Trial of “Cliff and Shore erosion under accelerating sea level rise: User Guide”

Coast and Estuaries Programme

Open Report OR/20/062

BRITISH GEOLOGICAL SURVEY

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Editor

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Front cover

Map showing the results obtained for Region 9 and Coastal Explorer dataset for years 2030, 2080, 2150 and R.C.P. 4.5. © OpenStreetMap contributors.

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Foreword

The Environment Agency (EA) in collaboration with WSP Group have developed a User Guide explaining how new indicators of cliff toe sensitivity to sea level rise may be used to conservatively estimate cliff retreat at suitable sites along the coastlines of England and Wales [1] (hereinafter referred as "**the User Guide**"). The EA and WSP commissioned the British Geological Survey (BGS) to carry out a trial of the User Guide. The findings from this trial were then presented during a technical workshop within which feedback from a broader spectrum of peers and end-users were sought. This document summarises the testing process followed by the BGS, as agreed with EA and WSP representatives. In particular it comprises; (1) a concise report, describing the perceived strengths/challenges encountered with the application of the User Guide to a selected number of study sites and (2) includes slides presented at the technical workshop.

This work has been done by the following BGS members of staff;

Dr Andres Payo (AP), *Project Leader*, is an internationally recognised coastal geoscientist who specialises in quantitative geomorphology applied to coastal protection against flooding and coastal erosion at decadal and longer time scales. His focus is on the use of long–term analytical capacity to avoid maladaptation of long–lived infrastructure systems. Andres is the led scientist of BGS's Coasts and Estuaries Programme which provides independent and expert geoscientific tools and advice for collaborative decision making to assess different adaptation options for coastal flooding and erosion. More information is available from: https://www.bgs.ac.uk/geology-projects/coasts-and-estuaries/ and https://www.bgs.ac.uk/people/payo-garcia-andres/

Catherine Pennington (CP), *Engineering Geologist, Landslide Specialist*, with 20 years' experience leads the BGS coastal landslide field observatory monitoring at BGS. She has published 18 research papers reflecting office- and field-based landslide data collection. These include the National Landslide Database and GIS of Great Britain; UK regional landslide mapping surveys, provision of bespoke assessments to national organisations, damage and loss impact from weather related disasters in India and Daily Landslide Hazard Assessment for Natural Hazards Partnership. Catherine has worked in science communication and has published to a range of audiences through different media channels. https://www.bgs.ac.uk/people/pennington-catherine/

Professor John G. Rees (JR), *Chief Scientist for Multi-Hazards and Resilience* has a background in a wide-range of earth hazards and associated risks. His knowledge and experience have shaped world-class research and innovation in the BGS, as well as UK Research and Innovation more widely on critically important topics including urban, coastal and marine hazards, climate impacts and disaster risk reduction, both globally and in the UK. https://www.bgs.ac.uk/people/rees-john/

AP was in charge of testing and reporting the results of applying the methodology for the ten study areas and drafting the report. CP was in charge of reviewing the User Guide and JR acted as BGS internal editor.

Acknowledgements

The following individuals in the EA and WSP Group have contributed to the project. This assistance has been received at all stages of the study. Dr Mike Walkden, associate director at WSP Group and lead author of the User Guide has provided support describing the User Guide rationale and scope of the audience for which it is being considered and advice on the study site selection. Dr Lee Swift, principal scientist, flood & coastal risk management research at the EA has steered the scope and aims of this review to complement and align with ongoing work at the EA.

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Summary

This report describes perceived strengths and challenges encountered with the trial of the User Guide [1], explaining how new indicators of cliff toe sensitivity to sea level rise may be used to conservatively estimate cliff retreat at suitable sites along the coastlines of England and Wales. The authors of the User Guide approached the British Geological Survey (BGS) to test the guide and invited BGS to present their experience during a technical workshop during which feedback from a broader spectrum of peers and end-users was sought. This document summarises the testing process and outcomes. The first part of the report introduces the project, the context and the approach followed. In the results section we have described, for each one of the 53 locations included in this study, the results of applying the User Guide including the description of the auxiliary data used and any pre- and post-processing done. We have used FutureCoast and Coastal Explorer as the primary sources of data. In the discussion section we summarise the lessons learned from applying the User Guide to all sites. We conclude this report with a series of recommendations that should help to maximize the strengths and alleviate some of the challenges identified. In Appendix 4 we include the slides that were used to summarise the results and main conclusions of this report to the broader technical community.

1 Introduction

1.1 AIMS

The aims of this project were to produce:

1. a concise report, describing the strengths/challenges encountered with the application of the User Guide to a selected number of study sites; and
2. slides to be presented at the technical workshop.

1.2 CASE STUDY APPROACH

We followed a desk-based case study approach. We have tested the methods described in the User Guide at ten different study sites. The User Guide divided the coastline of England and Wales into 82 regions as shown in Figure 1. There are 11 regions marked as ‘high sensitivity’, 55 are ‘normal’ and there are no data for 16 regions suggesting a ratio of 1 (high sensitivity) to 5 (‘normal’ areas). To avoid any bias in our analysis, and using this ratio (1 to 5), we have selected a total of ten study regions, out of which 2 (Regions # 68, 75) are from high sensitivity areas and 8 (Regions # 9, 17, 23, 28, 33, 39, 41, 50) from normal regions. Those ten regions are distributed along the East, South, and West coasts of England and Wales.

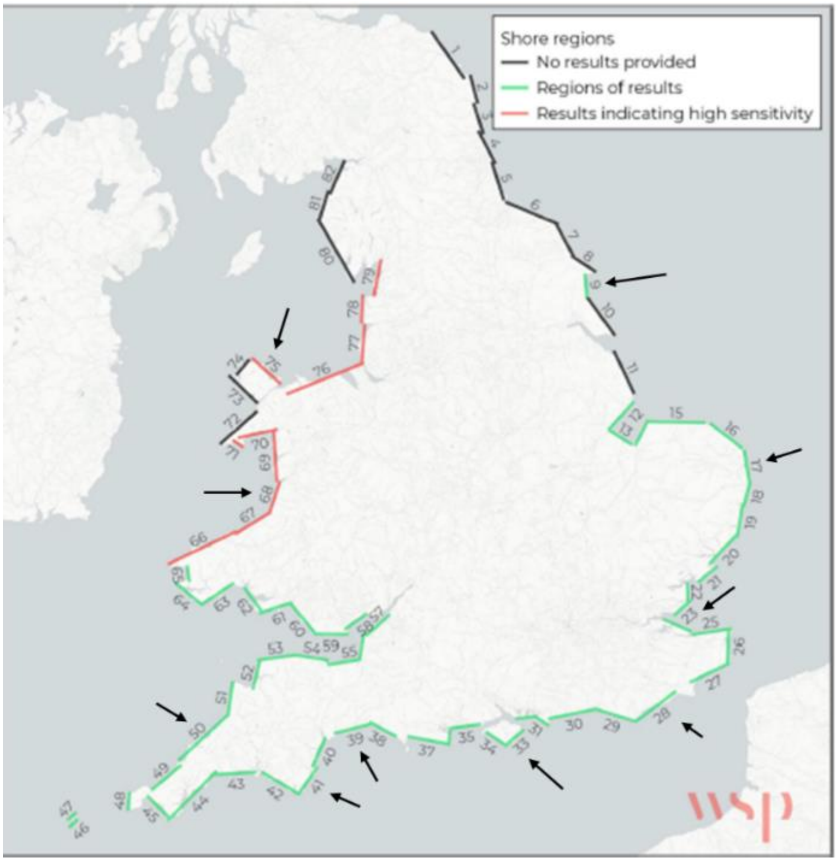


Figure 1.- Model regions; note that (1) black lines indicate regions where results could not be calculated, due to issues with the representation of Holocene sea levels, (2) red lines show areas of particularly high sensitivity and (3) Regions 14, 24 and 56 are not labelled, but exist in (clockwise) sequence. Black arrows indicate the regions on which the study cases have been selected (source “the User Guide” [1]).

For each of the ten regions, we selected sites to which the methodology described in the User Guide could be tested, based on availability of historical recession data (i.e. key input data required by the User Guide) and our interpretation of where the User Guide can and cannot be applied. For each site we produced a rapid assessment example (Section 3 of the User Guide) and a general assessment example (Section 4 of the User Guide). The rapid assessment provides a probabilistic estimate of **future cliff toe recession rate** and the general assessment provides a probabilistic estimate of the **future location of the cliff toe**. To illustrate the sensitivity of the User Guide results to the historical recession input data, for one region (Region #9) we used two different sources as input data.

1.3 WHERE IS THE USER GUIDE APPLICABLE?

The methods described in the User Guide are designed for **cliffed coastlines where a beach is limited** (i.e. the average beach volume does not extend across the whole intertidal zone)**.** The User Guide, in Section 5.3, indicates that there is a threshold value of beach volume below which the method should be considered valid, but does not provide a threshold value.

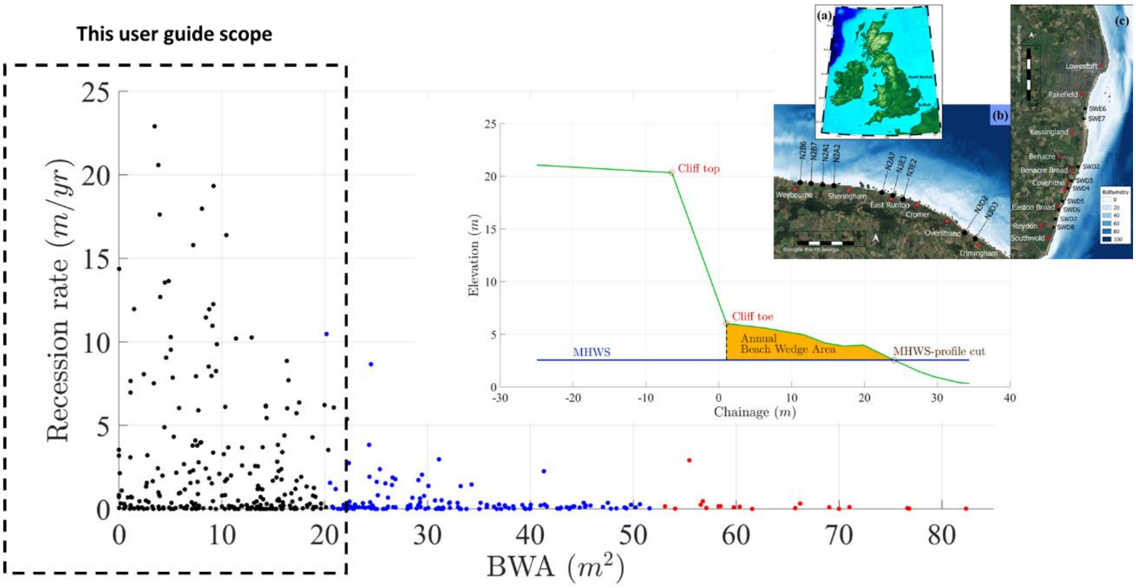


Figure 2.- Evidence of the relationship between cliff top annual recession rates and beach wedge areas (Suffolk and Norfolk). Source [2].

BGS recently explored the relationship between the beach volume and the cliff recession rate and showed the relationship between beach thickness - or beach wedge area (BWA) as a proxy for beach thickness - and annual cliff top recession rate along the undefended coast of North Norfolk and Suffolk [2]. This observation suggests that, as BWA increases (i.e. beach is present), not only does the cliff top recession rate decrease but it also becomes more predictable. This has important implications for coastal stakeholders, particularly for planning purposes at decadal and longer time scales. Our interpretation of the scope of this User Guide is indicated in Figure 2 by a dashed rectangle on the area for which BWA varies from 0 to 20 $m^{2,}$ where cliff erosion is more unpredictable and is mostly controlled by the wave energy reaching the cliff toe. For this range of BWA it is clear that a probabilistic approach (i.e. as the one proposed in the User Guide) to assess likely annual cliff recession is more appropriate than a deterministic approach. Whether the 20 m^2 of BWA is an appropriate threshold that can be applied elsewhere is outside the scope of this trial. The method described by [6] could be applied elsewhere in England and Wales to provide a proxy for this threshold beach volume value.

Figure 3.- Examples of where the methods described in the User Guide cannot be applied (Caister-on-Sea), can be applied (Sidmouth) and might be applied (Fraisthorpe). N.B. A limited beach refers to sites where the average beach volume that does not extend across the whole intertidal zone.

Our qualitative interpretation of sites where the methods described in this User Guide may be applied is illustrated in Figure 3 which shows three coastal sites: Caister-on-Sea, Sidmouth and Fraisthorpe beach. The method would appear to be unsuitable for Caister-on-Sea because the beach is clearly not limited and is backed by a dune instead of a cliff. The method is suitable for the case of Sidmouth where the beach does not cover the whole intertidal area and is backed by a cliff. The suitability for the case of Fraisthorpe beach is less clear, not because of the presence of a beach - which does not cover the whole intertidal zone - but because the cliff might not be high enough to ensure that erosion and not inundation is the main mechanism of coastal retreat. The User Guide does not provide guidance on either the minimum cliff height or sea level rise at different future times.

1.4 DOCUMENT STRUCTURE

This document is separated into two main sections. In the results section we describe, for each one of the ten regions selected, the results of applying the User Guide including the description of the auxiliary data used and any pre- and post-processing done. We have also included an indication of the time required (in working hours) for the BGS tester to go through the application process from data gathering to obtaining the results. We have also flagged any difficulties encountered. In the discussion section we have summarised the strengths and challenges of the User Guide. We conclude this report with a series of recommendations that should help to maximize the strengths and alleviate some of the challenges identified. In Appendix 4 we include the slides that present the results and main conclusions of this trial.

2 Data and methods

2.1 INPUTS DATA NEEDED AND DATA SOURCES USED

The minimum set of user inputs required to estimate the future cliff toe recession rate and cliff toe location is shown in Table 1.

The **baseline time window**, defined by baseline start and end year, and the **average cliff toe recession rate for that baseline time period** are the minimum inputs data required. If the user is also interested in estimating the future location of the cliff toe, it will require some additional inputs. The User Guide does not provide any information on how to estimate this future location and relies on user judgement.

consider that the minimum additional inputs are the **location of the cliff toe at baseline end year (or year 0**) **and an indication of the direction (bearing) along which cliff toe is likely to retreat (likely direction of retreat)**. We have chosen to specify the direction along which the cliff toe is likely to retreat by defining an additional point that represents the seaward end of an imaginary line segment, which starts at the cliff toe location at year 0 and ends at the specified seaward end. The bearing of the imaginary segment, not the distance between the cliff toe at year 0 and the seaward point, is the only relevant information needed for the calculation of the future cliff toe location.

For all regions included in this study, we have used the FutureCoast database[3] as the main data source of historical coastal recession rate and likely direction of cliff retreat. We have chosen this database because it covers the coastlines of England and Wales and is publicly available via the Coastal Channel Observatory website[1]. For each region, we have extracted a minimum of two points from the shape file "DD_Historic_Shoreline_Movement.shp". This is a geo-referenced point layer that includes links ("info_URL"; Figure 4) to graphs that show the historical location of, among others, the Back of the Beach position (BoB). The FutureCoast BoB position is dependent upon the nature of the beach/backshore, although it is generally taken as the toe of the feature forming the edge of the hinterland (examples include the toe of cliffs, toe of hard defences, seaward edge of dunes, etc.). In FutureCoast, the historic shoreline movement has been measured using a number of cross-sections aligned 'normal' to the coastline to ensure distances measured give an accurate representation of actual recorded change. We have used the MATLAB function GRABIT[2] to extract the year and location of the BoB for each point included in this study. The baseline start and year are defined for each point as the first and last year for which BoB is available. The average recession rate is calculated as the slope of the regression line fitted to all BoB historical positions. We have used the MATLAB polyval function to calculate the slope of the regression line. The Easting and Northing coordinates of the start and end of the retreat profile has also been extracted from the FutureCoast profile ("DD_Profile_Lines.shp").

Table 1.- Summary of inputs required to estimate future cliff toe recession and location and sources used.

Name	Units	Use case
Start year of the baseline time period	Gregorian calendar year	Always needed
End year of the baseline time period (year 0)	Gregorian calendar year	Always needed
Average cliff toe recession rate for time period	Metres per year	Always needed

[1] https://www.channelcoast.org/ccoresources/futurecoast/
[2] Jiro (2021). GRABIT (https://www.mathworks.com/matlabcentral/fileexchange/7173-grabit), MATLAB Central File Exchange. Retrieved February 1, 2021.

between baseline start and end years		
Geographical location of cliff toe location at baseline end year	Not specified in the User Guide. We have used Easting and Northing coordinates on British National Grid (EPSG 27700) coordinate reference system.	Only needed if user wants to estimate cliff toe location at different times after year 0
Likely direction along which cliff toe will retreat	Not specified in the User Guide. We have defined an additional point that represents the seaward end of an imaginary line segment, which start at the cliff toe location at year 0 that is aligned 'normal' to the coastline.	Only needed if user wants to estimate cliff toe location at different times after year 0.

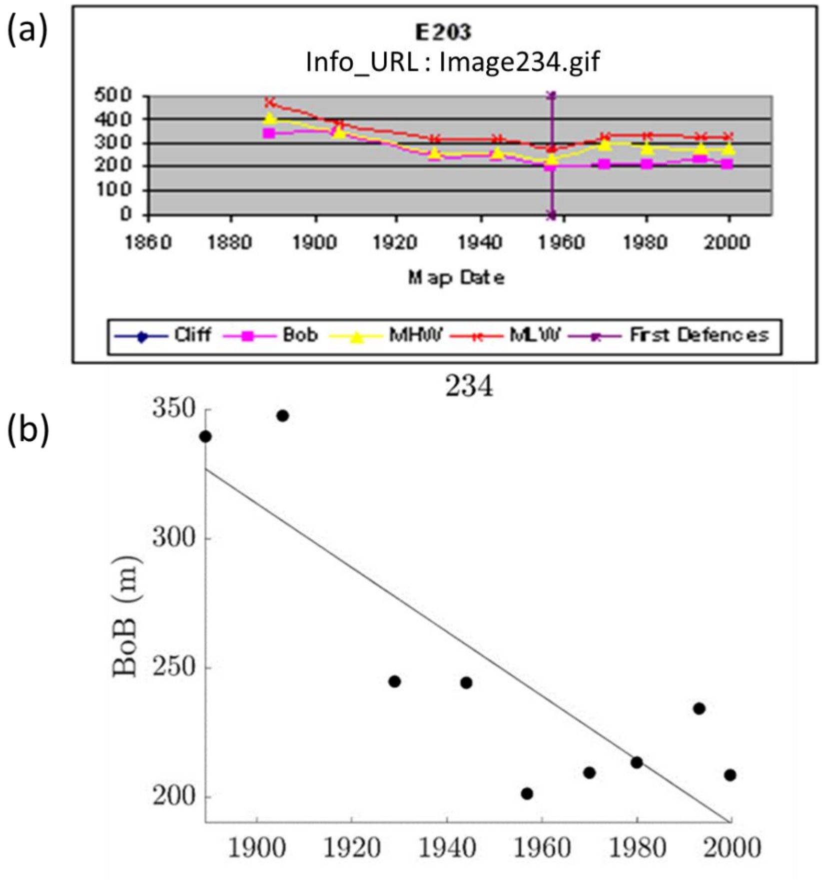


Figure 4 .- Example of how FutureCoast reported shoreline location change over time (a) and how we have extracted the historical recession rate (b). Panel (a) shows the different shoreline proxies included in FutureCoast database which are cliff top location (Cliff), Back of the Beach (BoB), Mean High Water (MHW), Mean Low Water (MLW). The approximate time of installation of the first defences installed shown by a vertical line. Numeric values shown on y axis represent the distance in metres from the landward end of the retreat profile to the location at any given time (i.e. the increase/decrease of distance over time, representing an represent advance/retreat of the location relative to land baseline). Panel (b) shows the extracted BoB locations (black dots) and the fitted regression line. The slope of the line is used to characterize the historical recession rate. Contains future coast data sourced

https://coastalmonitoring.org/ccoresources/futurecoast/ (DEFRA 2002, Environment Agency 2018) released under OGL.

East Riding of Yorkshire Cliff Erosion Monitoring — Cliff Erosion Data table — EAST RIDING OF YORKSHIRE COUNCIL

SMP2 Band	Erosion Profile Details		Erosion line OS co ordinates				Cliff erosion data: Cliff lost at profile over last year (m)		Erosion rate m/yr		Max cliff loss between profiles		
	Erosion Profile	Location	Easting	Northing	Easting	Northing	Nov 2014 to April 2015	April 2015 to Sept 2015	Historic 1852 to 1989	Recent 1989 to Sept 2015	Height of cliff m OD	Maximum recorded individual loss (m)	Date of max cliff loss
A	1	South Riviera Drive, Sewerby	519741.3	468778.7	520704.8	467875.7	0.00	0.00		-	25.7	5.24	April 2006
	2	North of Bridlington defences	519407.0	468360.5	520448.2	467548.6	0.00	0.00		-	16.6	1.81	April 2011
B	3 to 7	**Bridlington frontage**											
	8	Within car park to south of Bridlington defences	517020.0	464901.3	518274.9	464490.0	0.00	0.00	0.59	0.00	12.2	3.60	1890 to 1907
	9	Within South Shore Holiday Village, Wilsthorpe	516901.5	464377.8	518182.3	464055.9	0.00	0.00	0.41	0.03	11.2	2.47	1891 to 1907
	10	South end of Wilsthorpe village	516800.0	4663835.9	518106.3	463641.9	0.00	0.00	0.32	0.12	8.0	1.91	1892 to 1907
	11	On Field Boundary to the North of Auburn Farm	516714.1	463288.0	518033.5	463232.0	0.00	0.00	0.20	0.42	8.1	6.40	Dec 2013
	12	Opposite Auburn Farm	516692.9	462788.5	518012.3	462732.5	0.00	0.00	0.25	0.77	5.1	11.81	Dec 2013

Figure 5.- Headings and first few rows of historical cliff erosion at East Riding of Yorkshire used for this study (source Coastal-Explorer).

For Region 9, we used Coastal-Explorer[3] as an additional database for the East Riding of Yorkshire coast. This provides the historical recession rate and likely direction of cliff retreat along this coastline (Figure 5). The average recession rates are specified for a number of points along the coast, and for each location the database provides the Easting and Northing coordinates of the landward and seaward points. These represent an imaginary line segment normal to the coast along which the retreat has been observed. For each location, the historical cliff erosion rate (m/yr) is provided for two time periods: 'historic' (1852 to 1989) and 'recent' (1989 to 2015). We have combined these two periods to obtain a baseline time window from 1852 to 2015 (163 years). The cliff erosion rate for the baseline period has been calculated as the ratio of the sum of recession distances for the historic and recent period and the 163 years baseline time span. As a proxy for cliff toe location at year 0, we have snapped the landward end of the line segment to the UK Ordnance Survey Vectormap Local High Water Line (HWL) (from "Tidal_Boundary.shp" layer) for year 2020, January version. To simplify the comparison with the FutureCoast projected location, we have also snapped the FutureCoast landward coordinates to the same HWL.

2.2 MAIN CALCULATIONS

To facilitate the calculations, we formatted all the required input data as shown in Figure 6 and saved it as an excel spread sheet named "Historical recession". The inputs are organized in eight columns (A to H) and each row represents a site for which we are estimating future coastal cliff toe retreat rate and location.

- Column A and B contains the baseline start and end year values respectively.
- Column C, contains a unique site identifier (e.g. in Figure 6 we have chosen the profile number provided by the Coastal-Explorer).
- Column D to G, contains the Easting and Northing coordinates of the cliff toe location at baseline end year (year 0) and a seaward end of the likely direction of cliff retreat. The landward end of the likely direction of retreat is recorded first to ensure consistent use of the landward end as the baseline in advance/retreat measurements.
- Colum H, contains the historical recession rate for the baseline period at this location. Erosion is indicated as negative values.

[3] https://www.eastriding.gov.uk/coastalexplorer/homepage.html

Baseline Start Year	Baseline End Year	ID	Easting	Northing	Easting	Northing	Recession m/y
1852	2015	8	517388	464784.5	518274.9	464490	-0.50
1852	2015	9	517240.5	464299.8	518182.3	464055.9	-0.35
1852	2015	11	517042.2	463250.1	518033.5	463232	-0.24
1852	2015	12	517007.1	462778.6	518012.3	462732.5	-0.33
1852	2015	13	516976.4	462277.8	517991.1	462232.9	-0.52

Figure 6.- Headings and first few rows of historical cliff erosion at East Riding of Yorkshire used with the format used on this study.

We created an excel template named "GetRegionRecessionEstimates.xlsm", which is a Macros-supported-spreadsheet, to perform all the calculations described in the User Guide (Figure 7). From an application point of view, a Macro is a set of instructions that are used for automating processes. They are programmed with Microsoft's Visual Basic for Applications (VBA) from within the Excel Workbook using the Visual Basic Editor and can be run/debugged directly from there. XLSM files are similar to XLM file formats but are based on the Open XML format introduced in Microsoft Office 2007. We programmed a macro for each one the three main consecutive steps, with an additional fourth step should the user be interested in also estimating the future likely cliff toe location.

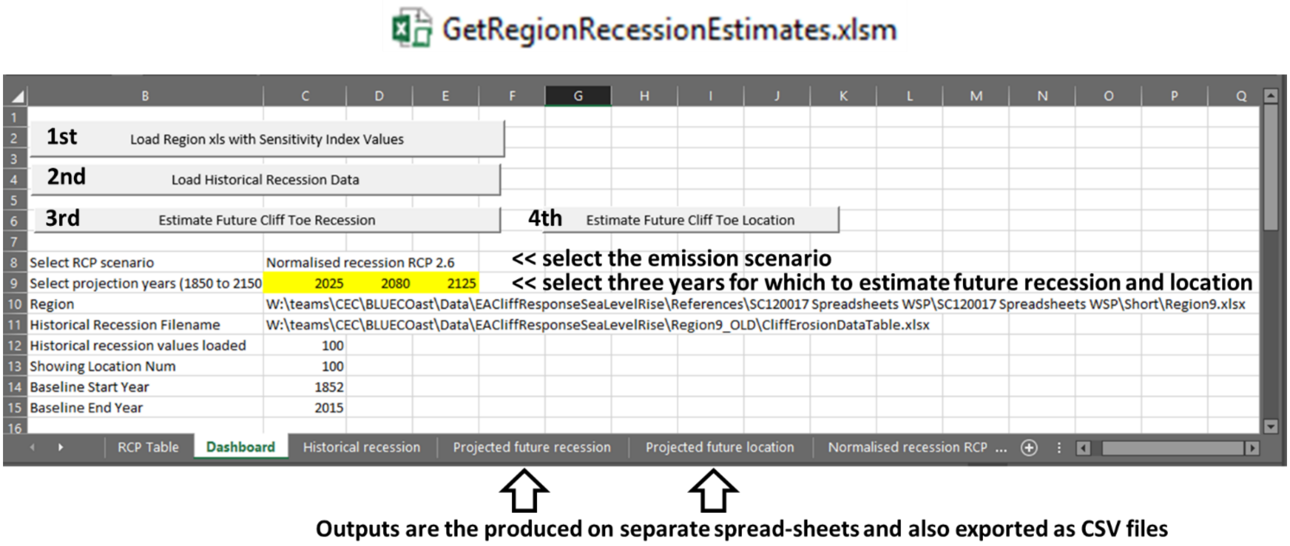


Figure 7.- Dashboard of the Macros-supported-spreadsheet created to facilitate the calculation of the different steps needed to estimate future cliff toe recession and location.

The calculations done at each step are summarised below.

- **Step 1: Load Region XLS with sensitivity index value**. The template is designed to calculate projections for one region at a time. This implies that the user needs to cluster the points by region when populating the input data. We have used a shapefile with the regions shown in Figure 1 as a guide to select which region sensitivity index to use. The macro first asks the user to locate the XLS file with the sensitivity index values and then loads the year time-series of normalised recession for each one of the three Repetitive Concentration Pathway (RCP) scenarios (2.6, 4.5 and 8.5). The User Guide provides a short (1850 to 2150) and long (1789 to 2300) lists of sensitivity index values. The template is programmed to operate with the short time series.

- **Step 2: Load historical recession data".** This input needs to be formatted as shown in Figure 6. The macro loads the input into the "Historical recession" spreadsheet and initialises the baseline start and end years to the default values of 1920 and 2020 respectively. The total number of sites loaded is indicated in the dashboard after loading them.
- **Step 3: Estimate the future cliff toe recession**. The macro calculates the recession for each of the loaded points and indicates which one is being calculated in the dashboard. The recession calculated represents the horizontal distance of coastal retreat relative to the cliff toe location at year 0. For each point, the macro reads the baseline start and end year and if they are different to the default baseline period (from 1920 to 2020) or to the previously used value it automatically re-normalises the sensitivity index for the entire time series. The re-normalisation is calculated as a linear correction to the sensitivity index values to ensure that the index value is -1 and 0 for the new start and end baseline years respectively. The macro then calculates the recession rate for the user-selected RCP scenario and three user defined years. For each year, it calculates the 5th, 50th and 95th percentile values are calculated and shows them in the spreadsheet named "Projected future recession". This is also saved as .csv file in the same folder where the macro-supported template file is saved. The .csv file can be uploaded to any Geographical Information System software to plot the site locations.
- **Step 4: Estimate the future cliff toe location**. Once the cliff toe recession is calculated, the cliff toe is obtained using the year 0 coordinates and the bearing of the imaginary line that the user has defined as aligned normal to the coast at each location. The macro automatically calculates the new Easting and Northing coordinates for each recession calculated in step 3 and saves it in the spreadsheet named "Projected future location" and as .csv file.

The template is available to download from the BGS secure sharefile repository[4]. The VBA code is shown in the appendices with further detail on Steps 1-4.

In the current version of the User Guide, the only indication on how to re-baseline the sensitivity index so that it precisely matches the baseline period is described on page 23. The User Guide states that *"…Figure 4-11 has been adjusted accordingly, so that the cliff is at position -1.0 in 1902 and 0.0 in 2018*", where 1902 and 2018 are limits constitute the baseline period that differs from the default values which are 1920 and 2020 respectively. How the sensitivity index has been corrected is not explicitly stated. We have interpreted that this correction is simply a linear correction to ensure that the new sensitivity index is -1.0 and 0.0 for the baseline start year, yr_1, and baseline end year, yr_0. The re-baselined sensitivity index for a given year, $SI_{new}(yr)$, is then obtained by applying a correction, $C(yr)$, to the default sensitivity index for a given year, $SI_{default}(yr)$, as

$$SI_{new}(yr) = SI_{default}(yr) + C(yr) \tag{1}$$

Where the correction values are obtained by imposing conditions (2) and (3) are met

$$SI_{new}(yr_1) = SI_{default}(yr_1) + C(yr_1) = -1.0 \tag{2}$$

$$SI_{new}(yr_0) = SI_{default}(yr_0) + C(yr_0) = 0.0 \tag{3}$$

And assuming a simple linear correction reduces to

$$C(yr) = m \cdot yr + b \tag{4}$$

$$m = \frac{C(yr_1) - C(yr_0)}{yr_1 - yr_0} \tag{5}$$

$$b = C_1 - m \cdot yr_1 \tag{6}$$

[4] https://bgs.sharefile.eu/d-s10e109999f0b4dcc93985483b11ae223

3 Results

3.1 HISTORICAL RECESSION RATE FOR SELECTED STUDY LOCATIONS

The extracted input data from FutureCoast database and Coastal Explorer are listed in Appendix 2. We have extracted a total of 33 points from FutureCoast database and 100 from Coastal Explorer. Out of the 33 points from FutureCoast, only 20 locations indicate a trend of historical BoB recession (i.e. negative slope of fitted linear regression). The average erosion rate from all eroding locations from the FutureCoast database is -0.175 m/y with a maximum erosion rate of-1.24 m/y at one location in Region 17. All values of historical cliff top retreat from Coastal Explorer database are from Regions 9 and 10 and indicate an erosive trend over the baseline period, with an average value of -1.32 m/y and maximum erosion rate of -2.64 m/y (Figure 8). Out of the 100 points, only 33 are within what we have interpreted as the Region 9 area, for which the User Guide has sensitivity index values. We noticed that at the interface between Regions 9 and 10 it is difficult to assess which region the points belong. For FutureCoast database extracted locations, the minimum and maximum values of the baseline start year is 1854 and 1978 respectively, and 1999 and 2002 for the baseline end year. The baseline time period for all points extracted from Coastal Explorer database is that from 1852-2015. The time series of the cliff sensitivity index provided in the short version ranges from 1850-2150 and is sufficient for all 120 locations included in this study. We compared the results obtained using the short and long time series for the 100 locations in Region 9 and, as expected, the results are the same.

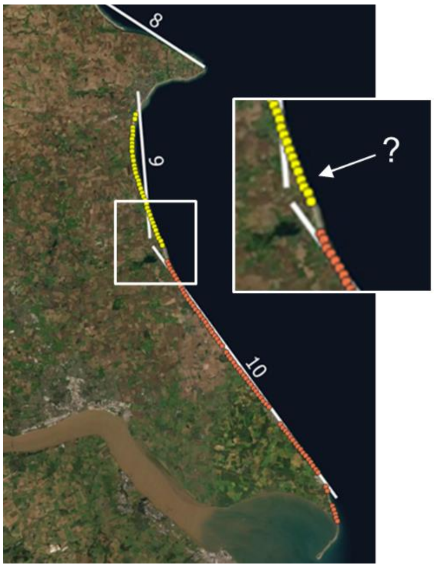


Figure 8.- Location of the points for which we extracted the required input data from the Coastal Explorer dataset from East Riding of Yorkshire. Locations are indicated by coloured circles. We were only able to find sensitivity index for the locations indicated by yellow coloured circles. The boundary between region 9 and 10 were not clear making difficult to assess which point belongs to what region. Aerial image source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

3.2 FUTURE CLIFF TOE RETREAT ESTIMATION PER REGION

3.2.1 Using FutureCoast input data

We used RCP 4.5 scenario for all our calculations and assumed that the BoB represents the cliff toe in all sites. Table 2 shows the estimated recession, in metres, relative to the cliff toe position in year 0 for future years 2030, 2080 and 2125. The minimum estimated recession is nearly 0 m for year 2030, 5th percentile, at Region 39 and point ID 769 (Figure 9). The maximum estimated recession is of -416 m for year 2125, 95th percentile, at Region 17 at point with ID 934 (Figure 10). These minimum and maximum recession rates are equivalent to an increase of the historical rate by a factor 1.3 and 2.7 respectively (Table 3). The minimum and maximum increase of the historical recession rates is 1.2 m by 2030 (at Region 50, point 250, 5th percentile) and 4.6 (at Region 75, points 530 and 534, 95th percentile). The second largest relative increase of cliff toe recession is 3.0 m (year 2125, 95th percentile) observed at Region 68 and Region 9. The highest relative increases for Regions 75 and 68 were expected as both regions are indicated in the User Guide as high sensitivity regions.

The BoB for all sites does not always represent the toe of the cliff. For example, a closer look at the site with ID 934 (Caister-on-Sea) Figure 3 clearly shows that BoB for the three FutureCoast profile shown in Figure 10 represents the toe of the dune and therefore the methods described in this User Guide are not applicable. A closer look at site with ID 769 (Sidmouth) suggests that a cliff is present, a beach is absent and therefore the BoB represents the toe of the cliff and the method described in the User Guide is applicable.

Table 2.- User guide region, FutureCoast ID and recession results for years 2030, 2080 and 2125 for the 20 locations from FutureCoast database. Recession distance is given in metres relative to the initial location at year 0.

Region	ID	2030 5th	2030 50th	2030 95th	2080 5th	2080 50th	2080 95th	2125 5th	2125 50th	2125 95th
9	853	-4	-5	-5	-14	-16	-19	-26	-30	-37
17	933	-1	-1	-1	-4	-4	-5	-7	-8	-10
17	934	-49	-53	-58	-159	-181	-213	-280	-334	-416
23	1013	-3	-3	-3	-8	-9	-11	-14	-17	-21
23	1014	-8	-9	-10	-27	-31	-36	-47	-56	-69
23	1015	-22	-24	-26	-73	-83	-98	-128	-152	-187
28	995	-4	-5	-5	-14	-16	-18	-25	-29	-35
33	676	-4	-4	-4	-12	-14	-17	-21	-25	-32
33	677	-1	-1	-1	-3	-3	-4	-5	-6	-7
33	678	-3	-3	-3	-8	-9	-11	-14	-17	-21
33	679	-8	-9	-10	-26	-30	-35	-46	-54	-67
39	769	0	0	0	-1	-1	-2	-2	-3	-3
41	807	-12	-13	-14	-37	-41	-48	-64	-74	-90
50	249	-1	-1	-1	-2	-3	-3	-4	-5	-6
50	250	-3	-3	-3	-8	-8	-9	-13	-15	-17
68	464	-6	-6	-7	-19	-22	-26	-34	-40	-52
68	466	-9	-9	-10	-27	-31	-37	-48	-58	-75
68	467	-2	-2	-2	-5	-6	-7	-10	-12	-15
75	530	-4	-4	-4	-12	-15	-19	-23	-29	-41
75	534	-1	-1	-1	-2	-2	-3	-3	-4	-6

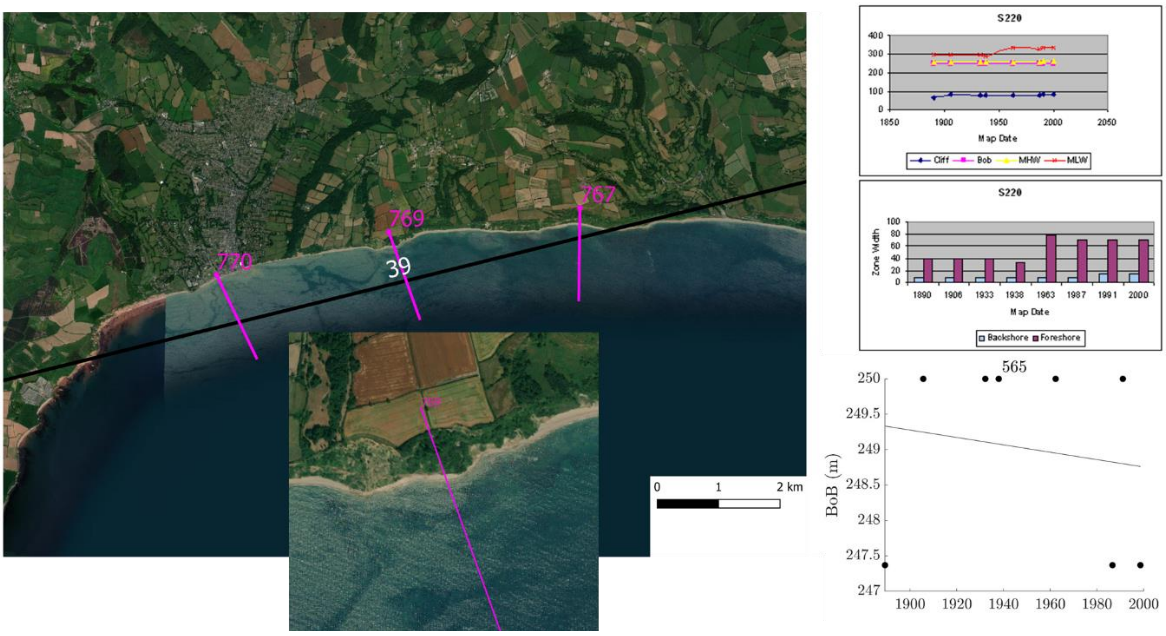


Figure 9.- The minimum recession, as estimated for location 769 near Sidmouth in South England which belongs to User Guide Region 39. In magenta we illustrate the imaginary line that is aligned with the coast from the FutureCoast database. For reference, the FutureCoast historical BoB change and the slope fitted are shown in the right top and bottom panels. Contains future coast data sourced https://coastalmonitoring.org/ccoresources/futurecoast/ (DEFRA 2002, Environment Agency 2018) released under OGL. Aerial image source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 10.- Maximum recession is estimated for location 934 near Caister-on-Sea in East England which belongs to User Guide Region 17. In magenta we illustrate the imaginary line that is aligned with the coast from FutureCoast database. For reference the FutureCoast historical BoB change and the slope fitted are shown in the right panels. Contains future coast data sourced https://coastalmonitoring.org/ccoresources/futurecoast/ (DEFRA 2002, Environment Agency 2018) released under OGL. Aerial image source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Table 3.- User guide region, FutureCoast ID, historical recession and ratio of future estimated recession rate and historical rate for years 2030, 2080 and 2125 for the 20 locations from FutureCoast database. Contains future coast data sourced https://coastalmonitoring.org/ccoresources/futurecoast/ (DEFRA 2002, Environment Agency 2018) released under OGL.

Reg.	ID	Hist. Rate m/y	2030 5th	2030 50th	2030 95th	2080 5th	2080 50th	2080 95th	2125 5th	2125 50th	2125 95th
9	853	-0.1	1.5	1.6	1.8	1.8	2.1	2.4	2.1	2.4	3.0
17	933	-0.03	1.3	1.4	1.6	1.6	1.8	2.2	1.8	2.2	2.7
17	934	-1.24	1.3	1.4	1.6	1.6	1.8	2.1	1.8	2.2	2.7
23	1013	-0.06	1.4	1.5	1.6	1.7	1.9	2.3	1.9	2.2	2.7
23	1014	-0.2	1.4	1.5	1.7	1.7	1.9	2.3	1.9	2.2	2.7
23	1015	-0.54	1.4	1.5	1.7	1.7	2.0	2.3	1.9	2.3	2.8
28	995	-0.11	1.4	1.5	1.6	1.7	1.9	2.2	1.9	2.2	2.6
33	676	-0.09	1.4	1.5	1.7	1.7	2.0	2.3	1.9	2.3	2.8
33	677	-0.02	1.4	1.5	1.7	1.7	2.0	2.3	1.9	2.3	2.8
33	678	-0.06	1.4	1.5	1.7	1.7	2.0	2.3	1.9	2.3	2.8
33	679	-0.19	1.4	1.5	1.7	1.7	1.9	2.3	1.9	2.3	2.8
39	769	-0.01	1.3	1.4	1.5	1.6	1.8	2.1	1.8	2.1	2.6
41	807	-0.3	1.3	1.4	1.5	1.5	1.7	2.0	1.7	2.0	2.4
50	249	-0.02	1.3	1.4	1.4	1.5	1.6	1.8	1.6	1.9	2.2
50	250	-0.07	1.2	1.3	1.3	1.4	1.5	1.7	1.5	1.7	2.0
68	464	-0.14	1.5	1.5	1.6	1.7	1.9	2.3	1.9	2.3	3.0
68	466	-0.2	1.5	1.5	1.7	1.7	1.9	2.3	1.9	2.3	3.0
68	467	-0.04	1.5	1.5	1.7	1.7	1.9	2.3	1.9	2.3	3.0
75	530	-0.07	1.7	1.8	2.1	2.2	2.6	3.3	2.6	3.3	4.6
75	534	-0.01	1.7	1.8	2.0	2.2	2.6	3.3	2.6	3.3	4.6

3.2.2 Using Coastal Explorer input data

As before, we used the RCP 4.5 scenario for all our calculations. Table 4 shows the estimated recession in metres relative to the cliff toe position in year 0 for future years 2030, 2080 and 2125. The minimum and maximum recession is -6 m and -845 m obtained for year 2030 - 5th percentile at point 11 and year 2150 - 95th percentile at point 22. These minimum and maximum recession figures correspond to erosion rates of -0.4 m/y and -7.7 m/y, which represent an increased recession rates by factors of 1.6 and 4.5 respectively. The future cliff toe positions calculated using the Coastal Explorer and FutureCoast databases as input source are shown in Figure 11.

The comparison of the future cliff toe location from FutureCoast versus the nearby locations from Coastal Explorer clearly illustrate how the predicted future location is very sensitive to the baseline historical recession input data. The average historical recession rate for locations 11 and 12 from the Coastal Explorer is -0.28 m/y. From FutureCoast at location 853 (between the locations 11 and 12) this is -0.1 m/y (i.e. a factor 2.8 larger for the Coastal Explorer database). The resulting maximum recession is -140 m from Coastal Explorer versus - 37m from FutureCoast (i.e. a factor 3.8 larger for the Coastal Explorer database).

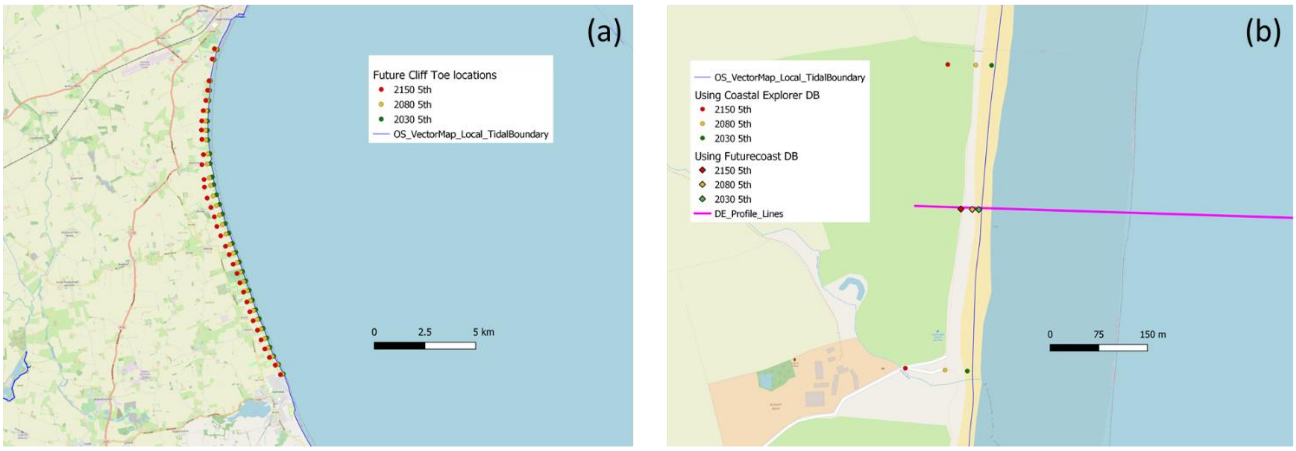


Figure 11.- Projected future cliff toe locations for RCP 4.5, 5th percentile for years 2030, 2080 and 2150 at East Riding of Yorkshire for; (a) selected 33 locations from Coastal Explorer database and (b) on location selected from FutureCoast database. Contains future coast data sourced https://coastalmonitoring.org/ccoresources/futurecoast/ (DEFRA 2002, Environment Agency 2018) released under OGL. © OpenStreetMap contributors.

Table 4.- Coastal Explorer ID, estimated recession for years 2030, 2080 and 2125 for the 33 selected locations in Region 9. Recession distance is given in metres relative to the initial location at year 0.

ID	2030 5th	2030 50th	2030 95th	2080 5th	2080 50th	2080 95th	2150 5th	2150 50th	2150 95th
8	-12	-13	-15	-63	-74	-89	-154	-189	-245
9	-8	-9	-10	-45	-52	-63	-109	-133	-173
11	-6	-6	-7	-30	-35	-42	-73	-90	-116
12	-8	-9	-10	-43	-50	-60	-104	-127	-165
13	-12	-14	-15	-66	-77	-93	-161	-198	-256
14	-20	-22	-24	-104	-121	-146	-253	-311	-403
15	-24	-26	-30	-127	-148	-178	-309	-379	-491
16	-25	-28	-31	-135	-157	-189	-328	-402	-521
17	-26	-28	-32	-136	-159	-191	-331	-406	-526
18	-27	-30	-33	-143	-167	-201	-348	-427	-554
19	-35	-39	-43	-186	-217	-261	-453	-555	-720
20	-36	-39	-44	-189	-220	-265	-460	-565	-732
21	-40	-45	-50	-215	-250	-301	-523	-641	-831
22	-41	-45	-51	-218	-255	-306	-532	-652	-845
23	-38	-42	-47	-202	-235	-283	-491	-602	-781
24	-36	-39	-44	-189	-221	-266	-461	-565	-733
25	-37	-41	-45	-196	-228	-274	-476	-584	-757
26	-35	-39	-44	-187	-218	-263	-456	-559	-725
27	-31	-34	-38	-163	-190	-228	-396	-486	-630
28	-29	-32	-35	-152	-177	-213	-370	-454	-589
29	-27	-30	-33	-142	-165	-199	-345	-424	-549
30	-24	-27	-30	-129	-150	-180	-313	-384	-498
31	-25	-28	-31	-133	-155	-186	-323	-396	-514
32	-24	-27	-30	-128	-149	-179	-311	-381	-494
33	-24	-27	-30	-129	-150	-180	-313	-384	-497
34	-26	-29	-32	-137	-160	-192	-334	-409	-530
35	-27	-30	-33	-142	-165	-199	-345	-424	-549
36	-25	-27	-30	-131	-152	-183	-318	-390	-505
37	-25	-28	-31	-135	-157	-189	-328	-402	-521
38	-22	-24	-27	-116	-135	-163	-283	-347	-450
39	-18	-20	-23	-98	-114	-137	-238	-292	-378
40	-14	-15	-17	-73	-85	-103	-178	-219	-283
41	-12	-13	-15	-62	-73	-87	-152	-186	-241

Table 5.- Coastal Explorer ID and estimated recession rate for years 2030, 2080 and 2150 for the 33 selected locations in Region 9. Recession distance is given in metres per year.

ID	2030 5th	2030 50th	2030 95th	2080 5th	2080 50th	2080 95th	2150 5th	2150 50th	2150 95th
8	-0.8	-0.9	-1.0	-1.0	-1.1	-1.4	-1.4	-1.7	-2.2
9	-0.6	-0.6	-0.7	-0.7	-0.8	-1.0	-1.0	-1.2	-1.6
11	-0.4	-0.4	-0.5	-0.5	-0.5	-0.6	-0.7	-0.8	-1.1
12	-0.5	-0.6	-0.7	-0.7	-0.8	-0.9	-0.9	-1.2	-1.5
13	-0.8	-0.9	-1.0	-1.0	-1.2	-1.4	-1.5	-1.8	-2.3
14	-1.3	-1.4	-1.6	-1.6	-1.9	-2.2	-2.3	-2.8	-3.7
15	-1.6	-1.8	-2.0	-2.0	-2.3	-2.7	-2.8	-3.4	-4.5
16	-1.7	-1.9	-2.1	-2.1	-2.4	-2.9	-3.0	-3.7	-4.7
17	-1.7	-1.9	-2.1	-2.1	-2.4	-2.9	-3.0	-3.7	-4.8
18	-1.8	-2.0	-2.2	-2.2	-2.6	-3.1	-3.2	-3.9	-5.0
19	-2.3	-2.6	-2.9	-2.9	-3.3	-4.0	-4.1	-5.0	-6.5
20	-2.4	-2.6	-2.9	-2.9	-3.4	-4.1	-4.2	-5.1	-6.7
21	-2.7	-3.0	-3.3	-3.3	-3.9	-4.6	-4.8	-5.8	-7.6
22	-2.7	-3.0	-3.4	-3.4	-3.9	-4.7	-4.8	-5.9	-7.7
23	-2.5	-2.8	-3.1	-3.1	-3.6	-4.4	-4.5	-5.5	-7.1
24	-2.4	-2.6	-2.9	-2.9	-3.4	-4.1	-4.2	-5.1	-6.7
25	-2.4	-2.7	-3.0	-3.0	-3.5	-4.2	-4.3	-5.3	-6.9
26	-2.3	-2.6	-2.9	-2.9	-3.4	-4.0	-4.1	-5.1	-6.6
27	-2.0	-2.3	-2.5	-2.5	-2.9	-3.5	-3.6	-4.4	-5.7
28	-1.9	-2.1	-2.4	-2.3	-2.7	-3.3	-3.4	-4.1	-5.4
29	-1.8	-2.0	-2.2	-2.2	-2.5	-3.1	-3.1	-3.9	-5.0
30	-1.6	-1.8	-2.0	-2.0	-2.3	-2.8	-2.8	-3.5	-4.5
31	-1.7	-1.8	-2.1	-2.0	-2.4	-2.9	-2.9	-3.6	-4.7
32	-1.6	-1.8	-2.0	-2.0	-2.3	-2.8	-2.8	-3.5	-4.5
33	-1.6	-1.8	-2.0	-2.0	-2.3	-2.8	-2.8	-3.5	-4.5
34	-1.7	-1.9	-2.1	-2.1	-2.5	-3.0	-3.0	-3.7	-4.8
35	-1.8	-2.0	-2.2	-2.2	-2.5	-3.1	-3.1	-3.9	-5.0
36	-1.6	-1.8	-2.0	-2.0	-2.3	-2.8	-2.9	-3.5	-4.6
37	-1.7	-1.9	-2.1	-2.1	-2.4	-2.9	-3.0	-3.7	-4.7
38	-1.5	-1.6	-1.8	-1.8	-2.1	-2.5	-2.6	-3.2	-4.1
39	-1.2	-1.4	-1.5	-1.5	-1.8	-2.1	-2.2	-2.7	-3.4
40	-0.9	-1.0	-1.1	-1.1	-1.3	-1.6	-1.6	-2.0	-2.6
41	-0.8	-0.9	-1.0	-1.0	-1.1	-1.3	-1.4	-1.7	-2.2

4 Discussion: strengths and challenges

Before we describe in detail the strengths and challenges of the proposed User Guide it is important that we contextualise this within the scope of the User Guide. The geographic scope of this User Guide is limited to the coastlines of England and Wales. The audience for which this User Guide was designed is not explicitly described in the guide but was discussed with the authors. It is suggested that it is the collective of consultants and government officials who need an order of magnitude assessment of how future cliff toe recession might differ from historically observed recession under different sea level rise scenarios. Additionally, the User Guide assumes that users have limited resources to perform this assessment; in particular, a time to do the assessment is in the order of hours not days, a basic coastal geomorphological understanding is assumed and only limited site-specific data.

The main strength is that the proposed method and User Guide effectively fills-in a gap on the existing tools able to assess the cliff response to accelerated sea level rise along the cliffed coast with a limited beach. The main weakness of the proposed method and User Guide is the lack of guidance on the backshore geometry for which this methodology is suitable. Without this information, the statement that the method conservatively estimates cliff retreat is not always valid, as inundation - instead of the assumed erosion - might be the driver of coastal change. Table 6 summarizes the other strengths and challenges that we have found as a result of this trial.

Table 6.- Summary of strengths and challenges of using the User Guide.

Strengths	Challenges
Easy to use.	Boundaries between regions unclear.
Data required is readily available around England and Wales.	Re-baseline calculations is key and need to be explicitly explained.
Requires only basic geomorphological knowledge.	What is the minimum cliff height to ensure that erosion and not inundation is the main driver for the simulation period.
	Geological descriptions are distracting and if maintained need to be reviewed for geoscientific correctness (Appendix 3).

We have found that the most time-consuming activity, in applying the method described in this User Guide is the gathering of the required amount of input data described in Table 1. We have tested two main data sources (FutureCoast and Coastal Explorer). If the user is familiar with these datasets, gathering the required information is a task that can be performed in minutes. Doing the calculation using the macros-supported spreadsheet can be performed in seconds and just four clicks, including the time required for documenting and reporting. We conclude that the method fulfils the requirement of obtaining results in a timescale of the order of a few hours.

We have also shown that the publicly available FutureCoast dataset contains all the required input data for England and Wales. In particular, we have shown how the BoB historical time series and the profile aligned normal to the coast could be used. We have also shown the sensitivity of estimated future recession to the recession data for the baseline period.

Users with a very basic understanding of coastal geomorphology or no site-specific knowledge should be able to assess the validity of the method. The User Guide does clearly state that the methods described should only be applied to places with beaches of limited volume or no beach at all (User Guide, page 6). This is reinforced in Section 5.3, where the User Guide states that the sensitivity indicators "*should be similarly valid for settings where the beach is either absent,* *or the average beach volumes does not extend across the intertidal zone*". If the user is able to differentiate between the beach and the shore platform (e.g. Fig 3-3, page 9, User guide) and have access to images of the study area at low tide, they should be able to assess if the beach is absent or does not extend across the intertidal area.

The methods described in the User Guide could be clearer for other users, with minor revisions regarding: the description about how to re-normalise the sensitivity index for baseline time periods different to the default baseline; how to confidently select the region for locations that are located at the interface between regions; and what is the minimum cliff elevation for which the method can be applied.

We suggest that equations (1) to (6) are included in the revised version to avoid any confusion on how to correct the sensitivity index for different baseline periods. It may be worth demonstrating how these equations can be programmed into an EXCEL template.

We also suggest that the instructions about the way the user should select a region sensitivity index file for a given location should be improved (for reference see the issues described above relating to uncertainties about which locations belong to Region 9 and which belong to Region 10). Plotting the locations spatially in a GIS software, together with the shapefile provided by the User Guide author, is useful but not enough. In particular the boundaries between regions could be more clearly labelled.

Finally, the section on how to map the future cliff toe locations would also benefit from a more detailed description about how to characterise the likely direction (heading) of retreat, and how to calculate the point coordinates. At present, only one example of how the estimated cliff line location is presented in Section 4.4. We have shown how by adding two points (point at year 0 and a seaward point) the location can be easily calculated.

5 Recommendations

The division of the English and Welsh coastline into regions, is a pragmatic and sound approach to represent the large variability of coastal environments and nearshore processes along these coastlines. The method requires data input that is readily available for English and Welsh coastlines (i.e. FutureCoast dataset) and requires only basic geomorphological knowledge (i.e. identify cliffed coast with absent or very limited beach). The calculations are straightforward, and if assisted by a macro-supported spreadsheet – for instance that used in our testing - can be performed almost instantaneously. **We strongly recommend the inclusion of a spreadsheet or similar tool that minimizes the time required to do the calculations and chances of human errors.**

The main weakness of the proposed method and User Guide is on the lack of guidance on the backshore geometry for which this methodology is suitable. Without this information, the statement that this method conservatively estimates cliff retreat is not always valid. At present, the user main criteria to assess if a location is suitable to apply this methodology is the beach being absent or very limited and cliff erosion not dominated by land sliding with no indication to backshore geometry. This weakness can be minimized by including information about the type of backshore geometry (i.e. cliff minimum elevation) for which this method is still valid. **We recommend that provision of information on backshore geometry to guide usage.**

Some of the geological descriptions, considerations and references are not entirely correct or are unhelpful (see Appendix 3). **We recommend that these should be amended prior to publication.**

Appendix 1 VBA scripts of EXCEL template used

This appendix contains the scripts used for all the calculations done by the "GetRegionRecessionEstimates.xlsm" template used to estimate future cliff toe recession and location values presented in this study. The calculations are done by combining macros for the main four steps with formulas embedded in the different spreadsheet tabs. The macro code is shown below and the file "GetRegionRecessionEstimates.xlsm" can be downloaded from BGS secure sharefile link[5].

VBA MODULE 1: LOAD SENSITIVITY INDEX

```
Sub Get_Sensitivity_Data_From_File()
    Dim FileToOpen As Variant
    Dim OpenBook As Workbook
    Application.ScreenUpdating = False
    FileToOpen = Application.GetOpenFilename(Title:="Browse for your file & Import Range", FileFilter:="Excel
Files (*.xls*),*xls*")
    If FileToOpen <> False Then
        Set OpenBook = Application.Workbooks.Open(FileToOpen)

        ThisWorkbook.Worksheets("Dashboard").Range("C10").Value = FileToOpen

        ThisWorkbook.Worksheets("Normalised recession RCP 2.6").Range("A1:F305").Clear
        OpenBook.Sheets("Normalised recession RCP 2.6").Range("A1:F305").Copy
        ThisWorkbook.Worksheets("Normalised recession RCP 2.6").Range("A1").PasteSpecial xlPasteValues

        ThisWorkbook.Worksheets("Normalised recession RCP 4.5").Range("A1:F305").Clear
        OpenBook.Sheets("Normalised recession RCP 4.5").Range("A1:F305").Copy
        ThisWorkbook.Worksheets("Normalised recession RCP 4.5").Range("A1").PasteSpecial xlPasteValues

        ThisWorkbook.Worksheets("Normalised recession RCP 8.5").Range("A1:F305").Clear
        OpenBook.Sheets("Normalised recession RCP 8.5").Range("A1:F305").Copy
        ThisWorkbook.Worksheets("Normalised recession RCP 8.5").Range("A1").PasteSpecial xlPasteValues

        OpenBook.Application.CutCopyMode = False
        OpenBook.Close True
    End If
    Application.ScreenUpdating = True

End Sub
```

VBA MODULE 2: LOAD HISTORICAL RECESSION DATA

```
Sub Get_HistoricalRecession_Data_From_File()
    Dim FileToOpen As Variant
    Dim OpenBook As Workbook
    Dim NumberOfLocationsLoaded As Integer

    Application.ScreenUpdating = False
    FileToOpen = Application.GetOpenFilename(Title:="Browse for your file & Import Range", FileFilter:="Excel
Files (*.xls*),*xls*")

    If FileToOpen <> False Then
        Set OpenBook = Application.Workbooks.Open(FileToOpen)

        'Copy Historical Recession filename
        ThisWorkbook.Worksheets("Historical recession").Cells.Clear
        ThisWorkbook.Worksheets("Dashboard").Range("C11").Value = FileToOpen
        OpenBook.Sheets("Historical recession").Range("A1", Range("A1").End(xlDown).End(xlToRight)).Copy
        ThisWorkbook.Worksheets("Historical recession").Range("A1").PasteSpecial xlPasteValues
        NumberOfLocationsLoaded = ThisWorkbook.Worksheets("Historical recession").Cells.Find(What:="*",
SearchDirection:=xlPrevious).Row - 1
        ThisWorkbook.Worksheets("Dashboard").Range("C12").Value = NumberOfLocationsLoaded

        'Initialize the Baseline start and end years
        BaselineStartYear = 1920
        BaselineEndYear = 2020
        ThisWorkbook.Worksheets("Dashboard").Range("C14").Value = BaselineStartYear
        ThisWorkbook.Worksheets("Dashboard").Range("C15").Value = BaselineEndYear

        'Close openbook without saving the data copied to the clipboard
        OpenBook.Application.CutCopyMode = False
        OpenBook.Close False
End If
```

[5] https://bgs.sharefile.eu/d-s10e109999f0b4dcc93985483b11ae223

VBA MODULE 3: ESTIMATE CLIFF TOE RECESSION

```
Sub Estimate_Cliff_Toe_Recession()

 Dim NumberOfLocationsLoaded As Integer
 Dim ThisLocation As Integer
 Dim BaselineStartYear As Double
 Dim BaselineEndYear As Double
 Dim ThisBaselineStartYear As Double
 Dim ThisBaselineEndYear As Double
 Dim BaselineRecession As Double
 Dim ThisRecession As Double
 Dim NumberOfProjectedYears As Integer
 Dim nProjectedYear As Integer
 Dim nProjectedCol As Integer
 Dim ThisProjectedYear As Double

 Dim vProjectedYears As Range
 Dim x As Range
 Dim y5th As Range
 Dim y50th As Range
 Dim y95th As Range


 Application.ScreenUpdating = False

 NumberOfLocationsLoaded = ThisWorkbook.Worksheets("Dashboard").Range("C12").Value

'Intialize headers of sheet with Projected recession
 ThisWorkbook.Worksheets("Projected future recession").Cells.Clear
 ThisWorkbook.Worksheets("Projected future recession").Cells(1, 1).Value = ThisWorkbook.Worksheets("Historical
recession").Cells(1, 3).Value 'Copy ID as header
 NumberOfProjectedYears = ThisWorkbook.Worksheets("Dashboard").Cells(9, Columns.Count).End(xlToLeft).Column - 2

'Headers for Projected future recession
 nProjectedCol = 2 'Projected years outputs starts on 2nd column
 For nProjectedYear = 1 To NumberOfProjectedYears
     ThisProjectedYear = ThisWorkbook.Worksheets("Dashboard").Cells(9, nProjectedYear + 2).Value ' Proyected
year value
     ThisWorkbook.Worksheets("Projected future recession").Cells(1, nProjectedCol).Value =
CStr(ThisProjectedYear) & " 5th"
     ThisWorkbook.Worksheets("Projected future recession").Cells(1, nProjectedCol + 1).Value =
CStr(ThisProjectedYear) & " 50th"
     ThisWorkbook.Worksheets("Projected future recession").Cells(1, nProjectedCol + 2).Value =
CStr(ThisProjectedYear) & " 95th"
     nProjectedCol = nProjectedCol + 3
 Next nProjectedYear

'Calculate future recession
 For ThisLocation = 1 To NumberOfLocationsLoaded
     'Tell user which location is been calculated
      ThisWorkbook.Worksheets("Dashboard").Range("C13").Value = ThisLocation
      ThisWorkbook.Worksheets("Projected future recession").Cells(ThisLocation + 1, 1).Value =
ThisWorkbook.Worksheets("Historical recession").Cells(ThisLocation + 1, 3).Value

      'Get This Baseline Start and End Year
       ThisBaselineStartYear = ThisWorkbook.Worksheets("Historical recession").Cells(ThisLocation + 1, 1).Value
       ThisBaselineEndYear = ThisWorkbook.Worksheets("Historical recession").Cells(ThisLocation + 1, 2).Value

      'If This baseline period is different to default/previous then copy the values to Dashboard
       If ThisBaselineStartYear <> ThisWorkbook.Worksheets("Dashboard").Range("C14").Value Then
          ThisWorkbook.Worksheets("Dashboard").Range("C14").Value = ThisBaselineStartYear
       End If

       If ThisBaselineEndYear <> ThisWorkbook.Worksheets("Dashboard").Range("C15").Value Then
          ThisWorkbook.Worksheets("Dashboard").Range("C15").Value = ThisBaselineEndYear
       End If

         'Calculate projections for user selected RCP scenario (stored in Dashboard C8)
         BaselineDurationYears = (ThisBaselineEndYear - ThisBaselineStartYear)
         BaselineEorsionMeterPerYear = ThisWorkbook.Worksheets("Historical recession").Cells(ThisLocation + 1,
8).Value

         SensitivityValue5th =
Module4.LinterpArray(ThisWorkbook.Worksheets(ThisWorkbook.Worksheets("Dashboard").Range("C8").Value).Range("H5:
H516"), ThisWorkbook.Worksheets(ThisWorkbook.Worksheets("Dashboard").Range("C8").Value).Range("I5:I305"),
ThisWorkbook.Worksheets("Dashboard").Range("C9:E9"))
         SensitivityValue50th =
Module4.LinterpArray(ThisWorkbook.Worksheets(ThisWorkbook.Worksheets("Dashboard").Range("C8").Value).Range("H5:
H516"), ThisWorkbook.Worksheets(ThisWorkbook.Worksheets("Dashboard").Range("C8").Value).Range("J5:J305"),
ThisWorkbook.Worksheets("Dashboard").Range("C9:E9"))
         SensitivityValue95th =
Module4.LinterpArray(ThisWorkbook.Worksheets(ThisWorkbook.Worksheets("Dashboard").Range("C8").Value).Range("H5:
H516"), ThisWorkbook.Worksheets(ThisWorkbook.Worksheets("Dashboard").Range("C8").Value).Range("K5:K305"),
ThisWorkbook.Worksheets("Dashboard").Range("C9:E9"))

        nProjectedCol = 2
        For i = 1 To UBound(SensitivityValue5th, 2)
            ThisWorkbook.Worksheets("Projected future recession").Cells(ThisLocation + 1, nProjectedCol).Value
= Round(BaselineDurationYears * BaselineEorsionMeterPerYear * SensitivityValue5th(1, i), 2)
            ThisWorkbook.Worksheets("Projected future recession").Cells(ThisLocation + 1, nProjectedCol +
1).Value = Round(BaselineDurationYears * BaselineEorsionMeterPerYear * SensitivityValue50th(1, i), 2)
```

```
            ThisWorkbook.Worksheets("Projected future recession").Cells(ThisLocation + 1, nProjectedCol +
2).Value = Round(BaselineDurationYears * BaselineEorsionMeterPerYear * SensitivityValue95th(1, i), 2)
            nProjectedCol = nProjectedCol + 3
        Next i
     Next ThisLocation
 'Save calculated values as CSV file
 ThisWorkbook.Worksheets("Projected future recession").Activate
 Module6.SaveSheetAsCSV
 ThisWorkbook.Worksheets("Dashboard").Activate

 Application.ScreenUpdating = True
End Sub
```

VBA MODULE 4: LINEAR INTERPOLATION FUNCTION

```
Option Explicit

Public Function LinterpArray(xColumn As Range, yColumn As Range, xQuery As Range, Optional checkSorted As
Boolean = False) As Variant
' linear interpolation/extrapolation with Arrays
'
' Inputs
' xColumn is the x values of the lookup table in a column. WARNING! xColumn must be in sorted ascending order!
This is only checked if you ask!
' yColumn is the y values of the lookup table in a column. yColumn must have the same number of rows as
xColumn.
' xQuery is the x query points. It may be any rectangular-shaped range.
' checkSorted - Optional argment. The default is false. Set this to true to check of xColumn is sorted. This an
important check that will save in debugging time if you can afford it.
'
' Outputs
' yQuery is the y values interpolate at the xQuery points. yQuery is the same size xQuery.
'
' Notes:
' LinterpArray() really should be used with dynamic/spill arrays or fixed arrays. It is about 100x faster for
interpolating 15000 points in an 18 point lookup table, for example. You can use it with a single cell, but
this is not the recommended way it should be used.
'
' Written by Jason Nicholson
' 1.2 2020-Nov-17 Added functionality to check if xColumn is sorted.
' 1.1 2020-Nov-16 Allowed dealing none numeric data so it only breaks that single cell.
' 1.0 2020-Nov-13

On Error GoTo FuncFail

Dim nRows As Long
nRows = xColumn.Rows.Count
If nRows < 2 Or xColumn.Columns.Count <> 1 Or yColumn.Columns.Count <> 1 Or nRows <> yColumn.Rows.Count Then
    GoTo FuncFail
End If


' Read in the table and query points
Dim xColumnLocal(), yColumnLocal(), xQueryLocal(), yQuery() As Variant
xColumnLocal = xColumn.Value2
Dim i As Long
If checkSorted Then ' Should we check the xColumn is sorted ascending?
    For i = 2 To nRows
        If xColumnLocal(i - 1, 1) >= xColumnLocal(i, 1) Then
            ' xColumn is not sorted ascending
            GoTo FuncFail
        End If
    Next i
End If
yColumnLocal = yColumn.Value2
If xQuery.CountLarge = 1 Then
    ReDim xQueryLocal(1 To 1, 1 To 1)
    xQueryLocal(1, 1) = xQuery.Value2
Else
    xQueryLocal = xQuery.Value2
End If
ReDim yQuery(1 To UBound(xQueryLocal, 1), 1 To UBound(xQueryLocal, 2))

Dim j As Long
Dim iLo, iHi As Variant
For i = 1 To UBound(xQueryLocal, 1) ' Loop over the rows
    For j = 1 To UBound(xQueryLocal, 2) ' Loop over the columns
        If IsNumeric(xQueryLocal(i, j)) Then ' Handle nonnumeric data cleanly
            iLo = Application.Match(xQueryLocal(i, j), xColumnLocal, 1)
            If IsError(iLo) Then  ' xQuery < xmin when Match returns NA, extrapolate from first two entries
                If iLo = CVErr(xlErrNA) And xQueryLocal(i, j) < xColumnLocal(1, 1) Then
                        iLo = 1
                        iHi = 2
                        yQuery(i, j) = yColumnLocal(iLo, 1) + (yColumnLocal(iHi, 1) - yColumnLocal(iLo, 1)) *
(xQueryLocal(i, j) - xColumnLocal(iLo, 1)) / (xColumnLocal(iHi, 1) - xColumnLocal(iLo, 1))
                Else
                    yQuery(i, j) = CVErr(xlErrNA)
                End If
            ElseIf xColumnLocal(iLo, 1) = xQueryLocal(i, j) Then ' xQuery is exact from table
                yQuery(i, j) = yColumnLocal(iLo, 1)
```

```
            ElseIf xQueryLocal(i, j) < xColumnLocal(nRows, 1) Then ' xQuery > xmax, extrapolate from last two
entries
                iHi = iLo + 1
                yQuery(i, j) = yColumnLocal(iLo, 1) + (yColumnLocal(iHi, 1) - yColumnLocal(iLo, 1)) *
(xQueryLocal(i, j) - xColumnLocal(iLo, 1)) / (xColumnLocal(iHi, 1) - xColumnLocal(iLo, 1))
            Else ' xQuery > xmax, extrapolate from last two entries
                iLo = nRows - 1
                iHi = nRows
                yQuery(i, j) = yColumnLocal(iLo, 1) + (yColumnLocal(iHi, 1) - yColumnLocal(iLo, 1)) *
(xQueryLocal(i, j) - xColumnLocal(iLo, 1)) / (xColumnLocal(iHi, 1) - xColumnLocal(iLo, 1))
            End If
        Else
            yQuery(i, j) = CVErr(xlErrNA)
        End If
    Next j
Next i

' Output
LinterpArray = yQuery
Exit Function

FuncFail:
LinterpArray = CVErr(xlErrValue)

END FUNCTION
```

VBA MODULE 5: ESTIMATE CLIFF TOE LOCATION

```
Sub Estimate_Cliff_Toe_Location()

 Dim NumberOfLocationsLoaded As Integer
 Dim ThisLocation As Integer
 Dim BaselineStartYear As Double
 Dim BaselineEndYear As Double
 Dim ThisBaselineStartYear As Double
 Dim ThisBaselineEndYear As Double
 Dim BaselineRecession As Double
 Dim ThisRecession As Double
 Dim NumberOfProjectedYears As Integer
 Dim nProjectedYear As Integer
 Dim nProjectedCol As Integer
 Dim ThisProjectedYear As Double
 Dim vProjectedYears As Range
 Dim x As Range
 Dim y5th As Range
 Dim y50th As Range
 Dim y95th As Range
 Dim dEastStart As Double
 Dim dEastEnd As Double
 Dim dNorthStart As Double
 Dim dNorthEnd As Double
 Dim dBearing As Double
 Dim dLength As Double
 Dim dblPi As Double
 dblPi = WorksheetFunction.Pi()

 Application.ScreenUpdating = False

 NumberOfLocationsLoaded = ThisWorkbook.Worksheets("Dashboard").Range("C12").Value

'Intialize headers of sheet with Projected recession
 ThisWorkbook.Worksheets("Projected future location").Cells.Clear
 ThisWorkbook.Worksheets("Projected future location").Cells(1, 1).Value = ThisWorkbook.Worksheets("Historical
recession").Cells(1, 3).Value 'Copy ID as header
 NumberOfProjectedYears = ThisWorkbook.Worksheets("Dashboard").Cells(9, Columns.Count).End(xlToLeft).Column - 2

'Headers for Projected future recession
 nProjectedCol = 2 'Projected years outputs starts on 2nd column
 For nProjectedYear = 1 To NumberOfProjectedYears
     ThisProjectedYear = ThisWorkbook.Worksheets("Dashboard").Cells(9, nProjectedYear + 2).Value ' Proyected
year value
     ThisWorkbook.Worksheets("Projected future location").Cells(1, nProjectedCol + 0).Value =
CStr(ThisProjectedYear) & " 5th Easting"
     ThisWorkbook.Worksheets("Projected future location").Cells(1, nProjectedCol + 1).Value =
CStr(ThisProjectedYear) & " 5th Northing"
     ThisWorkbook.Worksheets("Projected future location").Cells(1, nProjectedCol + 2).Value =
CStr(ThisProjectedYear) & " 50th Easting"
     ThisWorkbook.Worksheets("Projected future location").Cells(1, nProjectedCol + 3).Value =
CStr(ThisProjectedYear) & " 50th Northing"
     ThisWorkbook.Worksheets("Projected future location").Cells(1, nProjectedCol + 4).Value =
CStr(ThisProjectedYear) & " 95th Easting"
     ThisWorkbook.Worksheets("Projected future location").Cells(1, nProjectedCol + 5).Value =
CStr(ThisProjectedYear) & " 95th Northing"
     nProjectedCol = nProjectedCol + 6
 Next nProjectedYear

'Calculate future location
 For ThisLocation = 1 To NumberOfLocationsLoaded
     'Tell user which location is been calculated
      ThisWorkbook.Worksheets("Dashboard").Range("C13").Value = ThisLocation
```

```
      ThisWorkbook.Worksheets("Projected future location").Cells(ThisLocation + 1, 1).Value =
ThisWorkbook.Worksheets("Historical recession").Cells(ThisLocation + 1, 3).Value

      'Get Start and End of profile at this location
       dEastStart = ThisWorkbook.Worksheets("Historical recession").Cells(ThisLocation + 1, 4).Value
       dNorthStart = ThisWorkbook.Worksheets("Historical recession").Cells(ThisLocation + 1, 5).Value
       dEastEnd = ThisWorkbook.Worksheets("Historical recession").Cells(ThisLocation + 1, 6).Value
       dNorthEnd = ThisWorkbook.Worksheets("Historical recession").Cells(ThisLocation + 1, 7).Value
       'dBearing = Abs(Atn((dEastEnd - dEastStart) / (dNorthEnd - dNorthStart)))   ' bearing units are in
radians
       dBearing = Atn((dEastEnd - dEastStart) / (dNorthEnd - dNorthStart))   ' bearing units are in radians
       If dBearing < 0 Then
            dBearing = dblPi + dBearing
       End If



      'Calculate location for each future recession value
      nProjectedCol = 2
      For i = 1 To NumberOfProjectedYears * 3
          ThisRecession = ThisWorkbook.Worksheets("Projected future recession").Cells(ThisLocation + 1, i +
1).Value
          ThisWorkbook.Worksheets("Projected future location").Cells(ThisLocation + 1, nProjectedCol + 0).Value
= dEastStart + ThisRecession * Sin(dBearing)
          ThisWorkbook.Worksheets("Projected future location").Cells(ThisLocation + 1, nProjectedCol + 1).Value
= dNorthStart + ThisRecession * Cos(dBearing)
          nProjectedCol = nProjectedCol + 2
       Next i
Next ThisLocation
 'Save calculated values as CSV file
 ThisWorkbook.Worksheets("Projected future location").Activate
 Module6.SaveSheetAsCSV
 ThisWorkbook.Worksheets("Dashboard").Activate

 Application.ScreenUpdating = True
END SUB
```

VBA MODULE 6: SAVE FILES AS CSV

```
'VBA routine to save the currently active worksheet to a CSV file
'without losing focus AND retaining Unicode characters. This routine
'is extremely fast (instantaneous) and produces no flicker:
Sub SaveSheetAsCSV()
    Dim i&, j&, iMax&, jMax&, chk$, listsep$, s$, v
    Const Q = """", QQ = Q & Q
    listsep = Application.International(xlListSeparator)
    chk = Q & "," & listsep & "," & vbLf
    With ActiveSheet
        v = .UsedRange.Value
        iMax = UBound(v, 1): jMax = UBound(v, 2)
        For i = 1 To iMax
            For j = 1 To jMax
                If Not IsError(v(i, j)) Then s = v(i, j) Else s = .Cells(i, j).Text
                If AnyIn(s, Q, listsep, vbLf) Then s = Replace(s, Q, QQ): s = Q & s & Q
                BuildString s & listsep
            Next
            If i < iMax Then BuildString vbCrLf, -1
        Next
        s = .Parent.Path & Application.PathSeparator & Left(.Parent.Name, InStrRev(.Parent.Name, ".")) & .Name
& ".csv"
        SaveStringAsTextFile BuildString(Done:=True, Adjust:=-1), s
    End With
End Sub

Function BuildString(Optional txt$, Optional Adjust&, Optional Done As Boolean, Optional Size = "20e6")
    Static p&, s$
    If Len(p) Then p = p + Adjust
    If Done Then BuildString = Left(s, p - 1): p = 0: s = "": Exit Function
    If p = 0 Then: p = 1: s = Space(Size)
    Mid$(s, p, Len(txt)) = txt
    p = p + Len(txt)
End Function

Function AnyIn(s$, ParamArray checks()) As Boolean
    Dim e
    For Each e In checks
        If InStrB(s, e) Then AnyIn = True: Exit Function
    Next
End Function

Function SaveStringAsTextFile$(s$, fName$)
    Const adSaveCreateOverWrite = 2
    With CreateObject("ADODB.Stream")
        .Charset = "utf-8"
        .Open
        .WriteText s
        .SetEOS
        .SaveToFile fName, adSaveCreateOverWrite
        .Close
    End With
End Function
```

Appendix 2 Historical cliff toe recession data

FROM EAST RIDING OF YORKSHIRE COASTAL EXPLORER

Start Year	End Year	ID	Easting	Northing	Easting	Northing	Recession m/y
1852	2015	8	517388	464784.5	518274.9	464490	-0.50
1852	2015	9	517240.5	464299.8	518182.3	464055.9	-0.35
1852	2015	11	517042.2	463250.1	518033.5	463232	-0.24
1852	2015	12	517007.1	462778.6	518012.3	462732.5	-0.33
1852	2015	13	516976.4	462277.8	517991.1	462232.9	-0.52
1852	2015	14	516940.7	461771.5	517969.9	461733.4	-0.82
1852	2015	15	516922.3	461264.3	517948.7	461233.8	-0.99
1852	2015	16	516925.5	460803.7	517927.4	460734.3	-1.05
1852	2015	17	516949.5	460329.9	517906.2	460234.7	-1.07
1852	2015	18	517040.5	459663.8	518000.8	459804.7	-1.12
1852	2015	19	517071.8	459175.1	518078.9	459310.9	-1.46
1852	2015	20	517167.8	458515.7	518157.1	458817	-1.48
1852	2015	21	517252.9	458142.4	518213.5	458397.7	-1.68
1852	2015	22	517382.5	457645.8	518355.7	457994.5	-1.71
1852	2015	23	517530.1	457169.4	518519.9	457522.2	-1.58
1852	2015	24	517670.6	456694.1	518684.1	457049.9	-1.48
1852	2015	25	517810.1	456220	518848.2	456577.7	-1.53
1852	2015	26	517983.2	455751.8	519012.4	456105.4	-1.47
1852	2015	27	518156.6	455235.7	519176.6	455633.1	-1.27
1852	2015	28	518316.4	454802.1	519340.8	455160.8	-1.19
1852	2015	29	518487.8	454320	519504.9	454688.6	-1.11
1852	2015	30	518646.5	453852.6	519669.1	454216.3	-1.01
1852	2015	31	518799.9	453387.6	519833.3	453744	-1.04
1852	2015	32	518971.1	452928.7	519997.5	453271.7	-1.00
1852	2015	33	519134.2	452443.3	520161.6	452799.4	-1.01
1852	2015	34	519298.8	451968.3	520325.8	452327.2	-1.07
1852	2015	35	519475.6	451521.2	520488	451854.9	-1.11
1852	2015	36	519663.1	451049.5	520654.1	451382.6	-1.02
1852	2015	37	519846.9	450576	520818.3	450910.3	-1.05
1852	2015	38	519994.1	450111.4	520982.5	450438	-0.91
1852	2015	39	520177.8	449673.1	521146.7	449965.8	-0.77
1852	2015	40	520410.8	449267.5	521310.8	449493.5	-0.57
1852	2015	41	520639.8	448794	521475	449021.2	-0.49

Contains future coast data sourced https://coastalmonitoring.org/ccoresources/futurecoast/ (DEFRA 2002, Environment Agency 2018) released under OGL.

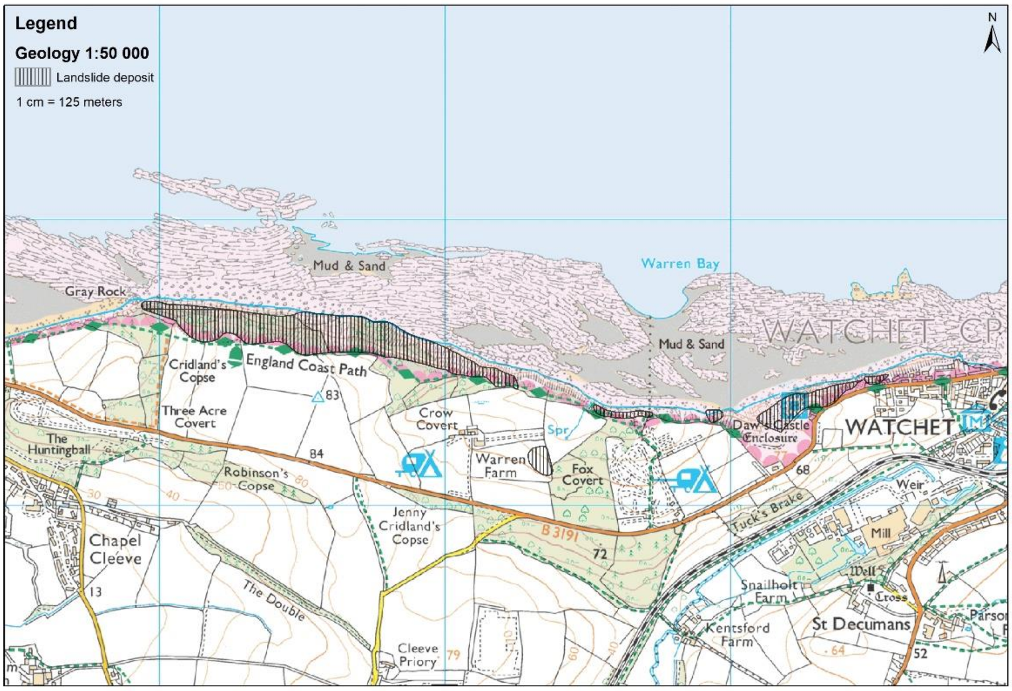
FROM FUTURECOAST DATA BASE

Reg	Start	End	ID	XStart	YStart	XEnd	YEnd	Recession m/y
9	1854	2001	853	517021.3	463027.8	518418.2	462986.3	-0.1
9	1892	2001	854	517199.8	458667.4	518624.8	458762.5	0.47
17	1889	2000	933	651452.0	315069.0	652852.3	315606.8	-0.03
17	1889	2000	934	652346.3	312603.1	653736.9	313165.5	-1.24
17	1888	2000	935	652997.2	309756.2	654494.1	309853.0	3.54
17	1906	2000	936	653013.1	306919.8	654512.8	306891.0	0.14
23	1880	1999	1013	603522.9	193850.8	604995.1	193563.6	-0.06
23	1881	2000	1014	601181.3	192012.0	602441.3	191198.1	-0.2
23	1880	2001	1015	596574.9	187307.7	597566.1	186181.8	-0.54
28	1878	2002	995	583416.9	109920.6	584267.6	108685.2	-0.11
28	1879	2001	1006	581628.3	109312.1	581933.2	107843.4	0.31
28	1878	2001	1018	579776.2	108878.2	579941.8	107387.3	0.02
28	1878	2001	1029	577262.7	108465.4	577880.9	107098.7	0.08
33	1867	2001	676	453863.9	76407.4	454728.9	75182.0	-0.09
33	1867	2000	677	456970.1	77624.5	457505.7	76223.4	-0.02
33	1866	2000	678	458324.7	78963.3	459824.4	78996.0	-0.06
33	1866	1999	679	458420.0	80365.6	459875.2	80729.5	-0.19
39	1890	1999	767	318367.6	88298.0	318348.2	86798.1	0.11
39	1889	1999	769	315256.1	87906.4	315759.3	86493.3	-0.01
39	1890	2000	770	312453.6	87203.2	313105.1	85852.0	0.05
41	1889	1999	806	286655.6	48488.2	287435.5	47206.9	0.1
41	1889	2000	807	285396.1	47937.8	286182.3	46660.4	-0.3
50	1907	2000	247	195731.9	79717.0	195708.4	81216.8	0.04
50	1907	2000	248	198128.0	81101.3	197288.8	82344.6	0.08
50	1888	2000	249	199618.1	80737.2	199133.5	82156.8	-0.02
50	1907	2000	250	203089.5	82075.0	201929.2	83025.6	-0.07
68	1890	2000	464	257079.1	278167.0	255741.8	278846.3	-0.14
68	1889	2000	466	258018.9	280453.0	256544.6	280176.5	-0.2
68	1889	2000	467	258425.3	282034.1	256964.2	282373.3	-0.04
75	1889	2000	530	248382.8	392283.9	249376.7	393407.3	-0.07
75	1889	2000	532	247232.9	393204.1	247328.4	394701.1	0.02
75	1978	2000	533	245006.7	393643.8	246230.0	394511.9	0.05
75	1890	2000	534	242686.8	394145.5	243948.5	394956.7	-0.01

Appendix 3 Notes on geoscientific correctness

We suggest that several geological descriptions, considerations and references require amendment.

- In Section 3.1, the Mercia Mudstone is described as “a relatively homogenous and iron-rich sedimentary rock”. This is a relatively poor description of the rocks at this location and where interbedded dolomitic mudstones and dolostones with common gypsum occur. There is also potentially 2-3m of Head deposited on top of the Mercia Mudstone. This deposit was omitted from the published geological map as it was ubiquitous.
- The Shoreline Management Plan (SMP2) for this area states that “within Blue Anchor Bay, the width of the nearshore zone is increasing with the 5m bathymetric contour moving seaward by about 500 m since 1982 … suggesting that this is an area of sediment accumulation, probably linked to the Bridgwater Bay mud belt; this is causing shallowing of the seabed, particularly in the eastern part of the bay, which in turn is likely to result in reduced wave action at the shoreline…”. This needs to be reflected in the text.
- Sections 4.1 and 4.2 describe the assessment area that comprises cliffs from Blue Anchor to Watchet in Somerset, South England. Coastal land sliding in this area has been underestimated in the User Guide. There are several active landslides along this section of coast in addition to that described (Figure 12). These include an active landslide at Cleeve Hill near Watchet that is monitored by Somerset Council and impacts a road. This landslide may also affect a future residential development currently in the planning stage. This omission has implications for the interpretation in Section 4.2 where “data from the western side of the Warren Farm CBU … were rejected because the large landslide in this area … made estimates of toe recession rates unreliable”.
- In Section 5, it is stated that this study excludes influences on recession such as land sliding but in Section 2, data are rejected based on the presence of a landslide. This rejection has not been extended to the other landslides that flank much of this 4 km coastal section (Figure 12).

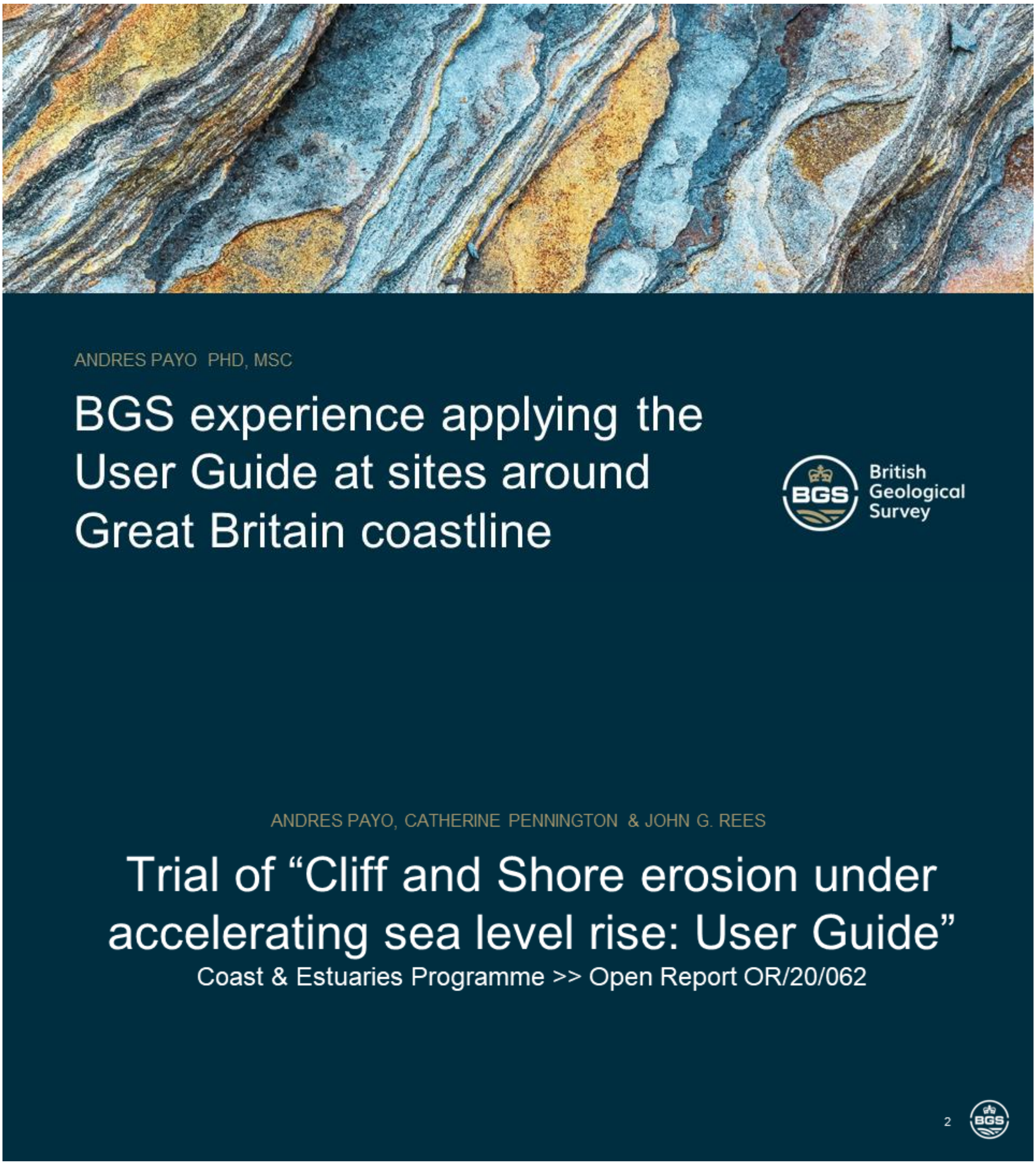


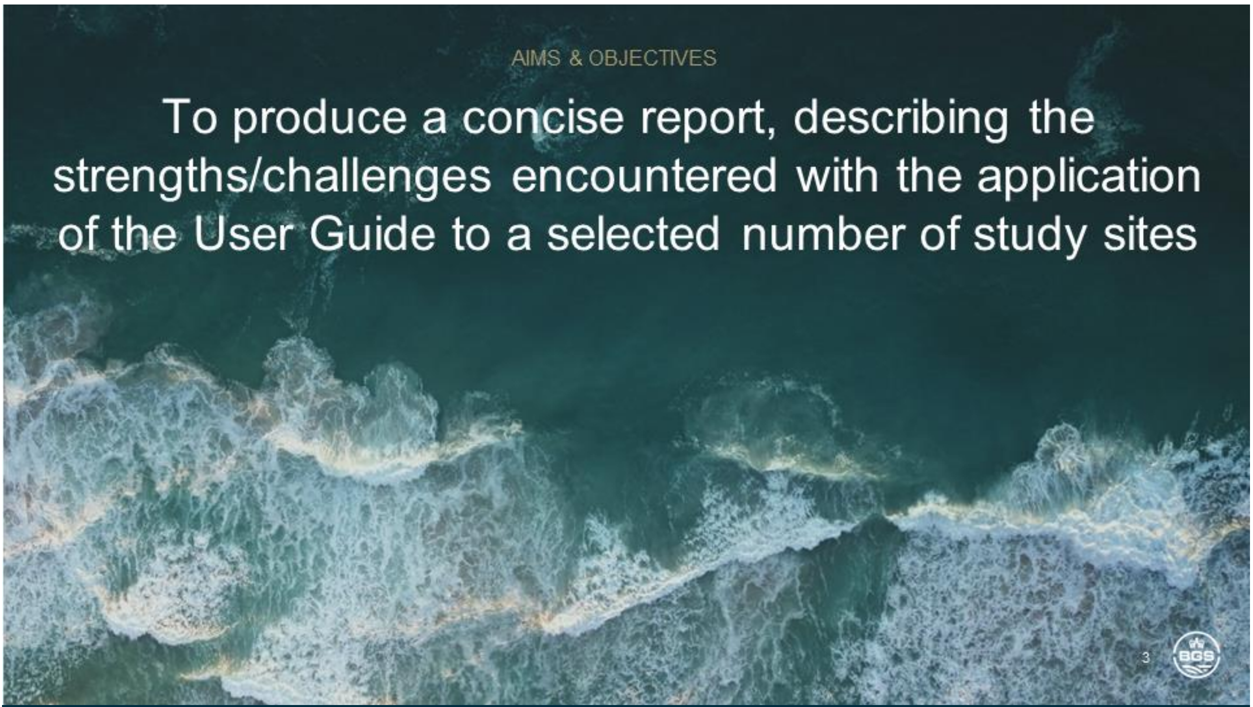
- Figure 12.- Landslide deposits near Watchet, Somerset, South England.

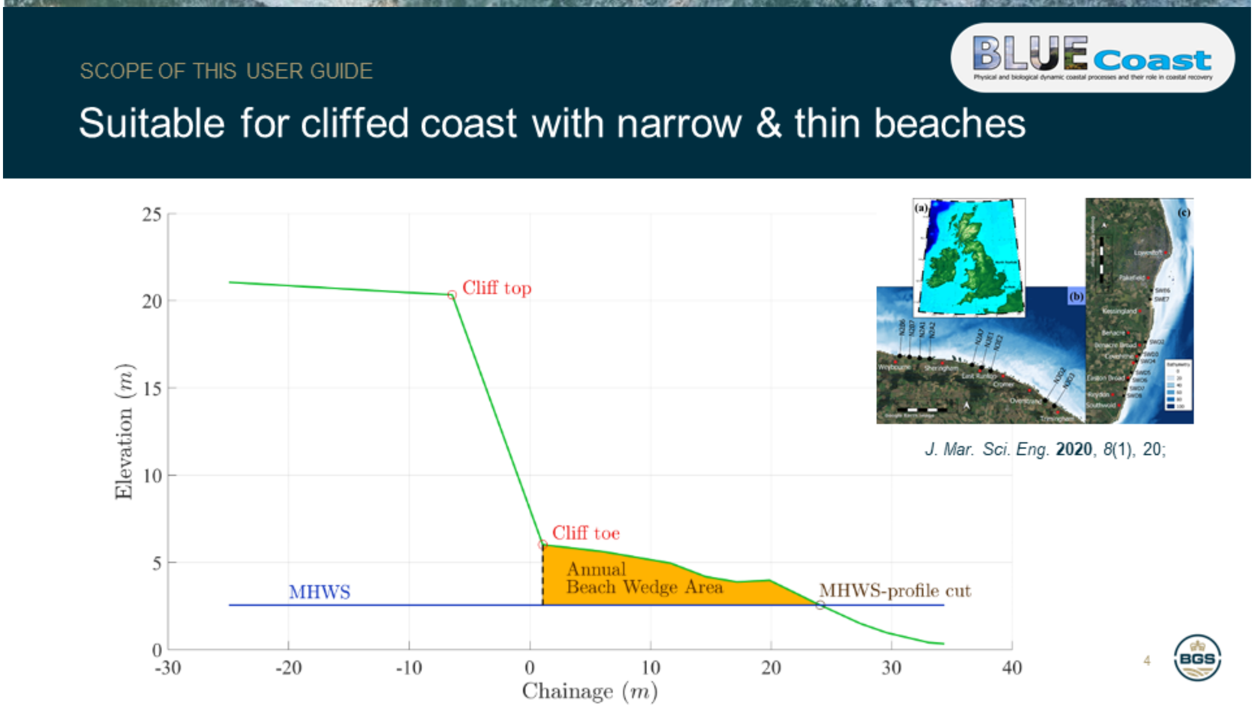
- "A significant trend was identified in the West Watchet CBU, such that recession was greater in the west (lower transect numbers) than in the east (higher transect numbers); this trend was accounted for by adopting different recession rates for each end". This may be due to the fault and its effect on the presence of the platform.
- Cliff height has an impact on landslide type and formation. The cliffs in the Blue Anchor CBU are lower than elsewhere. This has not been accounted for in its differences to the rest of the CBUs.
- In Section 5.2 data has been rejected based on the presence of a landslide. This rejection has not been extended to the other landslides that flank much of this 4 km coastal section.
- Section 5.2.1, the User Guide states that "It is not yet possible to directly relate a measurable parameter of rock strength to erosive forces; a problem compounded by the highly variable nature of cliff geology." Other work such as the SWEEP project[6] (p15) use other datasets as a proxy for geological strength. It may be useful to consider testing this against the method used in the User Guide where past rates of change are used to estimate geological strength.

[6] https://sweep.ac.uk/wp-content/uploads/WP2_CCMA_Report_V2.pdf

Appendix 4 Slides for the technical workshop

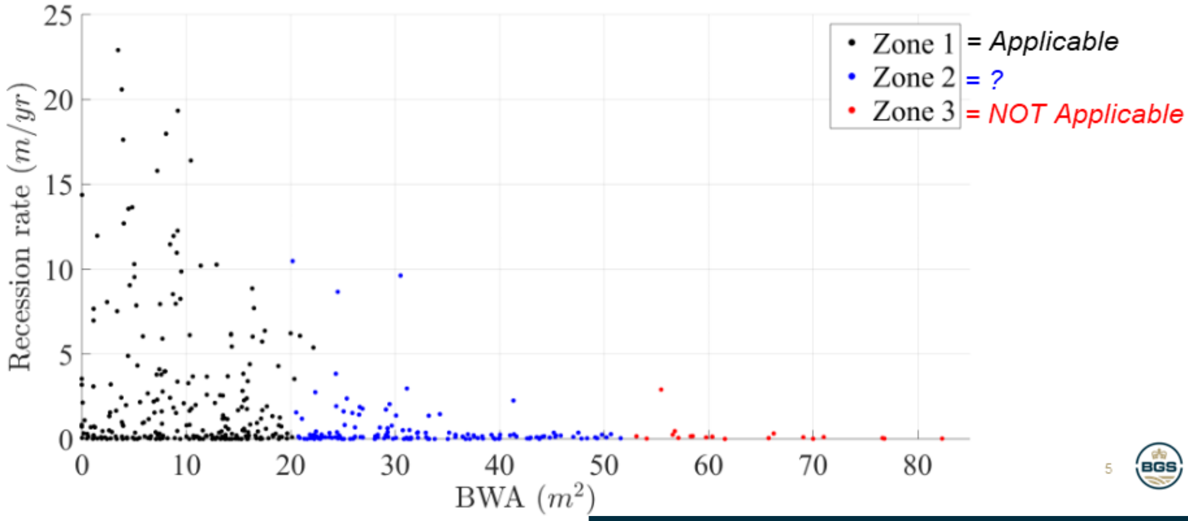



AIMS & OBJECTIVES
To produce a concise report, describing the strengths/challenges encountered with the application of the User Guide to a selected number of study sites
3


SCOPE OF THIS USER GUIDE
Suitable for cliffed coast with narrow & thin beaches
BLUE Coast
Cliff top
Cliff toe
Annual Beach Wedge Area
MHWS
MHWS-profile cut
Elevation (m)
Chainage (m)
25
20
15
10
5
0
-30
-20
-10
0
10
20
30
40
(a)
(b)
(c)
J. Mar. Sci. Eng. 2020, 8(1), 20;
4

SCOPE OF THIS USER GUIDE

Suitable for cliffed coast with narrow & thin beaches



5

Site selection approach

Rationale

- User guide has divided the GB coastline into 82 regions
- 11 regions marked as “High sensitivity”
- 55 marked as “normal”
- Ratio 1 (High sensitivity) to 5 (normal)
- 10 sites 2 + 8 from High/Normal regions
- Selected sites indicated by the arrows
- 22 points from Future coast & 33 Coastal Explorer
- Not all points selected from Futurecoast fulfils user guide requirements:
    - Beach absent
    - Cliff present

6

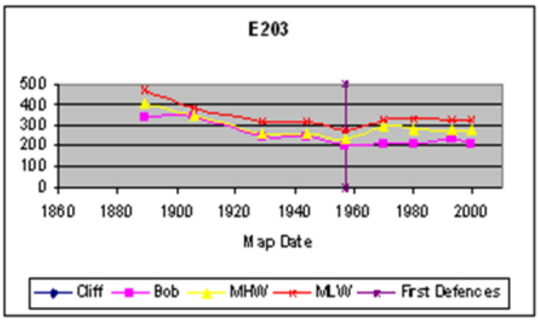
APPROACH

Data needed

Name	Units	Use case
Start year of the baseline time period	Gregorian calendar year	Always needed
End year of the baseline time period (year 0)	Gregorian calendar year	Always needed
Average cliff toe recession rate for time period between baseline start and end years	Metres per year	Always needed
Geographical location of cliff toe location at baseline end year	Not specified in the User Guide. We have used Easting and Northing coordinates on British National Grid (EPSG 27700) coordinate reference system.	Only needed if user wants to estimate cliff toe location at different times after year 0
Likely direction along which cliff toe will retreat	Not specified in the User Guide. We have defined an additional point that represents the seaward end of an imaginary line segment, which start at the cliff toe location at year 0 that is aligned 'normal' to the coastline	Only needed if user wants to estimate cliff toe location at different times after year 0.

APPROACH

We have used two data sources of historical recession



FUTURE COAST *BACK of the BEACH (BoB) time series*

Erosion rate for baseline period calculated as the slope of the regression line fitted to all BoB points

ble

EAST RIDING
OF YORKSHIRE COUNCIL

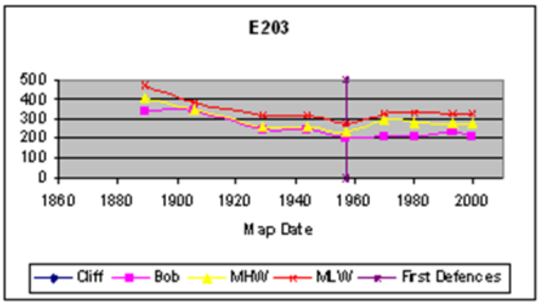
Cliff erosion data				Max cliff loss between pr	
Cliff lost at profile over last year (m)		Erosion rate m/yr		Height of cliff m OD	Maximum recorded individual loss (m)
Nov 2014 to April 2015	April 2015 to Sept 2015	Historic 1852 to 1989	Recent 1989 to Sept 2015		
0.00	0.00		-	25.7	5.24
0.00	0.00		-	16.6	1.81
0.00	0.00	0.59	0.00	12.2	3.60
0.00	0.00	0.41	0.03	11.2	2.47
0.00	0.00	0.32	0.12	8.0	1.91
0.00	0.00	0.20	0.42	8.1	6.40
0.00	0.00	0.25	0.77	5.1	11.81

COASTAL EXPLORER CLIFF EROSION MONITORING

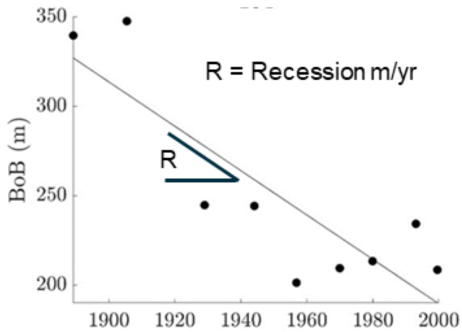
Erosion rate for period 1852-2015 calculated as the ratio of the sum of recession distances for the historic and recent period and the 163 years baseline time span

APPROACH

Example of historical recession rate extracted from FUTURECoast BoB time series



Original FutureCoast BoB time series



Extracted BoB points and fitted slope

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APPROACH

Historical recession from both DDBB were saved it as excel file

Baseline Start Year	Baseline End Year	ID	Easting	Northing	Easting	Northing	Recession m/y
1852	2015	8	517388	464784.5	518274.9	464490	-0.50
1852	2015	9	517240.5	464299.8	518182.3	464055.9	-0.35
1852	2015	11	517042.2	463250.1	518033.5	463232	-0.24
1852	2015	12	517007.1	462778.6	518012.3	462732.5	-0.33
1852	2015	13	516976.4	462277.8	517991.1	462232.9	-0.52

Data | Historical recession

Each row represents one point within the same region
(example from Coastal Explorer extracted data)

10

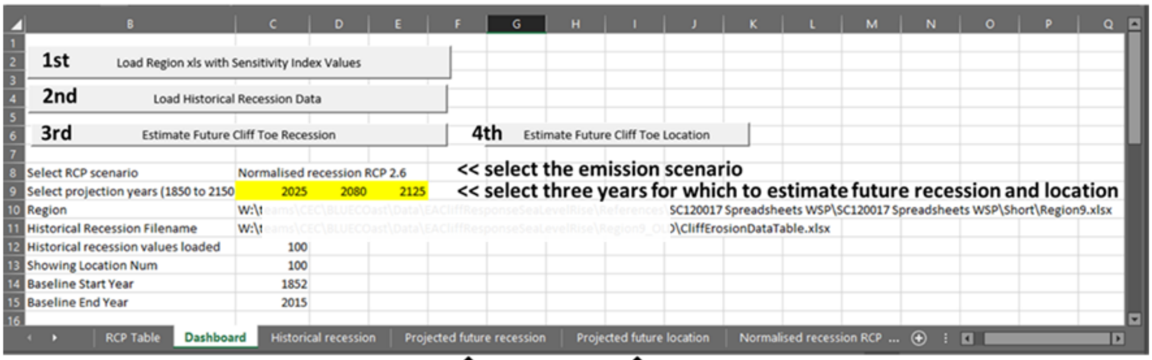
Region boundaries

- We used GIS software to plot study points and region's approximate spatial extent
- Yellow circles represent points from coastal explorer DB interpreted as within Region 9
- Unsure about region attribution for points near region boundaries

APPROACH

Three (four) step calculation approach

GetRegionRecessionEstimates.xlsm



Outputs are the produced on separate spread-sheets and also exported as CSV files

Re-baseline index values

- User need to re-baseline the sensitivity index if baseline period is different to default 1920-2020
- User guide indicates that of baseline periods different to default the re-baseline sensitivity index is -1.0 and 0.0 for the baseline start year and baseline end year respectively
- How the sensitivity index should been corrected is not explicitly stated in the user guide.
- We have interpreted that this correction is simply a linear correction.

Default Baseline 1920-2020 RCP 2.6 Region 9

Year	5th Percentile	50th Percentile	95th Percentile
1850	-1.527	-1.523	-1.514
1851	-1.521	-1.516	-1.508
1852	**-1.514**	**-1.51**	**-1.501**
1853	-1.507	-1.502	-1.494
1854	-1.5	-1.495	-1.487

New Baseline 1852-2015 RCP 2.6 Region 9

Year	5th Percentile	50th Percentile	95th Percentile
1850	-1.007	-1.008	-1.008
1851	-1.004	-1.003	-1.004
1852	**-1.000**	**-1.000**	**-1.000**
1853	-0.996	-0.995	-0.996
1854	-0.992	-0.990	-0.991

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RESULTS: RELATIVE INCREASE OF CLIFF TOE RECESSION RATE

Future coast

Reg.	ID	Hist. Rate m/y	2030 5th	2030 50th	2030 95th	2080 5th	2080 50th	2080 95th	2125 5th	2125 50th	2125 95th
9	853	-0.1	1.5	1.6	1.8	1.8	2.1	2.4	2.1	2.4	3.0
17	933	-0.03	1.3	1.4	1.6	1.6	1.8	2.2	1.8	2.2	2.7
17	934	-1.24	1.3	1.4	1.6	1.6	1.8	2.1	1.8	2.2	2.7
23	1013	-0.06	1.4	1.5	1.6	1.7	1.9	2.3	1.9	2.2	2.7
23	1014	-0.2	1.4	1.5	1.7	1.7	1.9	2.3	1.9	2.2	2.7
23	1015	-0.54	1.4	1.5	1.7	1.7	2.0	2.3	1.9	2.3	2.8
28	995	-0.11	1.4	1.5	1.6	1.7	1.9	2.2	1.9	2.2	2.6
33	676	-0.09	1.4	1.5	1.7	1.7	2.0	2.3	1.9	2.3	2.8
33	677	-0.02	1.4	1.5	1.7	1.7	2.0	2.3	1.9	2.3	2.8
33	678	-0.06	1.4	1.5	1.7	1.7	2.0	2.3	1.9	2.3	2.8
33	679	-0.19	1.4	1.5	1.7	1.7	1.9	2.3	1.9	2.3	2.8
39	769	-0.01	1.3	1.4	1.5	1.6	1.8	2.1	1.8	2.1	2.6
41	807	-0.3	1.3	1.4	1.5	1.5	1.7	2.0	1.7	2.0	2.4
50	249	-0.02	1.3	1.4	1.4	1.5	1.6	1.8	1.6	1.9	2.2
50	250	-0.07	1.2	1.3	1.3	1.4	1.5	1.7	1.5	1.7	2.0
68	464	-0.14	1.5	1.5	1.6	1.7	1.9	2.3	1.9	2.3	3.0
68	466	-0.2	1.5	1.5	1.7	1.7	1.9	2.3	1.9	2.3	3.0
68	467	-0.04	1.5	1.5	1.7	1.7	1.9	2.3	1.9	2.3	3.0
75	530	-0.07	1.7	1.8	2.1	2.2	2.6	3.3	2.6	3.3	4.6
75	534	-0.01	1.7	1.8	2.0	2.2	2.6	3.3	2.6	3.3	4.6

RESULTS: CUMULATIVE CLIFF TOE RECESSION DISTANCE

Futurecoast

Region	ID	2030 5th	2030 50th	2030 95th	2080 5th	2080 50th	2080 95th	2125 5th	2125 50th	2125 95th
9	853	-4	-5	-5	-14	-16	-19	-26	-30	-37
17	933	-1	-1	-1	-4	-4	-5	-7	-8	-10
17	934	-49	-53	-58	-159	-181	-213	-280	-334	-416
23	1013	-3	-3	-3	-8	-9	-11	-14	-17	-21
23	1014	-8	-9	-10	-27	-31	-36	-47	-56	-69
23	1015	-22	-24	-26	-73	-83	-98	-128	-152	-187
28	995	-4	-5	-5	-14	-16	-18	-25	-29	-35
33	676	-4	-4	-4	-12	-14	-17	-21	-25	-32
33	677	-1	-1	-1	-3	-3	-4	-5	-6	-7
33	678	-3	-3	-3	-8	-9	-11	-14	-17	-21
33	679	-8	-9	-10	-26	-30	-35	-46	-54	-67
39	769	0	0	0	-1	-1	-2	-2	-3	-3
41	807	-12	-13	-14	-37	-41	-48	-64	-74	-90
50	249	-1	-1	-1	-2	-3	-3	-4	-5	-6
50	250	-3	-3	-3	-8	-8	-9	-13	-15	-17
68	464	-6	-6	-7	-19	-22	-26	-34	-40	-52
68	466	-9	-9	-10	-27	-31	-37	-48	-58	-75
68	467	-2	-2	-2	-5	-6	-7	-10	-12	-15
75	530	-4	-4	-4	-12	-15	-19	-23	-29	-41
75	534	-1	-1	-1	-2	-2	-3	-3	-4	-6

RESULTS

Maximum erosion distance at profile ref 934 FutureCoast

- Futurecoast erosion line
- Beach present
- Non-cliffed coast
- Method **NOT** applicable

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RESULTS

Minimum erosion distance at profile ref 769 FutureCoast

- Near Sidmouth
- Very narrow beach
- Cliff coast
- Method **IS** applicable

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RESULTS

East Riding of Yorkshire from Coastal Explorer

- Excellent historical database
- Narrow beach
- Cliff coast

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RESULTS ARE VERY SENSITIVE TO HISTORICAL RECESSION DATA USED

FUTURECOAST VS COASTAL EXPLORER RESULTS

- Future coast results along the magenta erosion line
- Smaller historical recession rates from FutureCoast results in smaller future cliff toe retreats

RESULTS

How user knows if cliff is high enough to be confident that erosion and not inundation will dominate future coastal change?

Strengths

- Easy to use.
- Data required is available around GB (i.e. FutureCoast, Coastal Regional Monitoring program).
- Requires only basic geomorphological knowledge.

Challenges

- Boundaries between regions unclear
- Re-baseline calculations is key and need to be explicitly explained
- Define minimum cliff height to ensure that erosion and not inundation is the main driver for the simulation period

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British Geological Survey

ANDRES PAYO, CATHERINE PENNINGTON & JOHN G. REES

Review of "Cliff and Shore erosion under accelerating sea level rise: User Guide"

Coast & Estuaries Programme >> Open Report OR/20/062

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ANDRES PAYO PHD, MSC

BGS experience applying the User Guide at sites around Great Britain coastline

British Geological Survey

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: https://envirolib.apps.nerc.ac.uk/olibcgi.

1. WSP. *Cliff and shore erosion under accelerating sea level rise*; EA Ref: SC120017; 2020; p 40.
2. López, P.M.; Payo, A.; Ellis, M.A.; Criado-Aldeanueva, F.; Jenkins, G.O. A Method to Extract Measurable Indicators of Coastal Cliff Erosion from Topographical Cliff and Beach Profiles: Application to North Norfolk and Suffolk, East England, UK. *Journal of Marine Science and Engineering* **2020**, *8*, 20, doi:https://doi.org/10.3390/jmse8010020.
3. Burgess, K.; Jay, H.; Hosking, A.; Pinto, F.T. Futurecoast: Predicting the future coastal evolution of England and Wales. *Journal of Coastal Conservation* **2004**, *10*, 65-71, doi:10.1652/1400-0350(2004)010[0065:FPTFCE]2.0.CO;2.