Marine Geology 385 (2017) 131–145

Contents lists available at ScienceDirect

Marine Geology

journal homepage: www.elsevier.com/locate/margo

# Observations of morphological change at an ebb-tidal delta

Shawn R. Harrison *, Karin R. Bryan, Julia C. Mullarney

*Coastal Marine Group, School of Science, University of Waikato, Hamilton, New Zealand*

ARTICLE INFO

*Article history:*
Received 22 July 2016
Received in revised form 13 December 2016
Accepted 24 December 2016
Available online 7 January 2017

*Keywords:*
Ebb-tidal delta
Video observation
Coastal morphodynamics
Sediment transport
Raglan

ABSTRACT

Video observations of depth-limited wave-breaking patterns at an ebb-tidal delta on the energetic west coast of New Zealand at Raglan were used to identify geomorphic features over a 5-year period. The terminal lobe, mouth bar, channel margin linear bars, and swash bars were identified and tracked over the duration. Morphodynamic response was related to environmental conditions by correlating observed movements with concurrent wave and tidal conditions. Movements occurred throughout the record with a slight tendency to occur more during the transition between seasonal forcing trends. Winter deltas were generally broader and extended further seaward than the summer deltas which were more cuspate. The formation of a double-barred ebb-shoal was observed, with the cross-shore position of the outer bar influenced by wave conditions while the inner bar was influenced by ebb-jet strength. Furthermore, swash bars were observed to constrict the seaward extent of the main channel during large wave events, which was subsequently eroded by tidal currents. These observations are consistent with the present consensus that ebb-shoal features are dependent upon competition between ebb-jet strength and opposing waves. Interannual morphological changes were not significantly correlated to any particular environmental forcing, suggesting that either some process or combination of processes not considered were influential, or that the system might be showing signs of emergent behaviour.



## 1. Introduction

Ebb-tidal deltas are large sedimentary accumulations on the seaward side of tidal inlets that play a significant role in moving sediment around tidal inlets and influence transport pathways within coastal littoral cells (e.g. Fig. 1). Deltas shelter inlets by dissipating and redirecting wave energy offshore and onto adjacent beaches, respectively (e.g. Fitzgerald, 1984) and they provide a mechanism for sediment to bypass an inlet (e.g. Fitzgerald et al., 2001 and references therein). Deltas also function as both temporary and long-term sand storage, exchanging sediment between the adjacent beaches, nearshore and inlet mouth (e.g. Fitzgerald et al., 1984; Gelfenbaum, 1999). Despite the importance of ebb-tidal deltas, the processes governing their development, evolution, and interaction with adjacent beaches are not fully understood (van Leeuwen et al., 2003; van der Vegt et al., 2006; Fagherazzi and Overeem, 2007).

Ebb-tidal deltas form in response to tidal forcing through an inlet (Van der Vegt et al., 2006), with their equilibrium size and shape determined by the tidal prism (Walton and Adams, 1976), wave energy, and available sediment (e.g. Hicks and Hume, 1996). However, when short-term conditions (i.e. flow, waves, and sediment supply) deviate from long-term averages, a local morphodynamic response occurs, typically in the form of mobile bedforms or sandbars migrating along the delta towards the nearshore or adjacent beaches (Hayes, 1979; Sha, 1989; Hicks et al., 1999; Sherwood et al., 2001; Ruggiero et al., 2003; Ruggiero et al., 2009). For instance, following severe runoff through the Santa Clara River mouth in California, an abnormally large delta formed, which subsequently diminished in volume when the normal forcing conditions returned, with excess sediment transported to the downdrift beaches as a morphological 'wave' (Barnard and Warrick, 2010).

The physical processes occurring at an ebb-tidal delta are interconnected and vary depending on location. During ebb, a jet of water ('ebb-jet') interacts with channel morphology (e.g. Kilcher and Nash, 2010), the density structure (e.g. Wright, 1977), and with incident surface gravity waves (e.g. Ismail, 1980). The incident surface waves are influenced by the morphology, as well as by their interaction with tidal currents (Van Rijn, 1990). As waves propagate shoreward, their energy focuses on the shallowest part of an ebb-tidal delta. For conditions with sufficiently large wave energy, depth-limited wave breaking will occur, maximizing the effect of waves on the ebb currents and driving shoreward flow over the ebb shoal and into the inlet (e.g. Olabarrieta et al., 2011). In the case of stratified ebb-flows, the effects of buoyancy are decreased as the vertical stratification is destroyed by mixing during wave-breaking (Wright, 1977).

Recent numerical modeling investigations on the role of ebb-tidal delta morphology and wave-current interaction at inlets (Olabarrieta et al., 2014) show that Stokes drift and accelerations induced by wave

* Corresponding author at: U.S. Geological Survey, Pacific Coastal and Marine Science Center, 2885 Mission St., Santa Cruz, CA 95060, USA.
*E-mail address:* srharrison@usgs.gov (S.R. Harrison).

http://dx.doi.org/10.1016/j.margeo.2016.12.010
0025-3227/

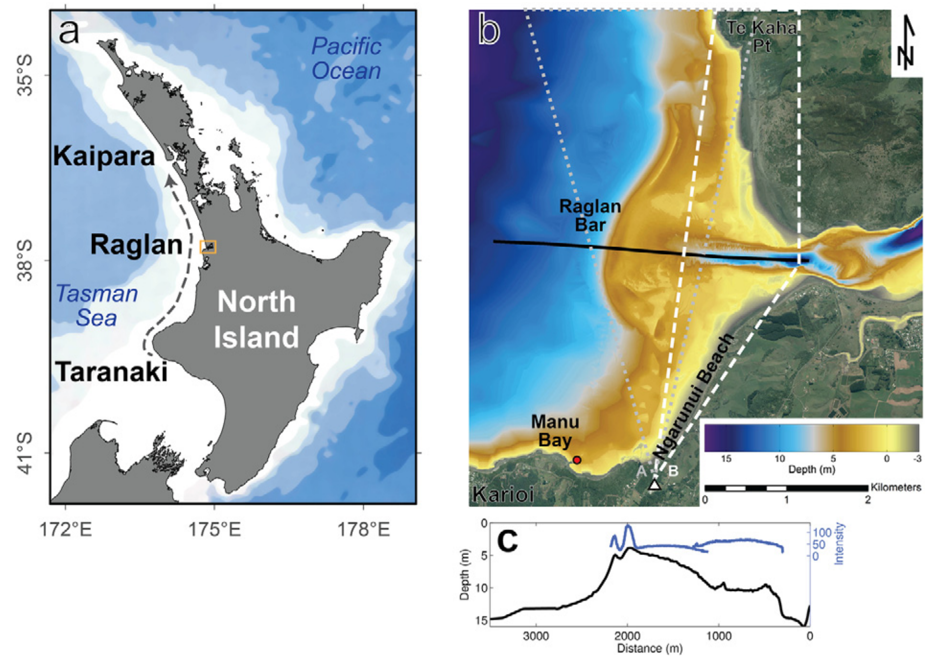


**Fig. 1.** (a) Whaingaroa (Raglan) Harbour (yellow rectangle), on the west coast of central North Island, New Zealand, is within the littoral pathway of sediment from Taranaki to Kaipara (dashed arrow). (b) Multibeam echo-sounder bathymetry data of the Raglan Bar (provided by Waikato Regional Council), with Cam-Era location (white triangle), Raglan A field of view (grey dotted line), Raglan B field of view (white dashed line), and Manu Bay water elevation gauge (red dot). The thalweg is indicated by the black line. (c) Distribution of depth (black line) and relative pixel intensity (blue line) of rectified image pair shown in Fig. 3a. Depth values in (b) and (c) are relative to mean sea level.

breaking produce shoreward water mass transport creating a wave setup that decreases with alongshore distance from the inlet. This wave setup causes an alongshore pressure gradient that forces alongshore currents along both sides of the ebb shoal towards the adjacent beaches (Shi et al., 2011). The gradient in alongshore current drives sediment convergence and coastal change in the form of deposition along the adjacent beaches. Changes in morphology feed back to the system by affecting the hydrodynamic and wave patterns which are responsible for further sediment transport and coastal change.

The need for improved model physics and parameterizations of the physical processes governing morphological evolution was identified as a major research direction for the immediate future of nearshore processes research (Nearshore Processes Community, 2015). The need arises because the dynamic behaviour of interacting coastal processes is highly nonlinear (De Vriend, 1991a; De Vriend, 1991b). The fundamental processes must be well represented or robustly parameterized in numerical models to achieve any predictive capacity. Sediment transport modelling can be 'difficult, highly empirical and inaccurate' for current-only situations, and difficulties are enhanced in locations such as ebb-tidal deltas where waves play a dominant role (Roelvink and Reniers, 2011). Waves interact with current to modify the bed shear stress (Grant and Madsen, 1979; Soulsby and Clarke, 2005), bed ripples (Traykovski, 2007), and sediment mobility (Li et al., 1996). Most of these interactions occur at much smaller spatial and temporal scales than are convenient to use when modelling the evolution of morphology, so parameterizations of the physical processes are necessary to include in numerical models (e.g. Fredsøe, 1984; Van Rijn, 2007). Coastal evolution is the result of time-integrated physical processes acting in the short term (Cowell and Thom, 1994). Yet, modelling detailed coastal change over morphological timescales is often impractical in linear time, and so the occurrence of events is typically parameterized by a few representative wave conditions (e.g. De Vriend et al., 1993; Daly et al., 2014). However, this approach often precludes consideration of the order of forcing events, which has been shown to influence the morphodynamic response of some coastal features (e.g. barred beaches and ebb-tidal deltas) (e.g. Plant et al., 1999).

The many uncertainties associated with modelling evolving morphology subject to wave-current interaction had led to a need for detailed observations, with which to verify models and guide further development (Nearshore Processes Community, 2015). However, few observations of ebb-tidal delta geomorphic features exist, and those that do exist tend to be infrequently sampled. The same high energy conditions that drive morphodynamic change at an ebb-tidal delta also inhibit the collection of adequate field measurements owing to logistical difficulties. Moreover, frequent observations are needed in order to track quickly-moving sandbars that are likely at ebb-tidal deltas. However, remote sensing can provide a potential solution to these problems of insufficient spatial and temporal resolution from in-situ measurements.

The use of video-based remote sensing in various coastal monitoring applications is attractive because video observation provides continuous and automated data collection (e.g. Holman and Stanley, 2007; Aarninkhof et al., 2003; Gallop et al., 2009). Pixel intensity associated with the dissipation of wave energy during depth-limited breaking is used to infer the position of shallow sandbars in time-averaged imagery. The method has been validated and widely used at beaches (e.g. Plant et al., 2007). Video data have only recently been used to observe ebb-tidal delta morphology (e.g. Balouin et al., 2004; Pianca et al., 2014).

Pianca et al. (2014) observed meso-scale sandbars move along the southern flank of the New River Inlet (North Carolina) ebb-tidal delta during a 23-day experiment. Their video observations were supported by a detailed field campaign (e.g. Wargula et al., 2014; Clark et al., 2014) and included in-situ current and wave measurements and multiple hydrographic surveys using a specialist Army amphibious vehicle (LARC-5) to validate the techniques for inferring sandbar migration from video. Meso-scale sandbars were observed to move at an average rate of 1.5 m $day^{-1}$ and up to 3.5 m $day^{-1}$ depending on wave conditions.

In this paper, we use video-based techniques to provide detailed observations of the annual and interannual changes to the terminal lobe position and shape and the propagation speed and direction of swash bars on an ebb-tidal delta. Further, we relate these seasonal trends in