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The sediment trapping efficiency of the macro-tidal Daly Estuary, tropical Australia

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Abstract

Field studies were carried out on the water and sediment dynamics in the tropical, macro-tidal, Daly Estuary. The estuary is shallow, very-turbid, about 100 km long, and the entrance is funnel-shape. In the wet, high flow season, normal tidal ranges can be suppressed in the estuary, depending on inflow rates, and freshwater becomes dominant up to the mouth. At that time a fraction of the fine sediment load is exported off-shore as a bottom-tagging nepheloid layer after the sediment falls out of suspension of the thin, near-surface, river plume. The remaining fraction and the riverine coarse sediment form a large sediment bar 10 km long, up to 6 m in height and extending across the whole width of the channel near the mouth. This bar, as well as shoals in the estuary, partially pond the mid- to upper-estuary. This bar builds up from the deposition of riverine sediment during a wet season with high runoff and can raise mean water level by up to 2 m in the upper estuary in the low flow season. This ponding effect takes about three successive dry years to disappear by the sediment forming the bar being redistributed all over the estuary by tidal pumping of fine and coarse sediment in the dry season, which is the low flow season. The swift reversal of the tidal currents from ebb to flood results in macro-turbulence that lasts about 20 min. Bed load transport is preferentially landward and occurs only for water currents greater than 0.6 m s^{-1}. This high value of the threshold velocity suggests that the sand may be cemented by the mud. The Daly Estuary thus is a leaky sediment trap with an efficiency varying both seasonally and inter-annually.

Keywords: sediment budget; flocculation; suspended sediment; bed load; tidal symmetry; ponding

1. Introduction

Since the pioneer work on estuarine dynamics by Pritchard (1952, 1967) and Postma (1967), processes such as tidal asymmetries (duration and peak velocity), baroclinic currents, storms, and human activities such as dredging, channelisation and hard structures, have been understood to result in patterns of deposition and erosion that make estuaries change and evolve on a wide range of time scales (Dyer, 1986, 2000; Perillo, 2000; FitzGerald and Knight, 2005). This knowledge led to the realization that estuaries are sediment traps. This trap is not 100% efficient, i.e. estuaries infill but still export some fine and coarse sediment particularly during periods of high river flow (Syvitski et al., 2005). The trapping and export have been well documented for fine, cohesive sediment in micro- and meso-tidal estuaries (Dyer, 2000; FitzGerald and Knight, 2005). The export of riverine fine sediment is poorly understood in macro-tidal estuaries since these estuaries import coastal fine sediment by tidal pumping (Chappell, 1993; Chappell and Woodroffe, 1994; Woodroffe, 2003; Wolanski, 2006). The estuarine trapping and export of riverine sand are barely understood (Milliman and Meade, 1983). In some estuaries the riverine coarse sediment (sand) may not reach the coast (Bryce et al., 1998), while in others the sand is exported to coastal waters and the continental shelf (FitzGerald et al., 2005). One reason for the difficulty in assessing sand transport

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is that there are no instruments to non-intrusively measure the bed load transport. Instead the net bed load has to be determined indirectly by methods such as grain size analysis, magnetism, and repeated bathymetric surveys to assess changes in sediment storage, and the direction of sand transport has to be inferred from the shape of sand shoals and asymmetries in bed forms (FitzGerald and Knight, 2005).

This paper reports on the case study of the macro-tidal Daly Estuary in tropical Australia (Fig. 1). The estuary is about 100 km long and the spring tidal range is about 6 m at the mouth. A strong tidal asymmetry exists in upper estuary in the dry season, with a small (0.3 m) tidal bore occurring at spring tides (Wolanski et al., 2004). The large catchment area (52,577 km^2) results in occasional major river floods, the largest peaking at about 8,200 m^3 s^{-1} in January 1998. The river is perennial due to spring discharge from limestone aquifers. The wet season occurs between January and April, the dry season during May to September, the remaining months are transitional periods. There are large seasonal and interannual fluctuations of the runoff. It is shown that the estuary exports riverine fine sediment during the high flow season while much of the sand and the remaining fine sediment fraction deposits near the mouth. The deposit can be up to 3 m high, 10 km long and extending across the full width of the estuary. This forms shoals offshore and in the lower estuary that partially pond the mid- and upper-estuary during the dry season. The sediment from these shoals is advected landward back into the estuary by tidal pumping during the dry season. The tidal pumping of the coarse sediment appears to be hindered by cementing by the clay. It takes about 3 dry years—i.e. 3 years of small river sediment inflow following 1 year of high sediment inflow—for this sediment shoal at the mouth to be removed and the sediment redistributed all over the estuary and the tidal ponding effect to disappear.

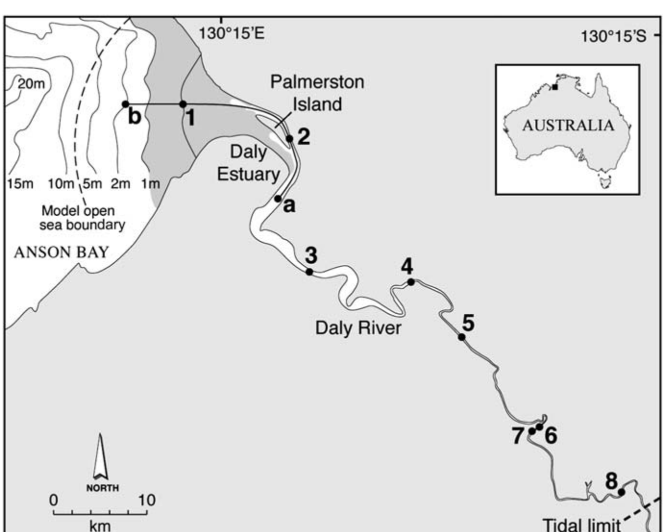

Fig. 1. A location map of the Daly Estuary and key measurement sites.

2. Methods

Monthly-averaged river discharges at Mt. Nancar, upstream of the tide limit, were available for the period 1970–2005. Half-hourly tidal elevation data at site 5 were available for the period 1968–1986.

Field studies were carried out during the dry season in August 2004, November 2004, and September 2005, and in the wet season in March 2005.

In all cruises vertical profiles of salinity, temperature and suspended sediment concentration (SSC) were collected at a number of sites in along-axis transects using a SeaBird CTD equipped with an Analite nephelometer.

In March 2004 moorings were deployed for 3 days at sites b and 1 (see a location map in Fig. 1), equipped with Nortek and RDI ADCP current meters cum tide gauges, SBE 16 salinometer-temperature recorders, and nephelometers spread from top to bottom.

In August 2004, Seabird and Diver tide gauges were bottom-mounted for 1 month at sites 2, 5, 6 and 8.

In November 2004, a mooring was maintained for 3 days at site 1, equipped with a S4 current meter, and SBE 16 and three nephelometers.

In September 2005, moorings were maintained for 1 week at sites 2–7 containing Nortek and ADCP RDI, SBE 26 tide gauges, SBE 16, and nephelometers.

The nephelometers were equipped with wipers cleaning the sensor every 30 min. No biological fouling was observed, probably because of the high turbidity in the area. The nephelometers were calibrated in-situ. The instruments saturated at about 30 kg m^{-3}.

The instruments logged data at 5 min intervals.

On one occasion a downward looking ADCP with bottom-tracking mode enabled was deployed on a frame at site 3, 1.5 m off the bottom, to measure the bed load velocity, logging every second. Another ADCP pointing upwards at site 5 logged velocity data every second.

Samples for microscopic observations of suspended particles were obtained using the technique of Ayukai and Wolanski (1997). The samples were examined under an Olympus inverted microscope with a Sony CCD video camera. The images were captured digitally.

A vertically and laterally-averaged 1-D discontinuous finite element model was used to model the dry season hydrodynamics of the estuary. This model is based on the discontinuous Riemann–Galerkin approach suggested by White et al. (2006). As the discrete surface elevation and velocity may exhibit discontinuities between grid cells, the model is able to accurately represent solutions with sharp gradients and even tidal bores. The upstream boundary was the river discharge at the tidal limit and the downstream boundary condition were the tidal elevations applied at the seaward limit of the model shown in Fig. 1.

3. Results

The monthly-averaged river discharge Q_f fluctuated seasonally and inter-annually (Fig. 2). Peak flow occurred in the wet