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Freshwater, tidal and wave influences on a small estuary

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ABSTRACT

Observations are presented of water levels, currents, salinity, turbidity, sediment grain sizes and sediment transport in the Devonshire Avon Estuary, UK, in order to improve knowledge of freshwater, wave and tidal influences on small, strongly tidal ría estuaries. A large reduction in tidal range occurred progressing from the coastal zone to the upper estuary that was mainly a consequence of rising bed and river water levels. The spring-neap cycle also had an influence on the reduction in tidal range along the length of the estuary. Surface gravity waves were completely dissipated propagating into the estuarine channel from the coastal zone, and despite strong wave-induced resuspension, suspended sediment was not transported into the lower estuary in observable amounts during the ensuing flood tide, indicating that the wave-suspended material was too coarse to remain in suspension once transported away from the surf zone. Turbidity in the lower estuary was relatively low during low runoff summer conditions and had largest values over low water, when turbid waters from farther up-estuary had been transported there. Strong resuspension events occurred at peak currents in the upper estuary during summer, reflecting the presence of finer-grained sediment sources. Turbidity was similar but greater in the lower estuary during high runoff winter conditions and strong resuspension occurred at peak currents, indicating an easily erodible, nearby sediment source, due to down-estuary movement and relocation of finer sediment over the winter. A large shoal in the lower estuary exhibited a consistent pattern of accretion/erosion during the high runoff months of late autumn and winter to spring that also was qualitatively consistent with sediment transport modelling and implied: (a), erosion from the up-estuary limit of the shoal with (b), down-estuary bed-load and suspended-load transport that accreted the centre and down-estuary limit of the shoal until (c), a diminished supply led to erosion *via* continued down-estuary transport from the shoal centre.

1. Introduction

Small estuaries often experience very pronounced tidal and seasonal fluctuations in salinity, turbidity, dissolved oxygen and other variables because of their short lengths, small volumes and short flushing times (e.g. Mitchell et al., 2006, 2008; Uncles and Stephens, 2011; Downing-Kunz and Schoellhamer, 2013; Uriarte et al., 2014). Spates and high-runoff winter conditions can lead to high water levels and saline waters being completely flushed from the estuary, along with substantial quantities of suspended and surficial main-channel bed sediment (e.g. Uncles and Stephens, 2010; Green and Hancock, 2012; Wiberg et al., 2013). Intertidal sand and mudflats also can be eroded and their sediments distributed down-estuary, together with large amounts of catchment-derived sediment and debris (e.g. Jackson, 2013).

The intrinsic and pronounced temporal variability of small estuaries and their sensitivity to perturbations can be problematic for their users; e.g. the Devonshire Avon, UK, is an estuary where boat owners and other water users have complained that rapid accretion has occurred in recent years (ACA, 2011). This article examines some of the important physical processes at work in a small estuary, using the Avon as an example that is typical of many strongly tidal ría systems (e.g. Perillo, 1995). Modelling indicates that sand transport is directed seawards in the main channel of the lower estuary (Uncles et al., 2013). Therefore, a possible source of newly imported accreting sand in the estuary is surf- and wave-suspended sand carried into the lower estuary by the currents of flooding spring tides (e.g. Shuttleworth et al., 2005; Downing-Kunz and Schoellhamer, 2013), especially during storms. That possibility is explored here. Also analysed are data on tidal and runoff effects, placed in a seasonal context, sediment grain-size distributions, and the movement of suspended sediment in the estuary and of deposited sediment on a sandy shoal in the lower estuary. While a

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number of studies have considered some of these latter aspects for large muddy systems (e.g. Uncles et al., 1998; Mitchell, 2005; Purnachandra Rao et al., 2011; Jiang et al., 2013), less physical-dynamical information appears to be available for small, predominantly sandy ría systems.

The overall objectives of this work are to determine the physical hydrodynamic and sediment transport behaviour of the estuary in the context of its relationships with the coastal sea and river, and its seasonal and spring-neap variability. Specific objectives are to: (a), measure tidal currents and water levels from coastal waters to upper estuary, in particular to quantify the damping of the tidal wave as it propagates from sea to estuary; (b), observe how these tidal characteristics vary with the spring-neap cycle and with season, especially changing freshwater inflows; (c), measure surficial sediment grain sizes through the estuary as a basis for sediment transport studies; (d), measure the seasonal variations in sediment bed levels at a site in the lower estuary as an indicator of seasonal variations in sediment transport; (e), measure turbidity (as an indicator of suspended sediment concentrations) in the coastal zone and estuary in order to determine their dependence on tidal water levels and currents and wave activity.

2. The estuary and its environment

The Avon Estuary is a small ría (e.g. Perillo, 1995) that is approximately 7.5 km long from its weir (section 16 on Fig. 1a) to English Channel waters in Bigbury Bay (section 1 and seawards). It is flanked by hills that rise to over 100 m above mean sea level, and water depths that exceed 20 m at lowest astronomical tide more than 1.5 km from its mouth in Bigbury Bay (Fig. 1a). Section 1 is 900 m wide with a maximum depth of 2.5 m at ODN (Ordnance Datum, Newlyn, about 0.2 m below mean sea level, Pugh, 1987, 2004). Within a kilometre of section 1 the estuary shallows slightly and narrows to just over 100 m (section 3). This outer estuary (sections 1 to 3a, light gray on Fig. 1a) is separated from the lower estuary (sections 3a to 8a, dark gray on Fig. 1a), central estuary (sections 8a to 12, light gray) and upper estuary (sections 12–16, dark gray) by a gap that is less than 70 m wide. The upper

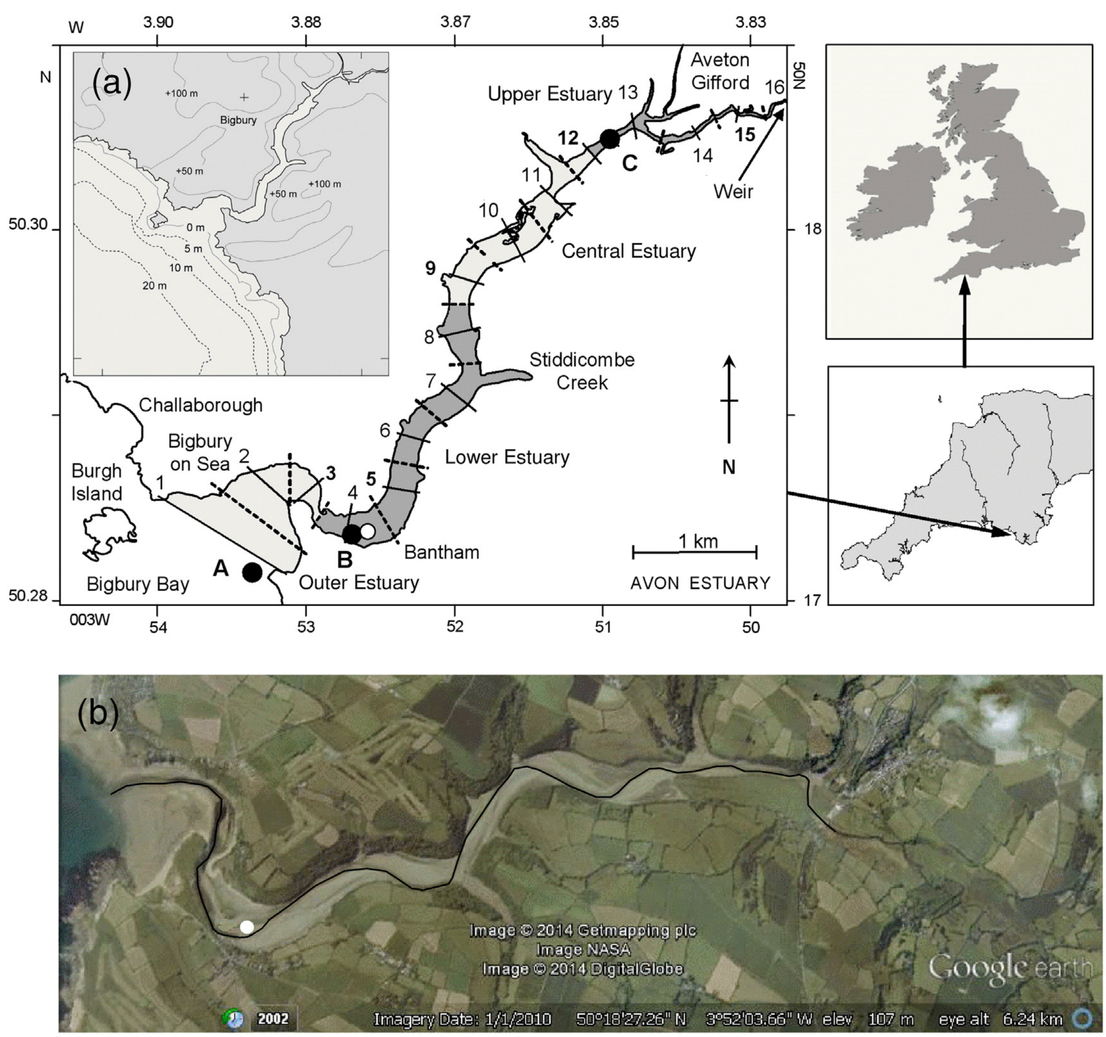

Fig. 1. Maps are drawn of the Avon Estuary, showing its location in southwest England, local topography and offshore bathymetry; (a), location, topography and offshore bathymetry. Sections drawn across the estuary with 250 m spacing (continuous and dashed lines: 1, 1a, 2, 2a … 16) are used to define bathymetry relative to Ordnance Datum Newlyn (ODN). Cross-estuary distributions of sediment grain sizes were measured over the sections shown as continuous lines. Seabed rigs at station A in the coastal zone and station B in the main estuary channel of section 4 were used to record tidal levels, currents, salinity, waves and turbidity during 4–5 August 2005; seabed rigs at station B and station C in the main channel of section 12a were used to record these variables during 4–9 July 2005 and 9–23 March 2007. The outer, lower, central and upper estuary are highlighted light and dark gray, alternately; (b), Google earth image of the Avon at LW of a spring tide, showing the narrow channel (highlighted with a black line) flanked by intertidal areas from outer to upper estuary. Location of the accretion/erosion posts are shown by the filled white circle on (a) and (b).