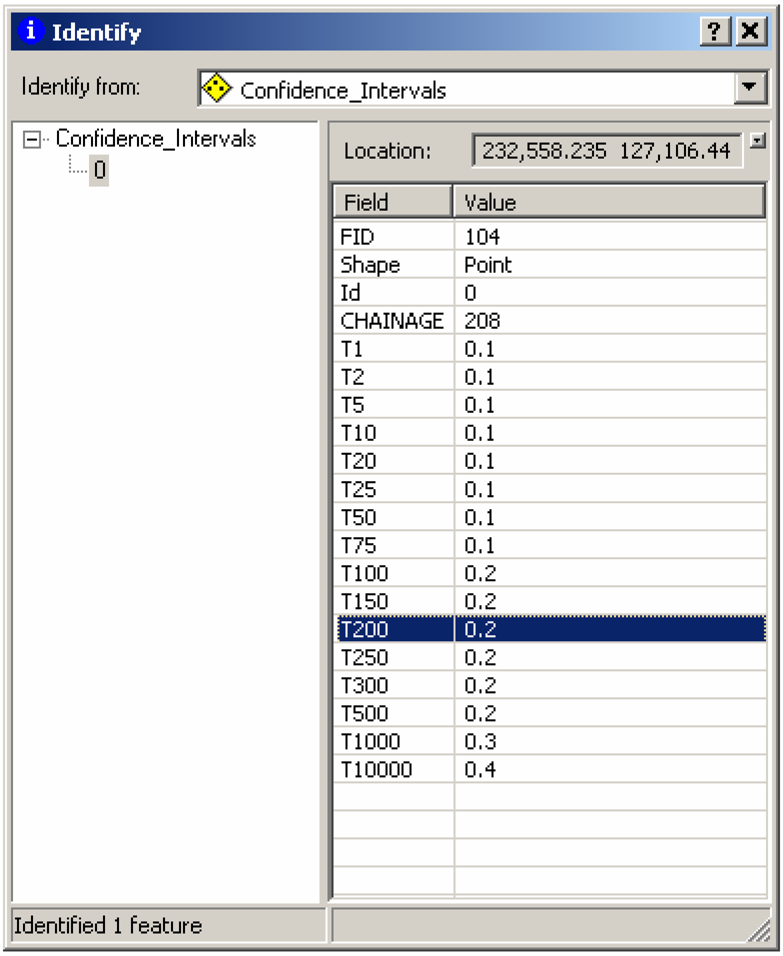


Figure 6.3 CFB_Confidence_Intervals.shp Metadata

Uncertainty information for Clovelly is shown in **Table 6.2**.

Table 6.2 Confidence intervals for Clovelly

Return period (years)	Ch208km confidence intervals (m)
1	0.1
2	0.1
5	0.1
10	0.1
20	0.1
25	0.1
50	0.1
75	0.1
100	0.2
150	0.2
200	0.2
250	0.2
300	0.2
500	0.2
1,000	0.3
10,000	0.3

Therefore, the confidence interval for the 0.5 per cent annual exceedence probability (200 years return period) is +/- 0.2 m. One may wish to consider the implications of this depending on the nature of the work being undertaken.

5. Identify base astronomical tide

The user needs to select a level between HAT and MHWS and identify an astronomical tide which corresponds to this level. **Table 6.3** presents HAT and MHWS levels for Clovelly and Milford Haven (the standard port used for Clovelly). The mid-point level has been selected. The tidal predictions are taken from the 2010 Admiralty Tide Tables Volume I (United Kingdom and Ireland).

Table 6.3 MHWS, HAT and nominated peak base tide level

Site name	MHWS (mCD)	HAT (mCD)	Base tide curve level (mCD)
Clovelly	8.3	9.2	8.75
Milford Haven	7.0	7.9	7.45

The next step requires the user to find a similar level in the Admiralty Tide Tables (ATT). Clovelly is not a standard Port, therefore predicted tides are not provided in the ATT (though they may be available in other publications). Therefore, use tide prediction tables for the appropriate standard port, Milford Haven in this example, to identify the dates of an appropriate tide event. The tables are in Part I of the ATT. The target high tide level for the astronomical tide should be the level between HAT and MHWS, selected above. Sufficient event duration is two days before and after the peak tide level. An example tide event to use is shown in **Table 6.4**.

Table 6.4 Tide curve durations

Site name	Peak level (mCD)	Date and time of peak	Design tide curve dates
Milford Haven	7.5	30 March 2010 06:08	28 March 2010 – 1 April 2010

Select harmonic constants for your site from Part III of the ATT. The harmonic constants are required to generate the base astronomical tide curve. In this instance there are no harmonic constants for our site, Clovelly. Therefore we recommend using the nearest suitable standard/secondary port, in this case Lundy. Use software to generate the base tide curve for the dates selected.

6. Convert levels to Ordnance Datum

Note the levels in Admiralty Tide Tables are quoted to Chart Datum. The extreme sea level estimates are quoted to Ordnance Datum. The conversion between Chart Datum and Ordnance Datum in the UK can be found in Table III of the Admiralty Tide Tables. The Chart Datum to Ordnance Datum conversion for Clovelly is shown in **Table 6.5**. Use this value to convert the levels of the base astronomical tide so they relate to Ordnance Datum. The peak base tide level becomes 4.35 mOD (8.75 mCD – 4.4 m).

In practice it is perfectly adequate for the calculated peak base tide level to be near to the target peak; an exact match is not necessary.

Paste the values (time/level) of the base tide into a site-specific spreadsheet. In order to match the surge shape data provided, values are needed for every 15 minutes.

Table 6.5 Chart Datum to Ordnance Datum Conversion

Site name	CD OD Conversion
Clovelly	-4.40

7. Identify surge shape to apply

The steps so far have led to selection of an extreme sea level and a base astronomical tide curve which reaches a peak between HAT and MHWS. It is now necessary to apply a surge shape to the base tide. From the surge shape Shapefile, the surge shape to use for Clovelly is the one from Ilfracombe. In the Design Surge Shapes spreadsheet, open the worksheet titled Donor Surge Shapes. Copy the time in hours (first column) and the surge values for shape 19 (Ilfracombe) and paste these into the site-specific spreadsheet. The Ilfracombe surge shape is shown in **Figure 6.4**.

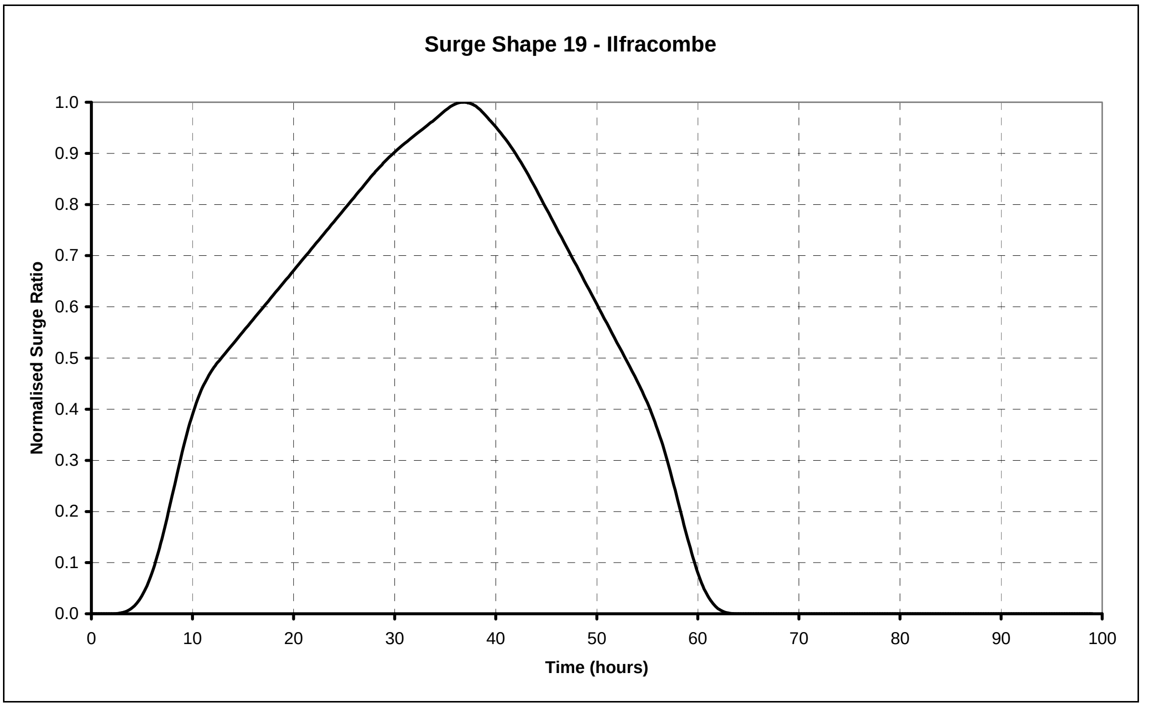


Figure 6.4 – Surge shape for Ilfracombe

8. Produce the resultant design tide curve

Using the site-specific spreadsheet, the three components of the design tide curve (extreme sea level, base astronomical tide curve and surge shape) can be combined to produce the resultant design tide curve. In this example, the peaks of the astronomical tide and the surge shape are set to coincide at the same time.

The peak of the base tide curve is 4.35 mOD. The target level as identified in Step 2 is 5.46 mOD. It is therefore necessary to scale the surge shape according to the difference between the target level and peak of the astronomical tide curve; here, this is 1.11 m. The peak of the surge shape and of the base astronomical tide curve are aligned at the same time, so the peak surge shape ordinate at this point is 1.0. Thus, the scaling factor to apply to all surge shape values is 1.11/1.0 = 1.11. Adding the scaled-up surge shape values to the astronomical tide levels creates the net design tide curve. **Figure 6.5** shows the base astronomical tide curve, scaled-up surge shape and resultant design tidal graph for Clovelly. This is the recommended tide curve to use with the 0.5 per cent annual probability (200-year return period) event at Clovelly.

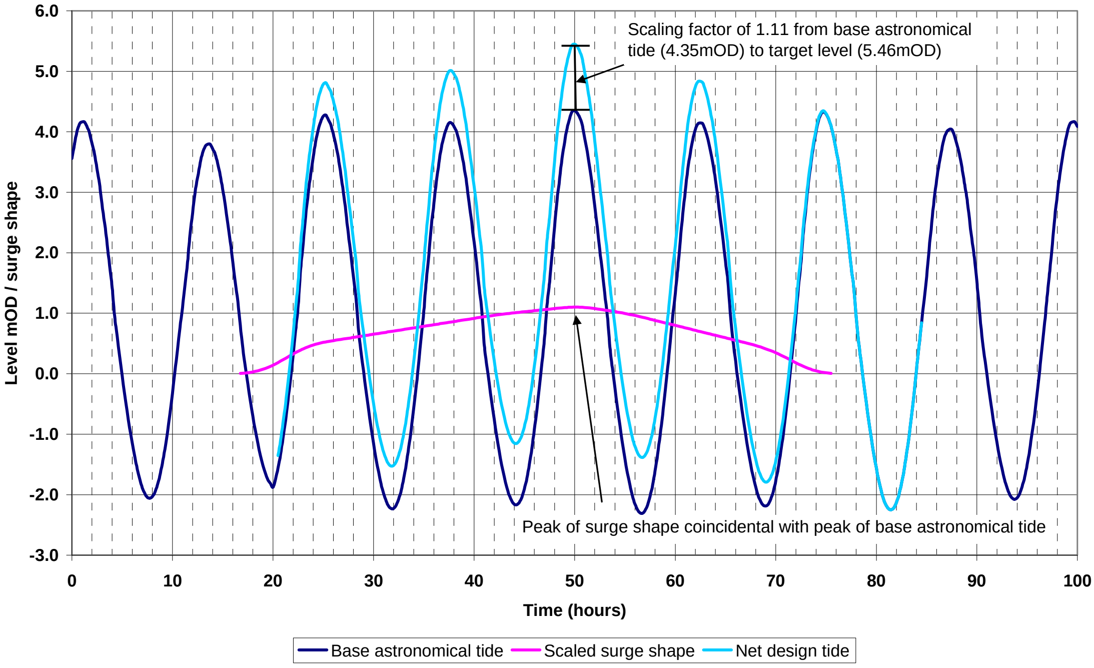


Figure 6.5 – Resultant design tide curve for Clovelly

9. Sensitivity test

As a sensitivity test, one can consider a case where the peak of the surge component is offset from the peak of the base astronomical tide. The example shown here considers moving the peak of the surge shape to two hours before the peak of the astronomical tide curve. The surge shape ordinate now coincident with the peak of the astronomical tide is the value at two hours after the surge peak. In this instance the value becomes 0.97 instead of 1.0. Our target level (5.46 mOD) and the base astronomical tide curve peak (4.35 mOD) remain the same. The scaling factor thus becomes 1.14 (1.11 divided by 0.97). This is applied to all the surge shape values. The net tide curve with the peak of the surge applied two hours before the peak of the astronomical tide curve is shown in **Figure 6.6**.

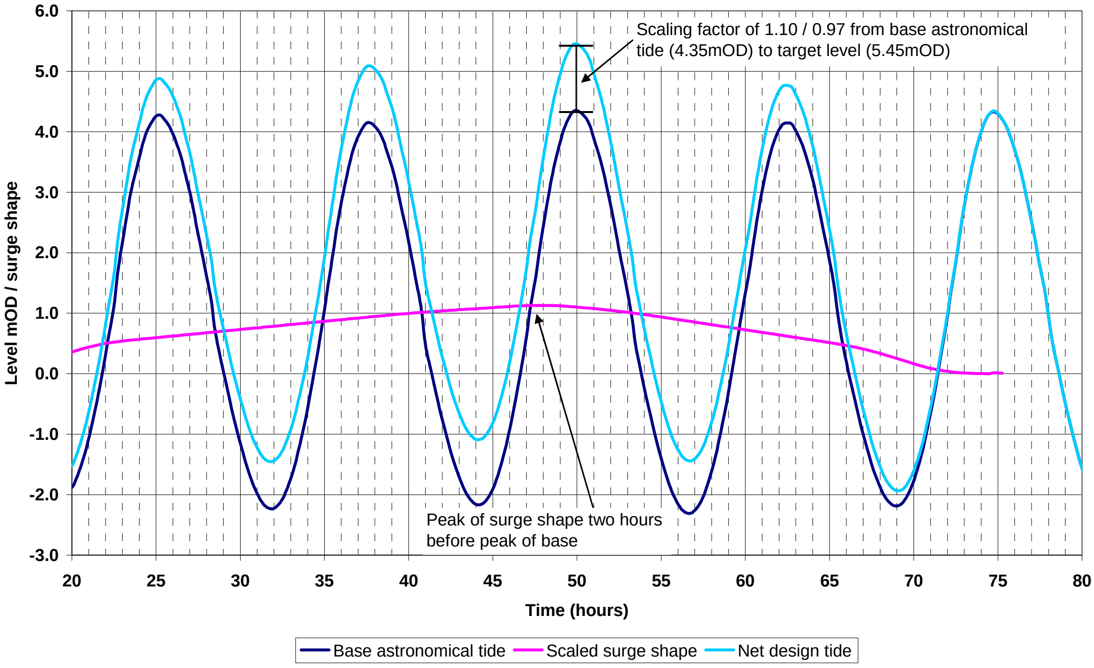


Figure 6.6 – Peak surge occurring two hours before peak base tide

10. Apply allowance for climate change

This project does not make predictions of future sea level rise due to climate change. We recommend consulting the most up-to-date Defra guidance. This allowance should be added to the entire design tide curve.

References

1. DIXON, M.J. AND TAWN, J.A. 1997. *Spatial analyses for the UK coast*, Proudman Oceanographic Laboratory Internal Document No. 112.

2. DEPARTMENT FOR ENVIRONMENT FOOD AND RURAL AFFAIRS. 2011. *Technical Report Design sea levels*. R&D Report SC060064. Defra/Environment Agency.

3. UNITED KINGDOM HYDROGRAPHIC OFFICE. 2009. *Admiralty Tide Tables Volume 1, 2010, United Kingdom and Ireland including European Channel ports*. Taunton: UKHO

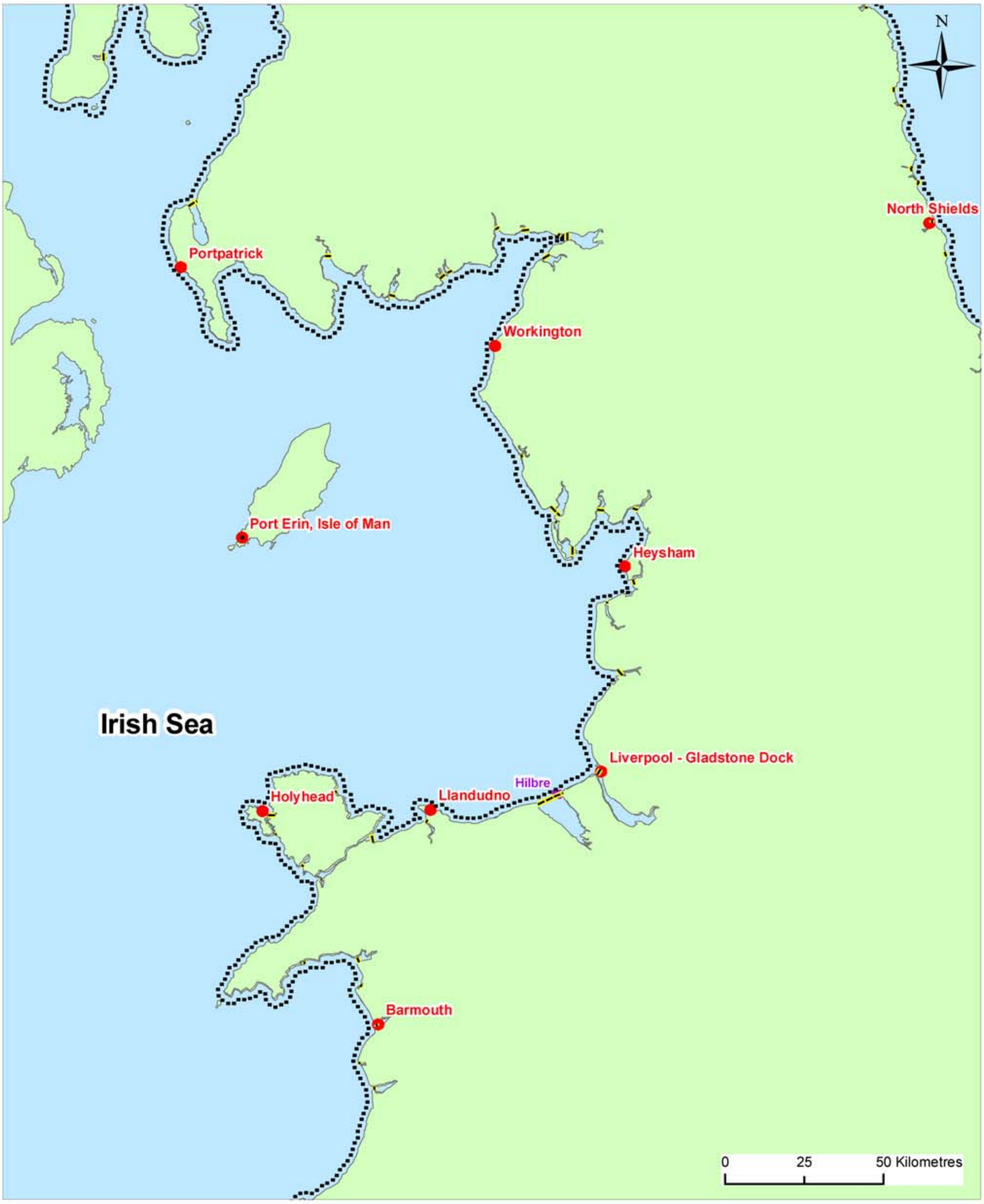
Key:

- Estuary Boundaries
- Coastal Chainage
- Supplementary Gauges
- Class A Sites

Source / Copyright

I:\9S7299\Technical_Data\F12_GIS\Projects\Report_Figures\Extreme_Sea_Levels

Title: Study Area - South West	Figure: 2.1
Project: SC060064: Development and Dissemination of Coastal and Estuary Extremes	
Client: Environment Agency	
Date: 2010	Scale @A4: 1:2,250,000



Key:

- Coastal Chainage
- Supplementary Gauges
- Class A Sites
- Estuary Boundaries

Title: Study Area - North West

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

Client: Environment Agency

Date:	Scale @A4:
2010	1:1,600,000

Figure: 2.2

defra Department for Environment Food and Rural Affairs

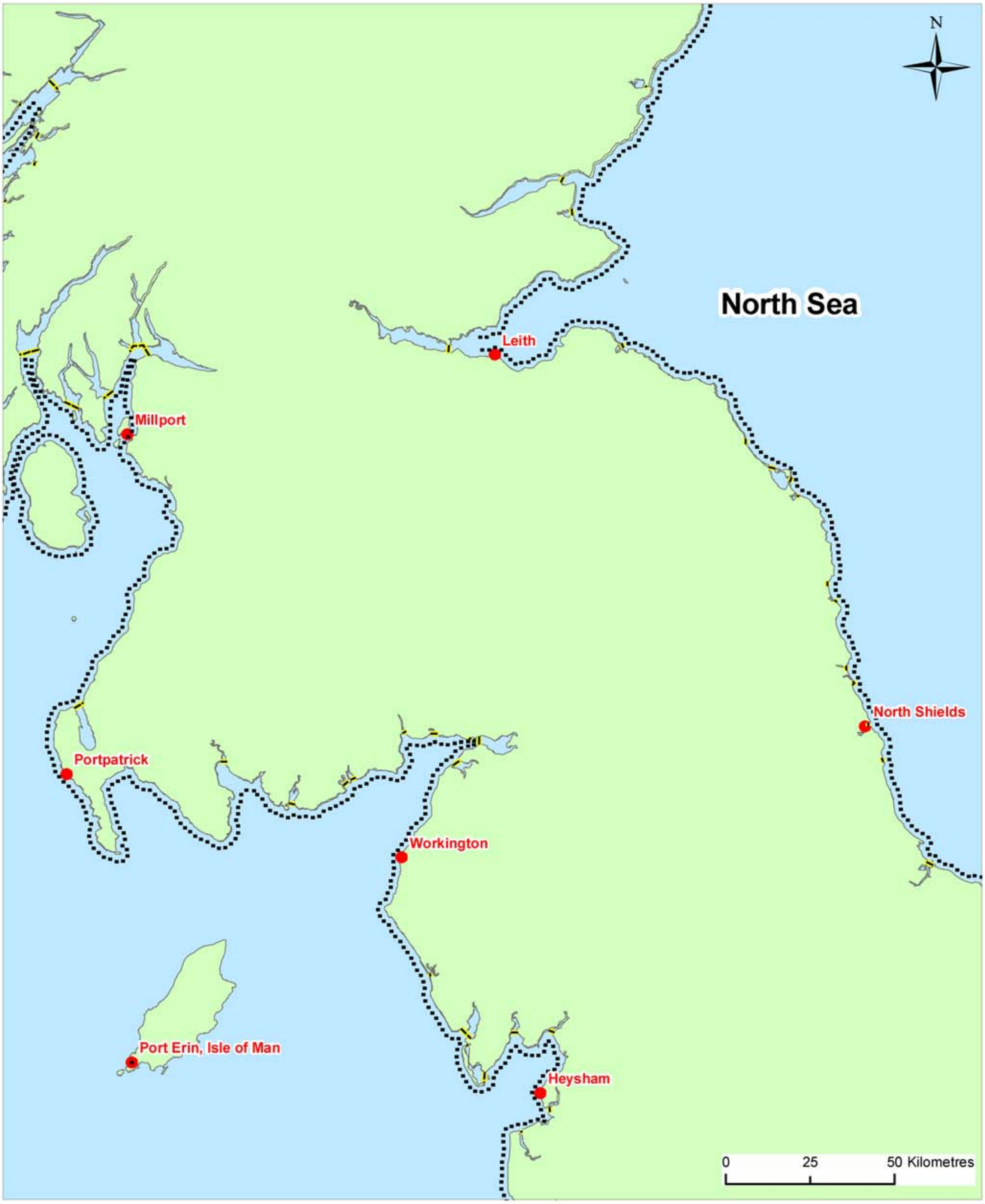
Environment Agency

ROYAL HASKONING

SEPA Scottish Environment Protection Agency

Source / Copyright

I:\9S7299\Technical_Data\F12_GIS\Projects\Report_Figures\Extreme_Sea_Levels



Key:

- Coastal Chainage
- Supplementary Gauges
- Class A Sites
- Estuary Boundaries

Source / Copyright

I:\9S7299\Technical_Data\F12_GIS\Projects\Report_Figures\Extreme_Sea_Levels

Title:
Study Area - Borders

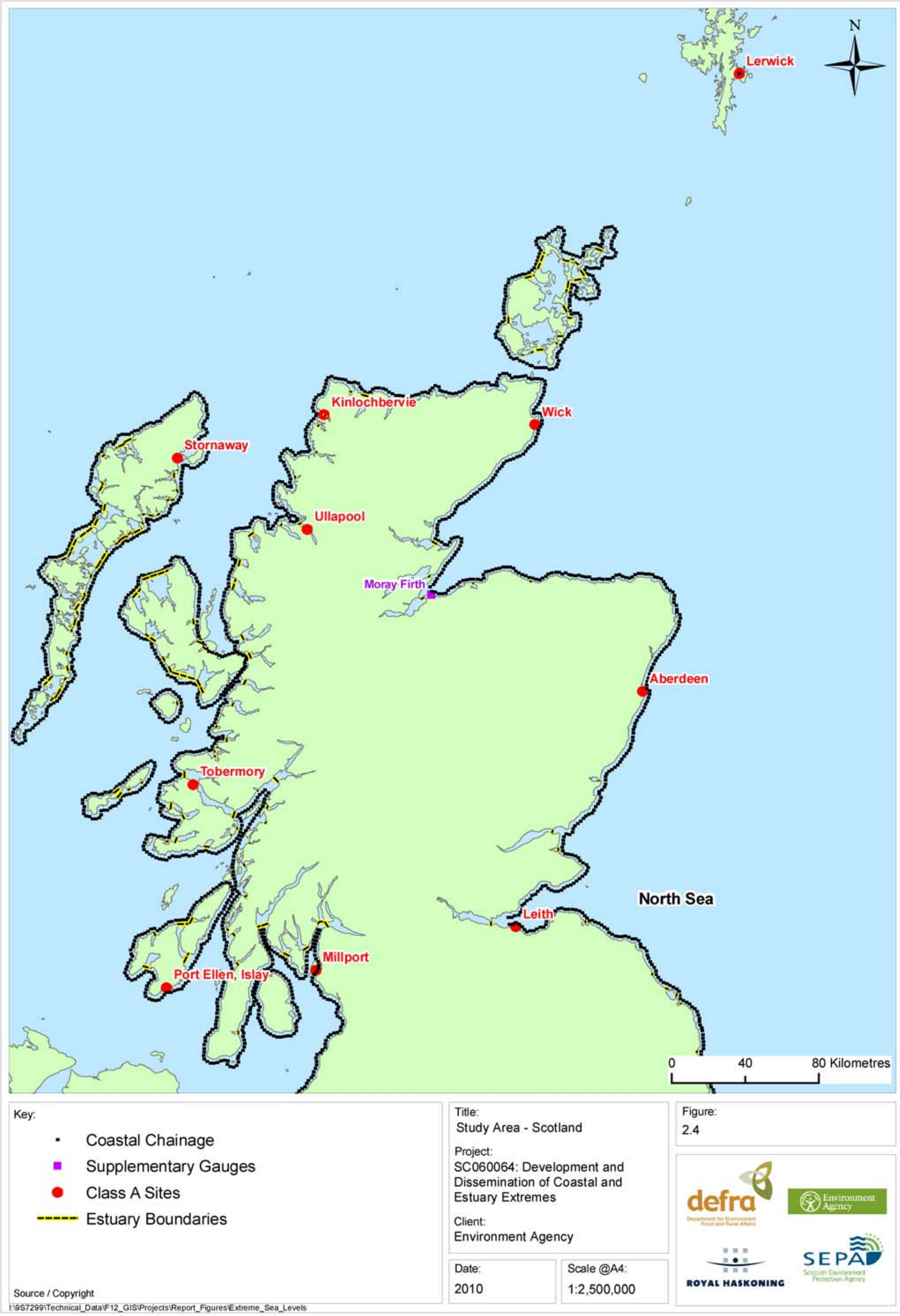
Project:
SC060064: Development and Dissemination of Coastal and Estuary Extremes

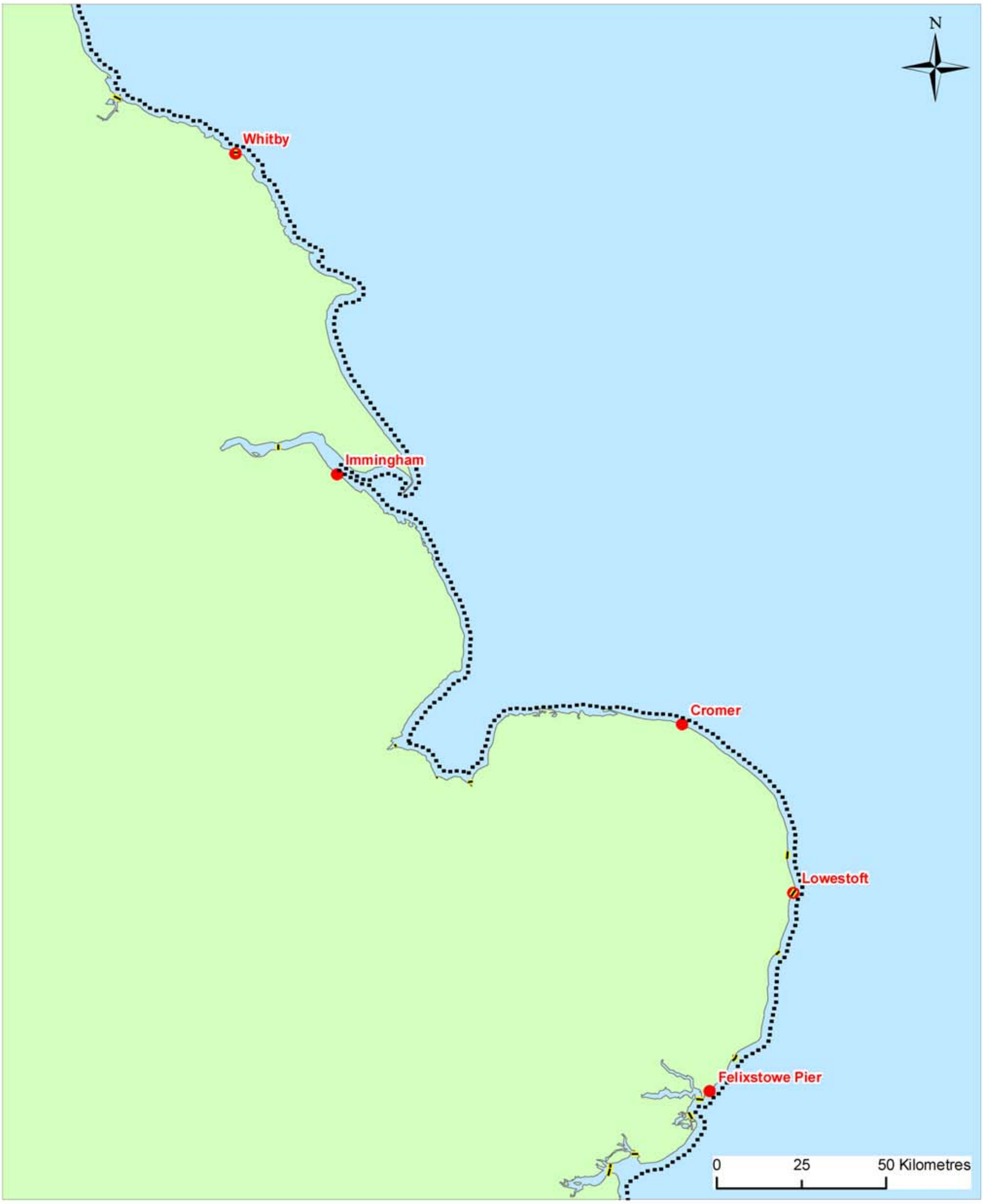
Client:
Environment Agency

Date:
2010

Scale @A4:
1:1,500,000

Figure:
2.3


N
Lerwick
Kinlochbervie
Wick
Stornaway
Ullapool
Moray Firth
Aberdeen
Tobermory
North Sea
Leith
Millport
Port Ellen, Islay
0
40
80 Kilometres
Key:
Coastal Chainage
Supplementary Gauges
Class A Sites
Estuary Boundaries
Title:
Study Area - Scotland
Project:
SC060064: Development and Dissemination of Coastal and Estuary Extremes
Client:
Environment Agency
Date:
2010
Scale @A4:
1:2,500,000
Figure:
2.4
defra
Environment Agency
ROYAL HASKONING
SEPA
Source / Copyright
I:\9S7299\Technical_Data\F12_GIS\Projects\Report_Figures\Extreme_Sea_Levels



Key:

- Coastal Chainage
- Supplementary Gauges
- Class A Sites
- Estuary Boundaries

Source / Copyright

I:\9S7299\Technical_Data\F12_GIS\Projects\Report_Figures\Extreme_Sea_Levels

Title:
Study Area - East

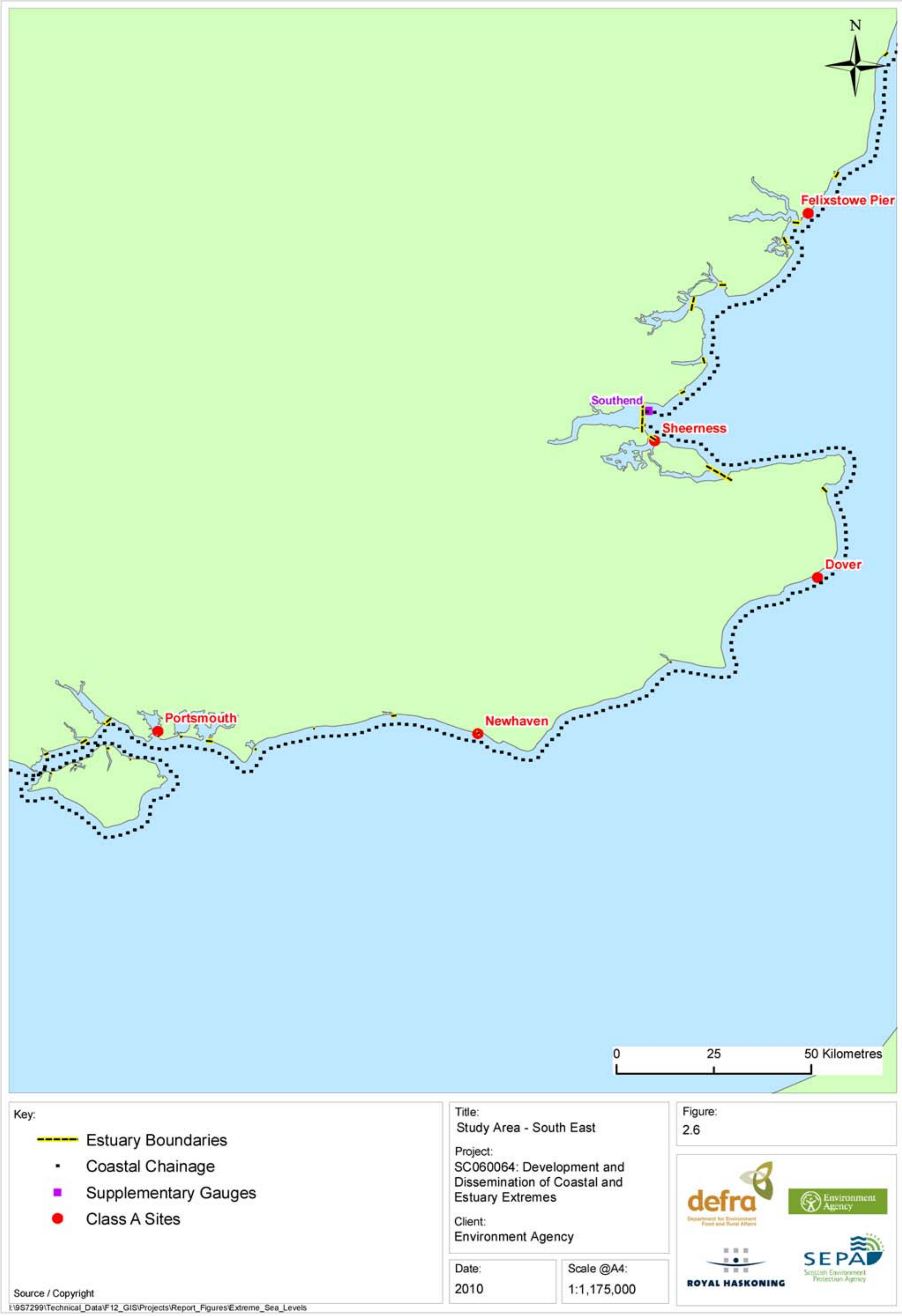
Project:
SC060064: Development and Dissemination of Coastal and Estuary Extremes

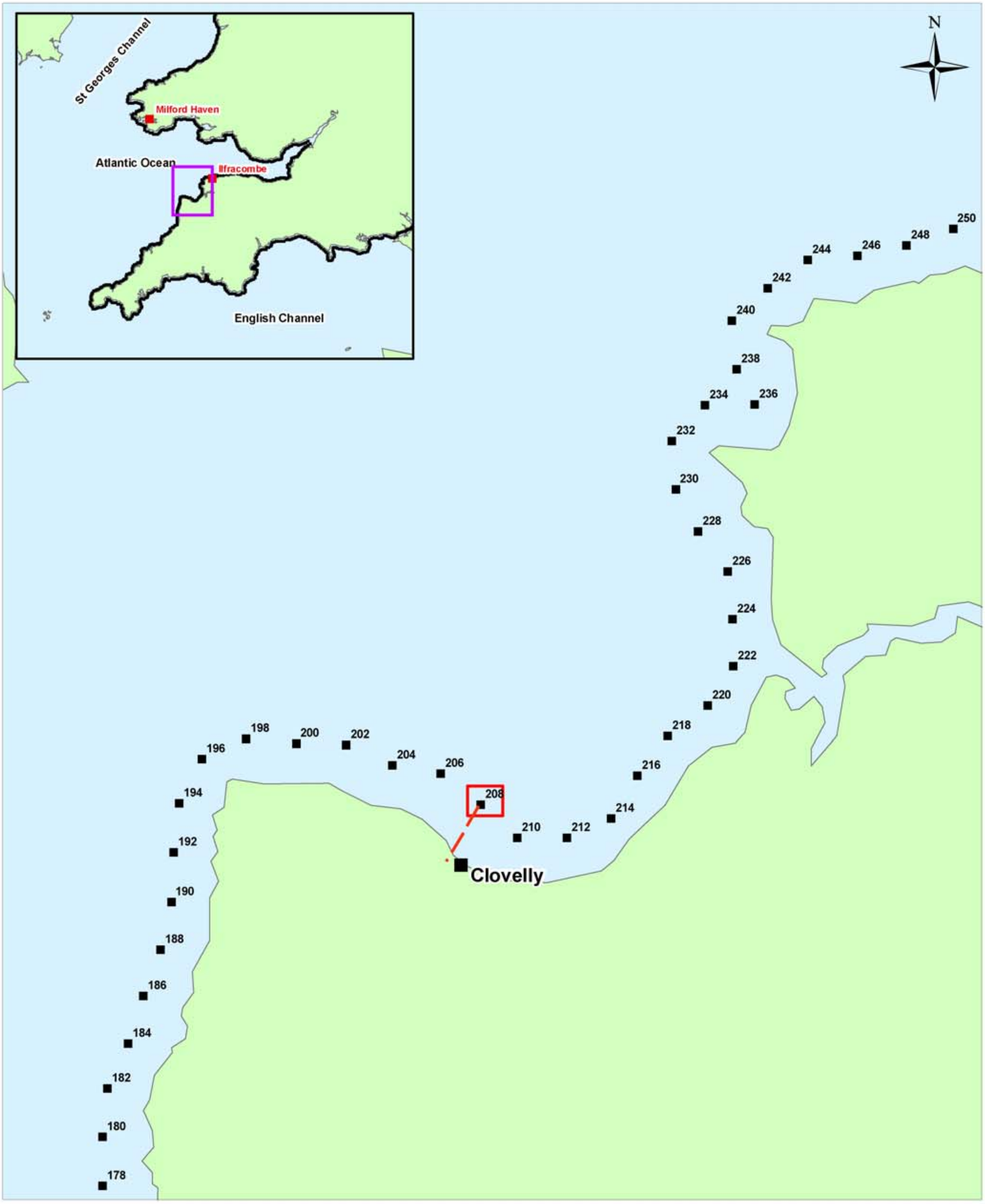
Client:
Environment Agency

Date:
2010

Scale @A4:
1:1,489,905

Figure:
2.5


N
Felixstowe Pier
Southend
Sheerness
Dover
Portsmouth
Newhaven
0
25
50 Kilometres
Key:
Estuary Boundaries
Coastal Chainage
Supplementary Gauges
Class A Sites
Source / Copyright
I:\9S7299\Technical_Data\F12_GIS\Projects\Report_Figures\Extreme_Sea_Levels
Title:
Study Area - South East
Project:
SC060064: Development and Dissemination of Coastal and Estuary Extremes
Client:
Environment Agency
Date:
2010
Scale @A4:
1:1,175,000
Figure:
2.6
defra
Environment Agency
ROYAL HASKONING
SEPA



Key:

■ Coastal Chainage

— — Selected Sea Level Chainage

Source / Copyright

I:\9S7299\Technical_Data\F12_GIS\Projects\Report_Figures\Extreme_Sea_Levels_Best_Practice_Guidance

Title: Selecting Sea Levels for Clovelly

Project: SC060064: Devlopment and Dissementation of Coastal and Estuary Extremes

Client: Environment Agency

Date: 2010

Scale @ A4: 1:215,000

Figure: 6.1

defra Department for Environment Food and Rural Affairs · Environment Agency · Royal Haskoning · SEPA Scottish Environment Protection Agency

List of abbreviations

ATT	Admiralty Tide Tables
CD	Chart Datum
Defra	Department for Environment, Food and Rural Affairs
GIS	Geographic Information System software
HAT	Highest astronomical tide
MHWS	Mean high water spring tide
OD	Ordnance Datum
SEPA	Scottish Environment Protection Agency

We are The Environment Agency. It's our job to look after your environment and make it **a better place** – for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

Published by:

Environment Agency
Rio House
Waterside Drive, Aztec West
Almondsbury, Bristol BS32 4UD
Tel: 0870 8506506
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

Would you like to find out more about us, or about your environment?

Then call us on

08708 506 506* (Mon-Fri 8-6)

email

enquiries@environment-agency.gov.uk

or visit our website

www.environment-agency.gov.uk

incident hotline 0800 80 70 60 (24hrs)
floodline 0845 988 1188

* Approximate call costs: 8p plus 6p per minute (standard landline).
Please note charges will vary across telephone providers