Assessment of Capital Works Options to Mitigate Shoaling at the Mooloolaba Harbour Entrance

Matthew Barnes[1], Ian Teakle[1], Peter Wood[2] and Chris Voisey[2]
[1] BMT WBM, Brisbane, Australia; matthew.barnes@bmtwbm.com.au
[2] Queensland Department of Transport and Main Roads, Brisbane, Australia

Abstract
A numerical modelling tool used to assess the performance of various capital works options designed to mitigate shoaling at the Mooloolaba Harbour Entrance is presented. The tool is underpinned by numerous calibration datasets, including a unique shoal evolution dataset developed from a sequence of hydrographic surveys undertaken by the Queensland Department of Transport and Main Roads (TMR). An eastern breakwater extension is shown to successfully intercept the design shoal event and significantly reduce the navigational hazard within the entrance. The tool is also used to optimise the breakwater extension design, reducing the required rock quantity and thereby minimising the estimated cost of any potential capital works strategy. Finally, it is predicted that an eastern breakwater extension would reduce the supply of sand to the adjacent downdrift shoreline within Mooloolaba Bay. A high-level assessment of a number of sand bypassing methods suggests a crane-mounted jet pump to be the most economically and operationally-viable impact mitigation method.

Keywords: sediment transport, entrance shoaling, coastal structures, numerical modelling

1. Introduction

The Mooloolaba Harbour is located at the Mooloolah River entrance, Sunshine Coast, Australia. The harbour is the base for the Brisbane Marine Pilots, two commercial marinas, commercial fishing fleets and a major launching point for recreational vessels.

The Queensland Department of Transport and Main Roads (TMR) manage the harbour entrance. The primary management objective is to maintain a navigable entrance with a minimum channel clearance of 2.5 m below LAT (however an operating depth of 3 m below LAT is preferred). Occasionally these objectives are not met due to episodic shoaling; with notable events in the early 1970s, 1985 to 1987, 1996, 2003/04, 2008 and 2011 to 2013.

The sequence of coastal processes understood to cause a significant entrance shoaling event were originally described by the Department of Harbours and Marine [3] who suggested sand bypassing mechanisms at Point Cartwright contributed to the “stockpiling” of sand deposits that can then move toward the entrance under certain wave conditions. This conceptual model illustrated in Figure 1 was generally supported in a subsequent investigation by WBM Oceanics [11].

Due to the relatively infrequent nature of the shoaling events, TMR adopted a reactive strategy to maintain the design depth of the entrance channel. The approach uses a "shoal indicator” tool originally developed by WBM Oceanics [12], along with monitoring of seabed changes via hydrographic surveys as an early warning system so that dredge equipment can be mobilised to mechanically move sand from the entrance. A detailed summary of the study area and the performance of the shoal indicator over an eight year period were recently provided in [10].

Figure 1 Conceptual model of sand bypassing at the Mooloolaba Harbour Entrance (modified from: [3])

Local geological constraints and wave conditions mean that the sand must enter the navigational channel before it can be intercepted effectively by a dredge. This weakness of the strategy was recently exposed (in terms of operation and cost) during a particularly persistent shoaling event that started during April 2011 and continued into early 2013. This event prompted an investigation of potential alternative capital works options for the harbour entrance. This paper describes the numerical modelling tools developed to test modified entrance configurations and the outcomes of this investigation.

2. Methods

2.1 Numerical Modelling System

The coastal processes modelling system developed to assess both the existing entrance configuration and proposed capital works options was comprised of:

- SWAN spectral wave model (third-generation), for example see [4];
- TUFLOW FV hydrodynamic model (2D mode) [2]; and
- TRANSPOR sediment transport model [9].

A dynamic 2-way coupling between the SWAN wave model and TUFLOW FV was implemented to provide the necessary littoral zone forcing of currents by the waves, as well as to provide temporally and spatially varying bed elevation, water level and current fields to SWAN. The dynamic 2-way coupling of SWAN and TUFLOW FV only occurred within an inner, 25 m resolution nested SWAN model of the nearshore region at the entrance. Outside this region an un-coupled wave model forcing from a 100 m resolution SWAN model was applied, which did not include dynamic variations in bed elevation, water level and current fields.

The short wave derived radiation stress gradients provide a source of momentum to the hydrodynamic model which primarily drives the longshore currents in the surf zone. In addition the short wave motion Stokes drift induces an additional mass transport in the direction of wave propagation that is applied to the hydrodynamic (long wave) model. Along an approximately straight and uniform coastline, the onshore mass transport is approximately balanced by an offshore directed current (or "undertow"). The short wave model also provides wave parameter fields (*Hsig*, *Tp*, *Dir*) to the TUFLOW FV sediment transport module.

The TRANSPOR model was used to predict sediment transport within TUFLOW FV. TRANSPOR is capable of representing multiple fraction sediment transport including wave and current related bedload and suspended load. The calculated bedload component is a direct input to the TUFLOW FV morphological bed update scheme, while the suspended load component is converted to an equivalent sediment pickup rate following Nielsen [6], which provides a suspended sediment source term to the TUFLOW FV water column advection-dispersion scheme (and corresponding sink term to the bed). Suspended sediment settling provides a sink term to the water column (and corresponding source term to the bed).

TRANSPOR represents the interaction of both current and wave related sediment transport. The presence of waves can enhance sediment pickup and therefore also the rate of transport by the local currents. TRANSPOR also includes the prediction of wave-related sediment transport due to processes such as wave velocity skewness and wave boundary layer streaming. These (and other) processes can generate a net transport in the direction of (or against) wave travel, even in the absence of a local current.

For the assessments described in this paper, a single sand fraction with median grain size D_{50} = 0.22 mm was adopted for sediment transport modelling. The initial condition bed mass corresponded to a 0.5 m thick layer of sand throughout the model domain. This assumption was based on previous investigations of the sand layer thickness in the vicinity of the entrance during non-shoaling periods. The initial condition model bathymetry was obtained from a Digital Elevation Model (DEM) created using a 2011 bathymetric LiDAR survey of the study area [7].

The internal routines in TRANSPOR were used to calculate bed roughness values based on sediment and hydrodynamic parameters. All other parameters adopted the default values described in [9], except that a calibration factor was applied directly to the total sediment transport as described in Section 2.2.2.

2.2 Model Calibration

The period December 2011 to May 2012 (during the 2011 to 2013 shoaling event) was used to calibrate the coastal processes modelling system. It was estimated from hydrographic surveys that approximately 100,000 m^3 of sand bypassed the entrance during this period. Key aspects of the coastal processes modelling system calibration are described below.

2.2.1 Waves and hydrodynamics

The wave and hydrodynamic components of the modelling system were calibrated using Mooloolaba Waverider buoy and storm tide gauge timeseries data provided by the Department of Science, Information Technology and Innovation. Additional boat-mounted Acoustic Doppler Current Profiler (ADCP) flow measurements obtained at the harbour entrance were used to verify the tidal exchange within the Mooloolah River estuary. Hydrodynamic and wave model calibration plots are show in Figure 2 and Figure 3. These standard coastal processes model calibration procedures are not described further here (the author may be contacted for further information).

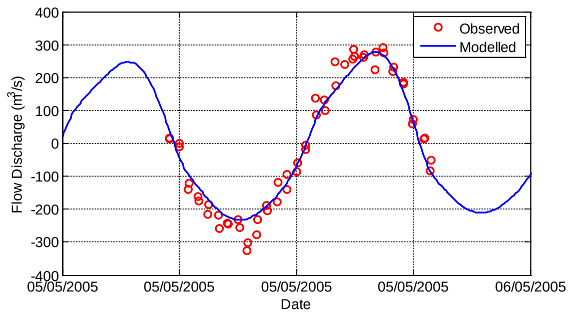

Figure 2 Mooloolaba Harbour tidal exchange calibration with ADCP flow measurements

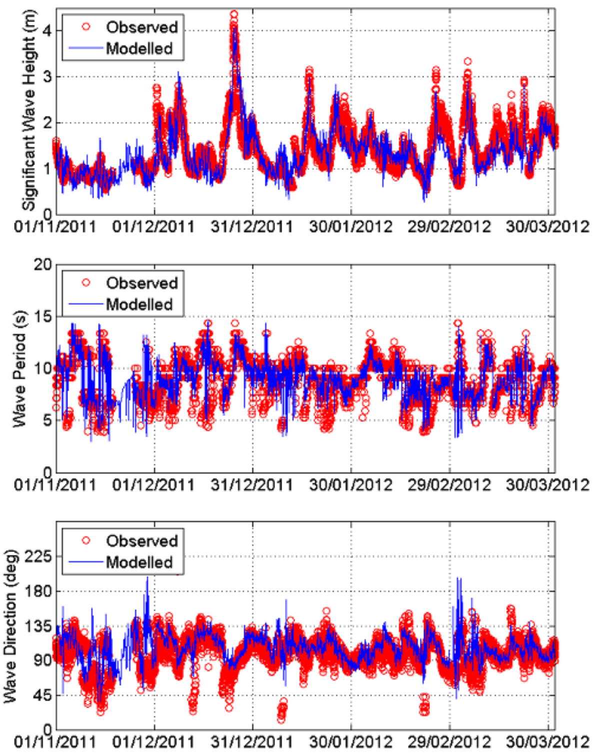

Figure 3 Wave model calibration with data from the Mooloolaba Waverider buoy

2.2.2 Sediment transport and morphology

Detailed sediment transport and morphology model calibration is often neglected due to difficulties associated with acquiring reliable datasets. Of particular interest to this paper is the sequence of hydrographic surveys undertaken by TMR between December 2011 and May 2012 during the persistent shoaling of the harbour entrance. The surveys were required to identify a navigable channel and were captured at approximately weekly intervals. A sequence of DEMs were created from the hydrographic survey data and used to estimate instantaneous shoal volumes. This information provided a means to quantitatively assess the predictive skill of the morphology model.

2.2.3 Shoal Calibration Event

The predicted shoal volume time series is compared to the observed volumes in Figure 4 and the observed and predicted shoal morphology at an instant during the calibration period is also qualitatively compared in Figure 5. The polygon shown in Figure 5 defines the area adopted to estimate the shoal volume. The morphology model predicts the general trend of sand accumulation during the calibration period and the difference between the observed and predicted instantaneous shoal volume is often less than 10%. The over prediction in shoal volume at certain times can be partly attributed to the limited volume of sand removed by maintenance dredging. This sediment sink was not considered in the modelling.

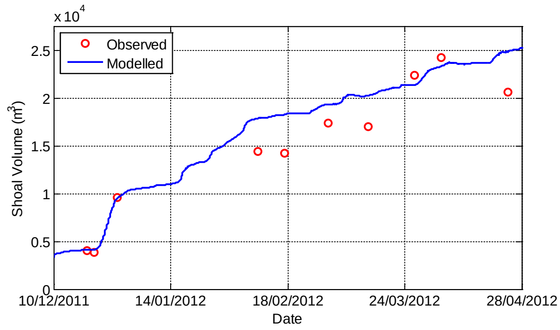

Figure 4 Shoal volume comparison between December 2011 and April 2012

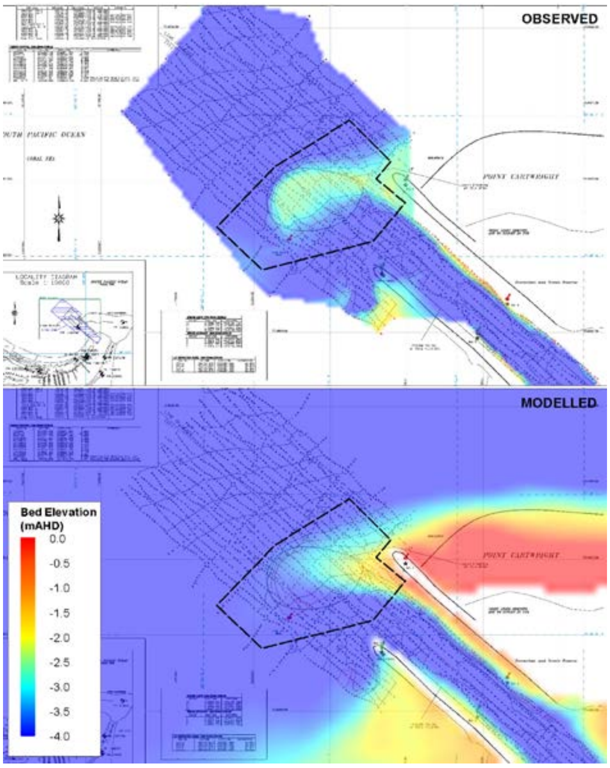

Figure 5 Qualitative shoal comparison on 13/03/2012: observed (top) and predicted (bottom). Dash-line polygon used to estimate shoal volumes in Figure 4.

As mentioned in Section 2.1, the default values described in [9] were adopted for sediment transport modelling. The only exception was the application of a 0.25 scale factor applied in both the bedload and suspended load sediment transport formulae. The application of the morphology model also adopted a 20 degree underwater critical bed slope.

3. Results

The persistent shoaling period between December 2011 and May 2012 adopted for model calibration was also the "design" event used to assess the effectiveness of various capital works options. The following assessment criteria are of interest to this paper:

1. Maintenance of navigation channel to a minimum depth of -3.0 m LAT (equivalent to -4.0 m AHD); and

2. Impact to Mooloolaba Spit and "natural" sand bypassing of the entrance.

In addition, an assessment of sand accumulation at the eastern breakwater was also completed to establish whether sand was being trapped in a manner that would allow mechanical bypassing to occur (discussed in Section 4).

3.1 Navigation Channel Depth

In order to establish the "baseline" conditions, the assessment criteria were first applied to the existing entrance configuration. The baseline assessment results provide the basis for the capital works options to be assessed against.

The top panel in Figure 6 shows the predicted baseline shoal and choked entrance channel at the end of the 2011/12 assessment period. The shoal position and alignment is typical of historical shoaling events that occurred in 1985 to 1987, 2003/04 and 2008; however, the shoal volume during this more recent event was larger than previously observed. During such events the navigation channel has been re-aligned to the west of the entrance in order to maintain navigable depths. This channel configuration is operationally difficult for harbour users, particularly when wave breaking occurs across the shoal.

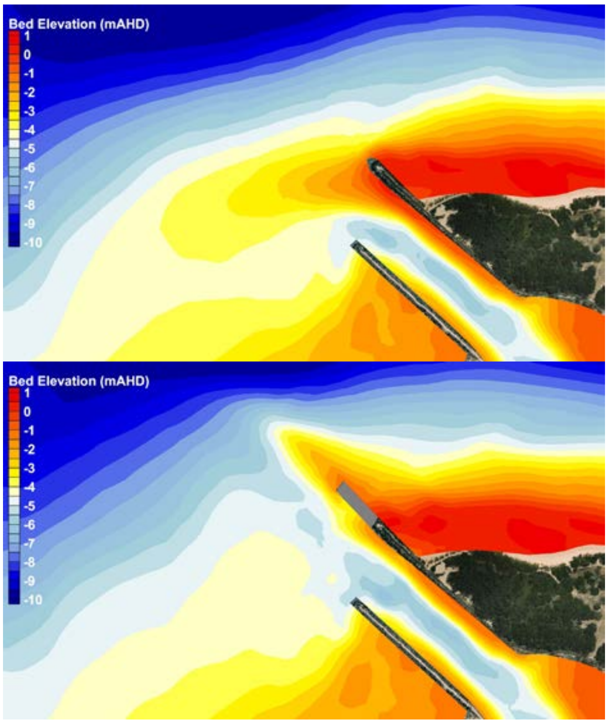

Figure 6 Predicted shoal location for the "baseline" (top) and "optimised" (bottom) entrance configurations

Numerous capital works options, focused on an eastern breakwater extension, were assessed using the numerical modelling system. Each capital works option tested with the tool was shown to maintain a navigable channel with depth greater than -3 m LAT (equivalent to -4 m AHD) during the design event. A capital works optimisation procedure was subsequently undertaken and focused on reducing the required rock quantity and thereby minimising the estimated cost of any potential breakwater extension strategy. The bottom panel in Figure 6 shows the proposed "optimised" capital works configuration, represented by a 60 m extension to the existing eastern breakwater. For this configuration shoal development is predicted offshore from the extended breakwater. Sand accumulation within the channel is significantly reduced in comparison to the baseline condition.

3.2 Natural Sand Bypassing of the Entrance

The longshore sand transport processes that contribute to bypassing of Point Cartwright and infrequent shoaling at the Mooloolah River entrance also supply sand to Mooloolaba Bay (refer to conceptual model in Figure 1). Modification of the entrance has the potential to interrupt the sediment transport pathway to Mooloolaba Bay, which unmitigated is likely to cause undesirable shoreline recession impacts.

In order to consider the potential changes in sand transport rates to Mooloolaba Bay, the volume of sand passing the western breakwater (to an offshore depth of -10 m AHD) during the 2011/12 assessment period was calculated using the numerical modelling tools. The results for the baseline and 60 m eastern breakwater extension are presented in Table 1 and suggest a ~70% reduction in natural sand bypassing of the entrance.

Table 1 Predicted natural sand bypassing to Mooloolaba Bay during 2011/12 assessment period

Breakwater Scenario	Bypass Volume (m^3)
Baseline (existing)	96,500
60 m eastern extension	26,600

4. Mitigation of Impacts to Sand Supply

On average, approximately 5,000-10,000 m^3/year of sand is estimated to bypass the Mooloolaba Harbour Entrance and enter the Mooloolaba Bay beach system (for example, [1]). However, the annual bypassing volume is observed to be an order of magnitude greater during episodic shoaling events.

The predicted reduction in natural sand bypassing has the potential to cause undesirable shoreline erosion impacts to Mooloolaba Beach and is expected to require mitigation via mechanical bypassing methods. Three potential sand bypassing methods are considered here:

1. Dredging and placement
2. Sand shifter system
3. Crane-mounted mobile jet pump

Discussion of the logistics to implement these sand supply management strategies is provided in the following Sections. It is noted that the success of these methods being used in conjunction with an eastern breakwater extension remains uncertain and may need additional design considerations and optimisation through field trials. Additional land based mechanical sand bypassing options may also need to be considered.

4.1 Dredging and Placement

Dredging of accumulated sand from the updrift side of the eastern breakwater and placement on Mooloolaba Beach via a pipeline is a potential method to mitigate a reduced rate of natural sand bypassing caused by the proposed breakwater extension. It is noted that the location where sand accumulates (i.e. in an exposed wave climate, including wave reflection from the extended breakwater structure) would present conditions that challenge standard dredging techniques. Based on previous dredging experience at the Mooloolaba Harbour, there are a number of concerns regarding the operational feasibility of this proposed bypassing method.

4.2 Sand Shifter System

A sand shifter trial operated by Slurry Systems Pty Ltd was commissioned by TMR during 2012 to investigate an alternative method to artificially bypass sand across the entrance. The sand shifter system was installed at Point Cartwright adjacent to the eastern breakwater where sand accumulation was anticipated. The system was designed to transfer accumulated sand via a pipeline from the eastern breakwater to the shoreline at Mooloolaba Bay (mimicking the "natural" entrance bypassing mechanisms). The trial showed that the system was not able to work efficiently due to the shallow depth of sand across the rock shelf and inadequate sand trapping capacity of the present entrance configuration [5].

A high-level numerical assessment of a sand shifter operating in conjunction with the 60 m eastern breakwater extension was undertaken for the design shoal event. Key assumptions of the assessment included:

- The sand shifter could be installed at the location where peak sand accumulation occurs;
- A total sand shifter production rate of up to 800 m^3/day (depending on the availability of sand within the model cell where the sand shifter unit was located);
- The sand shifter could operate continuously for the 2011/12 assessment period; and
- Sand could be extracted to the bed rock level (in reality, a sand shifter unit would be situated approximately 1 m above the bed rock and therefore could not extract sand from below this level).

The numerical assessment suggested relatively low daily transport rates and total bypass volumes would be realised with a sand shifter system, with production limited by a general lack of sand accumulation in the vicinity of the sand shifter units. Considering the natural bypassing volume associated with the design event and the baseline scenario (approximately 96,500 m^3), the predicted sand bypassing volume achieved with the sand shifter system was less than 10% of the baseline scenario. It is assumed that the sand shifter efficiency and production rates could be improved through optimisation of the unit locations. Given the limitations and uncertainty in representing a sand shifter numerically, this could be further explored through field trials if an eastern breakwater extension was constructed.

4.3 Crane-mounted Mobile Jet Pump

A jet pump, or "eductor", deployed by a crawler crane has been demonstrated to be an effective sand bypassing method. The system relies on a supply pump to deliver water to the eductor via a high-density polyethylene pipeline. The eductor is deployed by a crane to the target area where it excavates the sand and draws a sand/seawater mixture. The slurry is then pumped to the discharge location. This is the permanent sand bypassing method used at the Indian River Inlet, Delaware (shown in Figure 7), and has been successfully trialled by Slurry Systems Marine Pty Ltd at Lakes Entrance, Victoria [5].

Figure 7 Crane-mounted mobile jet pump sand bypass system – Indian River Inlet, Delaware (Source: [7])

The potential for a crane-mounted jet pump sand bypass system at the Mooloolaba Harbour Entrance was considered using the shoal morphology results presented in Section 3.1. An important parameter when assessing this bypassing method was the working range of the crane. To this end, the assessment considered the approximate sand volume that could be accessed using 50 t and 90 t crawler cranes with working ranges of 30 m and 50 m respectively. Key assumptions of the assessment included:

- The crawler cranes could access and be transported along the existing eastern breakwater and the proposed extension.
- The 50 t crane would require a 4 m wide area to operate and that this area was available at any position along the breakwater. Operating positions at the head of the breakwater and at a mid-point of the breakwater were adopted for the assessment.
- Shoreline accretion on the updrift side of the breakwater was sufficient to allow the crane to also operate from a beach position (close to the 0 m AHD contour).
- Bypassing volumes are based on the static shoal morphology predicted at the end of the design period.

The estimated bypassing volumes achieved by the two crane scenarios are presented in Table 2. These volumes have been estimated from the sand available at the end of the design event simulation period (above the bed rock layer) within the working range of each crane position.

Table 2 Estimated Mobile Jet Pump Sand Bypassing Potential

Breakwater Scenario	50t Crane (m^3)	90t Crane (m^3)
60 m eastern extension	14,810	22,680

The greater sand volume accessed with the 90t crane suggests this system may effectively mitigate sand supply impacts to the Mooloolaba Bay shoreline. It is noted that sufficient sand accumulation to allow bypassing using the crane-mounted mobile jet pump method may not occur for a number of years following a breakwater extension (depending on natural sand bypassing at Point Cartwright and sand transport rates). During this period sand supply impacts to Mooloolaba Bay may need to be mitigated using another method and material from an alternative nearby location.

5. Conclusions

An optimised Mooloolaba Harbour Entrance configuration has been shown to reduce shoaling using calibrated numerical modelling tools. The assessments also indicated that a breakwater extension would reduce sand supply to Mooloolaba Bay beaches. Without mitigation this impact would be expected to cause undesirable recession of the downdrift shoreline.

If an eastern breakwater extension is adopted, there will be an ongoing need to mechanically bypass intercepted sand to Mooloolaba spit in perpetuity. The ultimate sand bypassing strategy would need to be developed following trial and may include a combination of options. For this reason, in the event a capital works option is adopted, adequate funding contingency is recommended to enable the effective development of the most efficient shoaling management strategy. Of the various mechanical bypassing options considered in Section 4, a crawler crane and jet pump is expected to be the most economically and operationally viable method.

6. References

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