GEOMORPHOLOGICAL MODELLING OF ENTRANCE IMPROVEMENT OPTIONS – LAKE ILLAWARRA

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Abstract

The Delft3D Online Sediment modelling system has been used to investigate six preliminary designs for a northern entrance-training wall at Lake Illawarra on the NSW south coast. The designs were modelled under tidal conditions to investigate whether or not the ‘design’ entrance channels were self-scouring, and in a 100 Years Average Recurrence Interval (ARI) flood event to investigate the extent of any scour. The entrance to the lake has historically changed position due to the influence of tides, wave action, catchment runoff and longshore sediment transport, or been closed. This modelling study identified that some of these options did not provide a self-scouring channel under tidal flow, and others caused significant scour along the training walls during flood flows. Subsequently, two additional options were developed. They were designed to reduce the risk of entrance closure and to limit scour along the training walls during flood flows.

Introduction

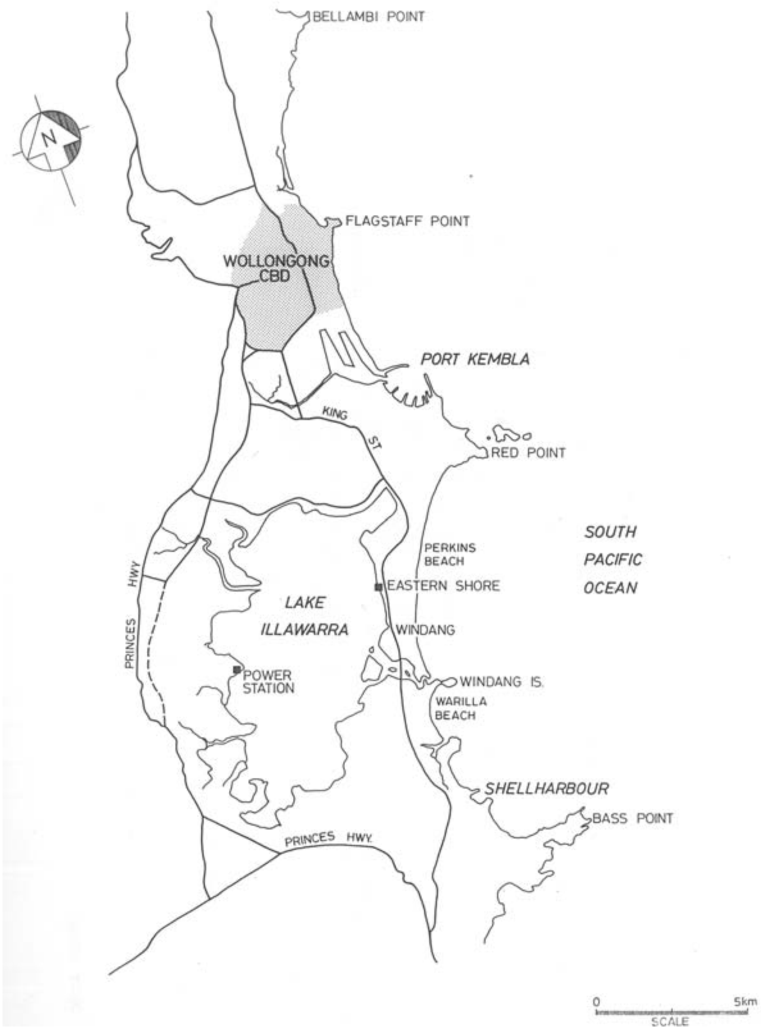
Lake Illawarra is a shallow coastal lagoon on the NSW south coast. The entrance to the lake has historically varied position due to the influence of tides, wave action, catchment runoff and longshore sediment transport and has been closed from time to time. Entrance works that included the construction of a southern training wall, intended to reduce the risk of entrance closure, were completed in 2001. As part of ongoing improvements to Lake Illawarra, the Lake Illawarra Authority (LIA) commissioned Lawson and Treloar to undertake numerical modelling of preliminary options for a northern training wall and six options were developed and modelled. The Delft3D Online Sediment morphological model was used to investigate the performance of these options under normal tidal conditions and in a 100 Years ARI flood event. The flood simulations also included a 5-day period of tide only forcing to examine post-flood recovery. Assessment of the model results led to the development of two additional northern training wall options, which were designed to reduce the risk of entrance closure and ensure safe conveyance of flood flows with acceptable sour along the training walls. Structural design details were addressed by Patterson Britton & Partners.

Site Description

Lake Illawarra is approximately 8km south of Wollongong on the undulating coastal plain between the ocean and the cliffs of the Illawarra Escarpment. Figure 1 provides a locality plan of the area. The lake is an important recreational asset for the Illawarra region, and also provides a habitat for wildlife and acts as a valuable recreational fishing ground.

The lake is relatively shallow, having an average depth of 1.7m, with the greatest depths being approximately 4m. Lake Illawarra is connected to the ocean by a 1.7km long entrance channel. In its existing state, the nature of the entrance is continually changing under the influence of catchment runoff and coastal processes

Figure 1: Locality plan**.**



such as tides, wave action, wind and littoral sediment drift, which all influence the entrance position and condition. Historically, the entrance had been either north or south of Windang Island and there has been intermittent closure of the entrance from time to time as a result of sand infeed from the Warilla and Perkins Beach coastal compartments, especially during periods of dry weather.In 2001 the Lake Illawarra Authority (LIA) completed entrance improvement works aimed at increasing tidal flushing of the lake, fish and prawn migration, and reducing the potential for flooding. Work included:-

- construction of a 700m long southern training wall connecting to Windang Island;
- channel dredging;
- a low level causeway between Reddall Reserve and the training wall to provide a passive recreation area; and
- a sand dune / tombolo at the northern end of Warilla Beach to prevent sediment transport from the beach into the entrance.

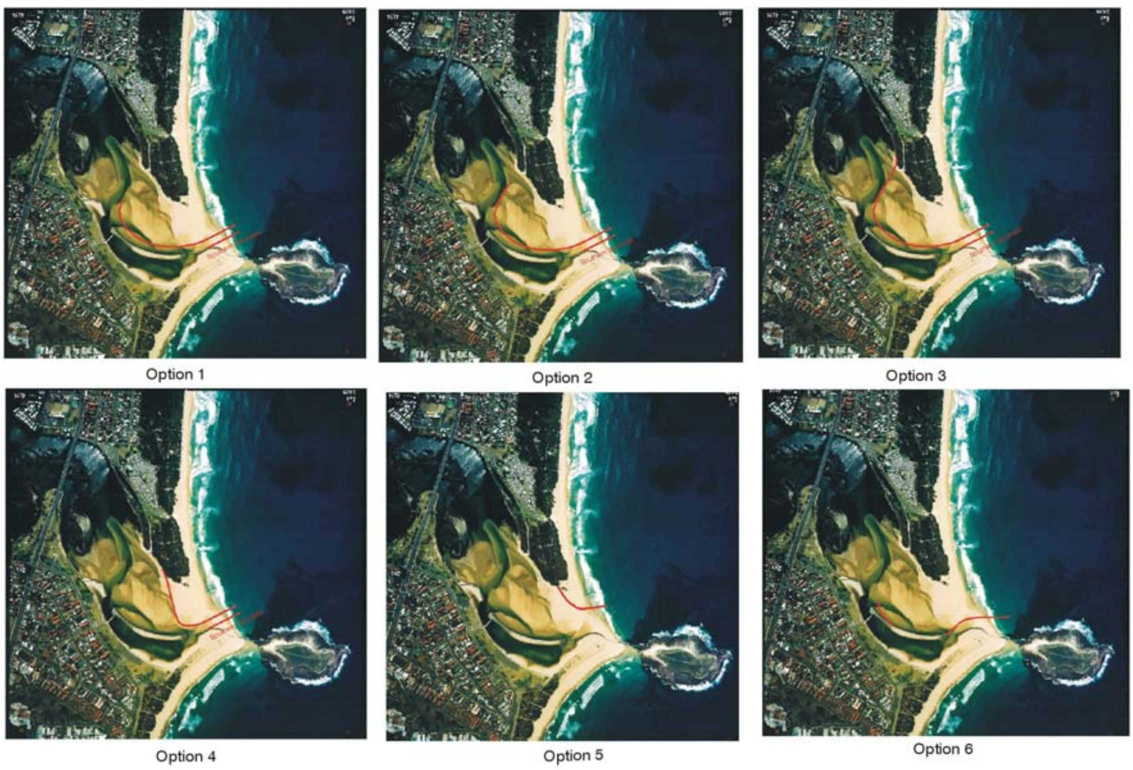
Figure 2 shows the completed works. The new entrance functioned satisfactory for several months, but during the 2002-2003 drought, sand infeed from Perkins Beach and insufficient catchment runoff to scour out the sand led to the closure of the entrance channel on 16 August, 2002. Concerns over water quality during the summer holiday period lead the LIA to attempt an opening of the lake on 17 December, 2002. The entrance channel operated for three days before it was closed by sand infeed and insufficient flow due to the low lake level.

Northern Training Wall Options

As part of continuing investigations into entrance management, the LIA commissioned Lawson and Treloar to undertake numerical modelling of a number of preliminary options for a northern training wall. A total of six options were investigated for two scenarios: tidal flows only and the 100 Years ARI flood event, followed by a post-flood period of tidal flows. The six options investigated with Delft3D are illustrated in Figure 3.

Figure 2: Completed entrance improvement works.

Figure 3: 6 Options investigated with Delft3D Online Sediment (Proposed works are shown in red).



The six options can be summarised as:-

- Options 1-3 are all designed to provide a 40m wide, 2m deep tidal channel. Previous investigations had shown that a cross-sectional area of about 80m^2 would provide a self-scouring channel (Lawson and Treloar, 1994). Option 2 has the northern training wall extending upstream to the north, but still allows an additional flow channel to develop along the northern bank of the entrance under flood conditions. Option 3 features a half-tide wall that extends from the western end of the northern training wall in Option 1 to the northern bank of the entrance region. The half-tide wall is designed to allow flood flows to easily overtop the wall to create a second flow channel to the north of the trained channel during flood events, yet contain tidal flow to the trained section. In Options 1-3, the entrance channel to the western end of the northern training wall in Option 1 would be dredged to -2mAHD. A southern spurwall extending off the existing eastern section of the southern training wall would also be constructed.
- Option 4 is a shortened version of Options 1-3. The 40m wide channel would be restricted to the eastern section of the existing southern training wall. Option 4 features the same dredged channel as Options 1-3 and a half tide wall.
- Option 5 provides a 100m gap between the existing southern wall and a proposed northern wall. The initial dredged channel would be of the same extent as Options 1-4.
- Option 6 features a realignment of the existing southern wall and removal of the causeway to the existing southern wall. This option would require the relocation of the passive recreation area shown in Figure 2. A short northern training wall would be built from the eastern end of the mid-section of the existing southern training wall. The entrance channel between the realigned southern wall and the southern bank would be dredged to -2mAHD.

In all options the northern training wall extends seaward to approximately -3mAHD. The seaward extent was chosen on the basis of observed behaviour of the northern training wall of the Swansea Channel, NSW.

Model System

For this investigation the Delft3D Online Sediment modelling system was applied in 2 dimensions. The model features a curvilinear computational grid. The curvilinear grid allows higher resolution through the entrance channel and better flow description because the grid cells can be aligned with the predominant flow direction. Delft3D applies an alternating direction, finite difference, implicit scheme to the solution of the equations of mass and momentum conservation. Density is included through an equation of state for salinity and temperature, as well as suspended sediment concentration. Model forcing can be by tides, winds, inflows, air pressure and density gradients. An accurate, stable wetting and drying algorithm is included to describe intertidal areas. Up to 5 sediment fractions can be specified. For sand fractions, sediment transport is based on the functions of van Rijn.

Delft3D modules can be dynamically linked through a common communications file. The modules used in this modelling were: FLOW (currents and water levels), SWAN (wave module), TRANPORT (sediment transport) and BOTTOM (morphological changes).

This model system has been validated by Delft Hydraulics and applied successfully by L&T to siltation investigations at Cairns, northern Australia, for the Royal Australian Navy. Recently L&T has been involved in morphological modelling of the Murray River Mouth and experience from that study was useful in this investigation. The Murray River Mouth entrance system is complex and very dynamic, and subject to frequent storms that influence entrance behaviour. The Delft3D model has shown good agreement with sediment transport rates determined from survey.

Model Setup and Verification

Bathymetric data for the entrance area was developed from survey undertaken by the LIA in September/October 2002. Additional information was developed from site inspections and an aerial photograph of the entrance on 29 August, 2002. During this period of data collection the entrance was closed. A design dredged channel was constructed in the model for each simulation. The extent of the dredged channel depended on the northern breakwater option. Sediment data collected by Manly Hydraulics Laboratory (1991) has been used in this study. A quartz sand with mass density of 2650kg/m^3, insitu dry density of 1600kg/m^3 and D_{50} of 0.35mm was applied.

The model included all of Lake Illawarra and extended to the -20mAHD contour offshore so that realistic tidal storage and flood hydrographs were developed. Two grid resolutions were developed for this investigation. A coarse grid with resolution of approximately 4m across the channel and 10m along the channel was used for most model runs. A fine grid with a four-fold increase in spatial resolution was developed to verify the suitability of the coarse grid. This investigation was focused on the tidal and flood performance of the northern training wall options. The coarse grid model was unable to adequately resolve waves at the shoreline. Therefore wave processes were turned-off for the simulations. The model was given a 24 hours hydrodynamic warm-up period before the morphological processes were turned-on. This allowed a realistic dynamic equilibrium of hydraulic and sediment transport processes to be established. Morphology (bed changes) was then updated every 0.5 hour.

The model was verified using measured water level data available from a previous study (Lawson and Treloar, 1994), for an entrance cross-sectional area similar to that which was modelled in this investigation. The modelled tidal ranges at locations upstream from the ocean entrance to the lake were compared with output data from the previous model at similar locations and there was reasonable agreement. The simulation results also reproduced observed entrance behaviour during historical flood events realistically.

Model Results – Tidal Conditions

All six northern training wall options modelled with Delft3D were investigated for morphological changes over a 5-day tide only simulation. Figure 4 shows the contoured morphological changes over 5-days for Option 1. Red areas are accretion (up to 1m) and blue areas are erosion (up to 1m). The large area of erosion and accretion at the western end of the proposed northern training wall corresponds to the western end of the dredged channel. The rapid changes in bed levels in this region are a result of the morphological smoothing of the sharp transition between the dredged channel and the natural bathymetry. In this region the levels of deposition and erosion are up to 0.95m and 0.65m, respectively. Observations over the following 10 days show that there was very little further change in bathymetry in the region over this period. Figure 4 shows that there has been no significant deposition or erosion through the trained tidal channel over the 5-day period. Detailed analysis indicated that over this time, along most of the trained channel there was a small amount of erosion. Options 2 and 3 performed very similarly to Option 1. The fine and coarse grid runs for Option 1 showed good agreement with each other.

Figure 5 shows the bed level change for Option 4. The dredged channel in Option 4 is of the same extent as Option 1. Figure 5 shows that there is some accretion and erosion at the western end of the dredged channel as the channel develops morphological equilibrium with the natural bathymetry, however, the levels of erosion and accretion are not as great as in Option 1. There is also some erosion and accretion to the west of the trained channel. Like Option 1, the trained tidal channel in Option 4 was generally self-scouring over the 5-day tidal simulation. The northern training wall in Option 5 did not influence the entrance channel under tidal conditions. This is due to the southern and northern walls being 100m apart, and the dredged tidal channel being only 40m wide. As a result, Option 5 did not perform differently from the existing case under tidal conditions and would be expected to close. The northern training wall in Option 5 is designed only to prevent sand from Perkins Beach from moving into the entrance area rather than produce a self-scouring entrance.

Figure 6 is a contoured bed level change plot for Option 6. In this option, the dredged channel had a similar western extent as the channel in Options 1 and 4, but the channel would pass between the mid-section of the existing southern training wall and the southern bank following removal of the causeway. There is up to 1m of accretion and erosion at the western end of the dredged channel as an equilibrium bed profile is developed. There is also some erosion and accretion as the channel passes through the seaward training wall gap. Detailed analysis showed the tidal channel in Option 6 did not have the general scour along the whole trained channel as observed in Option 1.

Figure 4: Option 1, bed level change 5-day tide simulation.

Figure 5: Option 4, bed level change 5-day tide simulation.

Figure 6: Option 6, bed level change 5-day tide simulation.

Model Results – 100 Years ARI Flood

Figure 7 shows a contour bed level change plot for Option 1 following the 100 Years ARI flood event peak discharge. Red areas are accretion (up to 5m) and blue areas are erosion (up to 3m). There is over 3m of scour along a significant length of the trained channel. A large offshore bar, with up to 5m deposition of sediment, has formed outside the trained entrance. A second flow channel to the north of the trained channel is evident. This channel developed through the wet notch maintained by the LIA at 0.8mAHD. Over the 5 days following Figure 7, there was some recovery of the bed level in Option 1 as sediment from the bar returned to the entrance channel. Some of the sediment from the bar moved north-west towards the wet notch channel seen in Figure 7. Options 2, 3 and 4 were not modelled with Delft3D for the 100 Years ARI event. It is expected that these options would produce more scour along the training walls because flow through the wet notch channel is more restricted than in Option 1. As a result these options are likely to produce higher currents through their main trained channels compared to Option 1.

Figure 8 shows the contoured bed level changes following the first 36 hours of the 100 Years ARI flood simulation for Option 6. This plot shows that the second flow channel opens up at a more southerly position compared to Figure 7 (Option 1). This is a result of some of flood flow outflanking the re-aligned southern training wall. This produces significant scour along the northern side of the extended training wall. Over the following 5 days post flood there was some recovery in the bed level along the training walls. The results over the following 5 days also suggested that the offshore bars produced in Option 6 were more likely to cause shoals at the seaward entrance to the trained channel compared to Option 1.

Option 5 also produced significant scour along the eastern section of the existing southern training wall. Although Option 5 features a minimum 100m gap between the northern and southern training walls, the momentum of the flood flow as it passes through the bend near Windang Bridge results in the flow converging on the eastern section of the southern training wall before turning east and heading offshore. That is, the flow does not occupy the full channel width. Like Option 6, the offshore bar produced during the flood appeared more likely to form entrance shoals during the post-flood recovery period.

Figure 7: Option 1 bed change over first 36 hours of 100 Years ARI flood.

Figure 8: Option 6 bed change over first 36 hours of 100 Years ARI flood.

DISCUSSION

The results from the Delft3D modelling highlighted the difficulty in meeting the requirements to produce a self-scouring channel under tidal conditions and allowing adequate conveyance of flood flows with acceptable levels of scour along the training walls, and also not increasing flood levels. Options 1-3 performed well under tidal conditions and produced a self-scouring channel along a large section of the trained channel. However, these options also conveyed most of the flood flows through the tidal channel, thereby causing significant scouring along the walls.

Option 4 did not perform as well as Options 1-3 under tidal conditions, and under flood flows it also caused significant scour along sections of the training walls. Option 5 did not change the tidal performance of the entrance compared to the existing case, and therefore it would not noticeably improve the reliably of the entrance. There was also significant scour along the southern training wall during the flood simulation. This is likely to occur to the southern wall in its existing state during a significant flood event.

Option 6 produced some shoaling in the channel under tidal conditions and also produced the most significant scour of all the options under flood flows. In addition, Option 6 appeared more likely to produce shoals at the seaward entrance to the trained channels during post-flood recovery.

Because none of the six preliminary layouts appeared to meet the required performance criteria under tidal flows and flood events, Lawson and Treloar, together with Patterson Britton & Partners and the LIA developed two additional options (Options 8 and 9) that were not tested with Delft3D. These options were designed to reduce the risk of entrance closure under normal conditions and safely convey flood flows with acceptable scour. These options are shown in Figure 9.

Option 8 shows a layout that combines Options 1 and 5. It features a half-tide training wall 40m to the north of the existing southern wall, a southern spurwall and a full northern training wall extending to -3mAHD. This option is designed to provide a self-scouring tidal channel like Options 1-3 and improve the flood performance by reducing the level of scour and allowing more flow through the flood flow channel to the north of the proposed wall. The northern training wall is designed to prevent the long-term movement of sand from Perkins Beach into the entrance area. As with Options 1-3, the tidal channel would be dredged to -2mAHD.

Figure 9: Developed Options 8 and 9.

Option 9 is a modification to Option 5. In this option, a southern spurwall has been added, and there is significantly more channel dredging. Whereas Options 1-6 generally required a 40m wide, 500m long channel dredged to -2mAHD, this option would include a 100m wide, 700m long channel to be dredged to -2mAHD. The dredged area in this option is shown by the yellow net in Figure 9. Because the existing entrance works and the proposed southern spurwall and northern training wall would largely isolate the entrance from the Warilla Beach and Perkins Beach sediment compartments, the dredged sand (170,000m^3) would be effectively removed from the entrance sediment compartment. This would reduce the risk of closure. The dredged sand may be used to nourish Warilla Beach, which has undergone significant shoreline recession at its southern end.

Lawson and Treloar and Patterson Britton & Partners are currently undertaking further investigations for the LIA to optimise a northern training wall option that is based on the Option 9.

CONCLUSIONS

These investigations have shown the capacity of the Delft3D Online Sediment modelling system in assessing preliminary designs for a northern training wall at Lake Illawarra. The model was verified with a previous numerical model of Lake Illawarra on the basis of water levels. The modelling indicated that it was unlikely that any of the six preliminary designs would meet the required conditions of a more stable and reliable entrance channel under normal conditions, and safe conveyance of flood flows with acceptable scour along the training walls. The results from the Delft3D modelling were used in the formulation of two additional options that were not investigated with Delft3D, but are designed to overcome the problems identified with Options 1-6.

Geomorphological modelling has the ability to highlight and quantify potential problems during investigations into entrance improvement options and can be a valuable tool in the assessment of such options.

REFERENCES

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