DYNAMIC MODELLING OF THE IMPACT OF ENTRANCE SCOUR ON FLOOD BEHAVIOUR IN COASTAL LAKES AND ESTUARIES.

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ABSTRACT

Foreshore flooding of coastal lakes and other estuaries is an important aspect of coastal management in NSW. Over the last 12 months, the authors have been involved in numerical modelling of entrance scour processes as part of flood studies for a number of coastal lakes in NSW. The dynamic nature of entrances is complicated during catchment floods by the scour of sand from the entrance berm and deposition in the nearshore zone. Entrance scour results in an increase in flood flow conveyance, which controls flood levels within the lake.

Some flood modelling techniques, which use a fixed bed at the entrance, are not capable of simulating variable flow conveyance. As such, assumptions in choosing an appropriate fixed bed level are required.

A robust sand transport, erosion and accretion module has been recently added to the TUFLOW flood modelling package. This module is dynamically linked to the hydrodynamic module. This new module calculates sand transport rates and updates the bed levels within the model at every time step. It enables the simulation of bed evolution and morphological change with time.

The modelling of flood-induced morphodynamic change is of particular interest when considering Intermittently Closed or Open Lakes and Lagoons (ICOLL's). The flood behaviour of these systems can be dramatically influenced by the dynamics associated with entrance breakout processes.

This paper discusses the advantages associated with utilising a morphodynamic flood modelling tool such as that presently available in TUFLOW. The paper is supplemented by examples of specific applications of the morphodynamic flood module.

KEYWORDS

Coastal Entrance Scour, Sediment Transport, ICOLL's, TUFLOW, Numerical Flood Modelling, Geomorphology.

INTRODUCTION

The numerical modelling of flood behaviour in estuaries with highly constrained or intermittently closed entrances is challenging. One important challenge is the provision for the morphodynamics of a mobile bed within the entrance compartment as scour and deposition occur during a flood event. If the model used to undertake the simulation is not capable of simulating changing bed levels within the entrance compartment during a flood event, coarse assumptions about the bed levels at the entrance need to be made.

This paper provides discussion on the issue of entrance scour and presents results from two flood models (developed for Burrill Lake and Lake Conjola, located within the Shoalhaven Area on the South Coast of New South Wales) that simulate dynamically linked hydrodynamics and entrance scour.

METHODS THAT DON'T UTILIZE MORPHODYNAMIC SIMULATION

Without a means to simulate the morphodynamic entrance behaviour, most traditional flood models need to adopt an approximated approach to entrance scour. A number of approaches are available, including:

- **Adopt a Constant Relatively Constrained Entrance Condition:** This will result in conservative estimates of flood levels within the estuary;
- **Adopt a Constant 'Representative' Condition:** By trying to estimate the 'average' or 'representative' condition, a less conservative estimate of flood levels may be achieved. However, derivation of a representative condition is difficult;
- **Adopt a Constant Very Scoured Condition:** This will result in non-conservative estimates of flood levels within the estuary;
- **Program how the entrance will change prior to the simulation:** In the absence of reliable data, it is also difficult and time consuming to derive how an entrance may change during a flood event. A difference condition needs to be derived for each of the design events.
- **Use a Dam Break model:** While this method does dynamically simulate a changing entrance condition, it does not fully represent the scour and accretion processes that are occurring

MORPHODYNAMIC SIMULATION

Traditional flood models have significant shortcomings when trying to address an erodable estuarine ocean entrance which scours during a flood simulation. In recent times, the TUFLOW (Two dimensional Unsteady FLOW) flood modelling package has been upgraded to enable direct morphodynamic simulation of ocean entrances during a flood event.

TUFLOW uses the comprehensive and internationally accepted method of Van Rijn (Van Rijn, 1993) in determining the concentration of sediment within the water column for a variety of different conditions.

To determine the rate of deposition of sand from the water column, as the sediment laden flow enters more quiescent waters, TUFLOW incorporates a discretised form of the Eysink & Vermaas relationship (Eysink & Vermaas, 1983).

Based on the entrainment / transport and deposition calculations, a balance of sand either removed or deposited in a given model cell is calculated. Furthermore, a mechanism to represent bank collapse has been included. This method determines whether the bed slope within the model is too steep and, if so, redistributes sand from higher to lower cells.

CASE STUDY

For comparison purposes, two case study sites are presented here to illustrate the impact of morphodynamic simulation on the results of predicted flood inundation.

The two coastal lakes discussed within this paper, Lake Conjola and Burrill Lake are respectively located to the north and south of Ulladulla on the NSW South Coast. Lake Conjola is around 170 km south of Sydney, and Burrill Lake is around 14 km south of Lake Conjola. The locations of the two lakes are shown on Figure 1.

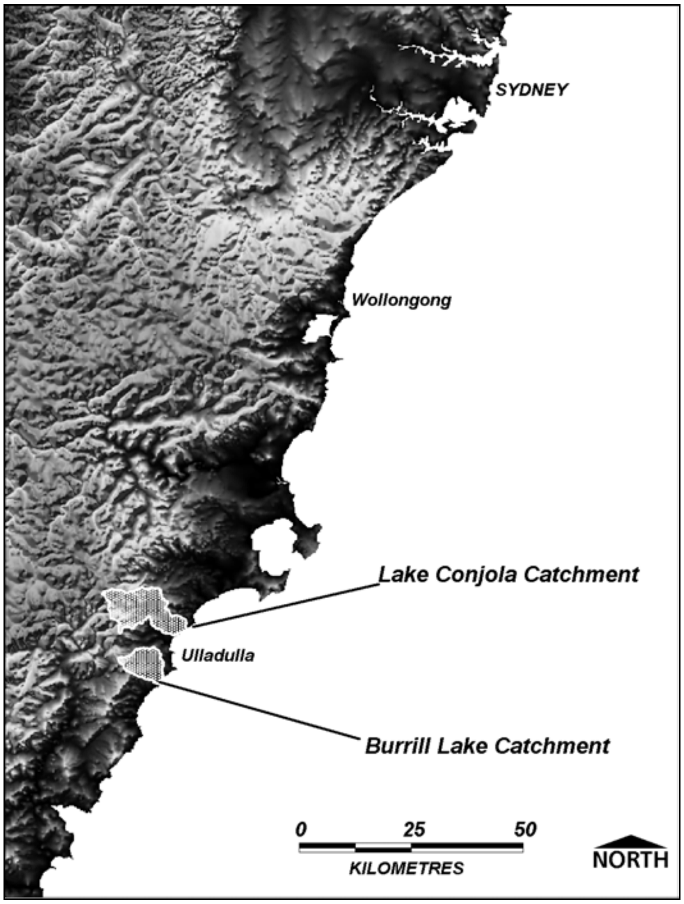

Figure 1 – Locations of Case Study Sites

Lake Conjola has a waterway area of around 4.3 km^2 and a contributing catchment area of 145 km^2. Its major tributaries include Luncheon, Conjola and Bunnaire Creeks and Berringer Lake. Typical depths within the Lake vary from 1 to 2 metres in the eastern parts of the Lake, with deeper parts (5m and greater in the western basin of the Lake).

Burrill Lake has a waterway area of around 4 km^2 and a contributing catchment area of around 78 km^2. Its major tributaries include Stoney Creek, which flows into the north of the Lake and an unnamed creek which flows into the southern parts of the Lake. Typical depths within the body of the Lake vary from 4 to 8 m (below AHD). The entrance to the Lake is connected to the main body of the lake by a 2 km long, sinuous entrance inlet (main channel depth 1 to 2 m below AHD). The mouth of the inlet is typically open to the ocean.

The hydrographs input to both flood models comprised uncalibrated flood estimates. In the case of Lake Conjola, it is estimated that the recurrence interval for the simulated flood would be around 100 years. For Burrill Lake, the simulated flood is more severe, comprising inflows of two times an initial estimate of the 100-year flood.

In other words, while the flows used would be classified as rare or extreme, the inflows that were used to drive the flood models were still well within the realms of possibility. Nevertheless, the results presented in this paper should not be considered indicative of the actual flood extents used for flood planning purposes.

RESULTS

As noted before, the results in this paper are indicative only and represent rare or extreme events.

Lake Conjola.

Two figures are presented below. Figure 2 shows the starting bathymetry used in the model simulations and the final bathymetry following the morphological simulation. Figure 3 shows the impact of using a morphodynamic simulation on flood extents, compared to a typical 'conservative' approximation for entrance conditions.

Figure 2 shows that, beginning with a fairly constrained entrance channel, the model has simulated the scour of a significant channel through the berm at the entrance to Lake Conjola. The material scoured from the entrance berm has been deposited on either side of the scoured channel as well as within deeper waters in the immediate nearshore zone in front of the entrance. In addition to the deepening and widening of the entrance channel, the channel has also straightened, resulting in an entrance channel that has a greater capacity to convey floodwaters.

In Figure 3, the light grey areas indicate the simulated area, within Lake Conjola township, that would be inundated to depths of greater than 0.5 m with the morphodynamic simulation enabled. The dark grey areas indicate the predicted additional area that would be inundated if the entrance bathymetry were fixed.

The difference in peak flood level between the two simulations was approximately 0.6 m. As ground levels around Lake Conjola are relatively flat, a 0.6 m difference in flood levels is significant with respect to extents of flood inundation.

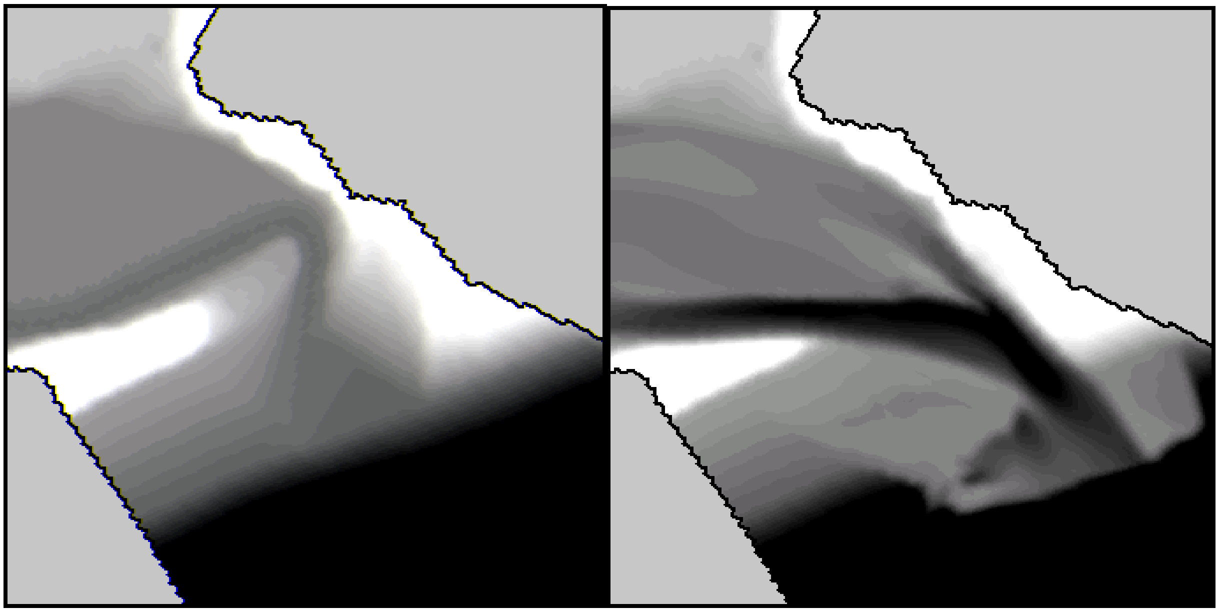

Figure 2 – Lake Conjola Start (Left) and Final (Right) Entrance Bathymetry

Grey Scale Representing Elevations: Black = -4 m AHD, White = +4 m AHD

Figure 3 – Extent of Inundation (>0.5m deep) at Lake Conjola Township for Simulated Flood
Light Grey: Morphological Simulation
Dark Grey: Additional Inundation – Simulation with fixed entrance bathymetry

Burrill Lake.

Two figures are presented below. Figure 4 shows the starting bathymetry used in the model simulations and the final bathymetry following the morphological simulation. Figure 5 shows the impact of using a morphodynamic simulation on flood extents.

Similarly to the entrance behaviour of Lake Conjola, Figure 4 shows an initially constrained entrance through which a significant channel is scoured during the simulated flood. Material has been scoured from the bed of the channel and the barrier dune and berm that extends southwards across the entrance. The material scoured from the entrance has been deposited on either side of the scoured channel as well as offshore of the entrance. Again, the model has predicted a tendency for the entrance channel to straighten as it develops.

In Figure 5, the light grey areas indicate the simulated area that would be inundated to depths of greater than 0.5 m with morphodynamic simulation enabled. The dark grey areas indicate the additional simulated area that would be inundated if the entrance bathymetry were fixed. In the areas upstream of the causeway (including Burrill Lake township and Bungalow Park), the morphodynamic simulation indicated a peak flood level of around 0.4 m lower than the predicted peak level for the fixed entrance simulation. Once again, the difference in flood extents associated with these two simulations is significant, and potentially affects many existing and potential future residential properties.

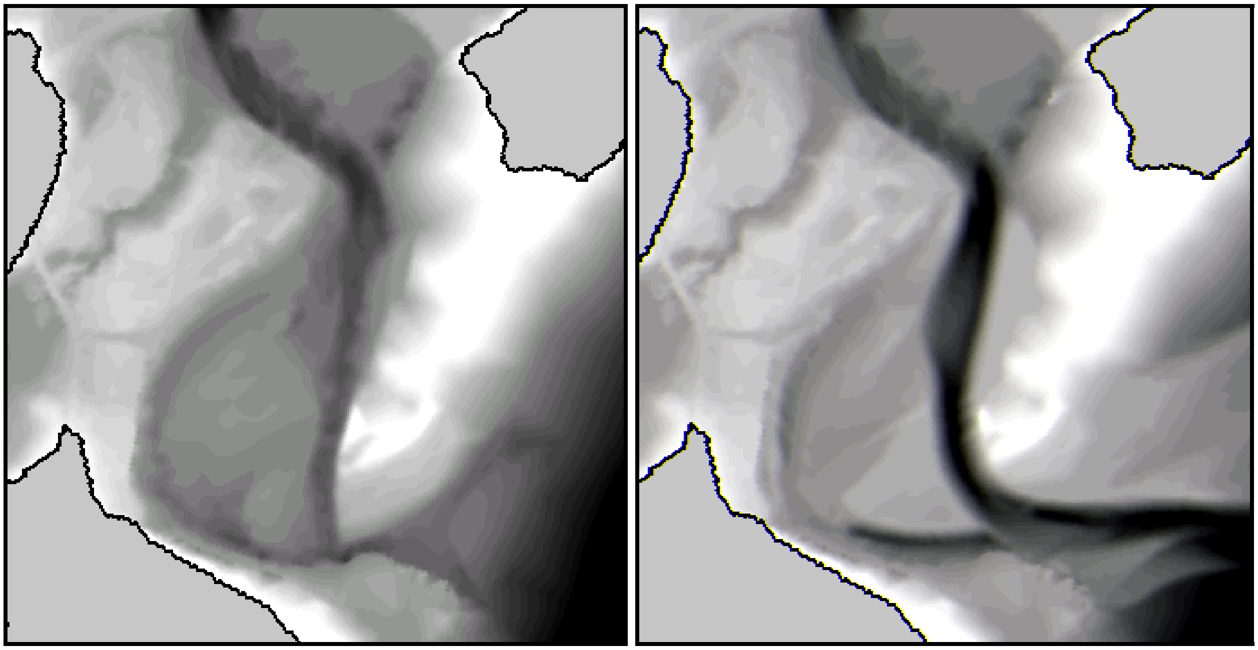

Figure 4 – Burrill Lake Start (Left) and Final (Right) Entrance Bathymetry

Grey Scale Representing Elevations: Black = -4 m AHD, White = +4 m AHD

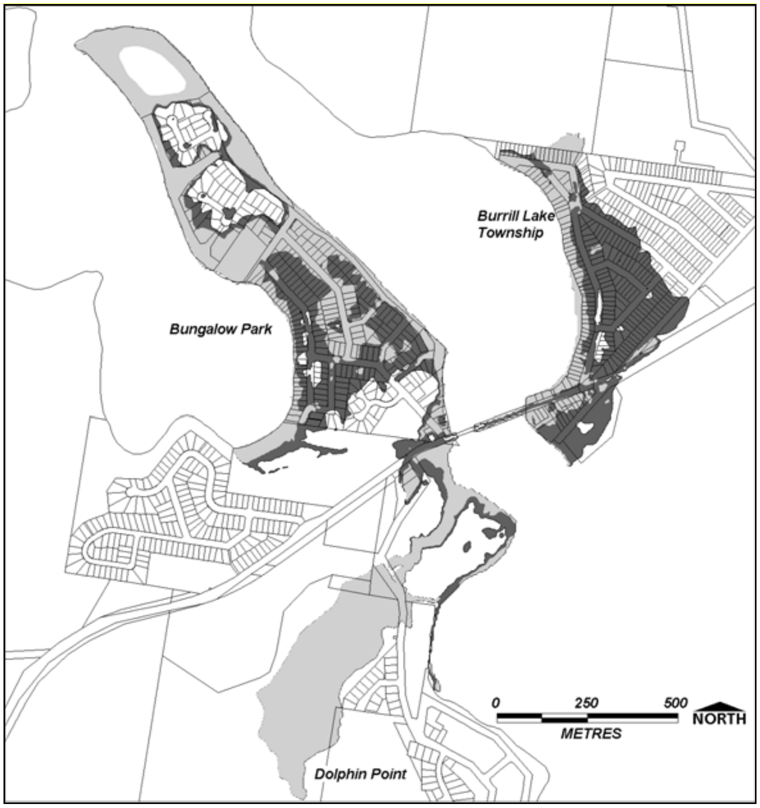

Figure 5 – Extent of Inundation (>0.5m deep) Surrounding Burrill Inlet for Simulated Flood

Light Grey: Morphological Simulation

Dark Grey: Additional Inundation – Simulation with fixed entrance bathymetry

DISCUSSION

The significance of entrance scour processes in flood levels is clear. The examples used within this paper represent rare to extreme conditions, but nonetheless, they fall within the range of floods that could be expected to occur in reality.

The use of an overly conservative assumption in determining the behaviour of an entrance during a flood, when using a numerical model to determine flood planning levels, will result in large areas of land potentially becoming unavailable for development.

As the trend for population growth continues within coastal townships in New South Wales, the availability of prime, waterfront land is a key concern. If land is prohibited from development on the basis of an overly conservative assessment of flood risk, the pressure to open up other, previously undeveloped areas to development will increase. Accordingly, it is important that an honest appraisal is made of entrance scour behaviour and the impact that this has on estuarine flooding.

There is a great deal of uncertainty associated with the bathymetric conditions that should be adopted at the coastal entrance to an intermittently open or closed estuary. Pre and post opening surveys, which could be achieved during planned and controlled artificial opening exercises, will also assist in providing a useful basis for calibrating scour processes in numerical models.

CONCLUSION

More advanced methods for modelling entrance scour processes during a flood are becoming feasible with increases in computational power. In order to provide for responsible flood management of the land surrounding coastal lakes and estuaries, these tools should be utilised to derive flood extent estimates that are as accurate as possible.

In the absence of these more advanced methods, it is important that the implications of adopting overly conservative estimates of entrance behaviour are fully appreciated and acknowledged.

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