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Published
2008

Conference Title

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Sustainability of reclaimed foreshore – case study: Southport Broadwater Parklands

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ABSTRACT

The sustainability of an upcoming reclamation project at Southport Parklands on the Gold Coast, Australia, was assessed. Southport Parklands has been under development for a long time, which led to irreversible damages to the coastal environment. Therefore, it is important to have a proactive design strategy for a sustainable development. In the present study, a numerical model has been established to simulate hydrodynamic processes. A better understanding of the physical processes advocated developers to adopt a proactive strategy for all new foreshore protection designing.

KEY WORDS: Estuarine environment; Foreshore management; Gold Coast; Hydrodynamic model; Reclamation; Sediment transport; Sustainability.

INTRODUCTION

Land reclamation has always been widely used for the development of coastal areas. Its impacts on the environment need to be considered. The purpose of this study was to assess the sustainability of the land reclamation to reshape coastal zones for human convenience. The new development to extend the foreshore at Southport Parklands, Gold Coast, within the Broadwater is shown in Figure 1. The Broadwater is a semi-enclosed estuarine which plays a significant role in the Gold Coast community life (Mirfenderesk, 2007). It has been continuously modified during the last 60 years to respond to the community aspirations. The earlier modifications have not always been conducted by a sustainable approach, and led the Southern part of the Broadwater to a dangerous situation (Burton, 2003; Mirfenderesk, 2007). The studied area is quite shallow (generally <6m), with a mean tidal range of 1.5m with a maximum of 2m. Water circulation is mainly driven by tidal inputs as their amplitude is significantly larger than the freshwater flows from the rivers, except during flood events (Burton, 2003; Mirfenderesk, 2007; McInnes, et al., 2000).

The geomorphology of the Southern part of the Broadwater is directly influenced by its entrance on the Coral Sea by the Spit on its southern part and by South Stradbroke Island on the remaining part. The Southern part of the waterway, which encompasses the proposed reclamation site, is linked to the ocean through the Gold Coast Seaway and alimented in freshwater by the Nerang River and a few creeks (Mirfenderesk, 2007). The studied area is quite shallow (generally <6m), with a mean tidal range of 1.5m with a maximum of 2m. Water circulation is mainly driven by tidal inputs as their amplitude is significantly larger than the freshwater flows from the rivers, except during flood events (Burton, 2003; Mirfenderesk, 2007; McInnes, et al., 2000).

The geomorphology of the Southern part of the Broadwater is directly influenced by its entrance on the Coral Sea. This entrance of the Broadwater has never stopped moving till 1985 with the creation of the Gold Coast Seaway. This shallow inlet was naturally migrated northward or southward under the action of alongshore sediment transport on the seaside, severe storms and flooding events. During the decades preceding the opening of the Gold Coast Seaway, the northward migration of the inlet generated numerous shoals. Those shoals proved to be naturally stable. As from the mid 1900’s, the increase of human activity within the Broadwater has led to an extensive dredging of the delta shoals coupled with land reclamation to extend the foreshore (Tomlinson & al, 2007). The land reclamation has been used at Southport Parklands to extend recreational purpose areas in an area facing strong growing urbanization stress.
Those modifications have irreversibly modified hydrodynamic and sediment transport processes within the Southern part of the Broadwater. Increase of the tidal dominance. The tidal range is estimated to have been increased in the Broadwater of ~0.3m/+0.1m (Smith, 1994), mainly due to the Gold Coast Seaway opening in 1986. The resistance of the flooding has been decreased. A simulation of the 1974 flooding event caused by the cyclone Wanda realized with the 1974 bathymetry and the present day bathymetry exhibits a reduction of 0.3 to 0.4 m of the storm surge within the Broadwater (McInnes, et al., 2000). The Broadwater development has made severe damages on the environment, through the destruction at 94% of sea grass and heavy metal pollution (Burton, 2003; Mirfenderesk, 2007).

Figure 1: Southport Parklands reclamation extension project

**Southport Broadwater Parklands extension project**

The present reclamation project at Southport Parklands deepens the South Wave Break Channel, which faces a slow but continuous infilling and consequently becomes unsafe for the navigation (See Figure 1).

The dredged sand will be reclaimed at Southport Parklands to extend the existing reclamation within the Broadwater in an intertidal area. The reclaimed area will be used as a recreational area and integrated in a local Master Plan of the Gold Coast City Council to enhance the community’s life at Southport. As the reclamation will cause destruction of seagrass, the full project includes a mitigation measure, through the rehabilitation of mangrove in the small shallow bay between the Swimming-pool and the Broadwater Tourist Park. For this purpose a small submerged reclamation will be realised to protect the bay from the tidal currents and wave agitation. The foreshore is currently planned to remain unprotected as a sandy beach front, which offers extra recreational open spaces to the Southport Community.

The total volume to be reclaimed slightly exceeds 100,000 m$^3$. The design of the reclamation and associated structures (jetties) is validated internally to the GCCC with the simulation of 100 year return flooding event (GCCC, 2008). This is a direct application of the GCCC policy which stipulates that such development may not have any negative influence on hydrodynamic processes during a severe flooding event.

Impacts of the proposed layout under normal conditions and foreshore stability were still to be assessed. For this purpose, a better understanding of involved hydrodynamics processes and stresses on the foreshore were required to allow a sustainable proactive approach.

**MODELLING**

**Hydrodynamics**

A depth averaged hydrodynamic model of the Broadwater, Gold Coast Estuarine Model System (GEMS), has been developed and validated by the Griffith Centre for Coastal Management (GCCM) for the Gold Coast City Council. It simulates the water circulation within the Broadwater, and estimate the influence of the tidal characteristics to the Broadwater’s geomorphology (Mirfenderesk, 2007). In present study, a finer resolution model GEMSZOOM has been established for more accurate simulation, which is forced at the boundaries by the coarse model GEMS. The main model parameters for both coarse and fine grids are described in Table 1 below.

<table>
<thead>
<tr>
<th>Items</th>
<th>Coarse model</th>
<th>Fine model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>45 km vertically 30 km horizontally</td>
<td>4.2 km vertically 2.4 km horizontally</td>
</tr>
<tr>
<td>Grid</td>
<td>30m x 30m</td>
<td>10m x 10m</td>
</tr>
<tr>
<td>Time step</td>
<td>10s</td>
<td>4s</td>
</tr>
<tr>
<td>Boundaries</td>
<td>Gold Coast Seaway, Jumpinpin Bar and Moreton Bay</td>
<td>2 (North &amp; South)</td>
</tr>
<tr>
<td>Boundary conditions</td>
<td>Tidal forcing (Surface elevation)</td>
<td>Forcing with data from the coarse model GEMS</td>
</tr>
<tr>
<td>Sources/sinks</td>
<td>No freshwater input included</td>
<td></td>
</tr>
<tr>
<td>Flood &amp; Dry</td>
<td>Drying depth: 2 cm / Flooding depth: 3 cm</td>
<td></td>
</tr>
<tr>
<td>Resistance</td>
<td>Bed roughness included as a fitting factor during calibration</td>
<td>Wind included</td>
</tr>
<tr>
<td>Wind conditions</td>
<td>No wind considered</td>
<td>Wind included</td>
</tr>
</tbody>
</table>

The domain for fine grid model are presented in Figure 2, which has been designed to fulfil the following criteria:
• Covering an area large enough to study eventual impacts of the upcoming project at Southport Parklands without any disturbance caused by the boundary conditions;
• No Flood/Dry process on the open boundaries, eventual obstacles (nearby foreshore, islands) have to be at least 10 cells from the boundary to ensure a stable and reliable computing;
• Usually, Flows parallel to the boundary have to be avoided but this last criterion was impossible to fulfill for the Northern boundary without extending the domain very far away from the area of interest.

The study period is 40 days from 25/12/2004 to 03/02/2005, which is summer period with high spring tides and slightly stronger wind conditions. The strong winds combined with spring tides observed during a classic summer on the Gold Coast can be considered as critical in terms of sediment transport.

In the case of a sub-model forced at its boundaries with data transferred from a coarse model, the transfer of data and the choice of boundary conditions can be considered a high potential source of discrepancies. In MIKE21 HD, two types of data can be applied to force the open boundaries: water surface elevation or flows. It has been expected and confirmed latterly that a combined data type import should present the best compromise. Therefore, the Northern open boundary has been forced with flow data and the Southern open boundary with water surface elevation data.

In addition to the coarse model GEMS, wind stress has been considered in this finer-scale model GEMSZOOM. This addition does not modify the main hydrodynamic patterns, but as a significant part of the study area is shallow, wind can be expected to have some influence on the hydrodynamic and sediment transport processes in shallow areas of the studied area. The wind data used has been provided by the BOM and measured at Gold Coast Seaway meteorological station.

Four different scenarios have been run for the fine-scale model GEMSZOOM:
  a. No wind – No reclamation
  b. Wind included – No reclamation
  c. Wind included – Reclamation included
  d. Wind included – Reclamation and related structures included

Sediment Transport

The GEMS model is currently being improved to include a sediment transport module. Nevertheless, from the hydrodynamic model GEMSZOOM, some partial remarks may be given on sediment transport processes, through the calculation of the bed shear stress generated by currents (tidal and wind-driven).

Foreshore Protection

The main purpose was to identify the foreshore protections used at Southport Parklands on the previous reclamations, roughly assessing their stability and possible factors influencing it. To reach this objective, aerial image archives from 1944 to 2005 have been used to understand the evolution of the reclaimed foreshore at Southport Parklands. This has been completed with a field investigation in September 2007.

RESULTS

Hydrodynamics

Before assessing any impact of the proposed reclamation on the hydrodynamic patterns within the studied area, it was essential to get a better understanding of them and the possible wind influence.

The influence of the wind on the hydrodynamic patterns within the studied area has been assessed in terms of surface elevation and current velocities. As expected, the first parameter is not modified by the addition of the wind stress. However, flows can be significantly impacted by strong wind but only locally. The most surprising effect of the wind influence has been observed at high tide under strong SSE wind conditions. Just before the flow turns back towards the Gold Coast Seaway, the flow within the lateral shallows channels appear to be reinforced which leads to an increase of the lateral flow towards the North (Gold Coast Seaway) while the main flow within the South Channel is still directed towards the South (Nerang River). The main flow in the South Channel is observed to be reinforced by strong wind blowing against it. This may result from the lateral flows coming back in the main deep channel where they are swept along towards the South again.

Moreover, it has to be observed that flows alongside Southport Parklands are very weak during the flow tide and the ebb tide. The flow through the section which is planned to be reclaimed is observed to be very low compared to the total flow at any time of the tidal cycle. This may justify the weak influence of the reclamation on the flow within the main deep channel. The major differences are the flow reduction within the two small shallow bays created by the proposed reclamation works (See Figure 3).

In term of hydrodynamic processes, we can conclude that the proposed reclamation at Southport Parklands appears to have negligible impacts, except in the two created small bays where the current velocity is
reduced up to 50%.

**Sediment Transport**

For each scenario, it has been calculated the mean values of the bottom shear stress in each cell of the modeled area during the full period of simulation. The obtained map for the scenario not including the upcoming reclamation exhibits very small values (Figure 4).

![Figure 4: Mean bottom shear stress for the scenarios b.](image)

The sand composing the seabed is characterized as medium sand ($D_{50}=0.294$ mm). The critical bed shear stress required to start generating the motion of sand grain is $1.92 \times 10^{-3}$ N/m$^2$. So it can be concluded that the bed shear stress generating by currents (tidal or wind-driven) are insufficient to generate the motion of grains on the bottom, even the finer part of the seabed. Even the maximal values of bed shear stress obtained during the simulation period were still too low to erode the bottom.

The differences between the two cases for the mean values are shown on the Figure 5 for the area directly surrounding Southport Parklands. It can be conclude that the variation of bottom shear stress generated by the reclamation and the structures are less than 10% almost in the full area, for the mean value of bed shear stress.

![Figure 5: Differential map of mean bottom shear stress between the scenarios b and c.](image)

The bed shear stress is increased by 10 % to more than 100% in the northern part of the reclamation which has been elevated but still covered by the water during high tide. This increase was expected and is a direct consequence of the purpose of this partially submerged reclamation which is to reduce the flow during the ebb tide within this small bay to support the rehabilitation of the mangrove. As a consequence too, a significant reduction of the bed shear stress is observed in the small shallow bay right behind. The diverted flow is observed to increase from 10 to 90% the bed shear stress on the outside edge of this reclamation with some variations resulting of the bed level change.

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**Foreshore Protection**

The analysis of the aerial image archives confirms that the foreshore at Southport Parklands is at 94% reclaimed, mostly from 1965 to 1980. The foreshore at Southport Parklands is mainly unprotected (70%). Rock revetment has been used by the Gold Coast City Council only in short sections where erosion was observed or foreseen. This results from the reactive approach of the Gold Coast City Council who considers erosion risk as low within the study area. Other hard foreshore protections exist within sections of the foreshore where
private assets are directly behind the shoreline. The reclaimed foreshore, even mostly unprotected, seems to be stable. Nevertheless, limited erosion is still observable in a few sections.

The sand has been dredged in the direct vicinity of the land reclaimed and has led to a significant reduction of the intertidal area. By consequence, many sand bars which were avoiding the propagation and generation of wind-driven waves have nowadays disappeared. The huge increase of boating within this part of the Broadwater has to be considered too, that the system which was mainly influenced by tidal currents and flooding events is now moreover influenced by wind and boat generated waves. They can be quantified roughly, but further investigation of their characteristics is suggested. This may involve finer modeling of the wind-generated waves with software like MIKE21SW, measurements of the wind and boat wakes.

Figure 6: Foreshore protection at Southport Parklands (Sept. 2007).

DISCUSSION
Impact Assessment of a reclaimed foreshore

It is required to identify and quantify eventual impacts of a reclaimed foreshore, and by extension of land reclamation, on its close environment. Will the project impact hydrodynamic and sediment transport processes, environmental values, community life conditions and economical values within the surrounding area?

Only the last parameters have been taken in account for decades within the studied area, and that had conducted to an advanced degradation of environmental, wide modification of hydrodynamic and sediment transport patterns within the studied area. Nowadays, all aspects are considered during the elaboration of projects like the proposed one at Southport Parklands. The reactive approach has been abandoned for a more proactive one and made such development more sustainable. As it will be discussed further down, the proactive approach requires a better understanding of the natural processes within the potentially impacted area to enable the forecast of potential consequences of land reclamation.

With the hydrodynamic model GEMS and its finer-scale output GEMSZOOM, a good knowledge of the hydrodynamic patterns within the studied area is obtained. Simulation results have been used to assess the upcoming project at Southport Parklands which appears very limited:

1. The land will be reclaimed within the Broadwater in a tidal area where the flow is low and counts only for a negligible part of the total discharge, the variations of current velocities induced by this extension appear to be small except at the direct vicinity of the proposed reclamation or within the two future embayment.
2. Within the Parklands beach bay, the current velocity is reduced by 20 to 30% at peak of tidal currents. Lowest current velocities are less affected.
3. Within the Mangrove rehabilitation bay, the current velocities remain unchanged during the flow tides and are divided by 2 during the ebb tides. This result is totally on line with of the expected aim of the partially submerged reclamation which is to support the mangrove rehabilitation by reducing current and wave stresses.

The results are coupled with the flood modeling, which led to a better understanding of the influence of upcoming reclamation and associated structures.

In term of sediment transport, it has been observed that the upcoming reclamation will modify bottom shear stress only locally around the proposed site, in an area characterized by very weak current-driven shear stress on the seabed. Moreover a rough estimation of wave-driven shear stress showed that even by adding the wave induced bottom shear stress, the critical value generating the sediment motion is most of the time not reached. The motion might be initiated only under very strong wind in very shallow areas (<1m deep). Moreover as the current velocities remain quite low during main part of the tidal cycles in the shallow areas, it is more likely that this transport remains limited to rolling of grains on the seabed. These phenomena are probably limited to short distances and very small quantities compared to the suspended sediment transport.

The above mentioned conclusions resulting from a hydrodynamic model should be confirmed by a calibrated sediment transport model.

By consequence it can be concluded that a very good knowledge of the hydrodynamic patterns is a first essential step towards the modeling and the understanding of other processes: sediment transport and water quality for example. Hydrodynamic results can be interpreted to give a rough estimate of sediment transport patterns, as it has been done within this study. But the view remains partial and can lead to misinterpretations. For this reason, it is strongly advocated to consider GEMS as a framework which may include numerous other calibrated modules coupled together: Waves generation, sediment transport, water quality…

Foreshore stability

Most of the time, land is reclaimed to support further development of assets. For this reason, it is expected that the reclaimed foreshore will be stable during the life time of the assets build on the reclaimed land.
A sustainable design should include the right protection which involves a perfect understanding of the features which may impact the reclaimed foreshore.

In the case of Southport Parklands, the reclaimed area is supposed to become a recreational area, so with small values assets, in a low-energy environment considered as stable compared to other more exposed areas in The Gold Coast. For this reason, the position adopted by the Gold Coast City Council is reactive. The reclaimed foreshore will be left unprotected, protection will be considered only if foreshore instabilities are observed and assets have to be considered as unprotected against major flooding events. By doing so, they avoid the risk of over sizing the foreshore protection and reduce significantly the project construction cost, but probably increase significantly the maintenance cost. Such methodology has been applied with a quite relative success during the last decades and seems to have been through the 1974 severe flood event. But will it remain successful for the future and the proposed upcoming reclamation at Southport Parklands? It is less sure. To avoid that, the understandings of the features which may threaten the stability of the foreshore have been enhanced through the field investigation and the hydrodynamic modeling. 4 forces were assumed to have a potential influence on the stability of the foreshore: the wind-driven waves, the boat-induced waves, the tidal currents and the flooding events.

From theoretical calculations using the JONSWAP method, it is known that the mean wind-induced waves affecting the Parklands reclaimed foreshore are usually small (5-10 cm significant wave height). Extreme wind driven waves are observed on the Gold Coast (above 30-40 cm significant wave height). The periods remain always very short (1 to 2 seconds). The boat generated waves are assumed to have characteristics quite close with a maximal wave height about 20 cm and a longer wave period (2-3 seconds). Such waves are not high enough to generate strong patterns of sediment transport within the intertidal area as observed on the field, but may cause erosions on vertical-front sandy foreshore left unprotected. For this reason, it is essential to leave unprotected sandy foreshore under a stable slope. The proposed reclamation on the South of Southport Parklands will be generally less exposed to wind-waves, except for winter wind blowing from the North. The Northern corner of the reclamation may then face slight or high erosion problems. But further wave modeling seems to be required to get a better estimate of wind-waves as they appeared overestimated with the JONSWAP calculation done here.

Based on the hydrodynamic model, along Southport parklands, the current velocities are quite weak and never exceed 0.3-0.4 m/s, and may not generate any erosion of the bed close to the reclaimed area. Therefore the tidal currents may not be considered as a threat for the foreshore.

During flooding events, those tidal currents are reinforced significantly. Modeling results of a 100 year-return flooding event led by the GCCC show that the upcoming foreshore extension will be particularly affected and significantly more than the areas of Southport Parklands reclaimed previously. Current velocities at the southern edge of the reclamation may reach up to 1.5 m/s. An unprotected beach profile may be severely eroded under such velocities.

The combination of effects from those 4 different factors is more difficult to foresee. This leads again to the need of developing coupled modeling tools to get a better understanding of coupled current and wave action on the reclaimed foreshore at Southport Parklands.

A first step towards sustainability should be to enhance the proposed unprotected design at low cost by integrating the techniques which may respond the best to the identified threats. A stable beach profile may appear sufficient to resist to usual or light severe events, but the capacity of the foreshore as designed now to go through a major flooding event should be assessed further.

An alternative may be to integrate a buried seawall to respond to this risk of major flooding event. The use for example of geotextile tube filled in hydraulically with dredged material may constitute an efficient buried seawall at low extra cost (See Figure 8). Such buried seawall will guarantee to avoid potential significant erosion during severe flooding event. Moreover, the beach can still be used as a recreational area.

Figure 7: Geotextile pipe of 1.2m diameter (www.soilfilters.com.au)

Shaping the sandy foreshore to a stable profile can be considered already to a sufficient way of protecting it under usual stress or small events. Such non-structural solution should be then reinforced, if possible, by a shadow protection to very severe events like 100-year return flooding event in the case of Southport Parklands. Sand-filling geotextile tube appears to be an ideal solution in land reclamation context.

CONCLUSIONS

The Gold Coast foreshore has been widely modified during the last decades to respond the Community aspirations and economical objectives. This contributes in many places to endanger the assimilative capacity of local ecosystems. Nowadays, through the example of the proposed land reclamation at Southport Parklands, a better assessment of eventual impacts has been undertaken. This better assessment has been made possible through the development of several numerical models, like the hydrodynamic model GEMS and its finer-scale GEMSZOOM. Those models coupled with field investigation allow a better understanding of involved processes and by consequence a better assessment of eventual impacts. This proactive approach leads reclaimed foreshore towards sustainability. Nevertheless, a last step still needs to be got over by keeping this proactive policy to the design of the foreshore protection. The stresses which may impact the stability of the reclaimed foreshore at Southport parklands have been reviewed and quantified. This review confirms that the design proposed might be the best economical solution under normal stress conditions. But, it is strongly advocated that a more proactive vision may be adopted, as for the impact assessment, to evaluate the stability under severe events, like a major flooding event. It has been often suggested during the last years, that a more efficient protection solution is in fact an integrated solution combining different types of foreshore protection to respond as closely as possible to the complexity and the specificity of each site (Hardaway, et al., 2002). For this reason, the proposed design should be reinforced with buried seawall made of geotextile tubes filled of
reclaimed material to respond to this major event erosion risk.

REFERENCES


