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Trialling a new approach to beach replenishment in Poole Bay

SC130035

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T: 03708 506506

Email: enquiries@environment-agency.gov.uk

Author:
Travis Mason

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Research Contractor:
Channel Coastal Observatory, National Oceanography Centre, Southampton, SO14 3ZH. Tel: 02380 598467
New Forest District Council

Environment Agency's Project Manager:
Eleanor Heron, Evidence Directorate

Collaborator(s):
Jon Evans, Channel Coastal Observatory
Matthew Linham, Fugro EMU Limited
Robin Newman, Fugro EMU Limited
Stuart Terry, Poole Borough Council

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Professor Doug Wilson
Director, Research, Analysis and Evaluation

Executive summary

This report presents the results of a year-long programme of fieldwork to monitor the behaviour of 30,000m^3 of sand deposited in the nearshore zone off Canford Cliffs in Poole Bay. The technique of replenishing beaches by deposition sand in the nearshore (sub-tidal) area is widely used in the Netherlands, but the project in Poole Bay was the first trial of the method in the UK. The material used was from maintenance dredging in Poole Harbour and thus was beneficial use of sediment that would otherwise have been dumped at sea.

A potential constraint on the experiment was the recently designated Poole Rocks Marine Conservation Zone (MCZ), located approximately 1km to seaward of the deposition zone. A condition of the Marine Management Organisation licence was a comprehensive and independent monitoring programme to assess the transport pathways of the deposited sand. The monitoring programme consisted of beach surveys, swath bathymetry and long-term measurement of the waves, currents and suspended sediment concentration in the water column, together with a sub-tidal tracer study and the deployment of silt traps near Poole Rocks (undertaken by the University of Southampton).

Some 14 months after deposition, the mounds remained distinct features, approximately 2m high. The sediment had remained in situ, with a net loss of only ~1,000m^3 (~3%) since deposition. Such small net volumes of sediment change are difficult to identify even from high precision bathymetric and topographic surveys. Between late December 2015 and April 2016, the mounds rolled forward in a similar manner to the shoreward translation of an offshore bar but, as yet, it is impossible to predict whether the ‘bar’ will remain as a semi-fixed feature or will migrate onshore.

A clear sediment transport link was established between the deposition on the 5m Chart Datum contour and the beach. However, the measured waves and currents indicated that deposition on the 8m Chart Datum contour is more likely to be transported alongshore rather than cross-shore.

The deposition had no discernible or detrimental impact on the Poole Rocks MCZ.

Although a sediment transport connection between the nearshore and the adjacent beach was proved (that is, nearshore deposition can replenish the beach), it remains difficult to assess the long-term fate of the material. It is likely that both a larger quantity of material and more time are needed for sediment dispersal at this site to demonstrate long-term viability of nearshore replenishment as an alternative to traditional methods. Furthermore, the success or otherwise of the technique of nearshore replenishment is clearly dependent on a wide range of site-specific conditions, where even subtle differences in tidal currents, wave period and direction can have a significant influence on net sediment transport in the nearshore region. As a result, it would not be appropriate to extrapolate the results from this study to other coastlines or to draw conclusions on the transferability of the method to other sites.

Acknowledgements

The Poole Bay nearshore beach replenishment trial monitoring was commissioned under the Flood and Coastal Erosion Risk Management Research and Development Programme (Project SC130035), funded by Defra, the Environment Agency and the Welsh Government, with additional contributions from the Borough of Poole, New Forest District Council (Channel Coastal Observatory) and SCOPAC (Standing Conference on Problems Associated with the Coastline).

'Copy the ideas, don't copy the results'

Marcel Stive, Professor of Coastal Engineering at the Faculty of Civil Engineering and Geosciences, Delft University of Technology
iCOASST Conference, Royal Society, London, January 2016

Contents

1 Introduction

Nearshore (sub-tidal) replenishment has been widely employed in the Netherlands and, more recently, in Denmark as a technique to renourish beaches whereby the sediment is deposited typically on an offshore sand bar and, over time, waves transport the sediment to the beach face. The technique promises several advantages over conventional methods of beach renourishment used in the UK, including the potential to be more economically and environmentally sustainable.

The first trial of the nearshore replenishment method in the UK was carried out by the Borough of Poole when 30,000m^3 of material dredged from Poole Harbour was deposited on the seabed approximately 350m offshore of Shore Road, Canford Cliffs, on 14 February 2015. The material used was from maintenance dredging and so the trial had the added benefit of using sediment that would otherwise have been dumped at sea (MMO 2014).

As a condition of the deposition licence issued by the Marine Management Organisation (MMO), an extensive monitoring programme was required to assess the behaviour of the deposited material. An important secondary requirement was to determine the potential impacts of the nearshore deposition on sensitive or protected marine features, particularly given the proximity of the Poole Rocks Marine Conservation Zone (MCZ). From a scientific and engineering point of view, the primary purpose of the monitoring was to establish whether small volumes of material deposited in the nearshore region can effectively trickle charge the beach in sufficient quantities to replace the more traditional beach replenishment method.

The Poole Bay Nearshore Replenishment Trial monitoring programme contained the following activities to track the dispersal of the deposited material:

- beach (topographic) surveys
- swath bathymetry (multibeam) surveys
- seabed tracer study
- waves, currents and turbidity measurements
- tidal monitoring
- silt monitoring (carried out by a team from the University of Southampton, commissioned separately by the Borough of Poole)

However, an important facet of the monitoring programme was to examine the results in context with longer term natural changes in terms of the transport rates and pathways of the recharge, and the hydrodynamic conditions experienced. An extensive database of morphodynamic and hydrodynamic conditions in Poole Bay, collected by the Southeast Regional Coastal Monitoring Programme and dating back to 2002, was available for this purpose.

This report is based around an assessment of trial monitoring data to answer 2 principal questions:

1. Is there a sediment connection between the nearshore (deposition area) and the beach of sufficient quantity to indicate that the process of nearshore replenishment could be a successful technique at this site?
2. Has the nearshore replenishment had a detrimental effect on the adjacent Poole Rocks MCZ? The effect is to be assessed in terms of whether the replenishment may have caused additional silt levels at the MCZ.

1.1 Structure of the report

First, the background information is presented, including a description of the field site, deposition operations and the methods and techniques used for data collection and analysis. The trial results are then presented and discussed. Finally, conclusions are drawn and the lessons learnt outlined.

The main report provides summary information, with much of the detail and supporting evidence contained in a series of appendices.

2 Field site

Poole Bay is a micro-tidal, shallow bay in the central English Channel. The western part of the bay is afforded some shelter from the prevailing south-west winds and waves by Durlston Head.

Beaches in Poole Bay are generally sandy, in contrast to the extensive shingle and mixed sand/shingle beaches to the west and east respectively. Much of the bay frontage is groyned and backed by a seawall, with extensive beach management and regular large-scale beach replenishment.

Poole Bay also contains the recently designated Poole Rocks MCZ, approximately 1km to seaward of the trial area.

The area chosen for the nearshore replenishment trial was a $1km^2$ box, ranging in depth from about 4 to 8 m Chart Datum (CD) (Figure 2.1). The actual deposition site was to be over about $150m^2$ within the box, depending on weather and tide conditions during the dredge and deposition.

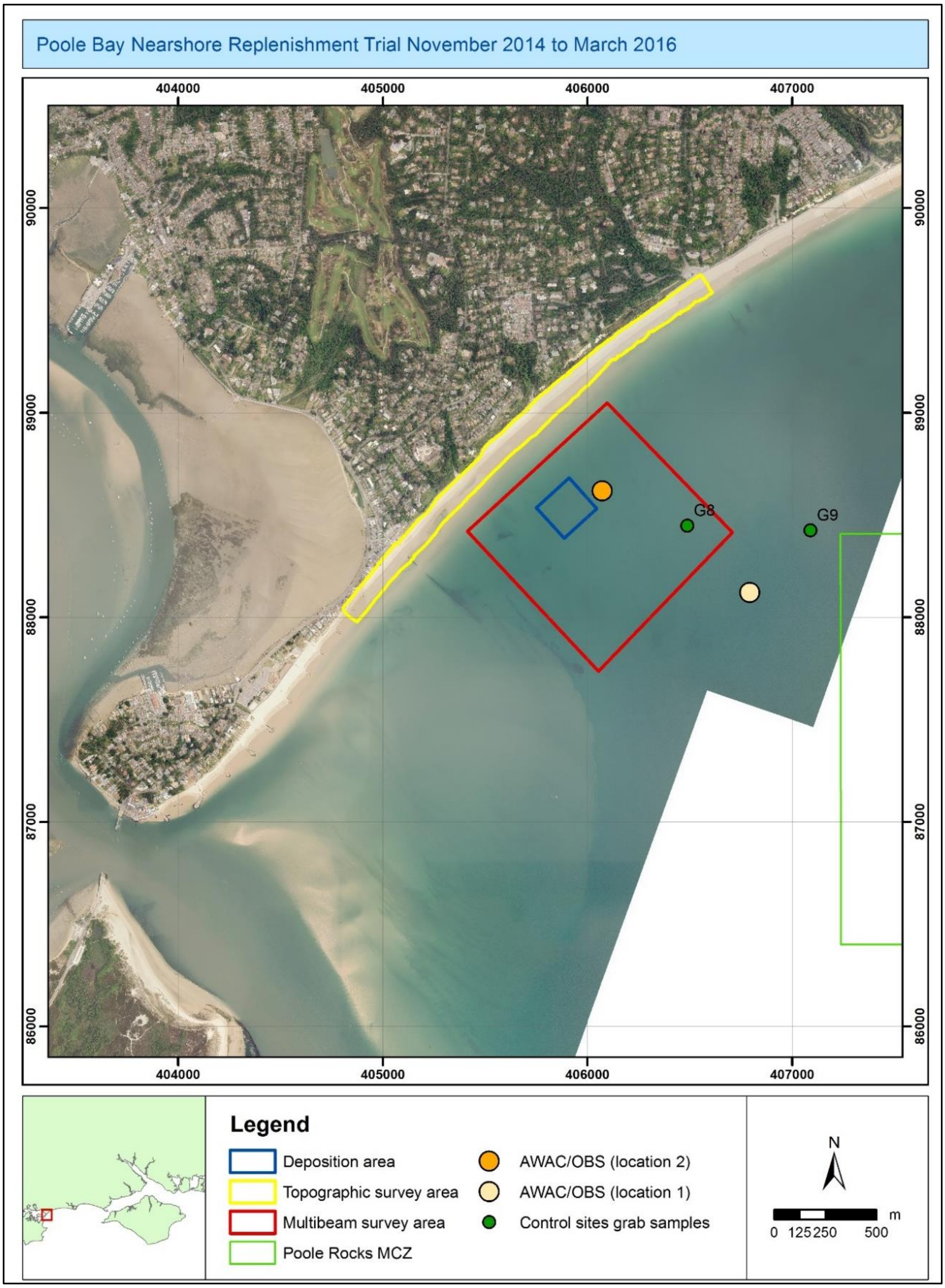


Figure 2.1 Field site and instrumentation

Notes: AWAC = acoustic wave and current profiler
OBS = optical backscatter sensor

3 Sediment deposition

Due to clement sea conditions for the early part of dredging operations, the chosen deposition site was towards the western, shoreward edge of the permitted area (Figure 2.1) in approximately 5m CD water depth.

Some 33 dredger loads totalling 30,000m^3 were deposited from the *Magni-R* (Figure 3.1), forming discernible mounds within the 0.04km^2 deposition box. After 5 days, dredging activities were suspended due to the weather but began again on 14 February 2015 and the dredger de-mobilised from site later that day. Figure 3.2 shows an image of the mounds immediately after completion of dredging operations.

(A)

(B)

Figure 3.1 *Magni-R* discharging at the deposition site

Notes: (A) Photo courtesy of T. Mason, Channel Coastal Observatory
(B) Photo courtesy of S. Terry, Borough of Poole

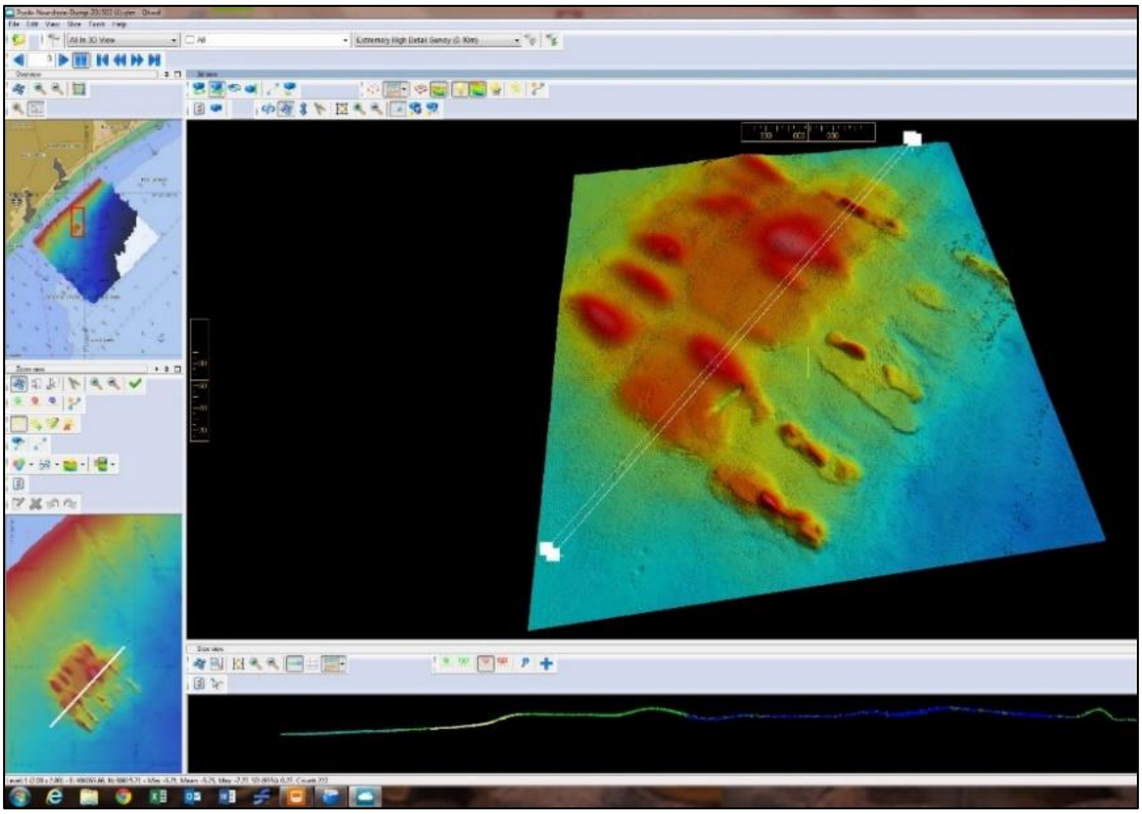


Figure 3.2 Illustration of sediment mounds on completion of deposition

Notes: Provisional swath bathymetry data, S. Pearce, Poole Harbour Commissioners

4 Monitoring methodology

The monitoring plan used a combination of beach and seabed surveys, employing modern survey techniques to map the changes in bed morphology, together with hydrodynamic instruments to measure waves, currents and high frequency turbidity fluctuations.

Topographic surveys were completed using a laser scanner and swath (multibeam) bathymetry surveys were conducted to International Hydrographic Organization (IHO) Order 1a standard. Wave height and direction, current profile and suspended sediment concentration (SSC) (a surrogate for turbidity) were measured using a Nortek acoustic wave and current profiler (AWAC) and co-located optical backscatter sensor (OBS). Turbidity/SSC is determined from the instruments' backscatter measurements, which together can monitor sediment sizes ranging from silt to coarse sand. The instruments and techniques used are widely accepted as the most accurate and precise in general use for coastal monitoring today. Further information about the survey techniques, instrumentation, sampling regimes and methods of analysis is given in Appendix A.

The long-term term morphodynamic and hydrodynamic regime in the western part of Poole Bay is described in Appendix B, which also provides the context of background changes with which to compare the short-term trial monitoring results.

For analysis purposes, the trial monitoring area encompassed 3 discrete areas, as illustrated in Figure 2.1:

- **Beach survey area**, extending some 2.5km from the first rock groyne west of Shore Road to Branksome Chine, and from the seawall or dune face at the back of the beach to the mean low water springs (MLWS) contour
- **Bathymetry survey area**, extending about 1km^2; later reduced in size to about 0.4km^2 once it was established that no measurable changes in bathymetry had occurred further offshore
- **Deposition area** spanning the deposition mounds, approximately 0.04km^2

Given the possibility that the material could disperse rapidly, most of the planned monitoring activity was compressed into a period of 6 weeks after completion of dredging activities. However, some adaption of the initial proposed programme was necessary to compensate for operational delays such as unsuitable sea conditions and in response to the survey results. For example, after several days of dredging and deposition, operations were suspended due to worsening weather conditions. In a similar vein, the timing of the tracer insertion was brought forward by a day so that the effects of the fresh southerly winds forecast for the following day might be captured. Furthermore, sticking to the original plan for tracer insertion the following day risked the operation not being completed until 3 or 4 days after the majority of the sediment had been placed, due to the need for calm seas.

The full fieldwork diary is shown in Table 4.1. Time intervals are expressed as days relative to deposition day, 'D', which is taken as the completion of deposition on 14 February 2015.

The pre-deposition bathymetry survey took place on 7 February 2015 (D-7), but poor weather delayed the post-deposition survey until 17 February 2015 (D+3). The pre-works beach survey was carried out 2 days before deposition started (D-6) and the post-works survey 3 days after deposition was completed (D+3) and hence 5 days after tracer insertion.

After 6 months of AWAC/OBS data collection, Natural England agreed that sufficient data had been collected to set the trial turbidity results into the context of naturally derived turbidity. Accordingly, the AWAC/OBS was re-sited further inshore for the remainder of its one year deployment to allow for a better understanding of the sediment transport regime in the hydrodynamic conditions experienced at the deposition site.

The Borough of Poole subsequently funded an extension of the AWAC/OBS deployment until March 2016. This allows for a year of measurements since the deposition, together with an additional swath bathymetry survey of the full area on completion of the trial.

Table 4.1 Fieldwork diary

Task	Milestone	Completed		Comments
Hydrodynamics	AWAC deployed	27 November 2014	D-79	Location 1 (~8m CD)
Survey set 0 (pre-dredge)	Pre-dredge swath	7 February 2015	D-7	
	Pre-dredge topography	8 February 2015	D-6	Scanned additional area at either end of box
Tracer	Placement	12 February 2015	D-2	Placed after two-thirds of deposition so as to capture forecast fresh southerly winds
Deposition	**Dredge and deposition**	**14 February 2015**	**D**	Started 9 February 2015; completion delayed by weather downtime
Tracer search 1	Tracer seabed sweep 1	15 February 2015	D+1	
	Tracer beach sweep 1	16 February 2015	D+2	Brought forward and combined with seabed sweep 1 due to southerly winds and indications from seabed sweep that tracer was approaching the shore
Survey set 1 (post-dredge)	Swath 1	17 February 2015	D+3	Delayed due to weather
	Topography 1			
Tracer search 2	Tracer seabed sweep 2	21 February 2015	D+7	
	Tracer beach sweep 2	22 February 2015	D+8	Brought forward and combined with offshore sweep 2 due to indications that offshore tracer was close to the shore
Survey set 2	Swath 2	25 February 2015	D+11	Postponed as surveys did not show much change other than from top of mounds
	Topography 2 (partial)			Brought forward due to appearance of sediment bulge on foreshore
Tracer search 3	Tracer beach sweep 3	19 March 2015	D+33	Additional sweep by the Borough of Poole
Survey set 3	Single beam inshore	20 March 2015	D+34	Profiles overlapping topographical profiles to tie in beach and nearshore
	Topography 3			
	Single beam nearshore	27 March 2015	D+41	Profiles overlapping swath area; replaced swath 3 to capture overlap with topographical survey
Hydrodynamics	AWAC serviced	27 February 2015	–	
Survey set 4	Swath 4	7 April 2015	D+52	
	Topography 4	16 April 2015	D+61	
Hydrodynamics	AWAC moved	14 June 2015	D+120	Serviced and moved shorewards to deposition contour, location 2 (~5m CD)
Survey set 5	Topography 5	8 July 2015	D+144	Channel Coastal Observatory profiles of Sandbanks and Bournemouth frontage, laser scan of beach trial area
	Swath 5	9 July 2015	D+145	
Survey set 6	Topography 6 (profiles)	1 October 2015	D+229	Channel Coastal Observatory profiles of Sandbanks and Bournemouth frontage
	Swath 6	14 December 2015	D+303	Additional swath (funded by Borough of Poole)
Hydrodynamics	AWAC serviced	23 November 2015	–	Additional 3 months deployment to complete year since deposition (funded by Borough of Poole)
Hydrodynamics	AWAC decommissioned	8 March 2016	D+388	
Survey set 7	Swath 7	5 April 2016	D+416	Additional swath to complete year since deposition (funded by Borough of Poole)
	Topography 7	6 April 2016	D+417	Channel Coastal Observatory laser scan of Poole frontage

5 Results

5.1 Inter-tidal beach

Table 5.1 lists the changes in inter-tidal beach volume above MLWS normalised in terms of net volume change per day (historical data are included for context). This method is particularly appropriate for the trial monitoring data. The trial was designed to concentrate surveys in the period immediately following the deposition, but as the intervals between surveys increase, any event-driven net volume changes inevitably become smoothed out and hence setting short-term values into the longer term (annual) changes becomes less conclusive. Survey-to-survey net volume changes are illustrated in Appendix C, Section C.1.

Table 5.1 Net volume change above MLWS (-0.8 Ordnance Datum, OD) in common beach trial area (0.208km²)

Survey dates		Number of days	Days relative to deposition	Net volume change (m^3)	Net volume change per day (m^3 day^{-1})
* Beach replenished December 2005					
9 June 2005*	28/06/2006	384		201,566*	
28 June 2006	20/06/2007	357		-35,738	-100
20 June 2007	03 June 2008	349		-51,218	-147
03 June 2008	12 June 2009	374		1,062	3
12 June 2009	17 June 2010	370		-452	-1
17 June 2010	7 April 2011	295		6,417	22
7 April 2011	22 March 2012	351		-4,995	-14
22 March 2012	1 May 2013	406		-14,058	-35
1 May 2013	4 April 2014	339		-46,418	-137
* Beach replenished November 2014					
4 April 2014*	7 February 2015	309		120,188*	389*
7 February 2015	17 February 2015	10	D-7 to D+3	341	34
17 February 2015	20 March 2015	31	D+3 to D+34	20,668	667
20 March 2015	16 April 2015	27	D+34 to D+61	4,515	167
16 April 2015	8 July 2015	83	D+61 to D+144	-25,890	-312
8 July 2015	6 April 2016	273	D+144 to D+417	-35,311	-129

However, the ‘whole beach’ volume changes can disguise some small-scale differences in beach behaviour. Around 24 February 2015, a noticeable beach bulge was observed near Canford Cliffs (Figure 5.1). An additional topographic survey was therefore conducted over approximately 550m of beach either side of the bulge on 25 February 2015 (Figure 5.2).

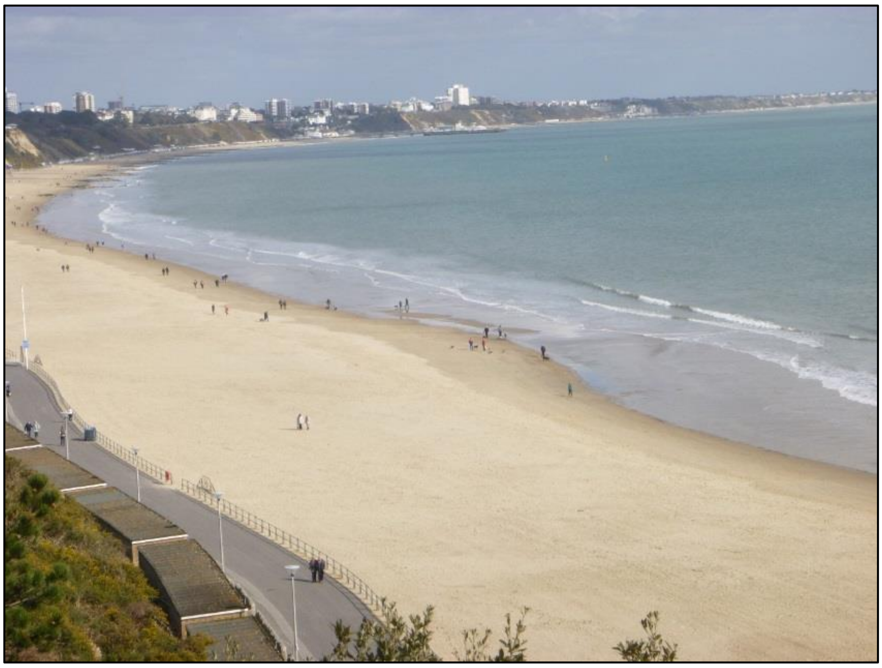


Figure 5.1 Sediment 'bulge' at Canford Cliffs, 27 February 2015 (D+13)

Notes: Photo courtesy of D. Robson, Borough of Poole

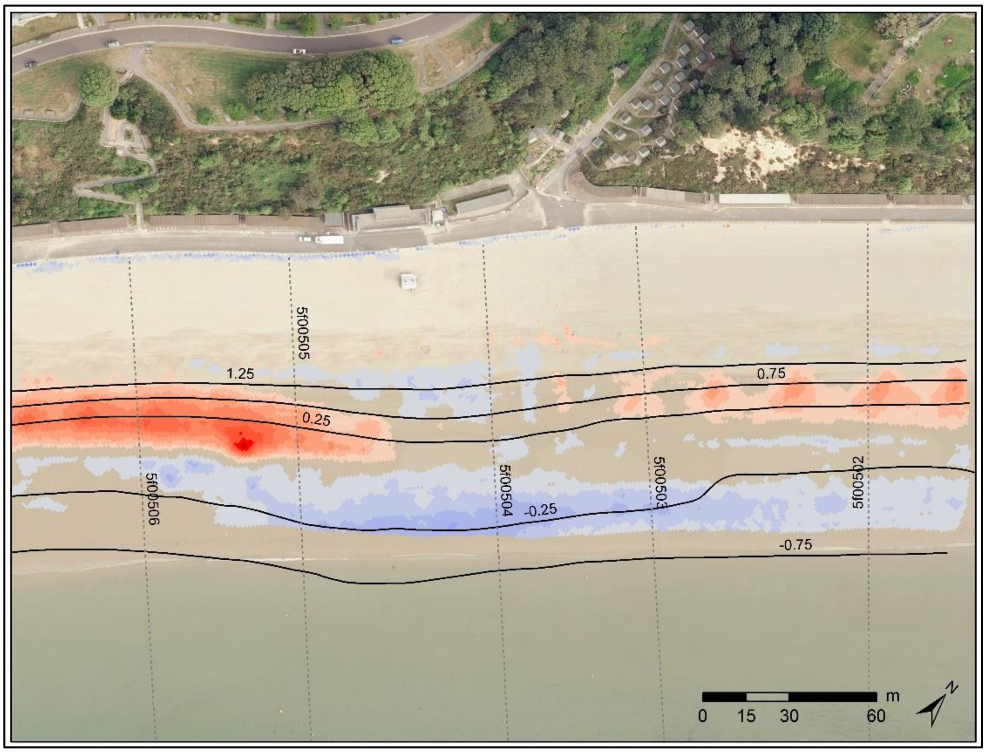


Figure 5.2 Difference model of sediment 'bulge' area, from D+3 to D+11 (17 to 25 February 2015)

The next survey on 20 March 2015 (D+34) took place over particularly large equinoctial tides, which allowed beach surveyors to reach levels close to CD. Although a nearshore bar has been observed at this location on occasions in the past, no bar was observed during this survey.

The sediment bulge coincided with the highest daily net gain in sediment observed during the trial (Table 5.1). Profile 5f00504 passes through the sediment bulge, which is prominent at elevations between 0.5m and -0.75m OD (mean high water (MHW) to below MLWS), that is, across the whole beach face. Sand continued to accrete at this location until April (Figure 5.3), but by July 2015, the whole beach trial area had lost around 25,000m^3, including at the bulge area profiles which eroded back some 5m. Nevertheless, this represented overall net accretion since the deposition, with a similar response over much of the beach trial area.

The ‘bulge’ was either maintained or reformed during much of the summer. It was observed in the Borough of Poole’s weekly photography until August 2015, although was not evident during the autumn or winter period.

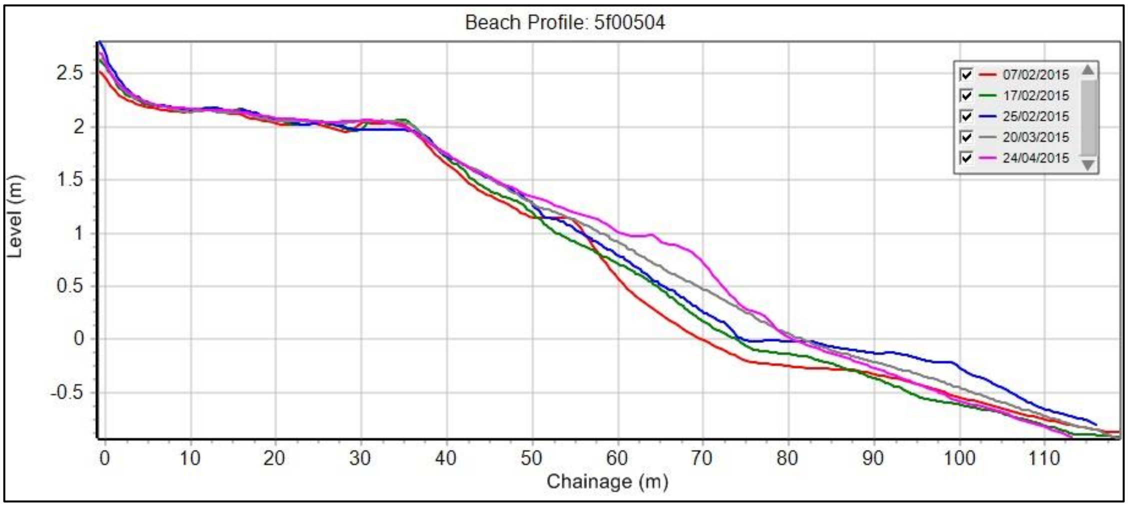


Figure 5.3 Profile 5f00504, D-7 to D+61

Notes: Red is 7 February 2015 (pre-deposition), green is 17 February 2015, blue is 25 February 2015, grey is 20 March 2015 and pink is 24 April 2015.
Profile has accreted around 12m at mid-tide level.

Some minor erosion continued through the summer but, by the following spring, the profile had eroded some 10m across much of the beach face, piling up sediment at the back of the beach (Figure 5.4). The winter of 2015 to 2016 was not overly stormy, but was marked by long periods of moderate waves, which caused considerable structural damage at a number of sites along the English Channel.

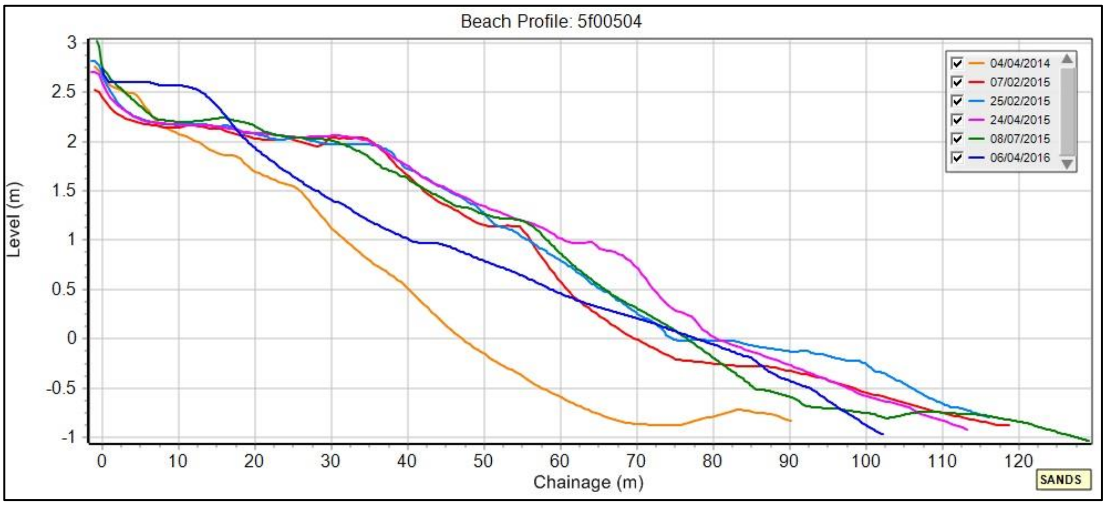


Figure 5.4 By April 2016, the profile had eroded across the beach face (blue), but not as far back as the pre-replenishment profile in April 2014 (orange)

Conclusions from topographic surveys
• Beach gained 20,000m^3 in 30 days following the deposition • Beach continued to gain sediment for a further month, but at a slower rate • Between mid-April 2015 and July 2015, beach lost sediment at approximately the same rate as it had gained since the deposition • Beach continued to erode for the remainder of the trial but at half the earlier rate of loss • Trend of sediment gains/losses at the 'bulge' generally mirrored over the rest of the beach trial area • One year after the deposition, the beach remained in a reasonably healthy state

5.2 Bathymetry

Even the highest standard swath bathymetry survey has a typical vertical error – total propagated uncertainty (TPU) – of at least 0.2m and so attempting to achieve accurate difference volumes from bathymetry surfaces that have minimal change is fraught with ambiguities. For example, within the 0.04km^2 deposition box, a vertical uncertainty of just 0.05m equates to a volume of 2,000m^3. Difference models for the outer bathymetry box showed negligible change when a survey tolerance of ±0.2m was applied. Subsequent analysis therefore concentrated on the deposition area box to assess the short-term losses from the deposition mounds (Table 5.2).

Table 5.2 Net volume change in deposition box (0.04km^2)

Survey dates		Number of days	Days relative to deposition	Net volume change (m^3)	Net volume change (m^3 day^{-1})
8 February 2015	17 February 2015	9	D-6 to D+3	30,959	-
17 February 2015	25 February 2015	8	D+3 to D+11	848	106
25 February 2015	7 April 2015	41	D+11 to D+52	-1,782	-43
7 April 2015	9 July 2015	93	D+52 to D+145	1,525	16
9 July 2015	14 December 2015	158	D+145 to D+303	-14	0
14 December 2015	5 April 2016	113	D+303 to D+435	-354	-3

About 1,000m^3 appeared to have been eroded off the top of the mounds within about 2 weeks of the deposition. However, there is no irrefutable evidence to indicate whether the eroded material diffused away from the mounds gradually or left the survey area rapidly. The interim surveys in April and July 2015 indicated net volume changes of around 1,500m^3 loss and gain respectively. Overall, by December 2015, the sediment change within the deposition box showed that the principal change was that sediment was planed off from the top of the mounds and deposited in the troughs, with almost negligible change to the sediment volume outside the deposition area (Figure 5.5 top panel).

By April 2016, however, there was clear evidence of shoreward movement of sand from the deposition mounds. Although there was little net change overall within the deposition box, the profiles in particular demonstrate that the mounds – acting effectively as a nearshore bar – have rolled landward, changing position and shape rather than changing volume (Figure 5.6).

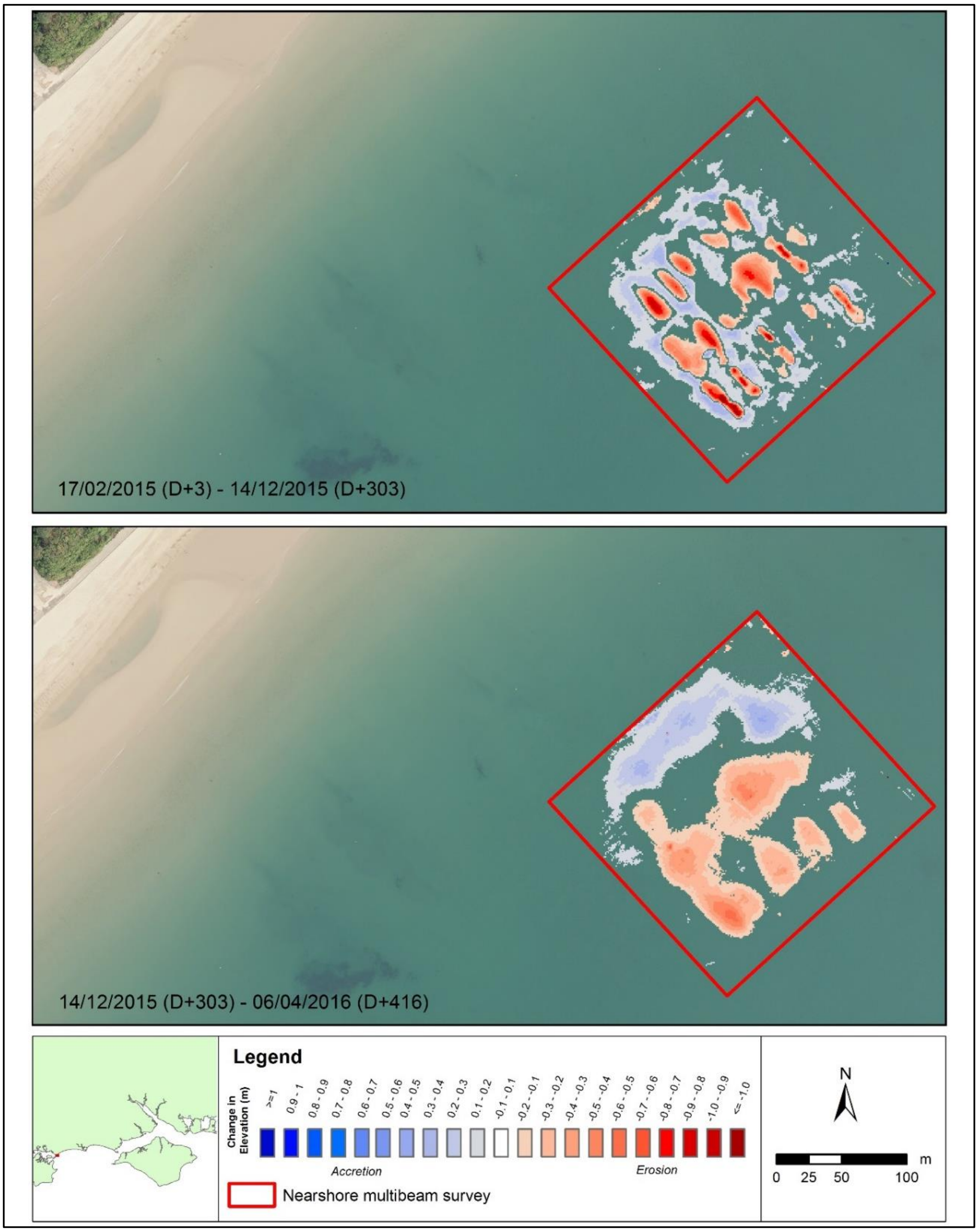


Figure 5.5 Bathymetric difference models post-deposition to December 2015 (top) and December 2015 to April 2016 (bottom)

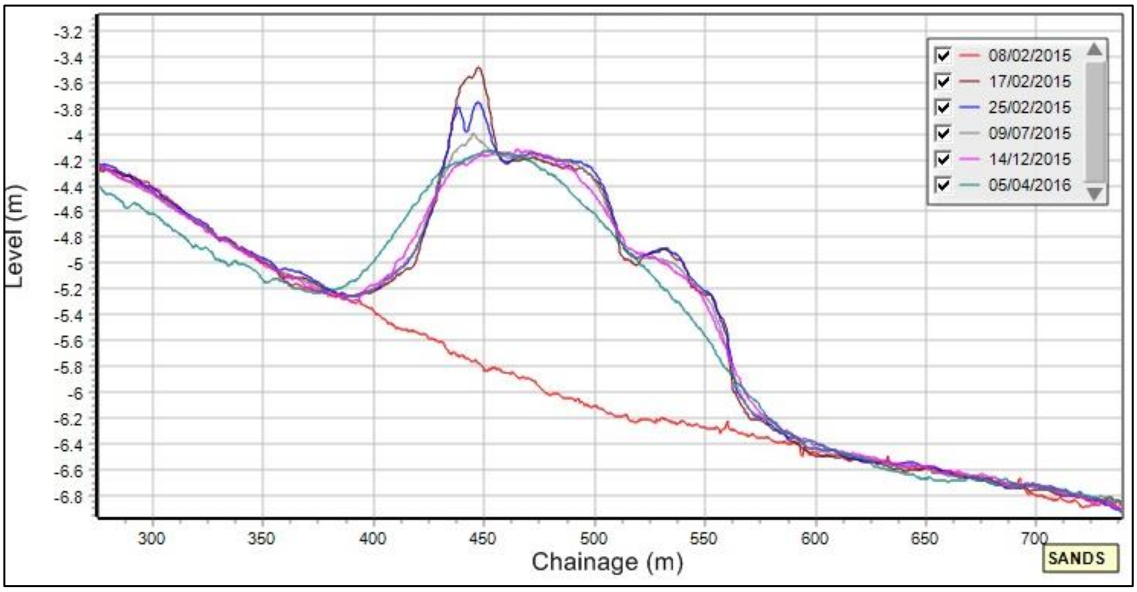


Figure 5.6 Bathymetry profile 5f00508_H

The same pattern of shoreward translation of the mounds was evident at all profiles crossing the mounds, but with no measurable change at adjacent profiles (additional results are given in Appendix C, Section C.2). Analysis of the AWAC data indicates that the majority of the movement is likely to have taken place during late December to early January 2016 (see Section 5.6).

Some significant changes to the seabed were also observed to the west of the deposition, with apparent shore-normal movement of some linear features between the shore and ~6m CD contour; they are prominent in the backscatter and are thought to represent different sediment textures (Appendix C, Section C.2). The features are not considered as integral to the trial, however, and their detailed examination is outside the scope of this report.

Conclusions from swath bathymetry surveys
February 2015 to mid-December 2015 • Net sediment transport from the deposition area was negligible • Net volume differences of sediment seldom exceeded the survey tolerance • Mounds flattened and infilled the troughs • Time period that saw large gains in sediment on the beach corresponded with only minor sediment losses in the deposition box Mid-December 2015 to April 2016 • Mounds translated shorewards but retained their sediment volume • Seabed was most mobile shorewards of the 5m CD contour, with negligible net change in deeper water

5.3 Tracer study

A tracer study was conducted to discern the short-term movement of sand particles from the deposition site. Full details of the method used are given in Appendix A, Section A.4. The results given here are from the second tracer search on D+7, since the longer time interval allowed for a wider dispersion of material.

Figure 5.7 illustrates the location of the tracer samples, colour-coded into 4 bands based on the onsite classification of the samples. A sub-selection of the tracer samples was later fully enumerated in the laboratory; the results are shown in Figure 5.8, together with interpolated contour bands, to illustrate the likely spatial distribution of tracer. An additional plot of the enumeration results is given in Appendix C, Section C.2.

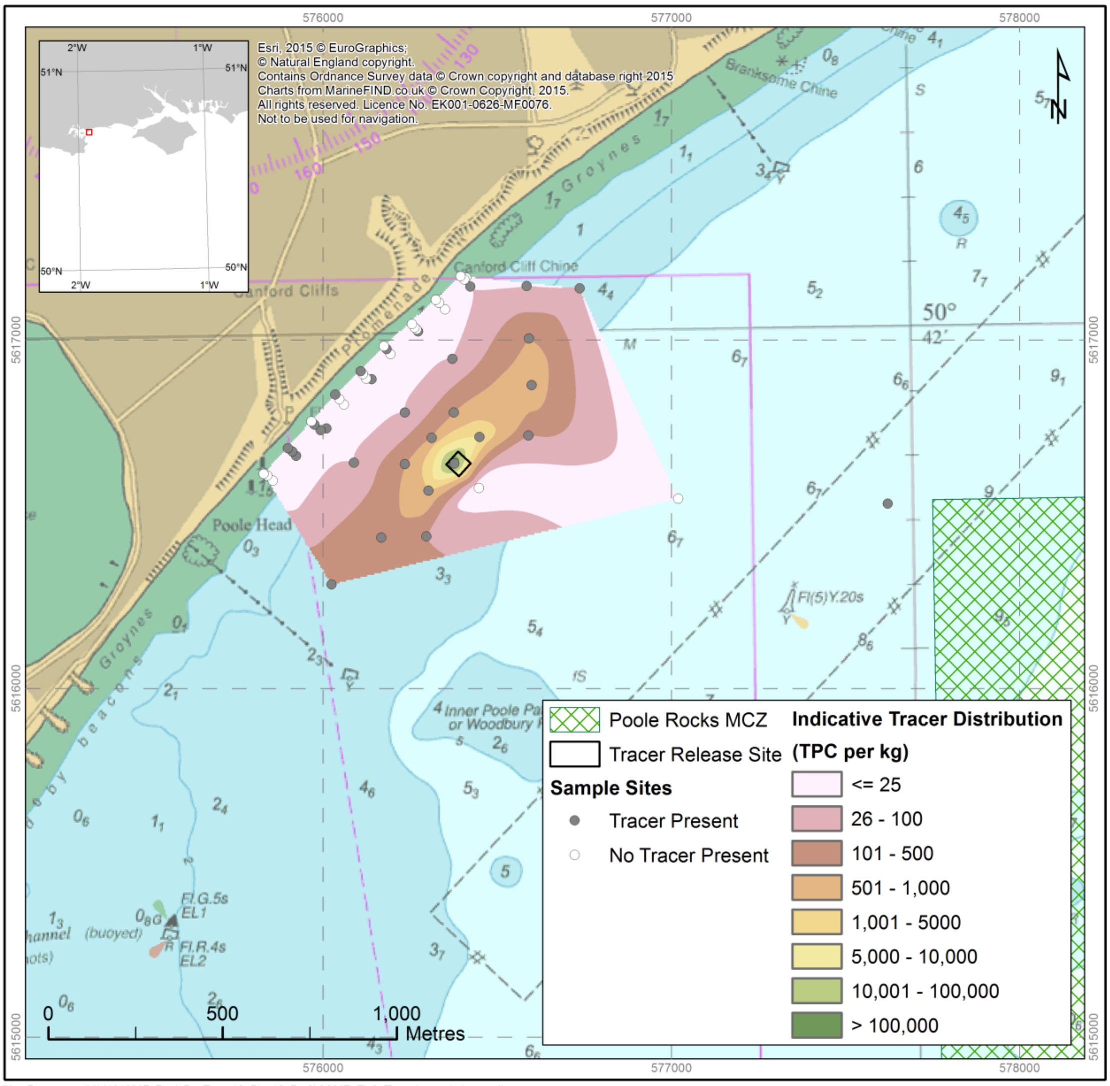
The tracer results demonstrated that the main sediment transport axis was north-east/south-west, with more transport towards the north-east (towards Bournemouth) than to the south-west (towards Poole Harbour entrance). Tracer was observed 600m away from the deposition site, towards the north-east. The northernmost sample contained ≤25 counts per kg, indicating that the sediment movement extended even further to the north-east. It is also likely that transport to the south-west is also more extensive than shown in Figure 5.8, since the southernmost sample analysed contained ≤500 counts per kg, although the rate of reduction in tracer concentration confirms that the predominant direction of transport was north-eastwards.

Twelve of the 31 beach samples analysed in the laboratory contained tracer, the majority in the western part of the beach trial area, although at a maximum concentration of ≤25 counts per kg. The tracer was found at both high water and low water locations, across at least a 750m length of beach. These results are unequivocal evidence of a sediment transport connection between the deposition site and the beach.

Although the tracer enumeration concentrated on Search 2 so as to assess the widest distribution of the tracer, Search 1 also demonstrated that tracer moved shorewards through the sub-tidal zone into shallow water, including a few tracer samples found on the beach. It is possible to identify a narrow period of wave conditions between 12 and 15 February that definitively bring sediment ashore from the deposition site. The implications for sediment transport are discussed further, in combination with the turbidity results, in Section 6.

Conclusions from tracer study
• A clear sediment pathway from the deposition site to the beach • Main sediment pathway was alongshore, north-east to south-west • Predominant direction of transport was north-east • Sediment from the deposition site reached 750m length of shoreline • Cross-shore, onshore transport exceeded offshore transport • No indication of significant sediment transport from the deposition site towards the MCZ

Figure 5.7 Field-based tracer result: Search 2 (all samples)



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18/08/2015 - 15:32:36

Figure 5.8 Results from tracer laboratory enumeration

5.4 MCZ control site sediment sampling

Sediment grabs were taken at 2 positions (G8 and G9) along a transect between the tracer insertion point and the nearest point of the Poole Rocks MCZ (see Figure 2.1), which are considered as control sites for the MCZ. Tracer enumeration was also carried out on these samples, with one tracer particle found at G9 (closest to the MCZ) and none at G8.

The grab samples underwent full particle size analysis (PSA), including silts. The results of the PSA (Figure 5.9 and Figure 5.10) are summarised in Table 5.3, together with the results from additional grab samples taken by the Channel Coastal Observatory in November 2015. Neither sample contained any silt in November 2015; the coarser silt found at G8 in February 2015 appeared to have been winnowed out.

Further results from the PSA are shown in Appendix C, Section C.6.

Table 5.3 Summary of PSA for MCZ control sites

	G8		G9	
	February 2015	**November 2015**	**February 2015**	**November 2015**
Sample type	Bimodal, very poorly sorted	Bimodal, poorly sorted	Bimodal, poorly sorted	Unimodal, moderately sorted
Folk (BGS modified)	Gravelly sand	Gravelly sand	Gravelly sand	Sand
Sediment name	Very coarse gravelly fine sand	Coarse gravelly fine sand	Coarse gravelly fine sand	Slightly very fine gravelly sand
Silt content	3.12%	0%	<0.1%	0%

Notes: BGS = British Geological Survey

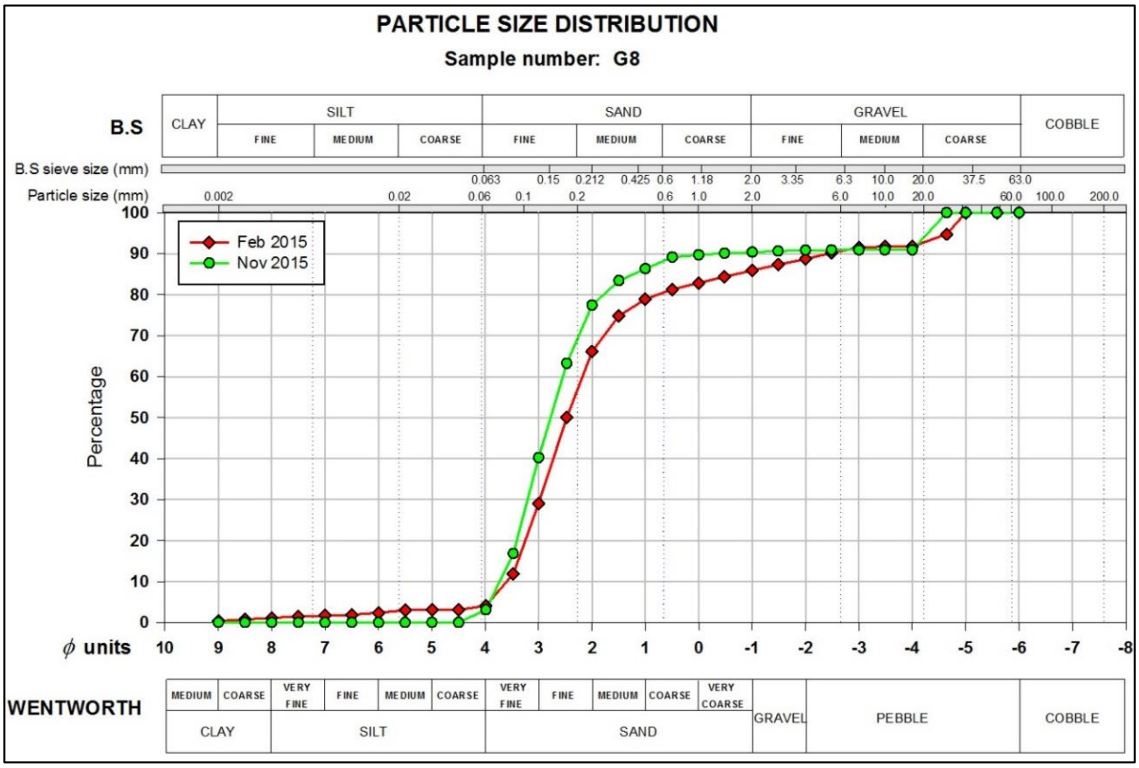

Figure 5.9 PSA for MCZ control site G8

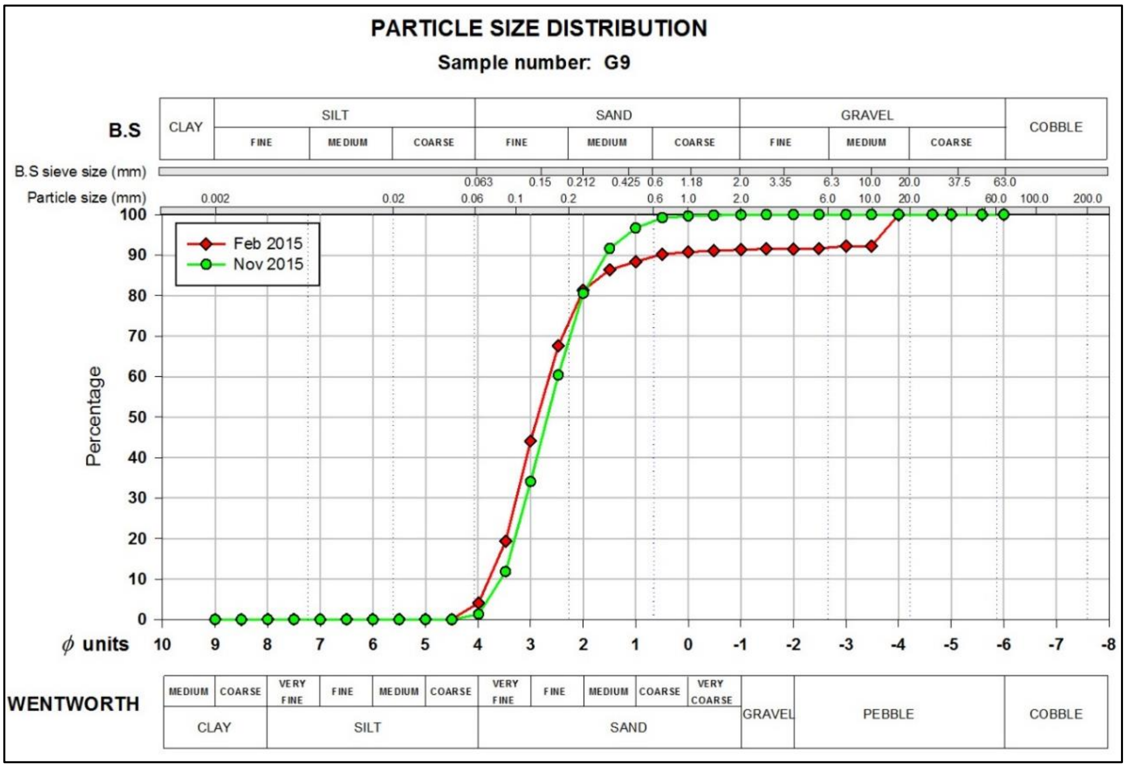

Figure 5.10 PSA for MCZ control sample G9 (nearest to Poole Rocks MCZ)

Conclusions from sediment sampling at the MCZ control sites
• Silt content at the MCZ control grab sites remained below 4% • Nine months after the deposition, there was no evidence of increasing silt content at either control site

5.5 Tides and tidal currents

The AWAC water level and current data were calibrated and quality controlled. Summary statistics were derived including tidal levels (Table 5.4) and depth-averaged mean current speeds (Table 5.5).

Table 5.4 Tide levels (Location 1)

Tidal stage		Tidal elevation	
		CD	OD
Highest astronomical tide	HAT	2.53	1.13
Mean high water springs	MHWS	2.19	0.79
Mean high water neaps	MHWN	1.80	0.40
Mean low water neaps	MLWN	1.34	-0.06
Mean low water springs	MLWS	0.94	-0.46
Lowest astronomical tide	LAT	0	-1.40

Table 5.5 Depth-averaged mean current speeds

Tidal phase	Depth-averaged current speed			
	Location 1 (~8m CD)		Location 2 (~5m CD)	
	ms^{-1}	knots	ms^{-1}	knots
Mean spring rate	0.24	0.46	0.16	0.31
Mean neap rate	0.13	0.26	0.10	0.19
Residual current	–	–	0.002	0.004

Overall, tidal currents are generally weak (that is, <0.3 ms^{-1}), orientated along a principal axis of approximately north-north-east/south-south-west at around the 8m CD contour (Location 1), becoming slightly weaker again and more shore-parallel north-east/south-west closer to the shore (~5m CD contour, Location 2). Residual currents are negligible, indicating that there are no significant non-tidal components to the mean currents such as river input and wind-driven currents.

Where there is a particularly complex tidal regime such as experienced in Poole Bay (that is, micro-tidal, weak currents and double high waters), statistics derived to produce a tidal diamond may not be entirely representative of accurate directional changes, particularly during the ebb on spring tides. Accordingly, for the purposes of this study, a representation of tidal currents was obtained from a single tidal cycle. The example used is on 21 March 2015, a large spring tide with minimal wave heights (significant wave height, Hs, ~0.3m or lower), so that the recorded mean currents can be considered as purely tidally induced (Figure 5.11).

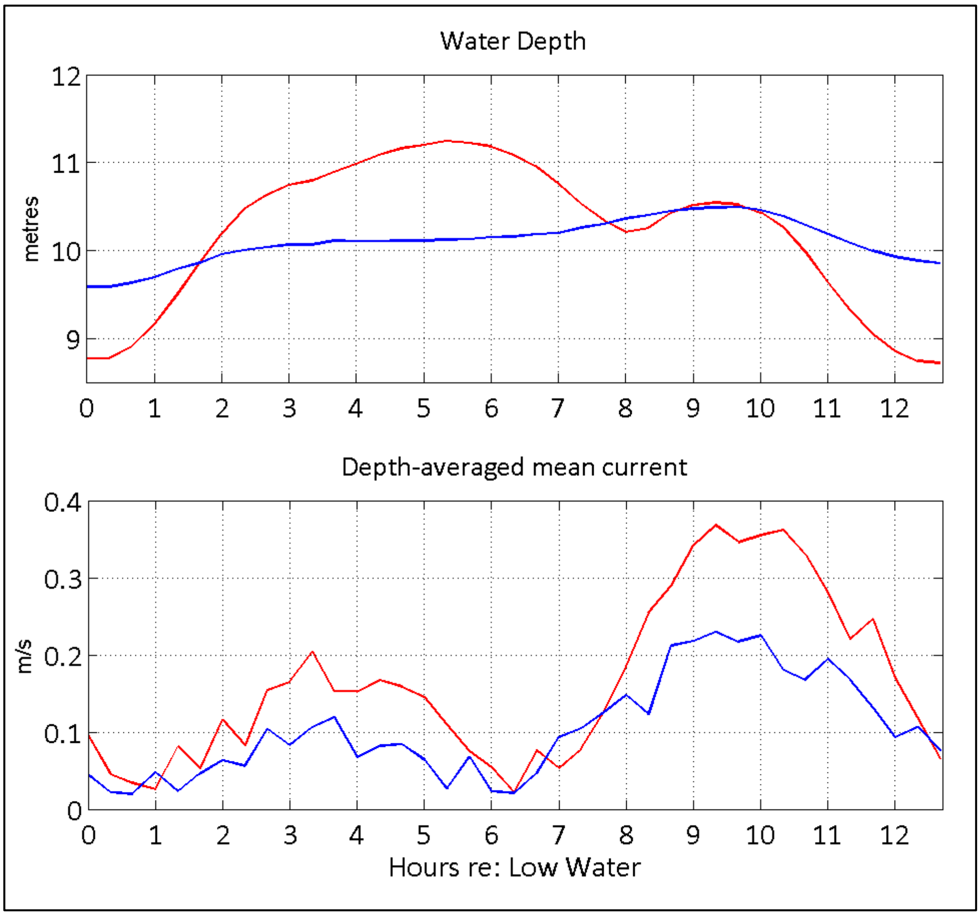

Figure 5.11 Water depth (top) and mean current (bottom) during spring (red) and neap (blue) tidal cycles (Location 1 ~8m CD)

The next series of diagrams (Figure 5.12 to Figure 5.15) illustrates the differences between the flood and ebb stages, over spring and neap tidal cycles. Flood currents are directed north-eastwards from 2 hours before high water until 1 hour after, while ebb currents persist for nearly 10 hours. North-easterly currents are weak, <0.2ms^{-1}, while currents are strongest from HW+3 to HW+5.

A mean current of around 0.3ms^{-1} is the minimum needed to mobilise sand from the seabed (see Section 5.7). Accordingly, the only circumstances where tidal currents alone can **both** mobilise and transport sediment is on large spring tides during the mid/later ebb tide and second high water. In these circumstances, the direction of transport will be to the south-south-west.

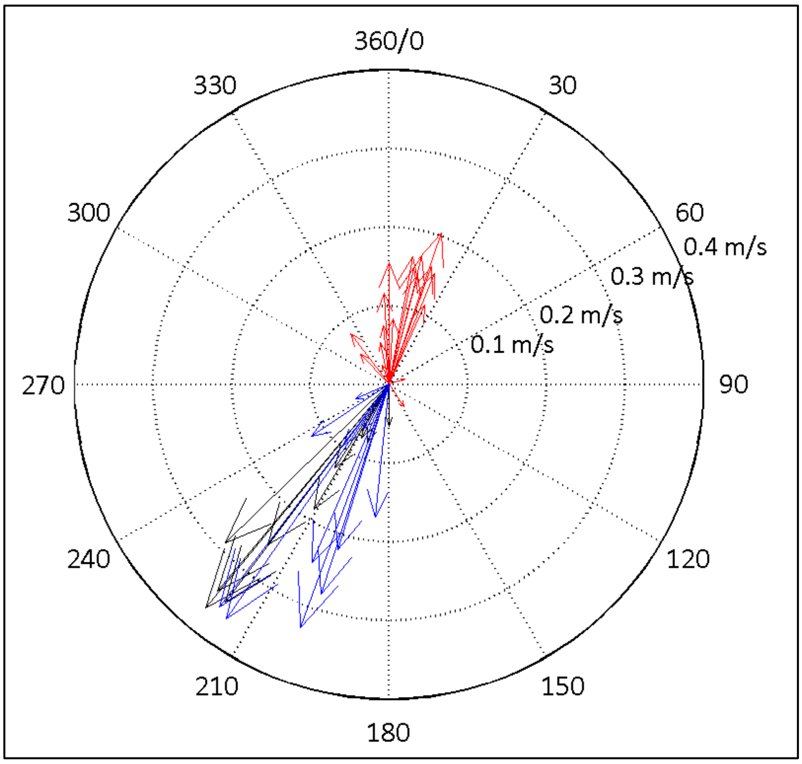

Figure 5.12 Depth-averaged current vectors at Location 1 on 21 March 2015 (spring tide)

Notes: Red vectors represent flood tide and high water stand; black vectors are the early ebb and second high water; and blue vectors are late ebb and low water. This diagram is shown in geographical context at Figure 5.14.

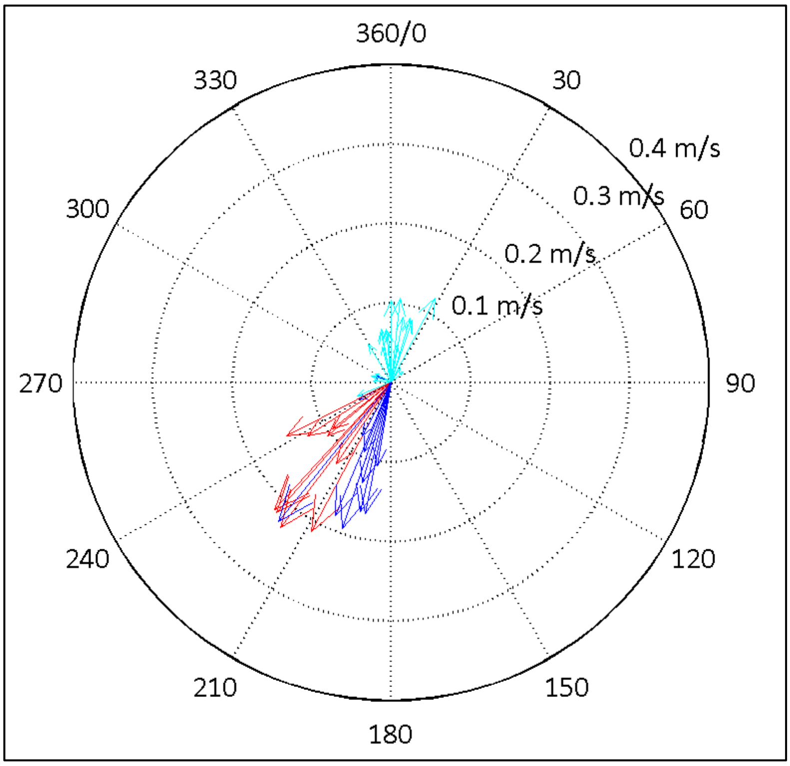

Figure 5.13 Depth-averaged current vectors at Location 1 on 14 March 2015 (neap tide)

Notes: Cyan vectors represent the main flood tide; red vectors the late flood tide and high water stand; blue vectors are ebb and low water.
This diagram is shown in geographical context at Figure 5.15.

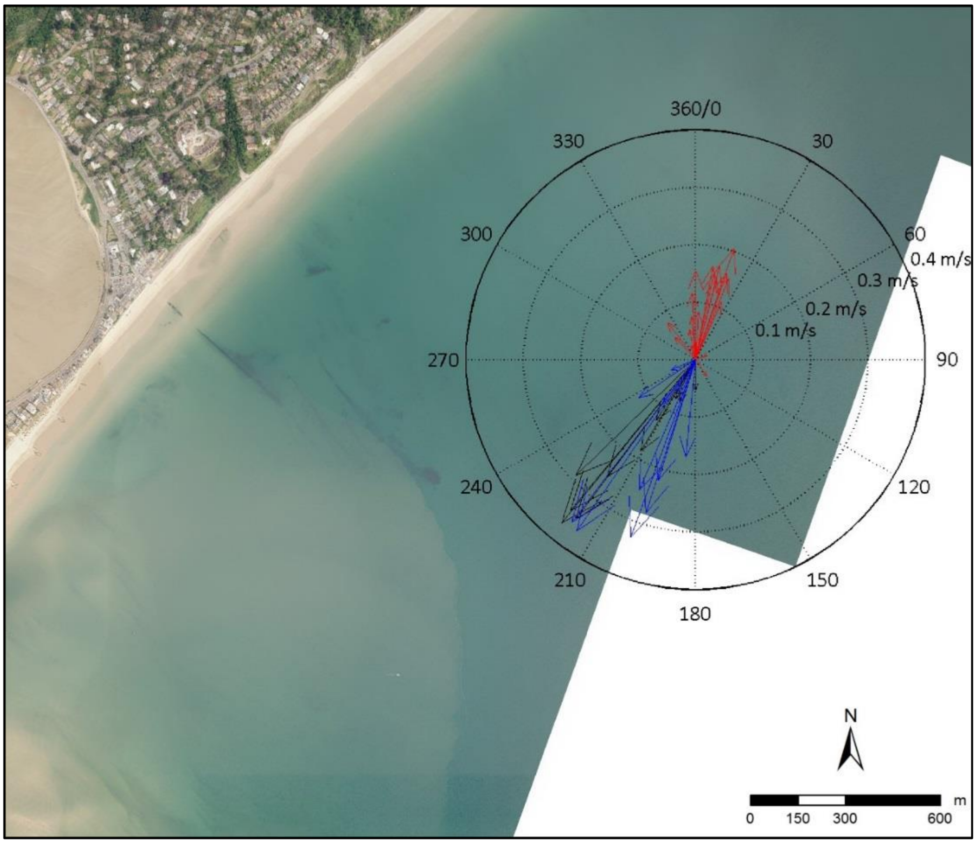

Figure 5.14 Spring tide (centre is at AWAC location)

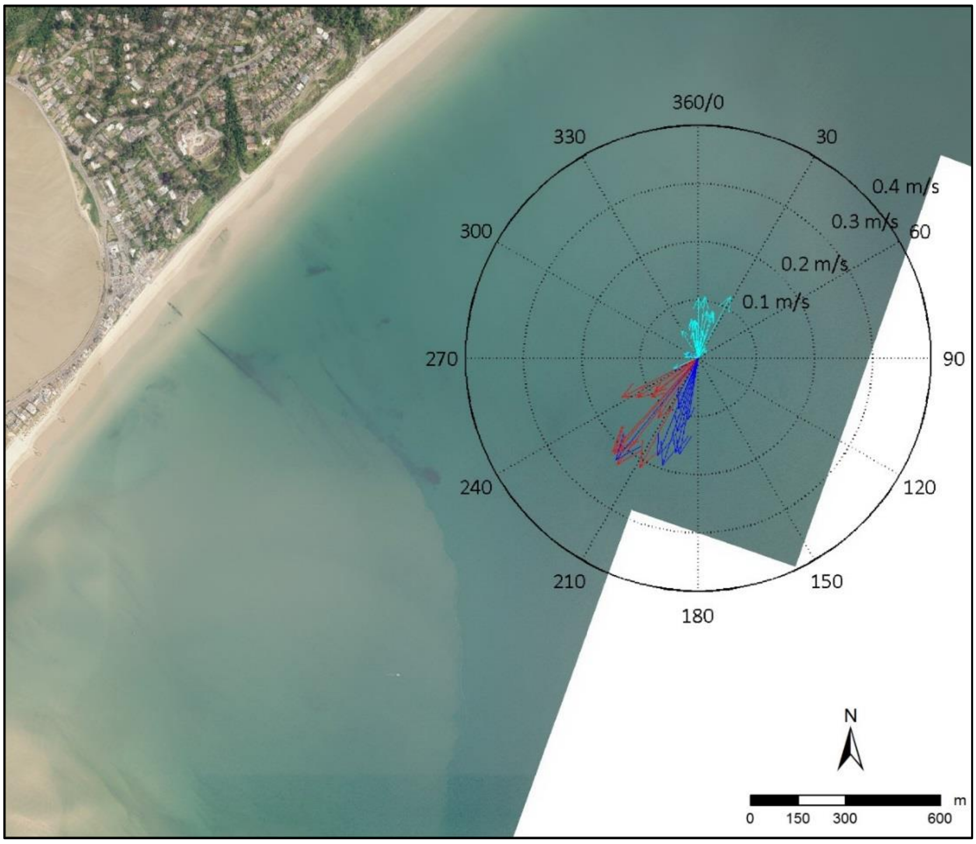

Figure 5.15   Neap tide (centre is at AWAC location)

The same pattern of tidal currents is replicated at Location 2 (5m CD) but with even weaker currents, as shown in Figure 5.16, where flood currents are negligible (~0.1ms^{-1}) and the maximum springs current barely reaches 0.25ms^{-1}. Accordingly, mean tidal currents alone are insufficient to mobilise sediment at the deposition site. Wave-driven currents are discussed in Section 5.6.

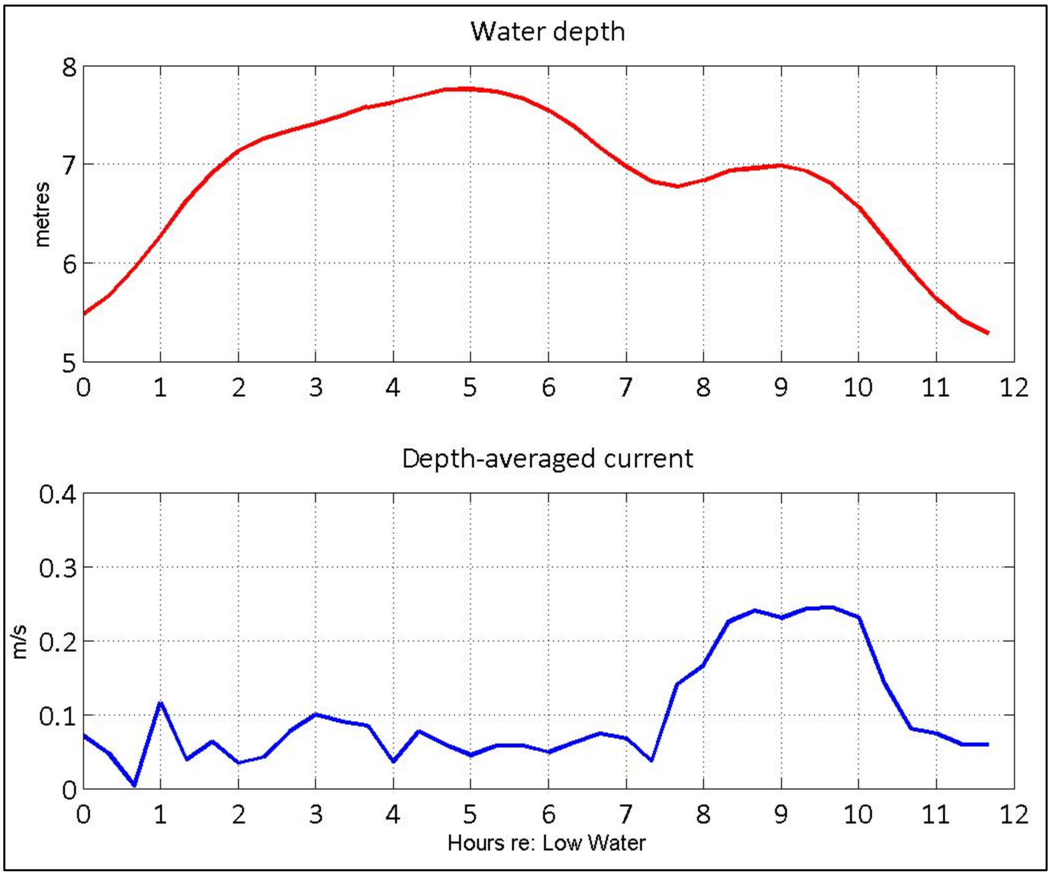

Figure 5.16 Spring tidal currents at Location 2 (example is 31 August 2015)

Conclusions from tidal current measurements
• Tidal currents are generally below the threshold to mobilise sand from the seabed • Neap tidal currents do not mobilise sediment (though may transport sediment mobilised by waves) • Equinoctial spring tidal currents in 8m CD can mobilise and transport sediment, but only during the mid/later ebb when transport direction is south-south-west

5.6 Wave-induced currents

There was no evidence for anything than negligible wave-induced currents at the offshore location on the 8m CD contour. However, analysis of the AWAC directional data at Location 2 (5m CD) identified a number of events where the usual pattern of mean (tidal) currents was disrupted or even reversed for extended period (for example, currents flowed near constantly towards the north-east for about 45 hours on 4 to 6 December 2015. Six such tidal disruption events were observed during the deployment (June 2015 to March 2016):

- 4 to 6 December 2015 (45 hours)
- 29 to 30 December 2015 (24 hours)

- 1 to 2 January 2016 (12 hours)
- 5 to 6 January 2016 (34 hours)
- 26 to 27 January 2016 (21 hours)
- 6 to 7 February 2016 (12 hours)

There were also 2 periods of significantly enhanced currents, both of which coincided with periods of tidal current disruption (Figure 5.17):

- 29 December 2015 21:00Z (Zulu time) to 30 December 2015 12:00Z, when the maximum currents reached around 0.5ms^{-1} directed consistently towards the north-east (45° to 75°N) and hence enhancing the flood tide
- 6 February 2016 02:00Z to 22:00Z, when the maximum currents reached nearly 0.5ms^{-1} and were directed consistently towards the north-east (between 40° and 50°N), again enhancing the flood tide

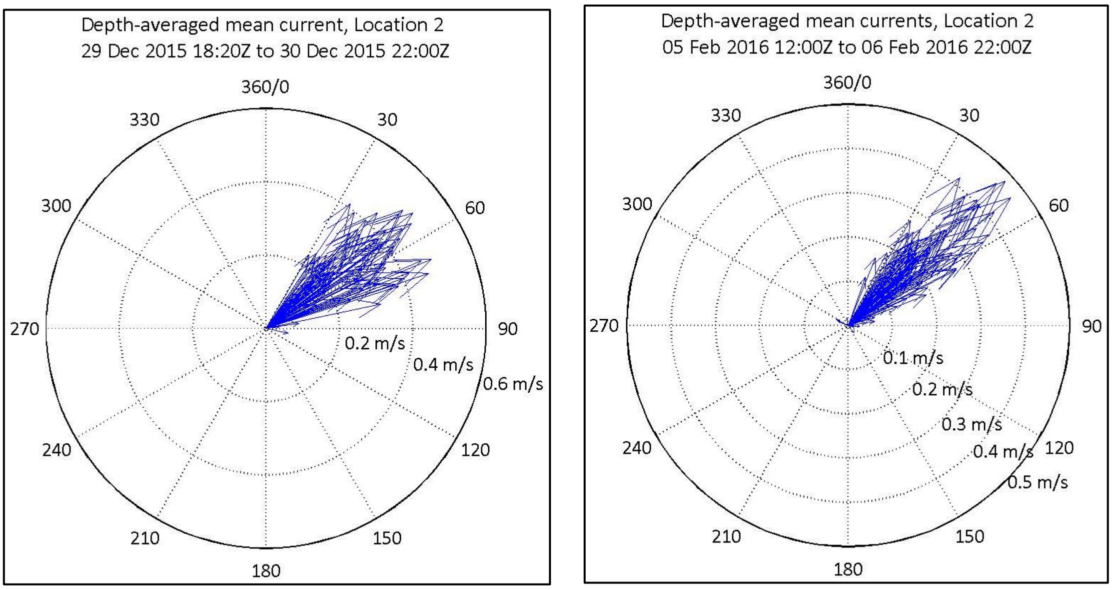

Figure 5.17 Examples of disruption in tidal currents for extended periods

The disruption and enhancement of tidal currents is clear evidence for wave breaking and surf zone generated currents, as captured by Figure 5.18.

Figure 5.18 Sea conditions on 31 December 2015 at 10:00Z

Notes: The red arrow indicates the AWAC surface marker buoy.
Photo courtesy of D. Robson, Borough of Poole

The current reversals were investigated further by resolving the mean currents into cross-shore and longshore components using the method given in Appendix A, Section A.4.1). These would be expected to be of significance only if there was a surf zone near the location of the AWAC.

In all cases bar one, the mean currents remained directed towards the north-east and did not reverse with the tide. The exception was a 12-hour period on 1 January 2016 when currents were directly broadly offshore (ranging from 120° to 210°N) but quite weak (~0.2ms^{-1}), but unusually with 1 hour due offshore from the shoreline at about 0.4ms^{-1} (Figure 5.19). This was the sole occurrence of significant offshore mean currents during the trial; an explanation for these conditions is given in Appendix C, Section C.4.

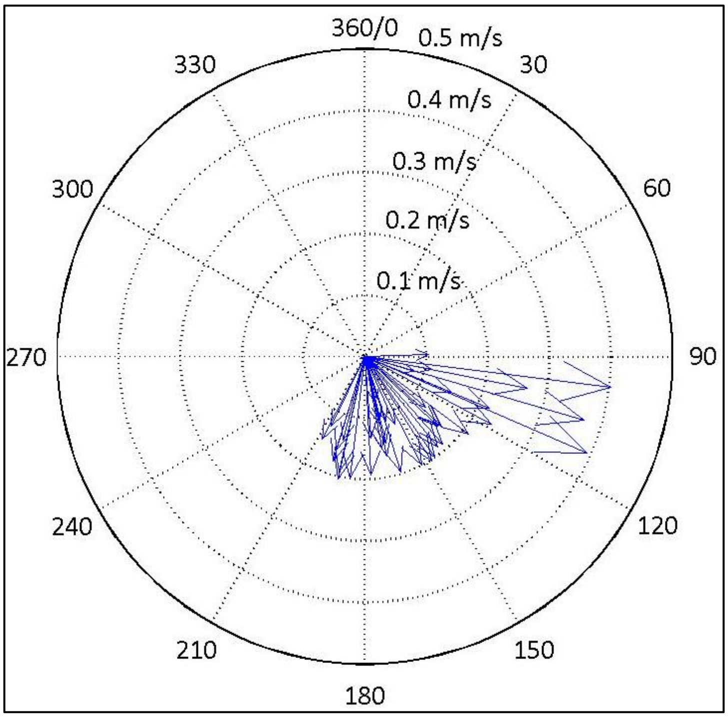

Figure 5.19 Depth-averaged mean currents at Location 2, 1 January 2015 at 17:00Z to 2 January 2016 at 06:40Z

One of the most notable periods of lively hydrodynamic conditions occurred on 30 December 2015. Wave height exceeded 1.5m for nearly 24 hours but with no swell, and wave direction at the AWAC was consistently 130° to 140°N (Figure 5.20). Once the Hs exceeded about 2m, there was a clear longshore current reaching ~0.5ms^{-1} and directed towards the north-east. From 06:00Z to 08:00Z, waves were at their highest (2.25–2.75m) and the north-easterly longshore currents were enhanced by weak north-easterly tidal currents, leading to the strongest currents measured during the trial.

Waves remained high over high water and through the ebb tide; a weakening of the longshore current to ~ 0.2ms^{-1} may be due to weak but opposing tidal currents. However, during this period, wave direction was also backing from 140º to 130ºN, and therefore likely to reduce the longshore current slightly, although it is difficult to apportion these relatively weak mean currents into their forcing components. By 21:00Z the waves had dropped to below 1.5m; the longshore current moderated to 0.3ms^{-1} but at this stage of the tide was in the same direction as, and hence enhanced by, the flood tidal currents.

The presence of well-defined longshore currents at the deposition site is quite surprising given the water depth, relatively sheltered location and small tidal range. The longshore currents are mostly still below the threshold speed to mobilise the seabed, but by implication their presence implies oscillatory currents that can mobilise the sediment to be transported subsequently by mean currents. Notwithstanding that any longshore current at this site is likely to retain some component of tidal current, it is clear that once significant wave height exceeds about 1.5m, some minor enhancement/opposition of the tidal current by longshore currents is likely. In the majority of cases, the enhancement is towards the north-east (see Figure 5.21, top panel). However, stronger longshore currents are associated with wave heights above 2m and are always directed to the north-east. The frequency of occurrence of waves of this magnitude is discussed in Section 5.7.

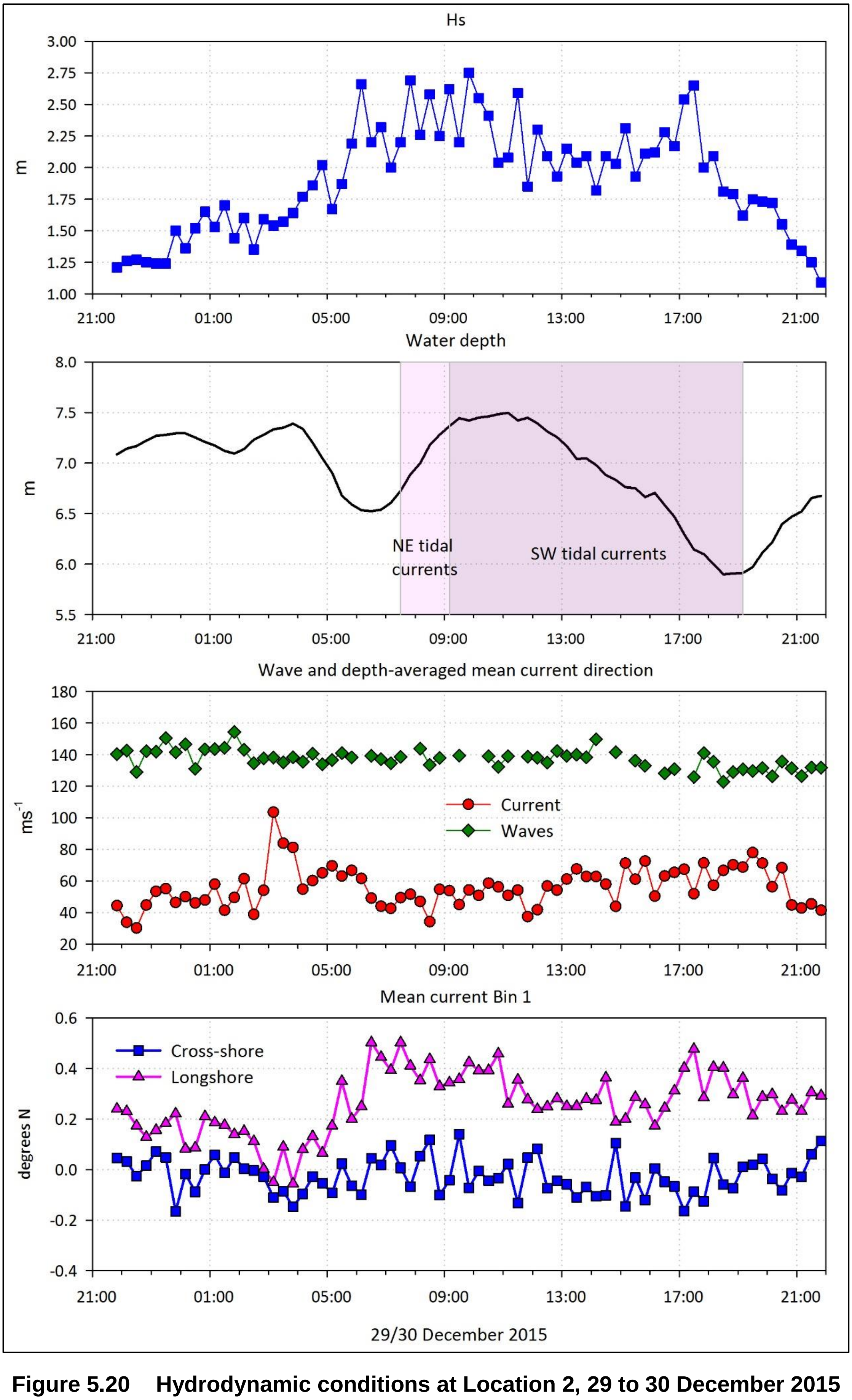

Figure 5.20 Hydrodynamic conditions at Location 2, 29 to 30 December 2015

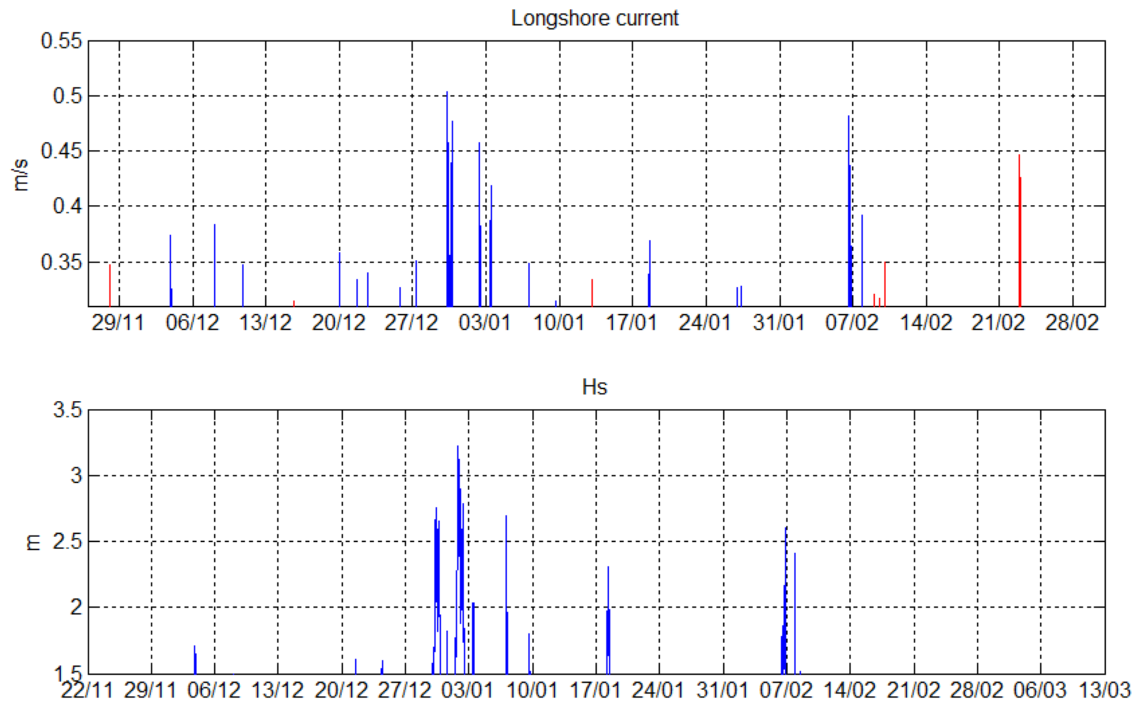

Figure 5.21 Incidence of high longshore current (top) and wave height (bottom) at Location 2, November 2015 to February 2016

Notes: Currents shown in blue are to the north-east and in red to south-west.

5.7 Wave climate

Most of the wave analysis concentrates on the deployment of the AWAC at Location 1 (~8m CD) since this spanned the period 2 months before and 4 months after the deposition when the majority of the surveys were performed. The methods of analysis used here are designed to compare wave fields measured over a common time period, but at different sites and with different burst sampling intervals (for example, every 20 or 30 minutes). Further details of the methods are given in Appendix A, Section A.4.2.

5.7.1 Location 1 (~8m CD)

The time series of Hs measured by the AWAC and the directional waverider (DWR) off Boscombe Pier in about 10m CD water depth are shown in Figure 5.22. Both the AWAC and DWR are measuring a broadly similar wave climate in the sense that maximum significant wave heights occur around the same time. As expected, the DWR in deeper water tends to experience higher waves than the AWAC. In terms of wave statistics, however, there is clearly a rather different wave regime at each site.

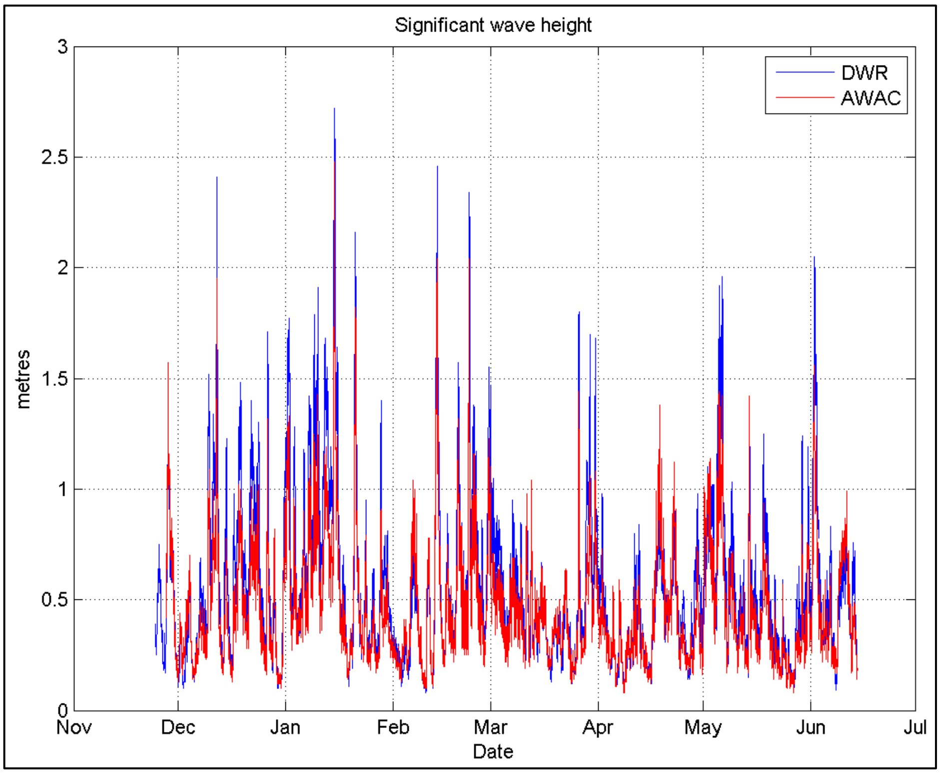

Figure 5.22 Time series of measured Hs at Location 1, November 2014 to June 2015

Regarding waves from all directions, waves are typically calmer at the AWAC site, particularly for Hs < 0.5 m, reflecting the more sheltered aspect of the AWAC site as well as the difference in water depth (Figure 5.23). The 2 sets of percentiles regressed against each other, showed a third order (that is, non-linear fit) (Figure 5.24).

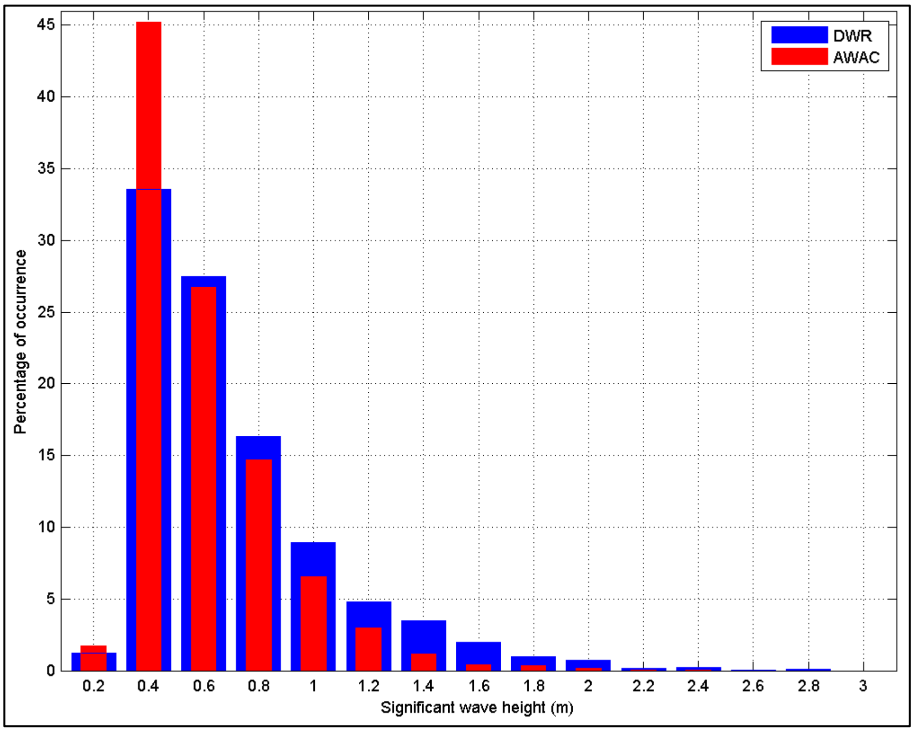

Figure 5.23 Histogram of measured wave heights, November 2014 to June 2015

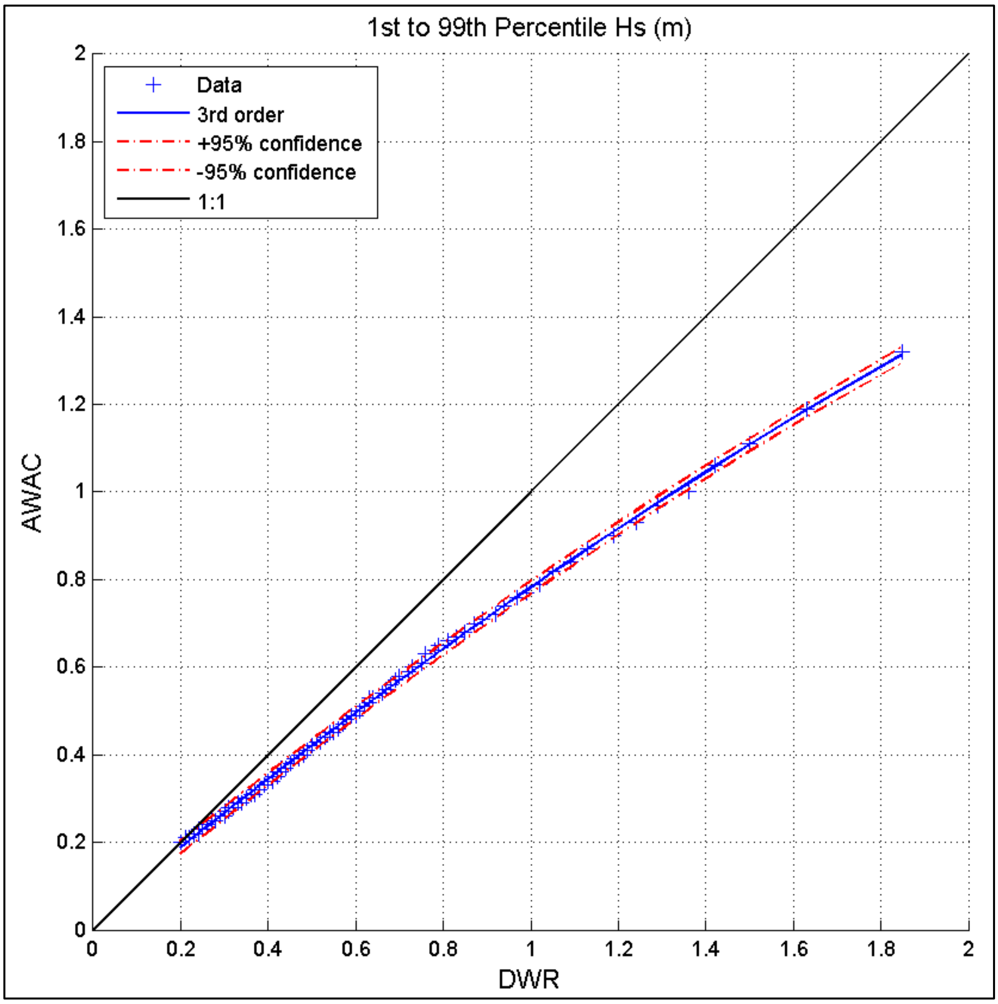

Figure 5.24 Hs percentiles for the DWR and AWAC, November 2014 to June 2015

The importance of exposure to wave direction is reinforced when the percentile analysis is repeated for directional sectors (Figure 5.25). It is clear that the majority of the waves at both sites are from the south and south-west; they follow a broadly similar trend to the 'all directions' results (Figure 5.25, centre panel), though there is noticeably different behaviour with south-easterly waves. For waves up to about 0.75m Hs, both sites measure an identical wave climate, but above that wave heights at the AWAC location can be higher than at the DWR site by a factor of about 1.5.

Although the directional regression does not take into account of the size of the sub-population, south-easterly waves (over 0.25m) occurred 47% of the time and 8 of the 9 occurrences of 2m waves were also from the south-east; see Appendix C, Table C.1 for the percentage of occurrence of wave heights over the same directional sectors. Since 140° is the 'onshore' bearing for the trial beach, these south-east waves are clearly of considerable importance for the sediment transport regime; they are not well represented by the DWR measurements, which would need to be handled separately when defining transfer functions.

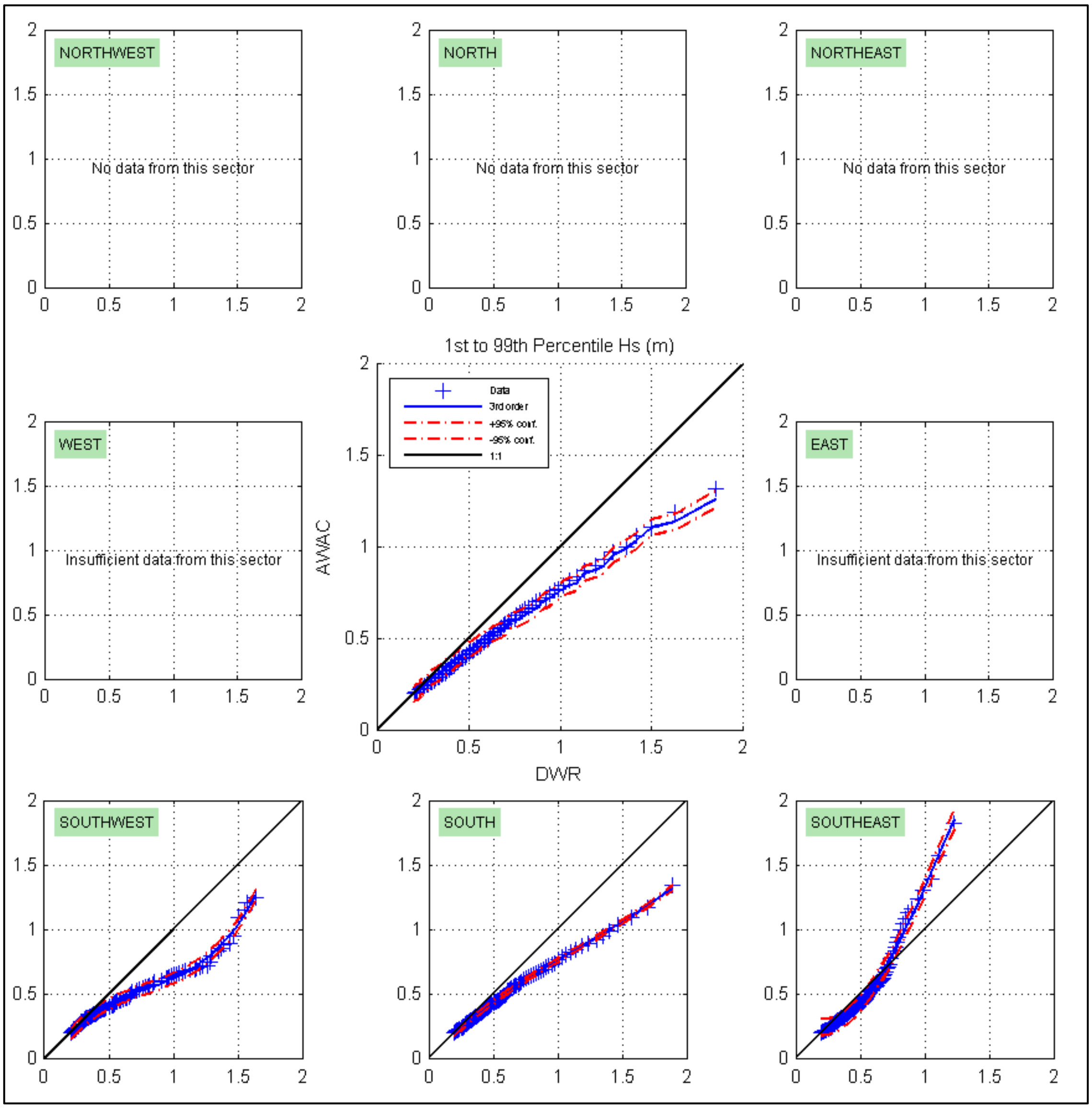

Figure 5.25 Hs regression for 45° direction bands (centred around cardinal points), November 2014 to June 2015

Notes: The centre panel shows results for 'all directions' as given in Figure 5.24.

5.7.2 Location 2 (~5m CD)

At the shallower location, the AWAC is also measuring broadly the same wave climate as the DWR (see Appendix C, Section C.4.2), but the relationship between waves from the south-east sector is highly non-linear. This is likely to be because higher waves are breaking in surf zone conditions at the AWAC (Figure 5.26). The highest waves all came from the south-east, as did 31 % of all waves above 0.5m.

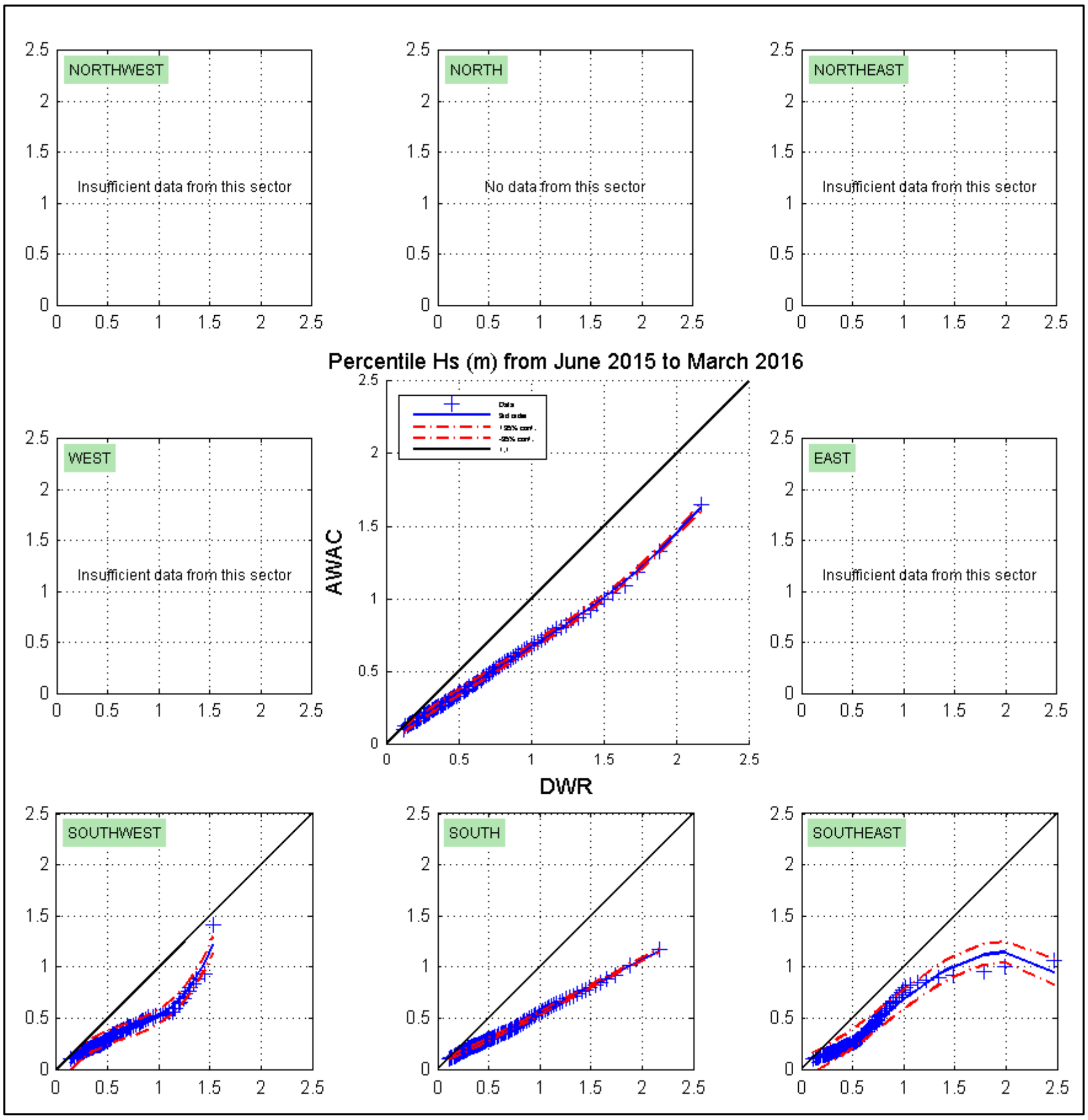

Figure 5.26 Hs regression for 45° direction bands (centred around cardinal points). June 2015 to March 2016

Conclusions from wave analysis
AWAC Location 1 (~8m CD) • AWAC Location 1 is more exposed to waves from the south-east sector than Boscombe Pier • Wave heights from the south-east sector can be larger at the AWAC than at the DWR • DWR is generally representative of waves from other sectors • Waves from the south-east occurred 47% of the time AWAC Location 2 (~5m CD) • Surf zone conditions can occur when Hs exceeds 1.5m • Longshore currents can achieve 0.4–0.5ms^{-1} and are typically directed towards the north-east, enhancing the flood tide

5.8 Suspended sediment concentration

On open coasts, waves typically tend to be responsible for mobilising sediment (that is, putting it into suspension) for subsequent transport by mean currents such as tidal currents or longshore currents in the surf zone. Currents can also mobilise sediment directly once the mean current exceeds about $0.3ms^{-1}$ (Mason 1997). An SSC of 0–$4mgl^{-1}$ is considered 'low', while values around $300mgl^{-1}$ are considered 'high' such as those experienced in the outer Thames and Humber estuaries (HR Wallingford et al. 2002). Within the surf zone, however, SSC can be an order of magnitude higher (Voulgaris and Collins 2000). For the purposes of this report, and given the vagaries of calibrating optical and acoustic backscatter sensors, the measured SSC is categorised in 5 bands to represent the turbidity regime (Table 5.6).

Table 5.6 Classification of turbidity regime

SSC (mgl^{-1})	Turbidity regime
0 to <5	No turbidity
5 to <50	Light turbidity
50 to <100	Moderate turbidity
100 to <250	High turbidity
≥250	Very high turbidity

Detailed analysis of the SSC measurements is given in Appendix C, Section C.5, with the main results summarised below.

5.8.1 Location 1 (~8m CD)

The average SSC was $18mgl^{-1}$ (December 2014 to May 2015), indicating that the waters of western Poole Bay are typically lightly turbid but experience conditions of no turbidity for ~21 % of the time. Winter conditions (December, January, February) averaged $24mgl^{-1}$, lowering to $11mgl^{-1}$ over spring (March, April, May). This was in line with average wave conditions at the site, where winter average Hs was 0.5m and spring average Hs was 0.4m.

Figure 5.27 shows the instantaneous hydrodynamic conditions at the offshore site when there was 'no turbidity'. From this it can be deduced that, once Hs exceeds about 1m, there is always some turbidity in the water column and confirms $\sim 0.3ms^{-1}$ as a lower threshold for current-derived suspension at this location. There was a broadly linear relationship between Hs > 1.5m and a minimum level of turbidity, but otherwise no discernible link between:

- peak wave period (Tp) and SSC
- zero crossing wave period (Tz) and SSC
- wave direction and SSC
- depth-averaged mean current speed and SSC
- Hs < 1.5 m and SSC

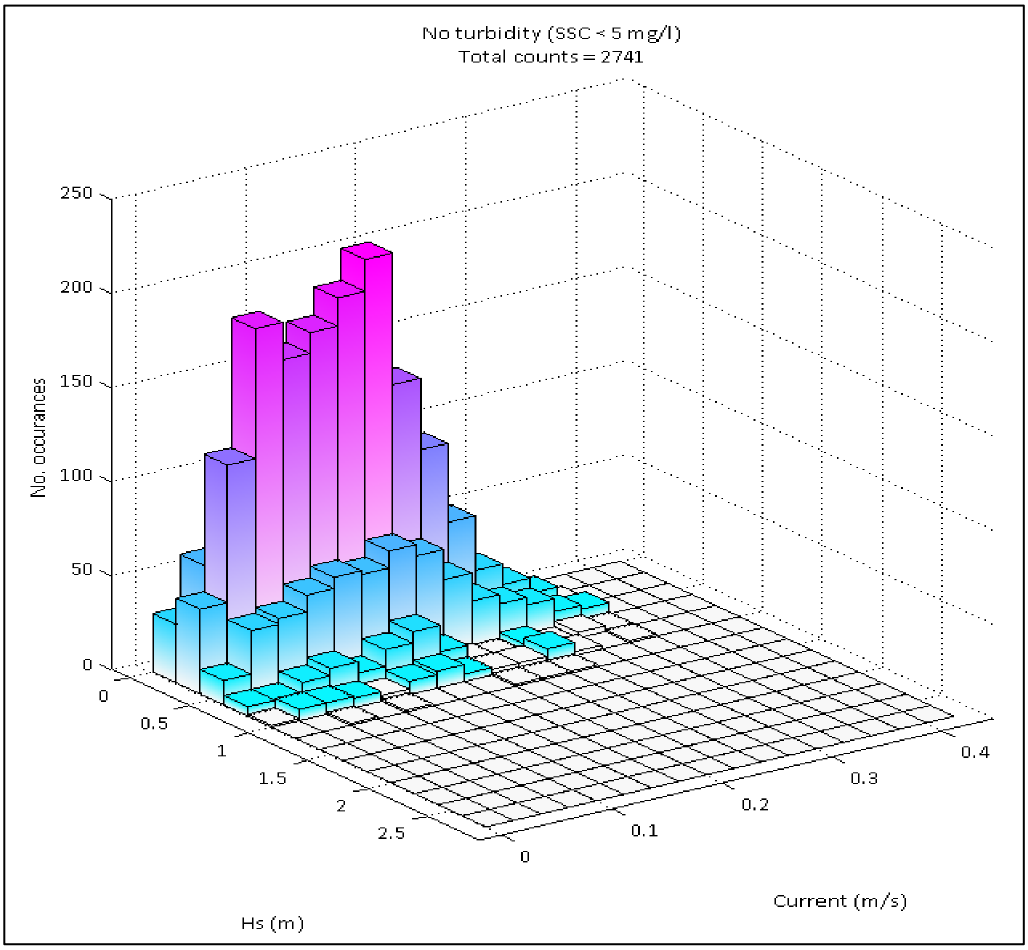

Figure 5.27 Histogram of significant wave height and mean current during periods of 'no turbidity' at Location 1 (~8m CD)

The time series of SSC was packaged into discrete suspension events separated by a clear 'trough' of light or no turbidity (see Figure 5.28 for examples). A total of 22 individual suspension events were identified and classified based on the turbidity regime given in Table 5.6. There were 5 high, 11 moderate and 6 light turbidity events; 4 of the 5 high suspension events occurred in December 2014 and January 2015 (that is, prior to the deposition).

Typically, a high suspension event took about 140 minutes for the sediment to settle to average turbidity levels (~20mgl^{-1}) once quiescent conditions prevailed; in a moderate suspension event, turbidity returned to background levels in around 100 minutes. In only 3 of the 22 suspension events did the turbidity continue to fall to 5mgl^{-1}, taking on average a further 100 minutes. This implies that, if moderate or high levels of SSC are generated, either naturally or externally induced, sediment will settle to natural, average levels of turbidity within around 2 hours once the disturbance stops and providing the hydrodynamic conditions are below the resuspension thresholds.

Conclusions from turbidity measurements

- Average SSC (December to May) was ~20mgl^{-1} (that is, lightly turbid)
- 'No turbidity' conditions occurred for about 20% of the time (December to May)
- Average winter SSC was double that experienced in spring
- High SSC can settle to average turbidity levels within about 2 hours
- No evidence of increased turbidity due to the deposition
- Turbidity levels increased in shallower water

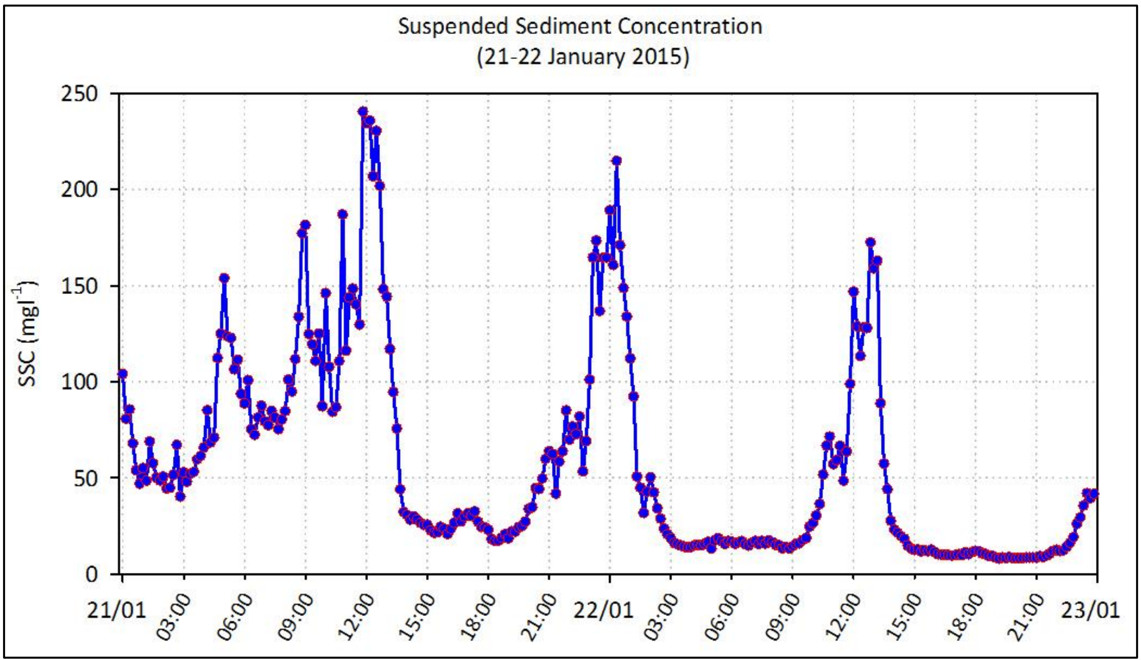

Figure 5.28 SSC at Location 1 (~8m CD) on 21 to 22 January 2015, showing 3 discrete high suspension events

5.8.2 Location 2 (~5m CD)

The OBS was out of service during the early part of the deployment at this position and therefore SSC measurements are available only from late November 2015. As a result of the winter conditions and shallower location, including surf zone conditions, 'no turbidity' was confined to Hs < 0.5m and mean currents <0.25ms^{-1}. SSC remained above 100mgl^{-1} almost constantly from 30 December 2015 to 16 January 2016, including readings exceeding 600mgl^{-1} during the periods of very high waves. Such high values are not inconsistent with other field measurements from surf zones. As a result, average SSC for the winter (November to March) was 105mgl^{-1}.

5.9 Silt monitoring (University of Southampton)

Silt traps were deployed near Poole Rocks MCZ from April 2014 to November 2015 by a team from the University of Southampton, together with a study of biota at Inner Poole Patch, as part of a separate study commissioned by the Borough of Poole. The results are given in Appendix D and are summarised below.

Conclusions from University of Southampton sedimentation study
• No significant impacts were detected on either silt deposition or biota at Inner Poole Patch

6 Discussion

Although the MMO requirement to locate the AWAC and OBS well offshore of the deposition site had its disadvantages in a scientific sense, several benefits could be salvaged. Firstly, the main instrument used for turbidity measurements (OBS) is better suited to finer material than to coarse, and is vulnerable to biofouling in long-term deployments. Hence, since Natural England was particularly concerned about changes in silt content near the Poole Rocks MCZ, the results obtained at Location 1 can be considered as unequivocal evidence of the presence/absence of an observable direct silt transport pathway between the deposition site and the MCZ. Furthermore, while the OBS was in pristine condition (that is, in the early months of its deployment before algal growth was extensive), the turbidity measurements can be considered as representative of overall turbidity levels outside the surf zone over a reasonably wide area.

Unfortunately, the OBS malfunctioned during the first part of the shallower water deployment, but worked satisfactorily for the remainder of the winter months (December, January and February) which fortuitously turned out to be the stormiest measured during the trial. Furthermore, by this stage of the trial the beach and seabed surveys were being made at about 3 monthly intervals and therefore the principal application of the AWAC and OBS data was to assess the hydrodynamic regime at the 5m CD contour so as to draw conclusions about the potential for onshore transport, rather than for detailed analysis of the link between hydrodynamic conditions and short-term morphological change.

6.1 Hydrodynamic regime

The pattern of tidal currents at both AWAC locations was similar, with the only appreciable differences between the 8m and 5m contours being that, as would be expected, the tidal currents at the shallower site were slightly weaker and slightly more shore-parallel than at the deeper site. The similarity in tidal regime notwithstanding, there is clearly a hydrodynamic disconnect between the 2 locations. On the 8m CD contour, the hydrodynamics are dominated by tidal currents and wave-induced currents were infinitesimally small. Currents are strongest during the ebb tide and directed to the south-west producing a slow, overall water movement to the south-west during periods of low or moderate waves, but of insufficient speed to mobilise sediment in the absence of waves other than during large spring tides.

In contrast, on the 5m CD contour, high waves (>1.5m) can generate fairly strong longshore currents, which can completely overwhelm the weak tidal current pattern for several tidal cycles. In most cases, the longshore current is towards the north-east, enhancing flood tidal currents. This wave-driven sediment transport closer to the shore is an important reason to place deposition material on the 5m CD contour rather than in deeper water.

6.2 Sediment transport

The tracer study provided a definitive answer to the question ‘Is there a sediment connection between the nearshore (deposition area) and the beach …’ by demonstrating that sediment from the deposition area can reach the beach very rapidly. However, the rest of the question ‘… of sufficient quantity to indicate that the process of nearshore replenishment could be a successful technique at this site?’ is considerably more difficult to answer despite an extensive programme of surveys and deployed instrumentation. One question yet to be addressed is the influence of swell waves on sediment transport at this site.

There were 2 definitive periods, one short term and the other longer term, where the sediment moved onshore. As described in Section 5.3, the first tracer search identified a narrow window where sediment was transported shorewards from the deposition site to the beach. Making the assumption that the transport occurred sometime during the 2 days following insertion once wave heights reached about 1m, 3 distinct phases could be isolated (Table 6.1).

Table 6.1 Phases of sediment transport detected

Date	Time period	Direction (peak)	Tp (s)
13 February 2015	03:50 to 18:30	135–150°N	6
13 February 2015	18:30 to 23:50	100–135°N	6
14 February 2015	00:00 to 23:00	150–165°N	14

A detailed account of this swell event is given in Appendix C, Section C.7, but in summary, wind waves dominated the first 24 hour period, associated with high turbidity levels. Once sea conditions had reduced, the combination of 12–14 s swell and ~0.5m waves continued to disturb the water column; without the presence of stirring forces, the suspended sediment would have settled out to average levels within 2–3 hours, rather than the 9–10 hours taken at the end of this suspension event. The swell is likely to have been a significant transporter of sediment, leading to a 10-hour period of longer run-up over the beach face.

This lends weight to the idea that a wave height exceeding about 1m (at 8m CD contour) is a reasonable threshold for a significant sediment transport event nearshore, but the waves need to persist for several hours to ‘fill the water column’. A subsequent period of swell waves may lead to sediment build-up on the beach. The combination of waves >1 m persisting for several hours to mobilise and keep turbidity levels high, followed by at least 8 hours of 14 s swell (transporting sediment shorewards) also occurred at the time of the sediment bulge on the beach.

A third incidence of onshore transport was the shoreward translation of the deposition mounds, although there is no way of knowing exactly what hydrodynamic conditions were responsible. It is unlikely to have been during the peak of the storm, when the undertow was strongly offshore through most of the water column. However, following the storm period, there were extensive bursts (12 hours or more) of swell waves (10–12 s) and low wave heights (≤1m) and it is feasible that these were responsible for periods of onshore sediment transport through oscillatory motion near the seabed. These periods would not be recorded by either the AWAC or OBS.

Six other critical combinations of waves/SSC/swell were observed during the trial – 21 January 2015, 31 December 2015, 1 to 2 January 2016, 3 January 2016, 22 January 2016, 8 February 2016 (maybe). However, they did not coincide with beach surveys and so it cannot be confirmed whether there was any sediment build-up on the beach. Furthermore, the existence of this combination of conditions does not imply that net sediment gain at the beach will follow. This is because the period of high wind waves preceding the swell may cause more sediment to be transported either alongshore or offshore within the surf zone than is subsequently transported onshore by the succeeding swell waves.

6.3 Turbidity and silt content

All strands of evidence – sediment sampling, silt and biota monitoring and waves/currents analysis – confirm that the deposition had no detrimental effect on Poole Rocks MCZ. Indeed, there is very little indication that there was any attributable effect at all.

Furthermore, the nearshore tidal conditions indicate that deposition anywhere along the Borough of Poole frontage shoreward of the 8m CD contour is unlikely to lead to additional siltation at the MCZ since there is no significant direct sediment pathway between the deposition zone and the MCZ. It should be noted, however, that this conclusion applies only to the western part of Poole Bay; it may not hold true for the eastern section of Poole Bay

These results should negate any further objections to subsequent deposition on the grounds of potential impact on sedimentation at Poole Rocks MCZ.

6.4 Engineering implications

Set in the long-term context, there is little evidence for much seabed mobility at the deposition site, although this location coincided with the long-term bathymetry profile that had shown the most change over the 13 years prior to the trial. This amounted only to 0.3m per metre length of chainage, with nearly all the 'movement' accounted for by the occasional development then disappearance of a small sub-tidal bar, although with no observable pattern of bar movement either seawards or landwards (see Appendix B, Section B.2.2). Seaward of about 200m, there was negligible change in profile (the deposition is at about 400m chainage). Thus the behaviour of the seabed during the trial was entirely consistent with the long-term surveys results, showing a reasonably stable seabed. Note, however, that this does not indicate that there is no sediment movement across the seabed, rather that there is little net change in elevation.

Together, this evidence leads to the conclusion that deposition in 5m CD will provide a long-term, relatively stable source of sediment to feed the adjacent beach and the updrift nearshore seabed.

It is possible that the mounds themselves act as an 'offshore breakwater', dissipating more wave energy by forcing wave breaking further offshore. However, there was no clear evidence for the sort of tombolo features that tend to be associated with such beach behaviour. Similarly, the 'bulges' have been observed along the Poole frontage in other years and are therefore not necessarily a new feature forced by the deposition, though they may be linked to subtle changes in the nearshore bathymetry. It is also possible that a much larger quantity of deposition material will have a more demonstrable effect on the nearshore, becoming a semi-permanent feature and generating a build-up of sediment in its lee.

There are some superficial similarities between the trial site in Poole Bay and the coast of the Netherlands (for example, substrate and tidal range), but also some notable dis-similarities, including lack of sediment and existence of natural multi-barred systems. The trial results showed that, although the anticipated onshore sediment movement did not happen in quite the same manner as happens with offshore replenishment on Dutch bar systems, there was evidence that an artificially created bar can translate shorewards with the right hydrodynamic conditions. But the different scales of operation involved mean that it should not be expected to necessarily copy the results of the Dutch. Even if the main effect of the deposition is as a 'slow release' store of sediment, it is still a useful byproduct of what is essentially waste material by ensuring that the sand remains in a sediment-poor bay rather than being effectively lost to the circulation.

6.5 Assessment of trial methodology

The adequacy of the monitoring programme to meet its aims was assessed in terms of:

- equipment
- survey frequency
- representativeness of the measurements
- value for money

6.5.1 Equipment

Sediment transport

Laser scanning was the best technique for beach surveys since it provided detail on the longshore and cross-shore variability of beach topography, which can be missed from beach profiles alone, and at an accuracy which gives confidence in resulting difference models to within ±0.1m.

Repeated swath bathymetry was similarly the best technique to attempt to track the movement of the sediment mounds, but at IHO Order 1a (or even at the higher Special Order, which is effectively the standard that the surveys met in such shallow water), the precision and accuracy are not sufficient to identify vertical changes less than ±0.2m, and so it is not good for identifying very small volume differences. However, there is no better technique available and the swath results were the lynch pin of the trial.

Hydrodynamics

The AWAC is a well-tested, rugged and reliable piece of equipment. It is superior to a conventional acoustic Doppler current profiler (ADCP) in that it also measures directional waves, which proved of real significance for the trial. Newer versions of this type of instrument have recently become available which produce a higher resolution (that is, smoother vertical profile), thus revealing finer current structure. However, the standard AWAC remains perfectly suitable for this type of study.

Turbidity

The ABS (acoustic backscatter sensor from the AWAC) appeared to underestimate the SSC at this site. Although it mostly responded to the same events ‘seen’ by the OBS (thus giving confidence that the measurements of both types of instrument did represent a change in turbidity), the ABS readings were on average between 30% and 60% lower than those given by the OBS. This is not unexpected as it is well-known that results from different types of turbidity instruments cannot be cross-related.

Acoustic backscatter systems respond better to coarser material so it is possible that the fine sand grains in this part of Poole Bay were insufficiently large to scatter enough of the acoustic signal. However, the OBS proved much less suitable for long-term deployments than the ABS, which can last up to 3 months without servicing (depending on the sampling regime) and in addition gives a vertical profile of turbidity. The OBS suffered from considerable biofouling despite its wiper arm and clearly required more servicing than was possible with the funds available for the trial. Having both instrument types provided some redundancy, but accurate and reliable long-term measurements of turbidity remain something of a problem.

Tracer experiment

This experiment worked particularly well and much better than had been feared. Marine tracer experiments have not been uniformly successful (see, for example, the Southern North Sea Sediment Transport Study; HR Wallingford et al. 2002) and there was a distinct possibility that the tracer would either not move at all, or disperse so rapidly and widely as to be near impossible to track reliably, or lead to results that were not statistically sound. Considerable efforts were made by the oceanographic contractors to seize upon optimum hydrodynamic conditions and it has to be admitted that a certain amount of luck was involved (calm – South-east Force 5 – calm). Ideally, a larger quantity of tracer would be used.

6.5.2 Survey frequency

The survey programme was designed around the funding available to make best use of the number of surveys that could be commissioned. Because of the novelty of the project, the speed of the dispersal of the sediment could only be guessed at – with the distinct possibility that 30,000m^3 of sediment might well have dispersed within a few weeks. This was the reason for the concentration of surveys in the first few weeks after the deposition.

Ideally, a further survey set following the late December 2015 to early January 2016 storms would have been useful, particularly for the beach, but sea conditions remained unsuitable for surveying for much of January and February 2016.

6.5.3 Representativeness of measurements

The ability to set the trial results into the context of long-term measurements allowed an assessment of the measurement methodology both spatially and temporally, that is:

- Over what area can the results be considered representative?
- Was one year of measurements needed or would 6 months have sufficed?

There are no measured current data with which to compare the trial data. The broad similarity of the pattern of tidal currents at the 2 AWAC locations indicates that the results may be considered as representative for their respective depth contours (5 and 8m CD), certainly for the western half of Poole Bay. In a similar vein, the strength of longshore currents is likely to be representative of surf zone currents for much of Poole Bay, together with the likelihood that surf zone conditions can extend to the 5m CD contour – though the amount of tidal enhancement or opposition will vary along Poole Bay, depending on exposure and refraction.

The measured data from the AWAC should be useful for validating any subsequent wave or sediment transport modelling over much of Poole Bay. Particularly valuable are the data from the shallow site, including surf zone conditions, which are difficult to obtain and mostly determined only by universities and other research institutions.

Comparison of the waves measured by the AWAC and the long-term DWR off Boscombe Pier demonstrated that, although wave heights in the trial area can be broadly represented by the DWR for most directional sectors, refraction modelling will be needed for waves from the south-east quadrant to establish reliable transfer functions. This should be a straightforward task and is needed only to establish the range of directions that require a different transfer function.

Since the measured conditions encompassed extensive periods of both high waves and calm conditions, the turbidity results can be accepted as representative of ambient turbidity at their water depths in the majority of the bay – unless there are additional physical factors such as near the harbour outlet. Furthermore, they should also provide a reasonable guide to the maximum and minimum levels of naturally induced turbidity (as measured by an OBS).

The decision of the Borough of Poole to fund an extension of the trial for an additional 3 months (thus covering the winter period following deposition) turned out to be a wise one since it fortuitously encompassed the highest waves measured in Poole Bay and hence captured (and defined) conditions which actually saw some dispersion of the mounds.

6.5.4 Value for money

Marine monitoring is expensive, vulnerable to equipment damage and at the mercy of the elements. The most expensive individual element of the trial was the sub-tidal tracer study, yet it turned out to be the most definitive in terms of meeting the aims. However, without some element of luck in that the hydrodynamic conditions were ideal, it could easily have produced nothing of significance. It was a risk worth taking.

Swath bathymetry surveys are also expensive, but the whole experiment would have been pointless without measuring what was happening to the mounds. The additional money spent on commissioning swath bathymetry, in preference to the cheaper but order of magnitude less informative single beam surveys, was money well spent.

The topographic surveys were the cheapest element of the trial, but this was mostly because the services could be provided 'in-house' by the Channel Coastal Observatory. They were also the least weather-dependent activity.

The AWAC is fairly expensive to purchase, but is robust and unless it suffers external damage (for example, from trawlers), is a long-lived instrument by hydrodynamic instrumentation standards. The optimum period to balance whether to purchase or hire is about 9 months. Once purchased, the main expense is in deployment and servicing costs, but it can measure for 2 or 3 months without servicing. Hence, the additional information that can be gained by a 12-month deployment compared with a 3-month set of measurements increases the possibility of capturing a much wider range of hydrodynamic conditions. Furthermore, since so little current information is available, the data provided (for example, tidal currents and longshore currents) can prove useful for future studies and model validation.

In contrast, absolute values of turbidity remain the most difficult parameter to obtain long term and furthermore difficult to translate into meaningful results (that is, to estimate instantaneous sediment transport rates that can be scaled up in both time and space to make predictions of the behaviour of the deposition). An OBS is a relatively inexpensive but well-established instrument and worth deploying, even though it is vulnerable to biofouling and the ABS results are part of the AWAC. Provision of turbidity measurements as an 'add-on' to and a byproduct of the AWAC offers good value for money; additional funds for specialist turbidity equipment could not be justified in this trial.

7 Conclusions

Some 14 months after deposition, the mounds remain distinct features, approximately 2m high. The sediment has remained in situ, with a net loss of only ~1,000m^3 (~3%) since deposition. Such small net volumes of sediment change, however, are difficult to identify even from high precision bathymetric and topographic surveys.

Overall

- Although little net volume change has occurred, the mounds have shown signs of shoreward translation by about 10m in the manner of an offshore bar.
- Under the right hydrodynamic conditions, sediment can be transported quickly from 5m CD to the beach, although the majority of sediment is transported alongshore. During storm conditions, longshore currents are generally directed towards the north-east.
- Any future deposition should be placed in ~5m CD, rather than further offshore in ~8m CD where it would be more likely to be transported parallel to the coast than onshore.
- No detrimental effect on the Poole Rocks MCZ was observed.

Question 1

> 'Is there a sediment connection between the nearshore (deposition area) and the beach …?'

Yes, there is a clear pathway from the deposition area in ~5m CD to the beach, both directly cross-shore and obliquely via longshore currents in a surf zone before reaching the beach. A direct pathway from the 8m CD contour is unlikely.

> '… of sufficient quantity to indicate that the process of nearshore replenishment could be a successful technique at this site?'

This is less certain. For the 9 months following the deposition, the sediment from the top of the mounds mostly just settled in the gaps between. Between late December 2015 and April 2016, the mounds rolled forward in a similar manner to the shoreward translation of an offshore bar but, as yet, it is impossible to predict whether the 'bar' will remain as a semi-fixed feature or will migrate onshore. It appears unlikely that it will migrate offshore.

Question 2

> 'Has the nearshore replenishment had a detrimental effect on the adjacent Poole Rocks MCZ?'

No effect was observed – either detrimental or constructive. Furthermore, the trial showed that there is no direct sediment pathway from the deposition site to the MCZ.

Although it was proven that there is a sediment transport connection between the nearshore and the adjacent beach (that is, nearshore deposition can replenish the beach), it remains difficult to assess the long-term fate of the material. It is likely that both a larger quantity of material and more time are needed for sediment dispersal at this site to demonstrate long-term viability of nearshore replenishment as an alternative to traditional methods.

Furthermore, the success or otherwise of the technique of nearshore replenishment is clearly dependent on a wide range of site-specific conditions, where even subtle differences in tidal currents, wave period and direction can have a significant influence on net sediment transport in the nearshore region. As a result, it would not be appropriate to extrapolate the results from this study to other coastlines, or to draw conclusions on the transferability of the method to other sites.

8 Lessons learnt

8.1 MMO licence

The timescale needed to obtain an MMO licence should not be underestimated. For this trial, there were no issues with contaminants or non-native sediments yet it took 18 months between licence application and award.

The volume of sediment agreed by the MMO and their consultee Natural England was restricted to 30,000m^3 on a precautionary basis given the proximity of Poole Rocks MCZ. However, this is a very small quantity of material in terms of coastal sediment, equivalent to 0.03m over the bathymetry survey area. It is to be hoped that experience from this trial will be helpful for the MMO to give more realistic bounds on minimum quantities of deposition in subsequent licence applications both at this and other potential sites.

Similarly, the MMO, via its consultee CEFAS, queried the 'large amount' (1 tonne) of tracer material to be used in the tracer experiment, yet the industry standard for sub-tidal tracer experiments is closer to 3 tonnes. The 1 tonne used in this experiment was a distinct compromise based on cost and was felt to be the very minimum quantity that stood any realistic chance of being tracked even within a few days of release. Had further funds been available, 3 tonnes of material would have been used.

8.2 Deposition size

The small quantity of sediment that left the mounds (a maximum of 1,800m^3 over 40 days) cannot be accounted for definitively even using the best and most-sophisticated survey method (IHO Special Order swath bathymetry).

8.3 Trial methodology

Long-term measurements of turbidity using an OBS require at least monthly service visits for cleaning. Turbidity remains a tricky parameter to measure reliably.

8.4 Historical information

Long-term historical measurements are vital to be able to set short-term monitoring trials into context.

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List of abbreviations

ABS	acoustic backscatter sensor
AWAC	acoustic wave and current profiler
CD	chart datum
DTM	digital terrain model
DWR	directional waverider (buoy)
HAT	highest astronomical tide
Hmax	maximum wave height [m]
Hs	significant wave height [m]
IHO	International Hydrographic Organization
LAT	lowest astronomical tide
MCA	Maritime and Coastguard Agency
MCZ	Marine Conservation Zone
MHW	mean high water
MHWN	mean high water neaps
MHWS	mean high water springs
MLW	mean low water
MLWN	mean low water neaps
MLWS	mean low water springs
MMO	Marine Management Organisation
OBS	optical backscatter sensor
OD	ordnance datum
PSA	particle size analysis
SSC	suspended sediment concentration [mgl^{-1}]
SST	sea temperature [°C]
Tp	peak wave period [s]
TPU	total propagated uncertainty [m]
Tz	zero crossing wave period [s]
UV	ultraviolet

Appendix A: Instrumentation, survey techniques and analytical methods

A.1 Topographic surveys

Topographic surveys were carried out either using a fixed-base laser scanner (Figure A.1) or with a real-time kinematic global positioning system (RTK-GPS), based on the Environment Agency's specification for topographic surveys.

The scanner captures millions of data points within a radius of about 150m and is moved along the beach to ensure that there are no blind spots in data capture. The beach structures, backing cliffs or dunes are also captured in great detail. The laser cannot reliably collect data over a wet surface, so the beach area close to MLWS is captured by a surveyor taking continuous RTK-GPS measurements, at a minimum interval of 5m, and including all breaks of slope.

The accuracy of both the laser scan and RTK-GPS systems is Plan ±15mm and Vertical ±15mm.

Figure A.1 Using a laser scanner on Poole beach

The resulting point cloud of thousands of data points is downsampled to produce a Digital Terrain Model (DTM) at a resolution of 1m. A recent DTM can be subtracted from an earlier DTM to produce a difference model, quantifying the elevation changes between the 2 surveys. But although vertical differences of ±15mm can be identified, in practice only elevation differences of ±0.2m can realistically be considered as anything other than ‘noise’, given the inherent daily changes in the beach caused by people walking on the beach and other human activity.

DTMs were produced for each topographic survey and differenced to produce net volume changes between surveys (over a common area). The sediment transport rate (within the survey areas) is calculated as the net volume change (m^3) per m^2 of beach per day.

A.2 Bathymetry

Swath bathymetry is carried out to the IHO Order 1a standard. This is the survey standard used for navigation safety (charting) surveys. In this method, 100% of the seafloor is isonified, giving complete coverage of the seabed. Processed data are output at 1m resolution. The TPU of an IHO Order 1a survey is Horizontal (THU) < 2 m and Vertical (TVU) 0.2–0.3m.

A.3 Tracer study

The tracer material (Figure A.2) was painted marine grade sand (150–425μm) chosen to match the natural sediment size distribution as closely as possible (see Appendix C, Section C.6). The tracer fluoresces under ultraviolet (UV) light (Figure A.3) and is treated for hydrophobic properties. A grab bucket was filled with tracer material and lowered to the seabed before releasing the jaws so as to reduce mid-water column losses of sediment to a minimum.

Figure A.2 Tracer material

Notes: Photo courtesy of Fugro EMU Limited

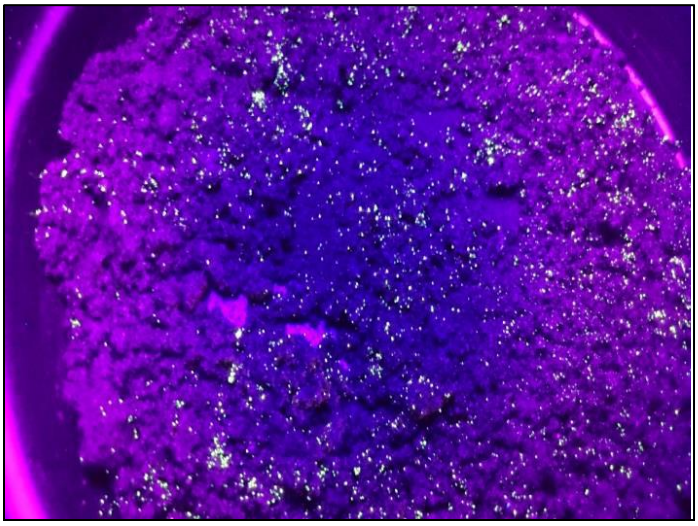


Figure A.3 Fluorescent tracer from a grab sample, viewed under a UV light in a dark box

Notes: Image courtesy of Fugro EMU Limited

Approximately 1 tonne (the maximum permissible under the MMO licence conditions) of yellow fluorescent tracer material was deposited in the middle of the landward row of mounds on 12 February 2015 (D-2). The position was chosen since the principal aim was to investigate whether material from the deposition site would be transported to the beach, but a practical advantage was to reduce any potential for the tracer to be covered by dredger activity further seaward. Different vessels were used for the tracer insertion (Figure A.4) and subsequent searches to prevent any potential for cross-contamination.

Figure A.4 *CH-Horn* at tracer placement site

Notes: Photo courtesy of S. Terry, Borough of Poole

The first seabed tracer sweep was originally planned for around 4 or 5 days after placement, with the first beach sweep several days later, depending on the findings of the seabed sweep. However, the shallow location of the deposition site and several days of south or south-easterly winds resulted in the first tracer sweep 3 days following tracer placement (D+1).

Seabed samples of ~5kg were taken using a day grab, broadly along 4 shore-parallel transects approximately 100m apart. Samples continued to be taken along each transect until no tracer was detected. Grabs were also made at 2 positions on a transect between the insertion point and the nearest point of the Poole Rocks MCZ. These 2 sites (G8 and G9) were considered as control sites for the MCZ. For the beach search, samples were taken at the locations of high water and low water.

During the first seabed sweep, some tracer was found in the most landward of the seabed grab samples and, accordingly, the first beach sweep took place the following day (D+2). Three of the 14 beach samples showed the presence of tracer and, as a result, the timing of the second tracer search was brought forward, taking place on 21 and 22 February 2015 (D+7, D+8). An additional beach sweep was made by the Borough of Poole on 19 March 2015 (D+33), collecting ~500g samples along the topographic beach profiles.

Subsequent analysis concentrated on the second tracer sweep since the longer time interval allowed for wider dispersion. Due to cost constraints, only half of the samples were selected for full laboratory enumeration: 20 offshore and 4 onshore samples, together with 27 beach samples collected by the Borough of Poole. These samples were prepared in the laboratory and categorised into one of the following bands:

- 0 tracer particles
- 1–25 particles
- 26–100 particles
- 101–500 particles
- 501–1,000 particles
- 1,001–5,000 particles
- 5,001–10,000 particles
- 10,001–100,000 particles
- >100,000 particles

The 2 MCZ control samples were also subjected to full PSA. PSA for sand and gravel fractions was by sieving in accordance with BS1377, with laser diffraction analysis for silt/clay particles.

A.4 Hydrodynamics and sediment dynamics

During the trial, hydrodynamic conditions were measured using a Nortek AWAC with a co-located OBS. Both provide a measure of SSC (a surrogate for turbidity) based on acoustic backscatter and optical backscatter respectively; as such, the instruments respond slightly differently to different sediment particle sizes. The AWAC responds preferably to sand-sized material and thus sand re-suspended from the seabed produces a particularly clear signal. In contrast, the OBS is more sensitive to very fine sand and silts. Both instruments rely on calibration against local sediment.

The AWAC worked well throughout the entire deployment period, with no significant data gaps. The OBS became contaminated during the latter part of the deployment period, when the wiper arm malfunctioned. However, estimates of turbidity could also be obtained from the AWAC.

Wave parameters, depths, current profiles and turbidity were measured by the AWAC every 20 minutes, with bursts of 20 minutes (AWAC). Current and turbidity profiles were binned at 1m intervals. Since the instrument has a blanking distance of 0.5m and was situated 0.6m above the seabed, the lowest AWAC bin represents the average reading of all measurements from 1.1m to 2.1 m above the seabed, thus the Bin 1 value is regarded as the measurement at 1.6m above the seabed. Suspended sediment concentration was measured by the OBS every 10 minutes with a 1-minute burst length. This is a fixed point measurement at 0.6m above the seabed.

Tidal elevations were converted to water depths by adding 8.4m (Location 1) and 5.1m (Location 2).

A.4.1 Currents

Mean currents were derived for each bin and also depth-averaged. Time series of mean currents were provided as resolved current (speed and direction) and rotated into Easting and Northing vectors. For the shallower site (Location 2), the currents were also resolved into cross-shore and alongshore components by rotating 41.6^{o} anti-clockwise from north. The standard right-hand convention is used to describe the cross-shore and longshore currents:

- x+ values represent cross-shore, onshore (that is, a bearing of 318^{o}N, NW from AWAC Location 2 to the beach)
- x– values represent cross-shore, offshore (bearing 138^{o}N, SE)
- y+ values represent longshore towards the north-east (bearing 48^{o}N, NE)
- y– values represent longshore towards the south-west (bearing 228^{o}N, SW)

The cross-shore and longshore currents were derived from Bin 1 (1.6m above the seabed). Longshore currents are primarily confined to the surf zone and decrease rapidly in magnitude seaward of the break point.

A.4.2 Waves

Direct comparison of the time series will show whether both instruments are measuring the same wave events; for example, in a period of higher waves, do both sites record the peak wave heights at approximately the same time? However, different methods are needed to compare measured waves over a common time period but with different sampling rates (DWR every 30 minutes, AWAC every 20 minutes) and at different locations and water depths.

Rather than decimate the 20-minute time series to 30 minutes, the waves are analysed here in terms of percentiles to examine whether essentially the same wave climate is being measured at both locations; since each dataset can be considered its own population, the different time base for the measurements is inconsequential. A further advantage is that the phase lag between the 2 sites is not material. Percentiles from the 2 populations can also be regressed against one another to establish whether there is any relationship between the 2 sites that would permit one site to be considered representative of the other. For example, if a linear relationship was established, measurements at one site could be calculated for the other site based on the equation of the regression: $y = mc^2$.

To illustrate the methods used, Figure A.5 shows an example of Hs percentiles measured during the first 6 months of the trial. Measured wave heights below 0.2m are removed from both datasets, since neither instrument is particularly good at measuring 'calm' waves, and then the percentiles calculated. In this example, the median wave height measured at the DWR was 0.5m, but 0.4m at the AWAC, while 80% of the waves measured at the DWR were 0.8m or lower and 0.65m at the AWAC.

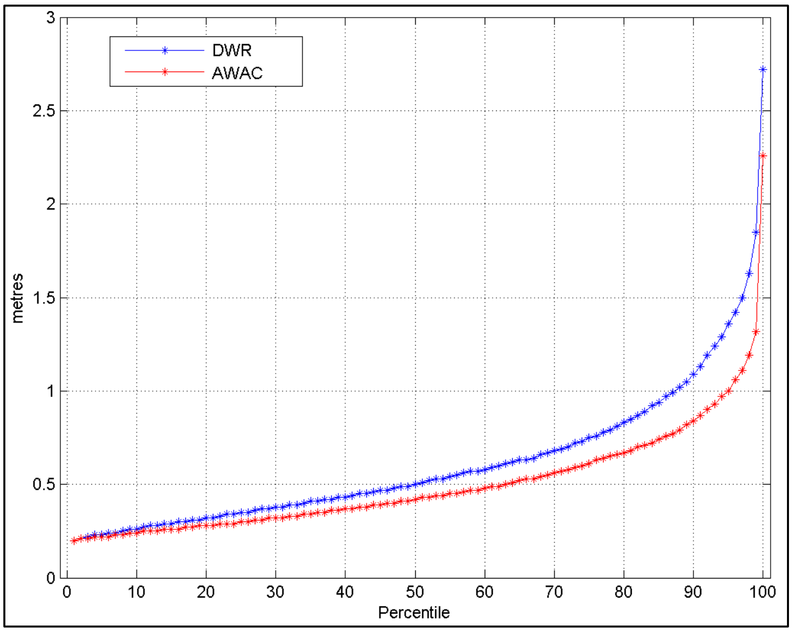


Figure A.5 Example of Hs percentiles

When regressed against each other, the relationship between the 2 sites in the example is shown to be non-linear; in this case a third order polynomial is a reasonable fit (Figure A.6).

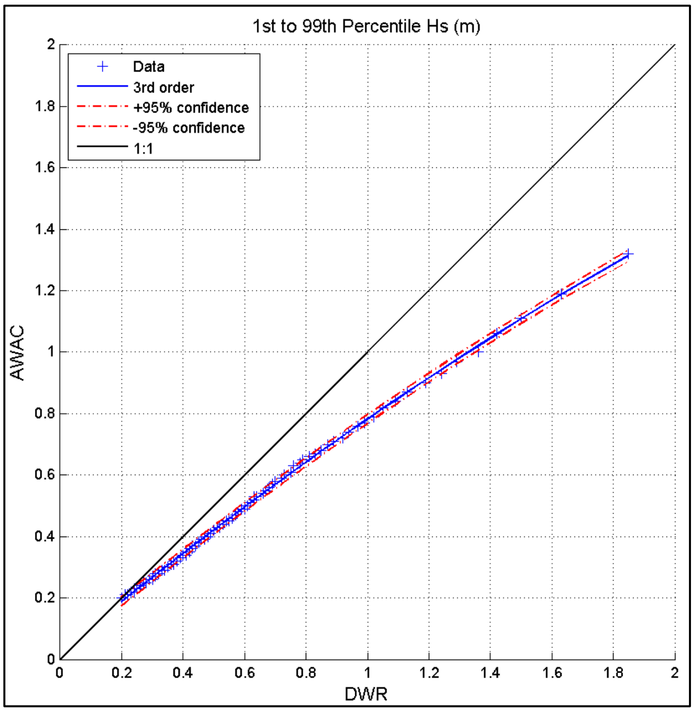


Figure A.6 Regression of Hs percentiles at 2 sites

Similar percentiles are calculated for sub-populations of the measured time series, notably for 45° directional bands, centred around cardinal points (Figure A.7). Sectors with no measured data points are shown as 'No data from this sector', while directional bands with fewer than 24 measurements per year are shown as 'Insufficient data from this sector'.

In the example shown in Figure A.7, waves from the south-west and south are the predominant since they show roughly the same relationship as for the 'all directions' central plot, but the AWAC is clearly more exposed to higher south-easterly waves than the DWR, despite being in shallower water. However, percentiles for the directional bands give no information about the number of data points used to calculate the percentiles; during this period, wave from the south-east occurred 47% of the time. Neither does the method take into account the wave refraction which occurs between the 2 sites (which will vary with directional sector) and which is beyond the scope of this study.

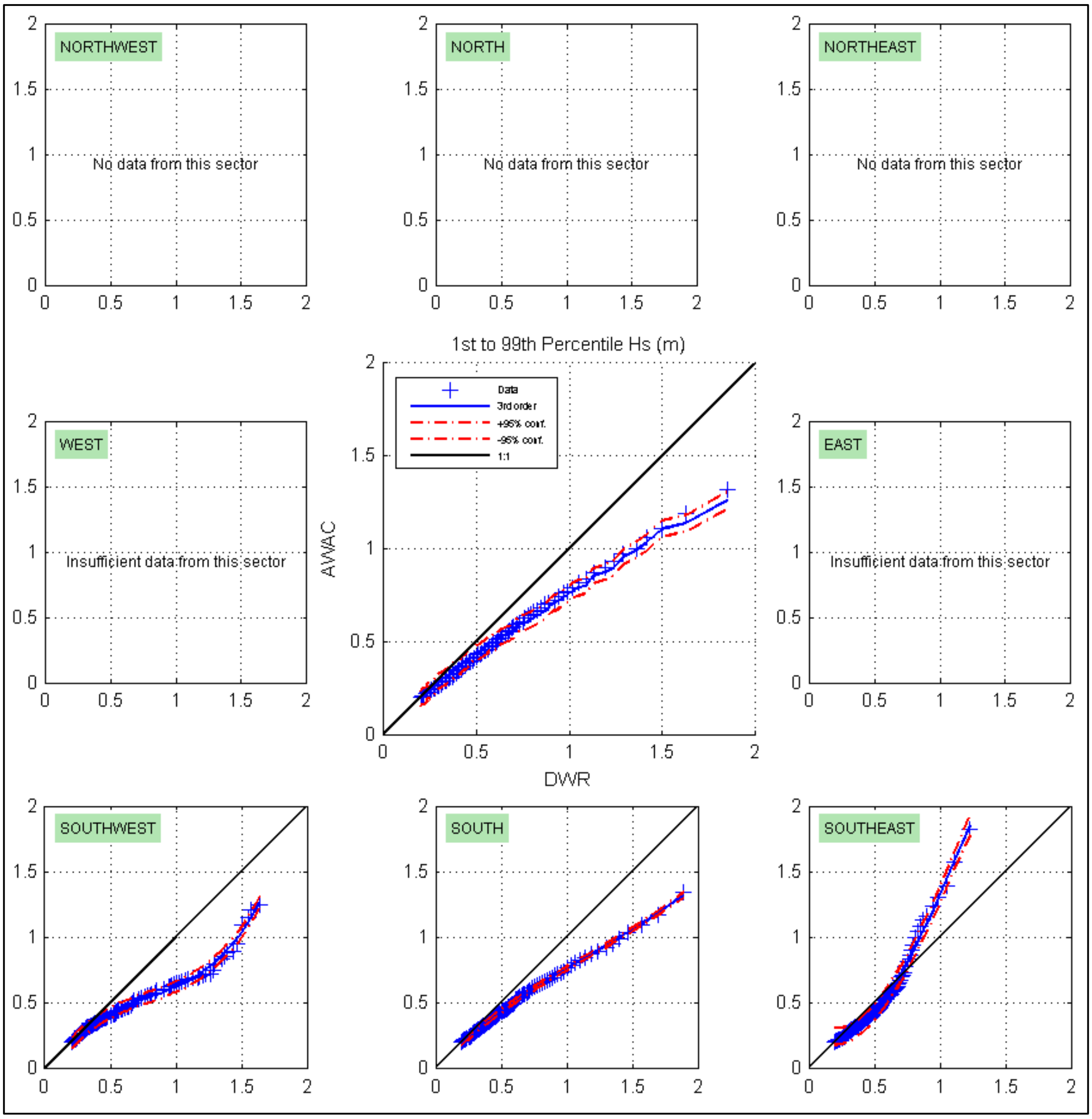


Figure A.7 Directional Hs percentiles

Appendix B: Long-term monitoring analysis

This appendix provides details of long-term historical data to enable the short-term trial results to be set into context.

B.1 Data sources

A summary of the pre-trial baseline data is given in Table B.1. Most of the pre-existing data were collected as part of the Southeast Regional Coastal Monitoring Programme and are in the public domain as Open Government Licence data via the Channel Coastal Observatory's website (www.coastalmonitoring.org). The level of detail of all surveys is consistent and all are carried out to a rigorous specification and subsequently quality controlled.

Topographic data included beach surveys conducted at a time interval of approximately 3 months, together with post storm surveys. Single beam bathymetry surveys have been carried out annually. An extensive swath bathymetry (multibeam) survey was completed in 2012 to IHO Order 1a standard by the MCA as part of the UK Civil Hydrography Programme.

Table B.1 Summary of pre-trial baseline information

Area	Survey type	Standard, coverage and resolution	Comments
Inter-tidal beach	Beach surveys	RTK-GPS surveys or laser scans, extending from the seawall to MLWS	3 surveys per year, 2003 to present
	Lidar	1m resolution, shoreward of MLW	3-yearly since 2003, latest survey 2013 to 2014
	Aerial photography	10cm resolution, shoreward of MLWS	2001, 2002, 2005, 2008 and 2013
Seabed	Swath (multibeam) bathymetry	IHO Order 1a, 100% seafloor coverage, 1m resolution	MCA, 2012
		Deposition trial area	2013
	Single beam bathymetry	Cross-shore profile lines at 50m intervals	Annually, 2002 to 2014
	Substrate	Surficial seabed sediment type	2012, 2013, 2014
	Dive records	Inner Poole Patch Rocks	University of Southampton
	Silt deposition		
Hydrodynamics	Waves	Datawell Directional Waverider Mk III	July 2003 to present
	Tides	A-class gauge, bubbler, 15-minute elevations plus residuals	1996 to present
		WaveRadar REX on Swanage Pier, 10-minute elevations plus residuals	2007 to present

B.2 Assessment of sediment mobility

B.2.1 Inter-tidal beach

Poole Bay has undergone several phases of beach replenishment since 2001. As a result, it is difficult to make meaningful comparisons of ‘whole beach’ volume changes from difference models since the survey coverage is markedly different. This is illustrated in Figure B.2, which shows the trial beach survey area superimposed on a 12-year time series of high resolution aerial photography.

In such cases, the beach profiles can present a clearer picture of the eroding nature of the frontage, such as Profile 5f00509 (the profile closest to the deposition area), given in Figure B.3. This highlights that, prior to the beach replenishment in November 2014, the beach at this location was at its lowest level for 8 years – as illustrated in Figure B.1.

Figure B.1 Beach erosion at Sandbanks following the winter 2013 to 2014 storms left the beach denuded of sand

Notes: Photo courtesy of D. Robson, Borough of Poole

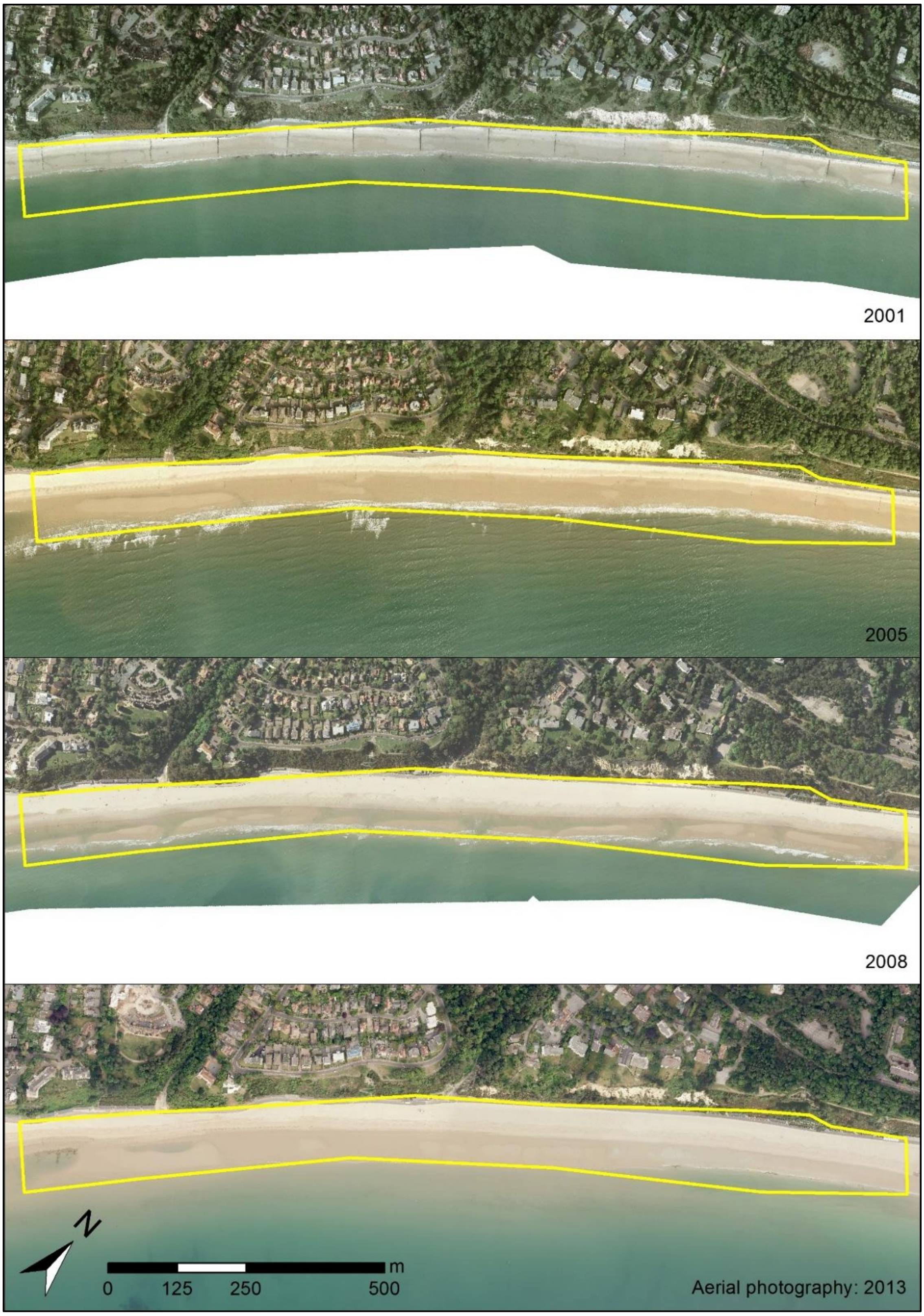


Figure B.2 Ortho-photography of beach trial area, 2001 to 2013

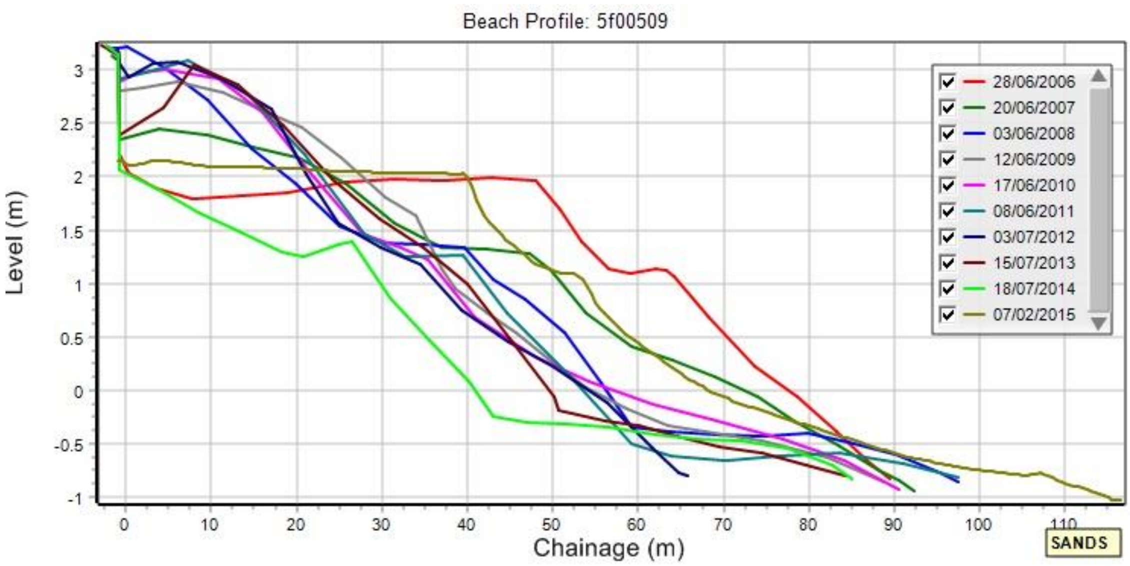


Figure B.3 Profile 5f00509 (June 2006 to February 2015)

Notes: The green profile shows the low state of the beach prior to the replenishment in November 2014.

B.2.2 Nearshore bathymetry

The MCA's Civil Hydrography Programme completed an extensive swath (multibeam) bathymetry survey of Poole Bay, excluding port authority areas, in 2012 (HI 1366), as shown in Figure B.4.

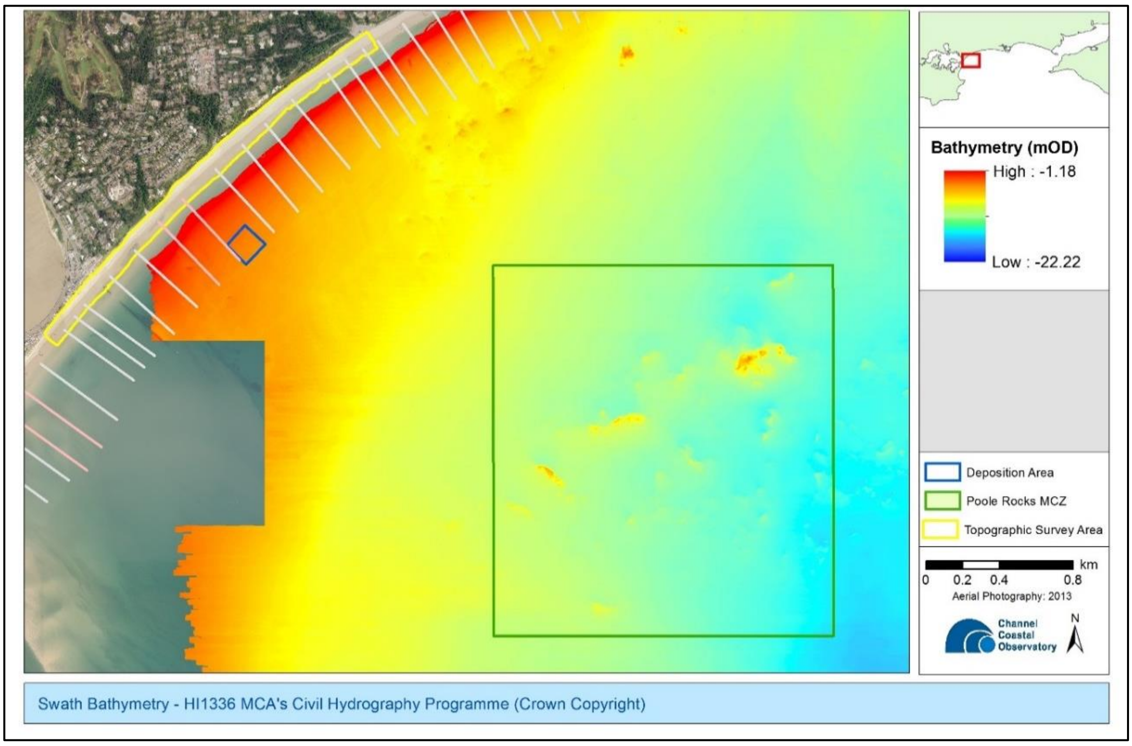


Figure B.4 Swath bathymetry, MCA's Civil Hydrography Programme, HI1366 (Crown Copyright)

Since the first swath survey was in 2012, an assessment of the longer term seabed sediment mobility in the nearshore region is based on a time series of single beam profile surveys. It is only seldom that the bathymetry and topographic surveys have taken place sufficiently close in time for the surveys to be effectively merged into a single profile. Hence, the analysis is performed separately for the single beam profiles, but in the same manner as for the topographic profiles. The single beam profiles are an extension of the topographic profiles and the cross-shore distance (chainage) is calculated from common start-of-line co-ordinates.

Figure B.5 shows selected profiles from a 12-year time series of single beam surveys for Profile 5f00509_H (the profile closest to the deposition area), where it can be seen that the majority of vertical change occurs within about 250m of the shore, mostly due to onshore–offshore movement of a semi-permanent bar. The same pattern of sediment movement is observed at all measured bathymetry profiles within the trial area. The majority of the long-term variation in the nearshore region is due to change in position of the sub-tidal bar, ranging from no discernible bar (which is the case for the majority of the time) to a well-defined feature in, for example, May 2006, March 2011 and June 2012 (Figure B.6). This profile exhibits the maximum change observed within the trial area, being the equivalent of 0.3m per metre length of profile. Most of the other profiles in Poole Bay, in contrast, exhibit 'no change' (that is, ±100m^2), equating to ±0.2m per metre length of profile, which can be considered as within survey 'noise' levels (Figure B.7 and Figure B.8).

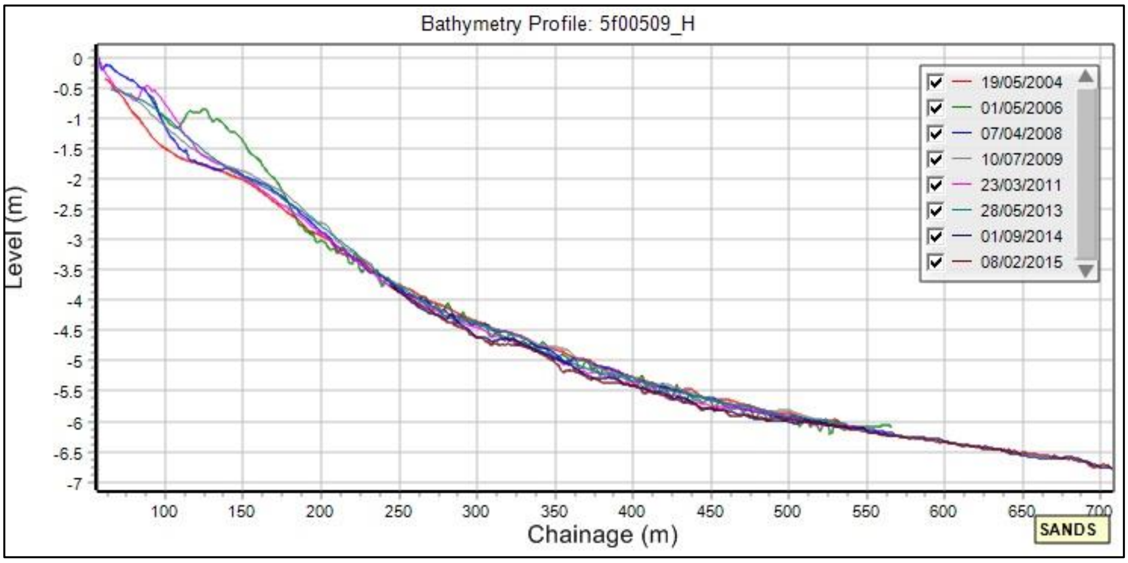


Figure B.5 Long-term bathymetry at Profile 5f00509_H

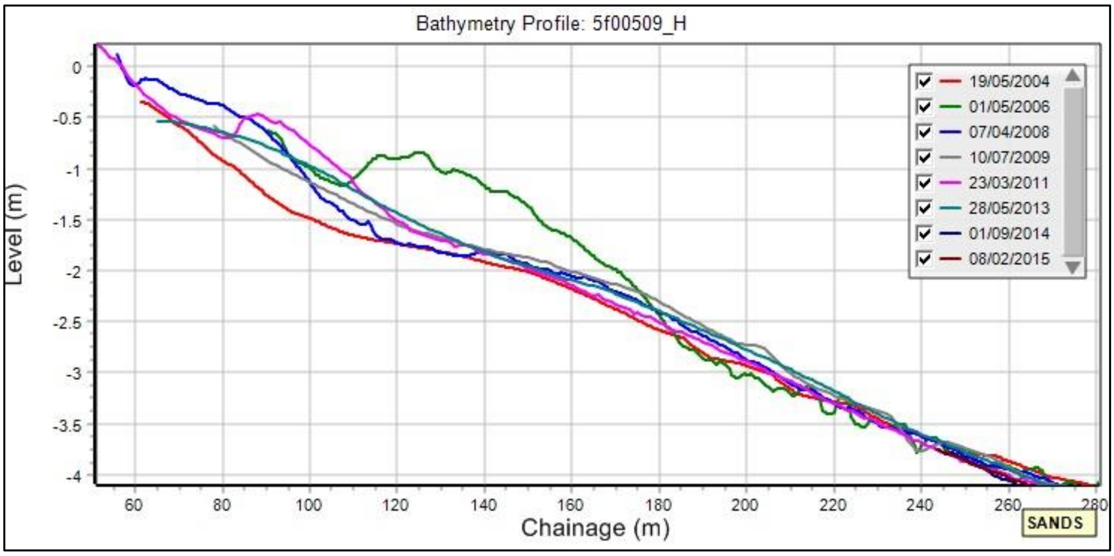


Figure B.6 Long-term bathymetry at 5f00509_H (zoomed to nearshore section)

Although the bar moves onshore and offshore and, in the Sandbanks end of Poole Bay, disappears altogether at times, there is no clear pattern of onshore migration, as occurs in the Netherlands, for example.

Figure B.7 Longer term change in bathymetry cross-sectional area in the trial area from May 2006 to May 2014

Notes: The profiles shown on the diagram represent their true location and surveyed length.

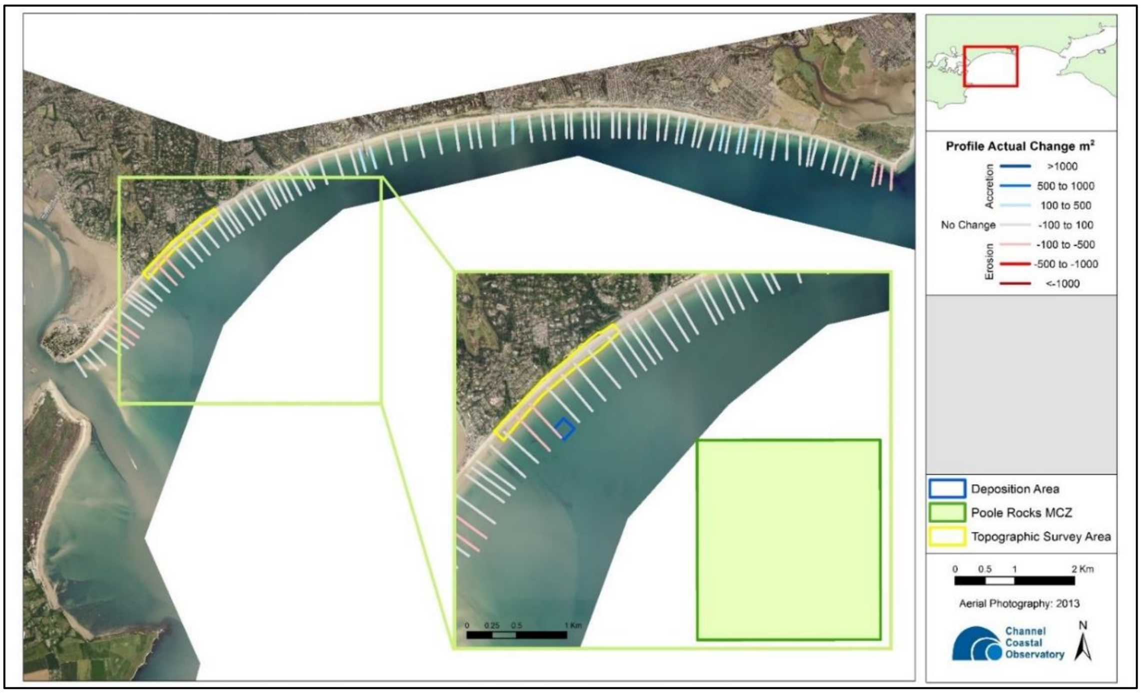


Figure B.8 Longer term change in bathymetry cross-sectional area from May 2006 to May 2014 (Poole Bay frontage)

In conclusion, the long-term bathymetry analysis shows that:

- the majority of nearshore sediment transport in the trial area takes place within about 250m of the shoreline
- the apparent erosion/accretion within 250m of the shore is due mostly to formation or movement of an offshore bar
- there is no historic pattern of shoreward migration of a bar system
- erosion or accretion is negligible in water depths of -2m CD and deeper

B.3 Seabed substrate

The MCA kindly provided a seabed substrate map for HI 1366. The substrate mapping was derived from the acoustic backscatter information collected with the swath bathymetry, along with some ground-truthing from grab samples. The substrate type for the western part of Poole Bay, including the Poole Rocks MCZ, is shown in Figure B.9. The trial area is shown more detail in Figure B.10, where it can be seen that the substrate can be classified entirely as sand and gravely sand, surrounded by areas of sand and gravel ribbons. This is the only pre-existing substrate mapping in the trial area.

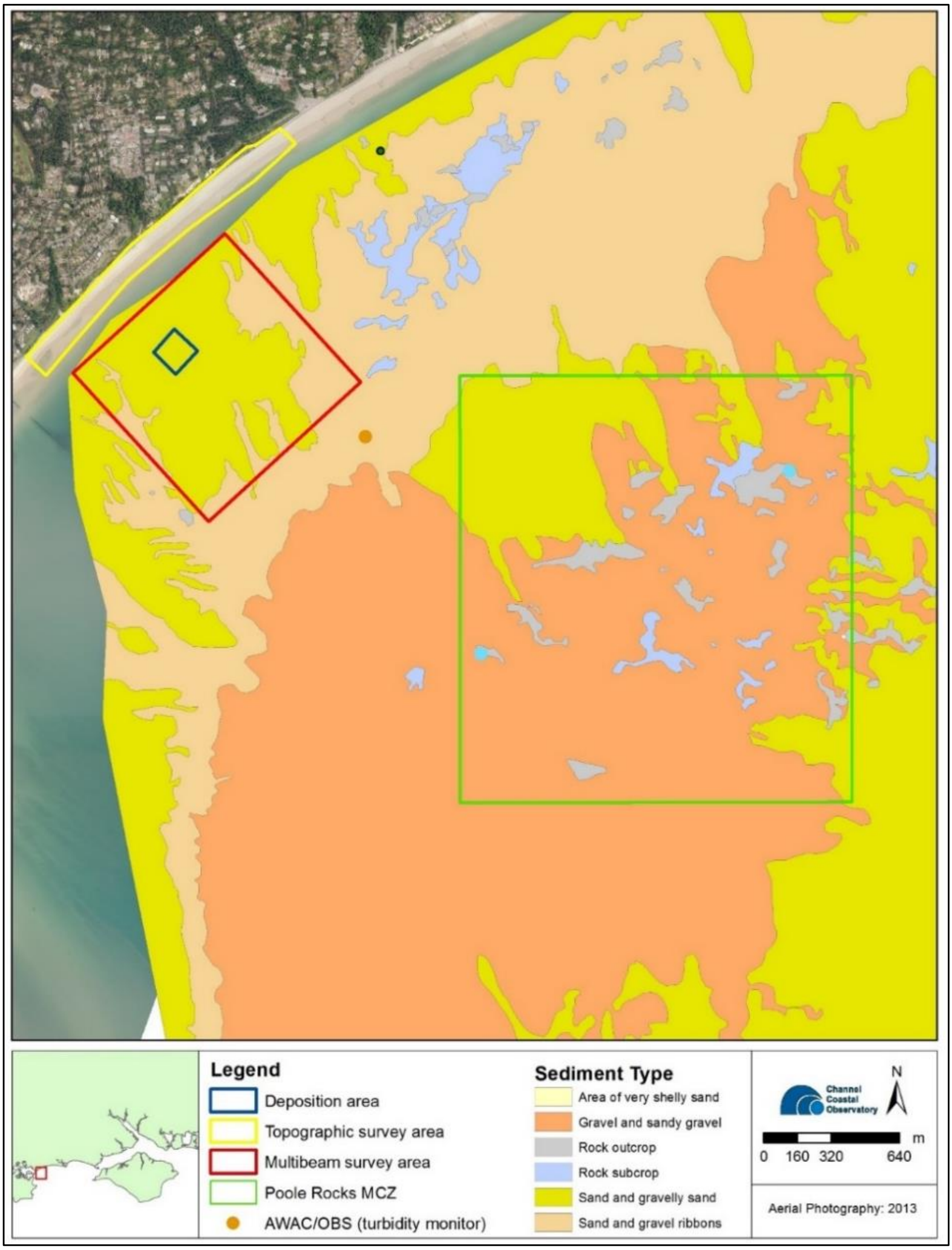


Figure B.9 Seabed sediment types (western Poole Bay), MCA's Civil Hydrography Programme, HI1366 (Crown Copyright)

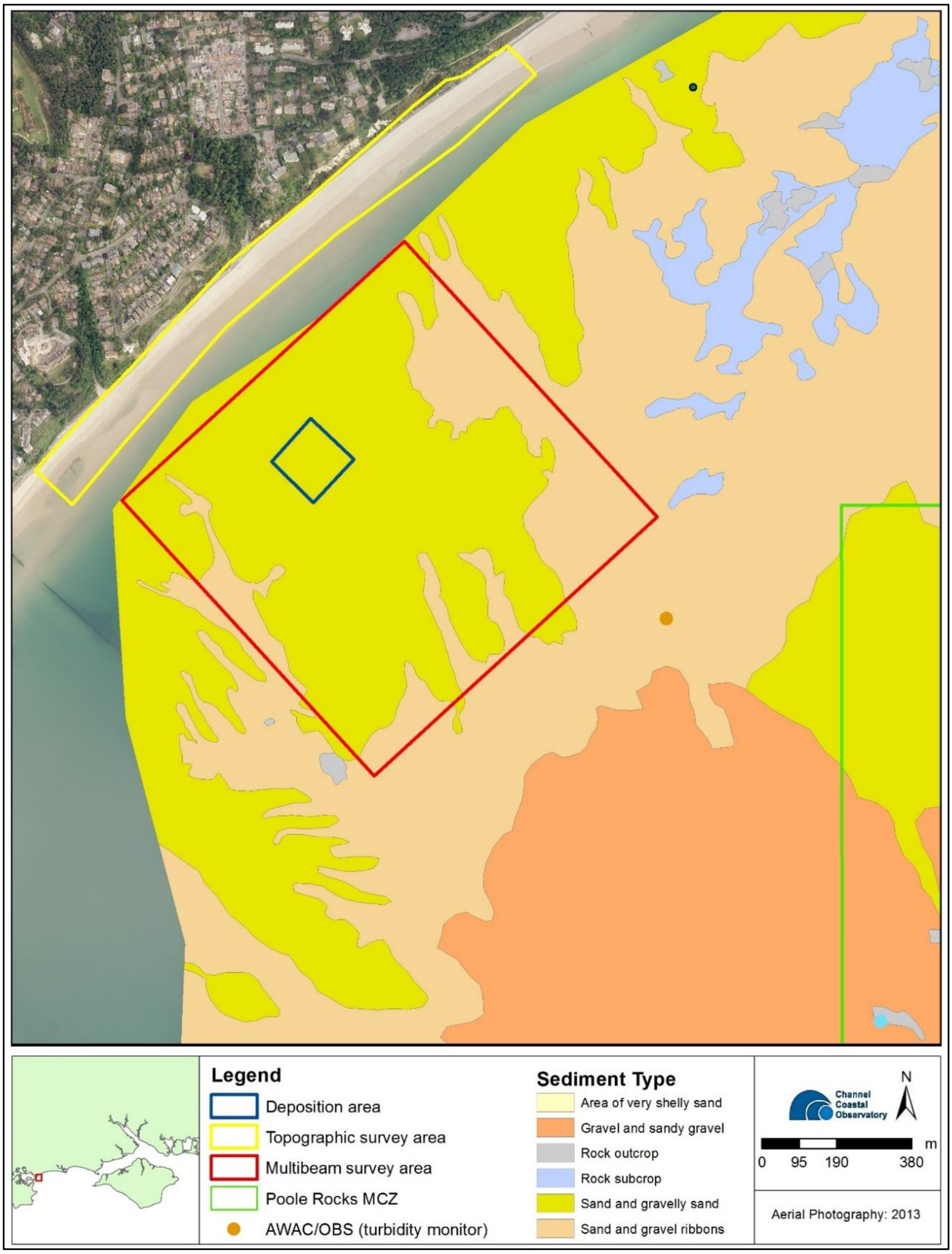


Figure B.10 Seabed sediment types (trial area), MCA's Civil Hydrography Programme, HI1366 (Crown Copyright)

Sediment grab samples were available for 3 locations along 4 shore-normal transects spanning the trial area in August 2013 and October to November 2014. The samples were sieved to derive particle sizes at 0.5 φ intervals (sands and gravel fractions only). An example of the results is shown at Figure B.11 for the sample closest to the deposition site (BP09 offshore), with all results given in Appendix C, Section C.6.

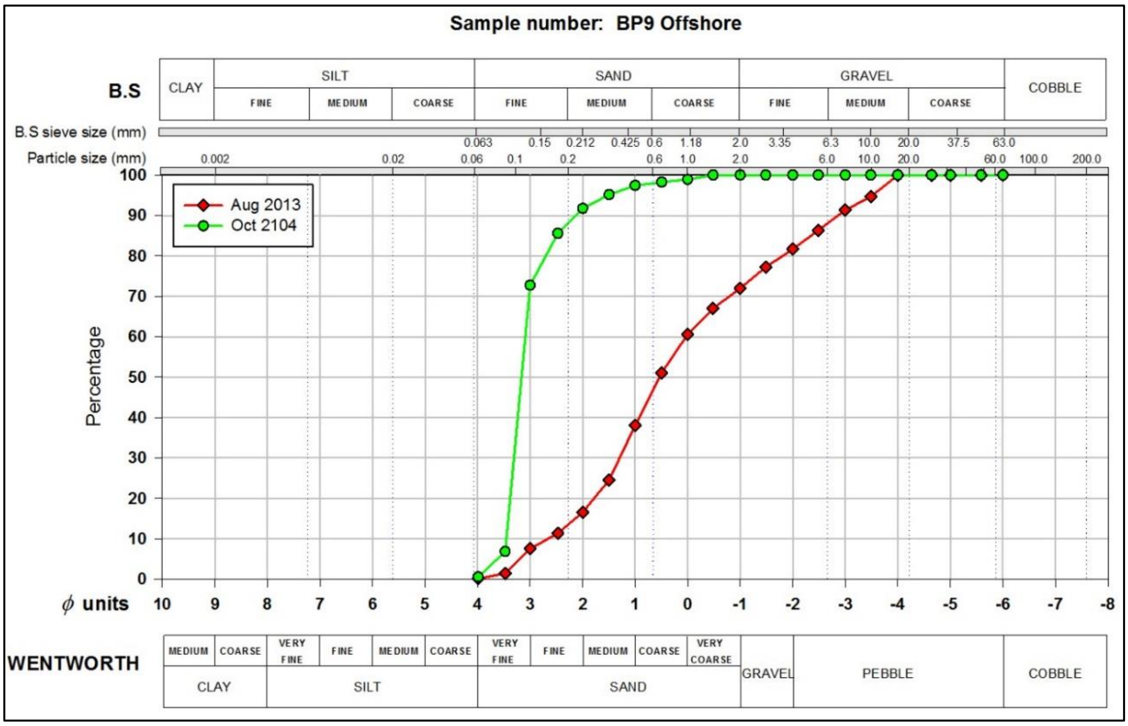


Figure B.11 PSA for sample BP09

All samples indicated that the seabed sediment type (as defined by D_{50}) was sand, confirming the information provided by the substrate mapping and indicating that there had been no change in substrate in the trial area between 2012 and October 2014.

B.4 Hydrodynamics

Long-term wave conditions are measured by a Datawell DWR buoy off Boscombe Pier, operated by the Channel Coastal Observatory (Figure B.12 and Figure B.13). The Datawell buoy is the industry standard for wave measurement and has been adopted by the Joint World Meteorological Organization (IMO) Intergovernmental Oceanographic Commissions (IOC) Technical Commission for Oceanography and Marine Meteorology as the instrument against which all other wave measuring devices are to be tested. The buoy has been deployed since 2003. It is located in approximately 10m CD water depth and measures continuously at 1.28Hz. Data parameters are calculated every 30 minutes, and are subsequently quality controlled and archived by the Channel Coastal Observatory.

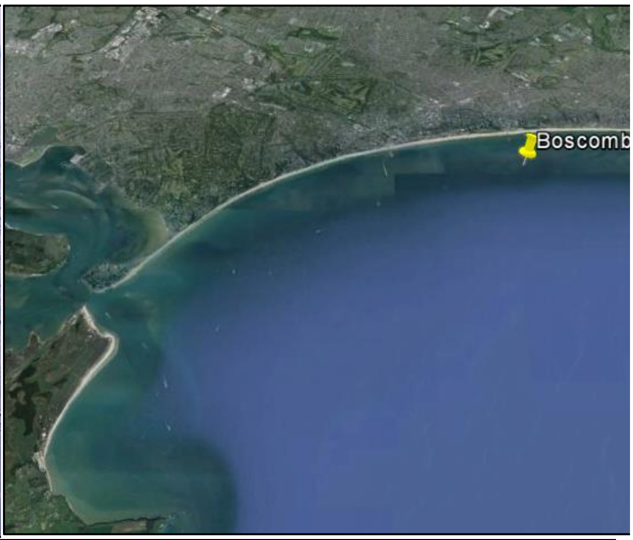


Figure B.12 Datawell DWR buoy off Boscombe (Fugro EMU Limited)

Figure B.13 Location of Boscombe DWR buoy (Google mapping)

Tidal elevations are measured by a gauge on Bournemouth Pier, which was first deployed in 1996. The gauge is one of the 44 A-class network operated by the National Sea and Sea Tidal Facility (www.ntslf.org), but was badly damaged during storms in October 2013 and was out of action for nearly a year.

Tidal elevations are also measured by the Channel Coastal Observatory's tide gauge on Swanage Pier. The instrument is a GLOSS-standard Rosemount WaveRadar REX (Figure B.14), which has been deployed since 2007. Tidal elevations are recorded at 10-minute intervals.

Figure B.14 WaveRadar REX on Swanage Pier

The wave climate (based on ~12 years of measured data) can be characterised by the average wave conditions together with a measure of the frequency and magnitude of storms. The monthly averages of all measured parameters are given in Table B.2. The principal wave direction is south by west (Figure B.15).

Table B.2 Monthly average of measured wave parameters at Boscombe DWR, July 2003 to March 2015

Month	Hs (m)	Tp (s)	Tz (s)	Direction (peak(°N)	Sea temperature (°C)
January	0.74	9.2	4.4	180	8.1
February	0.60	9.5	4.5	177	7.1
March	0.50	8.5	4.2	178	7.6
April	0.42	7.1	4.0	178	9.6
May	0.44	6.1	3.7	178	12.4
June	0.41	5.7	3.5	180	15.7
July	0.44	5.3	3.4	184	17.9
August	0.44	5.4	3.5	184	18.7
September	0.45	6.4	3.7	179	17.7
October	0.65	6.7	3.9	176	15.3
November	0.68	7.7	4.3	179	12.4
December	0.68	8.4	4.3	180	9.4

Hs return periods are shown in Table B.3. The approximate 0.25-year return period Hs is used as a storm threshold to indicate the 3 or 4 storms that are of operational significance to the coastal engineer in a typical year. Using the peaks-over-threshold method recommended by the CIRIA Beach Management Manual (Rogers et al. 2010), the highest Hs of each storm is shown in a storm calendar for the Boscombe DWR (Figure B.16).

Table B.3 Hs return periods for Boscombe DWR (June 2003 to December 2015)

Return period (years)	Significant wave height (m)	Comments
1	3.3	No depth-limitation
2	3.5	
5	3.7	
10	3.9	
20	4.1	Depth-limited at MLWS
50	4.3	
100	4.5	

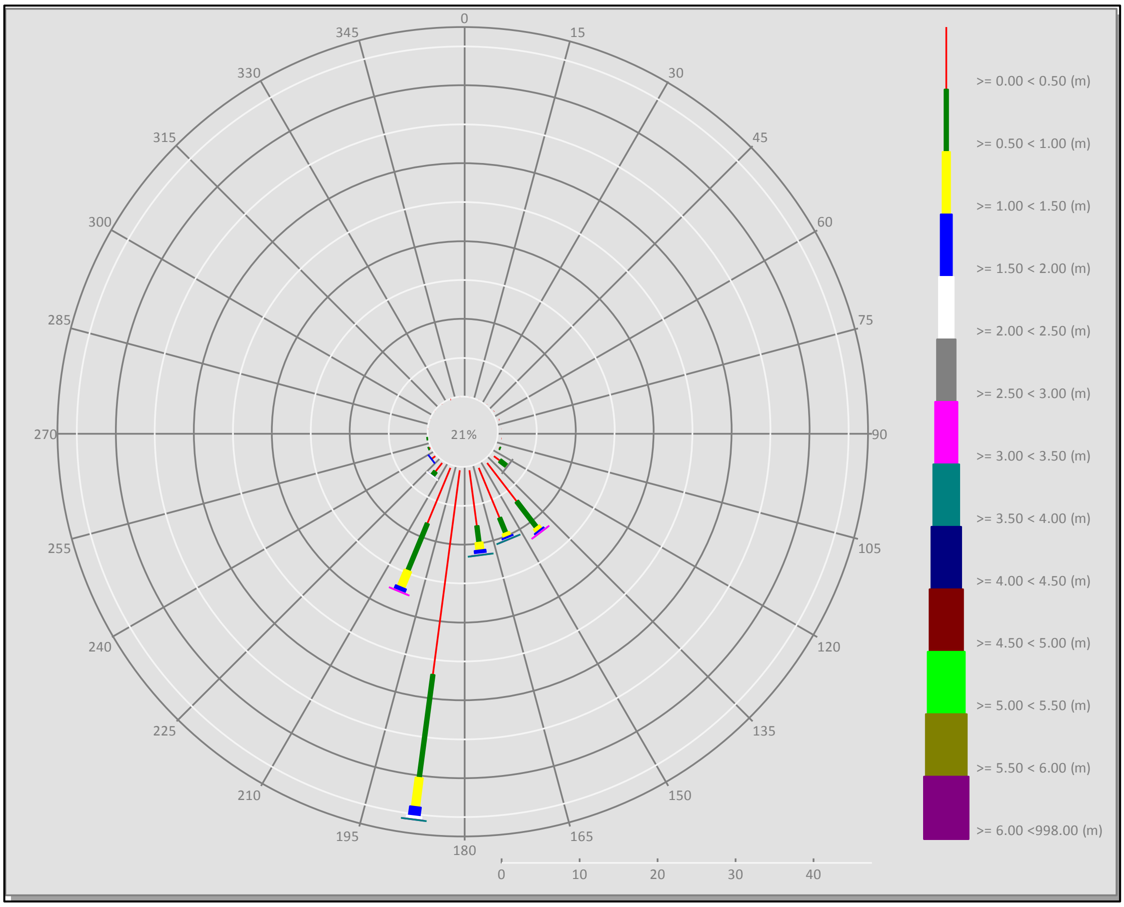


Figure B.15 Wave rose (Hs versus direction) for Boscombe DWR, July 2003 to December 2015

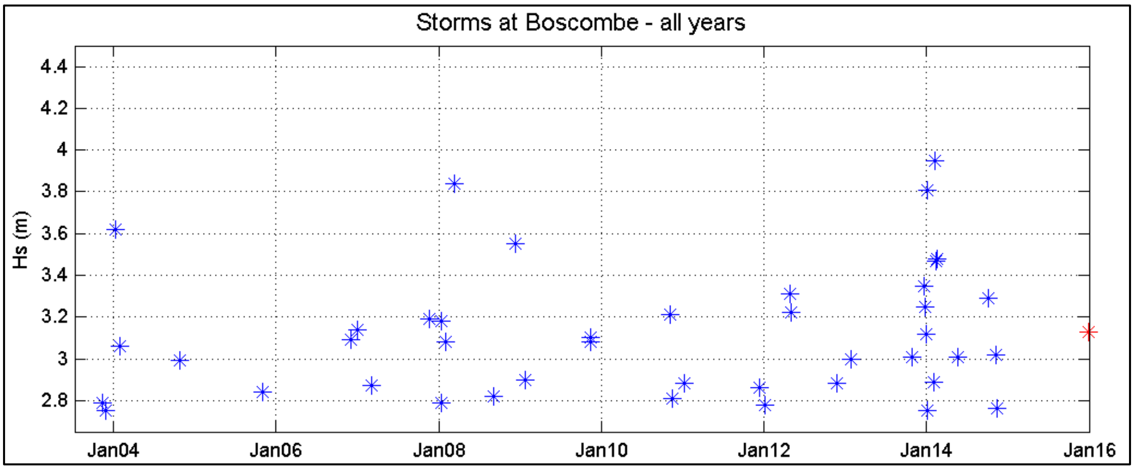


Figure B.16 Storm calendar for Boscombe DWR

Wave height exceedance is a useful parameter to help assess how stormy a given year is compared with others (that is, 1% exceedance in 2008 = 2.02m means that 99% of measured waves were lower than 2.02m). The annual wave height exceedance for Boscombe DWR is given in Figure B.17, where it can be seen that based on 10% exceedance, 2014 was similar to 2006, but for all exceedance values, 2014 was the stormiest since measurements began in 2003.

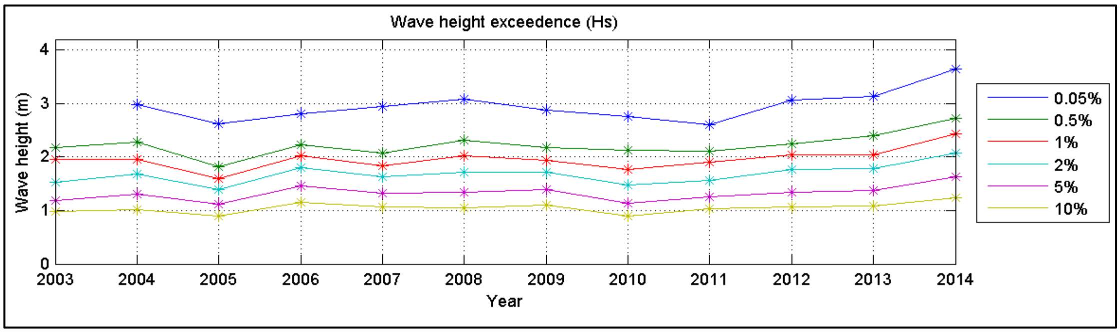


Figure B.17 Hs exceedance at Boscombe DWR

The tidal regime in Poole Bay is micro-tidal, with a spring range of ~1.2m at Swanage (Table B.4). The annual extreme and surge maxima at Swanage are given in Table B.5.

Table B.4 Tide levels at Swanage Pier

Tide level	Observation period: January 2008 to December 2012	
	Elevation (OD)	Elevation (CD)
HAT	1.22	2.62
MHWS	0.81	2.21
MHWN	0.44	1.84
MSL	0.26	1.66
MLWN	0.08	1.48
MLWS	-0.29	1.11
LAT	-1.34	0.06

Table B.5 Annual maxima at Swanage Pier tide gauge

Year	Annual extreme maxima		Annual surge maxima		Z_0 (OD)	Annual recovery rate
	Elevation (OD) (surge)	Date/Time (GMT)	Value (m)	Date/Time		
2008	1.66 (0.64)	10 March 10:10	0.91	10 March 05:40	–	94%
2009	1.33 (0.53)	9 February 20:50	0.80	19 January 05:20	0.242	90%
2010	1.34 (0.43)	30 March 08:20	0.65	12 November 16:00	0.263	96%
2011	1.14 (-0.04)	30 August 21:20	0.39	7 January 14:30		97%
2012	1.53 (0.39)	14 December 09:00	0.64	25 April 16:40	–	96%
2013	1.32 (0.26)	4 November 08:30	0.67	27 October 23:40	–	98%
2014	1.39 (0.48)	8 October 21:00	0.91	14 February 18:10	–	97%

There are no available measured tidal current data within Poole Bay. The nearest tidal diamond to the trial area is in Swanage Bay at 50° 39.23′N 001° 54.98′W in ~9.5m water depth CD (Table B.6).

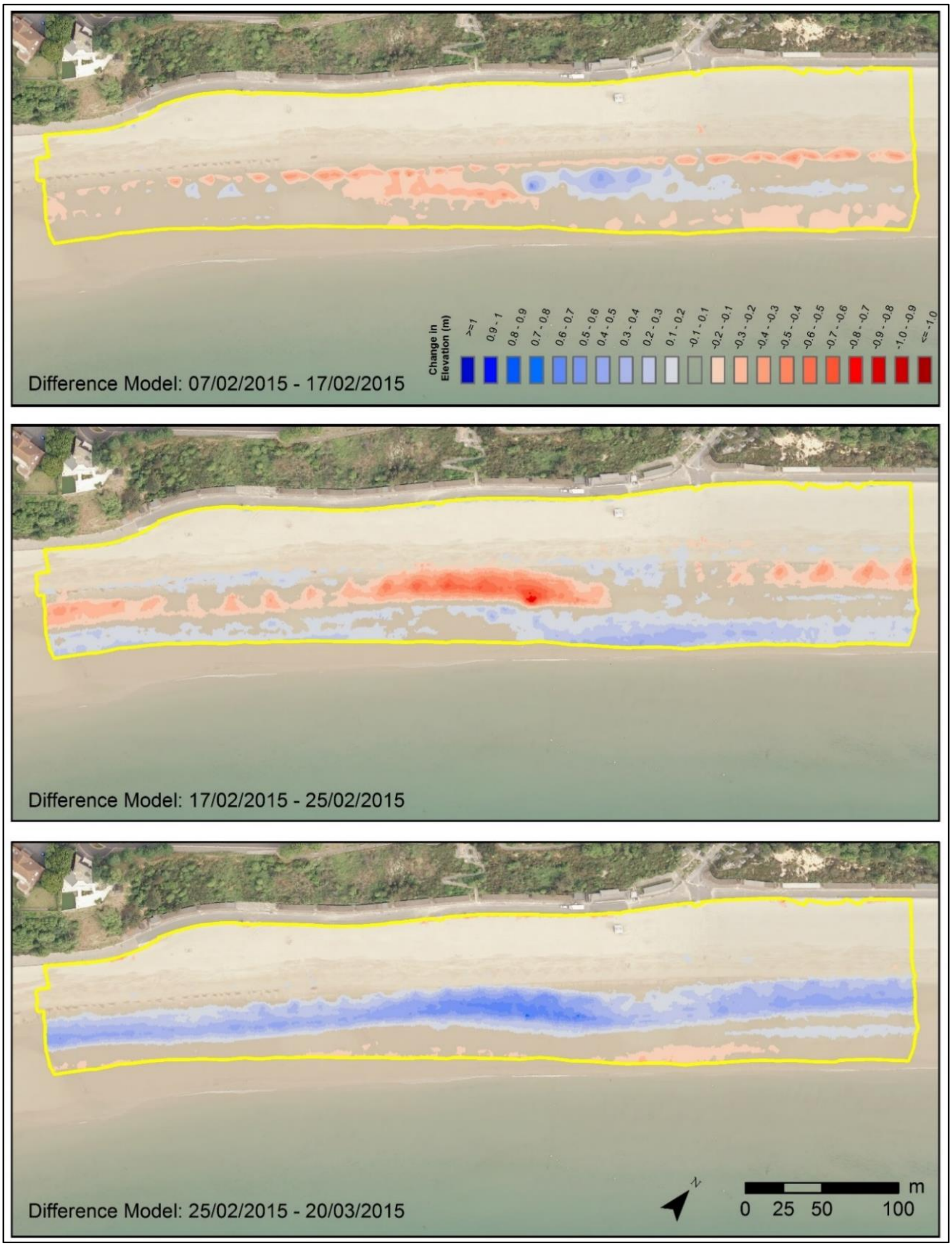
Table B.6 Tidal diamond off Swanage Bay

Time (hours)	Direction (º)	Spring rate (knots)	Neap rate (knots)
-6h	344	1.4	0.7
-5h	346	1.2	0.6
-4h	354	1.0	0.5
-3h	004	0.7	0.3
-2h	029	0.3	0.2
-1h	157	0.3	0.1
High water	179	0.8	0.4
+1h	180	1.1	0.5
+2h	178	1.2	0.6
+3h	172	1.1	0.6
+4h	156	0.6	0.3
+5h	026	0.3	0.1
+6h	347	1.2	0.6

Source: ADMIRALTY TotalTide

Appendix C: Additional results

C.1 Inter-tidal beach surveys



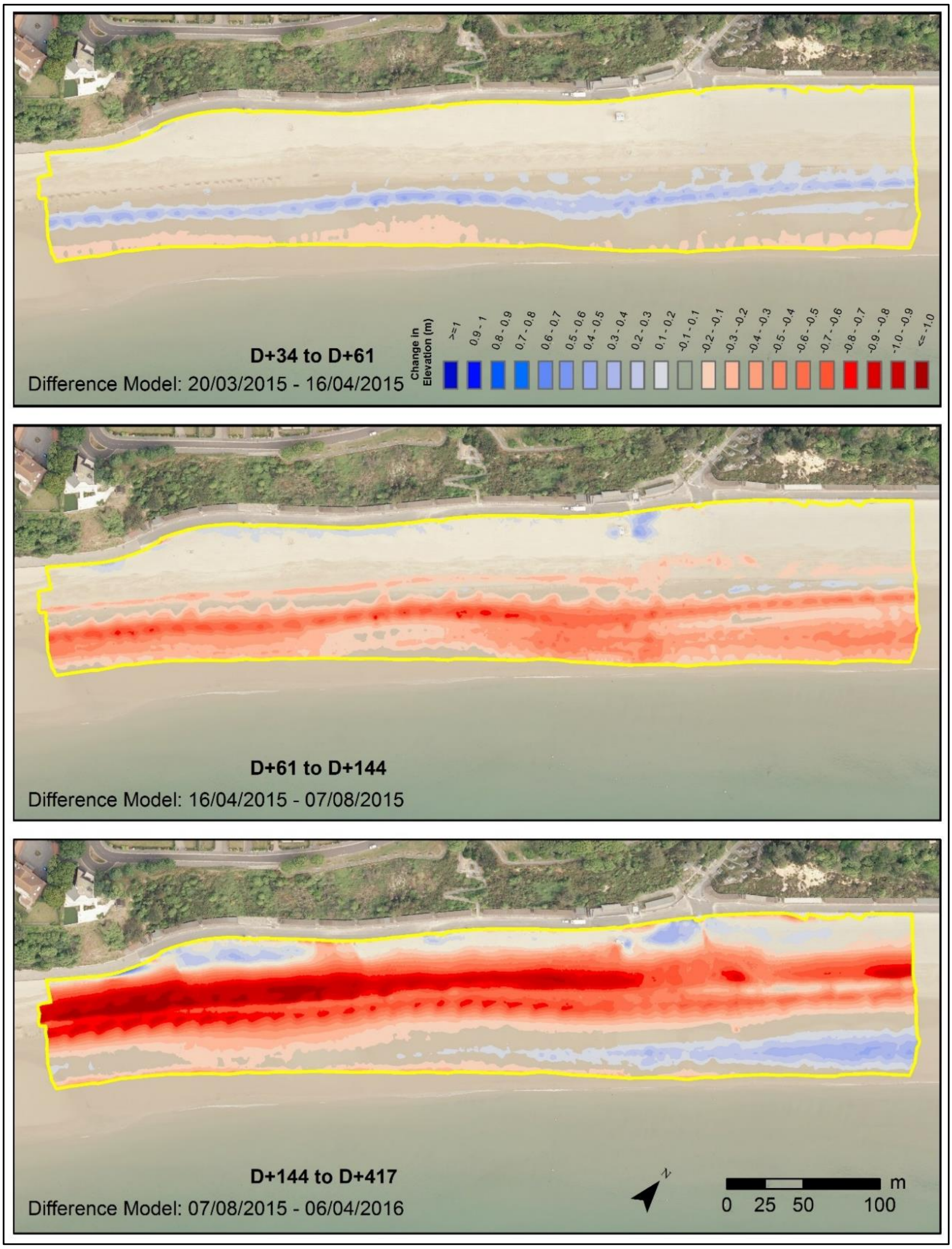
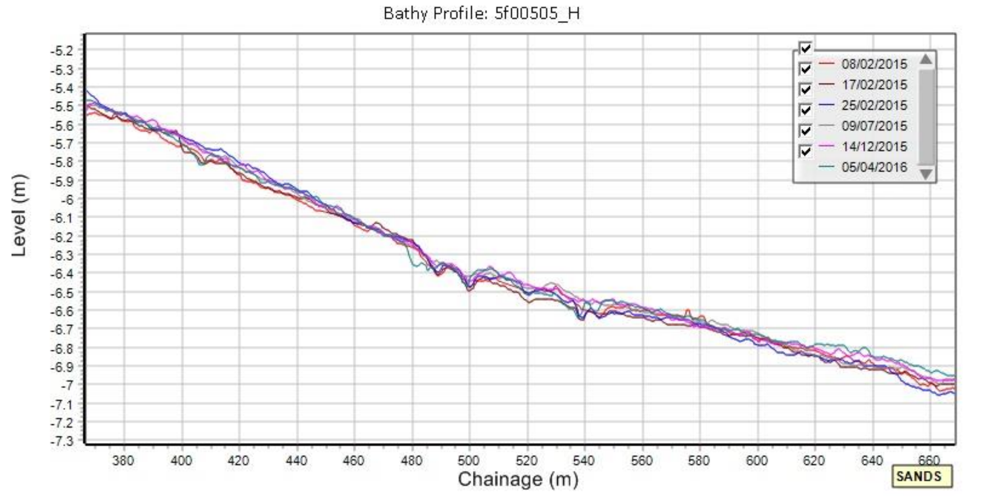
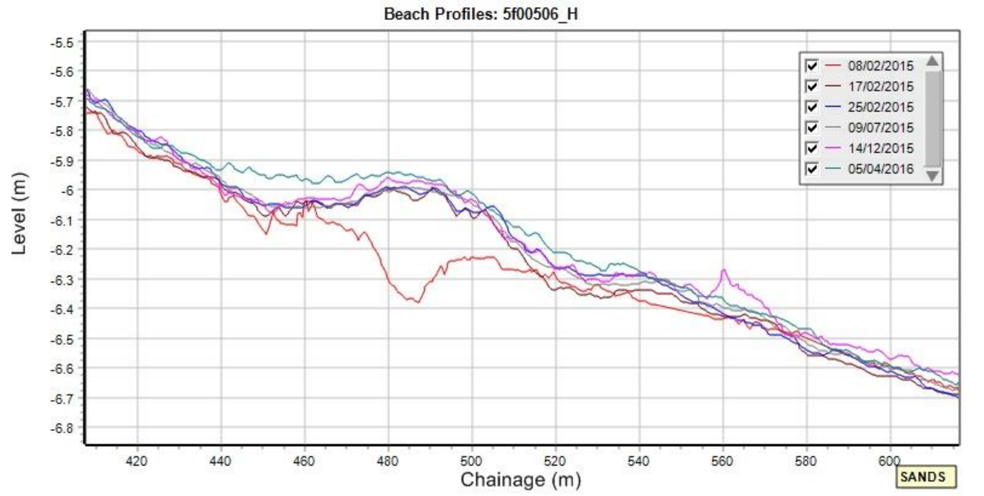
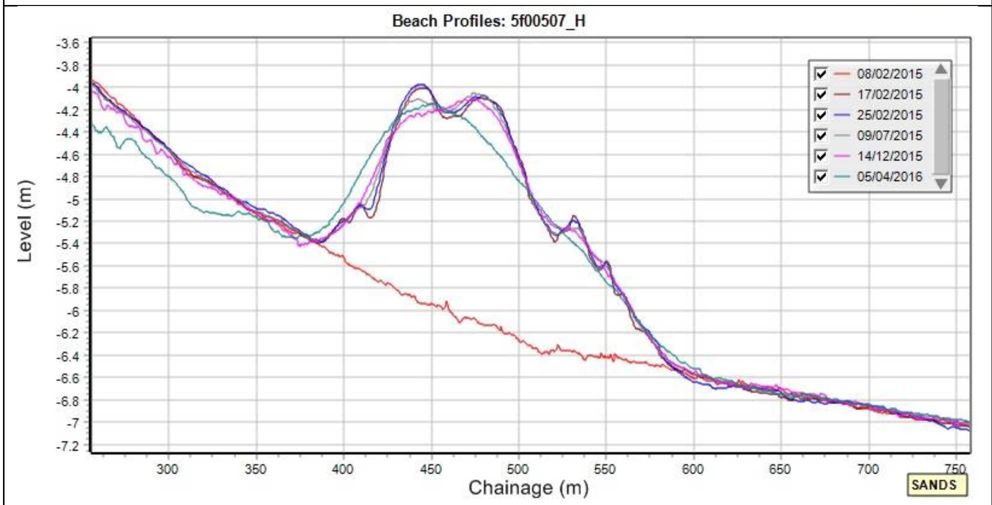
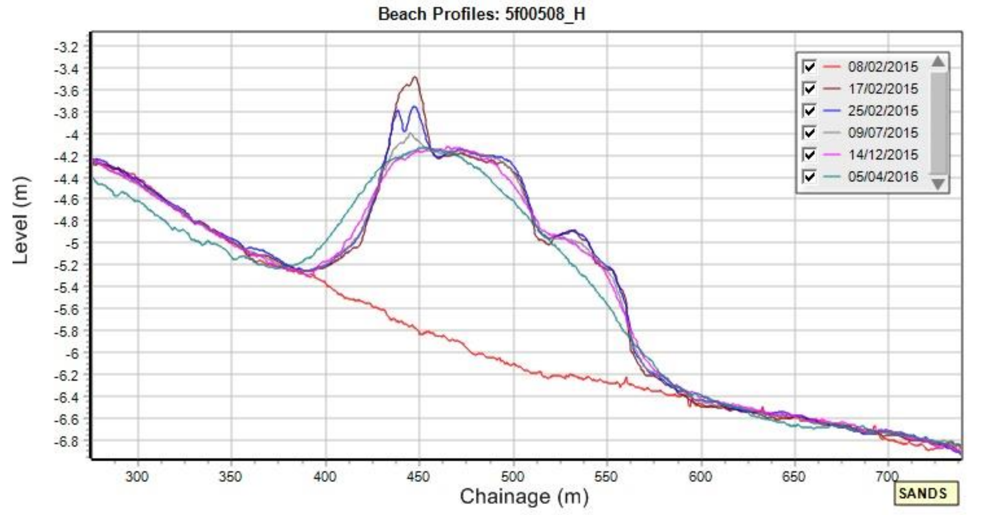


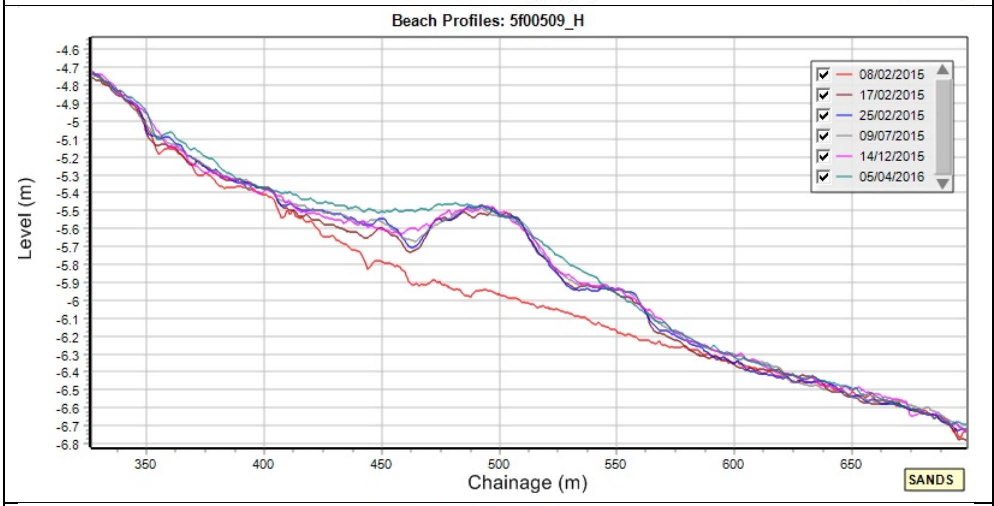
Figure C.1 Time series of survey-to-survey difference models of reduced beach survey area, March 2015 to April 2016

C.2 Bathymetry

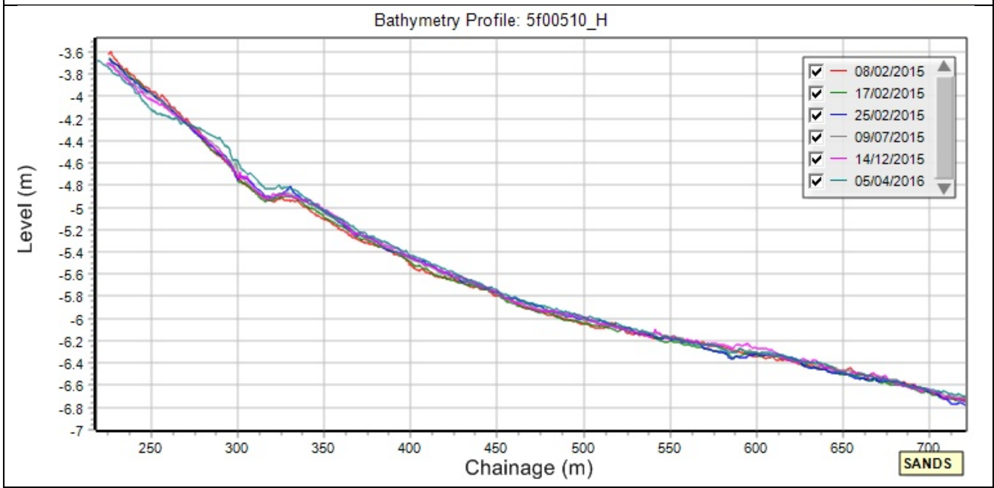
	East of mounds
	Eastern edge of mounds
	Central area of mounds



Central area of mounds



Western edge of mounds



West of mounds

Figure C.2 Time series of bathymetry profile graphs, spanning deposition mounds

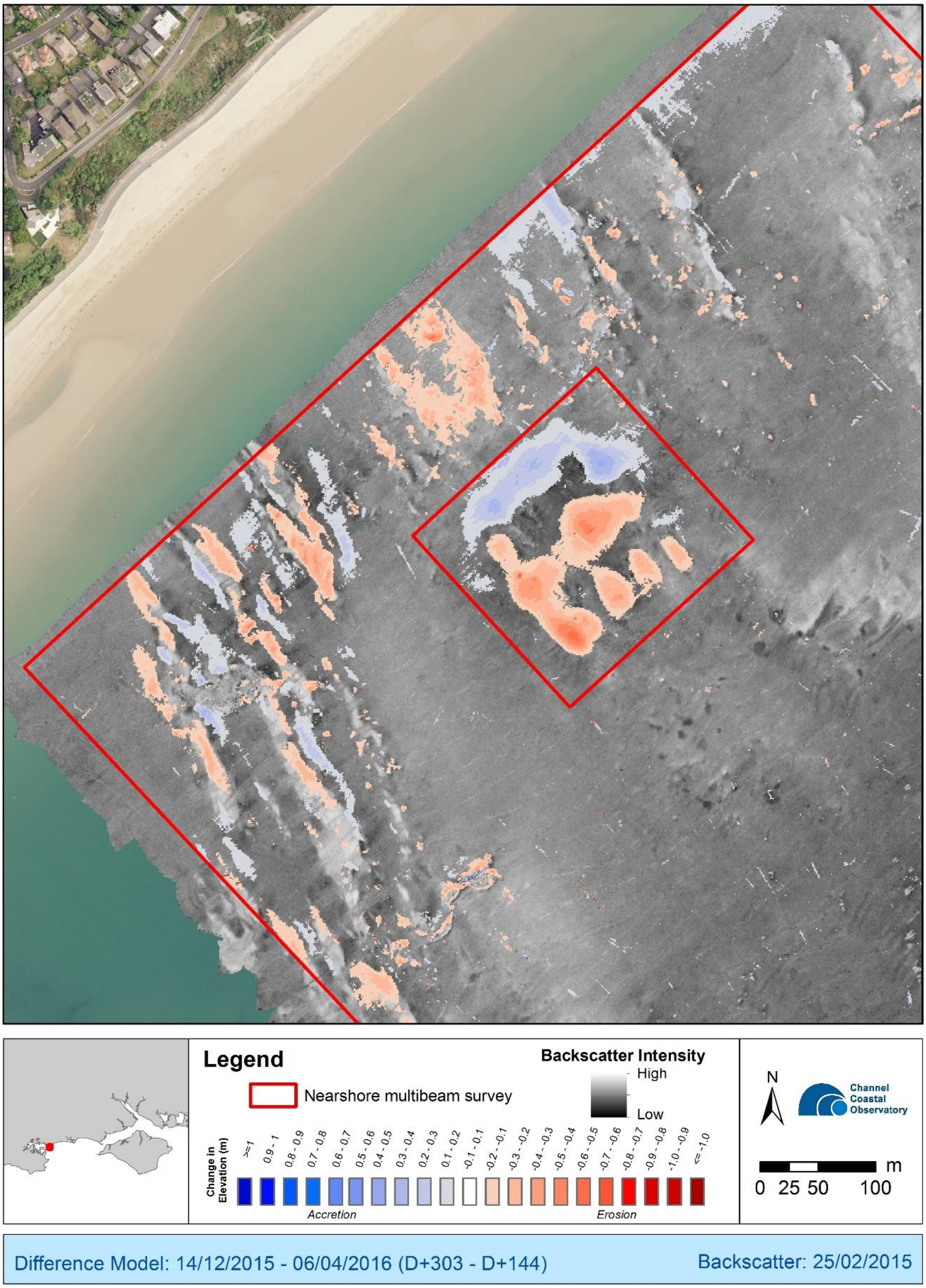


Figure C.3 Most recent difference model superimposed on earlier backscatter

C.3 Tracer study

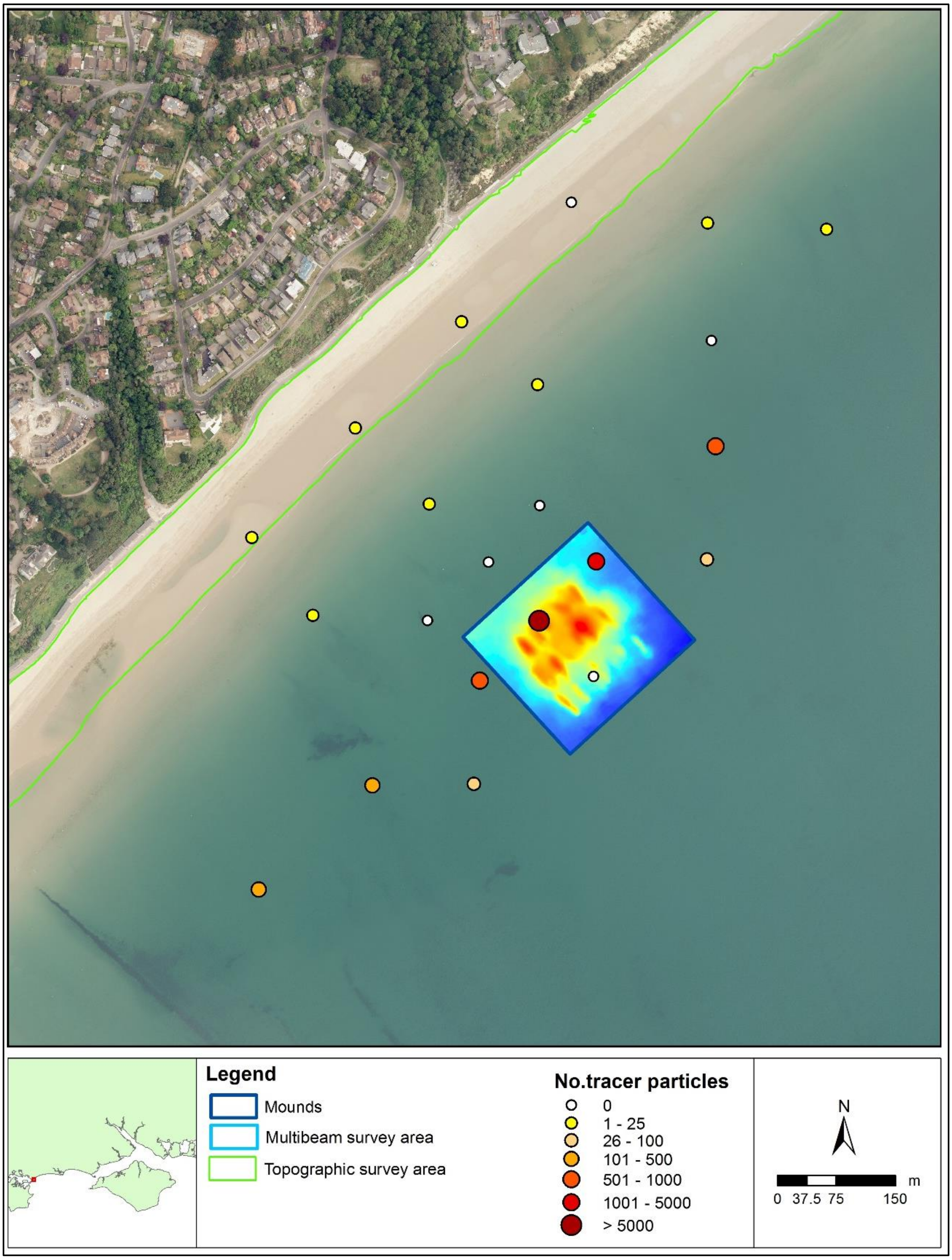


Figure C.4 Results of enumeration of Tracer Search 2

C.4 Hydrodynamics

C.4.1 Undertow

An explanation is provided for the depth-averaged mean currents observed on 1 to 2 January 2016. These coincided with the highest waves measured during the trial but were noticeably different to the pattern of currents measured during other storm periods (see Section 5.6 of the main report and Figure 5.19, reproduced below as Figure C.5). For a period of about 5 hours, the resolved depth-averaged current direction was in the south-east quadrant – the only occasion during the trial when this occurred. For the majority of the time, the currents were quite weak (~0.2ms^{-1}) but approaching 0.4ms^{-1} for about an hour during the flood tide.

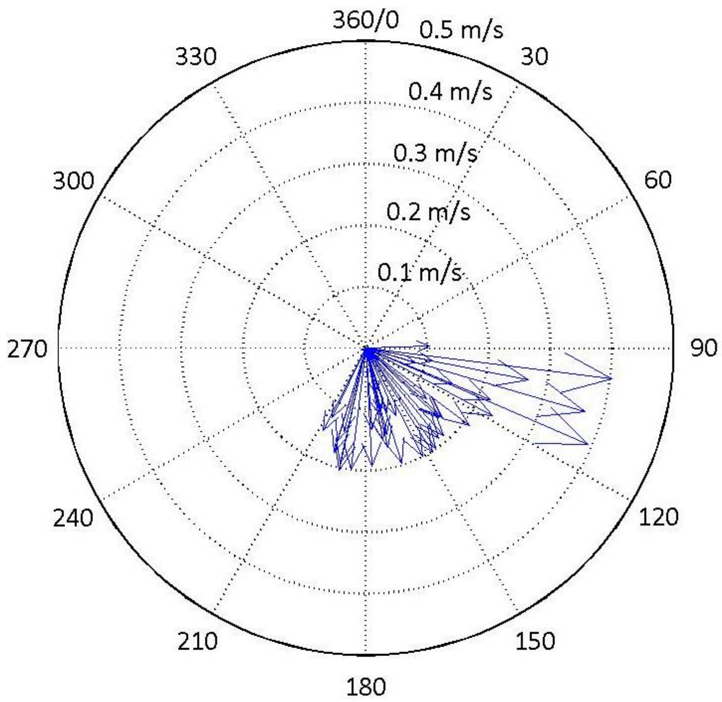


Figure C.5 Presence of undertow, 1 to 2 January 2016

A consistent mean offshore current of -0.2ms^{-1} started around low water, becoming stronger with the flood tide but accompanied only by a weak longshore/tidal current to the north-east (Figure C.6). As a result, the offshore current dominated the resolved current direction, which was towards the south-east.

The cross-shore mean current was directed offshore throughout the water column (at its strongest at Bin 3, 3.35m above the seabed), then weakening at Bin 4 (4.35m) and again by Bin 5 (5.35m). The expected onshore flow above the mean water surface could not be measured by the instrument since, by definition, it would be measuring air for half the time (that is, in the wave troughs). Since undertow by definition transports sediment offshore, it necessarily opposes onshore transport by wave-induced currents. Typically undertow is generally confined to the surf zone and is quite low velocity (0.05–0.5ms^{-1}).

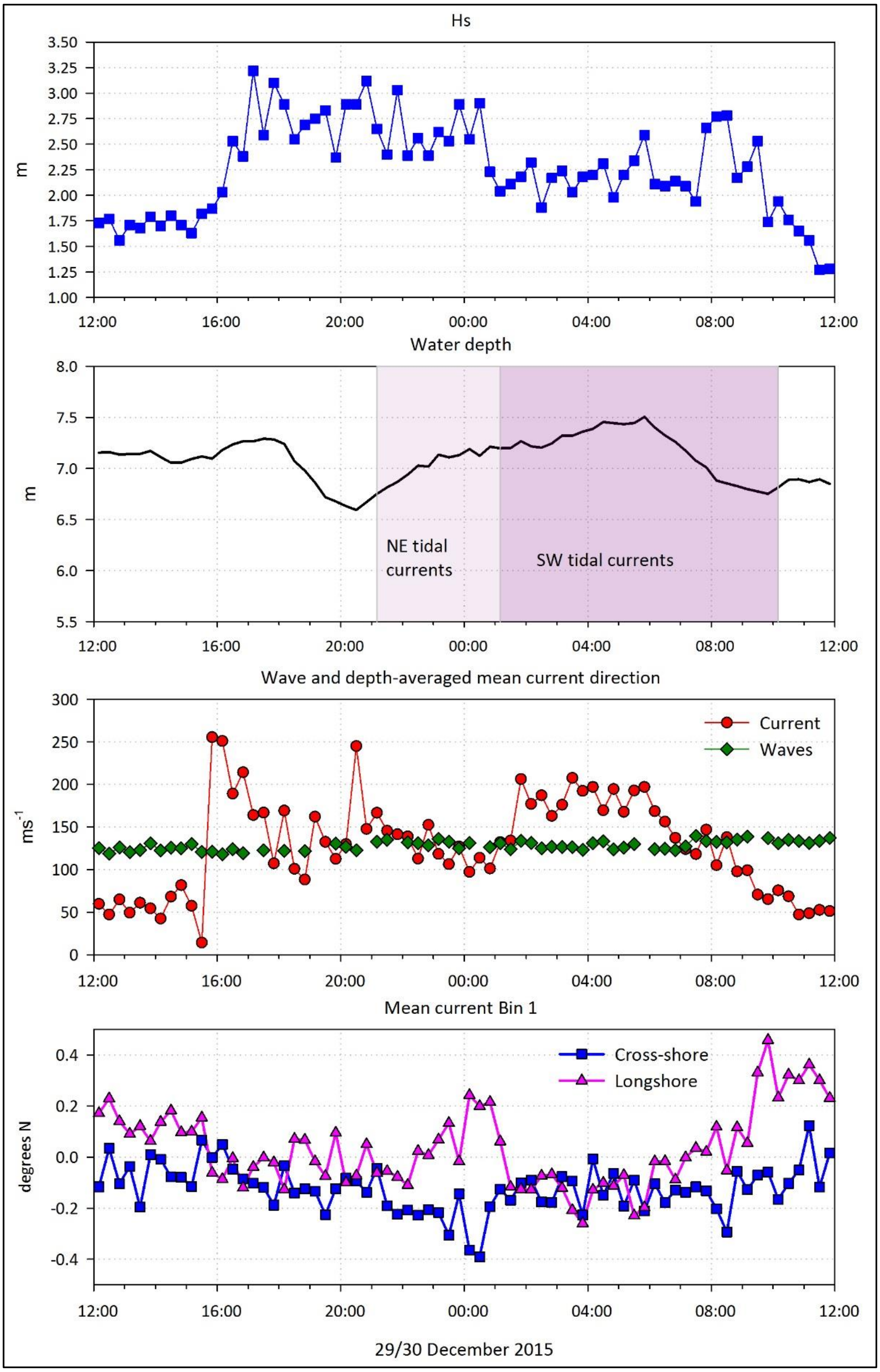


Figure C.6 Undertow event at Location 2, 1 to 2 January 2016

C.4.2 Waves

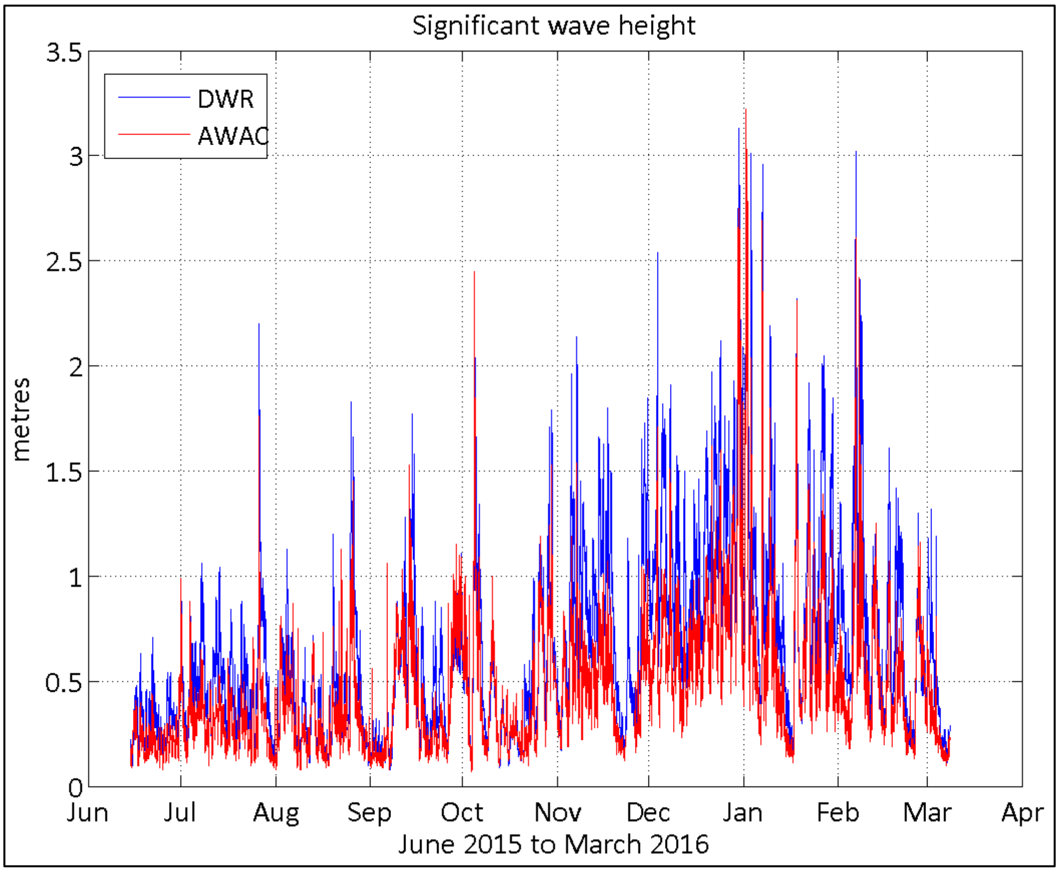


Figure C.7 Significant wave height at DWR and AWAC

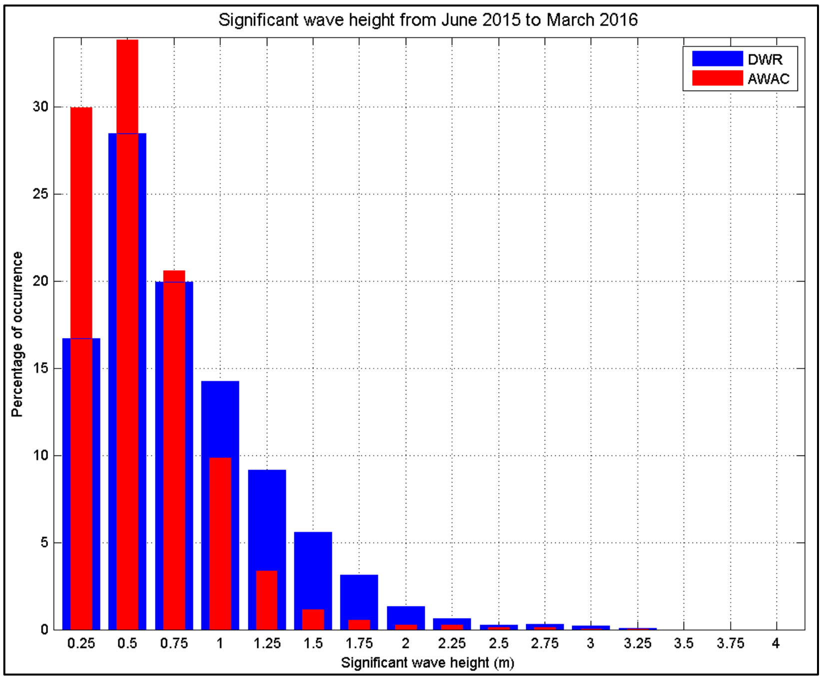


Figure C.8 Histogram of Hs for DWR and AWAC

Table C.1 Incidence of wave conditions at Location 1 (~8m CD)

Hs ≥	Tz ≥	No of occurrences	% of measurements	North	North-east	East	South-east	South	South-west	West	North-west
0.25	2	11,616	81.253	0.189	0.371	4.197	46.586	27.588	1.679	0.357	0.224
0.25	3	8,431	58.975	0.035	0.063	2.364	35.954	19.936	0.532	0.014	0.021
0.25	4	2,892	20.229	0.014	0.021	0.644	11.605	7.771	0.105	0.007	0.021
0.25	5	743	5.197		0.007	0.077	2.749	2.322	0.028		0.014
0.25	6	211	1.476			0.028	0.853	0.595			
0.25	7	52	0.364				0.196	0.168			
0.25	8	10	0.070				0.042	0.028			
0.25	9	3	0.021				0.014	0.007			
0.25	10	1	0.007				0.007				
0.5	2	5,012	35.059	0.007		1.168	21.447	11.472	0.804	0.077	0.028
0.5	3	4,373	30.589			0.958	19.635	9.667	0.280		
0.5	4	1,383	9.674			0.238	5.848	3.546			
0.5	5	307	2.147				1.126	1.021			
0.5	6	76	0.532				0.315	0.217			
0.5	7	29	0.203				0.119	0.084			
0.5	8	7	0.049				0.035	0.014			
0.5	9	2	0.014				0.014				
0.5	10	1	0.007				0.007				
0.75	2	1,923	13.451			0.364	8.611	4.043	0.385		
0.75	3	1,874	13.109			0.357	8.541	3.938	0.224		
0.75	4	665	4.652			0.133	3.043	1.434			
0.75	5	83	0.581				0.378	0.203			

0.75	6	15	0.105		0.063	0.042	
0.75	7	7	0.049		0.035	0.014	
0.75	8	3	0.021		0.021		
0.75	9	2	0.014		0.014		
0.75	10	1	0.007		0.007		
1	2	700	4.896	0.091	3.127	1.560	0.070
1	3	699	4.889	0.091	3.127	1.553	0.070
1	4	396	2.770	0.049	1.840	0.839	
1	5	38	0.266		0.175	0.091	
1	6	3	0.021		0.007	0.014	
1	7	2	0.014		0.007	0.007	
1	8	1	0.007		0.007		
1	9						
1	10						
1.25	2	234	1.637	0.028	1.063	0.504	
1.25	3	234	1.637	0.028	1.063	0.504	
1.25	4	200	1.399	0.028	0.965	0.364	
1.25	5	21	0.147		0.126	0.021	
1.25	6						
1.5	2	91	0.637	0.007	0.511	0.084	
1.5	3	91	0.637	0.007	0.511	0.084	
1.5	4	91	0.637	0.007	0.511	0.084	
1.5	5	13	0.091		0.084	0.007	

1.5	6				
1.75	2	35	0.245	0.168	0.042
1.75	3	35	0.245	0.168	0.042
1.75	4	35	0.245	0.168	0.042
1.75	5	5	0.035	0.035	
1.75	6				
2	2	9	0.063	0.028	0.007
2	3	9	0.063	0.028	0.007
2	4	9	0.063	0.028	0.007
2	5	1	0.007	0.007	
2	6				

C.5 Suspended sediment concentration

C.5.1 Turbidity relationships

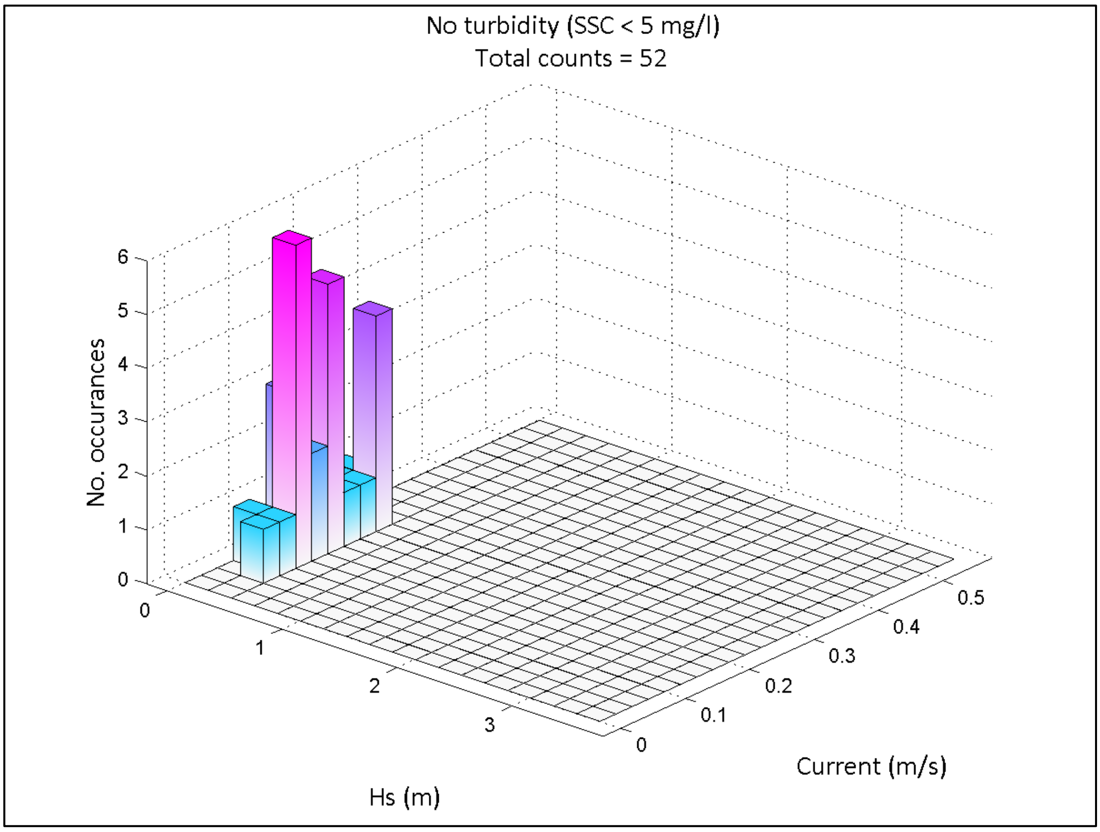


Figure C.9 Occurrence of 'no turbidity' at Location 1, November 2015 to March 2016

Scatter plots of instantaneous measured parameters can indicate whether or not there is likely to be some relationship between them. The following series of figures examines the potential relationship wave height and period on turbidity. The highest levels of SSC (150 to ~300mgl^{-1}) at Location 1 (end November 2014 to 20 May 2015) were experienced during 22 to 28 February, 2 weeks after completion of deposition (cyan stars on plots), when the hydrodynamic conditions were:

- Hs between 0.5m and 1m
- Tz typically 3–7s (4–5 s during highest SSC)
- Tp mostly 6–8 s
- wave direction between 110° and 160°
- depth-averaged mean currents 0.025–0.3ms^{-1}

Figure C.10 indicates that the minimum SSC increases linearly with wave height for Hs above 1.5m but, below that, there is no relationship between wave height and turbidity.

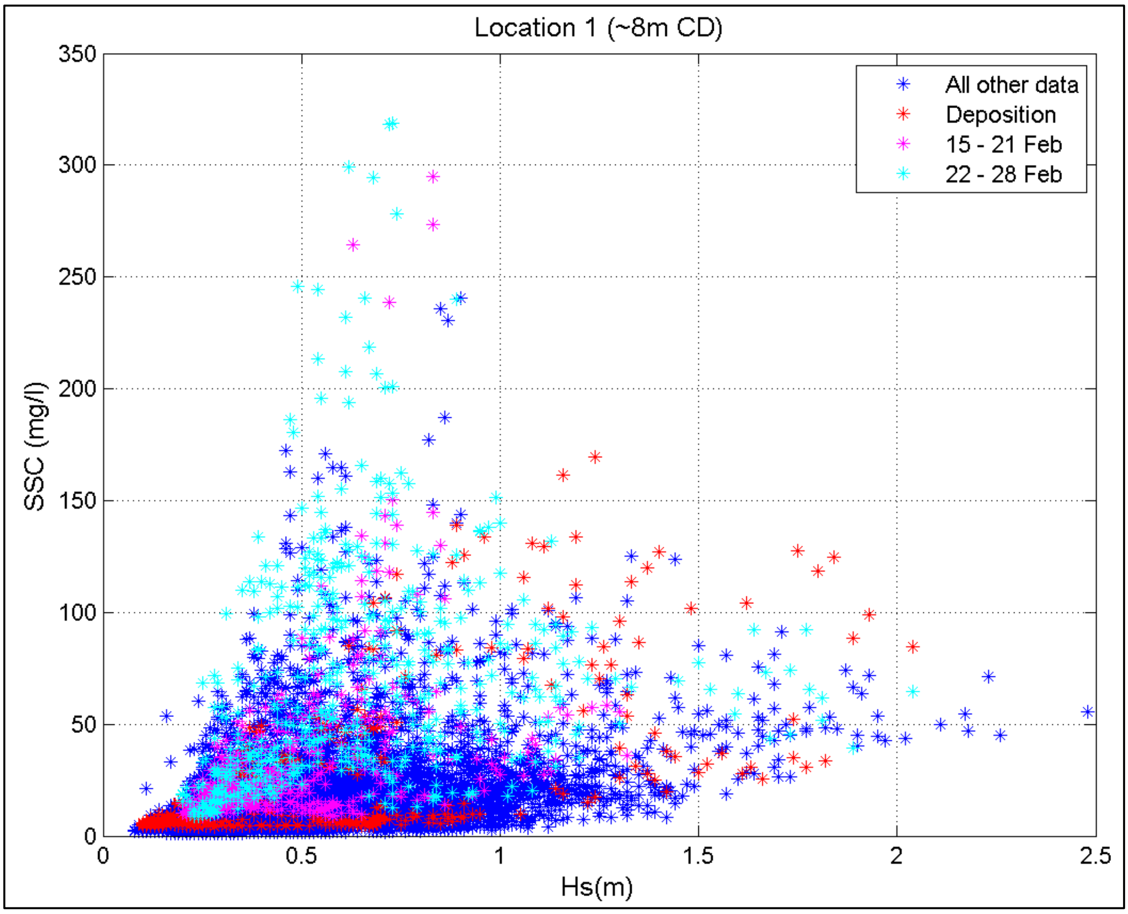


Figure C.10 XY plot of Hs and SSC

Furthermore, Figure C.11 to Figure C.14 show that there was no direct, linear relationship between individual instantaneous measurements of:

- Tp and SSC
- Tz and SSC
- wave direction and SSC
- depth-averaged mean current speed and SSC

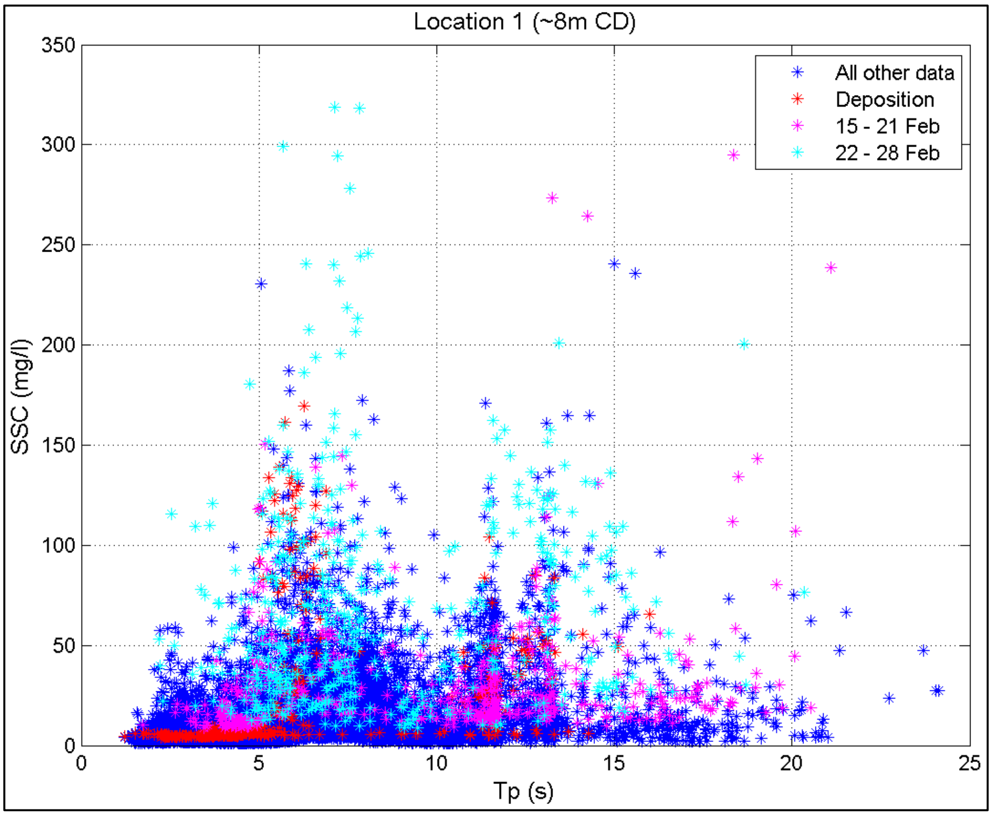


Figure C.11 Tp and SSC

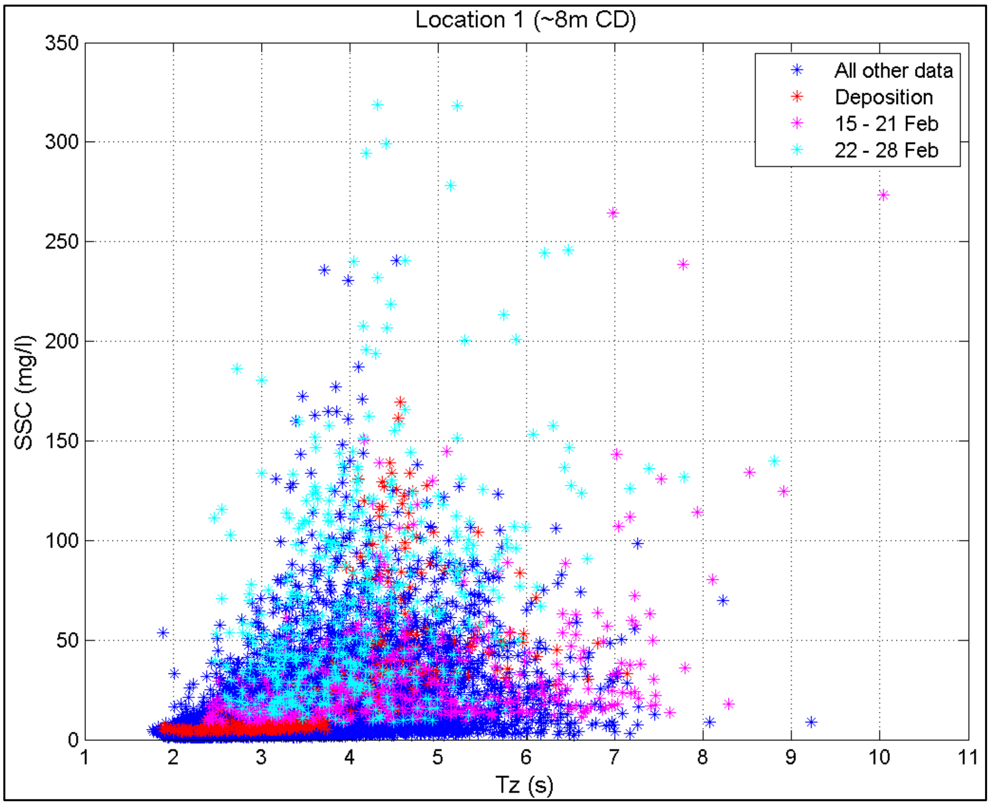


Figure C.12 Tz and SSC

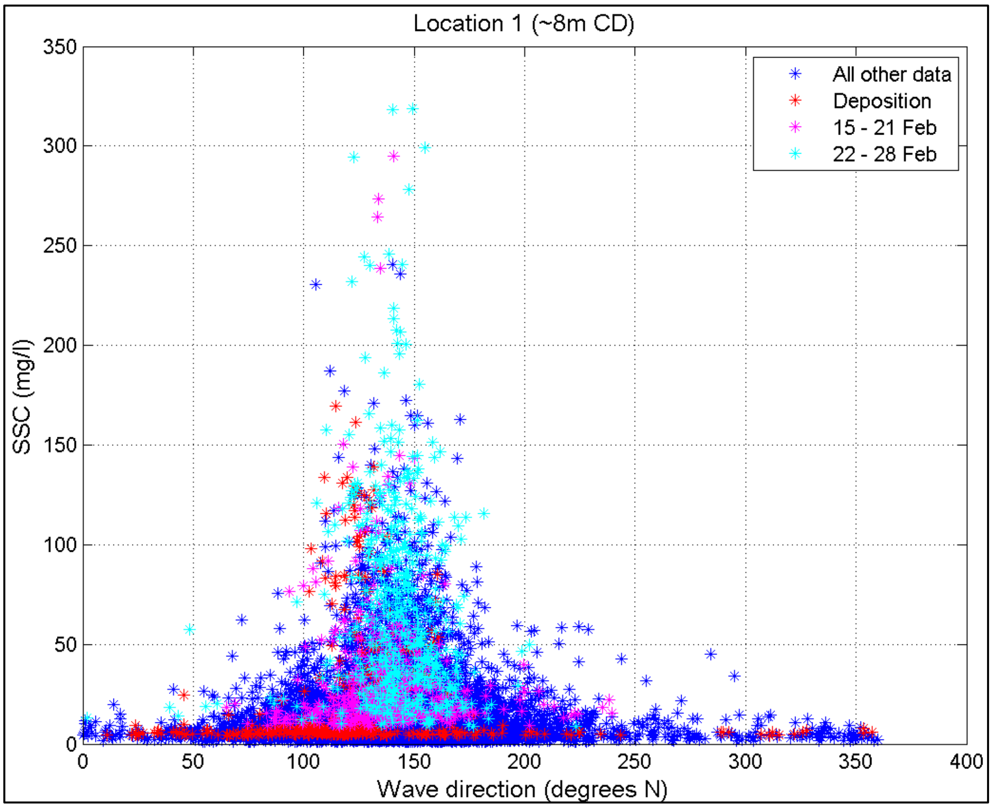


Figure C.13 Wave direction and SSC

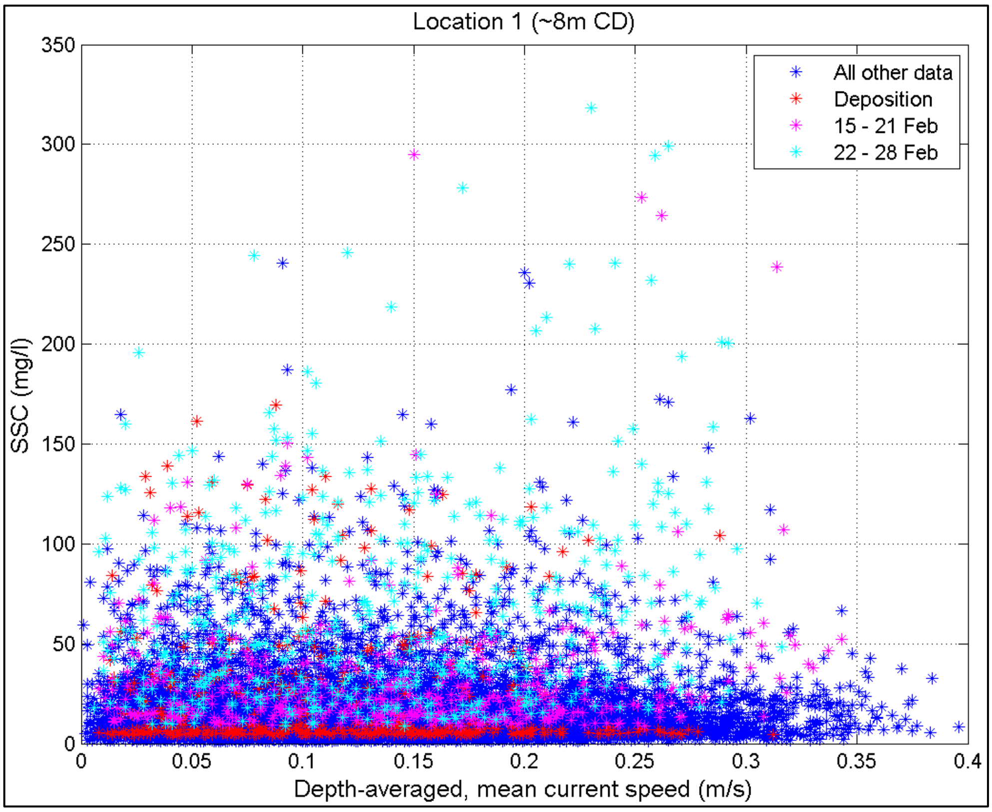


Figure C.14 Mean current and SSC

C.5.2 Settling rates

Settling rates were calculated following discrete suspension events, firstly for periods from the peak SSC (after which SSC decreased monotonically to ≤50mgl^{-1}), secondly for subsequent reduction in SSC to ≤20mgl^{-1} and finally for reduction to ≤5mgl^{-1}. In this way, settling rates can be derived for bulk sediment (that is, all sediment fractions in suspension, including the coarser fraction which will fall out of suspension first, and for the finer fractions which might be expected to remain in suspension longer than the coarser fraction) (Table C.1). By doing this for all suspension events, the average values can blur out any effect of hydrodynamic conditions.

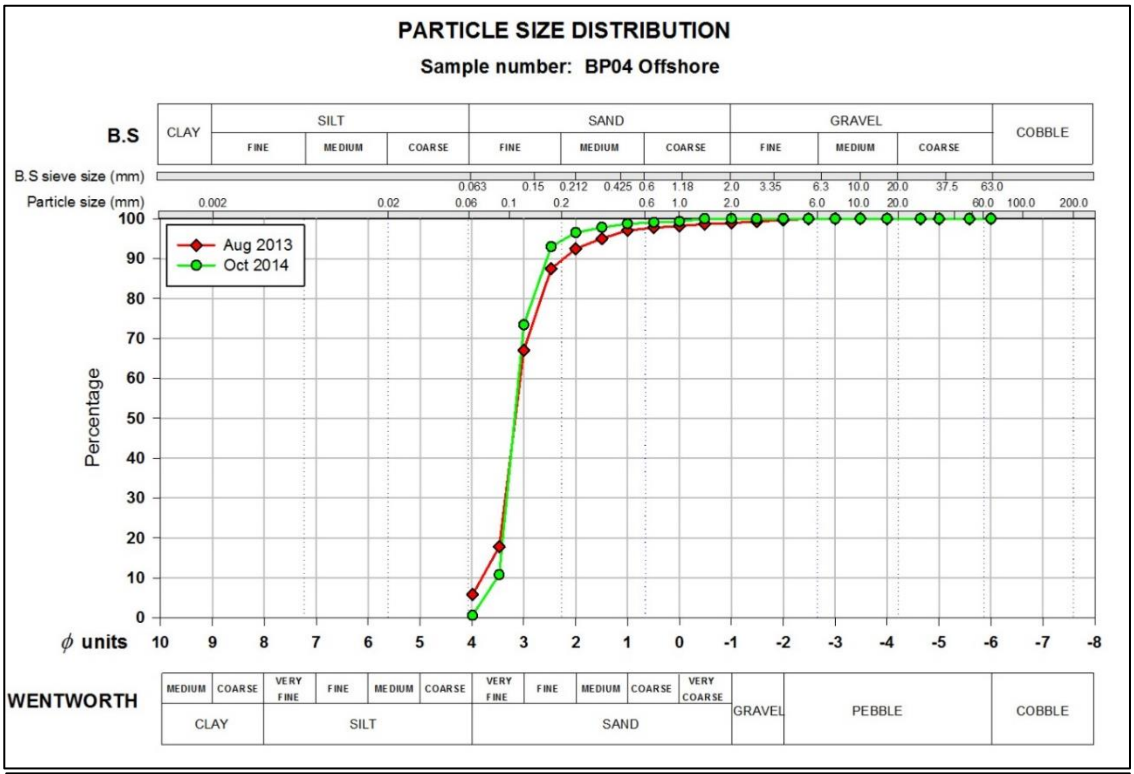
The sediment fall rate decreased exponentially with sediment concentration from 1.8mgl^{-1}min for high SSC and 0.4mgl^{-1}min for moderate turbidity to 0.2mgl^{-1}min for subsequent clearing of the water column from light to no turbidity.

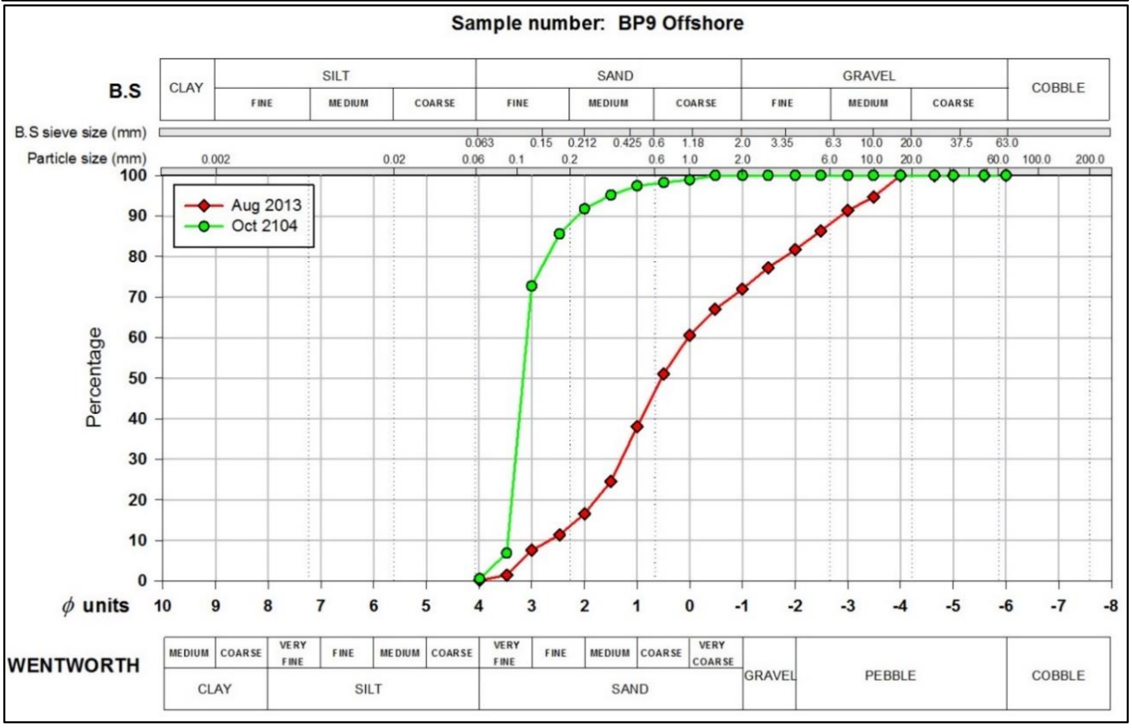
Table C.2 Settling rates for suspension events, Location 1

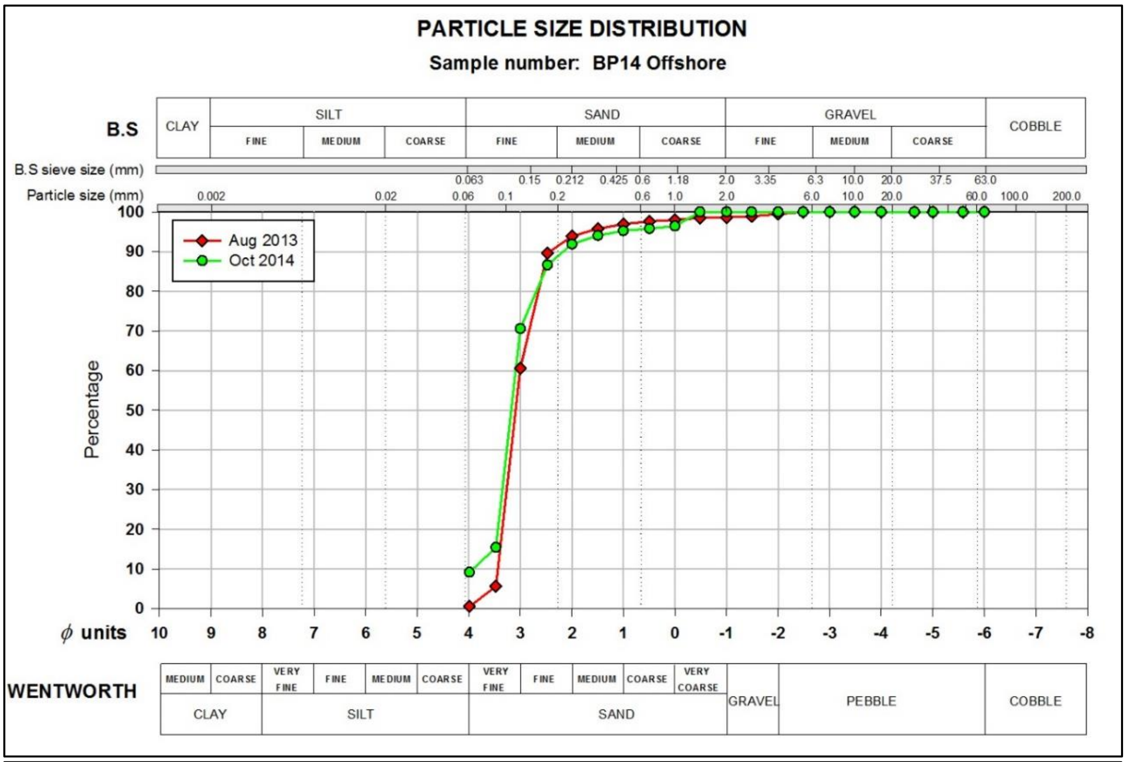
Date	Time of peak SSC	Peak SSC	Settling to ≤50 mgl^{-1}			Settling from <50 to ≤20mgl^{-1}			Settling from <20 to ≤5mgl^{-1}			Suspension event type
			Time reached <50mgl^{-1}	Elapsed time	Fall rate	Time reached <20mgl^{-1}	Elapsed time	Fall rate	Time reached <5mg/l	Elapsed time	Fall rate	
	GMT	mgl^{-1}	GMT	min	mgl^{-1}min	GMT	min	mgl^{-1}min	GMT	min	mgl^{-1}min	
10 December 2014	19:40	97	20:00	20	2.4	21:40	100	0.3				Moderate
11 December 2014	07:00	139	07:50	50	1.8	10:10	140	0.2				High
19 December 2014	22:10	85	22:30	20	1.8	00:00	90	0.3				Moderate
3 January 2015	23:10	67				00:20	70	0.7				Moderate
18 January 2015	09:50	58				10:20	30	1.3				Moderate
19 January 2015	21:50	46				23:10	80	0.3	00:00	50	0.30	Light
21 January 2015	12:30	230	13:40	70	2.6	15:20	100	0.3				High
22 January 2015	00:20	215	02:00	100	1.7	03:00	60	0.5				High
22 January 2015	13:10	163	13:40	30	3.8	14:20	40	0.8				High
27 January 2015	17:20	20							20:20	180	0.08	Light

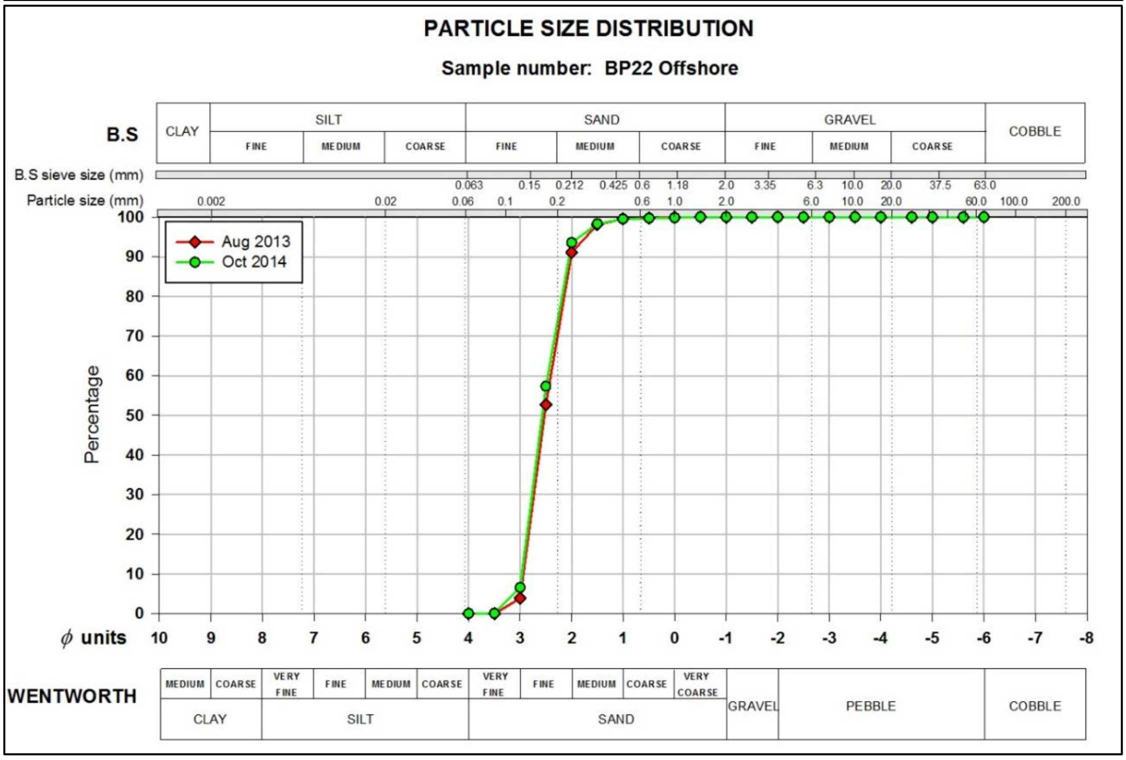
Date	Time of peak SSC	Peak SSC	Settling to ≤50 mgl^{-1}			Settling from <50 to ≤20mgl^{-1}			Settling from <20 to ≤5mgl^{-1}			Suspension event type
			Time reached <50mgl^{-1}	Elapsed time	Fall rate	Time reached <20mgl^{-1}	Elapsed time	Fall rate	Time reached <5mg/l	Elapsed time	Fall rate	
	GMT	mgl^{-1}	GMT	min	$mgl^{-1}min$	GMT	min	$mgl^{-1}min$	GMT	min	$mgl^{-1}min$	
6 February 2015	12:50	52				13:50	60	0.5				Moderate
7 February 2015	00:40	53				02:30	110	0.3				Moderate
16 February 2015	14:50	42				17:00	130	0.2				Light
17 February 2015	03:20	58				05:30	110	0.3				Moderate
17 February 2015	22:50	47				23:40	50	0.5				Light
18 February 2015	23:30	42				00:20	50	0.4				Light
22 February 2015	01:30	244	02:30	60	3	03:40	70	0.4				Moderate
25 February 2015	11:00	123	12:00	60	1							Moderate
26 February 2015	10:30	71	11:00	30	1	13:20	140	0.2				Moderate
2 March 2015	02:50	61	03:10	20	0.6	04:30	100	0.3				Moderate
19 April 2015	10:50	56				12:00	70	0.5				Moderate
19 April 2015	23:20	20							00:20	60	0.25	Light
Mean					1.8			0.4			0.21	

C.6 Particle size analysis






PARTICLE SIZE DISTRIBUTION
Sample number: BP14 Offshore
B.S
B.S sieve size (mm)
Particle size (mm)
Percentage
φ units
WENTWORTH
CLAY
SILT
SAND
GRAVEL
COBBLE
PEBBLE
Aug 2013
Oct 2014


PARTICLE SIZE DISTRIBUTION
Sample number: BP22 Offshore
B.S
B.S sieve size (mm)
Particle size (mm)
Percentage
φ units
WENTWORTH
CLAY
SILT
SAND
GRAVEL
COBBLE
PEBBLE
Aug 2013
Oct 2014

C.7 Discussion

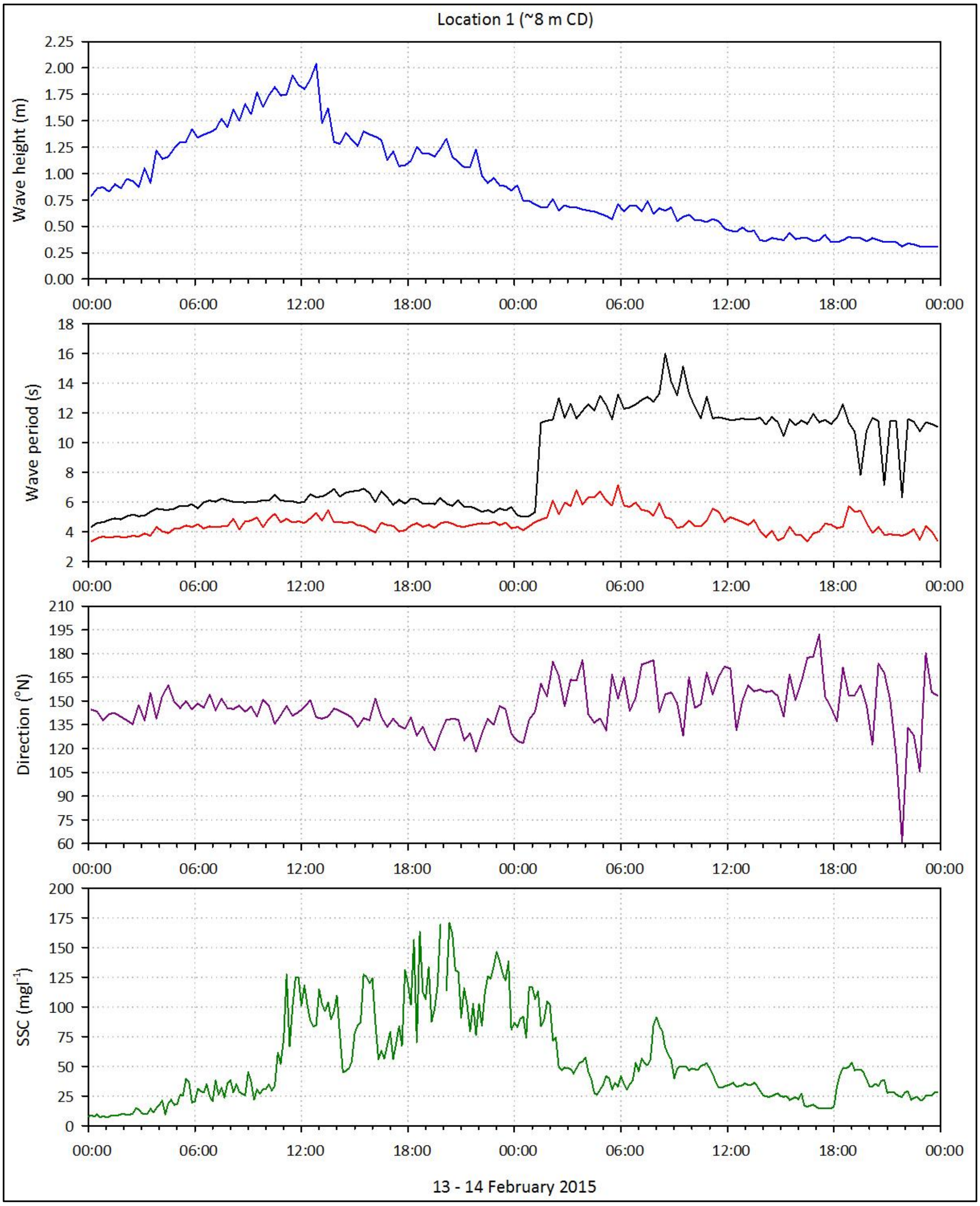


Figure C.15 Wave height, period (black = Tp, red = Tz) and direction, and SSC during onshore sediment transport event

Assumptions:

- Sediment mobilisation at the AWAC location is likely to mean mobilisation at the deposition site and shoreward
- No phase lag between mobilisation at AWAC and deposition site

That is, what is happening in terms of sediment suspension measured by the AWAC is representative of mobilisation events at the deposition site.

Table C.3 Anatomy of suspension event 12 to 15 February 2015

DTG (Z)	Hs (m)	SSC (mgl^{-1})	Tp (s)	Comments
12 February 18:10	0.5	<5	2	Hs reaches 0.5m; no swell; no turbidity
13 February 03:50	1.2	~15	6	Waves exceed 1m Hs; light turbidity; direction 120–140°
13 February 10:50	1.6	125	6	Rapid increase in SSC from ~30 to 120mgl^{-1}; high turbidity; moderate waves; no swell; weak currents <0.1ms^{-1}
13 February 12:50	2.0	85	6	Maximum Hs; high turbidity; no swell
13 February 13:30	1.6	104	6	Max current 0.29ms^{-1}, north-east; high turbidity; no swell
13 February 18:30	1.2	~160	6	Moderate waves; direction 100–120°, high suspension event; no swell
13 February 21:50	1.0	~100	6	Waves subsequently drop below 1m Hs; still high suspension; no swell
14 February 01:30	0.7	~100	11–15	Swell arrived; Hs starting very gradual drop off; still high turbidity
14 February 02:30	0.6	~50	11–15	Suspension events ceasing, gradual dropping of SSC; swell present
14 February 10:00	0.6	~25	11–15	Swell still present but Hs dropping further; SSC gradually dropping to below 50mgl^{-1}
14 February 12:00	0.5	<20	11	Waves ≤0.5m; swell present but only light turbidity
15 February 05:10	0.3	<15	5	Small waves; no swell; light turbidity sediment still settling out

So, in the absence of swell, wave heights need to approach 1m to initiate a moderate or high suspension event, but providing waves at or above this level persist for more than about 2 hours, turbidity increases rapidly and remains high even when wave heights subsequently reduce to around 0.6m. Interestingly, although the arrival of the swell may serve to help maintain moderate levels of turbidity (longer waves generating faster nearbed currents), in this case the swell did not appear to have any significant impact on the SSC in terms of putting sediment into resuspension. However, the combination of swell and ~0.5m waves clearly continued to disturb the water column, since without the presence of stirring forces, the suspended sediment would settle out to average levels within 2–3 hours rather than the 9–10 hours taken at the end of this suspension event. Furthermore, the swell is likely to have been a significant transporter of sediment, leading to an extended period (~10 hours) of longer run-up over the beach face.

Appendix D: Sedimentation studies, Poole Bay, 2014 to 2015

Dr Ken Collins, Ocean and Earth Science, University of Southampton

April 2016

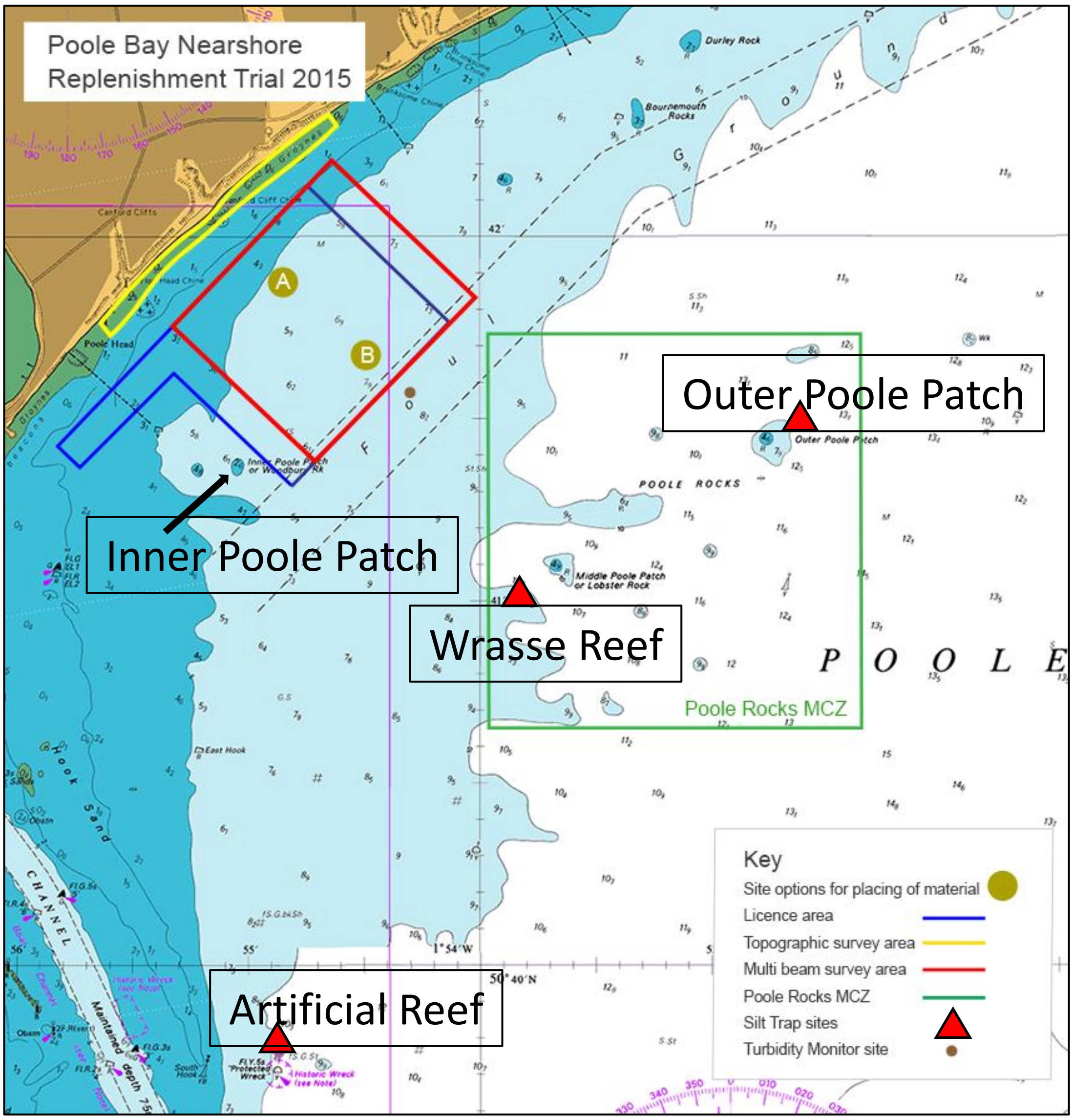


Figure D.1 Study locations

Source: http://www.poolebay.net/replenishment-trials.html

D.1 Summary

Two approaches were used:

- Monitoring of sediment traps at 3 sites, April 2014 to November 2015

- Monitoring of Inner Poole Patch biota pre- and post-replenishment, July 2014 and July 2015

In both cases no significant impacts were detected.

D.2 Sediment studies

All the fieldwork described below was carried out by scuba diving, with a core team of Health and Safety Executive (HSE) registered divers often supported by volunteer student and sport divers.

Sedimentation studies were conducted with pairs of sediment traps (vertical tubes 0.40m by 0.8m ID) (Figure D.2) at each of the 3 sites indicated in **Error! Reference source not found.**. Sediment (silt) traps were deployed on 4 April 2014 on Outer Poole Patch, Wrasse Reef and the Artificial Reef with 2 traps (at each site). These were recovered and replaced on 25 October 2014, 30 November 2014, 14 February 2105, 26 April 2015, 26 June 2015, 30 July 2015, 18 October 2015 and 22 November 2015.

Figure D.2 Diver preparing to replace sediment traps on the Artificial Reef, Poole Bay

At each site, 2 cylinders (0.3m long by 0.065m ID) were mounted vertically close to the seabed. The sites were by reefs, affording protection from disturbance by trawling or dredging, with the sediment traps simply attached to vertical steel posts with elastic cord and cable ties (Figure D.2**Error! Reference source not found.**). After recovery, the contents of the sediment trap were passed initially through a coarse 500μm sieve to remove large seaweeds and mobile fauna (crabs and molluscs) and finally washed through a 63μm sieve to collect the silt fraction. After settling and removal of supernatant liquid, this silt fraction was dried for 24 hours at 100°C. The dry silt weight was divided by the number of days deployed and scaled up from the trap cross-section to give a sedimentation rate ($mgm^{-2}day^{-1}$) which was averaged across the 3 sites, with 2 replicates at each site.

Figure D.3 shows the observed sedimentation rates against the beach recharge dates in November 2014 and nearshore deposition in February 2015. As can also be seen in Figure D.4 and Figure D.5, summer sediment rates are lower than winter ones when there is increased wave action re-suspending bottom sediments and river run-off bringing in new suspended material. High levels of sedimentation preceded the November recharge and there is no evidence that this caused elevated sedimentation. The same is true for the subsequent nearshore deposition event.

The sediment trap sites were chosen because they were continuously monitored from 2005 to 2009 as part of an Environmental Impact Assessment (EIA) study for Poole Harbour Commissioners (Collins 2010), providing an ideal baseline (Figure D.4). A notable feature (shown as *1 in Figure D.4) is the elevated sedimentation from February to April 2006, which the author attributes to sediment deposited during the winter of 2005 to 2006 on the offshore licenced dumping ground off Ballard Down, returning to inner Poole Bay.

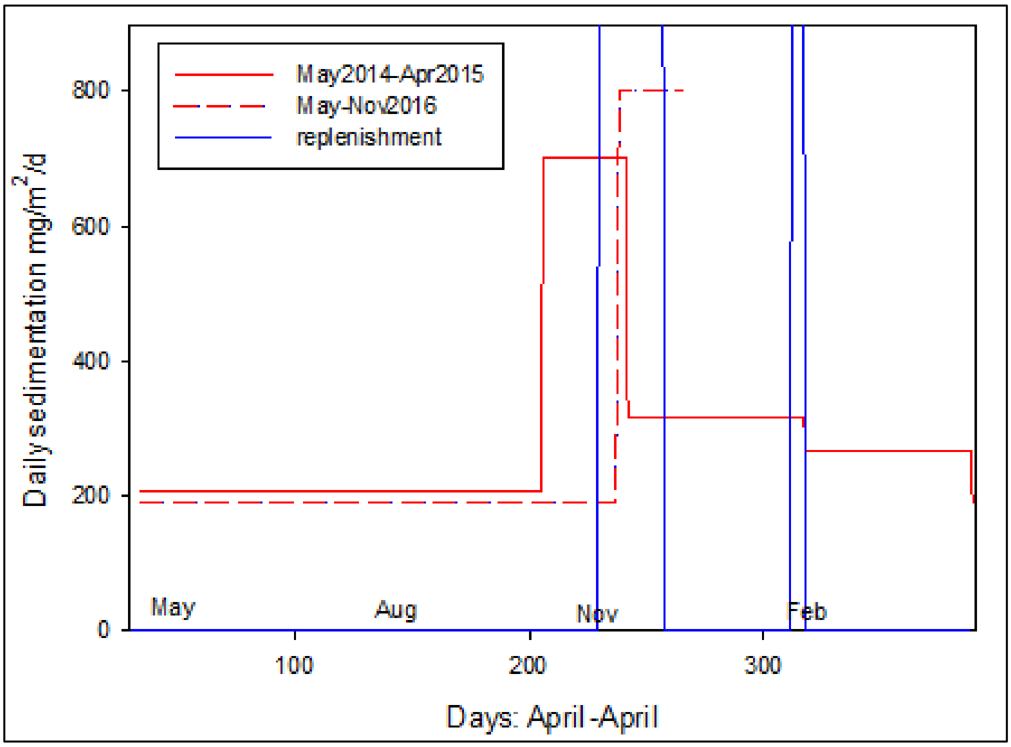


Figure D.3 Average observed daily sedimentation rates, May 2015 to November 2015

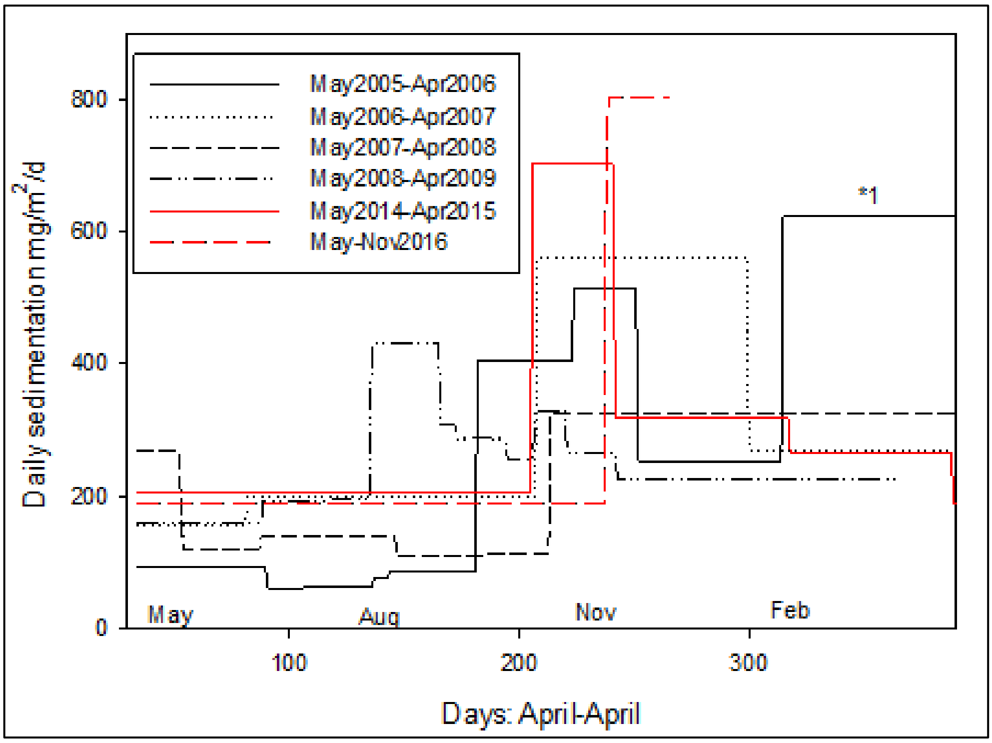


Figure D.4 Average daily sedimentation rates 2014 to 2015 (red) compared with those measured 2005 to 2009 (black)

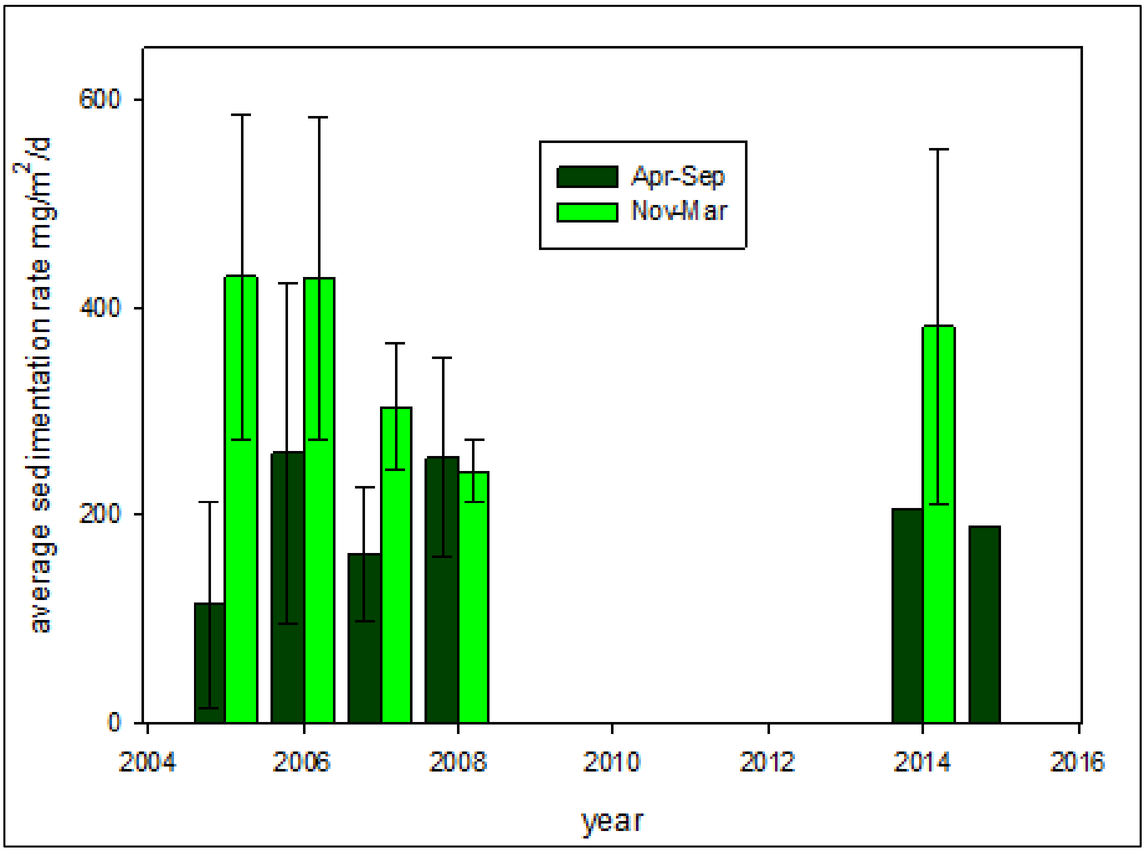


Figure D.5 Comparison of average (±1 standard deviation) summer and winter sedimentation rates, 2005 to 2015

Rigorous statistical analysis of the infrequent sedimentation data is difficult. Table D.1 presents the results of Kruskal–Wallis one-way analysis of variance on ranks, pairwise multiple comparison procedures (Tukey test) for the winter (November to March) data as significant ($P < 0.05$) or not significant (ns, $P > 0.05$).

Table D.1 Statistical analysis of sedimentation, November to March data

	2006 to 2007	2007 to 2008	2008 to 2009	2014 to 2015
2005 to 2006	ns	ns	ns	ns
2006 to 2007		ns	significant	significant
2007 to 2008			significant	ns
2008 to 2009				significant

Notes: Significant, $P < 0.05$; not significant (ns), $P > 0.05$.

The winter 2014 to 2015 rates are lower than those for 2005 to 2006 and 2007 to 2008, and higher than 2007 to 2008 (but not significantly) and 2008 to 2009 (significantly). Overall, there is no evidence for significantly raised level of winter or summer sedimentation rates during this study.

The Channel Coastal Observatory maintained a continuous optical backscatter recorder at the turbidity monitor site (see **Error! Reference source not found.**). The water column suspended sediment readings were averaged over the concurrent sediment trap deployments and compared (Figure D.6). The results show a surprisingly high correlation between water column levels and net sedimentation.

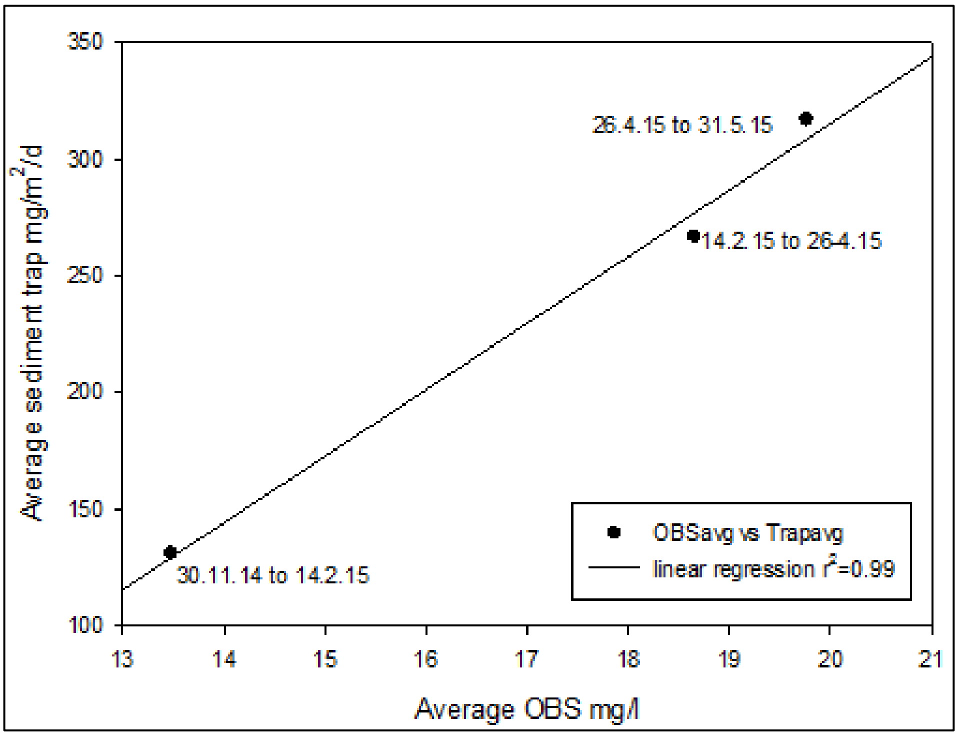


Figure D.6 Plot of average optical backscatter results with the observed sedimentation rates, November 2014 to May 2015

D.3 Inner Poole Patch biota

Poole Bay is noted for its patch reefs, some of which are contained within the Poole Rocks MCZ (**Error! Reference source not found.**). Inner Poole Patch, closest to the replenishment works, is a small (70m long × 10m wide × 2m high) reef in 5m water depth. One of the potential impacts of increased sedimentation arising from beach replenishment could be increased silt thickness on Poole Bay reef surfaces which, in turn, may adversely affect sessile fauna and flora growth.

A biological pre-survey was conducted on 30 July 2014 and a post-survey on 28 July 2015. On each occasion over 50 photographs (A4 size photo-quadrats) were taken randomly along a transect of the reef of horizontal and vertical surfaces for analysis of percentage cover by major taxonomic groups using Coral Point Count with Excel extension (CPCe). The image size was dictated by the limited visibility in Poole Bay and the need to for detail to identify the organisms. Since the reef is shallow, the cover was predominantly algal dominated by red species: *Cryptopleura ramose, Phyllophora pseudoceranoides, Phyllophora pseudoceranoides* and *Rhodomenia pseudopalmata.* On vertical surfaces, the foliose bryozoan *Chartella papyracea* and *Flustra foliacea* were the most common faunal species – hence the analysis below. Figure D.7 shows a comparison of the extent of horizontal and vertical coverage found by the 2 surveys.

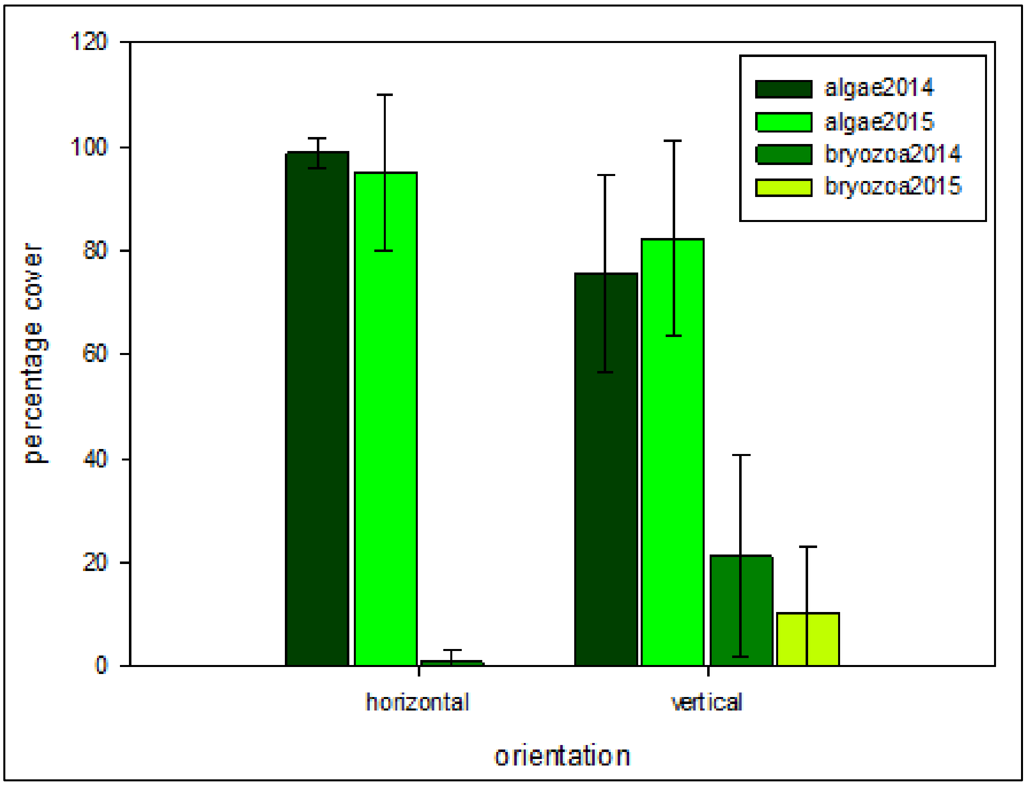


Figure D.7 Comparison of average (±1 standard deviation) cover by algae and bryozoa on horizontal and vertical surfaces

There is no significant difference between algal cover on both horizontal and vertical surfaces 2014 to 2015 (Table D.2). There appears to be a decline in bryozoan cover in 2015, but this likely to be due to a corresponding increase in algae overgrowing them.

Table D.2 Mann–Whitney rank sum test of algal and bryozoan cover on horizontal and vertical surfaces, 2014 to 2015

		Algae 2015		Bryozoa 2015	
		Horizontal (n = 26)	**Vertical (n = 29)**	**Horizontal (n = 26)**	**Vertical n = 29)**
Algae 2014	**Horizontal (n = 21)**	0.586			
	Vertical (n = 22)		0.186		
Bryozoa 2014	**Horizontal (n = 21)**			0.119	
	Vertical (n = 22)				0.023*

Notes: Shows sample size and *P* values (* denotes significant difference).

The Poole Bay Patch reefs are valued for their diversity and species were recorded in both years (Table D.3), with no loss of species noted in 2015.

Table D.3 Species recorded on Inner Poole Patch

Phylum	Group	Species	English name	Abundance
PERIFORA	sponges	*Amphilectus fucorum*	shredded carrot sponge	r
		Dysidea fragilis		r
		Hymeniacidon perleve		o
		indet.	sponge crust	o
CNIDARIA	hydroids	*Laomedea* sp.		
ANNELIDA	worms	*Bispira volutacornis*	twin spiral worm	r
		Pomatoceros sp.	keel worm	o
CRUSTACEA	barnacles	*Cirrepdia indet.*	barnacles	f
	crabs	*Necora puber*	velvet swimming crab	o
MOLLUSCA	sea slugs	*Elysia viridis*		p
	gastropods	*Crepidula fornicata*	slipper limpet	f
		Gibbula cineraria	grey topshell	r
		Rissoa parva		p
BRYOZOA	foliose	*Amathia lendigera*		p
		Bowerbankia cf pustulosa		o
		Chartella papyracea		o
		Flustra foliacea	hornwrack	o
	encrusting	*Electra pilosa*		f
		indet.	orange bryozoan crust	o

Phylum	Group	Species	English name	Abundance
		indet.	red bryozoan crust	f
TUNICATA	seasquirts	*Aplidium punctum*		o
		Botryllus schlosseri	star ascidian	p
		Corella eumyota		r
		Polycarpa sp.		r
		Styela clava	leathery sea squirt	r
	didemnids	*didemnidae indet*		o
PISCES	fish	*Crenilabrus melops*	corkwing wrasse	o
		Ctenolabrus rupestris	goldsinny wrasse	o
		Gobiusculus flavescens	two-spot goby	f
		Labrus bergylta	ballan wrasse	o
		Parablenius gattorugine	tompot blenny	o
		Syngnathus acus	greater pipefish	r
		Trisopterus luscus	pout	f
ALGAE	green	*Cladophora pellucida*		r
		Cladophora sp.		p
		Ulva lactuca	sea lettuce	o
		Ulva sp.		r
	brown	*Dictyopteris membranacea*		o
		Dictyopteris polyp		o
		Saccharina latissima (juvenile)		r
		Saccorhiza polyschides		r
		Sporochnus pedunculatus		r
		Taonia atomaria (epiphytic)		r
	red	*Aglaothamnion byssoides (= tenuissimum)*		c
		Asparagopsis armata falkenbergia phase		o
		Bonnamaisonia asparagopsis		r
		Brongniartella byssoides		o
		Calliblepharis ciliata		c
		Callophyllis laciniata		o
		Ceramium sp.		p

Phylum	Group	Species	English name	Abundance
		Chondrus crispus		o
		Compsothamnion thuyoides		p
		Cryptopleura ramosa		f
		Dasya pumicosa		o
		Dudresnaya veerticillata		o
		Gracilaria sp.		r
		Hypoglossum hypoglossoides		o
		Monospora pedunculata		f
		Naccaria wiggii		r
		Phyllophora crispa		o
		Phyllophora pseudoceranoides		f
		Plocamium cartilagineum		o
		Rhodomenia pseudopalmata		f
		Rhodophyllis divaricata		o
		Sphondylothamnion multifida		c
		Spyridia filamentosa		a

Notes: Abundance recorded using the ACFOR scale: a = abundant; c = common; f = frequent; o = occasional; r = rare; p = present.

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