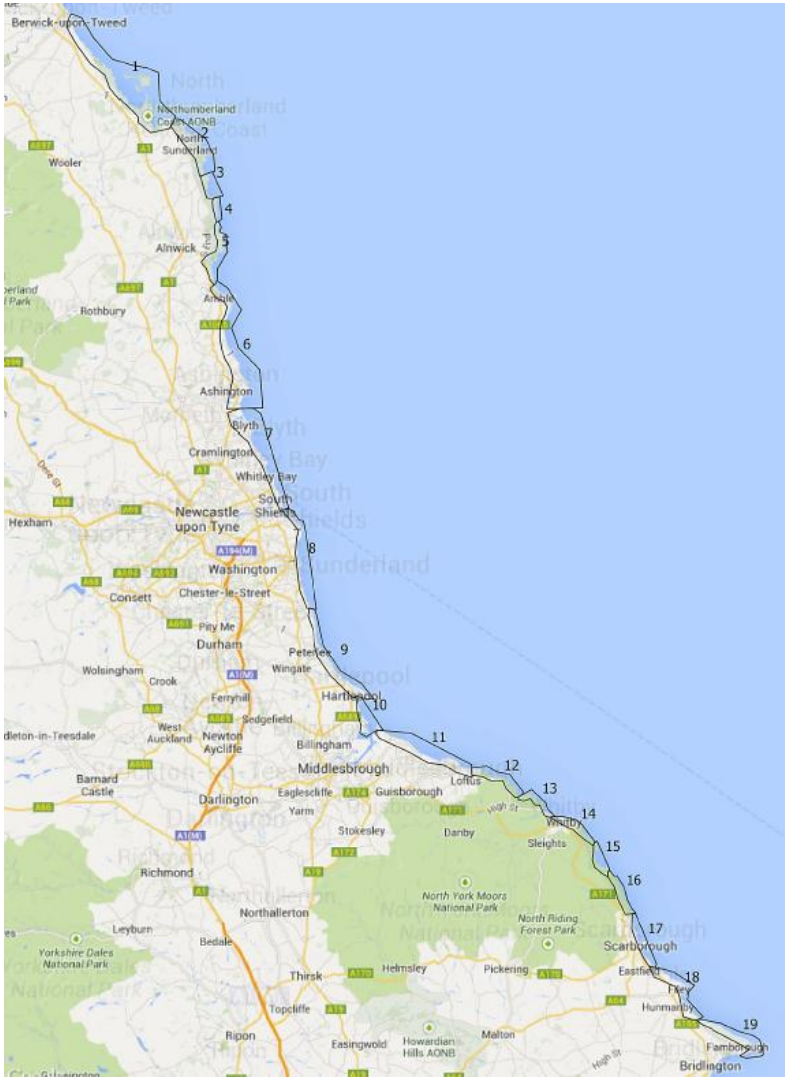
Northumberland County Council
Cell 1 Intertidal Habitats Study

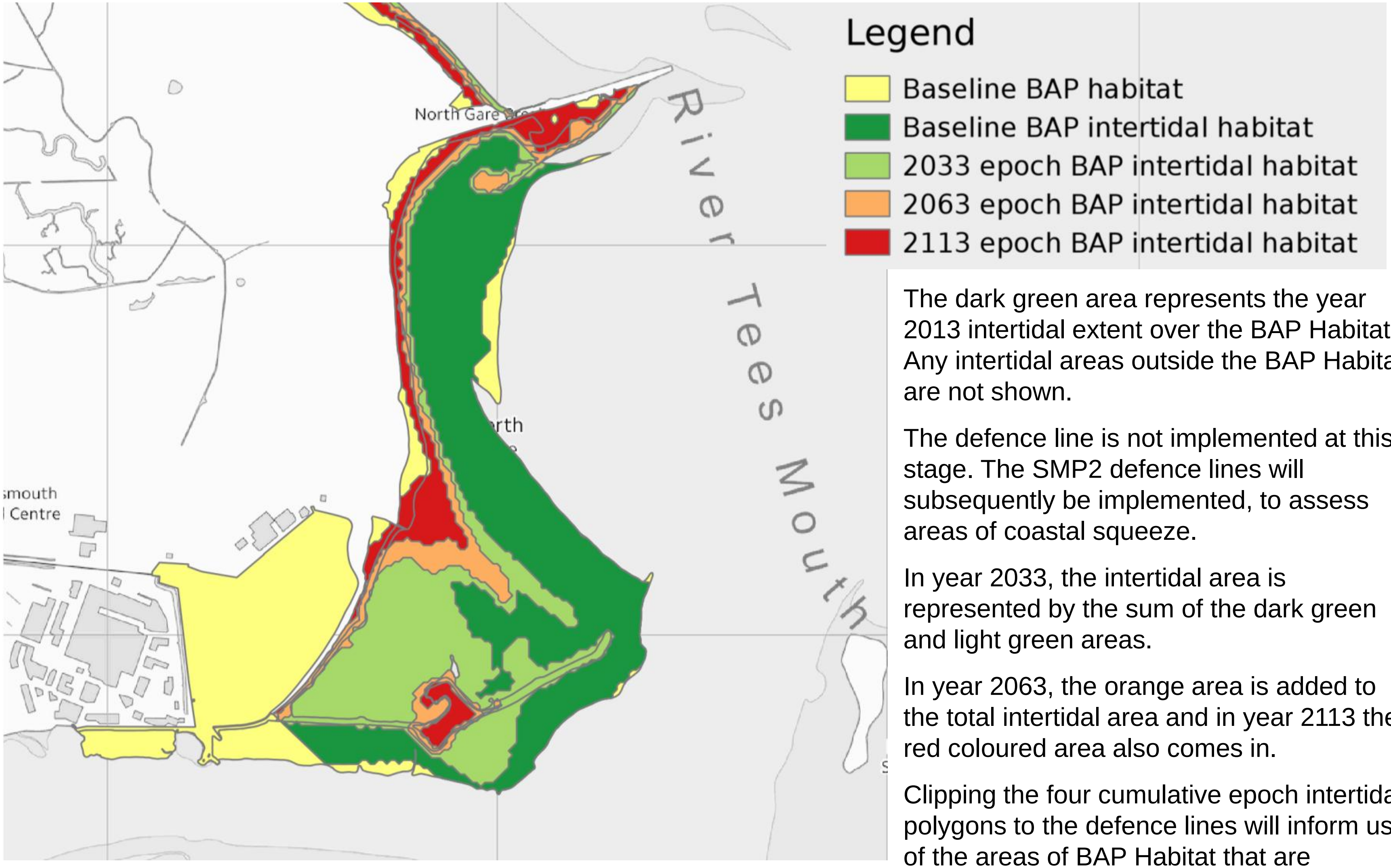


The 19 sub-areas are delineated by the predominant coastline geology type, as this is likely to exert an influencing factor on a number of parameters such as erosion, and the types of habitats present

Example of intertidal BAP Habitat evolution due to projected sea level rise

Seal Sands, Tees Estuary

Example of intertidal BAP Habitat evolution due to projected sea level rise – Seal Sands, Tees



The dark green area represents the year 2013 intertidal extent over the BAP Habitat. Any intertidal areas outside the BAP Habitat are not shown.

The defence line is not implemented at this stage. The SMP2 defence lines will subsequently be implemented, to assess areas of coastal squeeze.

In year 2033, the intertidal area is represented by the sum of the dark green and light green areas.

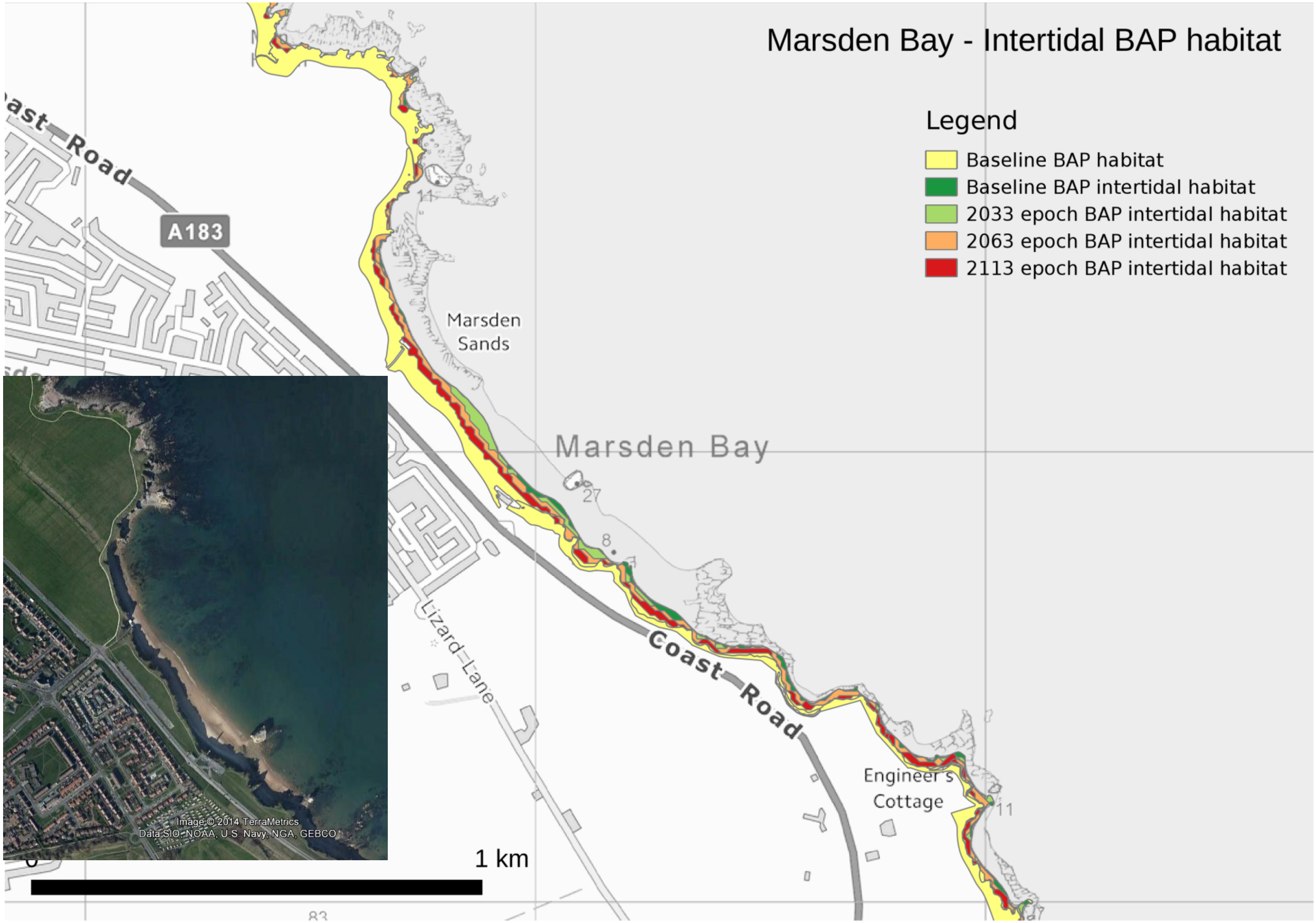
In year 2063, the orange area is added to the total intertidal area and in year 2113 the red coloured area also comes in.

Clipping the four cumulative epoch intertidal polygons to the defence lines will inform us of the areas of BAP Habitat that are squeezed.

Example of intertidal BAP Habitat evolution due to projected sea level rise - Marsden Bay

View looking south towards Marsden Rock

Example of changes to the BAP intertidal habitat in Marsden Bay due to projected sea level rise



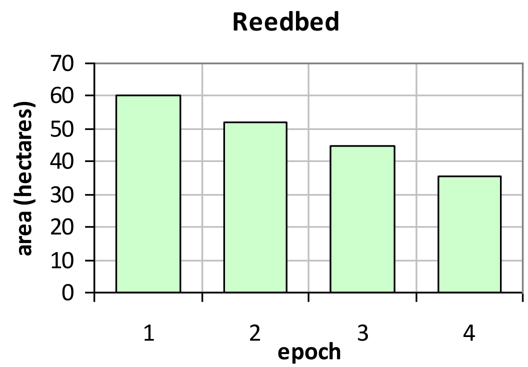
Predictions of evolution in the principle habitat areas during the four epochs

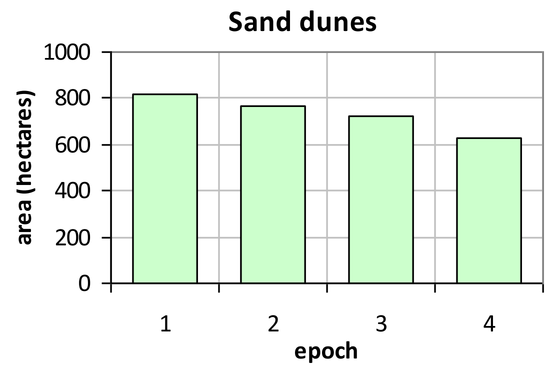
Epoch 1 – present day
Epoch 2 – end of 2033
Epoch 3 – end of 2063
Epoch 4 – end of 2113

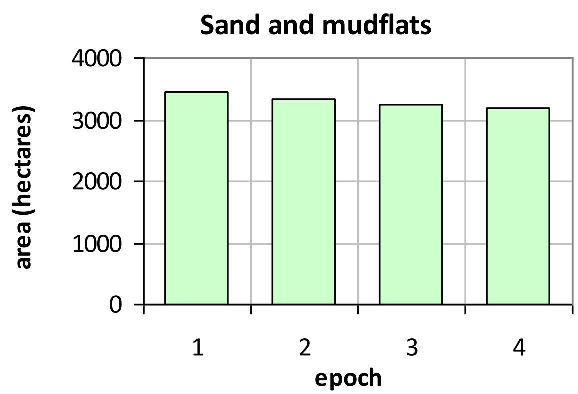
Baseline results, prior to
Implementation of SMP2
Policies

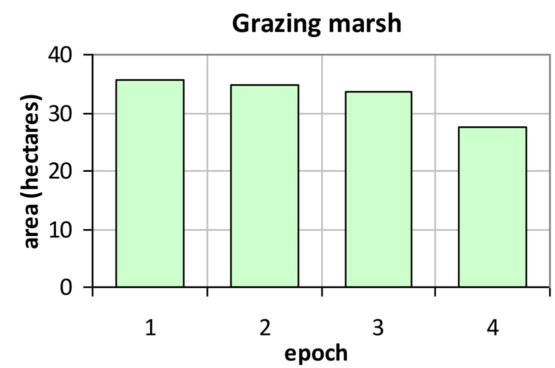
Includes:
Sea level rise
Coastal erosion

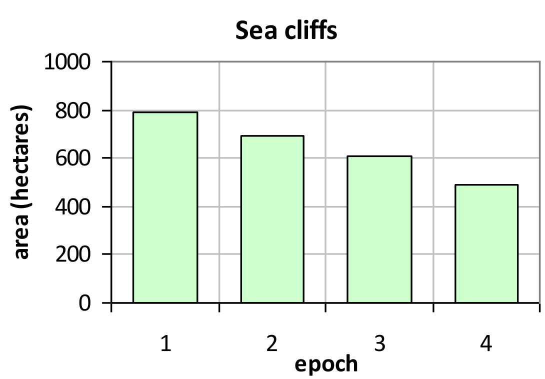
The salt marshes and reed beds
are sensitive to sea level rise,
as expected.
Sea cliff changes are dominated by
certain locations such as
the Speeton Sands area

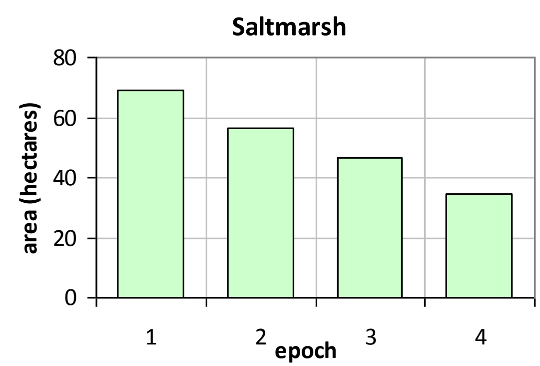




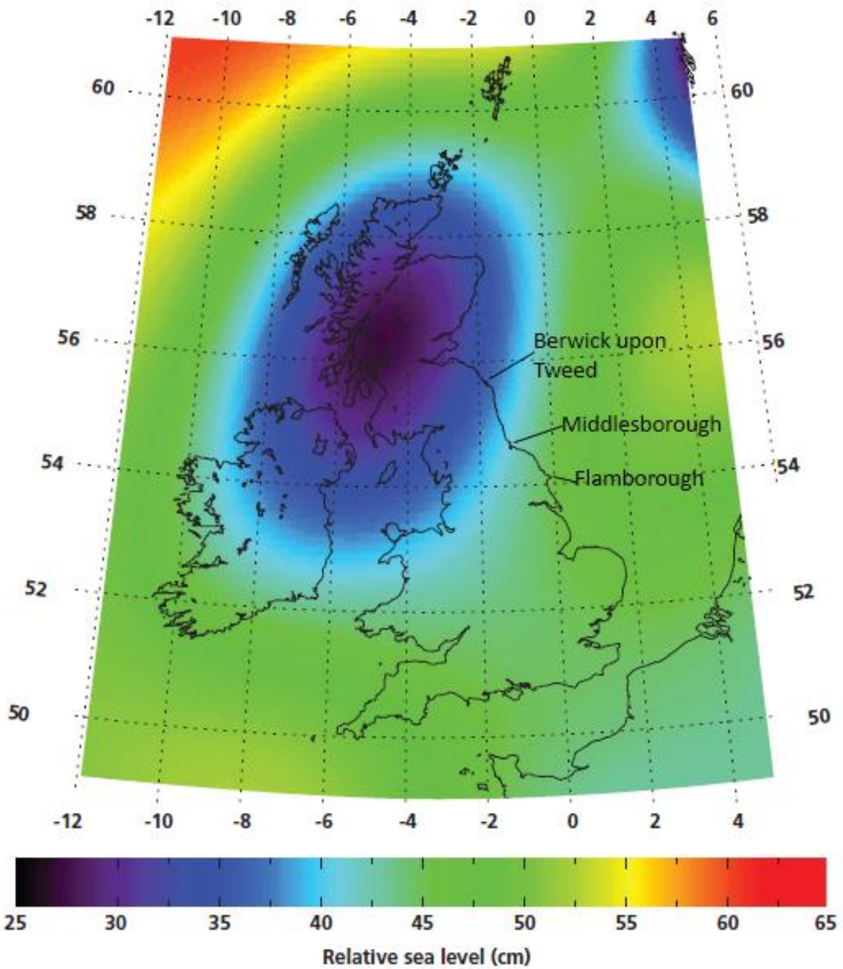






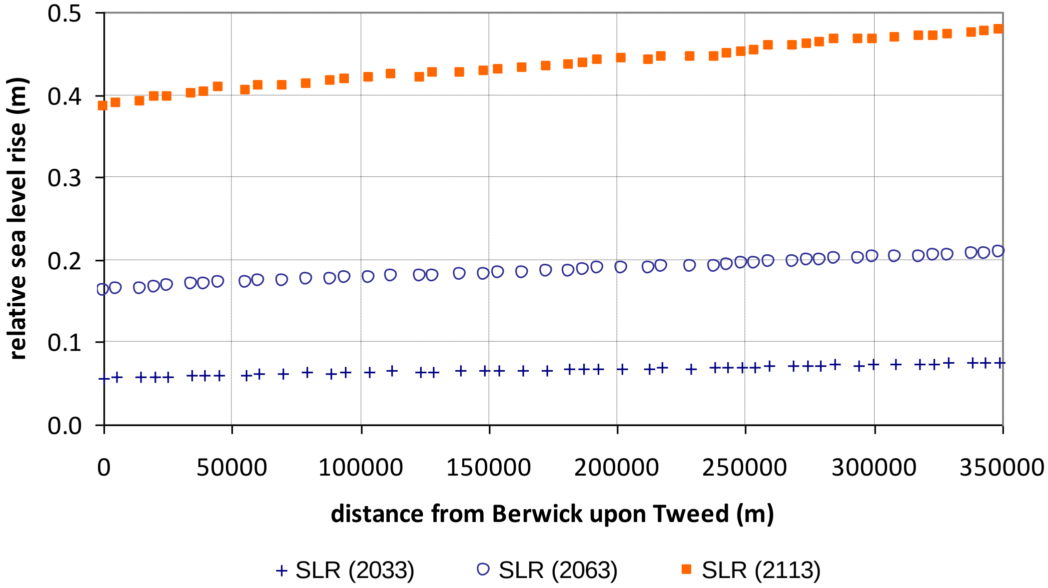


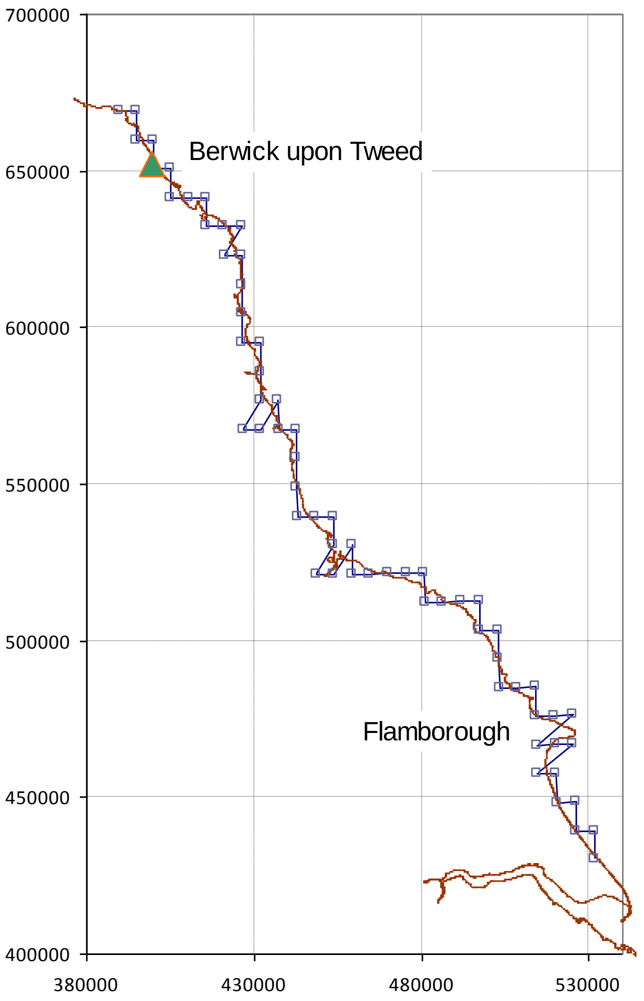
Sea Level Rise projections for the year 2095, relative to 1990
made by UKCP09 – Medium Emissions, 50%-ile level of uncertainty
due to the combination of global sea level rise and post-glacial isostatic compensation



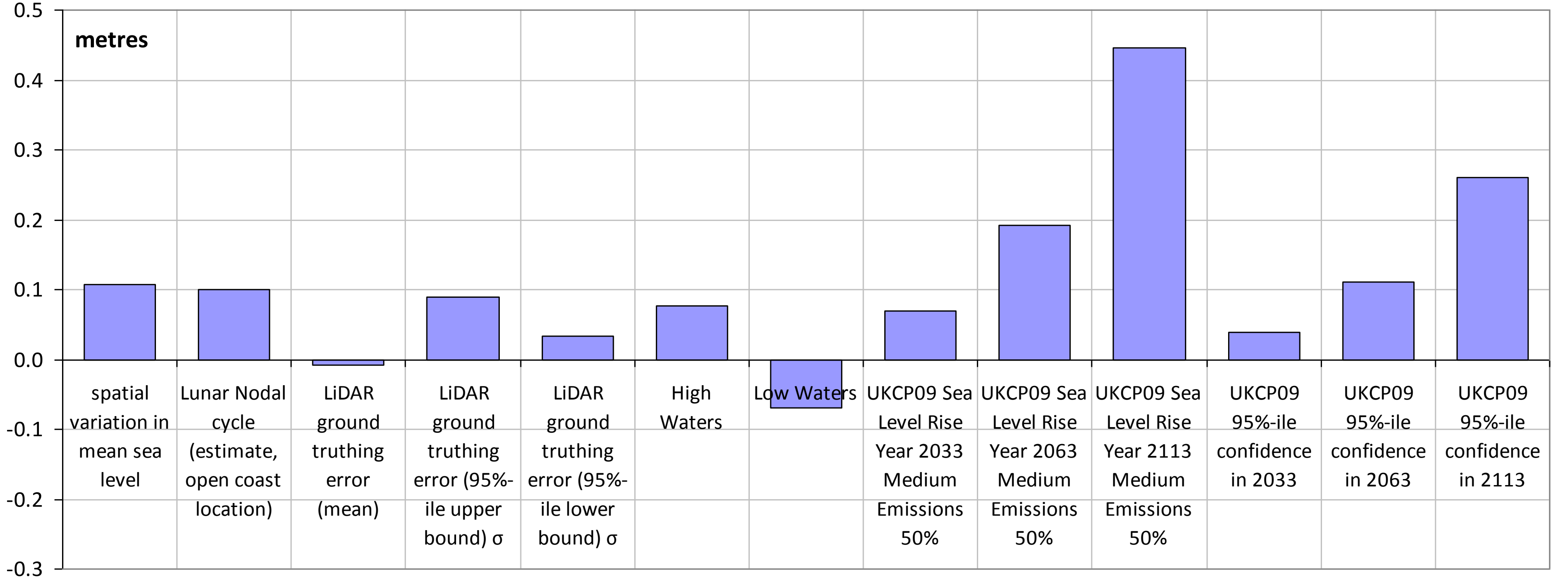
The project frontage exhibits significant spatial variation in sea level rise owing to the effects of isostatic compensation

Sea level rise along the frontage for the three epochs based on chainage around the UKCP09 climate change database tiles





Review of the contributory factors to sea level variation and water depths along the frontage



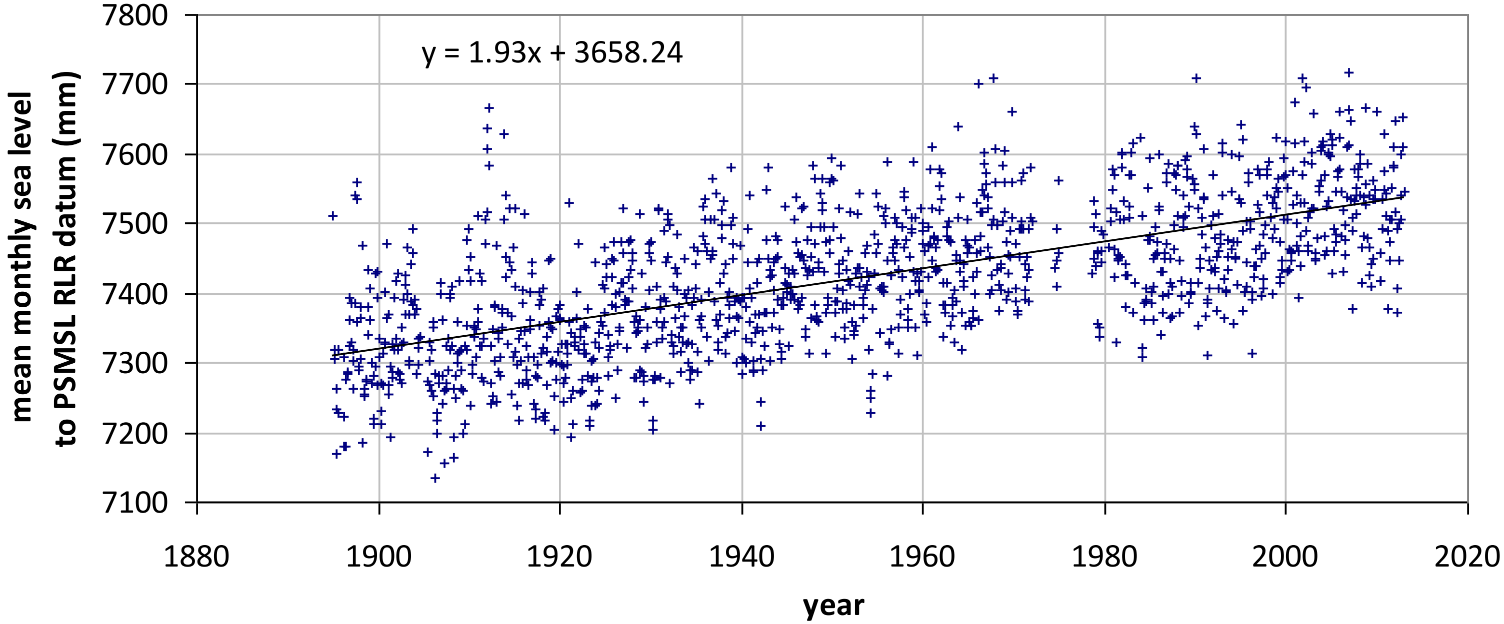
Spatial variation in mean sea level based upon tide gauge data from North Shields and Whitby (Class 'A') over the period from 1993 to 2012, and from Blyth and Tees Dock (EA) over the period from 1993 to 2012 and for Scarborough (EA) over the period from 2003 to 2012
Range of Lunar Nodal Cycle estimated for an open coast location such as North Shields
The mean error on the LiDAR is based upon set of 29 ground-truthing samples gathered and reported by Geomatics
The upper and lower bound σ (standard deviation) values for the LiDAR data are based upon a set of 29 ground-truthing samples gathered and reported by Geomatics and have been quoted here at the 95%-ile upper and lower bound values

The spatial variation in Mean High Waters and Mean Low Waters is represented by the difference between these two parameters as recorded by the Class 'A' tide gauges at Whitby and North Shields, over the period from 1993 to 2012, after data-cleaning

The UKCP09 sea level rise values are the Medium Emissions values for the 50%-ile level of uncertainty
The UKCP09 confidence limits constitute the 95%-ile upper bound intervals. These have to be added to the 50%-ile SLR estimates, to obtain the 95%-ile upper bound sea level rise projection.

Mean monthly sea level records for North Shields, datum-corrected from PSMSL; observed rate of sea level rise is around 2mm/year

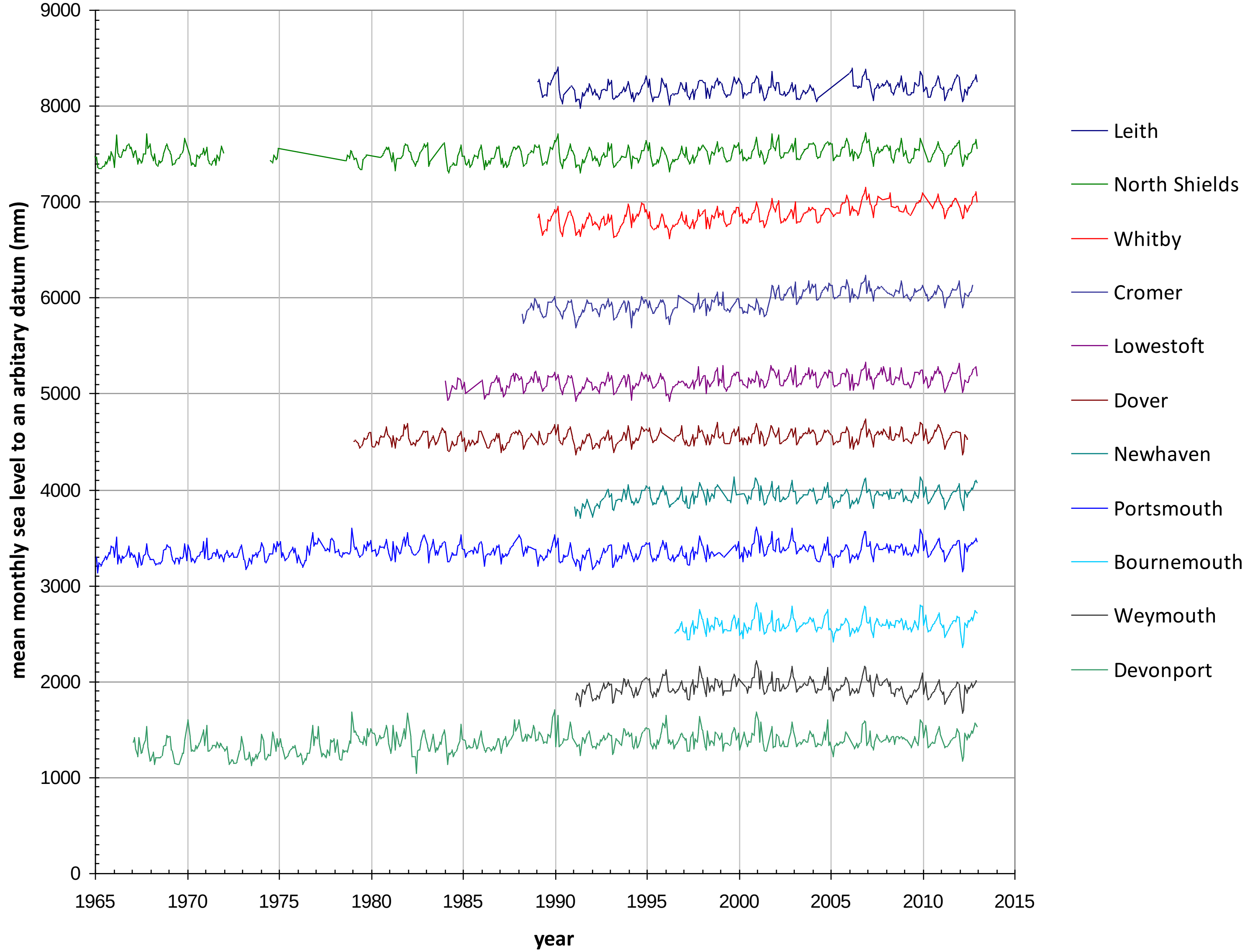
UKCP09 Sea Level Rise projections tabulated below – for Medium Emissions 50%-ile uncertainty level

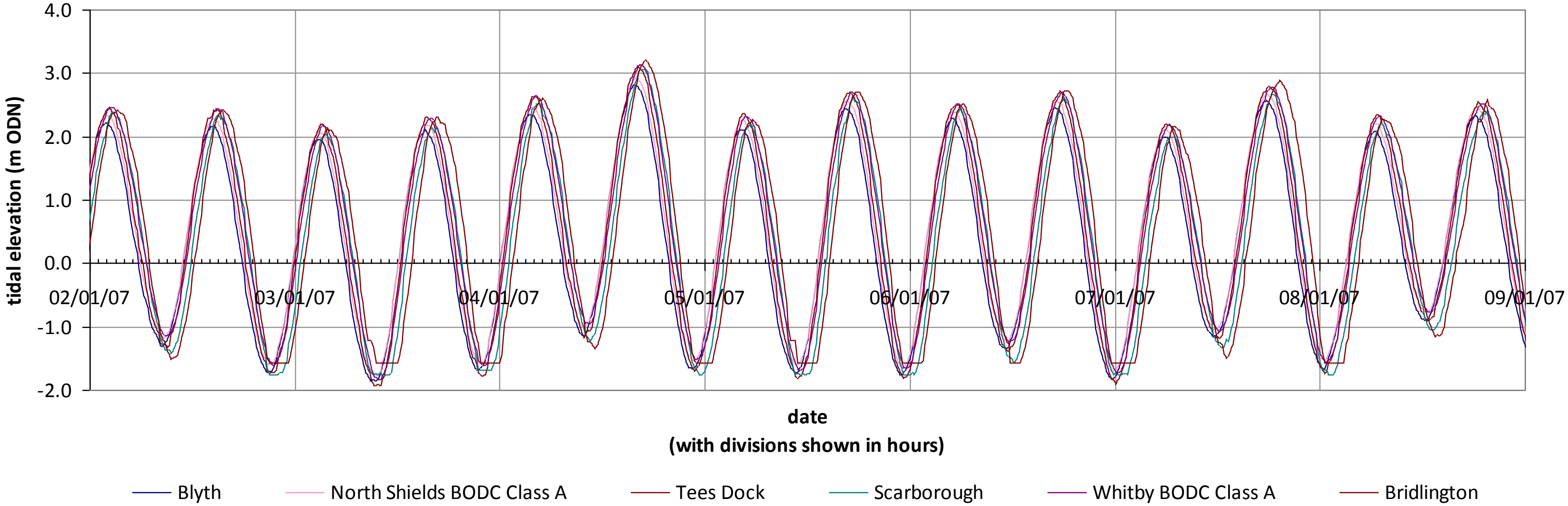


year	UKCP09 SLR relative to 2013 (metres)	UKCP09 95%-ile Confidence interval	UKCP09 Overall Sea Level Rise in mm/year
2033	0.064	±0.039	3.2
2063	0.179	±0.110	3.6
2113	0.419	±0.260	4.2

UKCP09 sea level rise projections are at least 67% larger than the observed values to date

Correlation between mean monthly sea levels exhibited by the Class 'A' tide gauge network around the coastline from Devonport to Leith





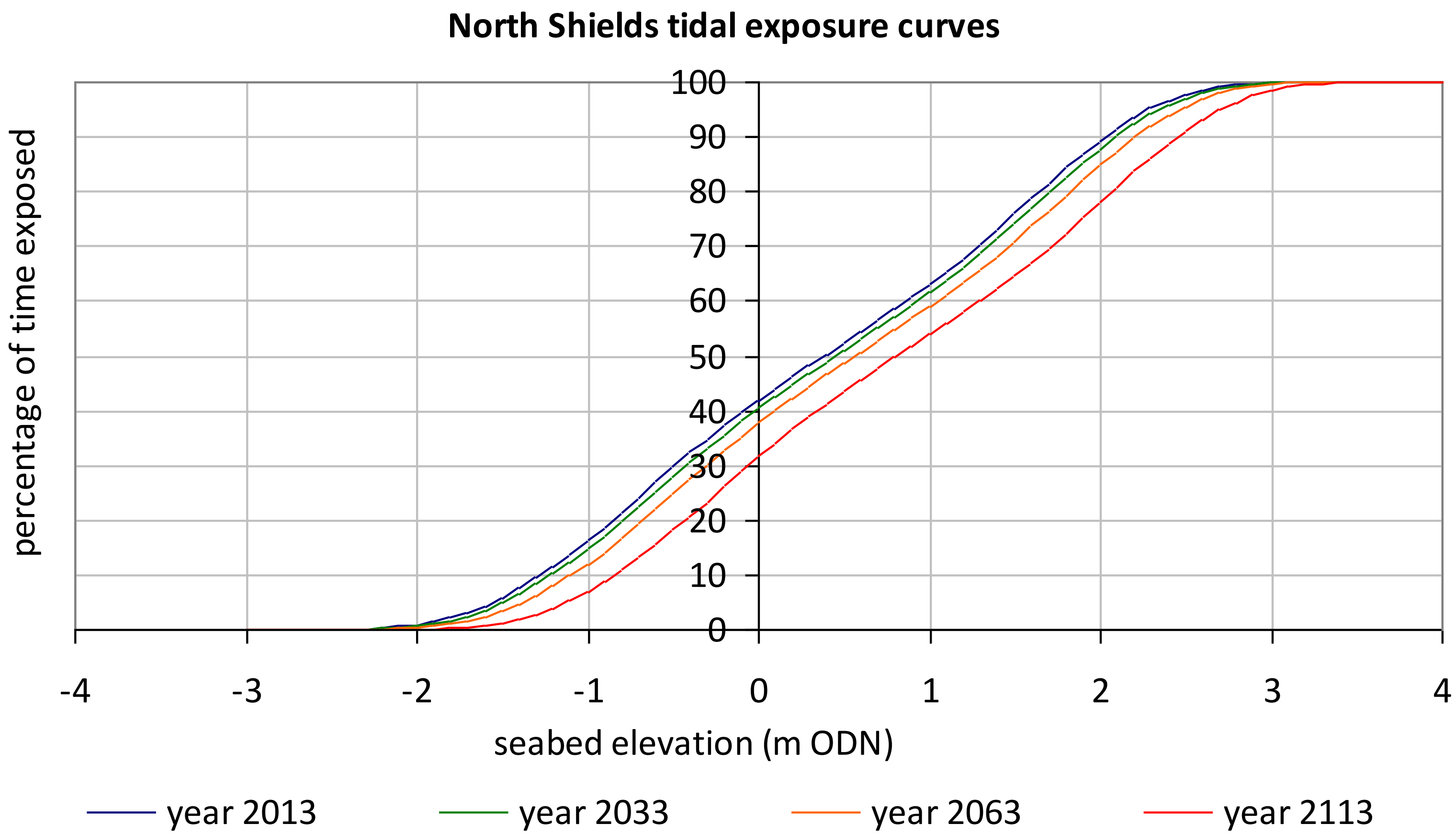
Tidal elevations along the frontage are closely correlated and the timing of High and Low Waters is close. This made it a relatively easy task to clean and verify tide gauge data. North Shields, the highest quality gauge, required some minimal cleaning and that was then used as a baseline against which to verify and clean data from the other gauges. The following table lists the gauges that were used in the study.

Bridlington loses the Low Water on every tide and was omitted; Berwick gauge is strongly affected by estuarine influences and was also omitted. Berwick High Waters are virtually identical to those at North Shields.

The following table summarises the UKCP09 projections of Sea Level Rise at the tide gauge locations

Tide gauge location	95%-ile lower bound			50%-ile			95%-ile upper bound		
	2033	2063	2113	*2033*	*2063*	*2113*	2033	2063	2113
Blyth (EA)	0.026	0.071	0.163	*0.065*	*0.181*	*0.425*	0.103	0.290	0.683
North Shields (Class ‘A’)	0.026	0.073	0.168	*0.065*	*0.182*	*0.428*	0.104	0.293	0.687
Tees Dock (EA)	0.030	0.081	0.185	*0.068*	*0.190*	*0.443*	0.107	0.300	0.703
Whitby (Class ‘A’)	0.034	0.092	0.207	*0.073*	*0.202*	*0.467*	0.112	0.312	0.725
Scarborough (EA)	0.035	0.095	0.213	*0.074*	*0.204*	*0.471*	0.113	0.314	0.729

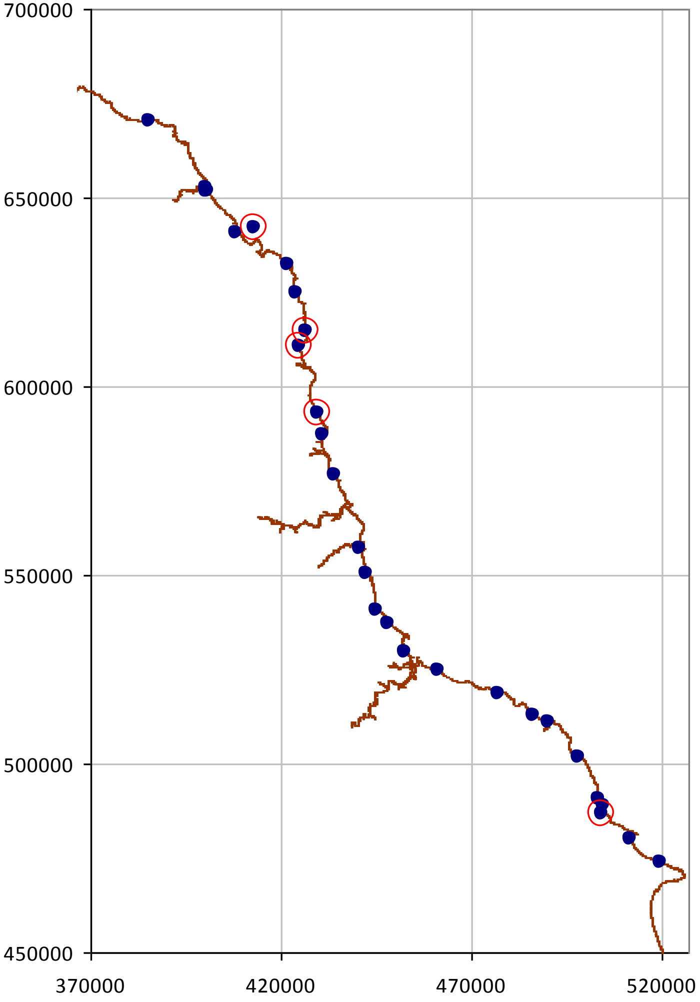
Use of tidal exposure duration curves expressed in percentage of time exposed



Maps were made describing the percentage of time for which intertidal areas were exposed as a function of the seabed elevation, during each epoch. In order to make these maps, tidal exposure curves such as this example for North Shields, were made for each of the tide gauge locations.

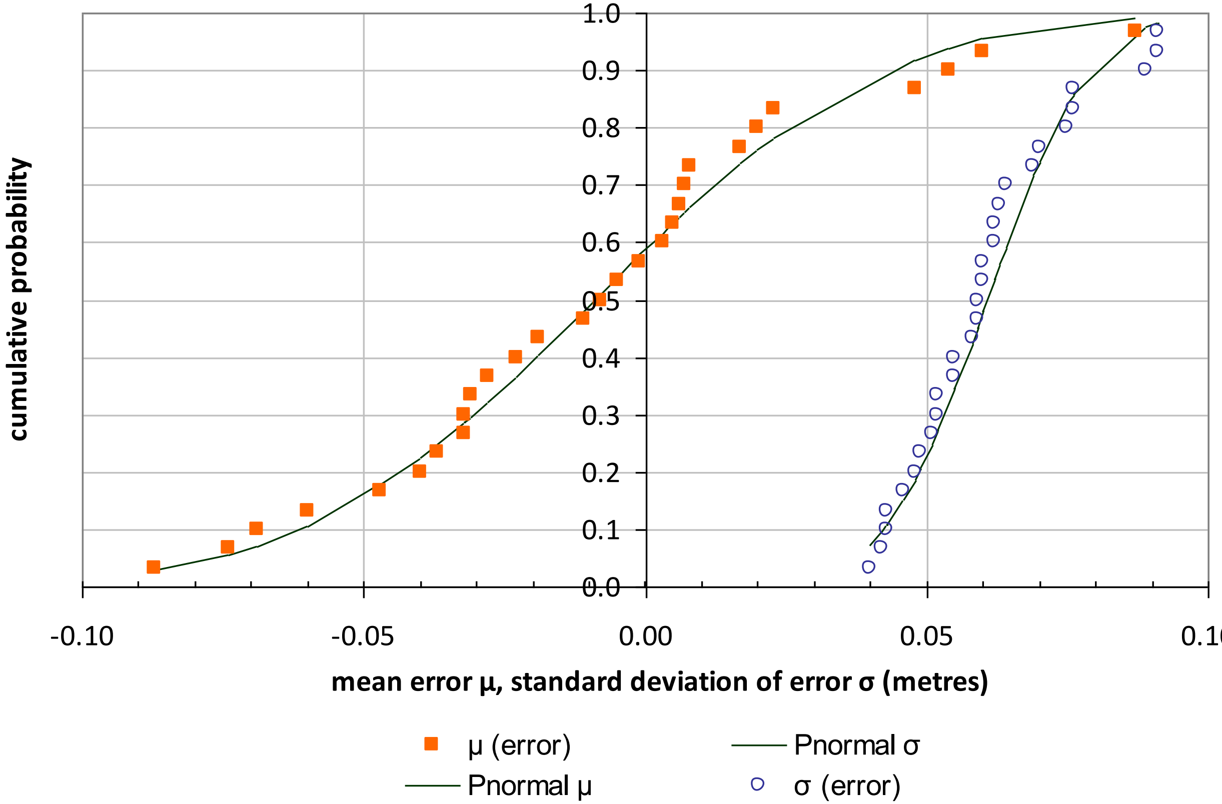
The maps of percentage of time exposed were then made, applying inverse distance weighting predictions taken from the exposure curves for the tide gauge locations. The maps were made on a 10m resolution grid constructed from the LiDAR data.

Use of LiDAR ground truth testing to estimate the level of uncertainty attached to habitat response owing the LiDAR accuracy variations



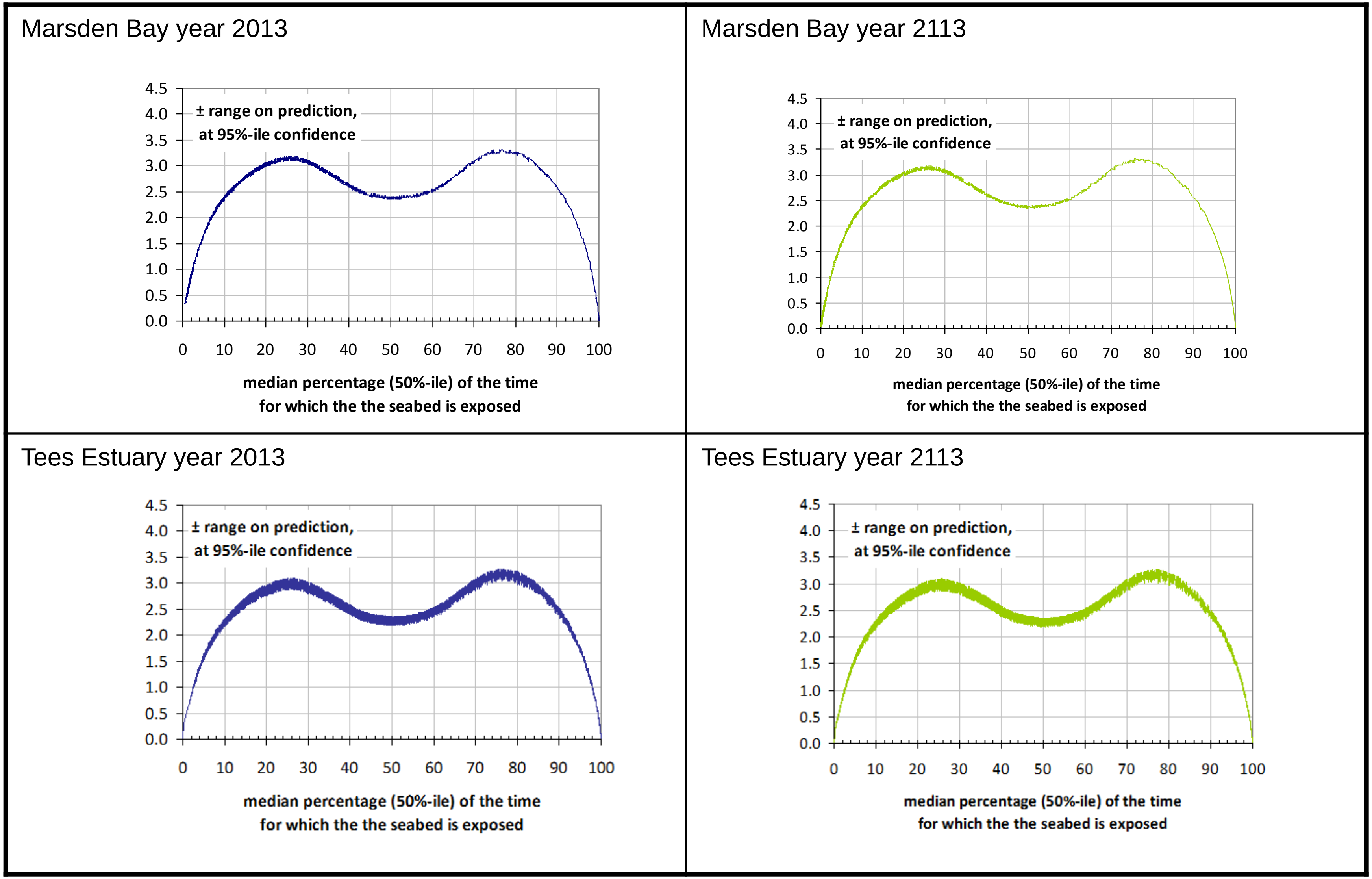
Locations of the 29 Geomatics LiDAR ground-truth areas. The locations circled in red have a mean error of between ± 0.061m and ± 0.087m. Elsewhere, the mean error is < 0.061m

Statistical distributions of mean error and standard deviations of errors attached to LiDAR data compared against ground-truth observations from topo surveys



The information regarding mean and standard deviations of LiDAR ground truth errors was mapped onto the 10m model bathymetry grid using inverse distance weighting.

The bathymetry was then calculated at the 95%-ile upper and lower bound elevations, with a view to establishing the effects of LiDAR uncertainty upon percentage exposure duration times and upon intertidal areas…



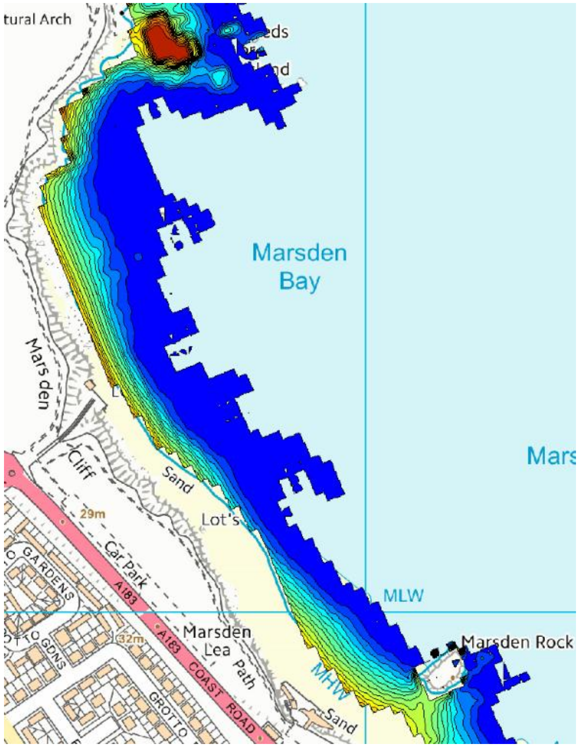
The 95%-ile confidence range on percentage of the time exposed for an intertidal location, owing to uncertainty in LiDAR elevations is approx ±3.5%. That is, if the percentage of time exposed is quoted as 75%, for example, then the actual range of possible values of time exposed, due to LiDAR uncertainty, is 71.5% to 78.5% of the time.

This result is independent of epoch and location along the Project frontage. The curvature in the plot is caused by the shape of the tidal exposure curves. Average errors in LiDAR data contribute a further ±2% maximum to the confidence

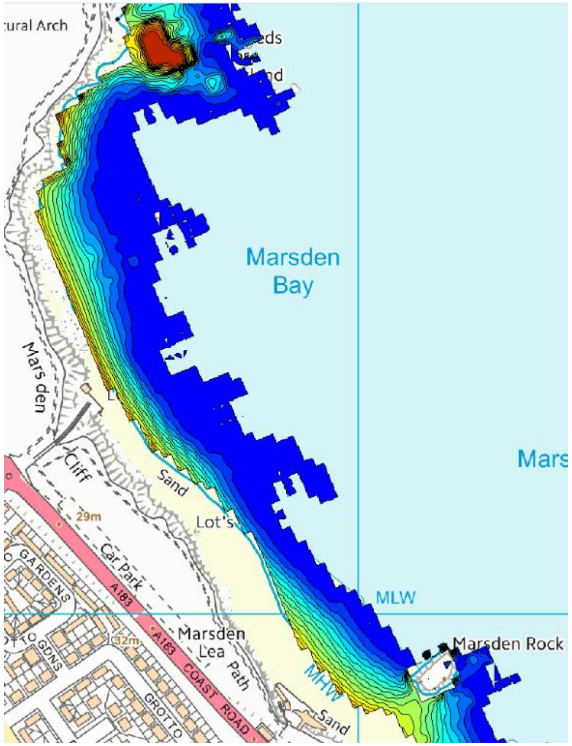
Marsden Rock; note the change in wave energy shoreward of the Rock

The next example shows the effects of LiDAR uncertainty upon intertidal exposure durations at Marsden Bay

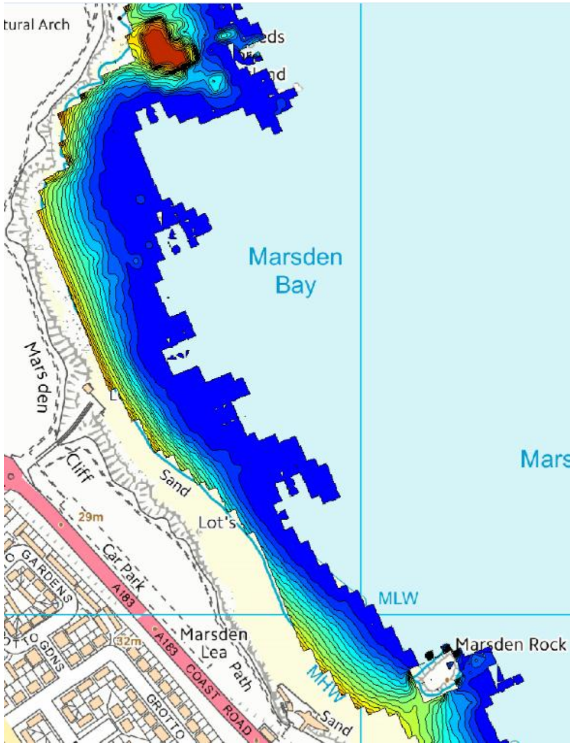
Example plots of percentage durations of tidal exposure time at Marsden Bay – average and ±95%-ile LiDAR confidence levels, year 2113



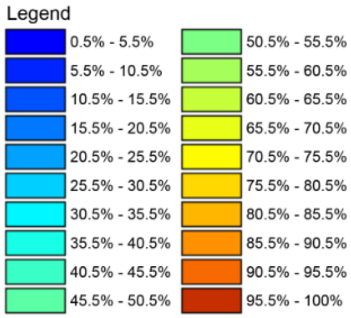
95%-ile lower bound bathymetry



Mean bathymetry



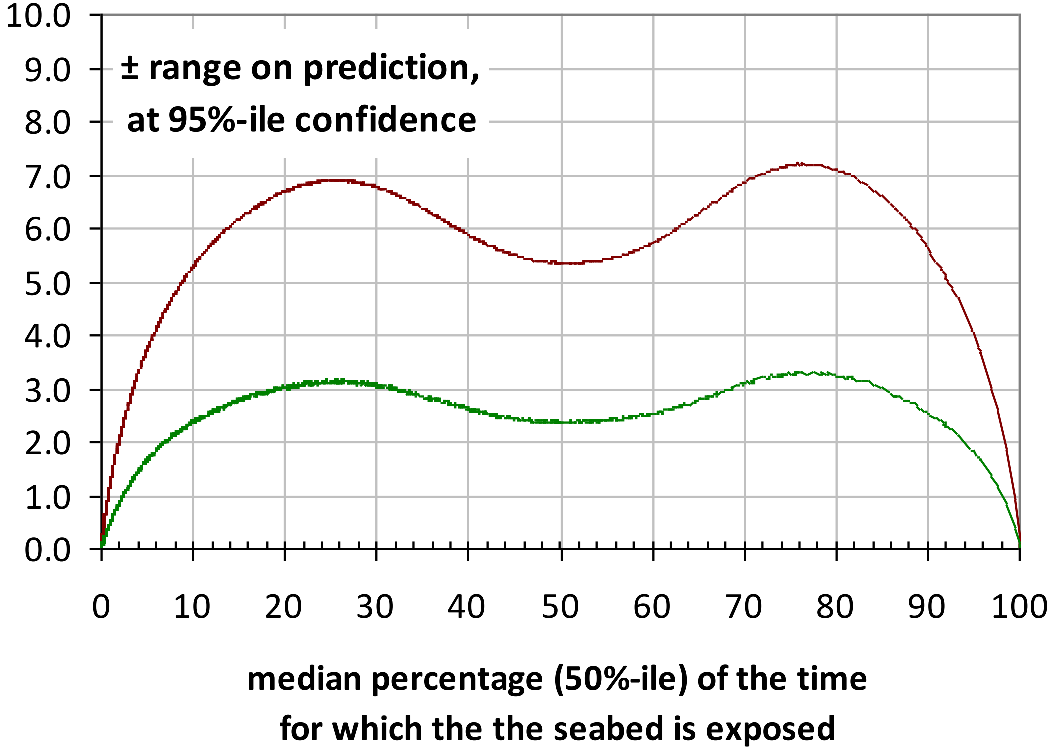
95%-ile upper bound bathymetry



The effect of implementing a 95%-ile lower bound bathymetry data set is to significantly tighten up the exposure duration contours and to limit the extent of the intertidal area. At the 95%-ile upper bound, the converse is true and the intertidal extends further seaward

Effects of uncertainty in sea level rise upon the prediction of tidal exposure duration

The higher curve in the plot below represents the effects of Sea Level Rise uncertainty in the year 2113, whilst the lower curve is that due to LiDAR uncertainty

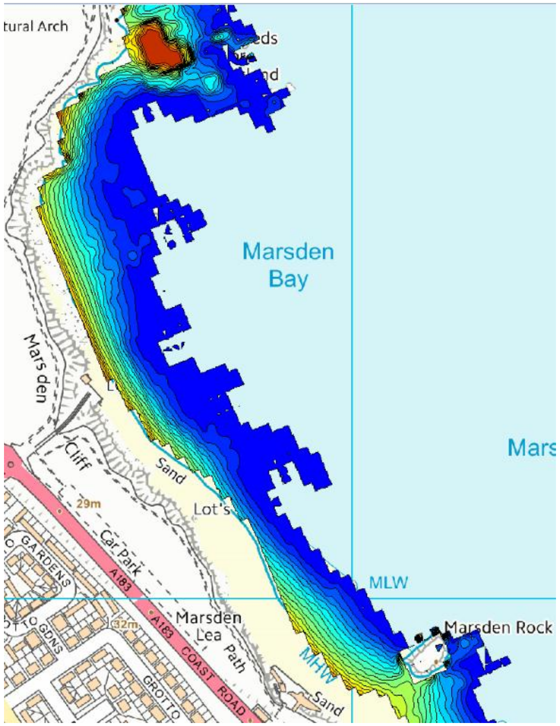


The above plot compares the effects of uncertainty in sea level rise, against those associated with the LiDAR, for the fourth epoch, year 2113.

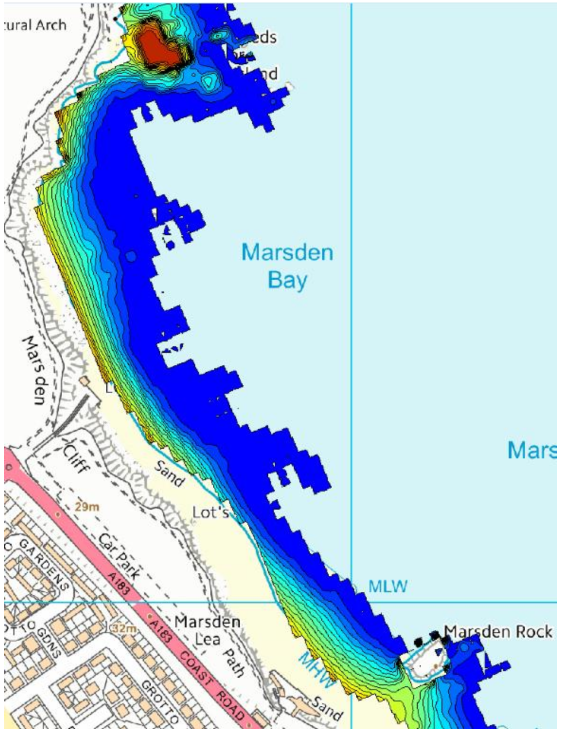
In the final epoch, which holds the sea level rise of most significant magnitude, the uncertainty in tidal exposure times due to sea level rise uncertainty, is more than twice that associated with the LiDAR.

In the earlier epochs, the uncertainty attached to SLR is less, so the comparison will be less severe. The following plot maps the year 2113 results for Marsden Bay…

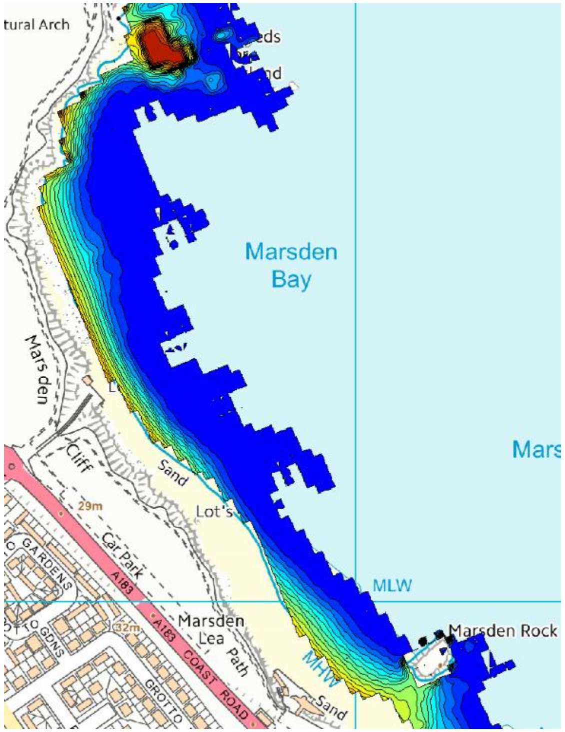
Example plots of percentage durations of tidal exposure time at Marsden Bay – average and ±95%-ile Sea Level Rise confidence levels, year 2113



95%-ile lower bound sea level rise, with median bathymetry



median sea level rise, with median bathymetry



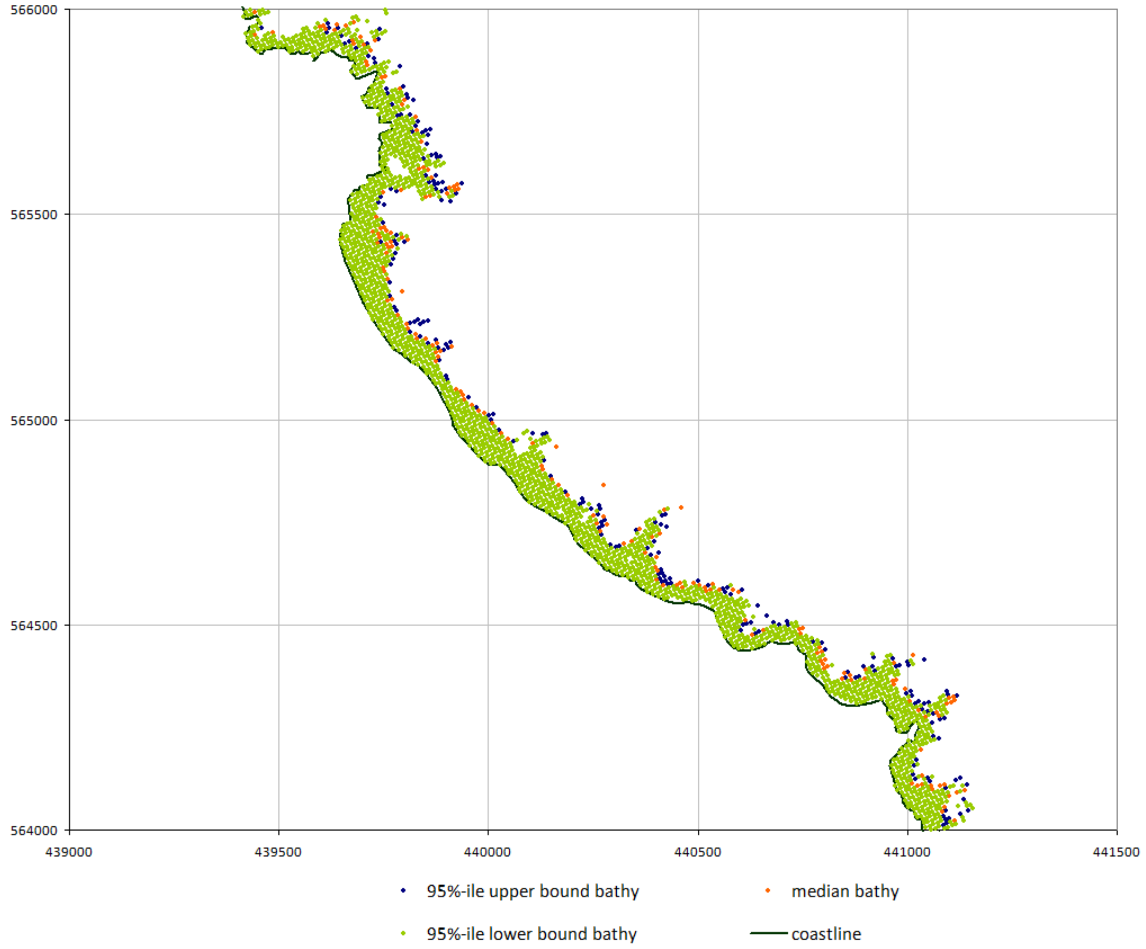
95%-ile upper bound sea level rise, with median bathymetry

In the above three plots, the bathymetry has been held at the median LiDAR level

The effect of the ±95%-ile Sea Level Rise confidence intervals leads either to a significant expansion of the intertidal area at the lower-bound, or to a strong contraction of the intertidal at the upper bound level of estimate

Effects of LiDAR uncertainty upon predicted coverage of intertidal areas

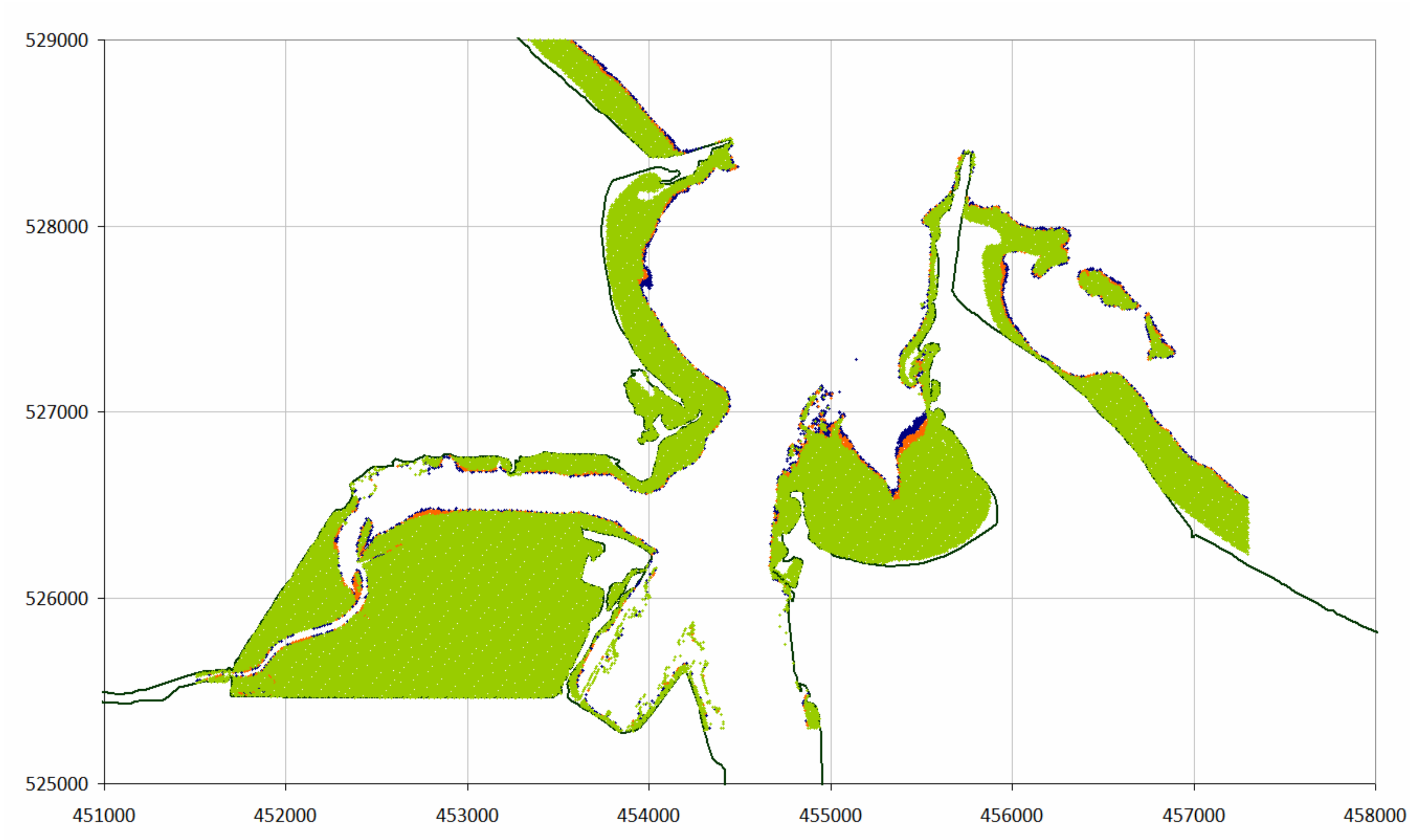
Example at Marsden Bay



This plot shows the individual model cells lying within the intertidal area in year 2013, based on median LiDAR bathymetry and the 95%-ile upper and lower bound data

The change in intertidal area due to LiDAR uncertainty is around ± 0.65 hectares per km length of coastline at the 95%-ile confidence level

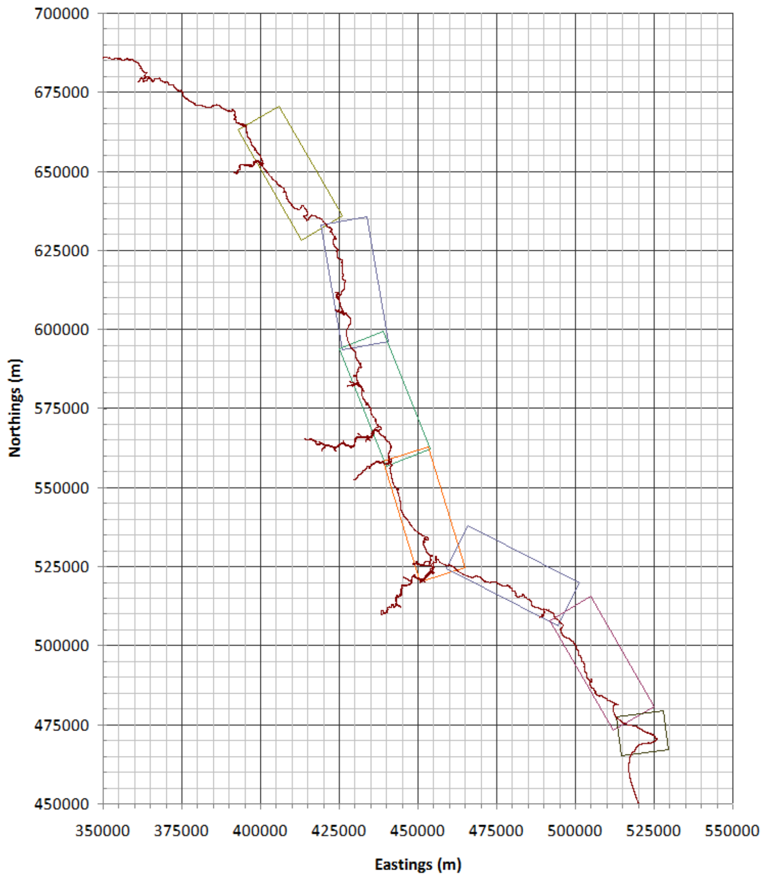
Effects of LiDAR uncertainty upon predicted coverage of intertidal areas
Example in Tees Estuary



In the Tees Estuary, the change in intertidal area due to LiDAR uncertainty is around ± 0.4 hectares per km length of coastline at the 95%-ile confidence level; more work is needed to refine this estimate, which will be undertaken

(note that the large area west of approx Eastings 453800 is outside the study)

Layout of suite of regional wave models

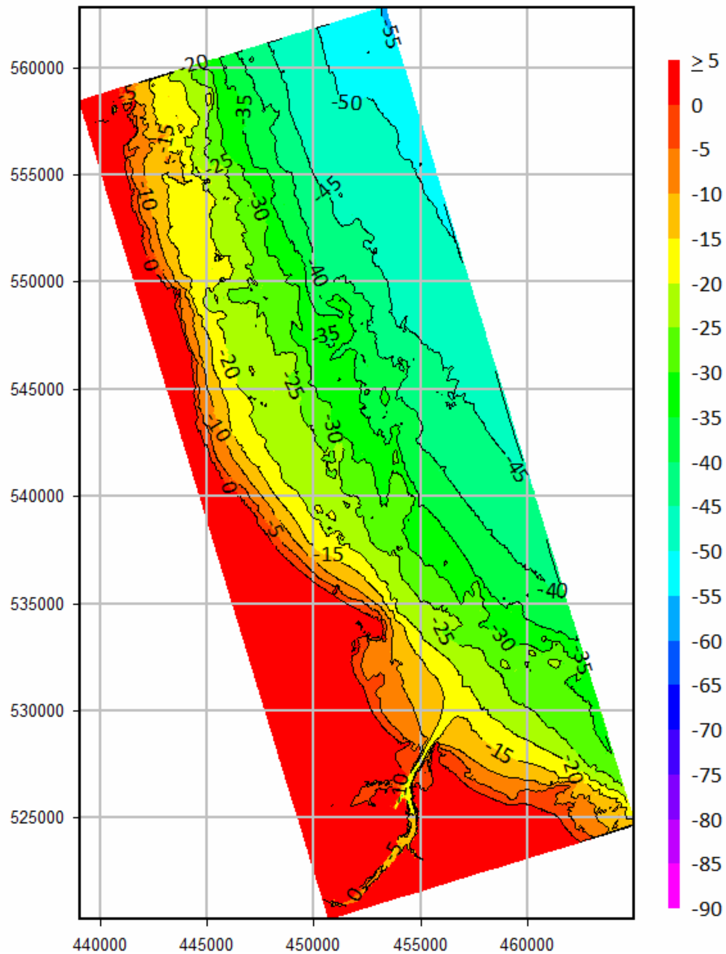


A suite of regional wave models has been built using the Swan module developed by Delft Hydraulics. The spatial resolution of the regional models is 100m.

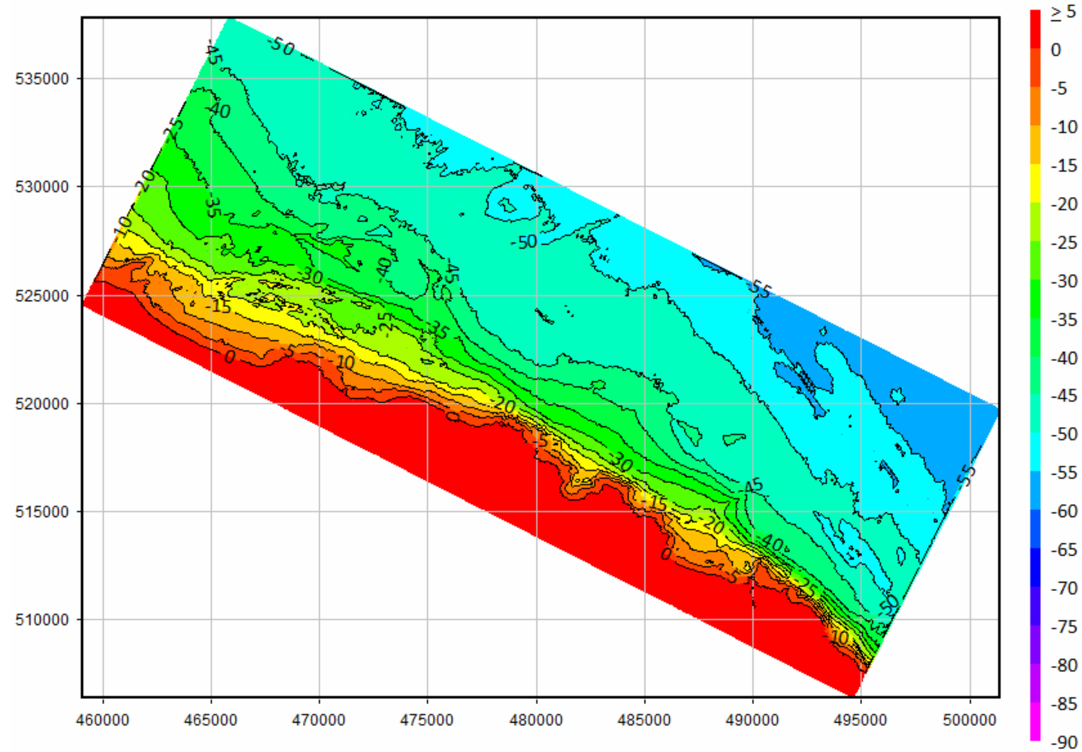
Seated within the regional models is a set of local 10m resolution nearshore and surf zone wave models, which are used to predict the effects of sea level rise upon wave energetics across the intertidals. Within major estuaries, such as the Tees, Tyne or Tweed, the Swan model is retained, to predict local wind-induced wave effects.

Offshore boundary conditions consist of representative mean waves that will deliver the same long-term sediment transport potential as a long offshore time series, transformed to the near shore (the '**morphological wave**'). Mean wind speeds are also included.

Two examples of the Swan regional wave models



Regional Wave Model ID05 –
Tees and north of Tees



Regional Wave Model ID06 – south of Tees towards Whitby

Bathymetric elevations in m ODN

Wherever possible, LiDAR data are used in preference to Admiralty bathymetry, over the inshore areas

Example of the directional morphological wave for the wave model ID05 –

Tees Estuary and north of Tees

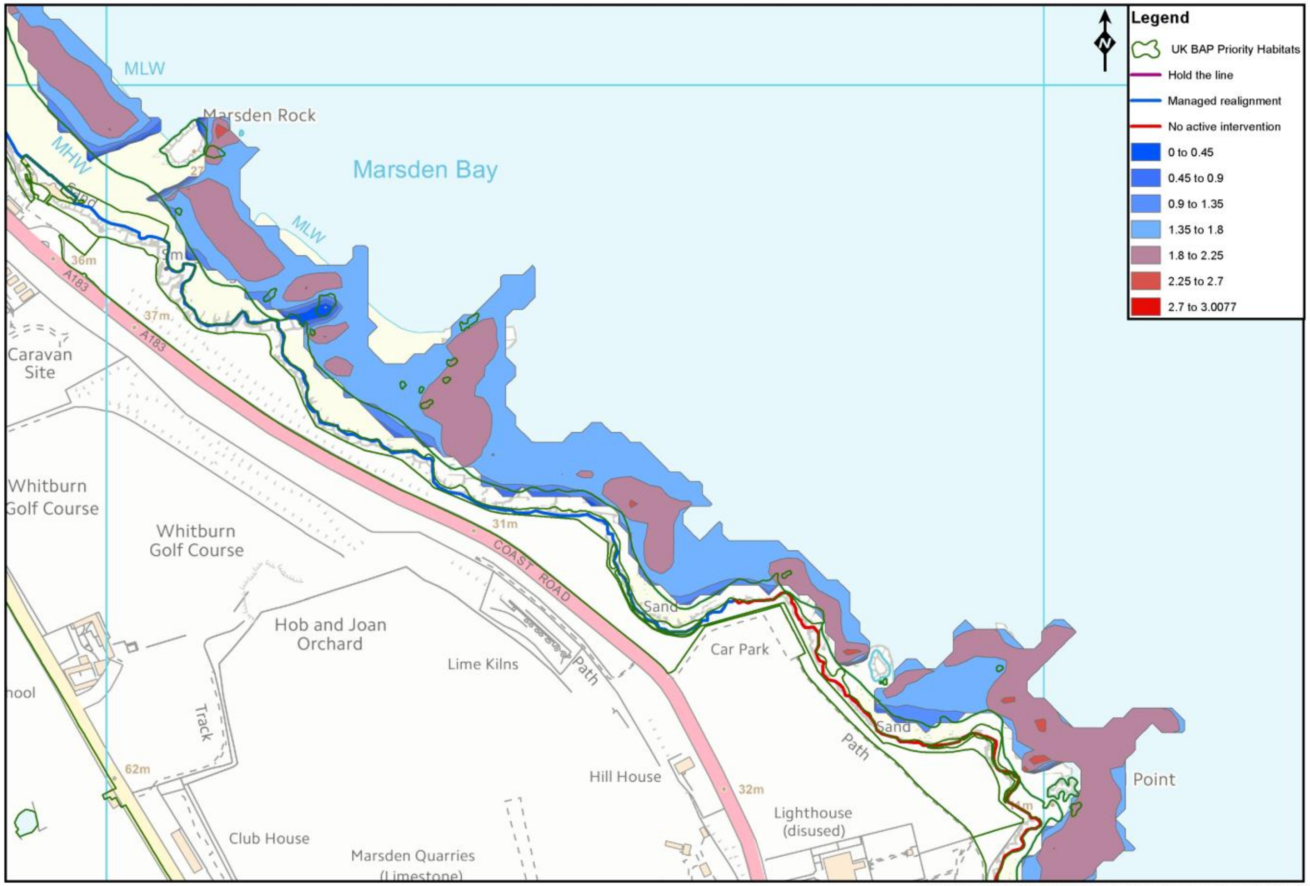
directional range °N for ID05	Hs (m)	Tp (s)	θ (°N)	mean Hs offshore (m)	mean wind speed (m/s)
339-359	2.197	8.68	351.19	1.99	9.21
000-029	1.362	8.34	13.58	1.20	5.60
030-059	1.396	7.80	43.03	1.24	5.36
060-089	1.729	8.04	76.50	1.45	5.89
090-119	1.575	7.70	102.96	1.40	6.45
120-158	1.347	7.22	135.21	1.19	7.42

In the above table, Hs is the value of the offshore morphological wave height and Tp is the associated spectral peak wave period. θ is the sediment transport-weighted mean wave direction.

The morphological wave height should be greater than the mean wave height because it is weighted by the sediment transport potential equation. In this study, a sand transport solution developed by Kamphuis has been used as the sediment transport predictor.

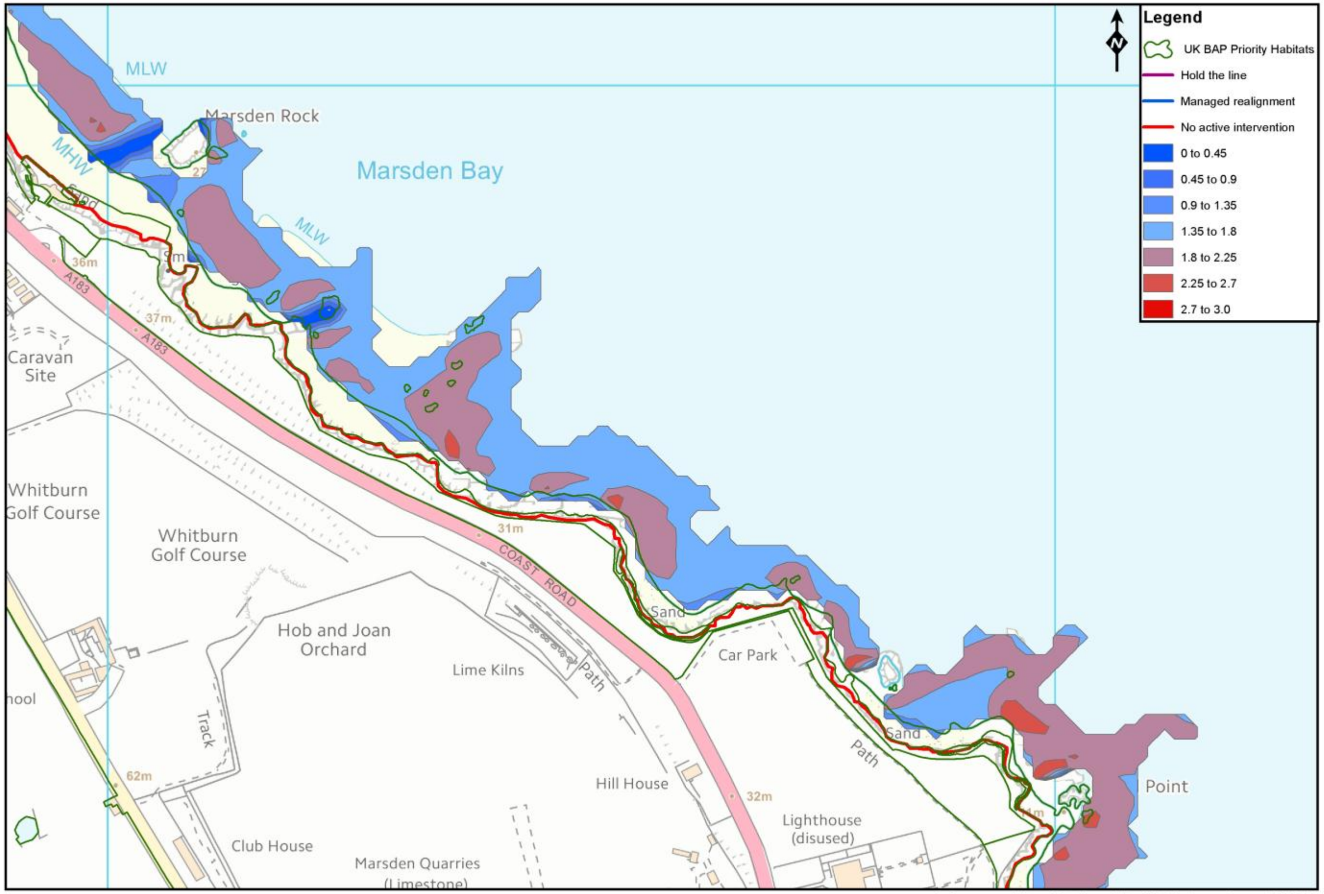
The above estimates are based upon the transformation of a Met Office European Wave Model data set for offshore of the Tees area at 3-hourly temporal resolution, from July 1988 to July 2008.

Example of intertidal wave model results for a length of coastline running south from Marsden Rock – year 2013



Year 2113 results in next slide…

Example of intertidal wave model results for a length of coastline running south from Marsden Rock – year 2013



Compared to the year 2013 scenario (previous slide), two changes have occurred: (i) an increase in intensity of wave activity in some areas and (ii) an expansion and shoreward movement of the more active wave climate areas that applied in year 2013.

The inshore wave model uses an accurate finite amplitude wave theory to predict the location of the breaking point and a surf zone module, including a rising set-up mean water level shoreward of the breaking area

UKCP09 projections for changes in mean winter and annual maximum significant wave heights from the period (1960-1990) to (2070-2100): at model mid-sensitivity

(At high and low model sensitivities, the conclusion is the same - there is a projected future reduction in mean wave severity off the North East Coast)