On sediment dispersal in the Whitsand Bay Marine Conservation Zone: neighbour to a closed dredge-spoil disposal site

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Abstract

Some ‘thought experiment’ modelling results and interpretations of data and theory are presented to investigate the possibility that Whitsand Bay, and its recently (2013) designated Marine Conservation Zone (MCZ), might have been affected in the past both by intrusion of dredge-spoil sediments from the now-closed disposal site located close to the seaward boundary of the MCZ and by suspended sediment and low salinity waters from the adjacent Tamar Estuary and Plymouth Sound. The schematic modelling work (2D and 3D) is considered to provide approximate indications rather than precise predictions. The component of Tamar waters present within the MCZ is computed to be small (<10%). The location of the dredge-spoil (model tracer/particle-release) source point is crucially important to the intrusion of tracer within the MCZ. Modelled bedload sediment transport from the disposal site toward or away from the MCZ occurs with high waves and is dependent on near-bed tidal, wave and wind-driven currents.

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1. Introduction

Dredged sediment from Devonport Naval Base on the Tamar Estuary (DP in Fig. 1b) and surrounding harbour areas was disposed of for about 100 years in the outer Whitsand Bay near Rame Head (located on the Rame Peninsula, southeast Cornwall, Fig. 1b).

The Whitsand Bay MCZ lies immediately to the north of the dredge-spoil disposal site (amber line, Fig. 1b). The original disposal site (yellow parallelogram, Fig. 1b) was last used for maintenance dredge spoil in 1995. This work investigates the possibility that the area now designated a MCZ might have been affected in the past by dredge-spoil sediments and by waters from the adjacent Tamar Estuary and Plymouth Sound.

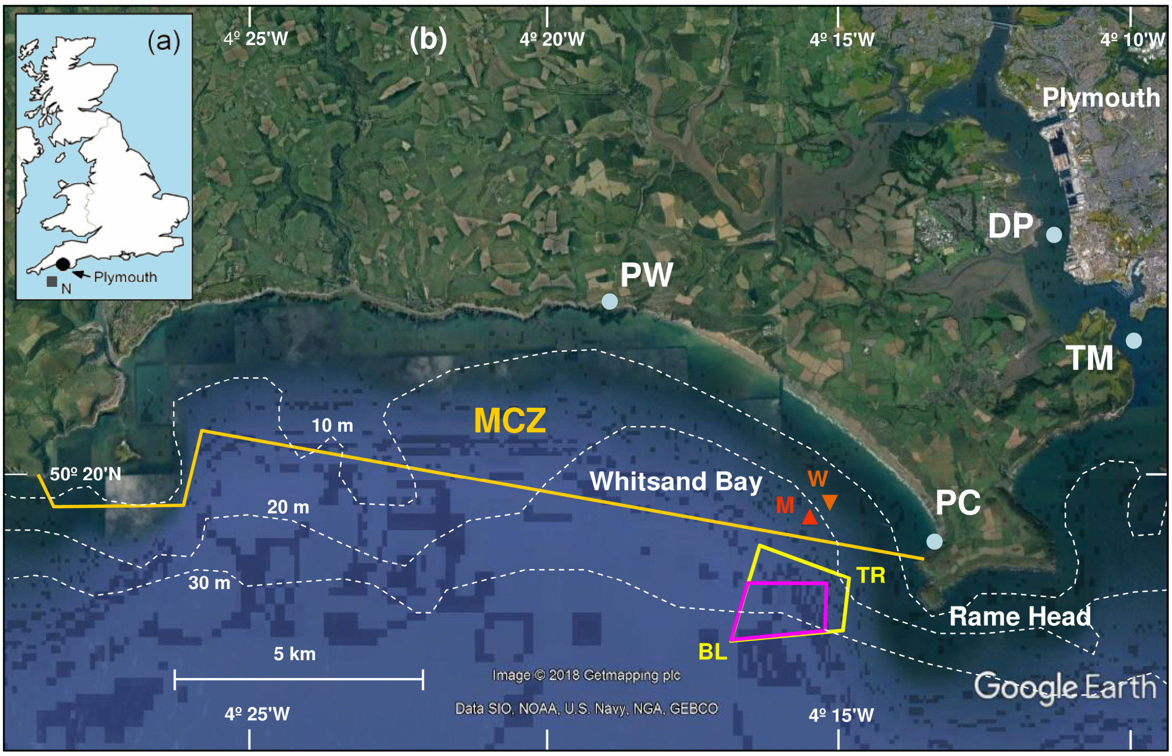

Fig. 1. *Location of Plymouth and Whitsand Bay, (a); Location of the MCZ (seaward boundary coloured amber) showing the perimeters of the historical (yellow) and more recent (magenta) dredge-spoil disposal ground, (b). TR and BL= Top right and bottom left corners of the historical disposal ground; PW=Portwrinkle; PC=Polhawn Cove; DP=Close to Devonport, Tamar Estuary; TM=Close to the Tamar mouth, Plymouth Sound; M=current meter station; W, N=wave stations.*

2. Physical Processes

Large waves can occur in the Bay, which thermally stratifies during summer but is well mixed during winter when most disposal activities took place. 2D (depth-averaged) modelling indicates that approximately 6% of the waters at PC and 4% of those at PW (Fig. 1b) can be ascribed to the Tamar system outflows during high runoff. Measured salinity data during vertically mixed conditions and high runoff demonstrates that 7% of the waters at PC and 3% at PW can be attributed to these outflows and ~1 mg l^{-1} of suspended particulate matter (SPM) compared with ~5 mg l^{-1} for typical *in-situ* concentrations.

The majority of Bay bed sediment is sand sized rather than silt and clay sized. Disposed dredge-spoil sediment typically comprised 38% sand and gravel, which would have been deposited to the seabed. However, previous studies concluded that there was no evidence of long-term accumulation of dredged material within the disposal site and surrounding area.

3. 2D Tracer dispersal

Two types of 2D modelling 'thought experiments' are explored for various winds and tides. The first uses a constant and continuous input rate of tracer solute, which attempts to represent very fine, continually suspended SPM. The second simulates, schematically, a dredge-spoil disposal campaign, noting the maximum transient concentrations at PC and PW as an indication of MCZ impact.

4. 3D Particle dispersal

A 3D hydrodynamic model was run for the winds and tides corresponding to November and December 2006 and used to drive a particle-tracking dispersal model, both for surface and near-bed particle inputs.

Winds speeds were low during 4 – 11 November 2006 and tides were large. Particles were periodically released into the water surface between 4 November and 6 November at location BL (Fig. 1b) simulating, in a very schematic way, a dredge-spoil disposal campaign.

Particle distributions illustrated a drift to the west and interactions with the coastline (red particles, uppermost panel, Fig. 2). Interaction with the coastline was much more pronounced for the near-bed release of particles (yellow particles, second panel, Fig. 2). For particle inputs at TR (bottom two panels, Fig. 2) the coastline was greatly impacted in the short term by dispersing particles.

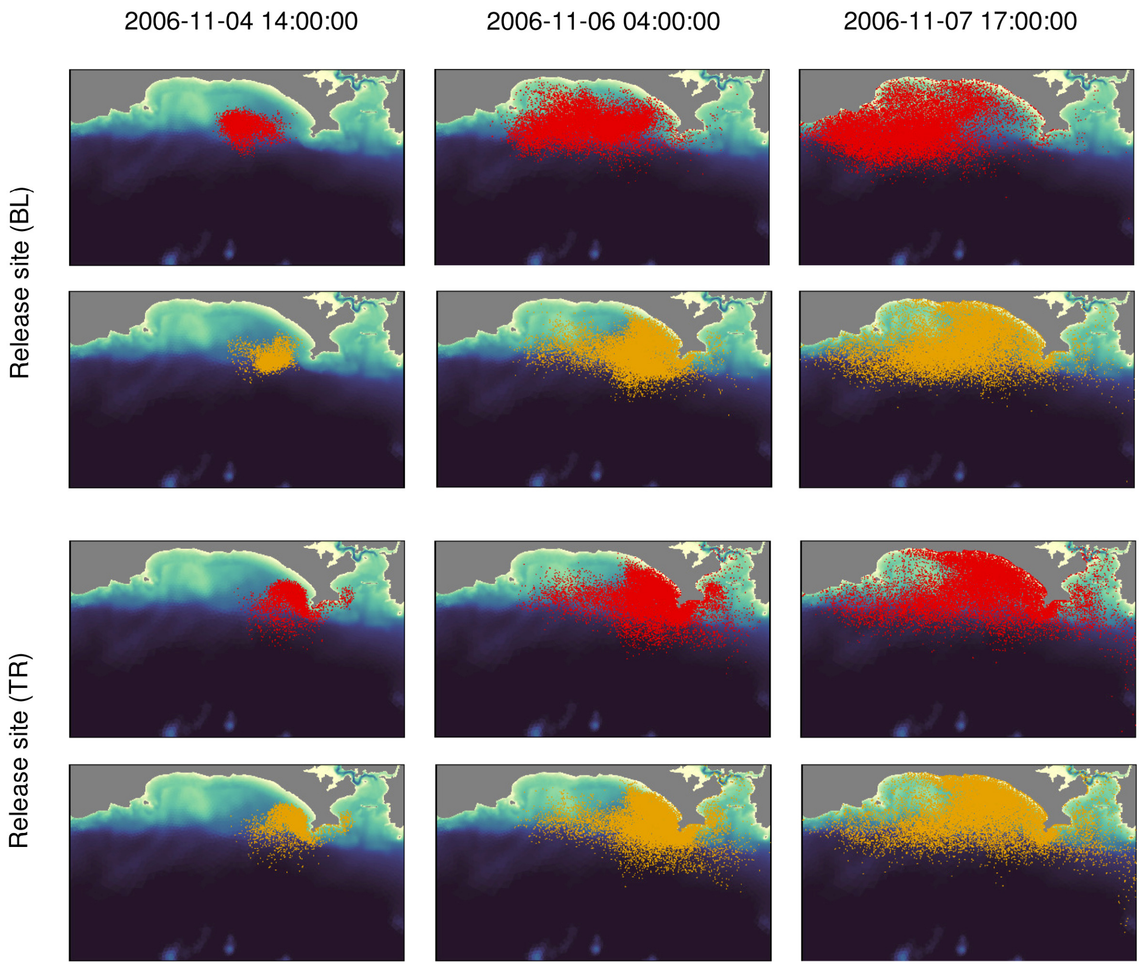

Fig. 2. *Particle positions at selected high water times for the November release scenario. Particles were released from disposal sites BL (top two rows) and TR (bottom two rows). Particles released at the surface are shown in red; particles released 2 m above the bed are shown in yellow.*

Winds were generally strong and typically from the south or southwest during the spring tides of 2 – 6 December 2006, usually greater than 10 m s^{-1} and reaching more than 19 m s^{-1} (gale force). Particles were periodically released into the water surface at location BL between 2 December and 4 December. Particles dispersed to the southeast with an overall drift to the east and had largely left the region by 6 December. For the near-bed release of particles, the southerly component of gale-force winds drove near-bed currents that transported most particles southward into deeper English Channel waters. Particles input at TR showed very similar behaviour to those at BL.

5. Dredge-spoil footprint

According to a local diver with >40 years of diving experience in the area, parts of the Bay were affected by silt deposits where, in earlier times, only sand and gravel had been evident. Our work indicates a high probability that dredge spoil has affected the MCZ region over ~100 years of disposal.

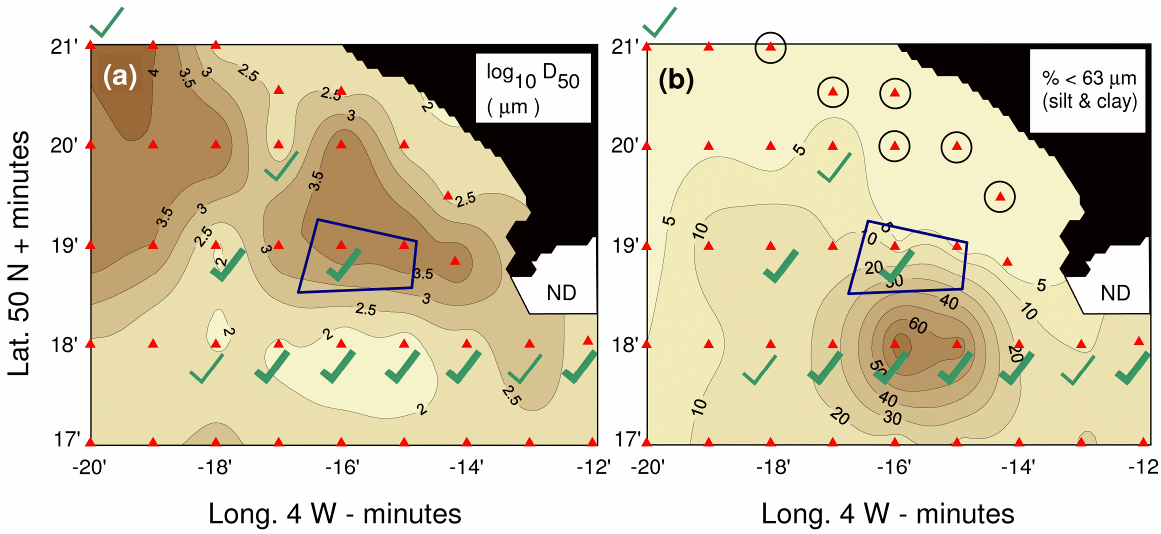

Fig. 3. *(a), Median grain-sizes of surficial sediment samples, D_{50}, in microns (plotted as $\log_{10} D_{50}$); stations are highlighted that have a fine-sediment component modal grain size in the range 30 – 35 and 45 – 50 µm, plotted as light green tick marks, and 35 – 45 µm, plotted as heavy green tick marks; (b), Percentage weight of dried sediment comprising silt and clay. ND=no data.*

A modal grain size of ~40 µm appears to provide a robust signature of dredge-spoil fine sediment within Whitsand Bay. From the fine-sediment components of a bed-sediment sample survey of the Bay we arbitrarily take an observed modal size range for our ensuing laser-diffraction data of 35-45 µm to represent a strong indication of the presence of dredge spoil (heavy green tick marks next to stations, Fig. 3a,b) and an observed modal size range of 30-35 µm and 45-50 µm to represent a weaker indication of its presence (light green tick marks, Fig. 3a,b).

Near-shore stations had negligible fine sediment in the samples (highlighted by circles, Fig. 3b). These data imply that the majority of dredge-spoil sediment deposited within the disposal site has eventually been transported offshore. The most likely cause of this implied transport is strong southerly and south-westerly winds, or winds with a strong southerly component, driving near-bed offshore currents during spring tides.