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POOLE BAY NEARSHORE REPLENISHMENT TRIAL

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Abstract

The paper describes the results of the first nearshore beach replenishment trial in the UK, using beneficial dredging material from an adjacent harbour to deposit sediment in the nearshore zone. Previously, repeated beach replenishment schemes used sediment transported from offshore sources pumped ashore and redistributed by plant. An extensive marine tracer study showed that sediment deposited in 5 – 7 m water depth can reach the adjacent shoreline, but the majority of the sediment remained in situ for the two years following the deposition. Long-term turbidity and current measurements provided baseline data. The Trial was confined in both volume and extent by environmental restrictions due to a newly-designated Marine Conservation Zone in Poole Bay. Evidence from the monitoring demonstrated that the deposition had no detrimental effect on the MCZ.

Key words: hydrodynamics, sediment transport, morphodynamics, beach replenishment, turbidity, tidal currents

1. Introduction

Beach replenishment in the UK is a long-standing soft engineering solution to management of eroding beaches, and is typically conducted either by pumping or rainbowing material ashore and re-distributing the sediment using heavy plant. The Poole Bay Nearshore Replenishment Trial was the first experiment in England to deposit material in the nearshore zone – The Netherlands style – to allow waves and currents to distribute the sediment shorewards eventually to replenish the beach.

The opportunity for beneficial use of dredging material from Poole Harbour offered a number of incentives: typical beach replenishment in Poole Bay costs £12.30/m^3, compared with £2.70/m^3 for the nearshore trial method; no need for beach pipeline operations thus reducing health and safety and public amenity issues; the sediment is locally-derived therefore likely to be closer to natural sediment properties, and here the sediment source is sustainable with further smaller amounts available for regular "top up"; the dredging material would otherwise have been deposited in a licenced disposal site much further offshore and hence lost to the sediment sub-cell. Furthermore, the interests of coastal engineering dovetailed with the use of beneficial dredging material which is a matter of active topical interest in the UK for coastal engineers, DEFRA, the Crown Estate and the dredging industry (Marine Management Organisation, 2014).

Due to the proximity of the recently-designated Poole Rocks Marine Conservation Zone (MCZ), 1 km to seaward of the Trial site, the UK's regulatory Marine Management Organisation (MMO) required an intensive fieldwork campaign to monitor the dispersal of the sediment as a condition of the deposition licence, notably to assess any effect on silt deposition near the MCZ, to account for the possibility of additional fine sediment smothering the maerl beds. Licence conditions also restricted the volume of deposited material to 30,000 m^3.

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The aims of the monitoring programme were to establish whether there is a sediment connection between the nearshore and the beach, of sufficient quantity to employ the nearshore replenishment technique in place of traditional methods, and to dispel or otherwise, environmental concerns for the effect of the replenishment on Poole Rocks MCZ.

2. Field site and monitoring methodology

Poole Bay is unique along the south-central coast of England, being both sandy and micro-tidal. The field site is afforded some shelter from prevailing south-westerly winds, by Durlston Head; the beach frontage is heavily managed with seawalls, rock groynes and regular large scale beach replenishment. During the Trial, 30,000 m^3 of dredged material was deposited into a 150 m^2 box on the 5 m CD contour (Figure 1).

The Trial monitoring schedule comprised regular laser scan topographic surveys of a 1 km length of adjacent beach, repeated swath bathymetry surveys, an extensive sub-tidal tracer study, aerial video of the sediment plume and sediment grab sampling. The forcing parameters were measured by a Nortek AWAC and co-located OBS supplemented by an existing Datawell Directional Waverider buoy in 10m CD water depth about 1 km to the southeast of the deposition site.

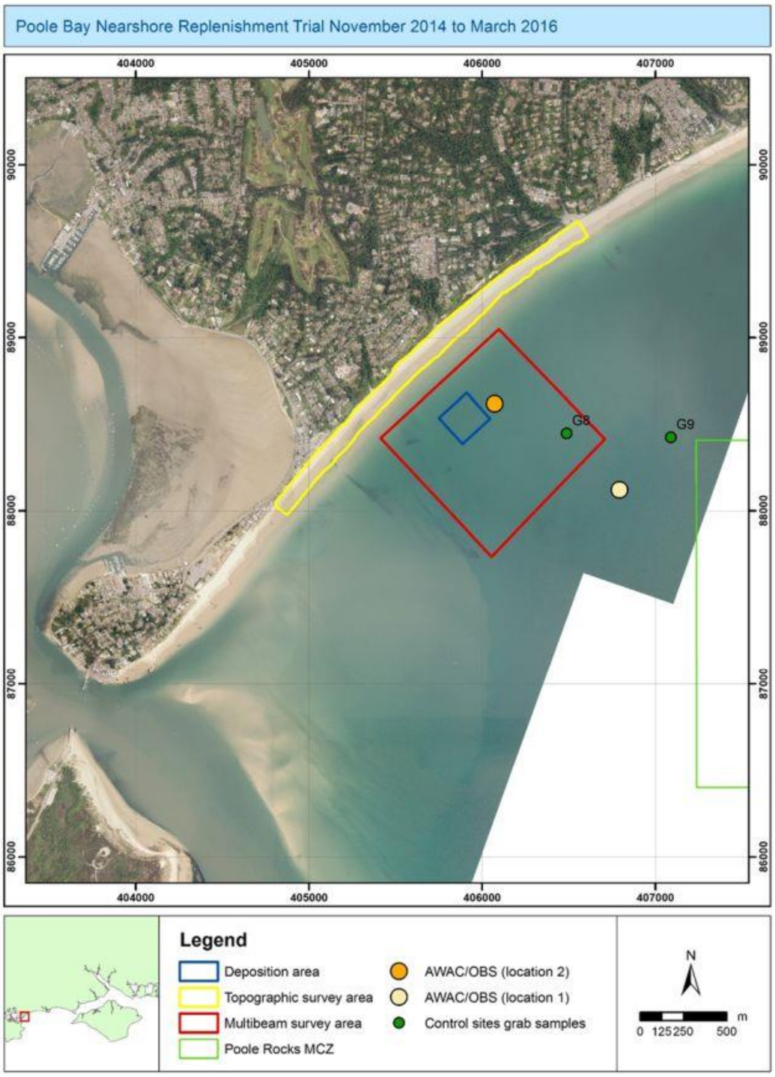

Figure 1. Field site and instrumentation

Fieldwork started 3 months prior to the sediment deposition in February 2015 and continued until April 2016, thus spanning two winter periods. The majority of the 8 topographic and bathymetry surveys were concentrated in the first 6 weeks following the deposition to account for the possibility that the material would disperse rapidly. Given the requirement to monitor potential effect of the deposition on sedimentation at Poole Rocks MCZ, the AWAC was located in its offshore position adjacent to the MCZ (8 m CD contour) for the first six months of data collection, after which Natural England agreed that sufficient data had been collected to set the Trial turbidity results into the context of naturally-derived turbidity. Subsequently, the AWAC was moved to the 5 m CD contour, adjacent to the deposition mounds for the remainder of its deployment.

A marine tracer study was conducted to track the short-term movement of sand particles from the deposition site. The tracer material was chosen to match the natural sediment size distribution as closely as possible. One tonne (the maximum allowed by the MMO) of yellow fluorescent painted marine-grade sand, treated for hydrophobic properties, was placed on top of the mounds of deposited sediment. The first sub-tidal sweep took place 3 days afterwards, following a spell of onshore winds, and a second sub-tidal search 4 days later. Grab samples were taken along four shore-parallel transects approximately 100 m apart, with samples continuing along the transect until no tracer could be detected. Control grabs were also taken at 2 positions between the deposition and the MCZ. Beach samples were taken at the location of Low and High Water.

3. Results

3.1. *Hydrodynamics*

The tidal regime is complex, with a small tidal range (2 m) and double High Waters. The pattern of tidal currents along the 8 m and 5 m CD contours was broadly similar, although weaker and more shore-parallel at the shallower location. Mean currents at 8 m CD were strongly asymmetric but generally weak and sufficient to mobilise sediment only during the ebb on large spring tides (Figure 2).

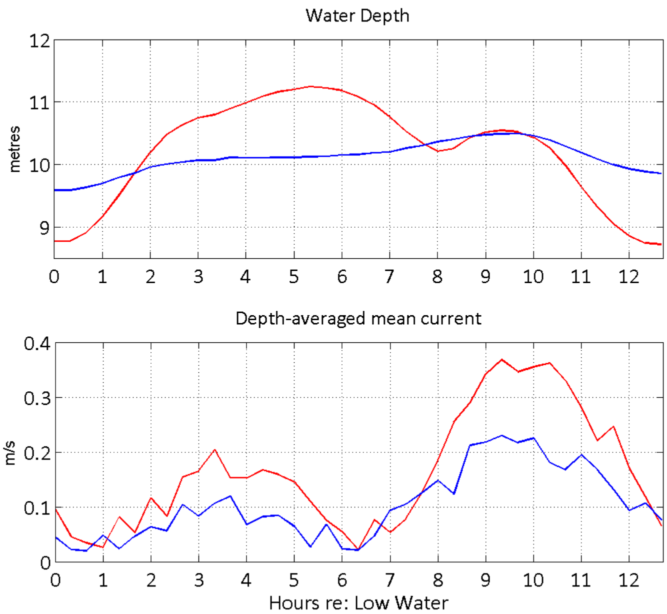

Figure 2. Water depth (top) and mean current (bottom) during equinoctial spring (red) and neap (blue) tidal cycles

Flood currents are directed northeastwards from 2 hours before High Water, whilst ebb currents persisted for nearly 10 hours (Figure 3), with the result that any net sediment transport by tidal currents alone is towards the SW *i.e.* in the opposite direction to prevailing wind and waves.

Wave-induced currents at 8 m CD were negligible, but at 5 m CD the tidally-induced mean current pattern was disrupted or reversed on 6 occasions between June 2015 and March 2016, all associated with high waves, and thus indications of surf zone conditions. In all cases bar one, the wave-induced mean currents served to enhance the flood currents, directed towards the NE (alongshore) (Figure 4).

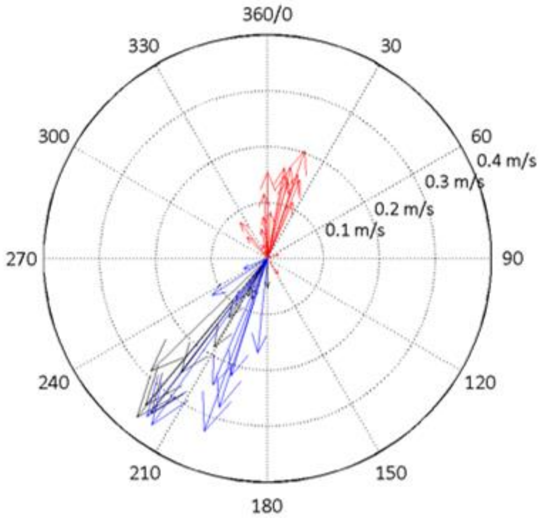

Figure 3. Depth-averaged current vectors, spring tide, 8 m CD. Red vectors represent flood tide and HW stand; black vectors are the early ebb and second HW; blue vectors are late ebb and LW

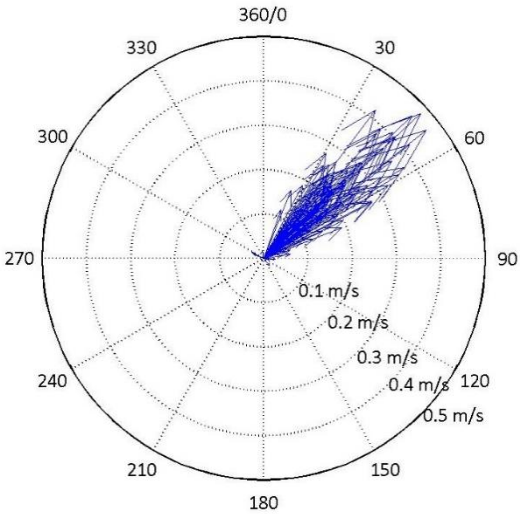

Figure 4. Depth-averaged mean currents at 5 m CD from 12:00Z 05 Feb to 22:00Z 06 Feb 2016

The exception occurred on 01 January 2016, where weak offshore currents were recorded for a period of ~13 hours, but approaching |0.4| ms^{-1} for an hour during the flood tide (Figure 5). Waves during this period were the highest measured during the Trial, with H_s reaching 3.2 m. The cross-shore mean current was directed offshore throughout the water column.

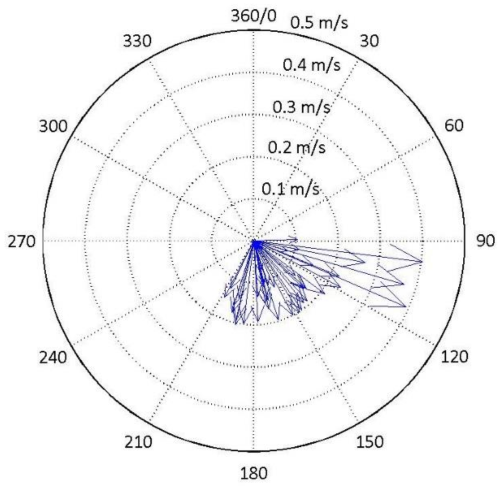

Figure 5. Depth-averaged mean currents at 5 m CD from 17:00Z 01 January to 06:40Z 02 January 2016

3.2. *Suspended Sediment Concentration*

The OBS deployment provided the first long-term measurements of turbidity in Poole Bay, which was classified using the thresholds shown in Table 1.

Table 1. Turbidity classification

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

The instantaneous hydrodynamic conditions at the offshore site during periods of "no turbidity" confirmed ~0.3 ms^{-1} as the threshold for current-induced sediment resuspension and demonstrated that, outside the surf and shoaling zone, once H_s exceeds about 1 m, the waters of Poole Bay are always at least lightly turbid (Figure 6). Turbidity in the winter months averaged 24 mgl^{-1}, double that of the spring months. In shallower water (5 m CD), winter turbidity averaged 105 mgl^{-1}, including periods of very high turbidity consistent with surf zone sediment resuspension conditions (Voulgaris and Collins, 2000).

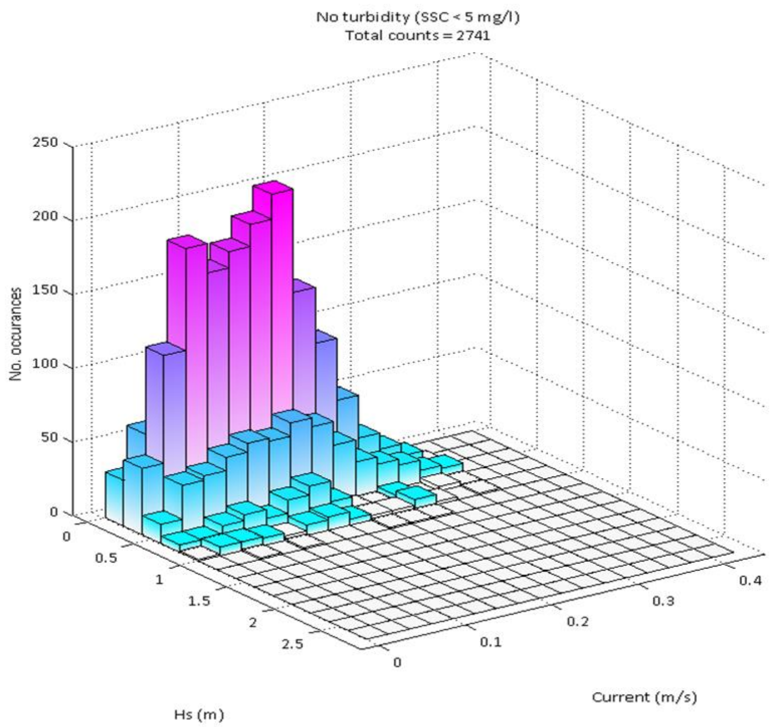

Figure 6. Histogram of significant wave height and mean current during periods of "no turbidity"

Settling rates were calculated following discrete suspension events, based on the time taken for peak SSC to decrease monotonically to ≤ 50 mgl^{-1}, subsequently to ≤ 20 mgl^{-1} and finally to ≤ 5 mgl^{-1} (Figure 7). In this manner the settling rate included all sediment fractions in suspension, including the coarser sediment which falls out of suspension before the finer fraction. Sediment fall rate decreased exponentially with concentration, from 1.8 mg/l/min for high turbidity levels, 0.4 mg/l/min for moderate turbidity decreasing to 0.2 mg/l/min for subsequent clearing of the water column to "no turbidity" conditions. Typically, a high suspension event took about 140 minutes for the sediment to settle to average turbidity levels, with a further 100 minutes needed to settle completely. The implication is that if moderate or high suspension is generated either naturally or by other factors such as nearshore replenishment, the sediment will settle to natural average levels within about 2 hours once the hydrodynamic forcing ceases.

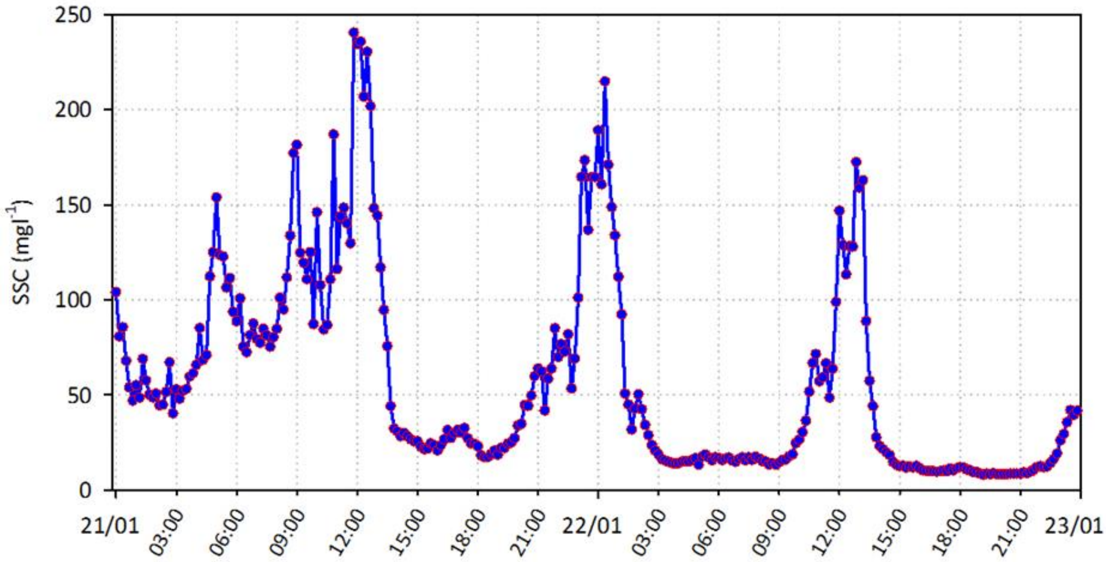

Figure 7. SSC 21 – 22 January 2015, showing 3 discrete high suspension events, settling to average levels

3.3. *Tracer study*

The sub-tidal tracer experiment demonstrated that the main transport axis was shore-parallel, NE/SW, with a predominant net transport to the NE (Figure 8). Within 7 days of the insertion, tracer material had spread along 750 m of shoreline; in the cross-shore direction, onshore transport by far exceeded offshore transport. 30% of the beach samples contained some tracer material, predominantly at Low Water locations. These tracer results were unequivocal evidence of a sediment transport connection between the deposition site and the beach.

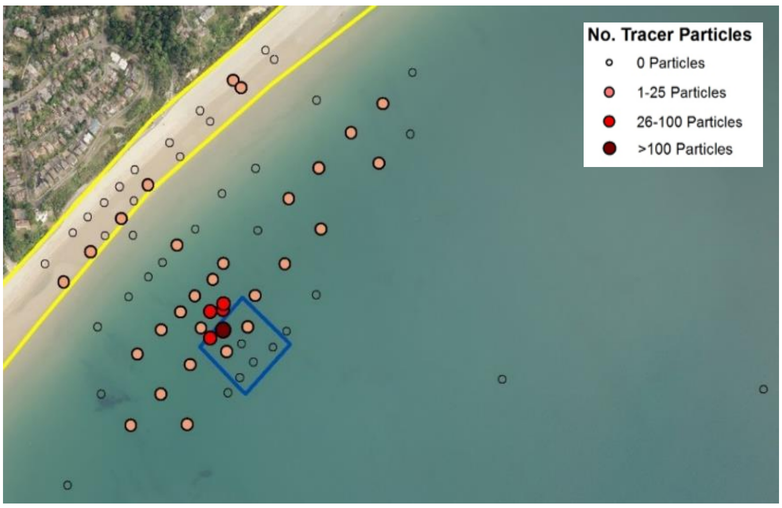

Figure 8. Results from tracer sweep 7 days after tracer insertion

3.4. *Morphodynamics*

Other than rapid planing off the high points of the mounds, there was very little change in either position or shape for the first 9 months after deposition (Figure 9). Analysis of swath bathymetry surveys in December 2015 and April 2016 showed a classic shoreward movement of the "bar" and development of a shallow trough to landwards but with no measurable loss of volume, and with no net change to the offshore seabed.

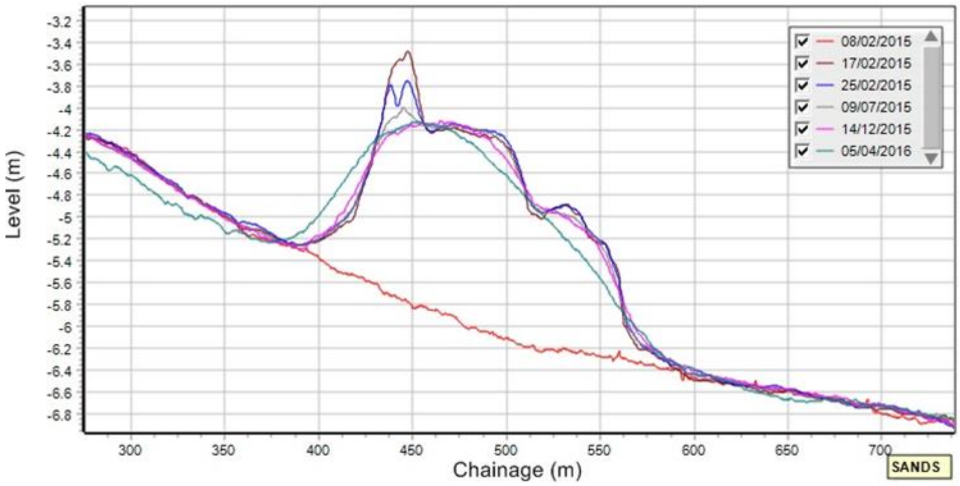

Figure 9. Profile through deposition central mounds showing 10 m shoreward translation between late December 2015 and April 2016

Long-term bathymetry profile data collected by the Southeast Regional Coastal Monitoring Programme had demonstrated minimal net change in seabed elevation seaward of about 450 m off the beach. This was confirmed by the repeated swath bathymetry surveys where the majority of observed seabed change was essentially "noise" in the data. A recent survey, completed some 26 months after deposition indicated a further but small onshore movement in sediment from the deposition mounds, but overall less than 1,500 m^3 had left the deposition box (Figure 10), indicating that the mounds are changing position and shape rather than changing volume.

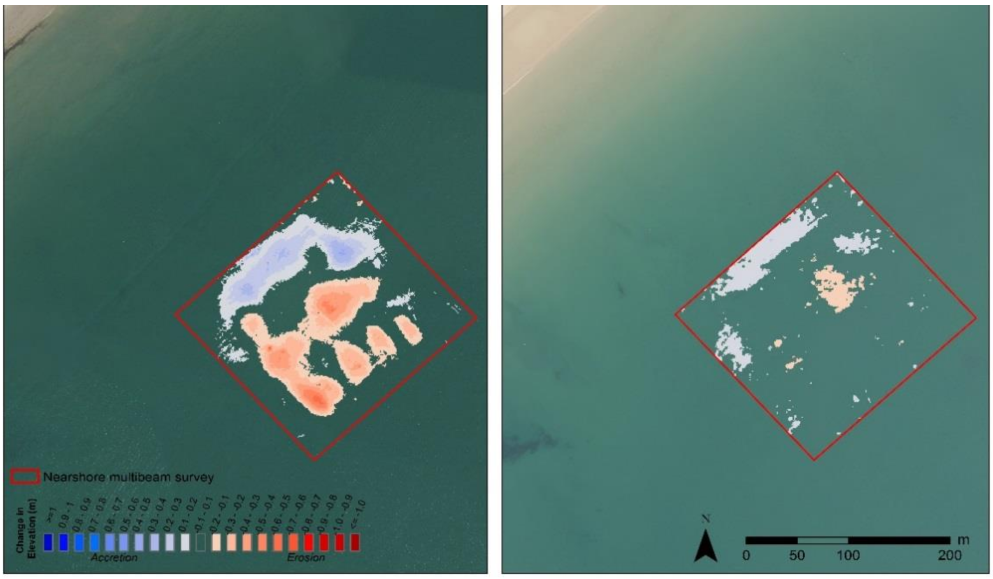

Figure 10. Difference model of deposition box between December 2015 and April 2016 (left) and between April 2016 and March 2017 (right)

The laser scan surveys of the inter-tidal beach showed that the beach gained 20,000 m^3 in the 30 days following the deposition and then continued to gain sediment for a further month at a slower rate. In the following 4 months, the beach lost sediment at about the same rate that it had accreted since the deposition, and then continued to erode at a slower rate for the remainder of the Trial. Within the whole beach changes, some small-scale differences in beach behaviour were observed, most notably a “bulge” of sediment across the whole inter-tidal beach face around 24 February 2015 (Figure 11), which coincided with the highest daily net gain in sediment observed during the Trial.

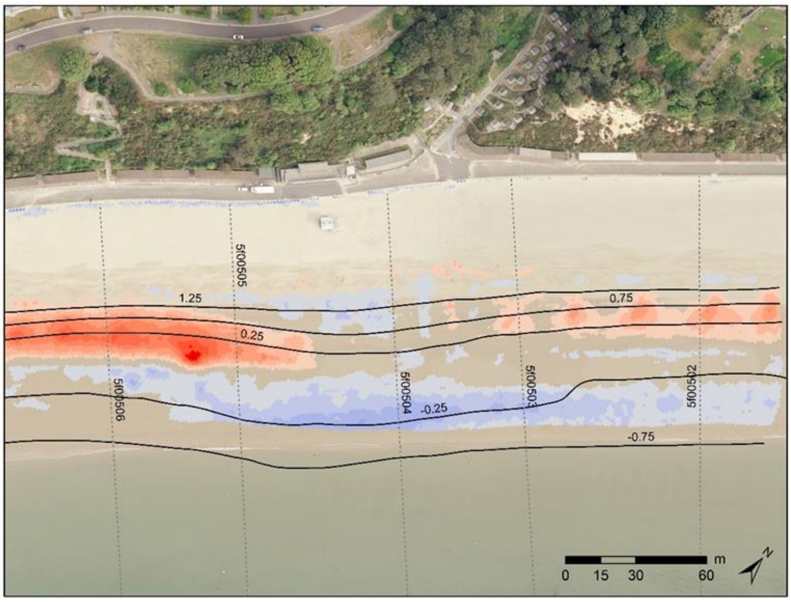

Figure 11. Difference model of inter-tidal beach showing discrete build-up of sediment (17 to 25 February 2015), superimposed on 2013 aerial photography

It is unlikely to be a salient formation behind the deposition mounds, since such features have been observed along this frontage in the past, neither was there any evidence from subsequent surveys of a pulse of sediment moving alongshore. A feasible explanation for this feature as the response to a focused swell event is discussed below.

4. Discussion

The presence of an MCZ was the main restriction on the use of beneficial dredging material, since otherwise the material was uncontaminated and native sediment, being deposited on a known benign seabed. Analysis of the mean current data indicated that there is no direct sediment pathway from the 8 m CD contour towards Poole Rocks MCZ. The SSC time series showed no evidence of increased turbidity near the MCZ due to the nearshore Trial, neither was there any evidence of increased quantities of silt in the control grab sites. Any increased turbidity during the deposition was short-lived and highly localized, never exceeding naturally-occurring levels. Furthermore, video footage from a drone filming the dredger depositing sediment qualitatively confirmed a fairly rapid settling of the plume. Sedimentation studies at Poole Rocks also concluded that there were no significant impacts of the Trial on either the sedimentation rate or the biota (Collins, 2017). Thus, all strands of evidence confirmed no detrimental impact on the MCZ and therefore it is to be hoped that a potential barrier to subsequent beneficial use of dredging material at this site will be removed.

Clement weather conditions during the dredging operations had meant that the material could be deposited on the 5 m CD contour, rather than near chosen poor-weather site on the 8m CD contour. This was fortunate since the AWAC results later demonstrated a sediment transport disconnection between the 8 and

5 m CD contours and hence a conclusion that, given the hydrodynamic regime in the western section of Poole Bay, deposition at the deeper location would not be appropriate as a nearshore replenishment technique. In contrast, sediment deposited at the shallower location was transported rapidly to the adjacent beach and alongshore, although in small quantities only, with the majority of the deposited sediment remaining in situ for two years to date. However, the economic case for trickle-charging the beach by repeated nearshore deposition requires only 10% of the sediment to reach some part of the beach frontage for the process to be cheaper than conventional beach recharge, along with the associated lessening of loss of beach amenity and other factors referred to above.

Sudden, significant build-up of sediment on the adjacent beach had been observed early on in the experiment, but also at intervals in previous years, so could not be attributed to the "offshore breakwater" effect of the deposition mounds; although a sub-tidal bar is occasionally present along the Poole frontage, it is a small and ephemeral feature in contrast to the well-defined and semi-permanent sub-tidal bar system in the eastern part of Poole Bay. The AWAC/OBS results identified the distinctive role played by swell waves at this central English Channel location, and the anatomy of a beach accretion event. In the absence of swell, wave heights needed to approach 1 m to initiate a moderate or high suspension event. However, providing waves persisted at this level for more than 2 hours, as occurred on 13-14 February 2015, turbidity increased rapidly and remained high even when waves subsided to ~0.6 m. The subsequent arrival of swell continued to maintain sediment concentration in the water since without the presence of stirring forces, the suspended sediment would have settled to average levels within 2 hours, rather than the 9 – 10 hours needed to complete this turbidity event. The swell is likely to have been a significant (onshore) transporter of sediment, with significantly longer run-up over the beach face. Since 2003, the Directional Waverider buoy at Boscombe has recorded waves of ≥ 0.5 m Hs and Tp ≥ 12 s about 6% of the time, mostly from the South but with 30% from SSW. Why the sediment build-up is spatially restricted is uncertain, but may be linked to subtle changes in orientation of the beach and seawall, combined with some swell focusing. It is expected that future work will involve modelling of this event, based on the extensive data set gathered by the Trial.

The 15-month hydrodynamic instrumentation deployment provided some of the first long-term measurements in Poole Bay and served also to produce threshold conditions for significant transport. Tidal currents along the 8 m CD contour were confirmed to be weak and insignificant as a transporter of sediment in the Bay's prevailing NE direction. The presence, though infrequent, of well-defined longshore currents in shallower water at the deposition site is somewhat surprising given the relatively sheltered location and small tidal range. The longshore currents for the most part were below the threshold needed to mobilise sediment, but their presence implies oscillatory currents which can mobilise the sediment for subsequent transport by alongshore currents. The longshore current mostly retained some tidal signature in addition, but could enhance/oppose the tidal current once H_s exceeded about 1.5 m. Typically, enhancement occurred, with currents directed to the NE; once Hs reached 2 m, the stronger longshore current reaching 0.45 ms^{-1} was always toward the NE, thus overcoming completely the extended ebb-dominated current.

The site-specific results are likely to apply to much of Poole Bay since the tidal regime, wave climate and the sediment distribution are broadly consistent across the Bay. The SSC results in particular, where natural turbidity levels were shown to increase fourfold in shallower water compared with 10-12 m water depth, should stand as defining natural levels of background turbidity and its variability, which can be submitted as evidence in subsequent beach replenishment licence applications in Poole Bay. However, the majority of the English coastline is notably different to this micro-tidal, sandy, relatively sheltered and semi-closed bay and therefore the results should not be extrapolated to other parts of the coastline. For example, in a similar use of dredging material from an adjacent harbour, ~17,000 m^3 was deposited close inshore in Pevensey Bay in April 2015 and again in May 2016 and all but dispersed totally within a year. Pevensey Bay, however, is macro-tidal (>7 m spring tidal range), more exposed and flood-tide dominated, reinforcing the prevailing SW wave conditions. The experiment here also concluded that significant quantities of sand and periods in excess of a year are needed to establish properly the feasibility and economic case for nearshore replenishment.

The results of the Trial have important implications for large scale beach operations in Poole Bay, particularly in the light of ever-increasing evidence requirements of the regulatory bodies. The costs of the 15-month monitoring programme exceeded those of the dredging and deposition operations. It would be a significant restraint on further small-scale beneficial use of dredging material if such detailed monitoring were required for all schemes of this type. An important by-product of the monitoring analysis was to aid regulators to assess what is and is not feasible both scientifically and economically.

5. Conclusions

The Trial demonstrated a clear sediment connection between the deposition site and the adjacent beach and hence that nearshore replenishment is a feasible method, but also showed that the process is not a short-term solution at this location; it is likely that a larger quantity of material and more time are needed at this site to be able to demonstrate its long-term viability. Nevertheless, with small volumes of sediment becoming available at regular intervals, close to the dredging site, there is no obvious reason not to continue with nearshore disposal of the sediment, providing the regulatory bodies concur and it remains economically viable to do so.

Acknowledgements

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