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Tidal currents and bedload transport at the mouth of a rock-bound estuary during low river discharge conditions (Guadiana Estuary, Portugal)

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The present study documents the poorly-described hydro-sediment dynamics of narrow bedrock-controlled estuaries during periods of low-river discharge. The results also contribute to assess the geomorphological evolution of these systems, when affected by drastic flow regulation.

The Guadiana Estuary is a narrow rock-bound mesotidal estuary, 80 km in length, located at the southern border between Spain and Portugal. Until recently, the river inputs to the estuary displayed high (annual and seasonal) variability, characterized by periods of droughts, and episodic flood events with (monthly-averaged) fluvial discharge as high as 5,000 m^3s^{-1} (160 m^3s^{-1} in average, for the period 1947/2001). This pattern has ceased in February 2002, with the impoundment of the main river by the large Alqueva dam, 60 km upstream from the estuary head. At present, the daily-averaged river discharge is generally kept low throughout the year (< 50 m^3s^{-1}). In the absence of significant flood events to expel massively sediment out of the estuary, concerns have been raised about sand infilling at the mouth and increased erosion at the adjacent coastline. For the assessment of the sediment balance of the estuary under present hydrodynamic conditions, this study examines the tidal currents and bedload transport at the entrance of the estuarine channel.

Current measurement transects were performed across the 600 m-wide channel entrance using a ship borne Acoustic Doppler Profiler (ADP, operating at 1.5 MHz frequency) during 2 entire tidal cycles, at spring (17 September 2008, 3.0 m tidal range) and at neap tide (21 October 2008, 1.6 m tidal range). Surficial sediment samples were also collected across the channel during the spring tidal cycle. The bed sediment consists of well-sorted medium sand with mean grain size ranging from 0.5 to 0.3 mm (with coarser material at the deepest part of the channel cross-section). Tidal currents were analysed along 6 sub-sections to take into account these grain size variations. The friction velocity and bed shear stress were computed based on the mean depth-averaged velocities of each sub-sections and considering a power law vertical velocity profile. The transport rate of sand was then estimated using Nielsen (1992) formula for bedload transport. The transport of sand in suspension was not considered in the study, as the skin friction velocities were lesser than the estimated settling velocities of the grains.

Maximum velocity values (about 1.2 and 0.8 $m.s^{-1}$ at spring and neap, respectively) were observed near the surface of the deepest sub-section of the channel. The tidal prism was about 1.5 times larger at spring ($39x10^6$ m^3) than at neap ($25x10^6 m^3$), whereas the fresh water inputs during both tidal cycles were comparatively negligible. Maximum depth-averaged, bed and surface current velocities were ebb-directed at both neap and spring tides, for each of the 6 channel sub-sections. No significant lateral variation of the tidal flow was observed, in relation with the narrowness of the channel. Vertical residual velocity profiles were also directed downstream at both neap and spring tide. At neap, however, the (ebb-directed) residual velocities were slower near the bed and faster near the surface, when compared to the spring tide. These differences were induced by the reinforcement of the estuarine circulation, in relation with enhanced stratified conditions during neap periods (weak currents and reduced mixing). The net bedload transport of sand was also directed downstream for all channel sub-sections. The transport rates of the entire channel were estimated to be of about 30 and 10 m^3 for the spring and neap tidal cycles, respectively. Extrapolation of these extreme (i.e. neap and spring) rates yielded a potential seaward export of sand of approximately 15,000 m^3yr^{-1}. This study suggests that the Guadiana estuary departs from typical estuaries where landward net transport of sediment is generally described. The outputs of the study are important with respect to the long-term (decades) geomorphological evolution and sustainable management of the estuary mouth and adjacent

coastline.