Calibration and Testing of a Hydrodynamic Model of the Gippsland Lakes

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Abstract: The calibration and testing of a complex, branched, one-dimensional hydrodynamic model of the Gippsland Lakes in south east Victoria is described in this paper. The model covers the entire lakes system including the five major rivers flowing into the lakes (total catchment area of 20,600 km^2), the three lakes (total surface area of approximately 400 km^2) and the entrance to Bass Strait. The model was developed using WL Delft's SOBEK modelling package. While the main model uses the one-dimensional schematisation, sensitivity testing using some two-dimensional sections in particularly complex regions was undertaken. The model was produced as part of a project to provide design flood-levels for the Gippsland Lakes. Sensitivity testing was undertaken to determine the importance of factors such as temporal discretisation of input data (discharge, wind and ocean water-level), methods for incorporation of wave set-up effects on offshore boundary conditions, simulation time step, bottom friction parameters, representation of the entrance and spin-up time. The focus of testing was performance during extreme water levels. The model was calibrated to data from a number of water-level recorders within the Lakes system, which have been in place since late 1998. These data include a number of low to medium-sized flood events, and a major wind event on Boxing Day 1998. Input data for the period 1977-2001 were available but only one water-level site was available over this time. Calibration was undertaken on significant events over this period.

Keywords: *Gippsland Lakes; Flood Modelling; SOBEK; Design Water Levels; Estuary Flooding*

1. INTRODUCTION

The Gippsland Lakes is a large coastal lagoon system in south east Victoria (see figure 1). The "Lakes" includes three major lakes, Lake Wellington, Lake Victoria and Lake King, into which five major rivers flow – the Latrobe, Avon, Mitchell, Nicholson and Tambo Rivers. The Lakes are joined to Bass Strait by a narrow man-made entrance at Lakes Entrance. The total catchment area of the rivers flowing into the Lakes is approximately 20,600 km^2, with the Lakes themselves having a surface area of approximately 400 km^2.

The depth of the "Lakes" varies from up to 20 m at scour holes, to the relative shallow waters of Lake Reeve that dry regularly. The average depth of water through the "Lakes" is about 3 to 4 m. Most of the Lakes system is saline to brackish, with salt levels varying with the amount of inflow from the rivers and increasing towards the entrance. Saline stratification occurs regularly throughout the lakes.

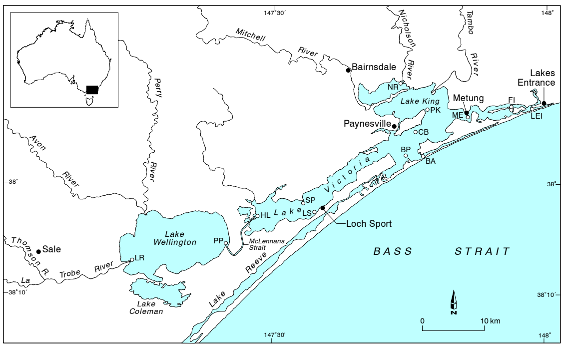

Figure 1. Location of the Gippsland Lakes

In 2001, a project team was formed involving the University of Melbourne, Gippsland Ports, the West Gippsland Catchment Management Authority, the East Gippsland Catchment Management Authority, the Gippsland Coastal Board, NRE Floodplains Unit and Lawson and

Treloar Pty Ltd. The aim of this project was to estimate design flood-levels for complex estuary systems, using the Gippsland Lakes as an example.

The approach adopted by the project team involves joint probability analysis, and the use of stochastically generated data in a Monte Carlo framework as inputs for the hydrodynamic model. This paper covers briefly the establishment, then in more detail the calibration and testing of the hydrodynamic model generated for this project. For the purpose of estimating extreme flood levels, the aim was for modelled peak levels to differ from observed values by less than 0.1 m for large events. Errors of >0.2 m are considered unacceptable.

2. HYDRODYNAMIC MODEL

The hydrodynamic model for this project was established using the SOBEK modelling package from WL| Delft Hydraulics. This is a commercially available package that has been used for flood projects both in Australia and overseas. It is a combined one and two-dimensional package that is suitable for riverine and estuarine areas.

2.1 Available Data

A Digital Elevation Model (DEM) was produced to define the topography (Wealands et. al. 2002). Cross sections for the one-dimensional model schematisation and two-dimensional grids were extracted from this DEM.

Other data required for the hydrodynamic model were collected and compiled by the University of Melbourne (Tan et. al., 2001, Tan et. al., 2002). This included;

- Water level record from various stations around the Lakes. Loggers installed and maintained by The University of Melbourne, with digital data available from November 1998 to present.
- Water level record from Bullock Island gauge at Lakes Entrance. Logger now maintained by Gippsland Ports. Data available from 1975 to present.
- Discharge data from major rivers. Complete data set available for Latrobe, Thompson, Avon, Mitchell, Nicholson and Tambo Rivers from 1977 to present.
- Wind data from East Sale Airport. This data is available from 1950 to present.

As there are very limited recorded water-levels for the down-stream boundary in Bass Strait, an estimation of this water level was generated using the following components:

- Low-frequency signal from Bullock Island tide gauge (the tidal signal from Bullock Island was filtered out using a low-pass filter). This was used during non-flood periods.
- A regression relationship was derived using, wind, atmospheric pressure, including gradients, and the SOI. This was used to generate low-frequency levels during flood periods (when the low-pass filtered data from inside the entrance was not indicative of offshore).
- Generated tidal signal for offshore (based on constituents from measured data) – this was added to the low-frequency data.

2.2 Set-up

The initial model was based on a one-dimensional schematisation. This allowed for definition of both the lakes and the narrow channels joining the lakes and Bass Strait. Run time was a critical factor in the selection of model parameters, as ultimately the model will be used to run several thousand years of stochastically generated data. Figure 2 shows the one-dimensional model schematisation. The solid lines represent the branches or flow paths, with the trapezoidal shapes representing the locations of cross-sections.

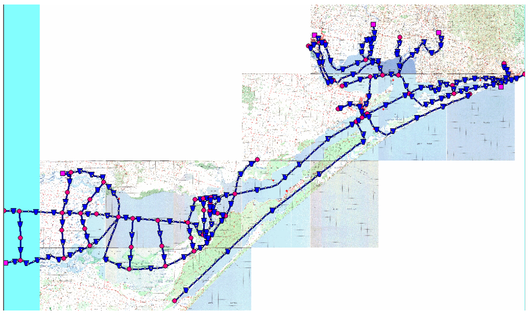

Figure 2. One-Dimensional SOBEK Model Schematisation

2.3 Calibration Periods

The period from November 1998 to February 2001 covers the "Boxing Day 1998" storm which had high winds but little rain. There were no large flood events in this calibration period, so this data was used to calibrate the general responses of the model for low flow conditions.

The second phase of calibration covered the period from January 1977 to February 2001. For this period we have a complete set of input data, but limited calibration data. Recorded water levels are available at Bullock Island for this entire period, with some gaps. There are also limited data available for Lake Wellington and Latrobe River at the other end of the system.

The model was initially calibrated to the data for the three-year period (1998 to 2001) representing low flow conditions. When the model was run for flood events, results were poor compared to the low-flow conditions. As the purpose of this model is to estimate flood levels, it is critical that flood events are well represented, while low-flow conditions are of little importance. For this reason, the model parameters were modified to better predict flood levels, even though this did not reproduce recorded water-levels during normal (low-flow) conditions. Some changes were required to friction values through the entrance for flood flow calibration. These changes are described in following sections.

The events used for flood calibration were June 1998, September 1993, April 1990, December 1985 and June 1978.

Due to the complexity of the system, various factors were found to be critical at different locations. River inflow is more critical at the river mouths, wind speed is critical at certain times, with the entrance schematisation and downstream boundary being critical near the entrance. It is the combination of all these factors that regulate levels throughout the Lakes.

2.4 Sensitivity Testing

Many model parameters were tested and varied in the calibration and testing phases of this model, including; model schematisation, entrance schematisation, offshore water level, wind, bed friction, temporal discretisation of input data, time step, spin-up time and two-dimensional sections.

Below is a brief description of the parameters and how they were used in calibration and testing of the model. The actual results from the sensitivity tests have not been presented, as this would take too much space. Only the outcomes of each investigation is presented here.

Model Schematisation

Several attempts were made in the early phase of this project to schematise the one-dimensional model to represent both 'normal' flow conditions and 'flood' flow conditions. The schematisation chosen to represent this complex physical system includes branches for the major rivers and lakes (normal flow conditions), with additional branches representing overland flow paths that exist during flood conditions. The overland flow branches and river branches generally run parallel to each other, with the banks of the rivers dividing the two branches. Link channels between the two branches allow for the exchange of water between the river and the floodplain.

Entrance Schematisation

The entrance is a narrow (about 120 m wide) man-made channel, connecting the Gippsland Lakes with Bass Strait. Schematisation of the sections through the entrance and in the channel upstream of the entrance was difficult, as the sections change regularly due to natural sediment movement and dredging practices. As the only calibration data available for the entire calibration period was for Bullock Island, just inside the entrance, schematisation of this area is very critical.

Sensitivity testing on these sections included widening, narrowing, deepening and shallowing of the critical sections. The schematisation finally used for the modelling was found to reproduce recorded water levels well during flood events.

Offshore Water Level

During the calibration of the model, offshore wind and wave set-up were considered and investigated in considerable depth. Changes in the downstream boundary water-level were used to represent these variations.

As calibration of the model for large flood events progressed, it was found that variation of the offshore water-levels via the additional wave set-up was not required. Therefore, the predicted coastal ocean level (COL), as described in a previous section, was adopted.

Wind

SOBEK takes the wind field (defined as wind speed and direction) in the meteorological data and applies a wind stress to the model. As a one-dimensional model schematisation was used, only wind stresses parallel to the direction of the branches are computed.

For the estimation of flood levels, wind stress in the direction of flow is thought to be sufficient, as this is generally the longest reach, which means the longest wind fetch, therefore the greatest impact of wind.

One wind field was applied as a time series over the entire model. Data were obtained from the RAAF base at East Sale. This station is several kilometres to the west of the model area, and is quite a distance from the coast. Wind speeds are generally higher on the coast, or over large bodies of water, as there are no topographic or vegetation effects and friction is lower.

For this reason, sensitivity testing was undertaken to find what multiplication factor gave the best model results. Tests were undertaken on the Boxing Day 1998 wind event, then verified on smaller wind events in the 1998 to 2001 calibration period. The results of this sensitivity testing indicated that the wind speeds from East Sale need to be multiplied by a factor of 1.5 before being applied to the model. A comparison of the wind speeds at East Sale and Kingfish B (an offshore oil platform) indicate that this number is reasonable.

Bed Friction

Bed friction or hydraulic roughness was represented in the model using Mannings 'n' values. The values used in the model ranged from 0.02 to 0.05 in the major channels and 0.05 to 0.10 in the overland flow branches. This is consistent with experience in one-dimensional hydraulic modelling, and common references such as Street et. al., 1996.

Using the calibration data for the three years (1998 to 2001), bed friction was firstly modified through the entire model. As there was calibration data for many sites, it was possible to get a good representation of water levels through the system for this period.

The model was then re-calibrated to flood events, and it was seen that the low-flow calibration was not suitable for flood conditions. The changes to the model for flood calibration involved varying the friction through the entrance and up the main channel to approximately Kalimna Jetty as shown on figure 3.

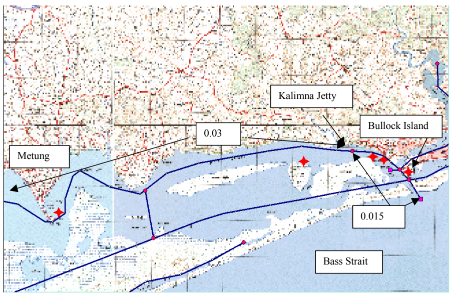

Figure 3. Mannings 'n' Roughness Values Used in Calibrated Model

This shows that a Mannings 'n' of 0.015 was used through the entrance, up to Kalimna Jetty. Although this value is lower than would generally be used in natural channels, it is required to represent flood conditions at Lakes Entrance. It is thought that mobilisation of sediment near the bed under flood flows may lead to the lower values of bed friction during a flood.

Temporal Discretisation of Input Data

Sensitivity testing was undertaken to determine the time step required for the input data. For the calibration phase of this project, all the data was available at an hourly time step, but the stochastic data will be generated at a daily time step. The question was what level of disaggregation of these data would be needed?

Model results were compared for runs with hourly, daily and three-day discharge data, and hourly and daily wind data. The downstream boundary data was kept at an hourly time step in order to accurately define the tides.

From these investigations it was concluded that daily and three-day discharge data is unacceptable, as is daily wind data, as all produce differences, when compared to hourly data, of greater than 0.10 m, at the peak of an event. All stochastic data will need to be disaggregated to hourly values.

Time Step

In the initial phase of set-up and calibration of the model, sensitivity testing was undertaken on the time step required to run the model. The time step needed to be low enough for the model to be stable, without increasing run time excessively.

SOBEK requires the definition of a time step and a maximum Courant Number. The actual time step used in the modelling is the minimum of the defined time step and the time step computed based on the defined Courant Number. The Courant Number is a measure of how many grid cells information will pass through in a single time step. This shows the ratio of local wave speed ($\sqrt{gh}$) to the velocity relative to grid spacing and time step. For stability, this is generally set to between 1 and 3. The following equation shows the definition of the Courant Number.

$$Cr = \frac{\sqrt{gh}\Delta t}{\Delta x} \tag{1}$$

Where: Cr = Courant Number

g = acc. due to gravity (9.81 m^2/s)

h = depth of water (m)

Δt = time step (s)
Δx = grid spacing (m)

This equation shows that the actual time step the model uses is dependent on the computation point spacing, the defined Courant Number and the depth of water. This indicates that as the modelled water level rises in a flood, the computation time step decreases and run time increases.

The defined time step was set to 10 minutes, and a maximum Courant Number of 1 defined. These values are considered suitable for this system, which involved a large area, and tidal flow.

Spin-up time

Sensitivity tests were undertaken in order to determine the spin-up time required for the model. This is the time required for the model to stabilise, the initial conditions to have no impact on the results and the model to produce results equivalent to those if the model was already running. This was needed because the Monte Carlo runs will be confined to larger flow and wind events, not a continuous series, to maximise computational efficiency. We therefore needed to define a period prior to an "event" for which the model would need to be run.

The results of these tests indicated that seven days is required for spin-up of the model.

Two-Dimensional Sections

Testing with two-dimensional model grids was undertaken on two of the most complex sections of the lakes; Lake Wellington and the surrounding morasses, and the entrance to Bass Strait.

The results of these investigations indicated that there were no significant impacts on water levels due to two-dimensional effects (such as eddies) occurring through these areas which was not accounted for in the one-dimensional SOBEK model.

2.5 Calibration Parameters

The calibration process used for this investigation has been explained briefly above. The following sections explain the ways in which the calibration was assessed, and gives the results for several flood events.

Graphs

The initial method of calibration was the visual comparison of recorded and modelled water level time series. When the difference between these two series was also plotted, a visual assessment was made as to the quality of the calibration.

Comparison of Peaks

A comparison of peak recorded and modelled water levels was undertaken for each event. This comparison allowed for a difference in the timing of the peaks in the recorded and modelled water-levels of up to five hours. That is, if the peak recorded water-level occurred at 10:00 am, the formula allowed for selection of the peak modelled water-level from between 8:00 am and 12:00 pm. This allowance was required, as the accuracy in timing of both the input and calibration data was not certain.

2.6 Calibration Results

Figure 4 is an indicative plot showing the recorded and modelled water levels for the April 1990 flood event, along with the difference between these two levels (recorded water level – modelled water level). This shows that the peaks of the tides match relatively well during the flood event, although there are larger discrepancies before and after the flood event.

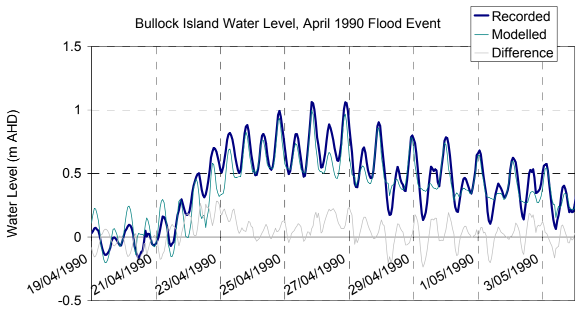

Figure 4 – Recorded and Modelled Water Levels for April 1990 Flood Event, Calibrated Model Schematisation

An analysis was undertaken on the highest 100 recorded water-levels from the period 1977 to 2001. When comparing the peak recorded water-level for an event with the peak modelled level for that event (allowing for the shift in timing), it was found that about 90% of the modelled water levels were within ±0.1 m of the recorded water levels. Table 1 below gives the statistics on these levels.

Table 1 – Results of Calibration based on highest 100 recorded water levels at Bullock Island

Variable	**Units**	**Value**
Mean difference	(m)	0.00
Minimum difference	(m)	-0.20
Maximum difference	(m)	0.19
Standard Deviation	(m)	0.08

Table 2 shows the recorded and modelled water levels, along with the differences for the highest 10 events at Bullock Island.

Table 2 – Peak Modelled and Recorded Water Levels for 10 highest recorded events

Rank	**Date and Time**	**Rec. WL**	**Mod. WL**	**Diff.**
		m AHD	**m AHD**	**m**
1	24/06/1998 21:00	1.25	1.11	0.14
2	25/04/1990 20:00	1.06	1.00	0.07
3	21/06/1978 21:00	0.91	0.98	-0.06
4	25/06/1978 0:00	0.90	0.87	0.04
5	7/06/1978 21:00	0.89	0.90	0.00
6	13/12/1985 10:00	0.88	0.87	0.02
7	6/07/1978 21:00	0.87	0.77	0.11
8	29/07/1984 21:00	0.86	0.93	-0.06
9	6/08/1991 16:00	0.85	0.81	0.04
10	26/05/1994 22:00	0.85	0.93	-0.08

These results show excellent agreement except for the June 1998 event, where the model under-predicted water levels by 0.14m. The reasons for this are not clear, but could be the result of problems with input flow or wind data, an unusually high offshore level that was not well captured by our boundary-level computation, or some problem with the model set-up that affected just this event (unlikely given the consistent performance for other large events).

3. CONCLUSIONS

For the purpose of this project, if the recorded and modelled flood levels were within ±0.1 m, the model is suitable.. Given the uncertainties of the input data, we believe this has been achieved as well as possible.

At the time of writing this paper, the project is nearing the end of the calibration/testing phase. This model, which has been extensively calibrated and tested against all available data, is suitable for use to estimate design flood-levels in the Gippsland Lakes. These design flood-levels will be used for planning purposes by the controlling authorities.

4. ACKNOWLEDGMENTS

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