Estuarine, Coastal and Shelf Science 187 (2017) 273–292

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Numerical modelling to assess maintenance strategy management options for a small tidal inlet

Saeed Shaeri*, Rodger Tomlinson, Amir Etemad-Shahidi, Darrell Strauss

Griffith Centre for Coastal Management and School of Engineering, Griffith University, Gold Coast Campus, QLD 4222, Australia

ARTICLE INFO

Article history:
Received 30 August 2016
Received in revised form
2 December 2016
Accepted 31 January 2017
Available online 1 February 2017

Keywords:
Tidal inlet
Infilling
Maintenance dredging
Alternative design
Numerical modelling
Delft3D

ABSTRACT

Small tidal inlets are found to be more sensitive to anthropogenic alteration than their larger counterparts. Such alterations, although typically supported by technical design reports, sometimes require amendments or modification. One of the most suitable tools to conduct the necessary studies in this regard is numerical modelling, since the behaviour of the inlet system in response to proposed remedial actions, can easily be identified. In this paper, various alternative proposals are investigated to determine the most practical and viable option to mitigate the need for ongoing maintenance at a typical small, jettied tidal inlet. The main tool to investigate the alternatives is the hydro-sedimentological modelling of the inlet system, which was performed using the Delft3D software package. The proposed alternative entrance modifications were based upon structural alterations of the inlet system (such as a jetty extension or submerged weir) and non-structural scenarios (such as a change of the time of the dredging campaign or the deposition location of the dredged material). It was concluded that whilst a detailed study is inevitable in order to achieve a comprehensive design plan, based upon the results of this study the construction of a submerged weir at the entrance channel can satisfy the needs of most of the stakeholders, with justifiable costs over a longer period.

1. Introduction

Tidal inlets provide an important connection between the ocean and a back-barrier water body (including lakes, lagoons, estuaries, etc.). Stability of tidal inlets is closely linked with the stability of the beaches surrounding them and may also be impacted by community usage (Alexandrakis et al., 2015). Some inlets are located on sandy beaches (with spits) which are susceptible to erosion, providing a mechanism for migration of the inlet (Duong et al., 2015; Hayes and FitzGerald, 2013). In contrast, other inlets are either bounded by natural rock outcrops or artificial jetties such that the inlet location becomes more stable over time (Garel et al., 2015; Komar, 1996; O'Brien, 1978). A typical inlet system has entrance shoals on the ocean-side (ebb tide delta) or the back-barrier side (flood tide delta) of the inlet (Hayes, 1980). An inlet shoal consists of a significant volume of sediment which is interconnected with all the other elements of the tidal inlet system. Hence, the shoals are also very important for the overall stability of the inlet system. Changes to the entrance shoals, whether natural or anthropogenic, can significantly affect the hydro-morphological status of the inlet system in the short and long-term (Hubbard et al., 1979; Panda et al., 2013). Thus, spits, jetties and shoals have attracted significant research interest with regard to management and maintenance of inlet systems (Boothroyd, 1985; Davis and Zarillo, 2003; Elias and Hansen, 2013; Finley, 1978; FitzGerald et al., 2000; Garel and Ferreira, 2013; Hubbard, 1975; Stapor and May 1987).

The partial blockage of the entrance can severely affect the entire inlet system in at least three major ways. Firstly, it can reduce the discharge capacity of the entrance, which is a key function during heavy rainfalls. The impediments of the creek mouth to flush the excess water may result in the accumulation of water across the entire creek and consequently, the increase of water level. As a result of the added water level, the low-elevated lands and properties surrounding the creek may become inundated, which may cause loss or damage to private assets and public infrastructure. A partially or completely blocked entrance can also result into a decrease in water quality, particularly increased salinity due to low freshwater input and the depletion of oxygen in

* Corresponding author.
E-mail addresses: saeed.shaeri@griffithuni.edu.au (S. Shaeri), r.tomlinson@griffith.edu.au (R. Tomlinson), a.etemadshahidi@griffith.edu.au (A. Etemad-Shahidi), d.strauss@griffith.edu.au (D. Strauss).

http://dx.doi.org/10.1016/j.ecss.2017.01.017
0272-7714/

the back-barrier waters (Ysebaert et al., 2016; Duck and da Silva, 2012; Panda et al., 2013). In turn, this would lead to loss of native plants and animals (Fagherazzi et al., 2014). The third concern regarding the partial blockage of small tidal inlets relates to the navigability. While many small watercraft are less affected by the blockage, safe navigation of larger vessels is quite dependent on the water depth, as well as the available width of the entrance channel.

Communities built around tidal inlets experience first-hand impacts of inlet migration, breaching and closure, and have used a variety of tools and techniques (such as jetty construction or maintenance dredging) to keep their properties safe from erosion and flooding or to maintain navigable entrances. Nowadays, not only have coastal communities surrounding tidal inlets grown significantly, but there are also a variety of other stakeholders and policymakers involved in the sustainable management of the coastal areas; such as conservation groups, local and regional authorities, and the tourism industry (Alexandrakis et al., 2015; Mani-Peres et al., 2016; Msomphora, 2015). Each of these groups has their own concerns, as well as strategies, to get the most out of these shared environments which sometimes are in conflict with that of the other groups.

A small inlet is considered to be one where the width of the entrance is less than 50 m or the channel cross-sectional area at the gorge is less than 100 m^2 (Behrens et al., 2013). This article investigates a number of structural and non-structural entrance modification strategies intended to maintain the usability of a small tidal inlet system and minimise long-term maintenance efforts. The current maintenance strategy (i.e. annual dredging) and proposed entrance modifications of the Currumbin Creek tidal inlet system represents a typical case of a jettied, small tidal inlet. Currumbin Creek is located in South-East Queensland, Australia and has a long history of ongoing traditional entrance maintenance activities such as periodic dredging. The considered alternatives encompass structural and non-structural cases where their proposal and comparisons are primarily supported by literature, as well as numerical modelling, as explained below.

Previous research has shown that some elements or characteristics of inlets are more influential in the overall stability of the inlet system. These are i) the inlet channel cross-sectional area (Escoffier, 1940; FitzGerald, 1996), ii) the volume of the tidal prism (Davis, 2004; Davis and Zarillo, 2003; FitzGerald et al., 2002; FitzGerald and Pendleton, 2002), iii) the strength and direction of the residual tidal currents (Aubrey and Speer, 1985; Brown and Davies, 2009; Jiang et al., 2013; Lincoln and FitzGerald, 1988; Zarzuelo et al., 2015), iv) the net longshore currents (Bruun, 1995; Goodwin et al., 2013; Keshtpoor et al., 2014), and v) the number, length and orientation of the entrance jetties (Bastos et al., 2012; Garel et al., 2015; Militello and Hughes, 2000; Seabergh, 2006). Since these factors can have a substantial influence on the overall evolution of inlet systems, it is worth considering them as the basis for designing alternative structural alterations.

Escoffier (1940) suggested that there is a relationship between the tidal prism and the cross-sectional area of the entrance channel which, according to O'Brien (1969), cannot be larger than a certain natural equilibrium area. Likewise, the planar area and volume of the back-barrier basin have a major influence on the tidal prism (Ridderinkhof et al., 2014). That is, the sedimentation in the back-barrier or at the entrance channel, results in the reduction of the tidal prism. In contrast, dredging of the back-barrier and increasing its average depth and volume, introduces a larger tidal prism (de Jonge et al., 2014; Ridderinkhof et al., 2014). In reality, the annual tidal range variations and the meteorological state of the ocean are continuously changing the inlet cross-sectional area (FitzGerald, 1996). Therefore, finding a suitable cross-sectional area for the entrance channel, as well as an appropriate volume for the back-barrier lagoon (including the planar area and the average depth); can potentially lead to a stable inlet. This idea assists in designing alternatives to the current dredging strategy, explained below, and for further investigations.

Over the natural course of events, the volume of the back-barrier varies during each tidal cycle. If the majority of the intertidal area is covered by tidal flats, or when there is a significant elevation difference between the lands above and below the mean sea level (MSL), the volume of the back-barrier changes notably during the earliest hours of the rising (or falling) tide, resulting in non-linear filling (or freeing) of the back-barrier with water (Lincoln and FitzGerald, 1988; Zarzuelo et al., 2015). This phenomenon consequently, causes changes in the current velocity, due to the variable back-barrier capacity for the incoming flood- (or outgoing ebb-) tide (Fields and Ashley, 1987; Lincoln and FitzGerald, 1988), affects the amplitude and phase of the water level variation within the back-barrier (Ridderinkhof et al., 2014), and creates asymmetry in the flood/ebb dominance. These changes may result in stronger residual currents (Luo et al., 2013; Speer and Aubrey, 1985) and changing of the net sediment transport, as well as a varied exchange of sediment between the ocean and the back-barrier (Bertin et al., 2013; Carniello et al., 2012; Cleary and FitzGerald, 2003; Van Leeuwen and de Swart, 2002). The changes can also cause a switch from flood- to ebb-dominance (Jiang et al., 2013), when the inlet main channel progressively becomes shallower. The time of peak flood (or ebb) current velocities can also be affected by the rate of water level changes in the back-barrier, causing a phase lag between the water level and current velocity (Fields and Ashley, 1987; Hayes, 1980; O'Brien and Clark, 1974). Such a lag (typically) results in larger flood (ebb) discharge values and consequently higher flood (ebb) current velocities (Hinwood and Aoki, 2013). Accordingly, the lag can generate a differential tidal flow and produces residual mass transport (Aubrey and Speer, 1985; Brown and Davies, 2009; Jiang et al., 2013; Lincoln and FitzGerald, 1988). Therefore, altering the volume of the back-barrier can be investigated as one of the possible structural alteration scenarios, as detailed below. However, the ebb velocity may only marginally exceed the threshold erosive velocity and may not be effective in the movement of sediments (Brown and Davies, 2010).

Davis and Zarillo (2003) regarded the entrance jetties as "the first major construction practice that altered tidal inlets", demonstrating the very vital effect of them in management of the inlet. Depending on the average littoral drift direction, navigational needs and the volume of sediment involved in the bypassing process, jetty construction can encompass one or two legged, equal or unequal length, parallel or converge orientated jetties. In many projects, the adjacent beaches to these structures encounter significant erosion and/or deposition, due to the blockage or diversion of the littoral drift and starvation of the downdrift beaches, the amount of which is sometimes unpredictable (Hayes and FitzGerald, 2013; Kieslich, 1981). For the cases when one of the two jetties is longer than the other, stronger currents occur close to the longer jetty, the flood jet becomes less effective (in comparison with the equal-length jetties) in terms of scouring the entrance channel, and a seasonal reversal of sediment transport direction would result in a huge deposition of sediment between the jetties, as well as in front of the shorter one (Hughes, 2000; Militello and Hughes, 2000). Consequently, erosion alongside the longer jetty is also more likely to occur. As this type of length difference is critically important for an effective inlet system design; a more detailed discussion is presented in the below considered alternatives. In summary, the above-mentioned aspects and rationales provide a suitable ground for study of alternative design as explained in section 3.1 below.