Liverpool Bay Composition Scenarios

22 July 2016

1. Introduction

The iCOASST project has been developing techniques to improve our understanding and modelling of the long-term evolution of coastal sediment systems (Nicholls et al, 2015a,b). A three-tiered approach is being taken, as described by van Maanen et al, (2016):

- The development and implementation of Coastal and Estuarine System Mapping (CESM) which characterises the relationships between coastal landforms and structures (Whitehouse et al., 2009, French et al., 2016);
- Coastal area modelling of inner shelf hydrodynamics and sediment transport to identify sediment pathways and onshore/offshore sediment fluxes (Brown et al., 2015); and
- Developing and applying coupled systems (or compositions) of specialised landform-scale models that interact by exchanging data at run-time and represent the coastal zone as a dynamic, evolving system that is, at least partially, self-regulating using feedback mechanisms.

The Liverpool Bay composition (Sutherland et al, 2015a,b) is described on http://www.channelcoast.org/iCOASST/liverpoolbay and the results from this composition are presented below.

2. The Liverpool Bay Composition

The Liverpool Bay composition is shown in Figure 1 and consists of:

1. A1 – ASMITA model representing the Ribble Estuary
2. U1 & U2 – UnaLinea models representing the Sefton and Blackpool/Fylde coastlines
3. P1 – POLCOMS model of area, which provides onshore feed inputs to the coastal models.
4. Exchanges:
    a. X1 – between Unalinea and ASMITA (two-way exchange)
    b. X2 – input from POLCOMS to UnaLinea (one-way)

2.1. Report Structure

This report briefly describes the ASMITA and UnaLinea model set ups used in the Liverpool Bay composition and describes the outputs from each model (Section 3). Section 4 describes the future scenarios that have been conducted with the composition. Section 5 list references and section 6 gives acknowledgements and provides details of the license this document is published under.

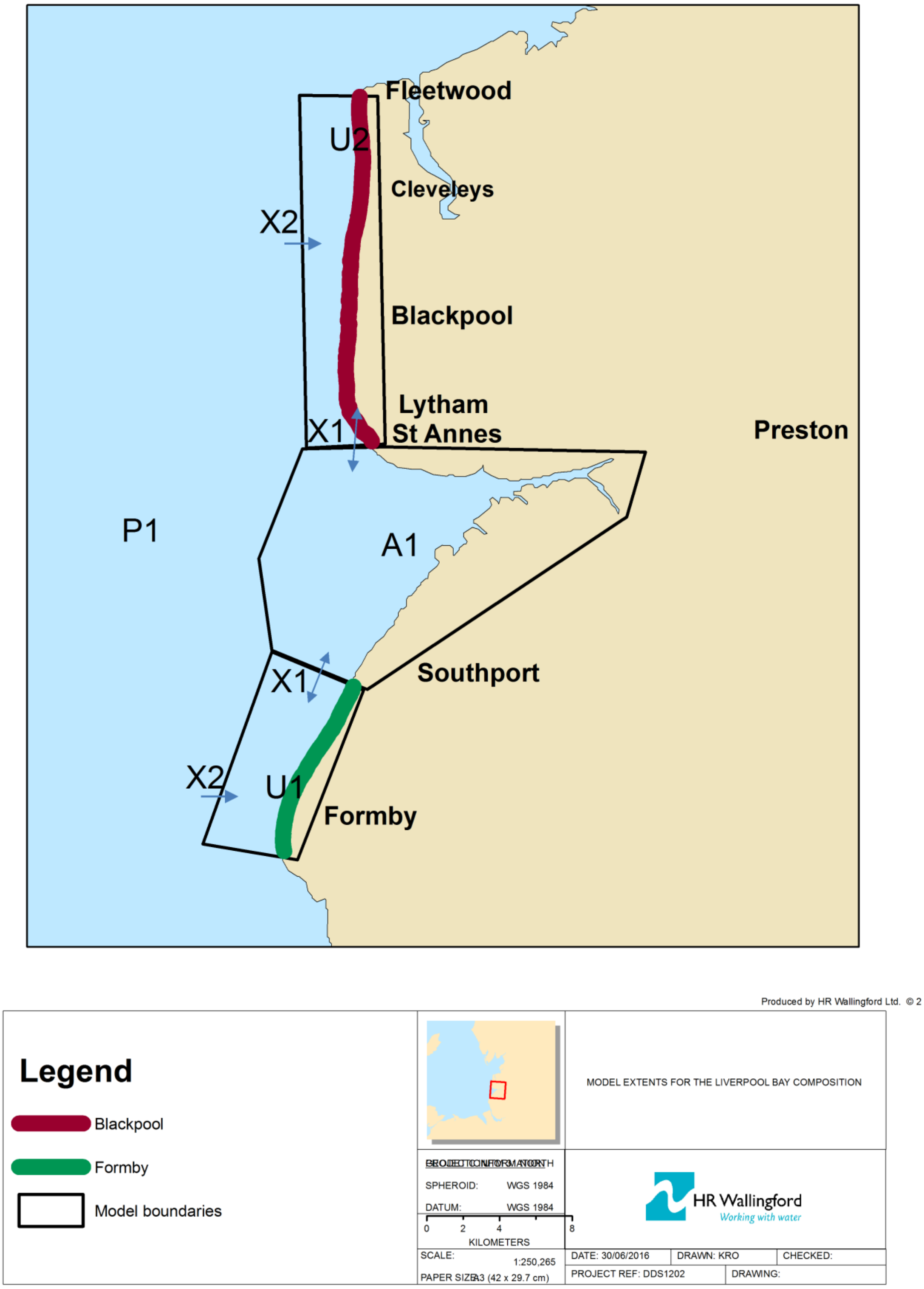


Figure 1: The Liverpool Bay composition.

3. Model descriptions

3.1. ASMITA

ASMITA was used to represent the Ribble Estuary in the Liverpool Bay composition. A three element schematisation consisting of sandbanks, channels and upper flats was used to capture the major morphological features of the estuary (Figure 2).

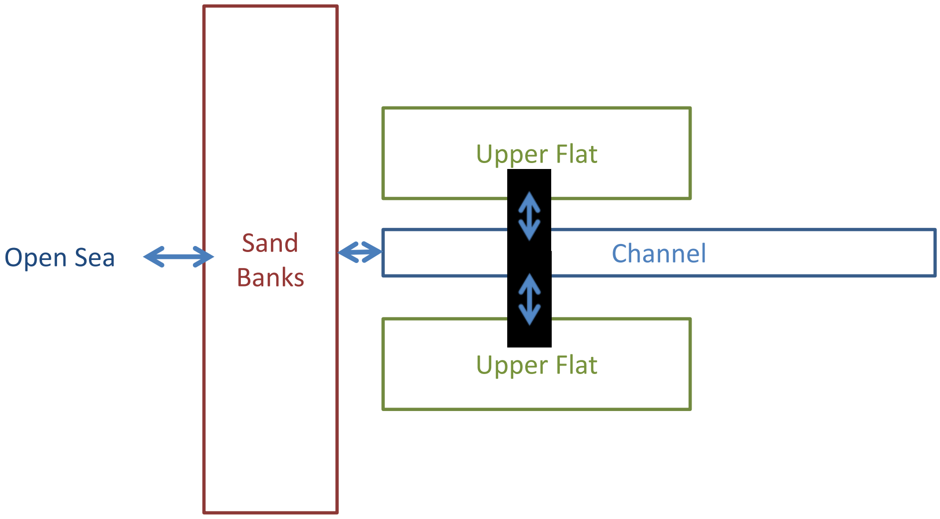
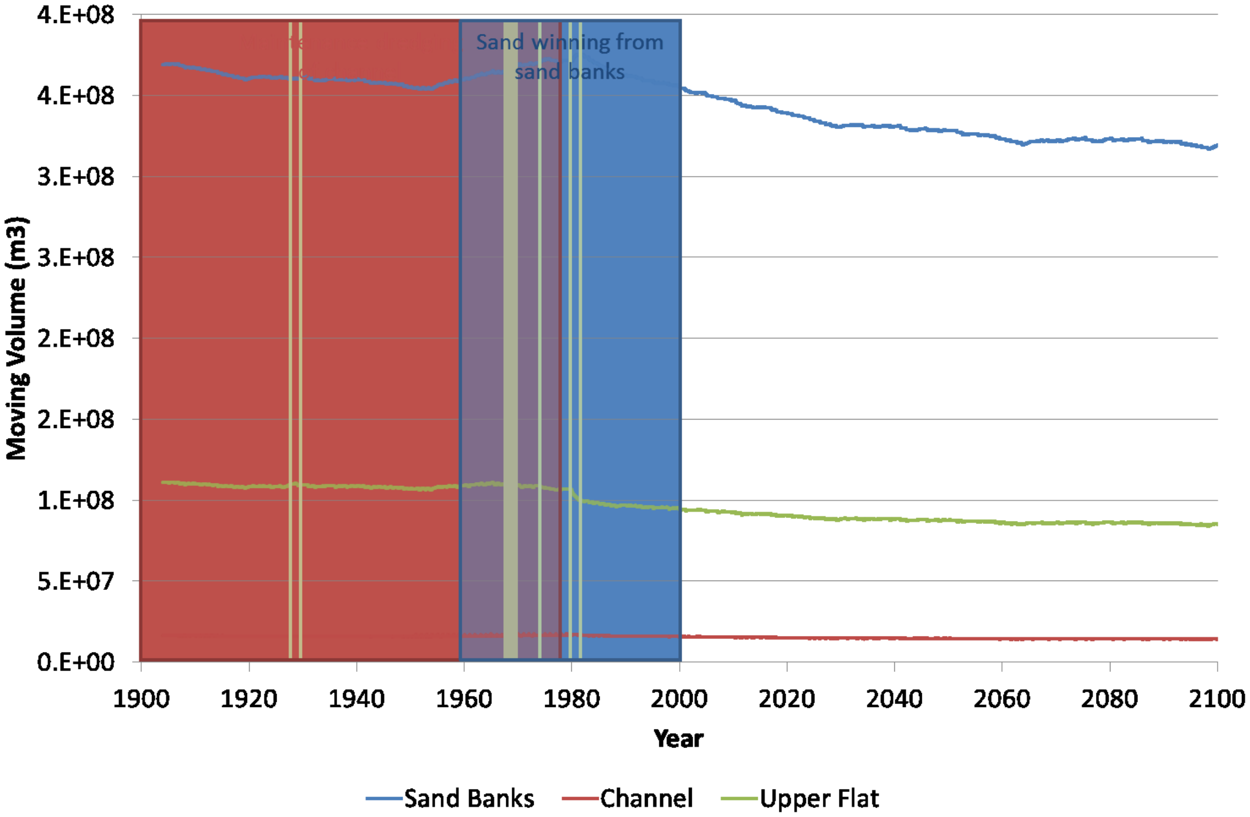


Figure 2: ASMITA schematisation for the Ribble Estuary

3.1.1. Outputs

The model results from ASMITA are output to an Microsoft Excel workbook. The workbook consists of a number of worksheets:

- Readme – a copy of the input data used
- Vm – the moving volume of each element through time (i.e. the volume relative to a moving reference level (sea-level). This shows the current volume of the element (**Error! Reference source not found.**).
- Ve – the equilibrium volume of each elements through time
- Vf – the volume of each element to a fixed reference level (i.e. to the water level at the start of the simulation). This is useful for showing accretion/erosion since the start of the model simulation.
- Sm – the moving area of each element through time (element area can only change due to external changes imposed by the user).
- Tr – the tidal range of each element through time (useful if cycles in tidal levels are included)
- Cn - the modelled concentration in each model through time. This can be useful in interpreting the volume changes of the elements, as it can be used to show the fluxes of sediment between elements.
- Drift – the volumes of Qs_{in}, Qs_{out}, Qs_{left} and Qs_{right}.



Further details of the ASMITA model can be found at http://www.channelcoast.org/iCOASST/ASMITA/ where details of the input and output files can be found in the model description.

3.2. UnaLinea

Two instances of the UnaLinea model were used to represent the beaches of 1) the Sefton coastline and 2) the Blackpool/Fylde coastline.

3.2.1. Sefton Coast

The Sefton coast UnaLinea model extended for 10 km, from just south of Formby Point to Southport. Dunes are not formally represented in UnaLinea, but were included here by modifying the berm height along the shore. This meant that if the beach face retreats, the dunes are assumed to retreat at the same rate and therefore release sediment to the beach. Key model parameters are summarised in Table 1.

3.2.2. Blackpool/Fylde Coast

The Blackpool/Fylde coast UnaLinea model extended for 19 km, from just north of the pier at Lytham St Anne's to Fleetwood. Much of this coastline is backed by sea-walls. The onshore feed from POLCOMS varied spatially, with representative values for approximately each 1 km stretch of coastline. Key model parameters are summaries in Table 2.

Table 1: Key UnaLinea parameters for Sefton Coast

Parameter	Value
Sediment transport formula	CERC
K1	0.1
Beach slope (tanbeta)	1 in 100
Along shore interval (dx)	100 m
Number of sections	100
Beach angle (from north)	17^{o}
Time step	1 week
External sources	Onshore feed from POLCOMS. Varies monthly but not spatially
Depth of Closure	13 m
Berm height	Varies spatially to account for differing dune heights
Backshore	Dunes

Table 2: Key UnaLinea parameters for Blackpool/Fylde Coast

Parameter	Value
Sediment transport formula	CERC
K1	0.08
Beach slope (tanbeta)	0.01
Along shore interval (dx)	100 m
Number of sections	191
Beach angle (from north)	2^{o}
Time step	1 week
External sources	Onshore feed from POLCOMS. Varies monthly and spatially.
Depth of Closure	23 m
Berm height	0 m
Backshore	Mostly seawalls

3.2.3. Outputs

For the composition scenarios, the following UnaLinea Outputs are supplied:

- RESU: File with the initial data and a summary of the data in control file.
- RESQ: File with sediment transport results for each time at which an output is required. For each output time step Qnet, Qleft, Qright, Qgross QK1 and QK2 are given for each model section, e.g.:

```
Results for time:     604800 seconds (        1 week )Q in m3/timestep

  SECTION      X          Qnet        Qright       Qleft        Qgross       QK1          QK2

     1      -50.0000   -6873.2376     0.0000    -6873.2376    6873.2376   -6873.2376     0.0000

     2       50.0000   -7190.1182     0.0000    -7190.1182    7190.1182   -7190.1182     0.0000

     3      150.0000   -7506.9987     0.0000    -7506.9987    7506.9987   -7506.9987     0.0000

     4      250.0000   -9442.5587     0.0000    -9442.5587    9442.5587   -9442.5587     0.0000

     5      350.0000   -8618.1559     0.0000    -8618.1559    8618.1559   -8618.1559     0.0000
```

- RESSH: File with shoreline positions results for each time at which an output is required [m from baseline]. For the shoreline outputs, the first two columns indicate the section number and X position and the following columns give the Y position at the required time steps starting with the initial position. The header number is the number of the time step of that output. RESMAX, RESMIN and RESAV have similar output formats but display the maximum, minimum and average for the outputting period respectively.

```
                      SECTION    X      Y        1       2       3       4
   1     0.00  2925.67  2925.81  2925.82  2925.84  2926.04
   2   100.00  2977.39  2977.53  2977.54  2977.56  2977.76
   3   200.00  3032.04  3032.86  3032.94  3033.06  3034.24
   4   300.00  3127.56  3127.21  3127.18  3127.27  3127.70
   5   400.00  3293.38  3293.35  3293.34  3293.35  3293.34
   6   500.00  3463.51  3463.19  3463.15  3462.96  3461.47
   7   600.00  3521.16  3521.01  3520.99  3520.98  3520.77
```

- RESMAX: File with maximum shoreline positions results for each time in which an output is required. RESMIN: File with minimum shoreline positions results for each time in which an output is required.
- RESAVGE: File with average shoreline positions results for each time in which an output is required.
- RESTCLF: File with the cliff toe position for each time in which an output is required, and
- RESYCLF: File with the cliff Y position (cliff top) for each time in which an output is required. RESTCLF and RESYCLF contain data in two columns for each output time, these being the section number and cliff toe/top position.

For further details of the UnaLinea models, see http://www.channelcoast.org/iCOASST/UNALINEA/ particularly http://www.channelcoast.org/iCOASST/UNALINEA/UnaLinea_Vos01_User_Manual.pdf.

Output times

Each UnaLinea output is given at the following times:

- Weekly for weeks one to twenty-six
- Yearly for years one to five
- Five yearly for years ten to thirty
- Years 40, 50, 75, 100, 125, 150, 175 and 200

4. Scenarios

The composition was run to predict the impacts of a number of future scenarios. These combined different representations of

- Sea level rise
- Managed realignments
- Wave time series
- Onshore feed of sediment (link X1)
- Beach nourishments

These are summarised in Table 3 and described in more detail below. The results from a scenario can be found in a directory with the same name as the scenario.

Table 3: Summary of the scenarios for Liverpool Bay

Scenario name	Sea-level rise	Realignment	Wave time series	Onshore feed	Beach nourishment
Baseline	2 mm/year		A	OF1	
SLR_High++	High++		A	OF1	
SLR_High50	High 50		A	OF1	
SLR_High95	High 95		A	OF1	
SLR_Low50	Low 50		A	OF1	
SLR_Med50	Med 50		A	OF1	
SLR_Med95	Med 95		A	OF1	
Waves1	Med 50		B	OF1	
Waves2	Med 50		C	OF1	
Waves3	Med 50		D	OF1	
Waves4	Med 50		E	OF1	
Waves5	Med 50		F	OF1	
Realignment1	2 mm/year	MR100	A	OF1	
Realignment2	2 mm/year	MR50	A	OF1	
Realignment3	Med 50	MR100	A	OF1	
Realignment4	Med 50	MR50	A	OF1	
OnshoreFeed1	Med 50		A	OF10	
OnshoreFeed2	Med 50		A	OF10	
SandEngine	Med 50		A	OF1	Sand engine

4.1. Sea-level rise

4.1.1. ASMITA

Sea-level rise was included in ASMITA as an increase to the wet volume of each element (dV_{slr}) on every time step ($dV_{slr}= R_{SLR}*dt*A$ *where* R_{SLR} is the rate of sea-level rise; *dt* is the time step and *A* is the element area). During the model spin up, between 1904 and 1990, the rate of sea-level rise was 2 mm/year for all scenarios. From 1990 onwards, an exponential increase in sea-level was used to approximate the UKCP09 scenarios (Table 4, Figure 3) which were extracted at point 17942, Lytham St Anne's.

Table 4: Relative sea-level rise (in metres) through time under different sea-level rise scenarios starting from 1990

	2000	2025	2050	2075	2100
Low 50	0.02	0.08	0.15	0.24	0.33
Med 50	0.02	0.10	0.18	0.29	0.41
High 50	0.03	0.12	0.23	0.35	0.50
Med 95	0.04	0.15	0.30	0.47	0.66
High 95	0.05	0.19	0.37	0.58	0.83
H ++	0.06	0.21	0.52	1.12	1.90

Source: UKCP09 Climate change projections (http://ukclimateprojections-ui.metoffice.gov.uk/ui/admin/login.php)

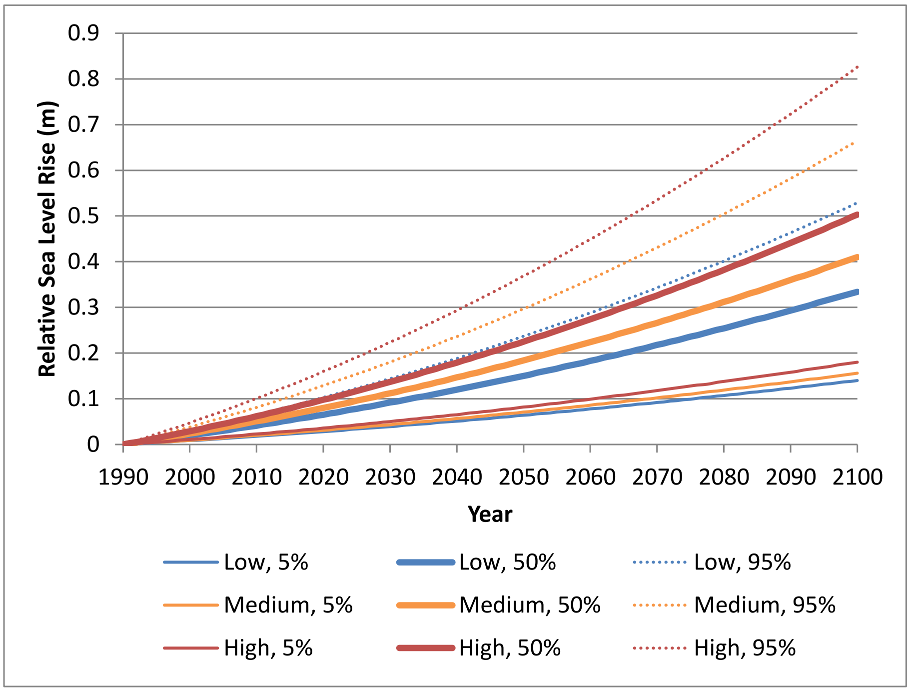


Figure 3: ULCP09 climate change scenarios

Source: UKCP09 Climate change projections (http://ukclimateprojections-ui.metoffice.gov.uk/ui/admin/login.php)

In total seven sea-level rise time series were run:

- **2 mm/year** – 2 mm / year sea-level rise from 1904 to 2115;
- **High ++** - 2 mm / year sea-level rise from 1904 to 1990 and exponential approximation to UKCP09 High ++ scenario sea-level rise from 1990 to 2115;
- **High 50**- 2 mm / year sea-level rise from 1904 to 1990 and exponential approximation to UKCP09 High 50th percentile scenario sea-level rise from 1990 to 2115;
- **High 95** - 2 mm / year sea-level rise from 1904 to 1990 and exponential approximation to UKCP09 High 95th percentile scenario sea-level rise from 1990 to 2115;
- **Low 50** - 2 mm / year sea-level rise from 1904 to 1990 and exponential approximation to UKCP09 Low 50th percentile scenario sea-level rise from 1990 to 2115;
- **Med 50** - 2 mm / year sea-level rise from 1904 to 1990 and exponential approximation to UKCP09 Medium 50th percentile scenario sea-level rise from 1990 to 2115; and
- **Med 95**- 2 mm / year sea-level rise from 1904 to 1990 and exponential approximation to UKCP09 Medium 95th percentile scenario sea-level rise from 1990 to 2115.

These are listed in column 2 of Table 3.

4.1.2. UnaLinea

Unalinea does not include rising sea-levels within the model. For our outputs we estimated the additional shoreline retreat caused by sea-level rise to be the sea level rise multiplied by the beach slope. For example, if sea level rise = 0.3 m and beach slope is represented by tanbeta = 0.01, then the shoreline can be moved landwards by 30 m during post-processing of the results to represent sea level rise.

4.2. Realignments

The Ribble Estuary has a long history of reclamation. The four reclamation scenarios examine the potential impacts of phased realignments of the existing defences. It was assumed that discrete areas were realigned at ten year intervals (Figure 4), with the first realignment being at Hesketh Out Marsh (Hesketh Out Marsh West was realigned in 2009; in these scenarios it is assumed that the remainder is realigned in 2020).

Different assumptions were made about the likely water depths over the reclaimed areas, leading to different sediment demands within ASMITA. The two options modelled were:

- **MR100** – phased re-alignment of areas (given in Table 5 and shown in Figure 4) assuming an average of 1 m water depth across the realignment area, giving an initial water volume at realignment of Volume 1 (Table 5);
- **MR50** – phased re-alignment of areas (given in Table 5 and shown in Figure 4) assuming an average of 0.5 m water depth across the realignment area, giving an initial water volume at realignment of Volume 2 (Table 5);

These are shown in column 3 of Table 3. Where no entry is present, no managed realignment was allowed.

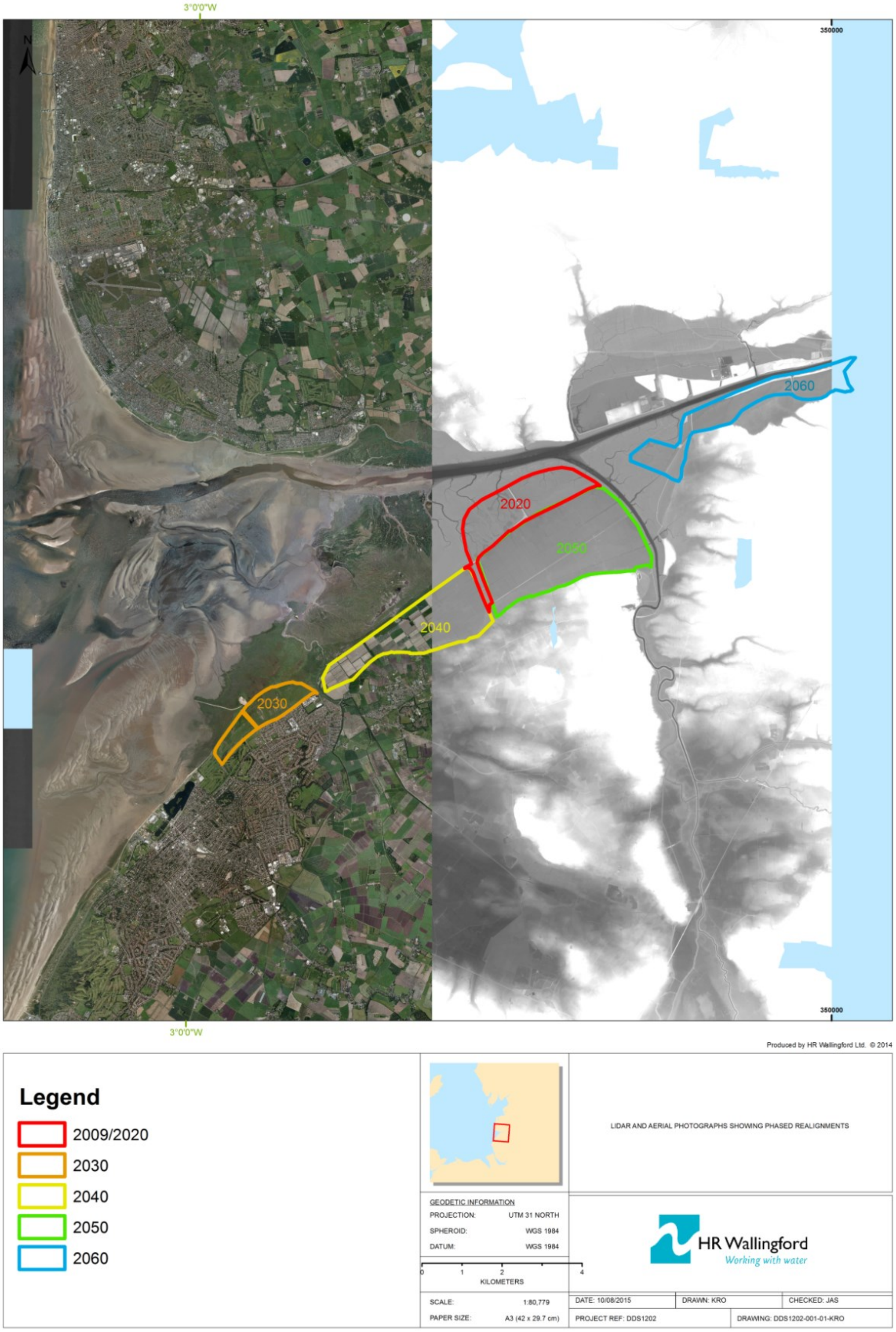


Figure 4: Phased reclamations used in the scenarios

Notes Hesketh Out Marsh, shown in red, was partially realigned in 2009.

Table 5: Area and volumes of phased realignments

Year	Area (m^2)	Volume 1 (m^3)	Volume 2 (m^3)
2009	1.65E+06	1.65E+06	8.23E+05
2020	1.81E+06	1.81E+06	9.03E+05
2030	1.57E+06	1.57E+06	7.87E+05
2040	4.42E+06	4.42E+06	2.21E+06
2050	7.50E+06	7.50E+06	3.75E+06
2060	3.14E+06	3.14E+06	1.57E+06

Notes: Volume 1 assumes an average 1 m water depth across the realignment area; Volume 2 assumes a 0.5 m water depth.

4.3. Waves

A 35-year long time-series of offshore wave conditions was obtained from the Wavewatch III model. For most model runs (scenario A, this time series was applied from the start of the model run (in 1904) and was repeated every 35 years until the end of the simulation (2115), giving just over six repeats of the same time series.

The Environment Agency's climate change allowances for planners (Guidance to support the national planning policy framework, 2013) includes recommended national precautionary sensitivity ranges for offshore wave height. For extreme wave height this includes an increase of 5% from 1990 to 2055 and an increase of 10% from 2055 to 2115. A revised long time series (scenario B) was created with the standard time series from 1904 to 1990, with significant wave heights, H_s, increased by 5% between 1990 and 2055 (with wave periods increased to give the same wave steepness) and with wave heights increased by 10% from the original time series, between 2055 and 2115 (again with increased wave periods to maintain the same wave steepness. In addition, sensitivity to changes in wave direction were explored by rotating the entire wave climate by +/- 2° and +/- 10° from 1990 to 2115.

Six wave time series were included:

A. Repeating sequence of present-day 35-year time series;
B. Time series A with H_s increased by 5% between 1990 and 2055 and H_s increased by 10% between 2055 and 2115 (while maintaining wave steepness);
C. Time series A with minor changes in wave direction (+2°) applied to all wave conditions from 1990;
D. Time series A with minor changes in wave direction (- 2°) applied to all wave conditions from 1990;
E. Time series A with major changes in wave direction (+ 10°) applied to all wave conditions from 1990; and
F. Time series A with major changes in wave direction (- 10°) applied to all wave conditions from 1990.

These are listed in column 4 of Table 3.

4.4. Onshore feed

In standard composition runs, there was a transfer of sediment from the coastal area model POLCOMS to the coastal models, UnaLinea and ASMITA (Figure 1). The Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS) is a three-dimensional baroclinic ocean circulation model which solves the hydrostatic Boussinesq equations in depth-varying and depth-independent parts (Holt and James 2001). Wetting and drying algorithms are used to cope with the large inter-tidal areas in the model. POLCOMS has been implemented within Liverpool Bay, including the shoreface adjacent to the study area, using a numerical domain with a resolution of ~180 m in the horizontal and 10 vertical sigma levels within the water column (Brown et al. 2015). The Liverpool Bay model boundary conditions at the northern and western boundaries were extracted from POLCOMS simulations of the full Irish Sea at ~1.8 km resolution. The Liverpool Bay model was run for the entire duration of 2008, using realistic atmospheric and riverine forcing. Hourly current vectors at each vertical level within the water column were used to simulate near-bed current stress by assuming a logarithmic profile for near-bed velocities. Bedload transport vectors were then calculated using the critical Shield’s stress for a chosen sediment class (Sutherland et al., 2015).

The POLCOMS – UnaLinea links (X2 in Figure 2, respectively) are derived from POLCOMS results files. Gridded hourly time series of bedload transport rates were averaged to give monthly values. These were extracted from POLCOMS along a line that represented the approximate offshore limit of the coastal models, as represented by the depth of closure for UnaLinea. Both are about 6 m to 8 m below mean sea level.

The POLCOMS model results were pre-computed, so results files were used to provide the rate of sediment exchange. So although the direction of sediment transport in the links X2 may be onshore or offshore (i.e. sediment transport is bi-directional) these links are implemented as uni-directional links in the present set-up as information is only passed from POLCOMS to UnaLinea, which pass no information back to POLCOMS.

In total three rates of feed were used to explore the importance of onshore feed from the seabed of the Irish Sea:

- OF0 - no offshore feed was included
- OF1 – onshore feed pre-computed by POLCOMS
- OF10 - ten times the onshore feed pre-computed by POLCOMS

These are listed in column 5 of Table 3.

4.5. Nourishment

One beach nourishment scenario was simulated. In this scenario, called SandEngine, a large volume of sand was placed to the north of Blackpool in the year 2020 of the model simulations (Figure 5). The SandEngine output times differ from the other scenarios and additional Med50 results are provided with the same output times to allow comparison.

This is shown in column 6 of Table 3. Where no entry is present, no beach nourishment was included in the scenario.

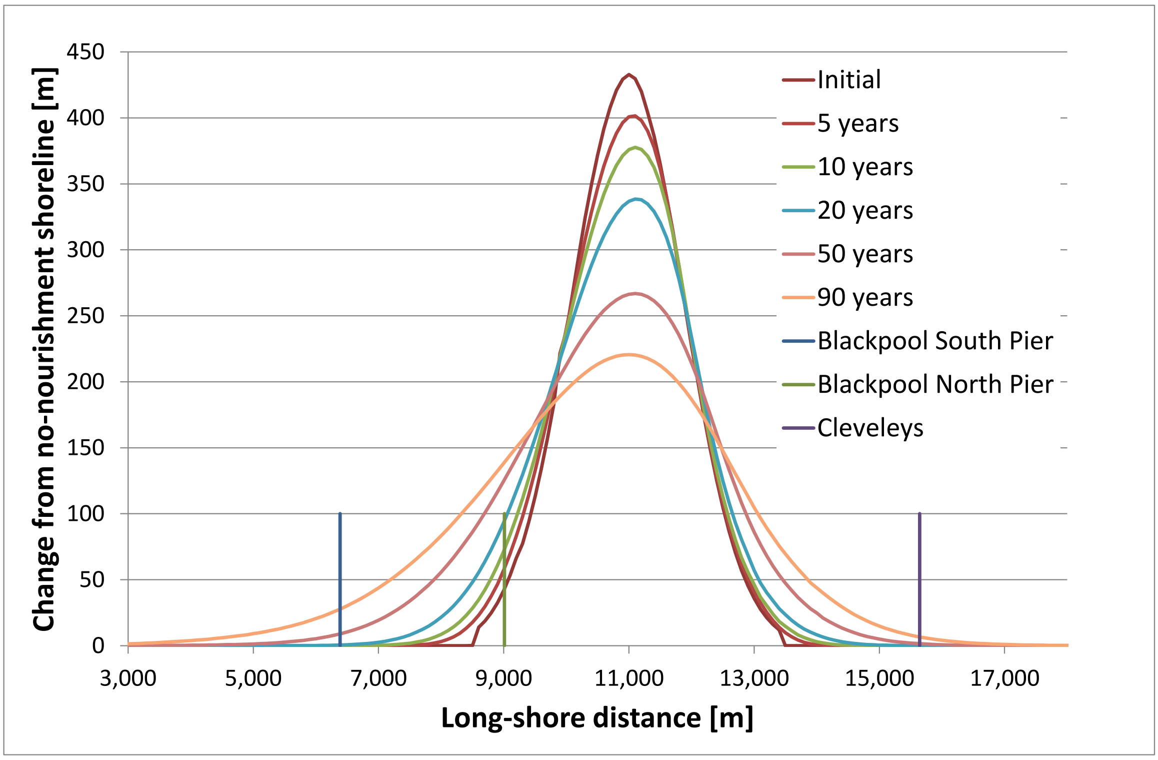


Figure 5: Initial placement of sand in the Blackpool SandEngine scenario and predicted evolution over 90 years.

5. References

Brown, J.M., Amoudry, L., Souza, A. and Rees, J. (2015). “Fate and pathways of dredged estuarine sediment spoil in response to variable sediment size and baroclinic coastal circulation.” *Journal of Environmental Management*, 149: 209-221.

French J, Burningham, H, Thornhill, G., Whitehouse, R. and Nicholls, R. (2016). Conceptualizing and mapping coupled estuary, coast and inner shelf sediment systems. Geomorphology, 256: 17-35.

Holt, J.T. and James, I.D. (2001). “An s coordinate density evolving model of the northwest European continental shelf: 1, model description and density structure.” J. Geophys. Res. 106 (C7), 14,015-14,034.

Nicholls, R.J., French, J., van Maanen, B., Burningham, H., Payo, A., Sutherland, J., Walkden, M., Thornhill, G., Brown, J., Luxford, F., Simm, J., Reeve, D.E., Horrillo-Caraballo, J.M., 2015a. “Improving decadal coastal geomorphic predictions.” Proceedings of the 36th IAHR World Congress, The Hague, Netherlands.

Nicholls, R.J., French, J., Burningham, H., van Maanen, B., Payo, A., Sutherland, J., Walkden, M., Thornhill, G., Brown, J., Luxford, F., Simm, J., Reeve, D.E., Hall, J.W., Souza, A., Stansby, P.K., Amoudry, L.O., Rogers, B.D., Ellis, M., Whitehouse, R., Horrillo-Caraballo, H.M., Karunarathna, H.U., Pan, S., Plater, A., Dix, J., Barnes, J., Heron, E., 2015b. “Improving decadal coastal geomorphic predictions: an overview of the iCOASST project.” Proceedings of Coastal Sediments ’15, San Diego, California, USA. ISBN 978-981-4689-96-0.

Sutherland, J., Rossington, K., Whitehouse, R., Blanco, B. and L’homme, J., 2015a. “Decadal simulations of coastal geomorphic evolution in Liverpool Bay, UK.” Proceedings of Coastal Sediments ’15, San Diego, California, USA. ISBN 978-981-4689-96-0.

Sutherland, J., Nicholls, R.J., Burningham, H., Rossington, K., Lopez de San Roman Blanco, B., Brown, J.M., 2015b. “Representing and modelling coastal systems over a regional scale for coastal management.” Proceedings of Coastal Management 2015, Changing Coasts, Changing Climate, Changing Minds. ICE, Amsterdam, Netherlands.

Van Maanen, B., Nicholls, R.J., French, J.R., Barkwith, A., Bonaldo, D., Burningham, H., Murray, A.B., Payo, A., Sutherland, J., Thornhill, G., Townend, I.H., van der Wegen, M. and Walkden, M.J.A., 2016. “Simulating mesoscale coastal evolution for decadal coastal management: a new framework integrating multiple, complementary modelling approaches”. Geomorphology 256: 68-80, http://dx.doi.org/10.1016/j.geomorph.2015.10.026

Whitehouse R, Balson P, Beech N et al. (2009). Characterisation and prediction of large scale long-term change of coastal geomorphological behaviours: final science report. Report SC060074/SR1, Environment Agency, ISBN 978-1-84911-090-7.

6. Acknowledgements and license

This report was prepared as part of the project “Integrating Coastal Sediment Systems” (iCOASST) which was led by the University of Southampton. For further details of the project, please see http://www.icoasst.net/.

The iCOASST project was funded by the Natural Environment Research Council (http://www.nerc.ac.uk) under grant NE/J00541X/1, with the Environment Agency (http://environment-agency.gov.uk) as an embedded stakeholder.