INFILLING AND SAND BYPASSING OF COASTAL STRUCTURES AND HEADLANDS BY LITTORAL DRIFT

Alessio Mariani, James Carley and Brett Miller
Water Research Laboratory, School of Civil and
Environmental Engineering, University of New South Wales, Australia

ABSTRACT

Every coastal structure that interrupts the natural littoral drift will eventually be filled to capacity and sand will start bypassing. Meanwhile, the down-drift area may erode and up-drift the beach may accrete. With sea level rise, the conditions of sand bypassing structures and headlands may change with significant impacts to the adjacent coastline. One of man's earlier attempts to stop coastal erosion consisted of constructing groynes running normal to the coast and retaining sand being otherwise transported by longshore current. An historical review of the coastline in Australia has found that most of the groynes have been either "drowned" by sand or "flanked' by water. Many river mouths in Australia have been trained, with training works consisting of breakwaters protruding perpendicularly from the coastline. The purpose of these training walls was to fix the position of the entrance and increase the navigability of the river entrance. A quick bird's eye view of our coastline today shows that many trained entrances are affected by sand bypassing, sand infilling and bar formation causing a decrease in navigation depths and an increase in wave breaking at the entrance, which presents a hazard for boats. In this paper we illustrate through a case study a state-of-the-art methodology to estimate littoral drift and sand bypassing of structures and headlands in the absence of dredging records or sand impoundment measurements. The methodology applies wave modelling (WAVEWATCHIII and Simulating Waves Nearshore, SWAN model), littoral drift modelling (Unibest and Kamphius) and a bypassing model (Bijker model). An accurate understanding of the littoral drift and sand bypassing processes allows optimisation of structures and their effect on adjacent beaches. Coastal managers and planners are then able to predict bypassing rates and future infilling of the structure while planning for dredging operations and/or artificial sand bypassing systems.

Keywords: Littoral Sediment Transport, Sand Infilling, Downdrift Erosion, Bypassing Rates, Groyne, Training Wall, Coastal Modelling

Introduction

Any interruption of the natural littoral drift along the coastline may change the coastal alignment. The construction of a harbour for example, on a shoreline with significant longshore transport may impede the natural drift of the sediment past the harbour breakwaters with consequent starving of the beaches down-drift and conversely accretion of the up-drift area. While the latter may cause siltation of the harbour entrance, the former will be observed as erosion of the beaches. In both cases the adverse effects of the longshore drift disruption may require remedies such as dredging operations to ensure safe access to the harbour, construction of groynes and seawalls to stop erosion, or sand bypassing systems to re-install the natural littoral transport. The knowledge of the sediment transport processes is essential in the design phase to prevent negative effects on the adjacent coastline as well as to plan for effective mitigation of the impacts of existing structures.

Structures or natural formations that protrude seaward from the shoreline disrupt the longshore sediment transport by retaining sand on the up-drift area. Groynes and detached breakwaters utilise this concept to prevent shoreline erosion. Similarly, training walls stabilize river entrances and tidal inlets for navigation by preventing sand from depositing in the channel. In 1977, a review of the coastline in Australia by Riedel and Fidge (1977) found that most of the groyne fields had been either "drowned" by sand or "flanked" by water. Presently, the knowledge in the design of groynes has increased considerably, nevertheless their effectiveness is still matter of debate and, if they locally succeed in preventing shoreline recession, they also transfer the erosional problem to the down-coast. Most of the river mouth training walls in NSW were completed by 1950 with the focus on the channel stability and little thought on the disruption to the longshore transport and impact upon adjoining beaches (Floyd, 1968). As a result many entrances are now affected by sand bypassing and bar formation. When the up-drift area is in-filled to capacity, sand starts bypassing the up-drift training wall forming a bar across the entrance. As a consequence, the water depth decreases and waves start breaking at the entrance presenting a hazard for navigation. Periodic dredging of the channel is then necessary to maintain a navigable entrance.

This paper illustrates through a case study a state-of-the-art methodology to assess local littoral transport and sand bypassing of coastal structures and natural formations. The estimate of the littoral transport is usually made through the analysis of dredging records, historical bathymetric survey and field measurements of sand impoundments. While these data are not always available for any particular study site, the assessment of the littoral transport rates can be reliably inferred from the offshore wave climate. Waves are ultimately responsible for the sediment transport and annual sediment transport rates can be calculated using established transport formulae coupled with the annual compilation of wave data.

Methodology

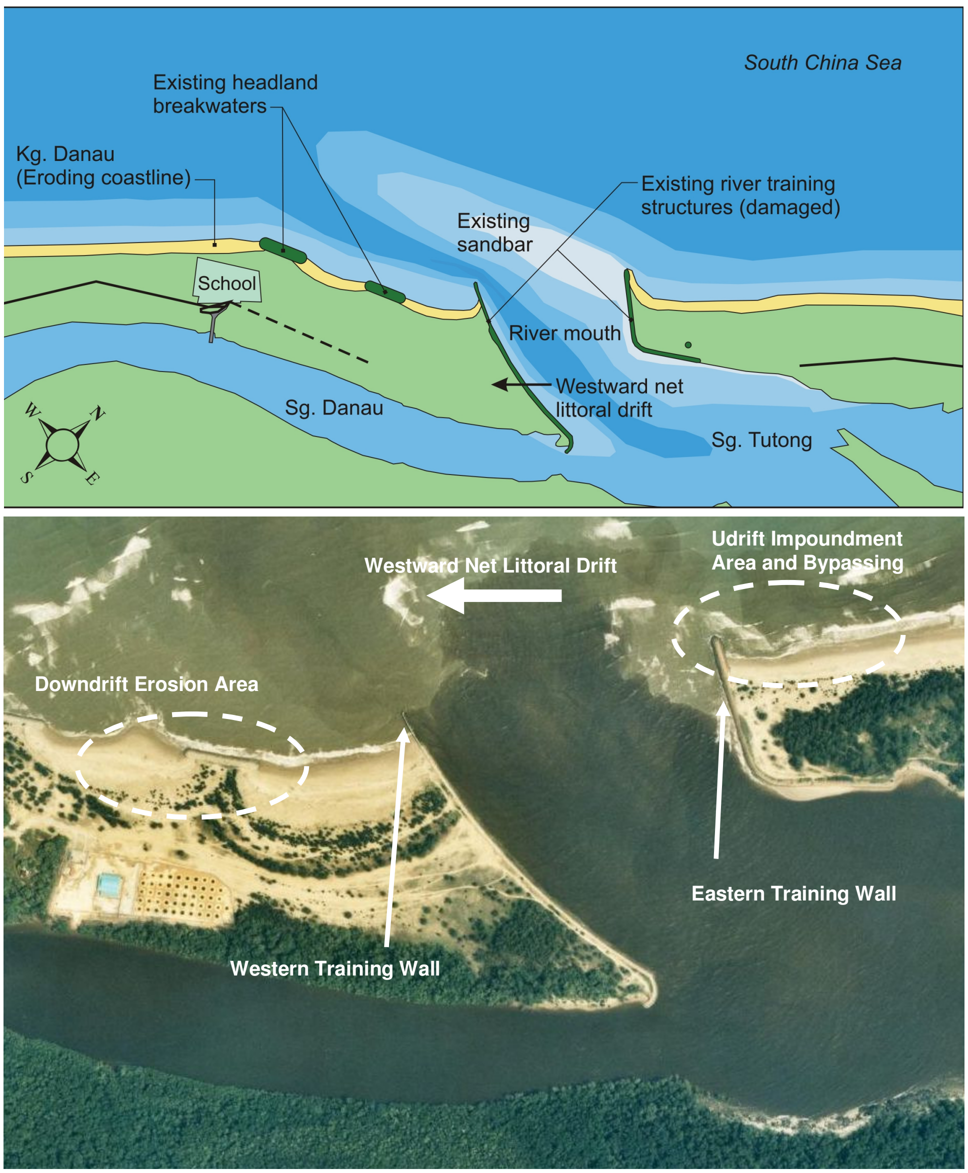
Waves and currents move sand cross-shore and longshore in the surfzone. For engineering purposes, the two processes (longshore sediment transport and cross-shore sediment transport) are usually assessed separately as their physical processes, timescale and magnitude are different. The noticeable effect of the cross-shore sediment transport evolves over hours to days to weeks, whereas for longhshore sediment transport it occurs over seasons and years. The longshore sediment transport is responsible for sand infilling and bypassing of structures at a particular site and it is described by annual or seasonal net and gross longshore rates expressed in m^3 per year.

The longshore transport cannot be measured directly and it is usually indirectly estimated through measures of sand impoundment at coastal structures and sand deposition in inlets and entrances (when available). The methodology presented in this paper does not need field measurements as the longhshore transport rates are inferred from the deep water wave data transferred to the nearshore. The methodology comprises the following steps:

- Long term (10 to 50 years) hindcast wave time series are acquired from global wave model output, for instance the wave model WAVEWATCH III (WW3) by the National Oceanic and Atmospheric Administration of National Weather System (NOAA-NWS) and/or the ERA 40 dataset by the European Centre for Medium-Range Weather Forecasts.
- A regional and local wave model is established for the study area using the nearshore wave model SWAN (Simulating Waves Nearshore by Delft Hydraulics, Netherlands). The deepwater wave climate is therefore propagated to the nearshore coastal waters where waves mobilise the sand and create the longhsore currents responsible of the sand drifting alongshore.

• Based on the long term dataset, annual longshore transport rates are calculated using the established Kamphuis/Queens (Kamphuis et al. 1986) transport formula. The Kamphuis/Queens formula calculates the sediment transport rate for the entire surfzone based on physical parameters such as wave height, period and angle, sand grain size, bathymetric slope.

• The Bijker sand transport model (Bijker, 1971) is then used to obtain the cross-shore distribution of the sediment transport. As the sediment transport rates are not constant across the surfzone (they are typically higher in the breaker zone), the Bijker model allows the estimation of the sand bypassing rates for structures built across the surfzone.



Aerial Photography 2002 (Courtesy Ove ARUP)

Figure 1. Tutong River Entrance - Brunei

Application to a case study – Tutong River entrance Brunei

Site Description

The Tutong River entrance, situated on the central part of Brunei coastline presents navigational problem due to a sandbar growth obstructing the majority of the channel cross-sectional area and subsequently restricting navigability in and out the river. The existing western training wall is damaged, while the eastern one is filled to capacity by the predominant westward littoral drift of sand.

The sand now bypasses the eastern training wall causing the sandbar formation while the area down-drift the river entrance has suffered erosion. The erosion is due to the interruption of sediment supply from the eastern area up-drift the entrance (Figure 1), however, with bypassing the rate of erosion may have reduced.

The Water Research Laboratory (WRL) of the University of New South Wales provided specialist advice in the engineering design of the Tutong River training works for the stabilisation of the river mouth. The construction and extension of the Tutong entrance training walls will necessarily obstruct the littoral transport of sediment across the river mouth. In order to determine the seaward extent of the entrance training walls, it was necessary to investigate the littoral sediment transport rates at Tutong. Higher transport rates would imply greater seaward extent of the training walls (and higher associated construction costs) to avoid sand bypassing the walls and subsequent channel navigational and operational issues.

Wave Transformation Modelling

A dataset of 12 years of offshore WW3 hindcast wave model output was obtained and analysed by WRL. The data consisted of a time series of significant wave height, peak spectral wave period and mean wave direction at 3 hour intervals. The offshore wave climate was then propagated nearshore using SWAN.

The deepwater WW3 model predictions were checked against the ERA 40 hindcast data set while the nearshore SWAN predictions were validated using wave measurements collected in several locations. As a sample of the verification, Figure 2 shows predicted and measured significant wave height for a given period of analysis. Good agreement was found between measured and predicted data especially during the peak of storm events.

The wave modelling allowed characterisation of the nearshore wave climate in the coastal waters fronting the Tutong River mouth. Wave roses were generated for the offshore and nearshore significant wave heights and are shown in Figure 3. It can be observed how the waves undergo reduction in wave heights and a general realignment parallel to the shore normal direction (approximately 310 deg TN) with waves from the north generally resulting in a greater angle of approach to the coast.

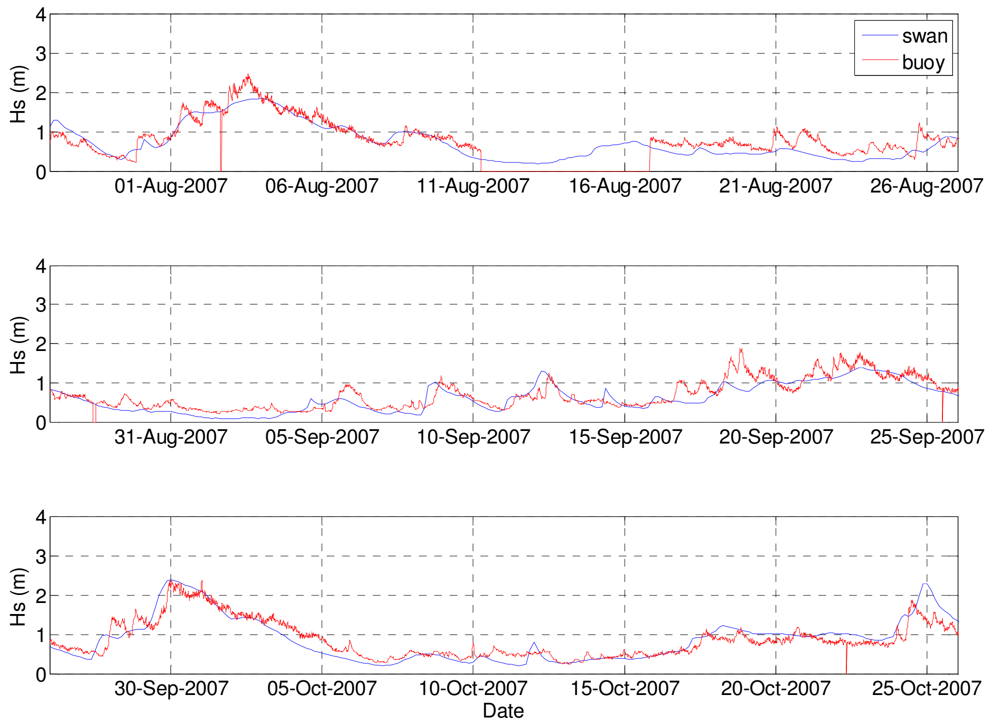


Figure 2. Predicted and Measured H_s at Champion Shoals Location

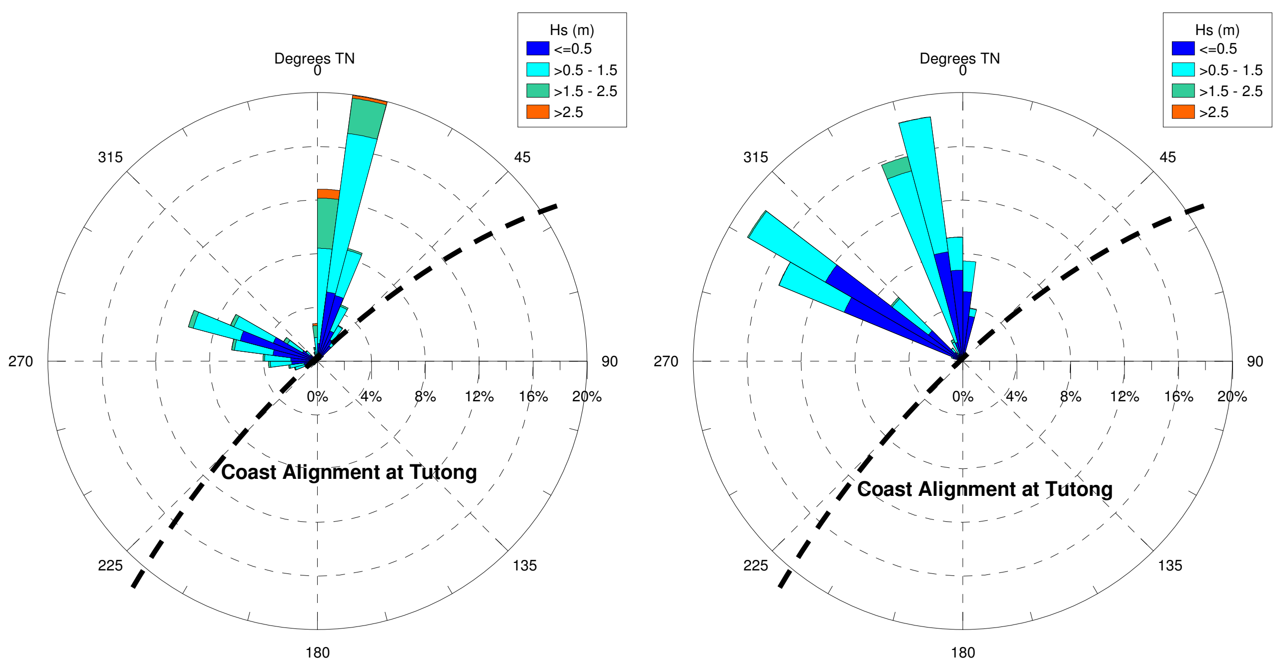


Figure 3. Offshore and Nearshore Wave Roses – Significant Wave Height

Littoral Sediment Transport

The wave transformation modelling output was used as the input for the Kamphuis formula. The wave transformation modelling results consisted of a 12 year (from January 1997 to March 2009) time series at 3 hour intervals of wave height, period and direction in the nearshore coastal waters of Tutong River entrance. For every 3 hour time step, an estimated transport rate (S in m^3/s) was calculated and annual transport rates were then derived. The eastward and westward sediment transport rates from 1997 to 2008 as well as the net sediment transport rates ($S_{westward}$ - $S_{eastward}$) are presented summarised in Table 1.

A mean net sediment transport towards the west of approximately 49,000 m^3/yr was estimated with 75,000 m^3/yr of sand being transported towards the west and 26,000 m^3/yr towards the east. Moreover the annual variability shows that the net littoral drift varied from approximately 27,000 to 66,000 m^3/yr owing to the annual variability in wave climate, but was always westward. Previous studies based on field measurements estimated net littoral drift at the Tutong River entrance to 30,000 – 50,000 m^3/yr which confirmed the findings of this study.

Table 1. Littoral Sediment Transport Characteristics

Year	**Net Sed. Transport (westward)** (m^3/yr)	**Gross Sediment Transport** (m^3/yr)	**Eastward Sediment Transport** (m^3/yr)	**Westward Sediment Transport** (m^3/yr)
1997	27,419	62,149	17,365	44,784
1998	36,067	72,942	18,438	54,505
1999	49,169	111,697	31,264	80,433
2000	41,719	106,310	32,296	74,015
2001	34,615	103,558	34,472	69,087
2002	37,735	96,136	29,201	66,936
2003	55,562	110,516	27,477	83,039
2004	55,164	108,855	26,846	82,009
2005	59,801	101,570	20,885	80,685
2006	57,697	103,790	23,047	80,743
2007	65,478	115,280	24,901	90,379
2008	65,702	114,969	24,633	90,335
Mean	48,844	100,648	25,902	74,746
St.Dev.	12,945	16,590	5,409	13,861

Sand Bypassing Curves

The Kamphuis/Queens formula estimates the total sediment transport rate over the entire surfzone. However, the sediment transport rates are not constant across the surfzone depending on the combined effect of wave breaking and longshore currents. The cross-shore distribution of the sediment transport rate is necessary to optimise the length of the training walls in order to reduce the sand bypassing and the subsequent entrance shoal formation.

Bijker's sand transport model (Bijker, 1971) was used to obtain the cross-shore distribution of the sediment transport based on the total transport rates previously calculated using Kamphuis/Queens. The Bijker formula was implemented at every 3 hour time step over the 12 years dataset and bypass rates were calculated for water depths from 0.5 to 3.5 m with 0.5 m increments. Annual tide levels were generated (from constituents based on tidal analysis) for the 12 years period (January 1997 to December 2008) and coupled with the bypass rate estimates at every 3 hour time step. Actual sand bypassing rates were estimated at the isobaths from 2 m BSD (Brunei State Datum) to -3 m BSD with 0.5 m increments. Mean (averaged over the 12 years period) annual bypassing rates towards the east and west of the Tutong entrance are presented in Figure 4.

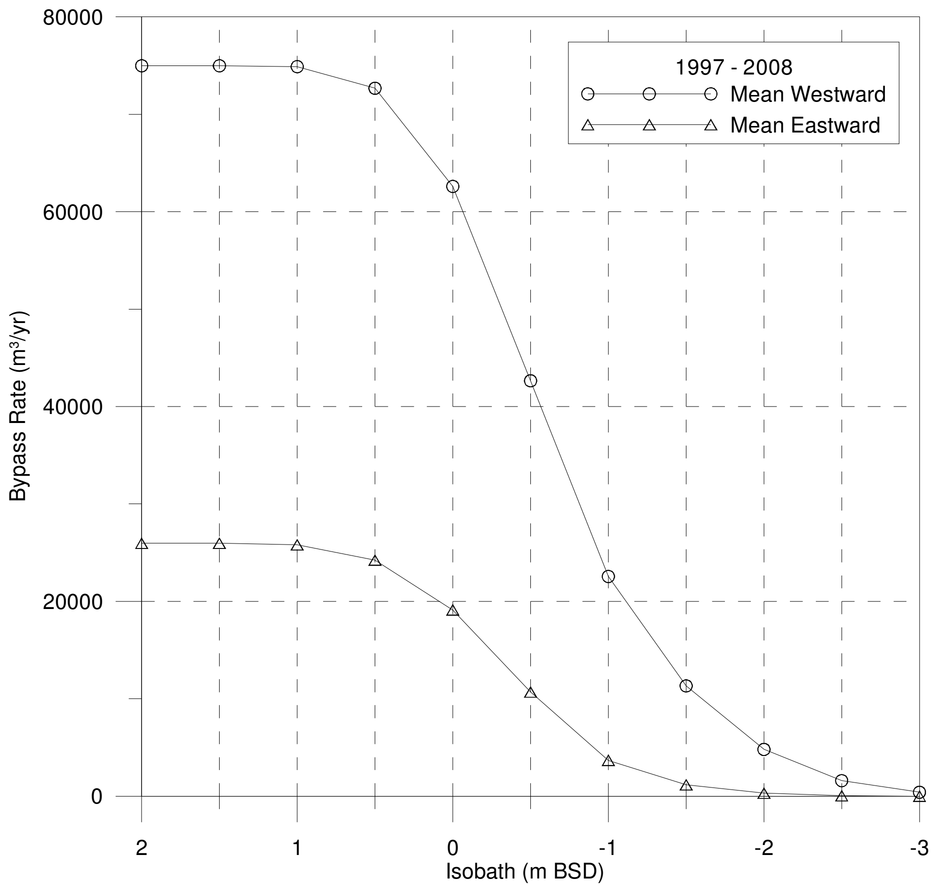


Figure 4. Sand Bypassing Rates Mean from 1997-2008

The curves presented in Figure 4 show that by extending the eastern training wall beyond the -2 m BSD (Brunei State Datum) contour and the western training wall beyond the -1 m BSD, the annual sediment bypassing rates would be reduced to below 5000 m^3/yr. If the eastern and the western training walls were to be extended to -3 and -2 m BSD respectively then minimal sand would bypass the river entrance. The above analyses represent best current engineering practice but do not consider sediment transport and bypassing which may result from rips which form along the training walls.

Conclusion

Any interruption of the natural sediment drift along the coastline will impact the adjacent beaches. The up-coast beaches accrete while the down-coast ones erode. A methodology to estimate the littoral transport and sediment bypassing rates in the absence of field measurements was presented in this paper through the application to a study case.

The knowledge of the sediment transport processes is essential to the correct engineering design of any structure that protrudes into the surfzone such as groynes, detached breakwaters and trained river entrances. Moreover, the analysis of annual sediment transport rates enables the planning for dredging operations as maintenance of existing river entrances and inlets, and the design of artificial bypassing systems.

As sea level rise may modify the dynamics of sediment transport along the coastline and sediment bypassing existing structures and natural formations, the knowledge of the sediment transport processes will be necessary for the assessment of the likely impacts on the adjacent shoreline.

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