North Tyneside Council

Working in partnership with CAPITA

Hartley Cove to the River Tyne Coastal Strategy

Technical Report 3:
Coastal Processes

August 2016

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Quality Management

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Abbreviations

EA	Environment Agency
EH	English Heritage
DCLG	Department of Communities and Local Government
HRA	Habitat Regulations Assessment
MMO	Marine Management Organisation
MU	Management Unit
NE	Natural England
NTC	North Tyneside Council
ODPM	Office of the Deputy Prime Minister
PRoW	Public Rights of Way
SAC	Special Area of Conservation
SAM	Scheduled Ancient Monument
SEA	Strategic Environmental Assessment
SMP	Shoreline Management Plan
SPA	Special Protection Area
SSSI	Sites of Special Scientific Interest

1. Structure of Technical Reports

1.1.1 The Coastal Strategy developed for the North Tyneside coastline, between Hartley Cove and the River Tyne, sets out the Council's defence management priorities for the coast.

1.1.2 The Strategy is presented as a series of reports, each dealing with a separate component of the plan along with a number of supporting Appendices

Technical Report No.	Title
1	Executive Summary
2	Background
3	Coastal Processes
4	Existing Defences and Historical Expenditure
5	Strategic Environmental Assessment - Environmental Report
6	Options and Economic Assessment
7	Monitoring
8	Risk Assessments
9	Public Consultation and Stakeholder Involvement
10	Glossary
Appendices	**Title**
Appendix A	Habitat Regulations Assessment
Appendix B	Water Framework Directive Assessment
Appendix C	Non-Technical Summary for the Strategic Environmental Assessment

Technical Report 3: Coastal Processes

1.1.3 This technical report provides information on:

- Coastal Evolution and Sediment Transport
  - Geology and geomorphology
  - Historical coastline evolution
  - Sediment transport modelling
  - Future coastline evolution
- Wave levels and wave climate.
- Joint probability of waves and water levels.
- Wave conditions inside the main Tyne Piers.
- Wave conditions in Cullercoats Bay.

2. Coastal Evolution & Sediment Transport

2.1 General Setting

2.1.1 The study area covers the coastline between Hartley Cove in the north and the River Tyne in the south, a length of approximately 11km. The coastline is made up of rocky headlands interspersed with bays. The majority is defended, mainly with concrete seawalls, and where not defended consists of rock or soft cliffs. The foreshore consists of rock platforms and long sandy beaches.

2.2 Summary of Previous Strategy Coastline Evolution and Sediment Transport Report

2.2.1 The previous strategy report provided erosion rates for sections of the coastline based on those derived in the first round of Shoreline Management Plans (SMPs). Table 2.1 from the previous strategy is reproduced as Table 2-1 below.

Table 2-1 Historical rates of coastline change (reproduced from previous strategy)

Location	Mean rate of change (m/yr) Cliff Line	Mean rate of change (m/yr) Mean High Water Line	Mean rate of change (m/yr) Mean Low Water Line
North of St. Mary's Island (approx. At administrative boundary for North Tyneside)	-0.3	-0.3	0.3
Golf Course	0	0	0
Whitley Bay	0	0	0
Southern end of Whitley Bay	0	-0.2	-0.4
Whitley Bay Headland	0	0.7	0
Northern end of Long Sands Bay	0	-0.2	-0.5
Long Sands Bay Headland	0	0.3	-0.8
Adjacent to North Pier	0	0	0

+ve denotes accretion, -ve denotes erosion

2.2.2 The previous strategy also carried out an analysis of high and low water line movement based on a comparison of OS maps surveyed in 1955 and 1999 and cliff recession rates based on a comparison of the 1955 maps with aerial photographs taken in 1999. No change was found in the high and low water lines between the 1955 and 1999 lines as it seems the OS maps had not been updated. Cliff recession analysis concentrated on Whitley Bay, as a representative section for the coastline. Results showed a recession rate of around 0.3m/yr with an error of +/- 0.1m/yr.

2.2.3 Cliff recession rates for Whitley Bay were used to derive recession rates for the entire coastline, with modifications made for geology, exposure and defences according to a methodology set out in the strategy. The model also took into account the predicted effects of climate change and sea level rise. Results for the 50%ile (i.e. mean likelihood) are reproduced in Table 2-2 below.

Table 2-2 Predicted erosion rates (reproduced from previous strategy)

Years from now (2007 baseline)	Total erosion distance (m) based on historical rate of 0.15m/yr	Total erosion distance (m) based on historical rate of 0.3m/yr
10	2	3
20	4	9
30	8	17
40	14	27
50	20	40
60	28	56
70	37	74
80	48	95
90	59	119
100	72	145

2.2.4 The strategy also considered sediment movement for the coastline and whether sediment modelling would be a worthwhile exercise. The strategy concluded that sediment movement was very low alongshore and from north to south. Due to the nature of the coastline, i.e. rocky headlands between which concave bays have formed, sediment movement appears to remain within the bays, with some drawdown during storm events, which subsequently recover in calmer periods. Additionally, due to the length of Tynemouth North Pier, this effectively limits the quantity of sediment that is able to enter the mouth of the Tyne from the north.

2.2.5 The previous strategy report concluded by producing a series of maps showing the predicted shoreline position, at a series of 10 yearly increments over 100 years, using the projected erosion rates previously derived from the recession model. These were plotted for the Do Nothing scenario (now known as No Active Intervention) and the Hold the Line scenario, which assumed that all current defences would be maintained and upgraded as necessary and that no new defences would be constructed on the undefended lengths of coastline.

2.3 Methodology

2.3.1 Two approaches have been taken to assess changes in geomorphology since the previous strategy assessment in 2007, as follows:

- Review of OS mapping and aerial photography – this is to identify high and low water lines and cliff lines from OS maps and aerial photography and compare them in a Geographical Information System (GIS) to produce recession rates. A similar methodology is used to that in the previous strategy.
- Review of beach profile data (2009-2013) – this is to assess changes in shoreline morphology and behaviour by considering changes in profile shape, volume, contour position and sediment changes. As there is only a short time series of profiles to date this assessment can only be indicative and is used to supplement the other findings rather than to produce firm conclusions as to shoreline evolution.

A summary of the methodology for each method is presented below, with a full explanation for the derivation of recession rates presented in Annex A. The results of the assessments are also supplemented by the findings of the Cell 1 Regional Coastal Monitoring Programme Update Reports published in 2013 by Halcrow consultants on behalf of North Tyneside Council and SMP2.

2.3.2 **Beach Profiles**

2.3.2.1 Beach profiles show the general shape of the beach for each location. There is a series of 10 profile locations along the study coastline. Eight of these have been surveyed annually since 2002 and bi-annually since 2010. The remaining two profiles (denoted by the suffix A) have been surveyed bi-annually since 2010. The profiles are split into sections that cover four bays as follows:

- Whitley Sands – Profiles 01 to 4A
- Cullercoats Bay – Profile 05
- Tynemouth Long Sands – Profiles 06 to 07

- King Edward's Bay – Profile 08

Additionally, there is topographic survey data available for Whitley Sands and Tynemouth Long Sands. The analysis of profile data is undertaken using the Shoreline and Nearshore Data System (SANDS) software. Profiles were assessed for three parameters:

- Cross-sectional Area and Volume Analysis – profile data was analysed to produce beach cross-sectional area and beach volume. Cross-sectional area shows how the profile shape changes between surveys. Volume analysis calculates beach volume above a specified reference profile and linearly interpolates between each profile. While this does not give realistic figures for actual volumes of beach material it does allow for trends in volume changes to be identified over the series. As there is only one profile each for Cullercoats Bay and King Edward's Bay, it is not possible to undertake volume analysis for these areas.
- Beach Gradient Analysis – Profile data was analysed to determine how beach gradients have changed over the time series, i.e. whether they have steepened or flattened.
- Beach Contour Positions – Profile data has been analysed for the position of the Highest Astronomical Tide (HAT) contour as changes in its position can be indicative of erosion or accretion as the contour position moves in relation to the hinterland.

2.3.3 Vertical Aerial Photography

2.3.3.1 Vertical aerial photography was assessed visually to identify any areas where significant changes had occurred between the available datasets. It was also used to compare the position of high and low water marks and cliff top positions with the OS mapping.

2.3.4 Coastal Process Assessment

2.3.4.1 The results from the assessment of available data was used along with information from SMP2 and Futurecoast and other relevant studies, as well as the findings from the previous strategy, to update the understanding of coastal processes for the study coastline. This was then used to produce a conceptual model for the study area.

2.4 Results

2.4.1 Geomorphology Assessment

2.4.1.1 This section provides the results of the geomorphological analysis from the beach profile data, vertical aerial photography and OS mapping. A discussion of the results and the conceptual model are then presented in section 2.6.

2.4.2 Beach Profiles

2.4.2.1 *Cross-sectional Area and Volume Analysis*

2.4.2.2 As noted in the methodology section above beach profiles were used to undertake cross-sectional area and volumes analysis using the SANDS software. The location of each profile is shown in Figures 2-1 and 2-2. Annex B presents a time series plot for each of the profiles to illustrate changes in cross-sectional area over time. Table 2-2 shows a summary of the changes in cross-sectional area for each profile over the time series and whether there is a trend of increasing or decreasing cross-sectional area.

Table 2-3 Trend of increase or decrease in CSA over the survey period (2002-2013)

Area	Profile	Trend
Whitley Sands	1ANTDC01	Slight increase
	1ANTDC02	No change
	1ANTDC03	Slight decrease
	1ANTDC04	Decrease
	1ANTDC04A	Decrease*
Cullercoats Bay	1ANTDC05	Slight decrease
Tynemouth Long Sands	1ANTDC06	Slight increase
	1ANTDC06A	No change*
	1ANTDC07	No change
King Edward's Bay	1ANTDC08	No change

* surveys from 2010 to 2013 only

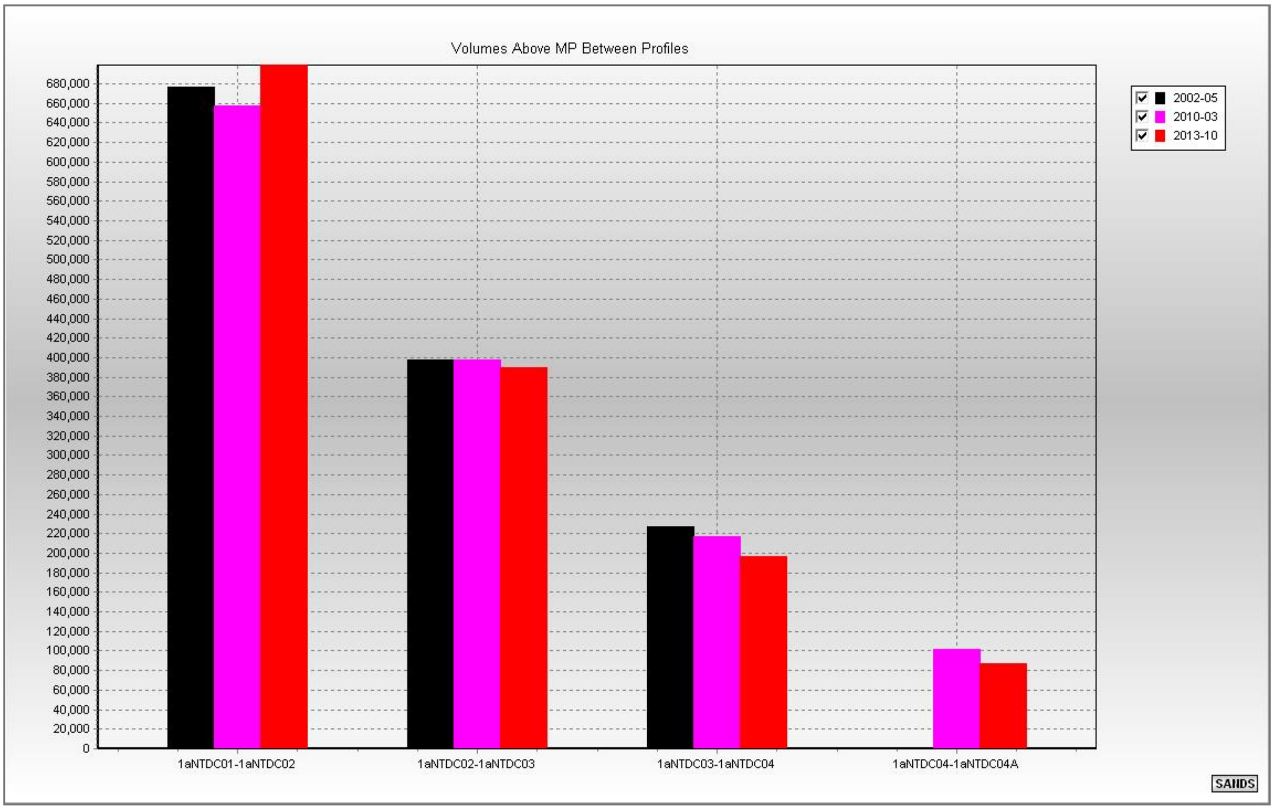
2.4.2.3 Generally, for all profiles there is either decreasing cross-sectional area or no change over the period between the first and last surveys. The greatest areas above the reference profiles are shown on Tynemouth Long Sands. The greatest fluctuations in cross-sectional areas are at Cullercoats Bay and King Edward's Bay.

Figure 2.1 Location of beach profiles 1 to 4A

Figure 2.2 Locations of beach profiles 5 to 8

2.4.2.4 Volume calculations for Whitley Sands and Tynemouth Long Sands have been made in SANDS. The volumes are linearly interpolated between the profiles and, as the gaps between profiles are not uniform, this does not give a means to compare one location to another. For example a bigger gap will give a larger volume. However, it does allow an assessment of volume changes over time.

Figure 2.3 Volume fluctuation between profiles above the reference profile (MP) between 2002 and 2013 for Whitley Sands

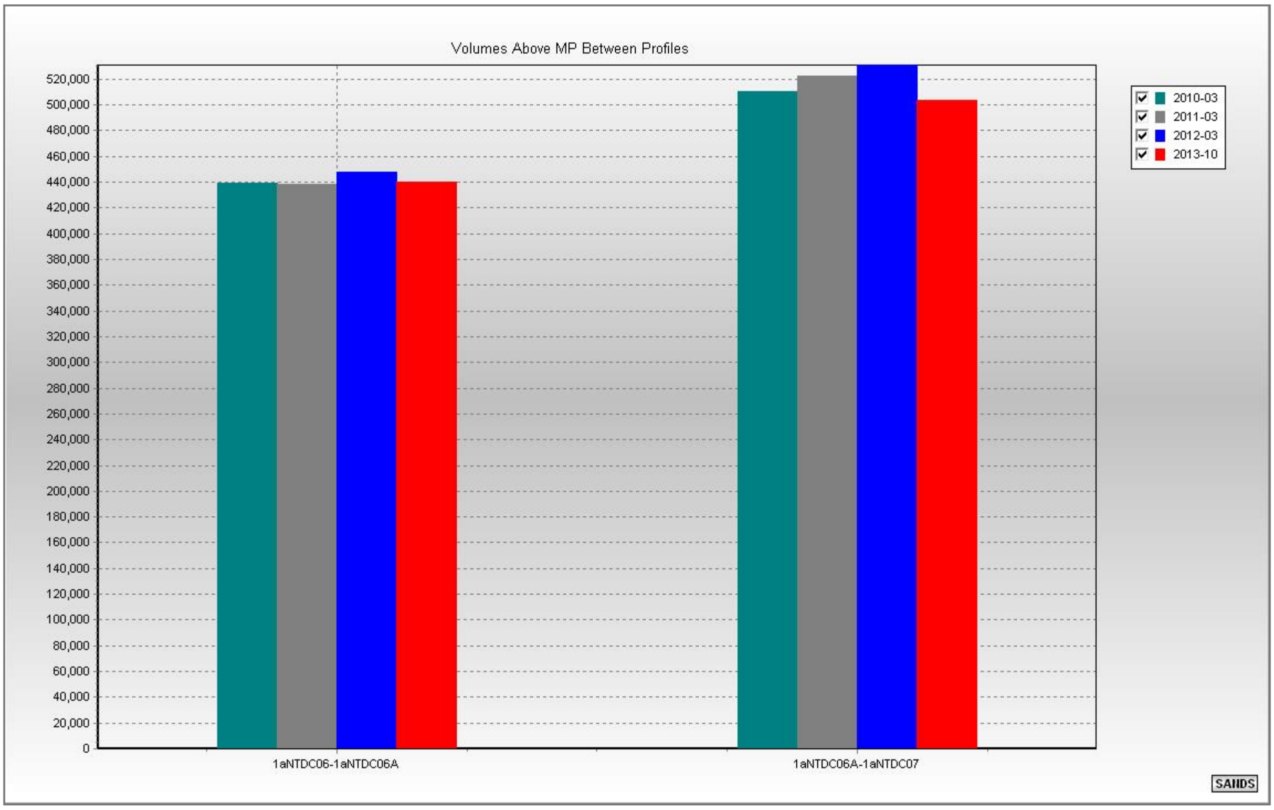


Note: 2010 is shown on the chart as this is when surveying of profile 4A commenced

2.4.2.5 For Whitley Sands the trends in volume fluctuations (Fig. 2-3) show that the northern end of the area eroded between 2002 and 2010 followed by accretion to 2013 and the rest of the area has eroded. Overall there is a net change of -29,049 cubic metres of volume for the whole of Whitley Sands, which equates to a loss of around 2% of the total volume.

2.4.2.6 Figure 2-4 shows the volume fluctuations for Tynemouth Long Sands between the 2010 and most recent surveys. Surveys before 2010 are not shown as was the earliest date from which profile 6A was surveyed. The area between profiles 06 and 06A has been stable with an overall gain of approximately 263 cubic metres between the first and last survey and between profiles 06A and 7 there was accretion between 2010 and 2012 followed by erosion to 2013. The net overall change for Tynemouth Long Sands has been a loss of around 7,015 cubic metres, which is less than 1% of the total volume.

Figure 2.4 Volume fluctuation between profiles above the reference profile (MP) between 2010 and 2013 for Tynemouth Long Sands



2.4.2.7 *Beach Gradient Analysis*

2.4.2.8 Table 2-4 below presents the results of the beach gradient analysis undertaken in SANDS. The Table shows the gradients for each profile, including minimum, maximum and average. Table cells are colour coded to show whether the gradients are steepening or flattening.

Table 2-4 Beach gradients with trends

Area	Profile	Gradients (1 in x)	
Whitley Sands	1ANTDC01	Maximum	33.9
		Minimum	20.8
		Average	27.0
	1ANTDC02	Maximum	38.5

Area	Profile	Gradients (1 in x)	
		Minimum	16.0
		Average	26.8
	1ANTDC03	Maximum	33.2
		Minimum	19.1
		Average	26.7
	1ANTDC04	Maximum	33.8
		Minimum	18.1
		Average	27.1
	1ANTDC04A	Maximum	33.1
		Minimum	17.6
		Average	26.7
Cullercoats Bay	1ANTDC05	Maximum	33.9
		Minimum	24.4
		Average	27.4
Tynemouth Long Sands	1ANTDC06	Maximum	46.0
		Minimum	22.6
		Average	36.2
	1ANTDC06A	Maximum	49.0
		Minimum	35.5
		Average	43.7
	1ANTDC07	Maximum	52.7
		Minimum	38.2
		Average	44.1
King Edward's Bay	1ANTDC08	Maximum	46.1
		Minimum	23.0
		Average	36.8

Gradient steepening (slope difference of 5 or more)	Gradient flattening (slope difference of 5 or more)	Little or no change (slope difference of 5 or less)

2.4.2.9 In general beach gradients for the study area show cyclical behaviour with flattening and steepening occurring over the survey period between the maximum and minimum values. Specific overall trends for each area are as follows:

- Whitley Bay – the beach gradient is either flattening or showing little change over the survey time period.
- Cullercoats Bay – flattening of the gradient
- Tynemouth Long Sands – the northernmost profile has flattened, while the other three profiles have steepened.
- King Edward's Bay – flattening of the gradient

2.4.2.10 *Beach Contour Positions*

2.4.2.11 The position of the Highest Astronomical Tide (HAT) contour, 3.1mAOD, has been extracted from each of the beach profiles and a comparison made between the earliest and latest surveys to calculate the change in position. The change in relation to the hinterland is indicative of erosion or accretion. The changes and rates of change for each profile are shown in Table 2-5. A positive rate shows accretion and a negative rate shows erosion of the coast.

Table 2-5 HAT contour position and movement trends

Location	Profile	Change 2003-2013 (metres)	Rate of Change (m/yr)
Whitley Bay	1aNTDC01	-13.08	-1.31
	1aNTDC02	0.07	Nil#
	1aNTDC03	-4.27	-0.43
	1aNTDC04	-1.44	-0.14
	1aNTDC04a	1.03*	0.34
Cullercoats Bay	1aNTDC05	0.52	0.05
Tynemouth Longsands	1aNTDC06	7.10	0.71
	1aNTDC06a	6.16*	2.05
	1aNTDC07	-1.65	-0.17
King Edward's Bay	1aNTDC08	-10.70	-1.02

*2010 to 2013 only
#recorded as Nil as the rate of change is negligibly small

2.4.2.12 It should be noted that movement in the HAT contour is not linear and there has been variation in its position over time, with both erosion and accretion occurring at various times, as illustrated in Figure 2-5 for the Whitley Bay profiles. This makes the identification of longer term trends more difficult. In the Figure the larger the spread in the lines the more variability there has been in the contour position.

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Figure 2.5 HAT contour variation in position - Whitley Bay

2.4.3 Historic OS Mapping

2.4.3.1 Historic Ordnance Survey (OS) mapping was obtained for the study for five epochs, along with aerial photography:

- Epoch 1 – surveyed between 1843 and 1893
- Epoch 2 – surveyed between 1891 and 1912
- Epoch 3 – surveyed between 1904 and 1939
- Epoch 4 – surveyed between 1919 and 1939
- Epoch 5 – surveyed from 1945 onwards
- Aerial photography – flown in 2010

2.4.3.2 The original strategy analysed OS mapping from 1955 and aerial photography flown in 1999 to determine the change in cliff toe position and thus estimate erosion rates. For this strategy the cliff toe line has been digitised from the Epoch 5 mapping, to give a similar baseline to the original strategy, and from aerial photography flown in 2010. A series of eight measurement points were used to derive the overall erosion of the cliff between 1955 and 2010.

2.4.3.3 The majority of the rest of the coastline is defended by hard defences, or is made up of rocky cliffs which erode very slowly, and thus there will have been little or no erosion and these areas have not been used for analysis. Table 2-6 shows the results of the current analysis and the erosion rates derived in the original strategy for comparison. As can be seen from the results, the erosion rates at individual measurement points differ from the original strategy and are generally greater. However, there appears to have been an error in the average erosion rate derived in the original strategy, which was stated as 0.3m per annum, when the calculated average erosion rate from the tabulated measurements was 0.23m per annum.

Table 2-6 Derived erosion rates for Whitley Bay

National Grid Northing (m)	Measurement Point	Original Strategy Rate (m/yr)	Current Rate (m/yr)
574620	A	0.30	0.27
574597	B	0.33	0.28
574564	C	0.28	0.29
574516	D	0.25	0.3
574440	E	0.19	0.38
574301	F	0.21	0.3
5474245	G	0.14	0.27
574097	H	0.16	0.31
	Average	0.23	0.30

2.4.3.4 The derived erosion rate from Whitley Bay has been used to represent erosion rates along the remainder of the study coastline following the same methodology as used in the original strategy and as described in Annex A. As the average erosion rate used in the original strategy is identical to that derived here, the total erosion distances that have been calculated are also the same. Table 2-7 shows the predicted future erosion rates in ten-yearly increments for the 50%ile (i.e. the mean likelihood) scenario. The 0.3m/yr erosion rate is applicable to lengths of coastline with softer geology, such as the Whitley Bay cliffs used for erosion measurements. The 0.15m/yr erosion rate is applicable to lengths of coastline with harder geology, which are more resistant to erosion.

Table 2-7 Predicted erosion rates

Years from now	Total erosion distance (m) based on historical erosion rate of 0.3m/yr	Total erosion distance (m) based on historical erosion rate of 0.15m/yr
10	3	2
20	9	4
30	17	8
40	27	14
50	40	20
60	56	28
70	74	37
80	95	48
90	119	59
100	145	72

3. Future Coastline Change

3.1 Do Nothing (No Active Intervention) Scenario

3.1.1 The methodology for projecting the future coastline position takes account of exposure conditions for each location and the residual life of any defence structures. Predicted sea level rise is also taken account of using a model, as described in Annex A. Those areas with higher exposure or softer geology have higher erosion rates applied. Where a defence is in place its residual life has been estimated using the visual inspection records and the estimates from the previous inspection reports.

3.1.2 Once the defence has failed it is assumed that it will take a further 10 years for natural erosion rates to resume. This is similar to the assumption made in the original strategy, however in the original strategy this assumption was applied to all structures and then erosion was assumed to resume from the rear of the structure. This was the case for those lengths of coastline where the structure was a narrow wall, such as at Freestone Point, and where the structure fronts a much wider area before higher ground, such as the Sea Banks sea wall. It is considered that projecting the total erosion distance from the rear of all structures may exaggerate the risks, where higher ground may be up to 45m back from the front edge, such as at Sea Banks. Therefore, for this study, projections of total erosion have been made from the front of structures to take account of the fact that the ground behind the structure and beneath the intervening area (promenade) will also need to be eroded before the higher ground is reached.

3.1.3 It should also be noted that many of the defences protect higher ground behind them, such as the cliffs around the Priory and the road behind Sea Banks. In these cases as the defences fail and erosion resumes there may be an increased risk of landslip. In that case much larger sections of the coastline could be eroded in one episode, rather than in a more gradual manner.

3.1.4 A further assumption is that human activities will remain constant throughout the appraisal period, for example the Port will continue dredging activities at present rates, land use will remain unchanged and no beach replenishment scheme will be introduced.

3.1.5 A series of figures in Annex C show the predicted erosion contours for the 20-year, 50-year and 100-year epochs.

4. Water Levels

4.1.1 This section includes details of the water levels experienced offshore from North Tyneside. This section provides a review of the previous data that was collected and reviewed as part of the previous Coastal Strategy Plan. The following data was reviewed as part of the previous plan:

- Admiralty Tide Tables (Hydrographic Office, 2002).
- St. Abb's Head to the River Tyne Shoreline Management Plan, (Posford Duvivier, 1998).
- Environment Agency Tidal Gauge Data (2001).
- Sunderland Coastal Monitoring Programme (Scott Wilson, 2003).

4.1.2 Since 2008 additional data has been collected as part of the North East Coastal Group's Cell1 Regional Coastal Monitoring Programme. The data collected as part of this programme includes:

- North Shields Tide Gauge (NTSLF Class A).
- National Coastal Flood Boundary Conditions Study (Environment Agency).

4.2 Review of Previous Studies

Admiralty Tide Tables

4.2.1 Levels given in the Admiralty Tide Tables for astronomical tides at the River Tyne are summarised in Table 4-1. Chart Datum at the River Tyne is –2.60m below Ordnance Datum and water level ranges during spring and neap tidal conditions are 4.3m and 2.1m respectively.

Table 4-1 Astronomical Tide Levels

Tidal State	Level (m Chart Datum)	Level (m Ordance Datum)
HAT	5.7	3.1
MHWS	5.0	2.4
MHWN	3.9	1.3
Mean Sea Level	2.9	0.3
MLWN	1.8	-0.8
MLWS	0.7	-1.9
LAT	-0.1	-2.7

Shoreline Management Plan

4.2.2 The Shoreline Management Plan (SMP) presents tables of water levels for a range of return periods. These are based on research undertaken by Proudman Oceanographic Laboratory (POL), using measurements of water levels at Standard Ports. For the results presented in the SMP, the nearest Standard Ports are North Shields and Whitby. No information is given in the SMP on the methodology used, and no reference is given. The results presented in the SMP are summarised in Table 4-2.

Environment Agency

4.2.3 Using an annual archive of water levels recorded on the North Shields Tidal gauge, the extreme water levels were deduced and are provided in Table 4-2.

Sunderland Coastal Monitoring Project

4.2.4 The information on water levels was extracted from the Report entitled *Sunderland Investigations & Monitoring – Joint Probability of Waves and Water Levels, 2003* submitted by Scott Wilson to the City of Sunderland. An assessment of the extreme water levels was carried out in this study using the data for North Shields for a fourteen year period from 1988 to 2002. The data was fitted to a Gumbel distribution (A special case of the Fisher-Tippet distribution). The results are presented in Table 4-3. The results published in this study were compared with the extreme water levels in the *River Tyne to Seaham Harbour Shoreline Management Plan (Babtie, 1987)* and found to be consistent.

Table 4-2 Comparison of all Water Levels for North Shields

Return Periods (years)	Extreme Water Levels (m, OD)			
	Shoreline Management Plan (Posford D	Environment Agency	Sunderland Coastal Monitoring Program (Scott Wilson. 2003)	SMP (Babtie, 1987)
5	-		3.32	-
10	3.28	-	3.38	3.25
20	-	-	3.44	-
25	3.37	-	-	-
50	3.47	-	3.51	3.44
100	3.59	-	3.57	3.55
200	3.69	3.89	3.62	-
250	-	-	3.64	3.65
500	3.78	-	-	-
1000	3.87	-	3.75	3.79

4.3 Cell 1 Regional Coastal Monitoring Programme

4.3.1 A monitoring programme is currently being carried out by the North East Coastal Group, this is called the Cell 1 Regional Coastal Monitoring Programme. This programme covers approximately 300 km of the north east coastline, from the Scottish Border (just north of St Abb's Head) to Flamborough Head in East Yorkshire.

4.3.2 The work commenced with a three-year monitoring programme in September 2008, which was managed by Scarborough Borough Council on behalf of the North East Coastal Group. This initial phase has been followed by a five-year programme of work, which started in October 2011.

4.3.3 The programme is responsible for collecting and collating water level and wave data along coast. There is only one gauge that is located within the Coastal Strategy Plan's study area, which is North Shields NTSLF Class A Tide Gauge (NOC, formerly POL). At this gauge water level data has been collected between 24/01/1946 and 28/02/2014 (Ongoing). The information recorded at this location is comparable to the data that was used in the previous studies for the extreme water level analysis. The location of the North Shields tide gauge is shown in Figure 4.1.

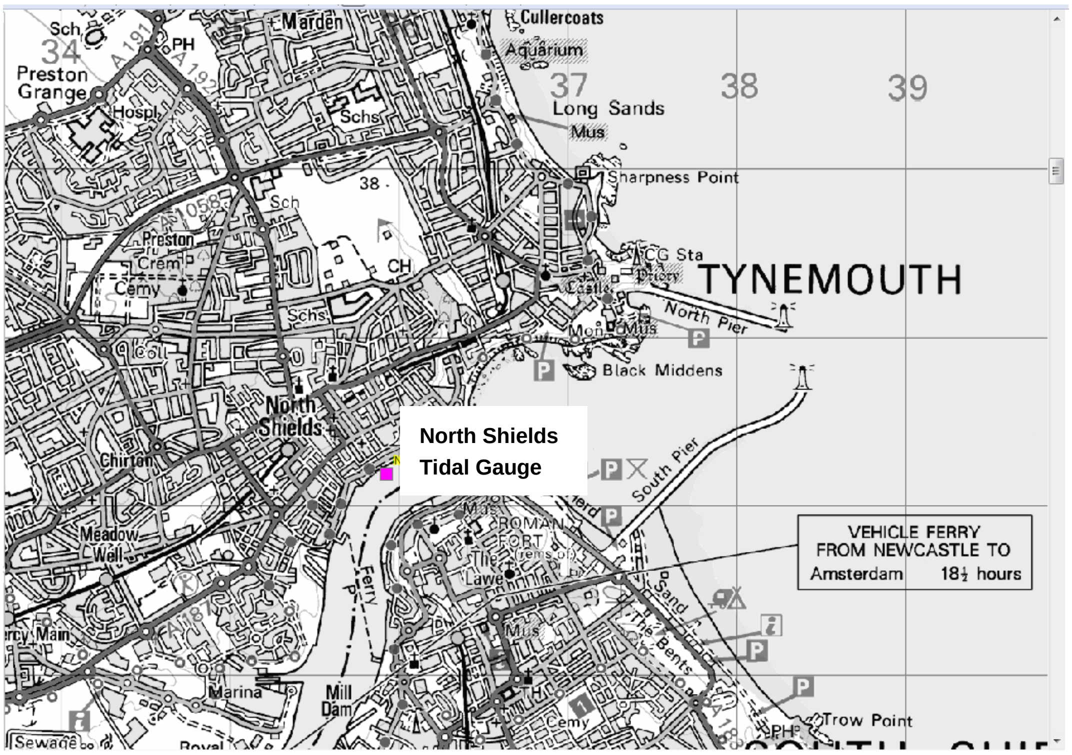


Figure 4.1 Location of North Shields NTSLF

North Shield Tidal Gauge

4.3.4 The tide gauge at North Shields is operated continuously by the National Tide and Sea Level Facility (NTSLF) on behalf of the Environment Agency as part of the UK Tide gauge network. The Chart Datum at North Shield is 2.6m below Ordnance Datum. Due to the location in the mouth of the estuary the recorded water levels can be influenced by freshwater flows in the River Tyne.

4.3.5 The North Shield gauge has the following history:

- 1946 – Earliest data available
- 1974 – A Munro gauge was installed over one of the stilling wells and an Ott digital gauge over the other
- 1984 – The Ott digital gauge was removed and a Wellhead unit was installed
- 1984 – The DATARING system was installed with potentiometers attached to the Munro gauge and the Wellhead unit
- 1993 – All equipment removed while a new tide gauge building was built
- 1993 – New building completed and all equipment reinstated
- 1998 – Wind speed and direction instruments installed
- 1998 – Both stilling wells blocked - the POL diving team cleared the blockage
- 2000 – POL data logger installed.

4.3.6 The predicted tide level at North Shields are shown in Table 4-3 have been downloaded from the National Oceanography Centre (http://www.ntslf.org/).

Table 4-3 Predicted tide levels at North Shields

Tidal State	Level (m Chart Datum)	Level (m Ordance Datum)
HAT	5.73	3.13
LAT	0.00	-2.60
MHWS	5.12	2.52
MHWN	4.08	1.48
MLWN	1.90	-0.70
MLWS	0.73	-1.87
Highest predicted 2014	5.68	3.08
Lowest predicted 2014	0.08	-2.52
Highest Predicted 2015	5.73	3.13
Lowest Predicted 2015	0.06	-2.54

4.3.7 The data was recorded at hourly intervals prior to 1993 and then at 15 minute intervals. During 1946 there are many large gaps in the record up until 1946, but the overall record is consistent. The spike in the high water level shown at the end of the plot is the storm surge of 3.98mOD at 16:15 on the 5th December 2013.

4.3.8 This shows how exceptional the conditions were, with the previous maximum recorded water level of 3.56m occurring at 17:00 on 31st January 1953 (note that prior to 1990 only hourly data are available and so the actual maximum water level in the 1953 storm event may have been higher than the recorded 3.56m).

4.3.9 The water level data from the North Shields tide gauge were also analysed in SANDS to derive extreme levels. The Peak over Threshold approach was used, with a threshold of 2.5m and data bins of 0.1m. This analysis excluded the 5th December 10 2013 storm as its inclusion would affect the statistical results. The results are shown in Table 4-4.

Table 4-4 Extreme Water Levels at North Shields

Return period (years)	Extreme levels from SANDS analysis of North Shields NTSLF (mOD)
1	3.16
2	3.25
5	3.37
10	3.46
20	3.55
50	3.67
100	3.76
200	3.85
300	3.91
500	3.97

Environment Agency National Coastal Flood Boundary Conditions Study

4.3.10 This project Coastal flood boundary conditions for UK mainland and islands (SC060064) was set up to develop and apply better methods to update datasets of coastal information available around the country and to derive information using a longer data record.

4.3.11 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).
- Provide a means of generating appropriate total storm tide curves for use with the extreme sea levels.
- Offer practice guidance on how to use these new datasets.

4.3.12 The extreme water level predictions from the Environment Agency's (EA) 2011 national Coastal Flood Boundary (CFB) Conditions study for a location offshore from North Shields are shown in

4.3.13

4.3.14 Table 4-5.

4.3.15 This indicates that the December 5th 2013 storm surge, which caused extensive damage to defences and beaches on the east coast had an annual exceedance probability (chance each year) of between 1 in 200 and 1 in 500 based on the analysis of previous data.

Table 4-5 Predicted Extreme tide levels at North Shields

Return period (years)	Extreme Level (m OD) from EA CFB Study (2011)	Confidence intervals (m) from EA CFB Study (2011)
1	3.20	0.1
2	3.27	0.1
5	3.38	0.1
10	3.46	0.1
20	3.55	0.1
25	3.58	0.1
50	3.67	0.1
75	3.72	0.1
100	3.76	0.2
150	3.82	0.2
200	3.87	0.2
250	3.90	0.2
300	3.92	0.2
500	4.00	0.3
1,000	4.11	0.3

4.4 December 5th Storm Surge

4.4.1 The most unusual event in the data records is the storm surge on the 5th /6th December 2013, this event caused significant damage to both built and natural coastal defences along the north east coastal of England. The event was recorded at North Shields, as well as two other gauges in that are part of the North East Coastal Group monitoring programme, Whitby and Scarborough gauges. The plot of the water level and the surge at during the event are plotted below, at North Shields and Whitby. All three site show a similar pattern with the maximum surge height occurring before high water and that the surge increased in height as it progressed along the coast.

4.4.2 Based on the EA (2011) Coastal Flood Boundary Condition extreme water level data the surge had the follow chance of occurrence each year: North Shields: between 1 in 200 and 1 in 500.

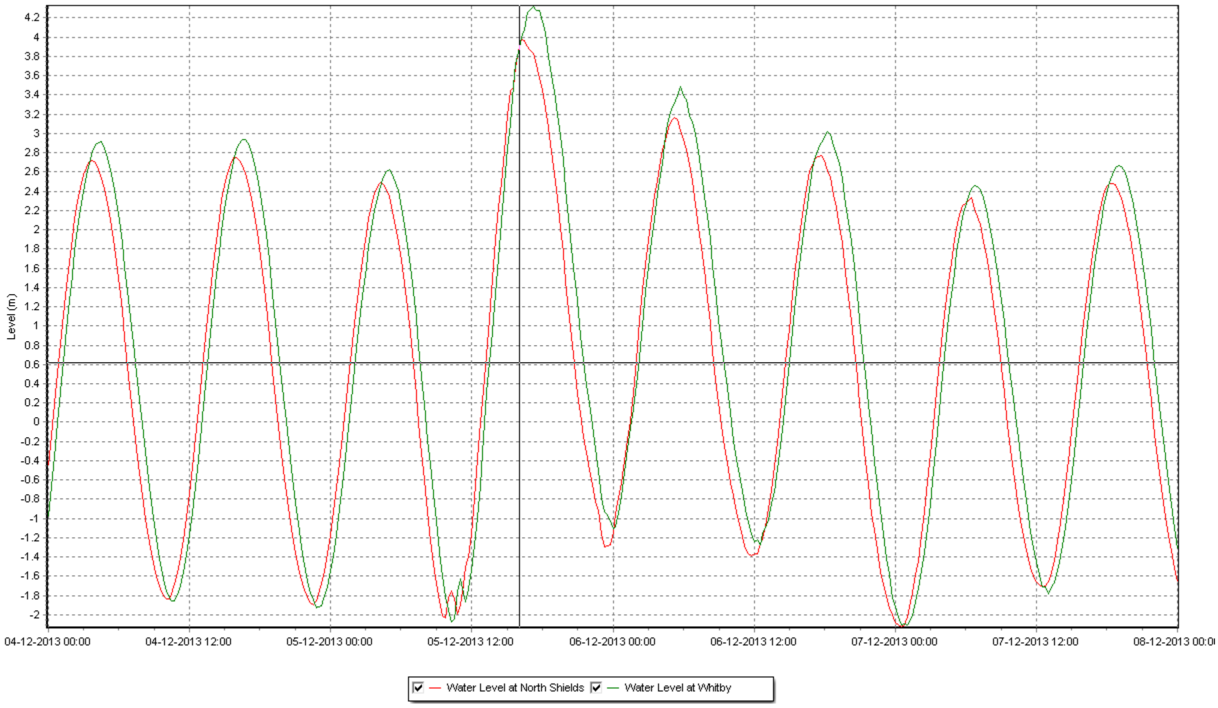


Figure 4.2 Water Level records for December 2013 Storm Surge (04/12/2013 to 08/12/2013)

Figure 4.3 Surge Residual Level records for December 2013 Storm Surge (04/12/2013 to 08/12/2013)

4.5 Comparisons

4.5.1 The updated extreme water level results, details above have been compared against the data collected as part of the Sunderland Coastal Monitoring (Scott Wilson, 2003). The comparison is shown in Table 4-6.

4.5.2 The Sunderland extreme water level study was based on fourteen years of water level data obtained for North Shields from the UK National Tide Gauge Network and hence it is of acceptable quality. This study has been carried out to give a comprehensive definition of water level climate for Sunderland in order to support the design of coastal structures. The updated data collected as part of the Cell1 Coastal Monitoring Programme is presumably from the same location.

4.5.3 A comparison of the extreme levels at North Shields is shown in Table 4-6. The comparison of the extreme levels shows that there is an increase between 10 to 30%.

4.5.4 The updated predict tide levels have been compared against each other in Table 4-7. The comparison of the predicted tide levels shows that there has been an increase in the level between 5-20%.

4.5.5 In conclusion the most up to date data should be used for development of the Coastal Strategy Plan, and this data is of acceptable quality for the detailed design of coastal structures.

Table 4-6 Comparison of Extreme Water Levels at North Shields

Return Periods (years)	Sunderland Coastal Monitoring (Scott Wilson 2003)	EA CFB Study (2011)	NTSLF (2014)
1	-	3.20	3.16
2	-	3.27	3.25
5	3.32	3.38	3.37
10	3.38	3.46	3.46
20	3.44	3.55	-
25	-	3.58	3.55
50	3.51	3.67	-
75	-	3.72	3.67
100	3.57	3.76	-
150	-	3.82	3.76
200	3.62	3.87	-
250	3.64	3.90	3.85
300	-	3.92	3.91
500	-	4.00	-
1000	3.79	4.11	3.97

Table 4-7 Comparison of Predicted Tide Levels at North Shields

Tidal States	Coastal Strategy Plan (2007)	NTLSF (2014)
HAT	3.1	3.13
MHWS	2.4	2.52
MHWN	1.3	1.48
Mean Sea Level	0.3	-
MLWN	-0.8	-0.70
MLWS	-1.9	-1.87
LAT	-2.7	-2.60

5. Offshore Wave Climate

5.1.1 This section includes details of offshore wave climate information that has been collected from a variety of sources. Firstly a review has been carried out of the information that was collected and reviewed as part of the Hartley Cove to The River Tyne Coastal Strategy plan. The following data was reviewed as part of the previous plan:

- UK Meteorological Office Model.
- Sunderland Coastal Monitoring Programme

5.1.2 Since the production of the existing Coastal Strategy Plan a wave buoy was deployed offshore of North Tyneside, Tyne Tees Wave Buoy. The buoy was deployed in 2006 by CEFAS. In addition there has been an update to the UKMO Global Wave model Wave Watch III, which became public in 2013.

5.2 Review of Previous Studies

UK Meteorological Office (UKMO) Model

5.2.1 For the previous study data on the offshore wave climate was obtained from the UK Meteorological Office (UKMO). The UKMO global wave model archive consists of the hindcast fields of winds and waves produced during the operation of the atmospheric and wave model forecast. All available reports of surface pressure, wind speed and direction (from ships, buoys, platforms, ERS-1 and DMSP satellites and land stations) are subjected to a range of consistency checks before being assimilated into the model's analysis.

5.2.2 The resulting wind field is then applied to modify the wave field derived at the previous timestep, using 16 directional and 13 frequency bands. Wave height is calculated at each model grid point, using the wind field and taking into account propagation, dissipation and transfer of energy between spectral bands. The model is run continuously in real-time, and the resulting wave conditions are archived every 6 hours. The model operates on a 55km grid, with depth dependency.

5.2.3 Data on the offshore wave climate was obtained from archive records of the UKMO's Global Wave Model for a point at 55^o North 0.9^o West, for the period from July 1988 to October 2002. Therefore the data represents a time span of just over 14 years. Table 5-1 shows the distribution of wave height for the complete data set. The highest recorded wave height (H_s) was in the band 6.6 to 7.0m. This was recorded 2 times in the 14-year period.

Table 5-1 Wave Height - Distribution of wave climate (UKMO, 2007)

Wave Height (H_s, m)	Number of Occurrence
0.0 to 0.5	7095

0.6 to 1.0	14234
1.1 to 1.5	9538
1.6 to 2.0	5266
2.1 to 2.5	2654
2.6 to 3.0	1374
3.1 to 3.5	638
3.6 to 4.0	377
4.1 to 4.5	192
4.6 to 5.0	99
5.1 to 5.5	52
5.6 to 6.0	19
6.1 to 6.5	9
6.6 to 7.0	2
Total	41549

Table 5-2 Wave Direction – Distribution of Offshore Wave Climate (UKMO, 2007)

Direction Sector (North)	Number of Occurrence
346 to 015	7884
016 to 045	4913
046 to 075	2441
076 to 105	3055
106 to 135	3234
136 to 165	2085
166 to 195	2652
196 to 225	3637
226 to 255	4693
256 to 285	3610
286 to 315	1854
316 to 345	1475
Total	41549

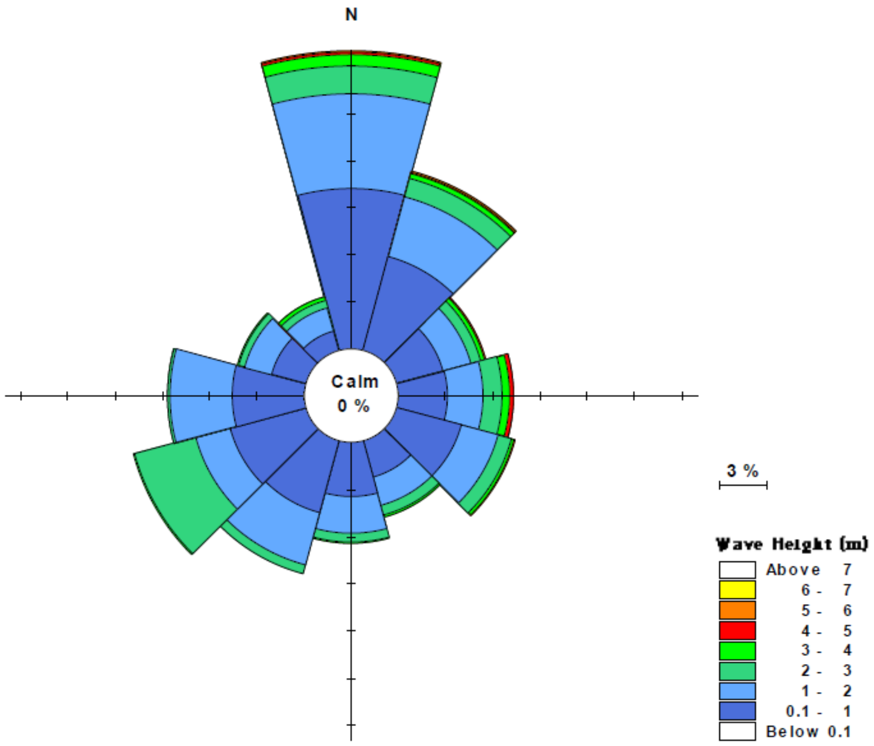


Figure 5.1 Wave Height Rose for Offshore Wave Climate (UKMO, 2007)

5.2.4 The offshore wave climate was analysed for a range of return periods from 50 to 1000 years, these ‘extreme’ wave conditions and their associated wave heights were determined using the Weibull analysis. The wave periods were calculated by applying best-fit wave steepness; the results are represented in Table 5-3.

Table 5-3 Extreme Wave Heights (Hs, m)

Return Period (years)	Direction Sector (degrees North)						
	016 - 045	046 - 075	076 - 105	106 – 135	136 - 165	316 - 345	346 - 015
1000	9.9	8.7	9.5	7.6	6.2	5.4	8.6
200	8.9	7.8	8.6	6.9	5.7	5.0	7.8
100	8.4	7.4	8.2	6.5	5.5	4.8	7.5
50	7.9	7.0	7.8	6.2	5.2	4.6	7.1
20	7.3	6.4	7.2	5.8	4.9	4.3	6.7
10	6.8	6.0	6.8	5.4	4.6	4.1	6.3
5	6.3	5.5	6.4	5.1	4.3	3.8	5.9
1	5.2	4.5	5.3	4.2	3.6	3.3	5.0

Sunderland Coastal Monitoring Project

5.2.5 The *Sunderland Coastal Monitoring Project* published the results of an extreme wave height analysis, shown in Table 5-4. The analysis has been carried out using Weibull distribution using fourteen years of offshore data spanning the period 1988-2002. The wave directional properties were, however, not taken into account in this study.

North Sands Feasibility Study

5.2.6 The North Sands Feasibility Study (HR Wallingford, 1987) published the results of an extreme wave height analysis which are also shown in Table 5-4. The HR Wallingford study was based on a data set from 1987-1995 for offshore and presented the extreme offshore wave heights against the wave direction and return period, however only the maximum wave height among all directional sectors was presented in the 2007 Coastal Strategy Plan.

5.2.7 A comparison of all the previous results are shown in Table 5-4. The results were found consistent with each other and do not vary significantly.

Table 5-4 Comparison of Offshore Extreme Wave Heights

Return period (yrs)	Significant wave height		
	Sunderland Coastal Monitoring Project	UKMO Model (2007)	North Sands Feasibility Study (HR Wallingford, 1987)
1	5.9	5.2	5.6
10	7.1	6.8	6.8
50	8.0	7.9	7.7
100	8.3	8.4	-
200	8.7	8.9	-
1000	9.4	9.9	-

5.3 Tyne Tees WaveNet Buoy

5.3.1 The Tyne Tees wave buoy was deployed by Cefas in 2006, and operates in conjunction with the National Network managed by Cefas for the Environment Agency alongside the UK strategic tide gauge network. Data on the wave climate was downloaded from the Cefas website (http://www.cefas.defra.gov.uk/).

5.3.2 The wave buoy is located at 54°55'.14N 000°44'.96W, in 63m water depth. The wave buoy is a Directional Waverider MkIII. The wave buoy has been collected data since 7th December 2006 and is due to end in 1st December 2014, data has been collected and inputted into SANDs from 7th December 2006 to 11th April 2014. This is only a short record and will not be used for modelling or the joint probability analysis. The data has been used for the validation of the model.

5.3.3 Table 5-5 shows the distribution of wave height for the data collected, the highest wave height recorded was in the band between 7 – 8 m, which has been recorded 11 times in 7 years. Table 5-6 and Figure 5-2 show the wave direction distribution and the wave rose for Tyne Tees, respectively. The wave rose indicates that the plot shows that the majority of the waves come from the north to north-northeast (0 to 30 degrees). There is a small secondary peak from the south east (120-150 degrees). Due to the offshore location of the buoy there are also small peaks from the southwest and northwest, however these event do not occur frequently.

Table 5-5 Distribution of Wave Climate by occurrence of Wave Height (Tyne Tee Wavenet Buoy)

Wave Height	Number of Occurrence	Percentage of Occurrences
0.0 to 0.5	11686.00	9.4%
0.6 to 1.0	40399.00	32.5%
1.1 to 1.5	30349.00	24.4%
1.6 to 2.0	19785.00	15.9%
2.1 to 2.5	9137.00	7.4%
2.6 to 3.0	5804.00	4.7%
3.1 to 3.5	3169.00	2.6%
3.6 to 4.0	1777.00	1.4%
4.1 to 4.5	935.00	0.8%
4.6 to 5.0	561.00	0.5%
5.1 to 5.5	321.00	0.3%
5.6 to 6.0	128.00	0.1%
6.0 to 7.0	103.00	0.1%
7.0 to 8.0	11.00	-

Table 5-6 Distribution of Wave Climate by occurrence of Wave Direction (Tyne Tee Wavenet Buoy)

Wave Direction	Number of Occurrence	Percentage of Occurrences
0° - 15°	34187	27.53%
15° - 30°	18939	15.25%
30° - 45°	2792	2.25%
45° - 60°	6405	5.16%

60° - 75°	4459	3.59%
75° - 90°	3408	2.74%
90° - 105°	5272	4.25%
105° - 120°	4964	4.00%
120° - 135°	6814	5.49%
135° - 150°	9392	7.56%
150° - 165°	1219	0.98%
165° - 180°	501	0.40%
180° - 195°	1277	1.03%
195° - 210°	3047	2.45%
210° - 225°	3033	2.44%
225° - 240°	3905	3.14%
240° - 255°	1938	1.56%
255° - 270°	1081	0.87%
270° - 285°	2215	1.78%
285° - 300°	2945	2.37%
300° - 315°	1455	1.17%
315° - 330°	974	0.78%
330° - 345°	1582	1.27%
345° - 360°	2363	1.90%

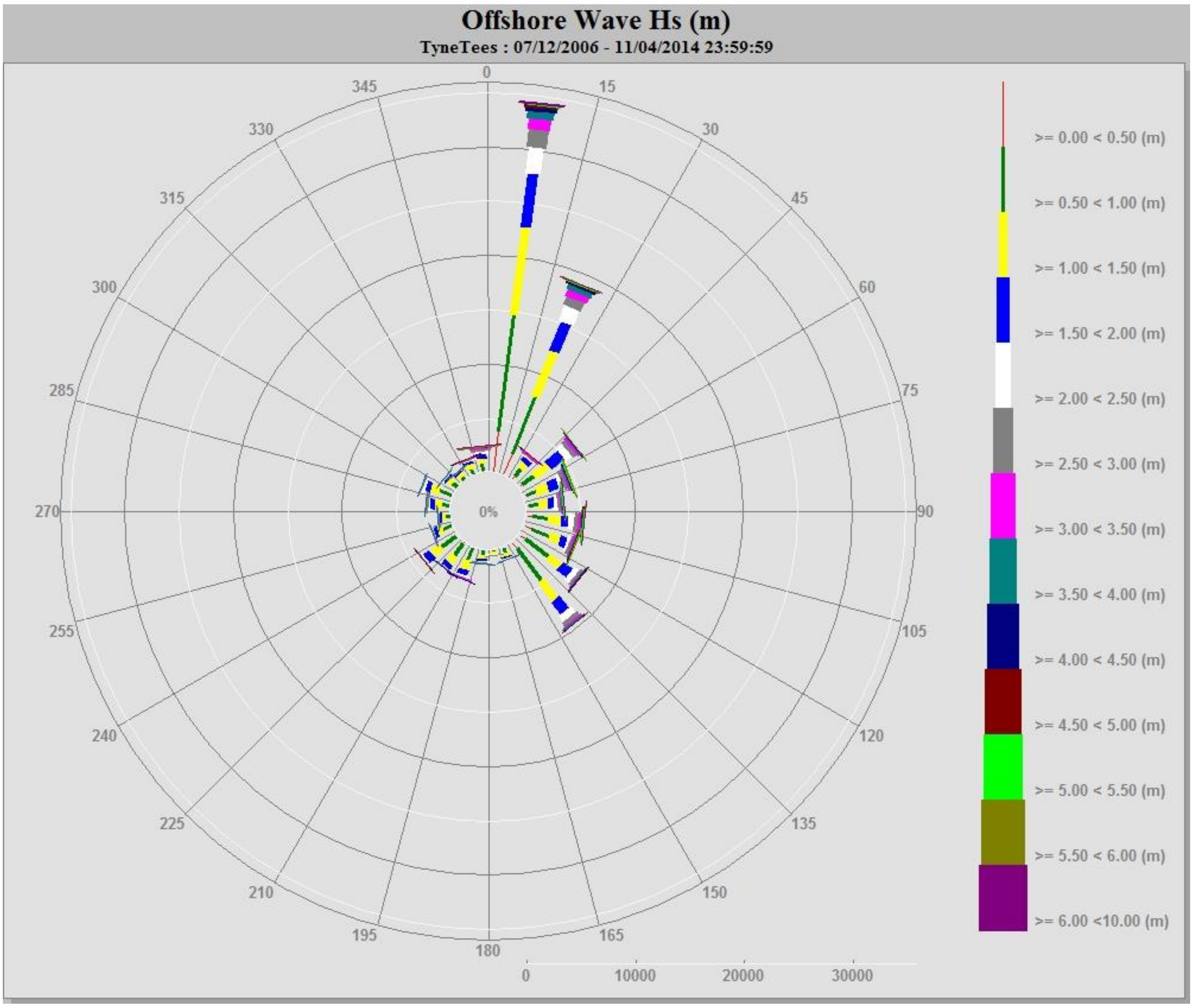


Figure 5-2 Offshore Wave Height for Tyne Tee from SANDs

5.4 Wave Watch III

5.4.1 A new Met Office hindcast of model called WaveWatch III has replaced the UKMO model. This model provides wave data at locations around the UK coast and became available through Cefas in 2013. The data covers the period 1st January 1980 to 31st December 2012.

5.4.2 WaveWatch III is a third generation community wave model developed and maintained by National Centre for Environmental Protection and contributed to by various national forecast centres internationally.

5.4.3 Data has been obtained from the MetOffice for the period of 2002 to 2014, in order to compare the wave height, period and direction to the CEFAS data.

5.4.4 Data was determined at an offshore location, 54.98° North 0.916° West, for the period from January 2002 to June 2014. Therefore, the data represents a time span of just over 12 years. Table 5-7 shows the distribution of wave height for the complete data set. The highest recorded wave height (H_s) was in the band 6.6 to 7.0m. This was recorded twice in the 14-year period.

Table 5-7 Wave Height - Distribution of wave climate (WaveWatch III, 2002 – 2014)

Wave Height (H_s, m)	Number of Occurrence	Percentage of Occurrence (%)
0.0 to 0.5	3693	10%
0.6 to 1.0	12511	34%
1.1 to 1.5	9851	27%
1.6 to 2.0	5377	15%
2.1 to 2.5	2581	7%
2.6 to 3.0	1160	3%
3.1 to 3.5	539	1%
3.6 to 4.0	298	1%
4.1 to 4.5	209	1%
4.6 to 5.0	85	0%
5.1 to 5.5	49	0%
5.6 to 6.0	24	0%
6.1 to 6.5	2	0%
6.6 to 8.0	6	0%
Total	36385	100%

Table 5-8 Wave Direction – Distribution of Offshore Wave Climate (WaveWatch III, 2002 – 2014)

Direction Sector (North)	Number of Occurrence	Percentage of Occurrence (%)
346 to 015	7662	21%
016 to 045	5620	15%
046 to 075	3622	10%
076 to 105	3541	10%
106 to 135	4371	12%
136 to 165	2416	7%
166 to 195	1713	5%
196 to 225	1553	4%
226 to 255	1104	3%
256 to 285	1302	4%
286 to 315	1688	5%
316 to 345	1793	5%
Total	36385	100%

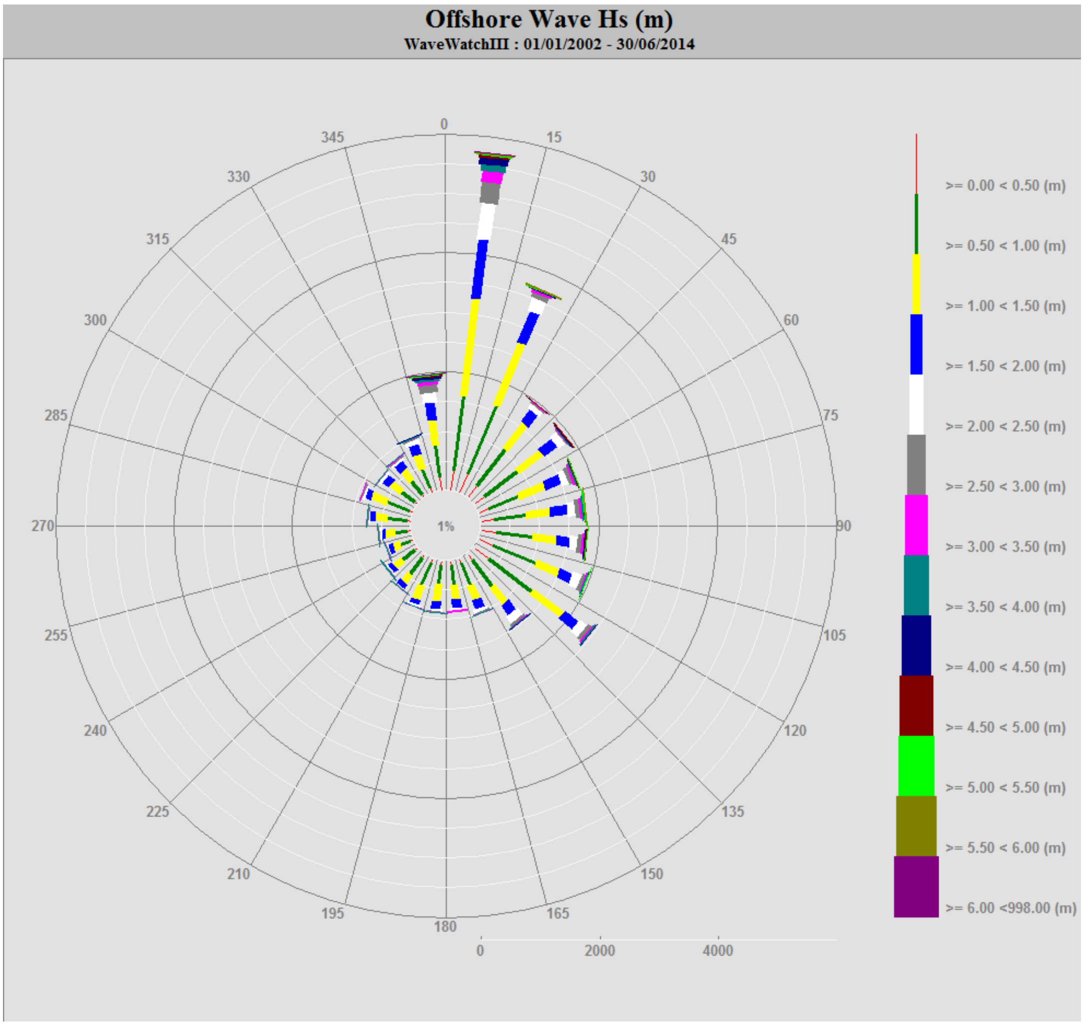


Figure 5-3 Offshore Wave Height for WaveWatch III (54.98N, 0.916W)

5.5 Conclusion

5.5.1 The data provided in this report is more up to date than the 2007 Coastal Strategy plan. Data is available from a buoy that has been deployed offshore of North Tyneside, known as the Tyne Tees Wave Buoy as part of the CEFAS programme. However, the buoy was decommissioned at the end of 2014 and only has 8 years of data and therefore, cannot be used for detailed studies. However the data can be used for validations and comparisons.

5.5.2 A comparison of the data collected from UKMO model and WaveWatch III shows that the size of the significant wave height and the dominant direction has not changed through the years. The significant wave height tends to be smaller and originates from the north east quadrant.

5.5.3 The best available offshore data is what has been extracted from UKMO model and WaveWatch III data. This data set extends from 1980 to 2012. Therefore this data is the most preferable to be used for development of Coastal Strategy Plan, and this data is of acceptable quality for the detailed design of coastal structures.

6. Nearshore Wave Climate

6.1.1 Wave data has been collected as part of the Cell 1 Regional Coastal Monitoring Programme, currently being carried out by the North East Coastal Group. The collection of wave data commences in June 2010 with the deployment of two buoys at Whitby and Newbigggin by CEFAS. The data collected from these buoys include:

- Significant wave height.
- Maximum wave height.
- Mean and peak period.
- Peak direction.
- Water Temperature.

6.1.2 Please note that data collected from these wave buoys is only a short term deployment.

6.1.3 Further offshore there the Cefas WaveNet Tyne Tees wave buoy has collected data since 2006, and has the longest consistent record of offshore data, this data has been discussed above in Section 5.3. The Tyne / Tees, Whitby and Newbiggins wave data has been uploaded into SANDs for analysis.

6.2 Newbiggin Ness Waverider Buoy

6.2.1 The Newbiggin Waverider buoy is located at 55°11'.12N 001°28'.71W, in 22m water depth, and is currently using a Directional Waverider. The data is provided by the Channel Coastal Observatory on behalf of the Environment Agency and Scarborough Borough Council.

6.2.2 The data at this buoy has been collected in two sets. The first set of data was collected using the Cell 1 programme and runs from 20th May 2010 to 7th June 2011. The second set of data was from the new buoy deployed by Fugro-Emu, and began in 21st June 2013. The following duration has been uploaded into SANDs.

6.2.3 The directional data of the wave record has been used to plot a wave rose showing the distribution by direction and wave height, refer to Figure 6-1. The predominant wave direction is from the North east (30 to 60 degrees). It appears that the wave buoy is relatively sheltered from waves from the north, unlike the Whitby wave buoy.

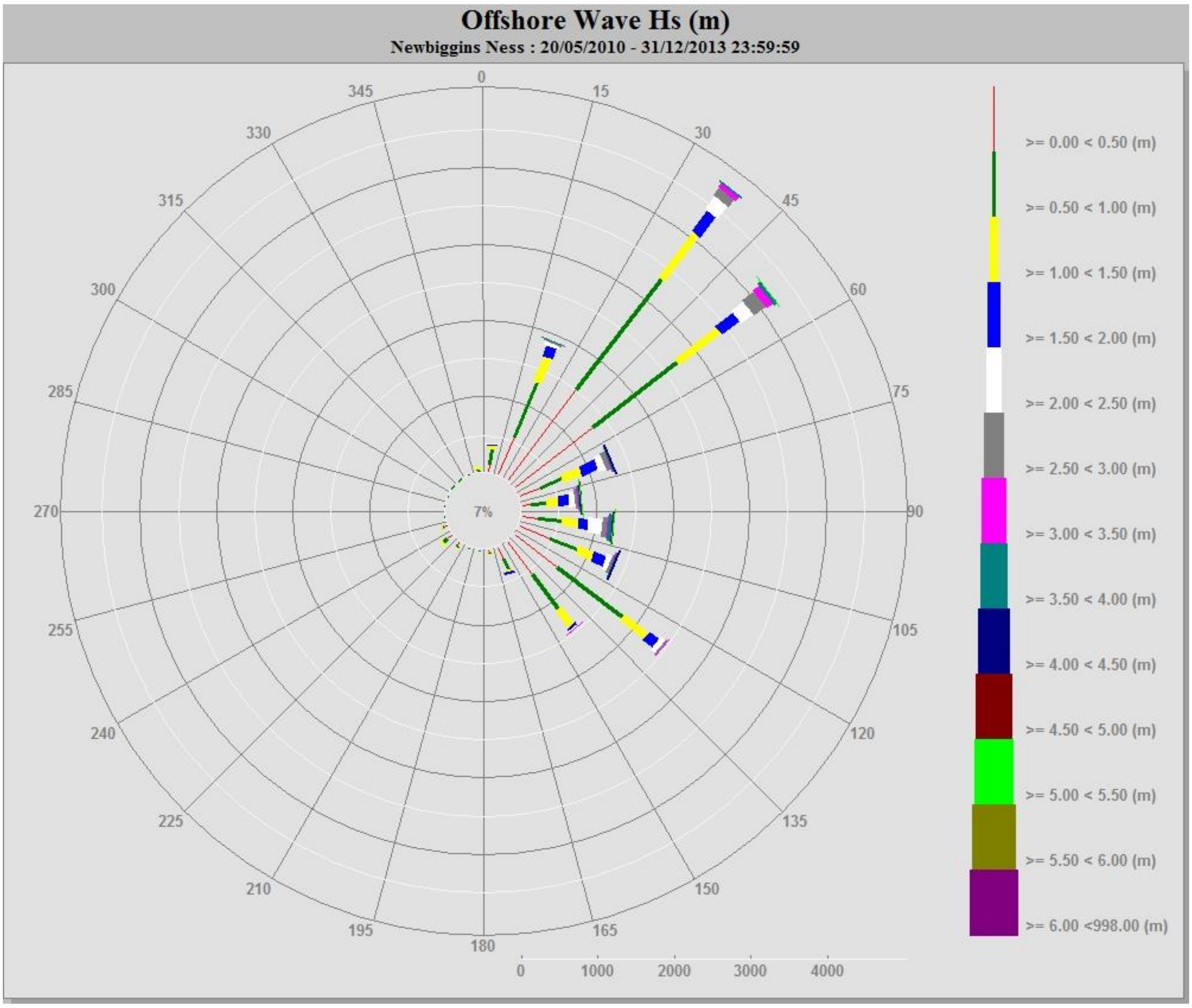


Figure 6-1 Newbiggins Ness Offshore Wave Rose (Hs, m)

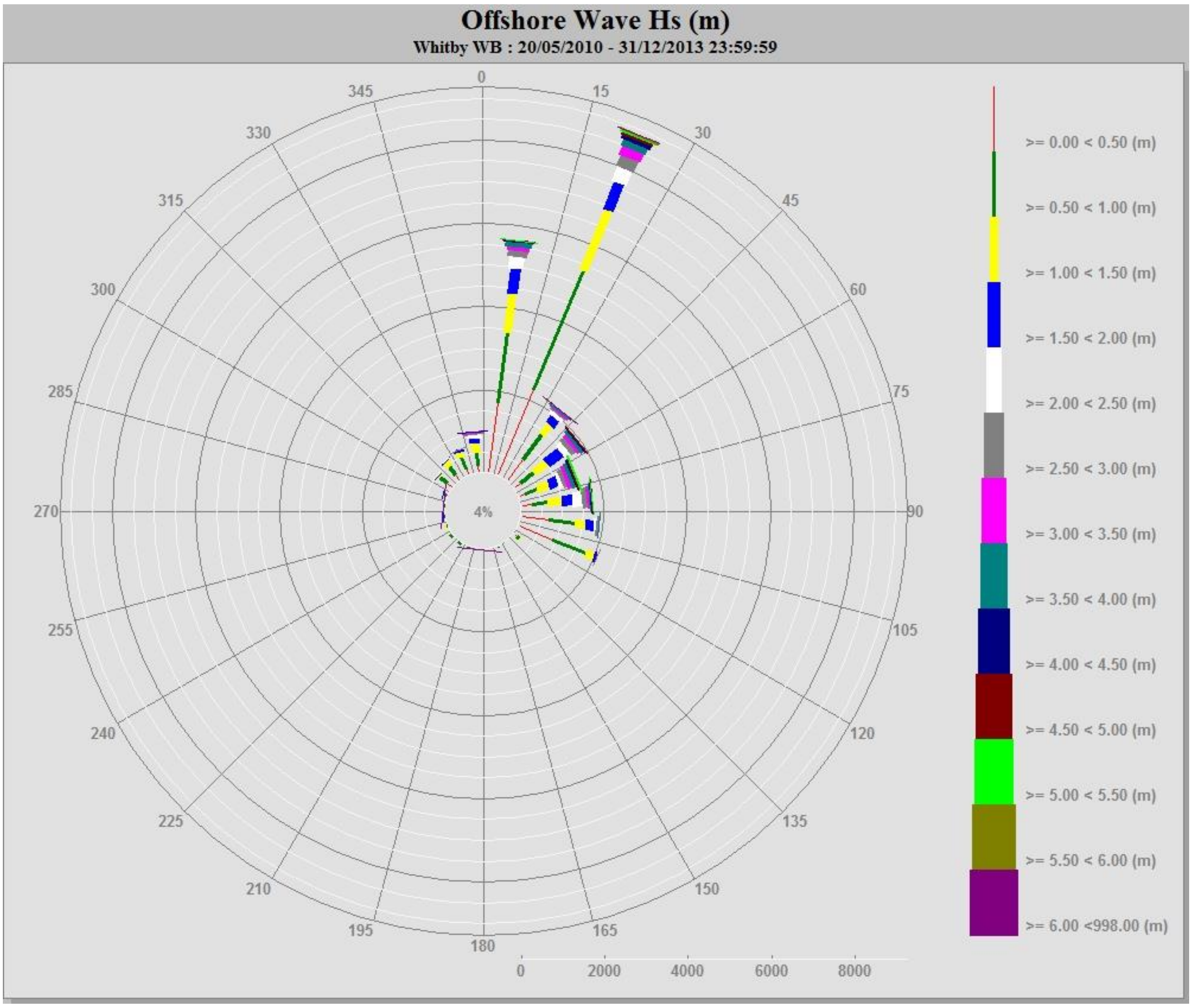
6.3 Whitby Waverider Buoy

6.3.1 The Whitby Waverider buoy is located at 54°30'.30N 000°36'.45W, in 17m water depth and is currently using a Directional Waverider. The data is provided by the Channel Coastal Observatory on behalf of the Environment Agency and Scarborough Borough Council.

6.3.2 Similar to Newbiggins Ness Waverider Buoy there are two separate sets of data. The first set of data is fairly short from October 2010 to October 2011. The new data was collected from a similar location from 17th January 2013 to 31st December 2014. There is a gap in the data record from 19th to 21st June 2013, while the buoy was off station following possible damage by a fishing vessel in the area.

6.3.3 The directional data of the wave record has been used to plot a wave rose showing the distribution by direction and wave height, refer to Figure 6-2. The predominant wave direction is from the North East by North direction (0 to 30 degrees). Due to the location of the buoy is it sheltered from waves from the South East (120 to 150 degrees) unlike Newbiggin Ness wave buoy.

Figure 6-2 Whitby Offshore Wave Rose (Hs, m)



6.4 December 5th Storm Surge

6.4.1 Recorded wave data during the storm surge

The data available at Newbiggin and Whitby was plotted with the recorded water level. The plots indicate that the peak wave heights were not exceptionally large at the time of the maximum surge and that large waves occurred on the following two high waters. The storm is evident in the wave recorded from Tyne Tees between 5th and 6th December 2013.

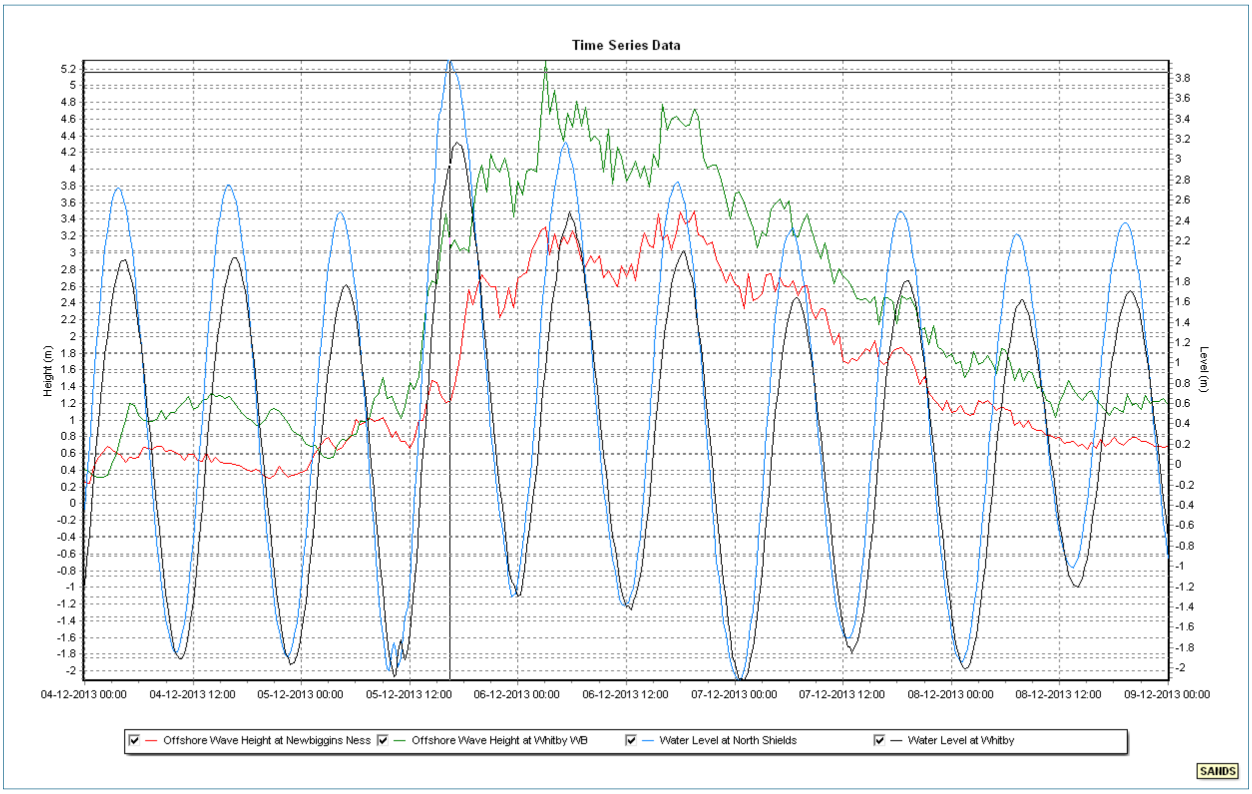


Figure 6.3 December Storm – Water Levels and Wave Heights

6.4.2 The data from the buoys indicates that at the time of the maximum water level the wave heights were still building and larger waves were experienced on the two subsequent high waters. The storm waves at the peak of the surge damaged many defences, consequently received significant media attention, but do not appear to have had exceptional wave condition. The larger waves experienced over the subsequent two days although at lower tide levels will have rapidly redistributed the storm beach profiles created during the highest water levels of the surge event on the 5th December.

6.5 Conclusion

6.5.1 The nearshore data provided in this section is only for a short time period, approximately 4 years. This data should not be used for design of coastal structure however is sufficient for analysis purposes of this Coastal Strategy Plan.

7. Joint Probability of Waves and Water Levels

7.1.1 This section describes the previous works on joint probability assessments which include:

- St.Abb's Head to River Tyne Shoreline Management Plan (Posford-Duvuvier, 1998)
- River Tyne to Seaham Harbour Shoreline Management Plan (Babtie, 1998)
- Sunderland Investigations & Monitoring – Joint Probability of Waves and Water Levels, (Scott Wilson, 2003) commissioned by City of Sunderland as part of the Sunderland Coastal Monitoring Project.

7.1.2 Additional work has been undertaken using SANDs to determine joint probability of the wave and water levels using the information that has been downloaded from WaveWatch III and the gauge information collections at North Shields Tidal Guage.

7.2 Review of Previous Studies

River Tyne to Seaham Harbour Shoreline Management Plan

7.2.1 The Shoreline Management Plan (Babtie, 1998) presented the results of a joint probability analysis for an inshore location of -10mCD depth. The Whitburn Bay to Ryhope Coast Protection Strategy (Scott Wilson, 2001), however, concluded that the joint probability information given in the SMP are of insufficient detail and quality for use in the design work. The study concluded that the SMP was based on an assumed level of interdependence between wave and water level events, and not on an analysis of simultaneous wave and water level data.

7.2.2 The Strategy (Scott Wilson 2001) recommended that a new and comprehensive definition of the joint wave/water level climate was to be established.

St Abb's Head to River Tyne Shoreline Management Plan

7.2.3 The joint probability of water levels and wave heights as given in the *St. Abb's Head to the River Tyne Shoreline Management Plan (SMP)* prepared by Posford Duvivier (1998) are presented in Table 7-3. The extreme wave heights for a location off North Shields at –20m depth (Chart Datum) are shown in Table 7-1 while the extreme water levels are shown in Table 7-2.

Table 7-1 Extreme wave heights for a location near North Shields at –20 CD depth (SMP, Posford Duvivier, 1998)

	Return Period (yrs)		
	1	10	100
Wave Height (m)	5.44	7.56	9.63

Table 7-2 Extreme water levels (SMP, Posford Duvivier, 1998)

Return Period (yrs.)	Extreme Water Levels (mOD)
10	3.28
25	3.37
50	3.47
100	3.59
200	3.69
500	3.78
1000	3.87

Table 7-3 Inshore joint probability of waves and water levels for a location –20m CD (SMP, Posford Duvivier, 1998)

SWL Return Period (years)	Joint Return Period (yrs.)			
	10	50	100	1000
	Wave Height (years)			
1	0.15	1.1	2.5	85
10	0.02	0.12	0.29	10
20	-	0.06	0.14	5.0
50	-	0.02*	0.06*	2.0
100	-		0.03*	1.0
200	-	-	-	0.50
1000	-	-	-	0.10

Sunderland Coastal Monitoring Project

7.2.4 The following table gives the joint probability results of waves and water levels for an offshore location at 55º North 0.9º West at a depth of –58m (CD) located offshore of North Shields.

Table 7-4 Offshore joint probability of waves and water levels (based on a 14 years of data from 1988-2002)

Water Level (m) OD	Joint Return Period (yrs)						
	1	5	10	50	100	200	1000
	Significant Wave Height, Hs (m)						
2.1	4.8	5.4	5.9	6.3	6.8	7.1	7.7
2.3	4.4	5.2	5.7	6.1	6.6	6.9	7.6
2.5	4.0	4.9	5.3	5.9	6.4	6.7	7.4
2.7	3.5	4.3	5.0	5.5	6.1	6.3	7.2
2.9	2.3	3.7	4.4	4.9	5.7	5.9	6.9
3.1	0.9	2.7	3.4	4.3	5.1	5.3	6.5
3.3		1.4	2.5	3.5	4.4	4.7	5.9
3.5				1.9	3.1	3.7	5.1
3.7					1.5	2.2	4.1
3.9							2.5

7.3 Joint Probability Analysis

7.3.1 The 2007 Coastal Strategy Plan concluded that when a comparison was made between the three studies detailed in the previous section. The River Tyne to Seaham Harbour SMP and then St Abb's Head to River Tyne SMP results were found to be conservative relative to the results of the Sunderland Coastal Monitoring Coastal Monitoring Project.

7.3.2 The joint probability analysis for the SMPs was based on assumptions rather than full analysis of simultaneous wave/water level data for a sufficiently long period. Some of the results that were obtained from the River Tyne to Seaham Harbour Shoreline Management Plan were erroneous due to a lack of sound mathematical and physical basis in the estimation procedure.

7.3.3 The joint probability results of the Sunderland Coastal Monitoring Project was based on a comprehensive study of simultaneous wave and water level data spanning the period 1988-2002. Overall for the 2007 Coastal Strategy Plan this dataset was the most reliable estimate for the offshore joint wave and water level climate off North Shields. However this data used for this study has been updated, an additional 10 years' worth of data is now available.

8. Inshore Wave Climate

8.1 Review of Previous Study

8.1.1 For the 2007 Coastal Strategy Plan a MIKE 21 NSW combined wind-wave modelling was carried out. The model provided the propagation, growth and decay of short-period and short-crested waves in near shore areas. The model took into account the effects of refraction and shoaling due to varying depths, local wind generation and energy dissipation due to bottom friction and wave breaking.

8.1.2 The basic output from the MIKE 21 model is significant wave height, wave period and mean wave direction.

8.1.3 Each of the wave height, period and direction combinations forming the offshore wave climate was transferred to the North Tyneside Coastline. The model was run for a combination of heights/periods/directions. Each model run represents the complete data set of 41,549 occurrences in the 14-year data set.

8.1.4 The wave climate transformation was undertaken at a sea level corresponding to Mean Sea Level.

8.1.5 For the modelling three digital elevation models of the seabed were created. The elevation models were digitised from the admiralty charts for the area (Admiralty chart 152). Each model was used for a specific range of offshore wave directions, as shown in Table 8-1. The model has been orientated south to north. The area represented extends from just north of Roker Pier in the south, to Blyth in the north of the model.

Table 8-1 Wave refraction model dimensions

Model Number	Orientation of onshore – offshore axis	Wave direction used in the model	Model grid spacing (offshore spacing by longshore spacing)
1	110º	030º	10m x 50m
2	160º	60º, 90º	10m x 50x
3	210º	120º, 150º	10m x 50m

The inshore wave climate for North Tyneside was analysed at 6 points along the coastline. location of these points is shown on

8.1.6 Figure 8.1. Three points located on the –5m contour (5m below Mean Sea Level) and are denoted A5 (St Mary's Island), B5 (Whitley Bay) and C5 (Long Sands). Similarly three points are located on the –20m contour (A20, B20 and C20).

8.1.7 The –5m contour is approximately 700-800m from the shoreline, and the –20m contour is about 2-3km from the shoreline.

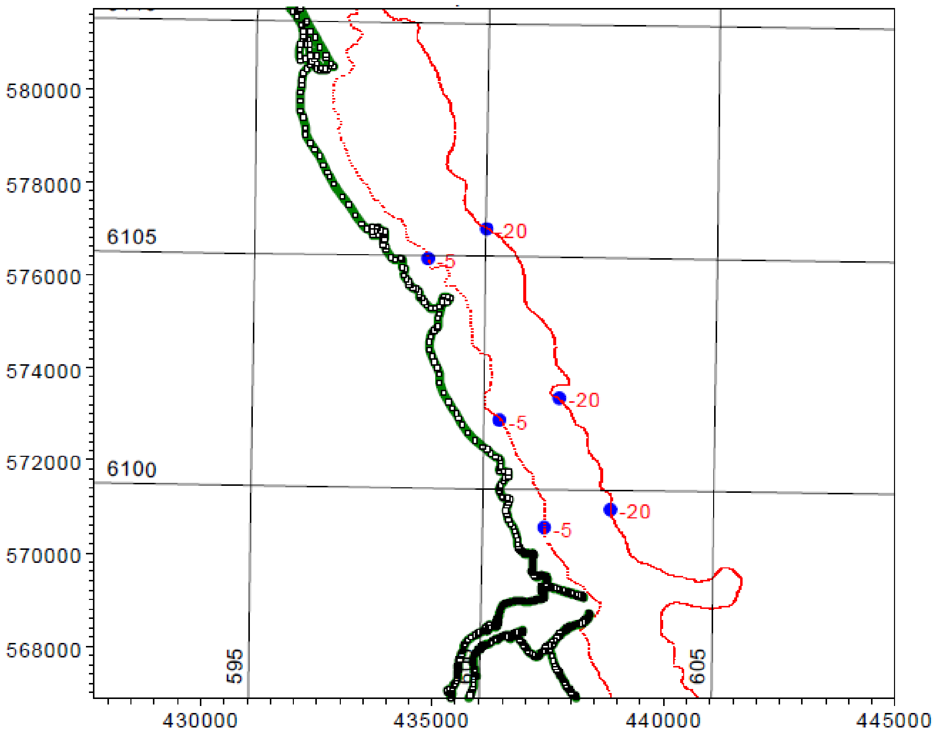


Figure 8.1 Location of Inshore Wave Model Points

8.1.8 In conclusion the results of the nearshore wave modelling exercise has been undertaken to simulate wave conditions on the North Tyneside coastline. The results indicate that for much of the coastline the wave climate is depth limited. The shallower water depths around the –5m contour have a maximum significant wave height of around 3.5m or less. Because the conditions in this area are basically depth limited, water level is the dominant parameter in overtopping. The principal areas of concern at Cullercoats and Fish Quay. These areas were studied in greater detail using a Boussinesq model and MIKE 21 PMS wave model to simulate the wave conditions for these areas.

8.1.9 The model was also used to transfer extreme wave conditions to determine inshore extreme wave heights for the 100 year return period. The Weibull method was used to determine the extreme wave heights. Results were extract for all six points. The results can be seen in table 4-3.

8.1.10 Wave Heights at points all six locations (A2-C20) are presented in Table 8-2 for a simulation of a 100 year wave height from different directions. The above table of results shows a marginal increase in wave height for the 90° wave direction, at all locations and depths. The highest wave heights are observed at Long Sands due to absence of protective headlands in this area.

Table 8-2 Inshore extreme wave conditions

	A2	A5	A20	B2	B5	B20	C2	C5	C20
60º	4.93	5.81	6.86	4.15	5.12	6.80	4.70	5.32	6.87
90º	5.00	5.89	7.50	4.25	5.39	7.40	4.88	5.52	7.50

8.2 Conclusion

The recent data collected offshore, is from the WaveWatch III model as discussed in Section 5.4. The results of the modelling undertaken for the original Strategy and as discussed above are dependent on the offshore wave climate, and comparison of the most recent data with the older data shows that there has not been a significant change in the wave climate. Therefore, the results of the previous modelling are still appropriate, as are the analyses presented in Section 9 below.

9. Failure of Piers

9.1 Port of Tyne Piers

Objectives

9.1.1 Wave modelling was undertaken to assess the impacts of waves on the defences within the North and South Piers at the mouth of the River Tyne.

9.1.2 The model used was the Mike 21 Boussinesq model, the model takes into account diffraction refraction, reflection and shoaling.

Methodology

9.1.3 The MIKE 21 model was run for a nearshore (on the –20m contour) 100 year extreme wave condition of Hs = 8.5m, Tp =13.1s. This represents an extreme event, occurring once every 100 years.

9.1.4 The model was first run for waves from due east, see Figure 8.1 for results. Waves penetrate the outer harbour piers and impact on northern harbour coastal defences, concentrating the wave energy onto Freestone Point. Elsewhere conditions are relatively mild. Very little wave energy enters the inner harbour as can be seen from the wave height contours. Wave heights quickly decrease to about 0.4m within the harbour, representing a reduction to 10% of the conditions at the –20m contour.

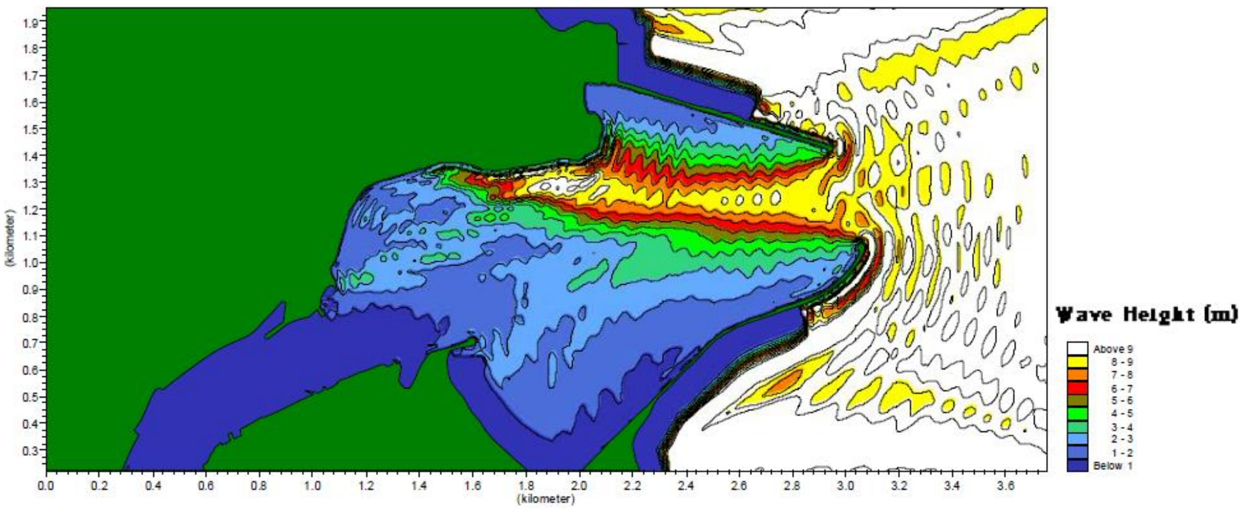


Figure 9-1 Boussinesq Wave Model Results for Easterly 90° direction

9.1.5 The model was then run for waves from the North East at a 75° wave direction (see Figure 9-2), combining the predominant wave direction with a 100 year wave event. The notable feature of this model is the decreased wave height on the lee side of the pier structures and the transfer of the wave energy further to the west, away from Freestone Point.

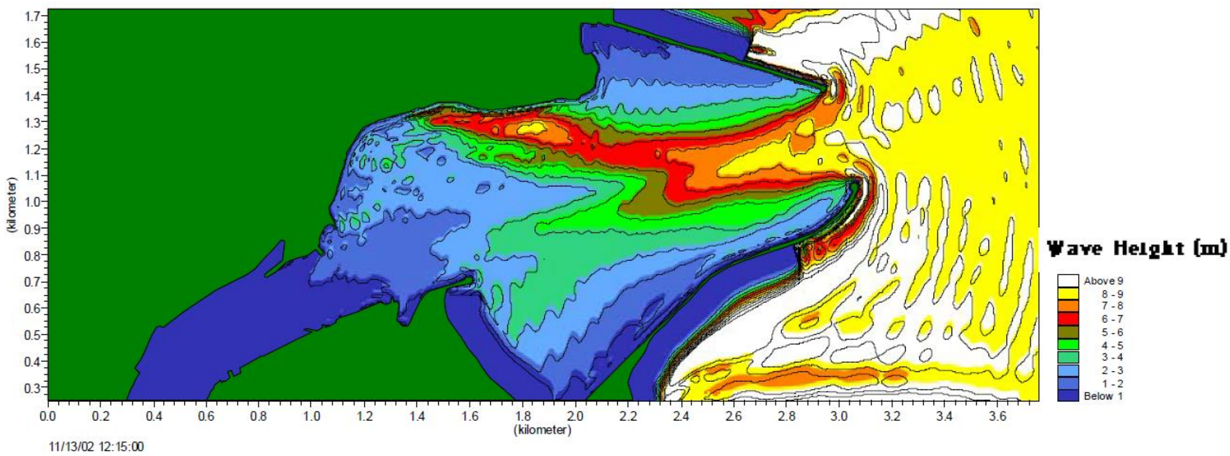


Figure 9-2 Boussinesq Wave Model for 075° North-Easterly wave direction.

9.1.6 If the outer north or south pier failed the wave conditions in the Port of Tyne would be severe. From these two models (Figure 9-1 and 9-2) it can be seen that the piers reflect the majority of the wave energy. Waves from easterly and northeasterly directions that do penetrate the piers are concentrated on the northern shoreline in shallow water areas, away from high-urbanised development. The piers are very efficient in protecting the inner harbour and surrounding areas.

Conclusions

9.1.7 A failure of either pier would lead to increased wave action within the harbour, around the Fish Quay, and greater wave energy at Freestone point. The existence of these defences ensures that wave energy is currently diffracted onto an area of coastline where wave conditions are less critical to land use.

9.2 Cullercoats Piers

Objectives

9.2.1 Wave modelling was undertaken to assess the impact of waves on the defences of the north and south piers at Cullercoats, and to understand the extent of wave disturbance within and immediately outside of the harbour.

9.2.2 The MIKE 21 PMS model was used for the modelling. It takes into account wave diffraction, refraction, shoaling, bottom friction and wave breaking. MIKE 21 PMS does not include effects of wave reflection unlike MIKE 21 BW.

Methodology

9.2.3 The model was run to simulate wave refraction and shoaling in the nearshore zone when waves propagate from offshore (approximately at the -10m bed contour) to shallow depths (around the –2m contour) for a 100 year extreme wave condition of H_s = 6.28m, T_p = 11.7s.

9.2.4 This represents an extreme event, occurring on average once every 100 years. The still water level was specified at 6.19m CD, equivalent to the 100 year return water level of 3.59m AOD (SMP, Posford Duvivier, 1998).

9.2.5 The model bathymetry was chosen to represent an area covering 1.6 km x 1.0 km at a resolution of 2m x 2m. The waves were made to enter the model from the East offshore boundary at the –10m bed contour. The model was run for 060°, 090° and 120°N wave directions.

Model Results

9.2.6 The model results obtained for all three cases generally indicated more or less the same pattern of wave height distribution inside and immediately outside harbour. The average significant wave height (H_s) obtained outside the harbour entrance close to the –2m contour was 2.4m. The wave heights inside the harbour close to the Dove Marine Laboratory were found to be about 1.5m.

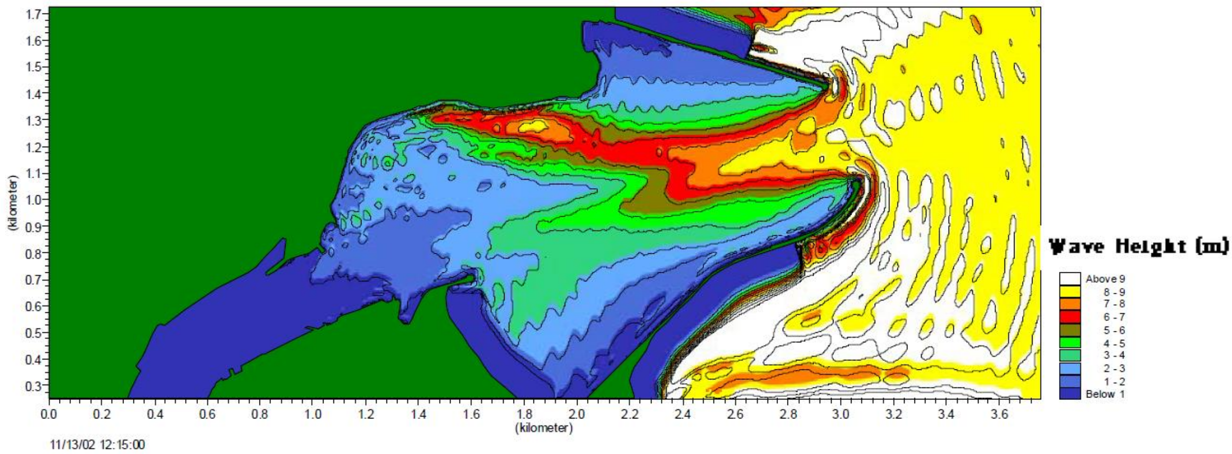


Figure 9-3 Cullercoats 090 deg 1 in 100 year condition: Wave direction and height (H_{rms}) are given by the direction and strength of the vector respectively while contours represent wave height bands

Conclusion

9.2.7 The nearshore bathymetry causes wave heights to reduce by approximately 62% in the vicinity of the –2m bed contour relative to the input offshore wave height. The sheltering effect of the piers produces a significant reduction in wave heights on their lee side. The north and south piers provide calm waters within the harbour. Should part of the north or south pier fail as a result of storm damage, a significant amount of wave penetration would occur through the enlarged gap causing the Dove Marine Laboratory and the southern part of the bay to be exposed to direct wave attack. This would bring about extensive damage to the Marine Laboratory and other properties lying on the periphery of the bay.

10. East Coast Process Review

10.1 Approach

10.1.1 Section 10 has been taken from the FutureCoast CD supplied to North Tyneside Council by DEFRA.

10.1.2 The hydrodynamic forcing fundamentally affects the energy reaching the coast, which drives the process of accretion, erosion and longshore transport. The driving forces are waves, water levels, tidal currents and wind. Generally at the coastline the primary driving mechanism for sediment transport in the near shore zone are waves, although this of course varies with location. A review has therefore been undertaken of the modern hydrodynamic regime including waves and tide driven currents and predicted sea floor residuals. This work has identified likely sources, sinks and pathways from hydrodynamic and modelling evidence, which has been combined with the geological/ geomorphological evidence to assist the analysis of linkages and controls and thus shoreline behaviour.

10.1.3 No new modelling of sediment processes has been undertaken, instead an extensive review of existing information has been carried out. A key source of information has been the Shoreline Management Plans, but this information has been supplemented through a review of other studies, such as the strategy plans, which have since been completed. Sediment transport rates have not been quoted because the various studies undertaken around the coast have used different approaches, therefore the results are not directly comparable and reproducing them for this study would be misleading.

10.1.4 Due to the inconsistencies such as disparity in quality and age of available information on the wave climate, an independent assessment of inshore wave conditions has been undertaken (described section 6) and wave data produced to assist in the understanding of wave climate around the coast.

10.1.5 POLPRED, an offshore tidal software package developed by Proudman Oceanographic Laboratory, has also been used to predict offshore tidal elevations and tidal currents. From this information, tidal ellipses have been created for various locations around the coast. This information has been used (in conjunction with available tidal residuals for the Bristol Channel and English Channel areas, generated by ABPmer from regional scale hydrodynamic models), in order to understand regional tidal regimes.

10.2 Overview of Processes

10.2.1 The North Sea provides the driving force for many of the processes, which act upon the East Coast. There are two open-sea entrances to the North Sea:

- the wide northern entrance between Scotland and Norway; and
- the much narrower entrance through the Dover Straits at the eastern end of the English Channel.

10.2.2 The North Sea is typically less than 40 m water depth (although depths of greater than 90m exist to the west and east of Dogger Bank). In addition, the Southern North Sea is typically shallower than the northern. This means that during the Holocene sea level rise the southern region was inundated after the northern region and, as such, may still be adjusting to the hydrodynamic forces (cf. Coles, 2000). The North Sea can be subdivided on the basis of difference in bathymetry and process regimes. The effect of these regimes, in combination with the summer heat input to the surface waters, leads to a stratified water column within the central North Sea and a mixed water column in the coastal region and in the Southern Bight. Further division of the North Sea has been made, by including the water mass characteristics such as nutrient levels and turbidity. Details of the hydrodynamic and sedimentological regime of this region are given in the following sections.

10.3 Tides

10.3.1 The Atlantic tidal wave enters the North Sea i) between Scotland and Norway; and ii) through the Dover Straits. The timing of the tidal wave propagation along the East and South coasts is such that the High Water (HW) of both coincides at the Dover Straits. However, the East Coast's tidal wave reaches the Straits one tidal period ahead of that of the South Coast (Hardisty, 1990). It should also be noted that the Dover Straits is the location of some of the highest tidal velocities observed in the English Channel (Velegrakis *et al.,* 1997), and coincides with a zone of sediment transport convergence. The tidal wave exits the North Sea through the Baltic Sea and along the western coast of Norway. The result of this tidal propagation is an anticlockwise circulatory pattern of water movement within the North Sea. The inflow rate is greater through the northern entrance to the North Sea than the southern (Lee, 1980; Lisitzin, 1967; Dooley, 1974).

10.3.2 There are three amphidromic points (for the M2 component) in the North Sea:

- Between the Anglian and Holland coasts;
- Offshore from Esbjerg, Denmark; and
- Offshore from Stavenger, Norway.

10.3.3 The tidal ranges between 1.5 and 5m along the open coast. The highest tidal range along the East Coast is located between the River Humber and the Wash embayment. In the Wash, a mean spring range of 6 m and a mean neap range of 3 m occurs (Anglian Water, 1988) due to resonance and shallow water coastal bathymetry. Maximum depth-averaged M2 tidal currents are found:

- within the Dover Straits, extending to North Foreland (> 1 m/s);
- to the north-east of Anglia (0.8 -0.9 m/s); and
- at the mouth of the Humber (0.7 -0.8 m/s) (DoE, 1990).

10.3.4 The maximum depth-averaged S2 tidal currents are found:

- within the Dover Straits (0.3 -0.4 m/s);

- to the north-east of Anglia (0.25 -0.3 m/s); and
- from Flamborough Point to the Wash (0.2 -0.3 m/s) (DoE, 1990).

10.3.5 Hence, the maximum depth-averaged tidal currents occur:

- within the Dover Straits, extending to North Foreland (> 1 m/s); and
- to the north-east of Anglia (0.8 -0.9 m/s).

10.3.6 The tidal ellipses show a distinct change offshore, where they become more circular due to the absence of coastal boundary effects.

10.4 Waves

10.4.1 The direction of wave approach varies from the northern North Sea (north-east and north-north-east) to the southern North Sea (east-north-east to south-east). In the north of the region, the hydrodynamic climate contains a significant swell component with the predominant waves originating from the north-east and north-north-east, arising from the North Atlantic. Under certain conditions, swell can also propagate into the southern North Sea.

10.4.2 Extreme wave heights in the North Sea show a significant decrease from the north to south. Based upon the 10 year return period, the extreme wave height varies from 16m, in the north, to 7m, in the south. This large difference results from a number of factors:

- Depth limitation effects;
- Extreme mean wind speed variation; and
- Breaking/refraction processes.

10.4.3 Such changes in the wave climate will lead to significant variations in the sea bed processes, such as boundary layer thickness and turbulence, which impact on sediment transport processes.

10.4.4 There is presently some uncertainty regarding whether or not the hydrodynamic climate around the UK is showing temporal change. Any trend is complicated further by the degree of variation within the wave climate, which masks the underlying trend; "what is clear is that the North Sea and north-east Atlantic region is liable to bigger variation of its climate than have hitherto been appreciated" (cf. Lamb, 1985). Data obtained from the north-east Atlantic (Carter and Draper, 1988) has been used to show that, between 1962 and 1984, significant wave heights have increased. This trend would imply that there has been a gradual increase in storminess over this period. However, the most recent research into this trend shows that, although there has been an increase in wave height and storminess since 1962, the recorded values of the last two decades are comparable to those obtained from the beginning of the 20th century (WASA, 1998).

10.5 Storm Surge

10.5.1 Extreme water levels along the East Coast are dominated by surges, which act to increase the water levels by > 2 m. The surge effect increases from north to south, due to the funnelling effect of the North Sea (Huntley, 1980).

10.5.2 The North Sea is highly susceptible to storm surges, in response to a number of characteristic features:

- shallow water depth in the south;
- large area over which the wind stress can build up; and
- a northern opening, which lies in the track of many atmospheric depressions passing between Iceland and Scotland.

10.5.3 The storm surges of the North Sea can be divided into two types:

- external; and
- internal.

10.5.4 External surges originate from the shelf seas off northern Scotland and propagate into the North Sea, with only small changes in amplitude. It has been suggested, although not proven, that another source of external surges could be deep ocean disturbances generated in the Atlantic, which propagate into the shallow Scottish shelf waters (Heaps, 1969). The internal surges result from wind action over the North Sea and can be generated either in localised areas, or over the whole area. Low pressure systems could also be important for internal surges. It should be noted that the non-local internal surges are typically combined with external surge characteristics.

10.5.5 Probably the most well-known storm surge is the disastrous event of 1953. A deep depression passed to the north of Scotland, before veering south-eastwards into the North Sea, causing a shift in the wind direction. This movement resulted in very severe north-westerly gales over the majority of the North Sea (Huntley, 1980) and as a result water piled up creating a surge, which raised the sea level by more than 2.4 m in places (Harland and Harland, 1979).

10.5.6 Although North Sea storm surges have the potential to be disastrous, there are a number of factors which act to reduce the frequency occurrence of these events (Huntley, 1980): (1) the time of high water (HW) and (2) Inflow/outflow through the Dover Straits for an outflow through the Straits can suppress surge residuals by up to 1 m (Heaps, 1969).

10.5.7 Short-lived storm surges tend to be confined to the rising tide, rather than HW. The explanation for this is that: ‘the long duration of a positive surge relative to the semi-diurnal tide, results in an effective increase in the mean water depth on which the tidal wave is superimposed. Hence the tidal wave travels faster than expected, resulting in a tide whose high point reaches a given point earlier than predicted. When the predicted tidal curve is subtracted from the resulting time-displaced tidal curve, the resulting maximum positive residual occurs on the rising tide. This then combines with the surge to produce a surge maximum; at the predicted time of HW the tide-surge interaction residual will be negative, thus lowering the total residual caused by the surge’ (Huntley, 1980);

10.5.8 Note that future changes in storm surge levels may be important in future shoreline evolution since present evidence suggests that these surge levels have increased over the past 100 years (OSPAR Report, 2000).

11. Tidal Flood Risk

11.1 Historical Flooding

11.1.1 There is limited information available concerning tidal flooding along the North Tyneside Coastal frontage. There are a number of events pre 1980 that have been recorded where tidal flooding affect homes and commercial properties which include October 1824, February 1827, February 1868 and January 1834 (Water Cycle Study, April 2013)

11.1.2 Since 1980 there have been a number of individual flooding events along the North Tyneside frontage, 1980, 1996 and 2003.

11.1.3 Fish Quay tends to experience flooding quite frequently, the previous Coastal Strategy Plan indicated that tidal flooding occurred along this stretch at least 5 times a year, mainly shallow floods on high tides with easterly/north easterly wind.

11.1.4 Along the left banks at North Shields the elevations tend to be lower thus the riverside road and many properties flooding. . Much of the Fish Quay area is below the 10-year tide level, although parts of it, such as Union Quay, are protected by slightly higher bank levels. At the 25-year level, the car park along the Western Quay, Bell Street, the shops along Union Quay, the roads and buildings surrounding Cliffords Fort, the Fish Market and the Lifeboat Station are all at risk. Depths and likelihood of property flooding increase up to the 200-year return period, when depths could be up to 1m around the Fish Market. (Rivers Tyne and Derwent FRM Study, 2005).

11.1.5 North Tyneside Council have GIS datasets which show the properties that have experienced flooding during the following flood events 2005 (flooding occurred at 598 properties), 2007 (flooding occurred at 74 properties) and 2008 (flooding occurred at 171 properties). Some of the same properties flooded in multiple events, however it does not show the source or severity of the flooding rather than it was just flooded. The data represents surveys of flooding done by Traffic, Dev - Engineering, Design and Partnering.

11.2 Storm Surge, December 2013

11.2.1 At the beginning of December 2013 (5th and 6th), the East coast of Britain experienced the largest tidal surge in 65 years. The surge, which saw around 1,400 properties flooded in Britain, resulted in record sea levels, which in places were higher than those seen during the devastating floods of January 1953. Environment Agency warnings had suggested that the North Tyneside area would be affected by tides up to a height of 3.61m at North Shields the tide peaked at 4.03m.

11.2.2 The two days of severe weather in the North East has caused travel disruption and storm damage in our region after strong winds and rain combined to create a tidal surge which caused several rivers to burst their banks. Teams of staff from North Tyneside Council have been patrolling the local coast ensuring areas affected by the tidal surge were safe.

11.2.3 Following the event most of Long Sands beach was closed off due to concerns of stability of the sand dunes and missing fencing. Concrete and tarmac is missing from Watts Slope, the area outside the Boardwalk Café in Whitley Bay, making it potentially hazardous. At High Point, where fencing is missing, workers have made the area safe, since there is a drop of around 20 feet onto the rocks and sea below. Tynemouth Long Sands beach has sustained substantial coastal edge damage with a significant amount of sand gone from the shore. This will be replaced through the natural process of renewal. There has also been some damage to the caves at Cullercoats Bay.

11.2.4 Further details of the exact damage are provided in TR04 Existing Defence and Historical Expenditure, and the intensity of the waves and tide levels are provided in Section 4 and 5, experienced during the December 2013 storm surge.

11.3 Environment Agency

11.3.1 The North Tyneside coastline covers a length of 15km from Seaton Sluice to Fish Quay north of the River Tyne estuary. The coastline is a mix between cliff frontage to the north, a number of bays and sea walls from Whitley Bay to Tynemouth North Pier and heavily defended concrete masonry walls around Fish Quay. Due to the nature of the coastline, tidal flood risk is relatively small. Both Flood Zone 2 and 3a follow the Mean High Water (MHW) line, placing no properties at risk, except along Fish Quay.

11.3.2 The tidal sources at North Tyneside are the North Sea and Tyne Estuary. The National Planning Policy Framework (NPPF) provides a definition of the following tidal Flood Zones as provided in Table 11-1.

11.3.3 Tidal flood risk areas defined by the Environment Agency Flood Zones are shown in Annex D. The flood zones indicate that tidal flood risk threatens a narrow area immediately adjacent to the estuary and coast.

Table 11-1 NPPF (March 2012) Tidal Flood Zone Definitions

Flood Zone	Defintion	Probability of Flooding
1	Land at risk from flood event less than the 1 in 1000 year event (less than 0/1% annual probability of flooding each year)	Low Probability
2	Land at risk from flood event between the 1 in 200 and 1 in 1000 year event (between 0.5% and 0.1% annual proability of flooding each year)	Medium Probability
3a	Land at risk from flood event equal to, or greater than, the 1 in 200 year event (greated than 0.5% annual proability of flooding each year)	High Probability
3b	Land where water has to flow to be stored in time of flood or land purposely designed to be flooded in an extreme flood event (0.1% annual probaiblity). The 1 in 20 year annual probability floodplain is the starting point for consideration but	Function Floodplain

	local circumstances should be considered and alternative proability can be agreed between the LPA and the EA	

11.3.4 NPPF Technical Guidance, allowances for climate change, based on the UKCIP02 scenarios, should be made on tidal flood sources for a 75 and 100 year design horizon. This requires an assessment of the impact of 10% sensitivity allowance on offshore wind speeds and extreme wave heights for the period 2055-2115 when modelling flood events (WCS, April 2013).

11.3.5 There are Flood Warning Areas (FWA) located along the North Tyneside Council coastal frontage. Flood warning schemes have been set up for a number of areas that are considered to be at particular risk from flooding, these areas are called FWA. Within these areas the EA are able to warn residents in advance when flooding may be likely to occur and how severe the flooding could be. Some FWA within North Tyneside Council area cross over administrative boundaries i.e. 121FWTNST50 - Tyne Estuary.

11.3.6 The FWA are detailed below:

1. 121FWTNWT40 - Whitley Bay, Whitley Sands Cafe
2. 121FWTNWT41 - Cullercoats Bay
3. 121FWTNWT42 - Tynemouth Long Sands
4. 121FWTNWT43 - Tynemouth Sailing Club
5. 121FWTNWT44 - North Shields, Fish Quay
6. 121FWTNWT45 - North Shields, Western Quay Promenade
7. 121FWTNWT49 - Tyne Estuary Riverside
8. 121FWTNST50 - Tyne Estuary
9. 121FWTNWT70 - Cullercoats Bay

12. References

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CH2MHILL, August 2014, *Cell 1 Regional Coastal Monitoring Programme: Walkover Visual Inspection of Assets North Tyneside Council Final Report*

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Annex A: Derivation of Coastal Recession Rates

A.1 Methodology

This strategy review has used the same methodology to derive recession rates as was used in the original strategy as the historic erosion rate from the soft cliffs in Whitley Bay was found to be the same. The method uses a simple model that adjusts the historic erosion rate by a number of factors to take account of expected future changes in key factors that affect erosion, namely sea level rise, rainfall, beach levels, shoreline exposure and shoreline management policies. A full explanation of the development of the methodology is included in Appendix B of Technical Report 2 of the original strategy and a shortened explanation is presented below.

The model is presented in Figure A-1 and involves a series of stages at which judgements, based on available data, are made about the need to adjust the historic recession rate because of changing future conditions.

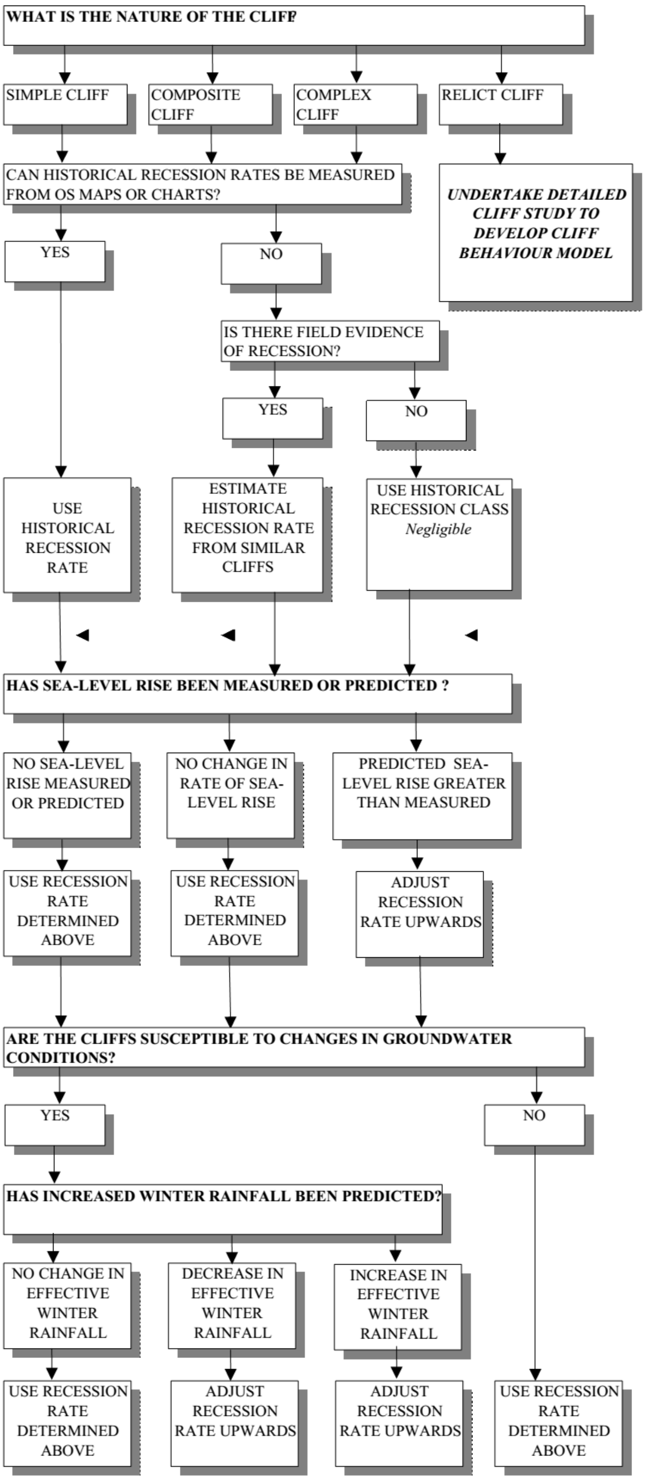


Figure A-1: Model methodology

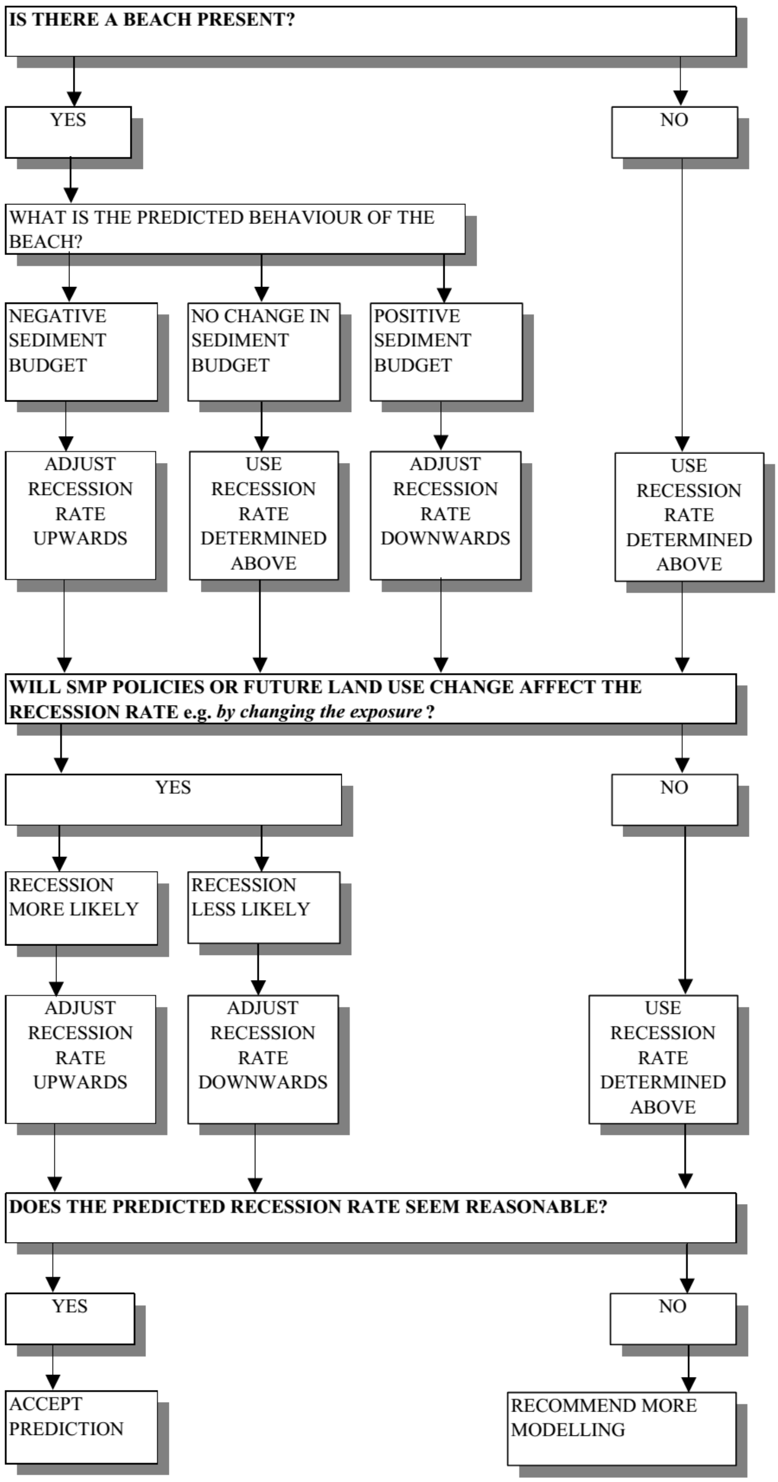


Figure A-1: Model methodology (continued)

For example, consider a composite cliff that has been retreating at an average annual rate of 1.0m per year. Available data suggests that the rate of sea level rise will be higher than the historic rate, beach levels will decline faster due to a net deficit in the sediment budget and that shoreline exposure would increase due to loss of a protective headland. In this case the predicted erosion rate would be calculated as follows:

Predicted recession rate = historic rate x sea level rise factor x sediment budget factor x exposure factor

Where:
- Sea level rise factor represents the change in the annual average recession rate due to changes in sea level rise
- Sediment budget factor represents the change in the annual average recession rate due to the change in the degree of protection provided by the beach
- Exposure factor represents the change in the annual average recession rate due to the reduction in protection provided by the headland

As there is a degree of uncertainty in predictions of the changes in these factors it is possible to produce a series of possible cases, each with different combinations of changes in the factors. Each of these possible scenarios will produce a different recession rate and can be assigned a conditional probability as follows:

Probability (case *n)* = Prob. (sea level rise) x Prob. (rainfall) x Prob. (beach levels)

The sum of probabilities for all possible cases adds up to 1.0.

The model was adapted for use in the strategy to produce a probability distribution for the average annual recession rate applicable over the following time periods:

Scenario 1: 0-20 years
Scenario 2: 0-25 years
Scenario 3: 0-50 years
Scenario 4: 0-100 years

Development of the model involved:

1. Determination of historic recession rates – as described in Section 3 of this report, historic recession rates were determined by comparing cliff toe positions between OS mapping from 1955 and aerial photography from 2010. Exposed and undefended soft cliffs used the derived rate of 0.3m per year. Areas of similar geology, but which are less exposed used a rate of 0.2m per year. Areas of hard rock used a rate of 0.1m per year after failure of defences, where present.
2. Assigning subjective probabilities – The original strategy team made judgements on the following factors:
    a. The probability of the future rate of sea level rise being 0mm, 1mm, 2mm, 3mm, 4mm, 5mm, or 6mm per year.
    b. The probability of the beach experiencing net loss, net accretion or no change (sediment budget factor).
    c. The probability of a change in the degree of exposure experienced along the coastline, e.g. the gradual emergence or loss of a headland.

    Table A-1 presents the probabilities for each of the factors that were used in each of the four scenarios.

3. Determining appropriate adjustment factors – to reflect the available knowledge of specific conditions at the site for each of the factors as follows:
    a. Sea level rise – the methodology uses a modified form of the Bruun Rule to predict the change in average annual recession rate resulting from sea level rise opf between 0mm and 6mm in 1mm increments. The results are presented in Tables A-2 and A-3.
    b. Sediment budget factor – this was considered for three conditions: no change, net accretion and net depletion. An adjustment of 1.0 was used for no change, 0.8 for net accretion and 1.5 for net depletion. Adjustment factors for the four scenarios are presented in Table A-4
    c. Exposure factor – this factor reflects the judgement on the expected emergence or loss of headlands and considered three conditions: no change in exposure, net reduction in exposure and net increase in exposure. Adjustment factors used were 1.0 for no change, 0.75 for net reduction in exposure and 1.5 for net increase in exposure. Adjustment factors for the four scenarios are presented in Table A-5.

A.2 Results

The model results provide a probability distribution for the average annual recession rate that would be applicable over the four scenarios. These are projected over the relevant time period (10, 20, 50, or 100 years) and yield a probability distribution of the position of the cliff top at the end of that time period.

Table A-6 presents the predictions for the undefended soft cliff area of the Golf course for the current erosion rate of 0.3m per year. The results show that over the 50 year period the 50%ile estimate of cliff erosion is 40m, whereas the 98%ile is 93m.

Table A-7 presents the predictions for the defended, sheltered and undefended hard geology areas using a current rate of 0.15m per year. The results show that over a 50 year time period the 50%ile estimate of cliff recession is 20m, whereas the 98%ile is46m.

A.3 Discussion

The results show that for softer undefended areas the estimate for the 98%ile is more than double that for the 50%ile. The predicted recession rates for the harder more sheltered areas are half that predicted for the softer more exposed areas of coastline.

North Tyneside Coastal Erosion Study: Sheltered, undefended and defended hard geology sections.

Scenario 1: Average Clif Top Recession Rate Over 10 years

Rate of Sea-level Rise m/year	Estimated Probability	Sediment Budget	Estimated Probability	Shoreline Exposure	Estimated Probability	Rationale
0	0	Accretion	0.01	Less exposed	0.01	
0.001	0.1	No Change	0.95	No change	0.95	
0.002	0.75	Depletion	0.04	More exposed	0.04	
0.003	0.1					
0.004	0.05					
0.005	0					
0.006	0					

Scenario 2: Average Clif Top Recession Rate Over 25 years

Rate of Sea-level Rise m/year	Estimated Probability	Sediment Budget	Estimated Probability	Shoreline Exposure	Estimated Probability	Rationale
0	0	Accretion	0.05	Less exposed	0.01	Sediment budget conditional on fate
0.001	0.05	No Change	0.7	No change	0.95	of outfall structure
0.002	0.2	Depletion	0.25	More exposed	0.04	
0.003	0.5					
0.004	0.2					
0.005	0.05					
0.006	0					

Scenario 3: Average Clif Top Recession Rate Over 50 years

Rate of Sea-level Rise m/year	Estimated Probability	Sediment Budget	Estimated Probability	Shoreline Exposure	Estimated Probability	Rationale
0	0	Accretion	0.05	Less exposed	0.01	Sediment budget conditional on fate
0.001	0	No Change	0.7	No change	0.95	of outfall structure
0.002	0.05	Depletion	0.25	More exposed	0.04	
0.003	0.2					
0.004	0.5					
0.005	0.2					
0.006	0.05					

Scenario 4: Average Clif Top Recession Rate Over 100 years

Rate of Sea-level Rise m/year	Estimated Probability	Sediment Budget	Estimated Probability	Shoreline Exposure	Estimated Probability	Rationale
0	0	Accretion	0.05	Less exposed	0.01	Sediment budget conditional on fate
0.001	0	No Change	0.7	No change	0.95	of outfall structure
0.002	0.05	Depletion	0.25	More exposed	0.04	
0.003	0.15					
0.004	0.5					
0.005	0.25					
0.006	0.05					

Table A-1 Probabilities for sea level rise, sediment budget and shoreline exposure

R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2
0.3	0.0018	0	0.25	2100	16	15	-0.0018	7.75	-0.488	-0.188
0.3	0.0018	0.001	0.25	2100	16	15	-0.0008	7.75	-0.217	0.083
0.3	0.0018	0.002	0.25	2100	16	15	0.0002	7.75	0.054	0.354
0.3	0.0018	0.003	0.25	2100	16	15	0.0012	7.75	0.325	0.625
0.3	0.0018	0.004	0.25	2100	16	15	0.0022	7.75	0.596	0.896
0.3	0.0018	0.005	0.25	2100	16	15	0.0032	7.75	0.867	1.167
0.3	0.0018	0.006	0.25	2100	16	15	0.0042	7.75	1.138	1.438

Table A-2 Bruun Rule: soft undefended and exposed areas - predicted recession rates due to sea level rise

R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2
0.15	0.0018	0	0.25	2100	16	15	-0.0018	7.75	-0.488	-0.338
0.15	0.0018	0.001	0.25	2100	16	15	-0.0008	7.75	-0.217	-0.067
0.15	0.0018	0.002	0.25	2100	16	15	0.0002	7.75	0.054	0.204
0.15	0.0018	0.003	0.25	2100	16	15	0.0012	7.75	0.325	0.475
0.15	0.0018	0.004	0.25	2100	16	15	0.0022	7.75	0.596	0.746
0.15	0.0018	0.005	0.25	2100	16	15	0.0032	7.75	0.867	1.017
0.15	0.0018	0.006	0.25	2100	16	15	0.0042	7.75	1.138	1.288

Table A-3 Bruun Rule: sheltered undefended and defended hard areas - predicted recession rates due to sea level rise

	Adjustment Factor	Rationale
Accretion	0.8	
No Change	1	
Depletion	1.5	Based on Bullen 2001

Table A-4 Sediment budget factors

	Adjustment Factor	Rationale
Less exposed	0.75	
No Change	1	
More exposed	1.5	

Table A-5 Exposure factors

Period (Years)	50% ile Recession (m)	90% ile Recession (m)	98% ile Recession (m)
10	**3.0**	**5.5**	**9.0**
20	8.7	15.7	24.0
25	**12.5**	**22.5**	**33.7**
30	16.8	29.7	43.5
40	27.2	46.8	66.0
50	**40.0**	**67.5**	**92.5**
60	55.8	93.2	125.5
70	74.1	123.1	163.4
80	95.0	157.0	206.1
90	118.5	194.9	253.6
100	**144.8**	**237.0**	**306.0**

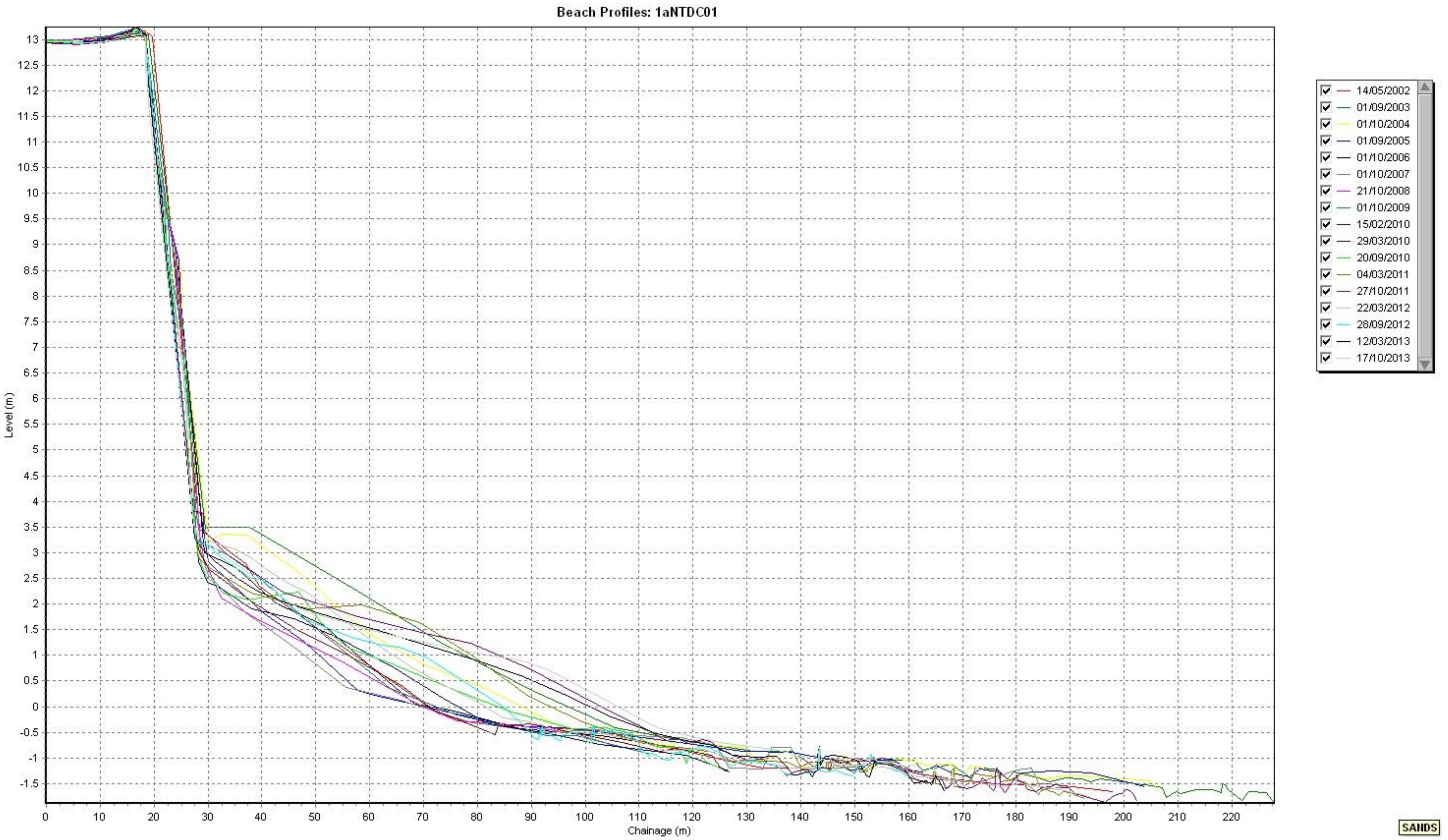
Table A-6 Results of the cliff recession model based on a current recession rate of 0.3m per year

Period (Years)	50% ile Recession (m)	90% ile Recession (m)	98% ile Recession (m)
10	**1.5**	**2.8**	**4.5**
20	4.3	7.8	12.0
25	**6.3**	**11.3**	**16.8**
30	8.4	14.8	21.7
40	13.7	23.4	33.0
50	**20.0**	**33.7**	**46.3**
60	28.1	46.6	62.8
70	37.2	61.5	81.7
80	47.5	78.4	103.1
90	59.1	97.5	126.8
100	**72.4**	**118.5**	**153.0**

Table A-7 Results of the cliff recession model based on a current recession rate of 0.15m per year

Annex B

Beach Profile Time Series Plots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Chainage (m)
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01/10/2009
15/02/2010
29/03/2010
20/09/2010
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28/09/2012
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17/10/2013
SANDS

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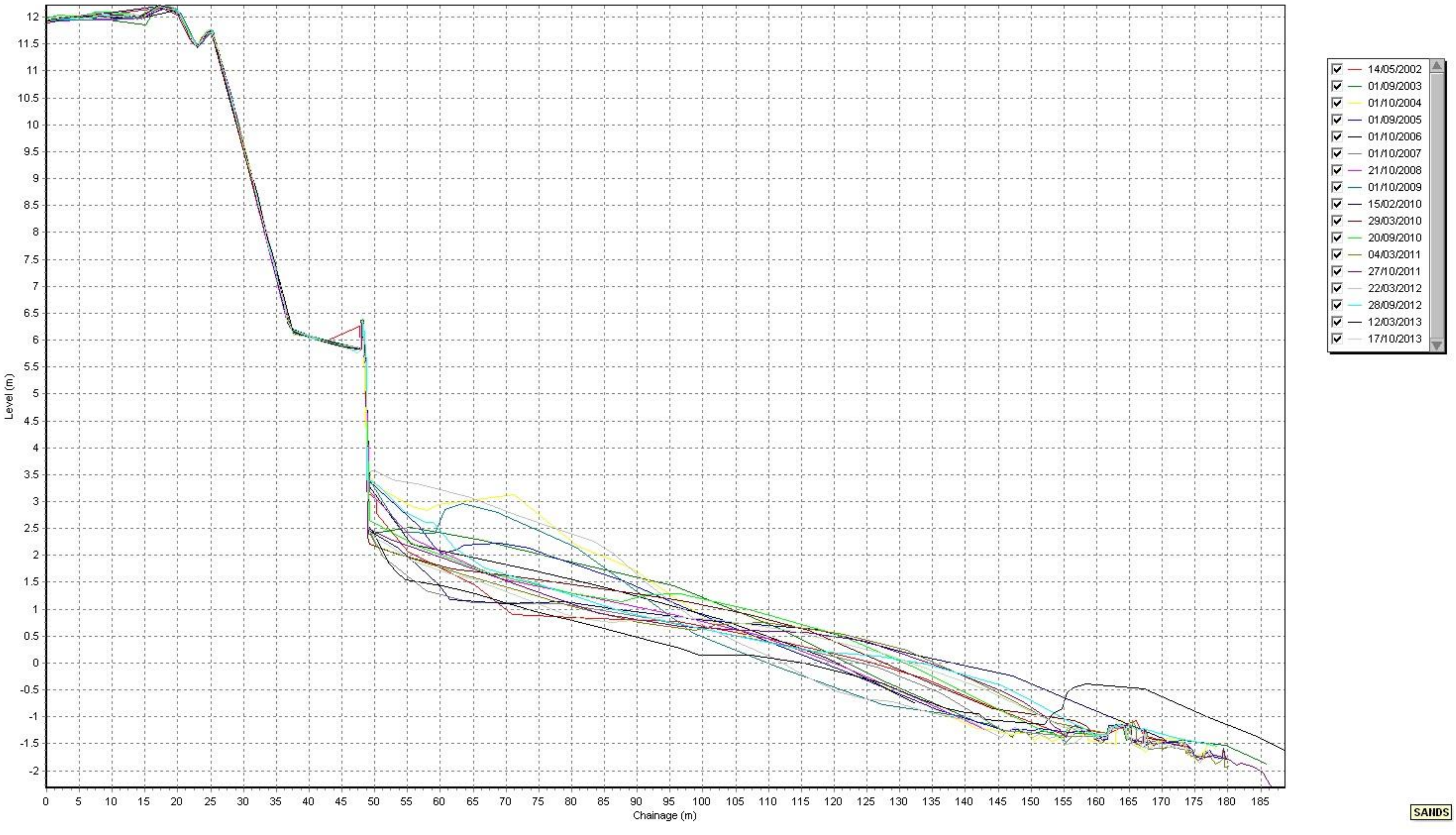

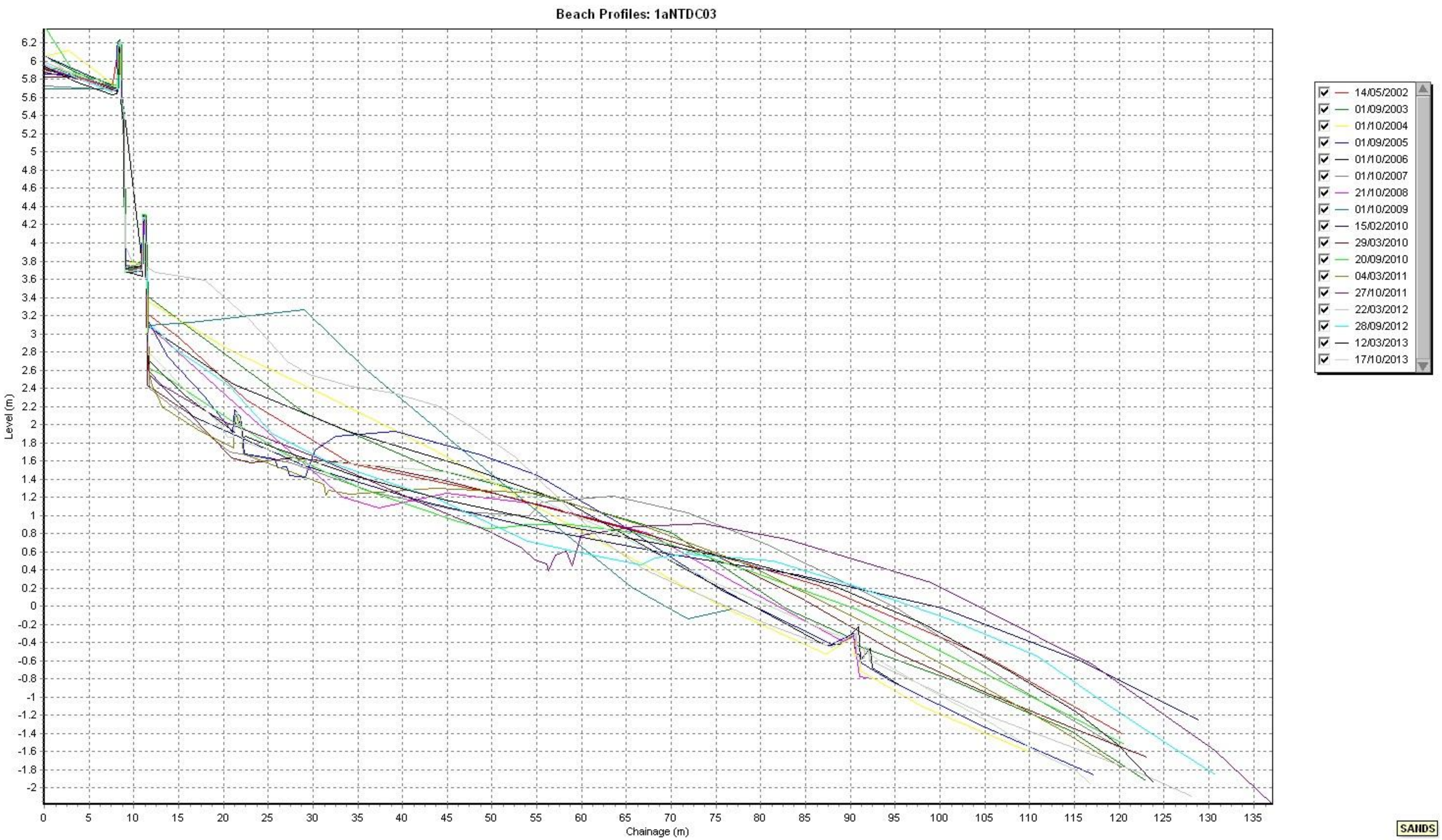
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15/02/2010
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28/09/2012
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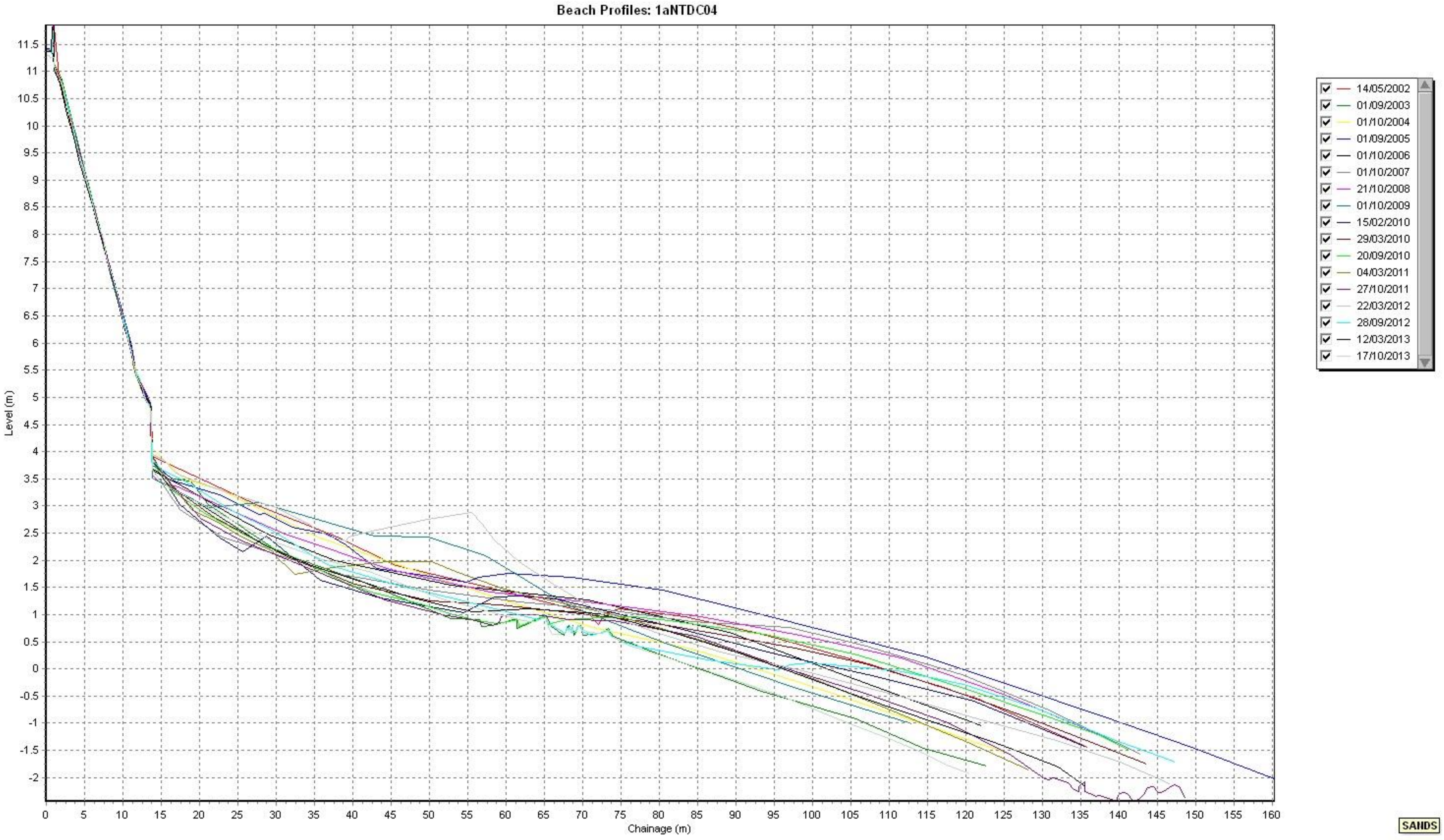
17/10/2013
SANDS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15/02/2010
29/03/2010
20/09/2010
04/03/2011
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22/03/2012
28/09/2012
12/03/2013
17/10/2013
SANDS

Annex B


Beach Profiles: 1aNTDC04A
Level (m)
Chainage (m)
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04/03/2011
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22/03/2012
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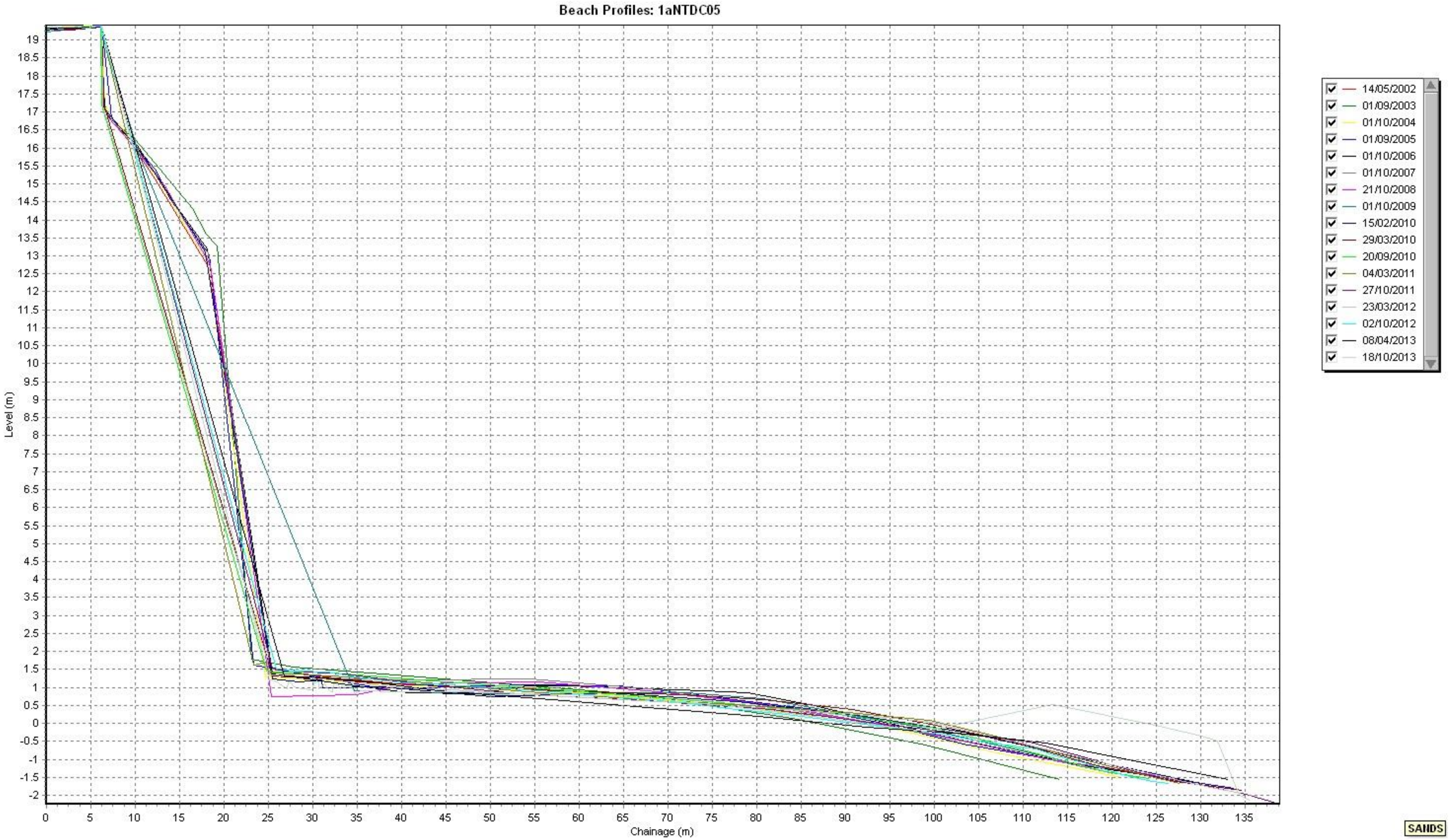
SANDS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15/02/2010
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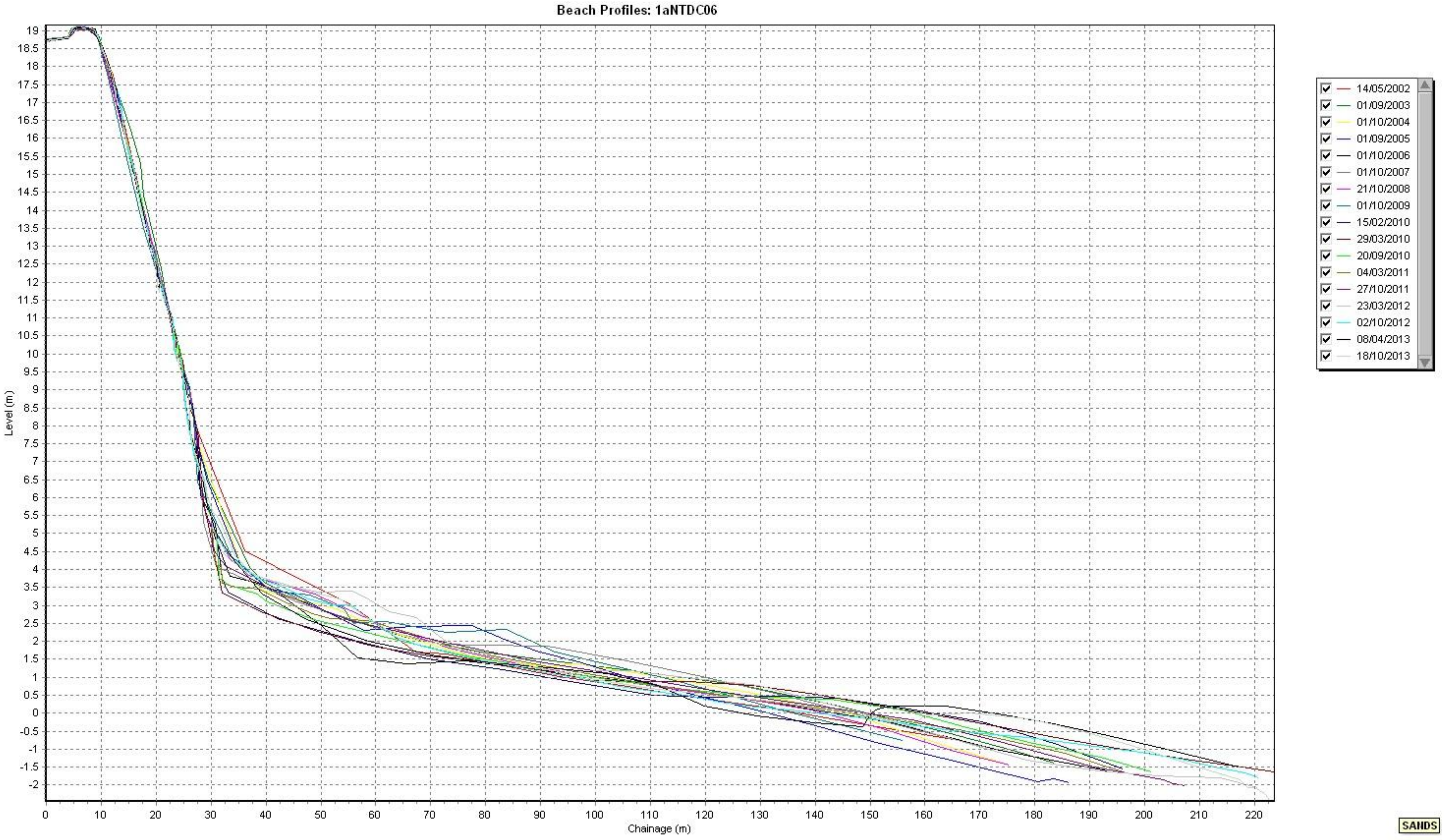
SANDS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15/02/2010
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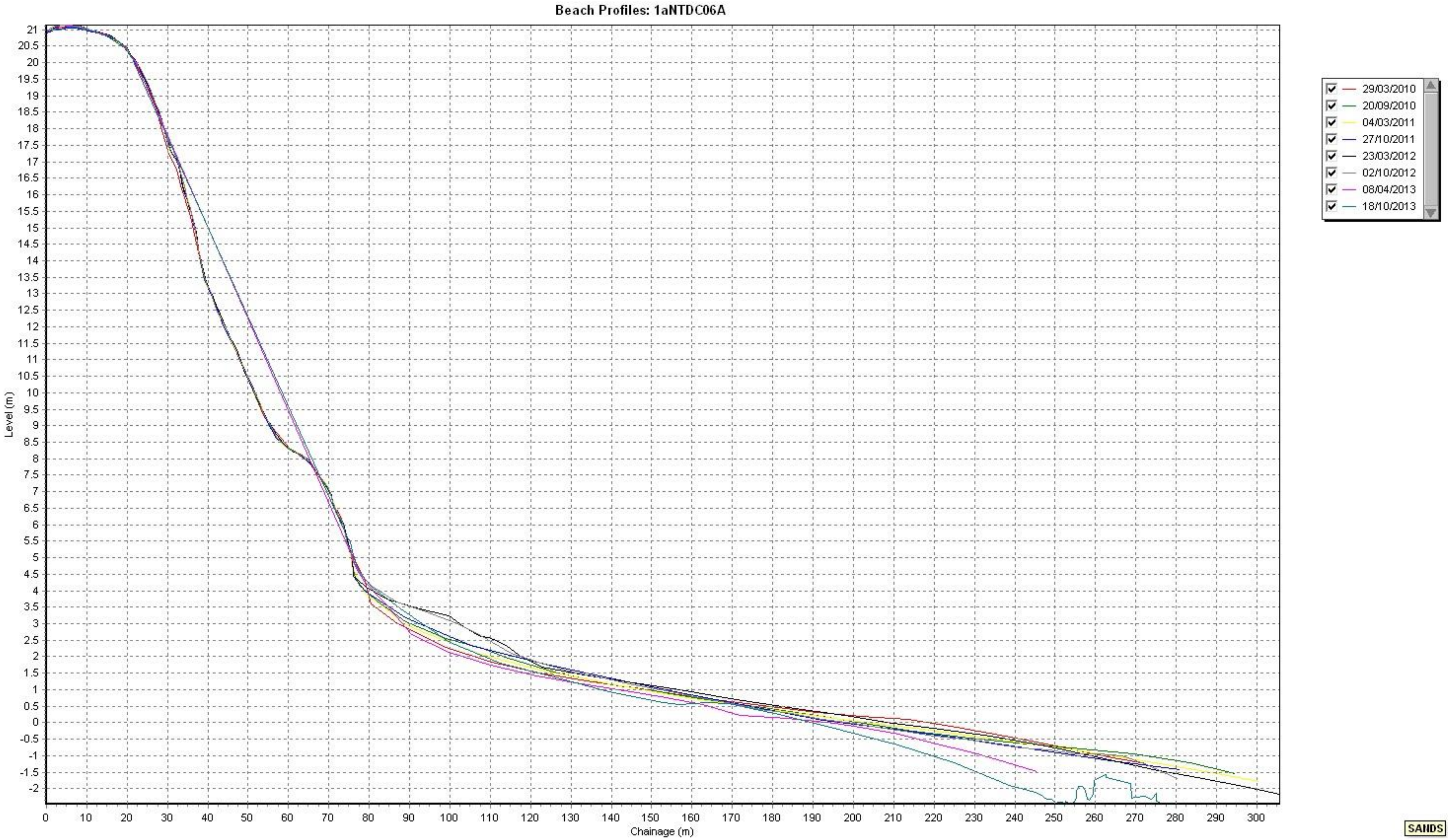
08/04/2013
18/10/2013
SANDS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Chainage (m)
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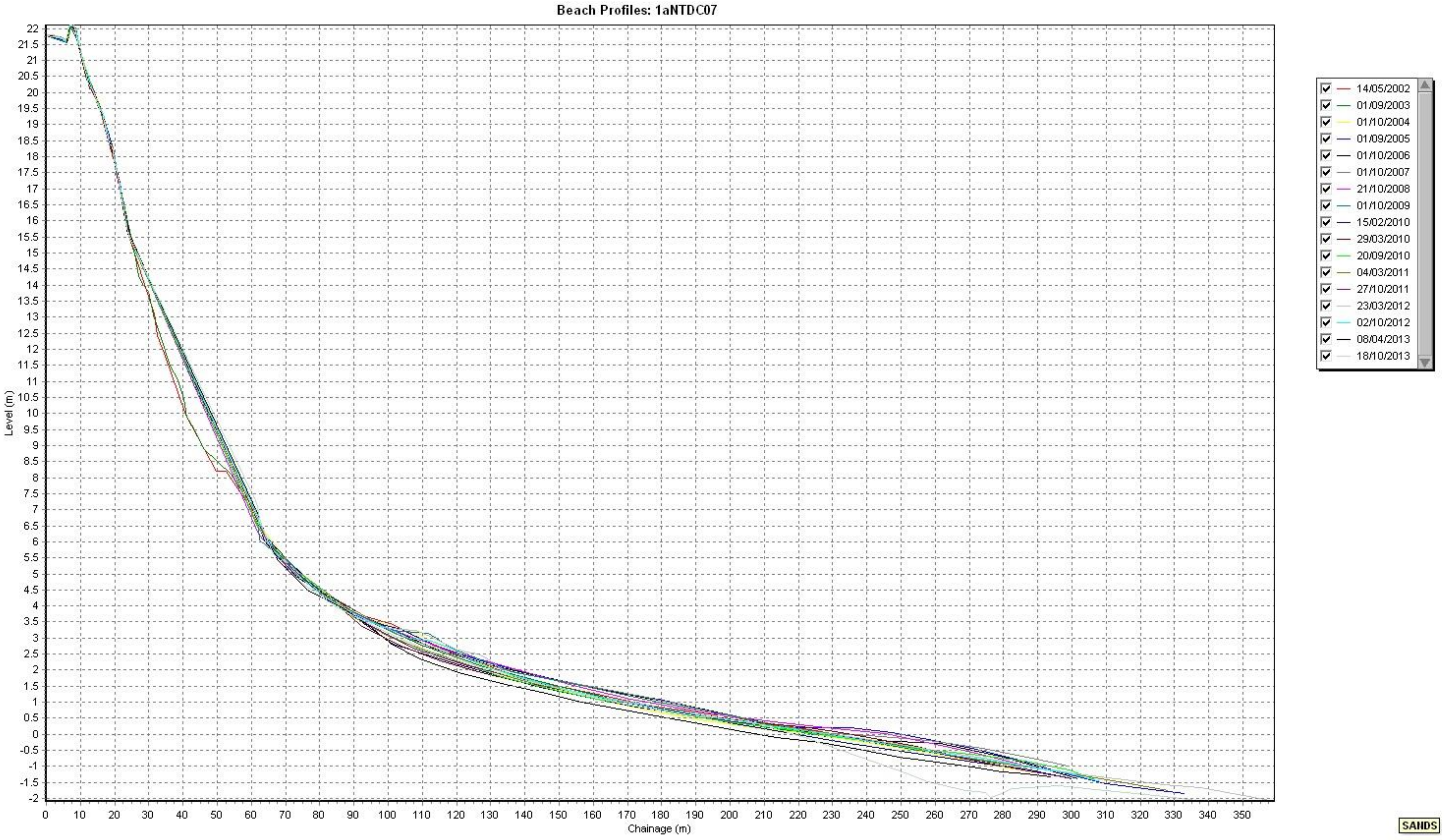
08/04/2013
18/10/2013
SANDS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01/10/2004
01/09/2005
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15/02/2010
29/03/2010
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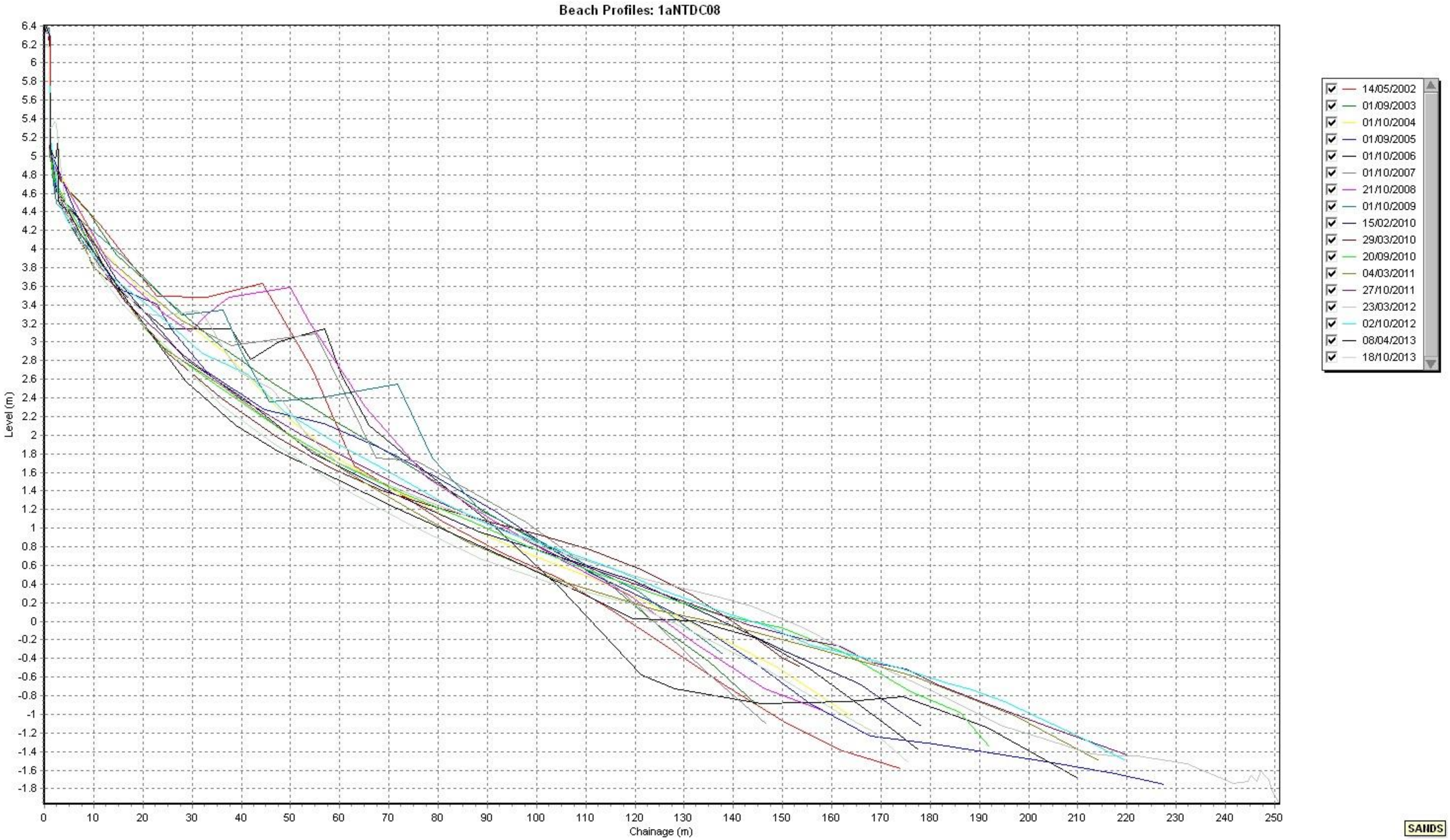
04/03/2011
27/10/2011
23/03/2012
02/10/2012
08/04/2013
18/10/2013
SANDS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15/02/2010
29/03/2010
20/09/2010
04/03/2011
27/10/2011
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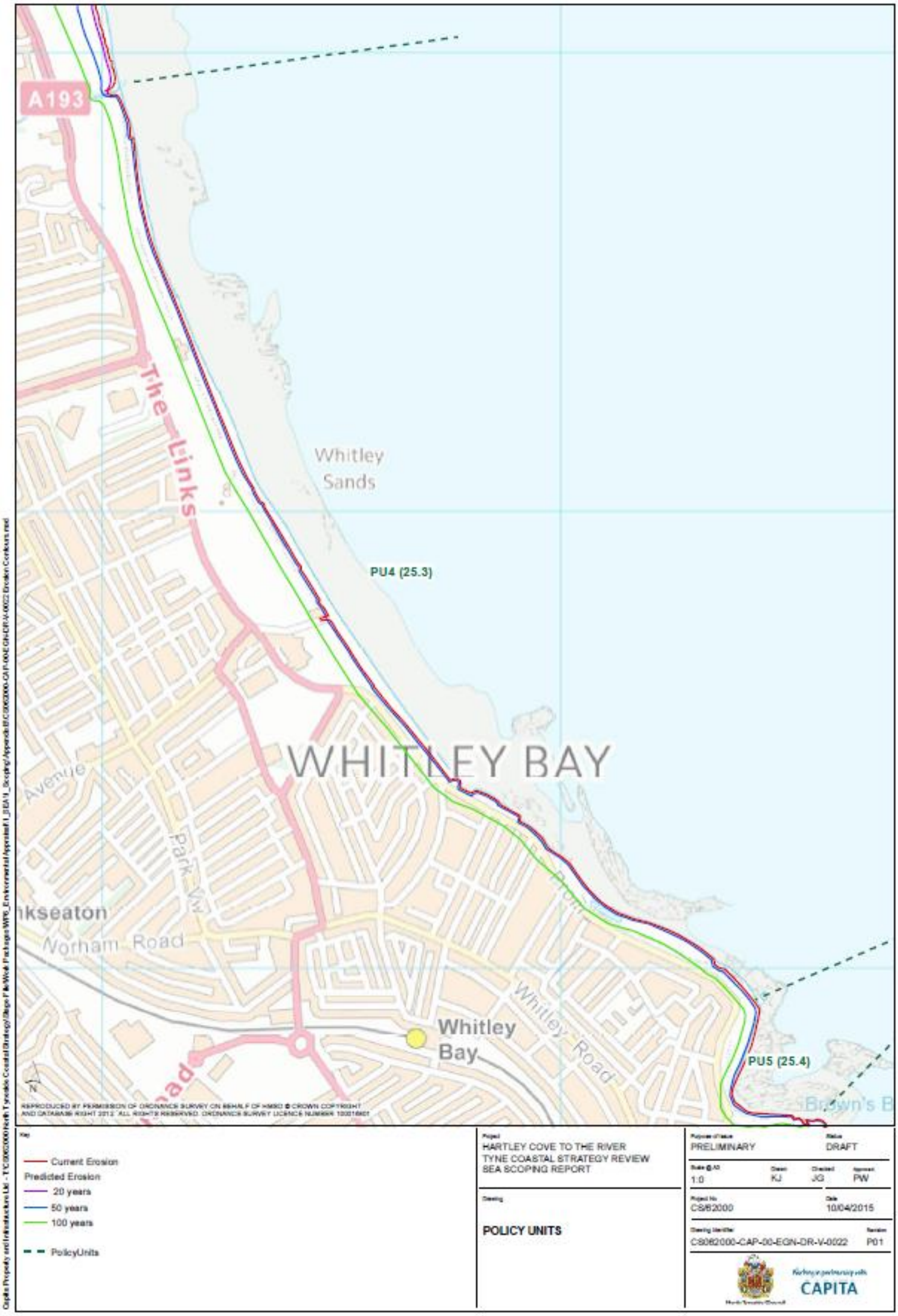
08/04/2013
18/10/2013
SANDS

Annex C
Predicted Erosion Contours

Predicted Erosion Contours


A193
The Links
Whitley
Sands
PU4 (25.3)
WHITLEY BAY
Avenue
Park Vw
ikseaton
Norham Road
Whitley Road
Whitley
Bay
PU5 (25.4)
N
REPRODUCED BY PERMISSION OF ORDNANCE SURVEY ON BEHALF OF HMSO © CROWN COPYRIGHT
AND DATABASE RIGHT 2012. ALL RIGHTS RESERVED. ORDNANCE SURVEY LICENCE NUMBER 100016801
Current Erosion
Predicted Erosion
20 years
50 years
100 years
PolicyUnits
HARTLEY COVE TO THE RIVER
TYNE COASTAL STRATEGY REVIEW
SEA SCOPING REPORT
POLICY UNITS
PRELIMINARY
DRAFT
1:0
KJ
JG
PW
CS/62000
10/04/2015
CS062000-CAP-00-EGN-DR-V-0022
P01
CAPITA


Whitley Bay
Whitley Road
Brown's Bay
Southcliff
Cullercoats
Cullercoats Bay
Smuggler's Cave
Beverley Terrace
Cullercoats
Grand Parade
Long Sands
The Broadway
Broadway
Mast La
Beach Road
A193
A1058
PU5 (25.4)
PU6 (26.1)
PU7 (26.2)
PU8 (26.3)
PU9 (26.4)
PU10 (26.5)
N
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Key
Current Erosion
Predicted Erosion
20 years
50 years
100 years
PolicyUnits
Project
HARTLEY COVE TO THE RIVER TYNE COASTAL STRATEGY REVIEW SEA SCOPING REPORT
Drawing
POLICY UNITS
Purpose of Issue
PRELIMINARY
Status
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Scale @ A3
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Drawn
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Checked
JG
Approved
PW
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Date
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Revision
P01
CAPITA

Predicted Erosion Contours

Key
- Current Erosion

Predicted Erosion
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Project
HARTLEY COVE TO THE RIVER TYNE COASTAL STRATEGY REVIEW SEA SCOPING REPORT

Drawing
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Project No: CS/62000			Date: 10/04/2015
Drawing Identifier: CS062000-CAP-00-EGN-DR-V-0024			Revision: P01

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Annex D
EA Flood Zone Maps

Key
- Flood Zone 3
- Flood Zone 2
- PolicyUnits

Project	HARTLEY COVE TO THE RIVER TYNE COASTAL STRATEGY REVIEW SEA SCOPING REPORT
Drawing	FLOOD ZONES
Purpose of Issue	PRELIMINARY
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Approved	ME
Project No	CS/62000
Date	01/10/2015
Drawing Identifier	CS062000-CAP-00-EGN-DR-V-0031
Revision	P01


A193
The Links
Whitley
Sands
PU4 (25.3)
WHITLEY BAY
Avenue
Park View
Prom
kseaton
Norham Road
Whitley Road
Whitley
Bay
PU5 (25.4)
N
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Flood Zone 3
Flood Zone 2
PolicyUnits
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HARTLEY COVE TO THE RIVER
TYNE COASTAL STRATEGY REVIEW
SEA SCOPING REPORT
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Purpose of Issue
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North Tyneside Council


Whitley Bay
Whitley Road
Cullercoats
Mast La
The Broadway
Broadway
A193
A1058
Beach Road
Beverley Terrace
Grand Parade
Southcliff
Long Sands
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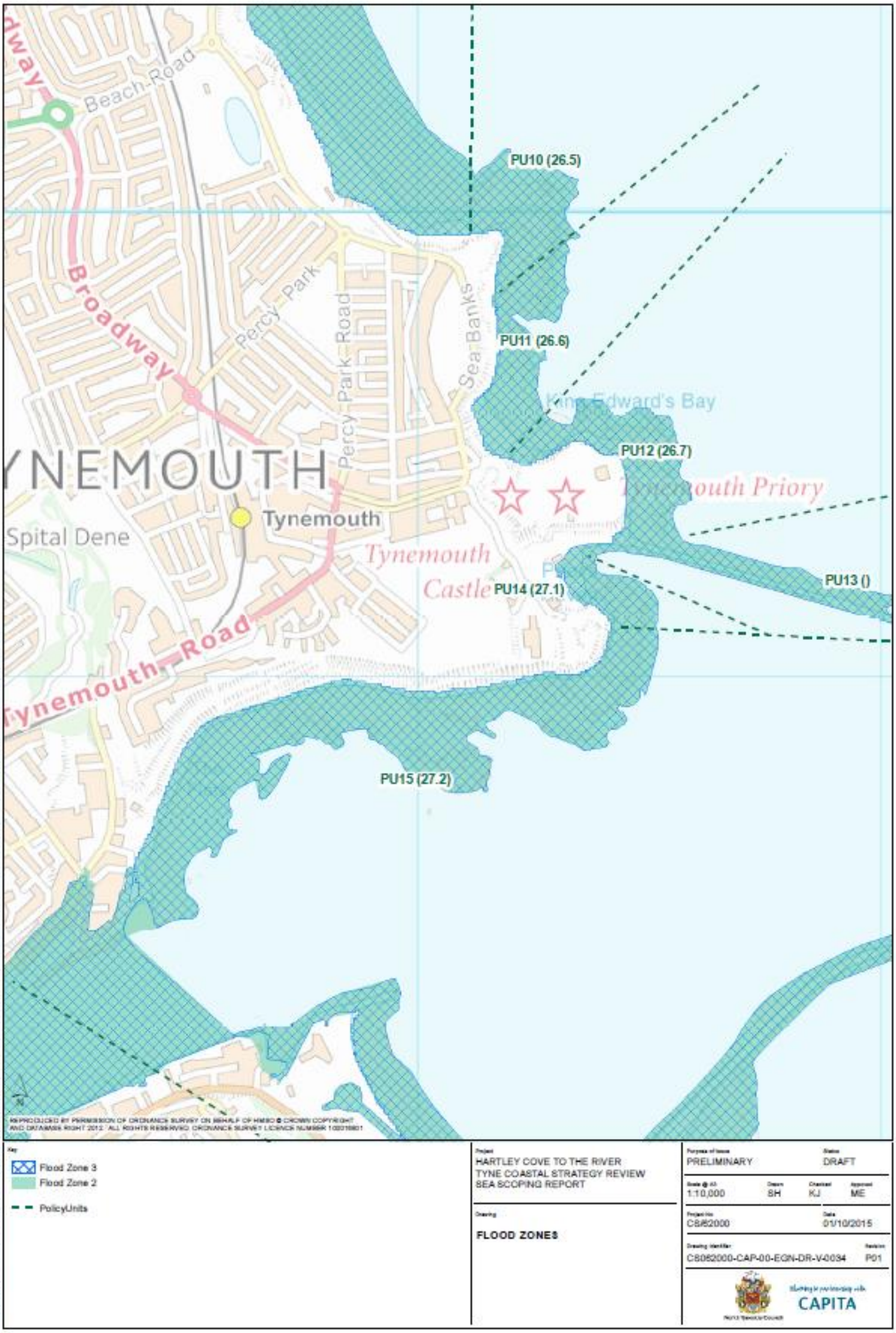
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King Edward's Bay
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Drawing
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Date
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Revision
P01
CAPITA

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