Morphological evolution of the Nerang River Entrance ebb-tidal delta

Mahnaz Sedigh1*, Rodger Tomlinson1, Nick Cartright1 and Amir Etemad-Shahidi2

1Griffith Centre for Coastal Management
Griffith University, Gold Coast Campus, Australia
2Griffith School of Engineering, Griffith University, Gold Coast Campus, Australia

ABSTRACT


The Nerang River entrance is a tidal inlet that connects the Pacific Ocean to the extensive Gold Coast estuarine system known as the Broadwater. Due to relatively fast northward migration of the inlet from 1920 to 1985 and the importance of having a safe navigable channel, the inlet was stabilized with two training walls in 1986. A sand bypassing system was implemented upstream with an average sand bypassing rate equal to the estimated net northward longshore sediment transport in the area to prevent the formation of a bar across the entrance. However, historical analysis of survey data has shown an ongoing growth of the ebb-tidal delta at the river mouth. Thus, despite the sand bypassing system, costly dredging of the ebb-tidal delta is required to maintain safe navigation through the entrance. A number of studies have been undertaken to investigate sediment transport and hence morphological evolution. However, despite all the previous efforts, the cause of the ongoing ebb-tidal delta accretion is still not known with any degree of certainty. According to recent numerical modeling efforts, there is a considerable amount of longshore sediment transport leakage past the sand bypassing system, particularly during storm events. This paper will present a brief history of the dynamics of the Nerang River entrance since the early 1820s before reviewing historical sand volume analysis based on available survey data. An updated conceptual model will then be developed in order to better understand the morphological change in and around the Nerang River entrance area.

ADDITIONAL INDEX WORDS: Ebb-tidal delta, morphological evolution, tidal inlet.

INTRODUCTION

In the case of the Nerang River Entrance (NRE), which has been called the Gold Coast Seaway (GCS) since stabilization, and many other waterways that have entrance mouth infilling problems and navigation issues, it is crucial to understand the waterway dynamics and the different variables that affect their morphology. Since the late 1800s, there have been considerable variations in the location of the NRE due to the formation of sandbars around and within the entrance and its dominant northward migration attributable to the dominant northward wave-induced longshore current (Polglase, 1987). After the construction of the Seaway, despite the existence of a bypassing system, the growth of the ebb-tidal delta is still one of the main navigational safety concerns. There have been a number of studies that have examined the hydrodynamics in the vicinity of the GCS, such as that of Mirfenderesk and Tomlinson (2008). Moreover, a number of studies have also been carried out on the different factors that influence the morphological changes in the GCS area, history, hydrodynamics and morphological changes are briefly presented, then the morphological evolution of GCS in the past decade is discussed.

Background

The GCS is located on the Australian East coast and links an intra-coastal waterway known as The Broadwater with the Pacific Ocean (Figure 1). The available history of the case study starts from 1820’s when there was no permanent opening between the ocean and the Broadwater (Helman, 2010). In 1823, NRE was one of the two openings which formed at the most seaward meander bends of the Nerang River. Due to northern longshore sediment transport (LST), the southern opening was gradually closed, and the spit elongated to the north until the 1860’s. The entrance widened due to severe storms in the 1870’s and moved to the south about 1,300 m from 1840 to 1880’s and did not change its location until 1901 (Longhurst, 1996). There has been conjecture about the southward relocation of the entrance, such as that of WRL and GCCM (1998), in which it was suggested that this might have indeed been a southern breaching. Permanent opening of the Jumpinpin inlet further to the north in 1898 has captured much of the river and tidal flow which previously flowed south and outflowed at the NRE.

D’Agata and Tomlinson, 2004; Voisey, 2004; Patterson, 2007; Sennes et al., 2007). Nevertheless, the dynamics of the GCS and the development of the ebb-tidal delta are not completely understood. In this context, literature which has focused on the GCS area, history, hydrodynamics and morphological changes are briefly presented, then the morphological evolution of GCS in the past decade is discussed.
Consequently, the ebb tide flow in the NRE was decreased, and the tidal prism of the inlet was significantly reduced. As a result of the re-distribution of tidal flow, the entrance migrated to the north again after 1901 with an increased rate (Brooks, 1953; Munday, 1995). The rate of northward migration during this time has been variable, with an average rate of about 60 m/yr during 1901-1968, which slowed down in the last few years of this period (1944-1968) to 26 m/yr (DHL, 1970).

From 1901 to 1968, the average diversion of sand to the Broadwater from LST, which resulted in the spit elongation and northward migration of the entrance, was suggested to be approximately 143,000 m$^3$/yr, while there was about 9,000 m$^3$/yr riverine contribution to the ocean (DHL, 1970). It should be noted that during all these years, South Stradbroke Island beach alignment was stable. This means that the sand that was supplied from natural bypassing of the entrance was in equilibrium with the LST potential at South Stradbroke Island.

The developed and permanently dynamic entrance with a nearshore ebb-tidal delta, which had a crest depth of -2.5 to -3.5 m, was a dangerous obstacle which resulted in a number of boating accidents. Therefore, it was then decided to train the NRE to provide a safe navigation channel (Sennes et al., 2007). The entrance was relocated 500 metres updrift (south of) its natural location in 1985 and was stabilized with two rock walls with a design depth of 5.5 m below Australian Height Datum (AHD) at the time of construction (Munday, 1995). Due to the high magnitude of the northerly LST on the Gold Coast, a bypassing plant was implemented and completed in 1986 (Sennes et al., 2007).

The dredging of the stabilized channel was followed by dredging of the navigation channel in the Broadwater. Due to increased capability of the jetted ebb flow to move sediment seaward, and also reduction of sand supply to the entrance mouth, the ebb-tidal delta crest moved much further offshore as compared to the old ebb-tidal delta (Munday, 1995). Before stabilization, the natural ebb and flood shoals in shallow depths near the entrance attenuated the ocean tidal range by up to 60% within the Broadwater (WBM, 1992). Therefore, dredging and construction of the new entrance increased the tidal range in the Broadwater to that of the ocean coast, which resulted in the growth of the tidal prism and finally more channel scouring. The average depth in the GCS channel increased over the following 20 years, (Mirfenderesk and Tomlinson, 2009; Mirfenderesk et al., 2006). According to Mirfenderesk and Tomlinson (2009), the average depth of the inlet channel was about 11m in 2005, with a maximum depth of about 20 m at some points.

Analyses of historical survey data until 1997 have shown continuous growth of the ebb-tidal delta since the entrance was stabilized in 1985. There are various estimations of the rate of the ebb-tidal delta growth. WRL and GCCM (1998) analysis suggested that between 1986 and 1992 the average net rate of deposition on the ebb-tidal delta was around 185,000 m$^3$/yr which decreased to 75,000 m$^3$/yr from 1992 to 1998. Andrews and Nielslen (2001) also used historical survey data from 1986 to 1998 and estimated much higher delta growth rates which was initially around 450,000 m$^3$/yr, and then decreased to about 200,000 m$^3$/yr. Generally the growth of ebb-tidal delta was to the northeast, probably due to the combination of dominant waves (from the Southeast) and the mean ebb-tide discharge path to the delta (to the northeast). Some wave induced swash bars also formed on the southern part of the ebb-tidal delta. (Andrews and Nielsen, 2001).

Andrews and Nielsen (2001) suggested that the main source of sand for the continuous growth of the ebb-tidal delta was supplied by the leakage of sand seaward of the sand bypassing system (around 115,000 m$^3$/yr), and also partly through the bypassing jetty (around 80,000 m$^3$/yr). Mirfenderesk and Tomlinson (2008) also suggested that the crescent like seaward lobe of the ebb-tidal delta after stabilization, which has connected upstream to downstream, indicates that the LST partially transported naturally along with the artificial sand bypassing system. It has also been suggested that another probable source of sediment for the ebb-tidal delta was the redistribution of sand from the discharge location of the bypassed sand downstream. Scouring of the channel between 1990 and 1995 was initially at a rate of 100,000 m$^3$/yr and gradually diminished to about 10,000 m$^3$/yr. The scoured sediment was the other source of sand trapped in the ebb-tidal delta (Andrews and Nielsen, 2001). On the other hand, WRL and GCCM (1998) suggested that there are about 50,000 m$^3$/yr of natural bypassing on the ebb-tidal delta, while the major supply of sand to the ebb-tidal delta growth is from the broadwater input (0-240,000 m$^3$/yr). In this paper, the morphological evolution of the GCS ebb-tidal delta in the past decade was investigated and linked to the previous studies. The main purposes of the study were to understand the more recent pattern of the ebb-tidal delta morphological evolution, whether the ebb-tidal delta has reached or is close to an equilibrium condition, and also the factors involved in its more recent trend of changes.

**METHODS**

In order to understand the pattern of morphological evolution of the GCS ebb-tidal delta during the past decade, hydrographic survey data have been used. These detailed survey data of the entrance, with variable extensions to the north and south, mainly cover the ebb-tidal delta area and the GCS channel. The final survey data sets of 12 were selected based on the coverage of the data included, since some of the available sets did not cover the whole ebb-tidal delta area. The survey data used for the analysis...
Morphological evolution of the Nerang River Entrance ebb-tidal delta cover a period of 11 years from Jan 2004 to Apr 2015. The sets, in a year/month format, are as follows: 2004/01, 2004/07, 2005/07, 2007/04, 2008/08, 2009/06, 2010/07, 2011/03, 2012/03, 2012/09, 2013/07, 2015/04. Survey data of Dec 1997, which encompasses the major portion of the defined ebb-tidal delta, was also used to join the analysis of the WRL and GCCM (1998) to the current study.

The area of the ebb-tidal delta for volumetric analysis was defined based on the area with active morphological evolution from Jan 2004 to Apr 2015 as illustrated in Figure 2 (A1). To analyse the ebb-tidal delta growth as a continuation from the WRL and GCCM (1998) study, the volumetric change of the ebb-tidal delta between Dec 1997 and Jan 2004 was estimated. Since Dec 1997 survey data did not include a northern portion of the defined ebb-tidal delta area, this volume was enlarged relatively. The cumulative volume of the ebb-tidal delta for Dec 1997 compared to Mar 1997 (Last data set in the study of WRL and GCCM (1998)) was estimated based on the trend of volumetric changes of previous years. Dredging in the study area as well as the artificial sand bypassing volumes were also considered in the analyses.

Figure 2. Morphological evolution of the GCS, on the offshore extension of the GCWA survey data, from Jan 2004 to April 2015. A1 is defined as the area of ebb-tidal delta, and A2 is the GCS channel.

Measured wave data at the Gold Coast offshore wave buoy located about 1km offshore with a water depth of about 17 metres and about 3.5 km south of the entrance (Figure 1), as well as major flooding event dates and intensities were also considered. In order to analyse the effects of storm events, the storm events’ resultant wave power ($P_w$) between consecutive surveys were calculated (Vila-Concejo et al., 2004). Then, the total storm wave power for each storm was calculated from equation (1).

$$W_{tr} = P_{wm} \times D_s$$  \hspace{1cm} (1)

where $P_{wm}$ is the mean wave power for each storm event, and $D_s$ is the storm duration in seconds. The storm threshold used was defined as high energy events with $H_s > 3$ and a minimum duration of two hours. The storm events were also categorized to storm events with a dominant wave direction of less than 90 degrees (from North clockwise), and more than 90 degrees, which due to the approximate Northward-Southward direction of the GCS adjacent coastline can be assumed to generate southward and northward longshore sediment transport respectively. The storm events with dominant wave direction of less than 90 degrees were called north-east (NE) storm events, and the ones with dominant direction of more than 90 degrees were called south-east (SE) storm events.

RESULTS

The trend of the ebb-tidal delta cumulative volume evolution since 1980 is shown in Figure 3. The first two part of the graph was extracted from the WRL and GCCM (1998) report. The results show the ebb-tidal delta growth at an average rate of 12,500 m$^3$/month or 151,000 m$^3$/yr from Oct 1984 to Apr 2015.

As shown in Figure 2, the net growth of the ebb-tidal delta is more offshore, similar to a typical ebb dominated tidal inlet. The more northward orientation of the growth is due to the dominant northward longshore current owing to wave action. The ebb-tidal delta volumetric analysis in the WRL and GCCM (1998) report was dependent on the seaward extension of the survey data sets supplied by GCWA from February 1993 to March 1997 (last data point of WRL report in Figure 3). The seaward extensions of these data sets were less than the ones used in this study, which explains the suggested decreased rate of ebb-tidal delta growth for 1992 to 1998 (75,000 m$^3$/yr ) in the WRL and GCCM (1998) study.

Figure 3. Cumulative volume of the ebb-tidal delta since 1984 based on Department of Environment (DoE) and Gold Coast Waterways Authority (GCWA) survey data (left graphs); cumulative artificial sand bypassing volume since Jan 2004 (right graph).

There are several sand sources that may have supplied the sand for the ebb-tidal delta growth. Since stabilization, during past decades, the GCS channel (A2 in Figure 2) has kept scouring much more than its designed depth of 5.5 m. Since the tidal current in the GCS channel was found to be ebb dominated (Sedigh et al., under review), it can be concluded that the eroded sand was flushed to the ebb-tidal delta by the ebb tidal flow jet and trapped somewhere in the ebb-tidal delta shoal, depending on the combined action of tides and waves. Figure 4 shows the trend of the accumulative morphological changes in the GCS channel since 1984. It should be noted that there were some dredging activities in this area. The first one was a major dredging of the whole GCS and the northern and southern channels at the time of the GCS construction in 1985. There are two other recorded dredgings specifically within the inlet channel (A2 in Figure 2). These include 15,000 m$^3$ in 2009 and
about 65,000 m$^3$ in 2013. The second dredging is part of the reason for the major drop (erosion) from July 2013 to April 2015 shown in Figure 4. Including the dredging activities, the average rate of the inlet scouring from Oct 1984 to Apr 2015 was about 2,600 m$^3$/month or 31,000 m$^3$/yr, which is about 20% of the average accretion rate in the ebb-tidal delta.

An analysis by Mirfenderesk and Tomlinson (2009) has shown a flood-dominant tidal regime within the estuary of the Nerang River (Broadwater), and has suggested that any eroded sand in the Broadwater channels will remain in the estuary. However, the study by Mirfenderesk and Tomlinson (2009) has also shown that the estuary has become less flood-dominant in the past two decades, and it was suggested that as a result, more sand might be transported out of the estuary compared to previous years. For a more detailed study of the morphological evolution of the Broadwater and its effects, subsequent survey data of the whole estuary is required, which is not available at this stage.

Another source of sediment for the ebb-tidal delta is from the leakage of the LST offshore sand-bypassing system and the southern training wall. However, there are significant differences between the rates suggested for this source in previous studies, which ranges from 50,000 m$^3$/yr (WRL and GCCM, 1998) to 195,000 m$^3$/yr (Andrews and Nielsen, 2001). Sedigh et al. (under review) suggested that the main drivers of LST in this region are SE storm events. Therefore, to investigate the relationship between the ebb-tidal delta growth and the storm events further, the cumulative $W_{pt}$ for NE and SE storms for each time interval were calculated and plotted versus the volumetric change of the ebb-tidal delta, as shown in Figure 5.

As illustrated, the accretion in the ebb-tidal delta was more significant in the Jul 2005-Apr 2007, Aug 2008-Jun 2009, and Mar 2012-Sep 2012 intervals, during which the accumulated SE storm event powers were more significant, and at least one significant SE storm event with $W_{pt} \geq 3 \times 10^7$ (W.s/m) occurred as well. However, it should be noted that the rate of deposition was not proportional to the cumulative (SE) $W_{pt}$ in these intervals, which is due to the effect of the length of intervals, the dominant direction of waves during lower energy wave conditions, and the recovery process after dredging activities. In addition, in the time intervals where the cumulative $W_{pt}$ from NE was more dominant, erosion occurred in the ebb-tidal delta; the exception was Jul 2004-Jul 2005, during which a major flood event with a return period of about 1 in 20 years occurred at the end of June 2005. Also of note is that the more significant erosion in Mar 2011-Mar 2012 was due to approximately 260,000 m$^3$ dredging from the ebb-tidal delta area from May 2011 to March 2012. As shown in Figure 5, in the time intervals where the cumulative $W_{pt}$ from the SE and NE were approximately the same, the ebb-tidal delta net morphological evolutions were negligible.

DISCUSSION

Figure 3 and Figure 4 suggest that the GCS region is still in a transitional zone, and has not reached an equilibrium yet. Also, the trend of the ebb-tidal delta evolution since 2004 does not show any decrease in the average rate of the ebb-tidal delta growth compared to the study of WRL and GCCM (1998). The average artificial sand bypassing rate from Jan 2004 to Apr 2015 was about 650,000 m$^3$/yr (Figure 3) which ranged from 480,000 m$^3$/yr in 2004 to 770,000 m$^3$/yr in 2011. The max rate of delta growth during these years was approximately 620,000 m$^3$/yr, which occurred from Aug 2008 to Aug 2009 when about 600,000 m$^3$/yr sand bypassed artificially. Assuming that the coastline alignment has remained stable during these years, and no leakage has occurred in 2004 (since no accretion occurred in the ebb-tidal delta) it can be concluded that the net northward LST updrift the entrance varies from $4 \times 10^2$ to $1,050 \times 10^3$ m$^3$/yr. This rate is extremely dependent on the frequency of the major SE storm events.

As explained and shown in Figure 5, the rate of ebb-tidal delta growth was much higher during the intervals which included major SE storm events. It is suggested that this was due to the more offshore extension of the resultant significant northward LST during these events. The governing relationship found between the occurrence of the major SE storm events and the ebb-tidal delta growth confirms that the prevailing source of sand for the continuous growth of the ebb-tidal delta is from the dominant northward LST, specifically during storm events. It is suggested that the leakage of LST seaward of the southern
training wall also occurs during calm weather conditions due to the dominant northward wave direction, but it is much less compared to the storm events.

The suggested conceptual model of the sediment transport from Jan 2004 to April 2015 is shown in Figure 6. It should be noted that this conceptual model is based on the assumption of no changes in the coastline alignment during these years.

**CONCLUSIONS**

The morphological evolution of the GCS ebb-tidal delta in the past decade was investigated. The results confirm the continuous growth and extension of the ebb-tidal delta offshore. However, the rate of ebb-tidal delta growth during various time intervals is quite variable. This rate is the highest during the intervals with major SE storm events. This shows that a significant portion of the ebb-tidal delta growth is storm-event based. Other less significant sources of sand to the ebb-tidal delta were found to be from the scouring of the inlet channel, some offshore sand supply, as well as sediment from within the eustuary in the case of major flood event. Based on the analysis of available data, a conceptual model of sediment transport has been presented. For a more precise analysis, further subsequent survey data of the Broadwater as well as detailed survey data of the adjacent coastlines are required.

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**LITERATURE CITED**


