PROOF-OF-CONCEPT HYDRODYNAMIC MODEL AND MARINE AND ATMOSPHERIC FORECAST DATA INTEGRATION FOR FLOOD FORECASTING IN THE GIPPSLAND LAKES

Womersley, T.[1], Leahy, C.[2], Hudson, K.[2], Anderson, B.[2], Kazazic. E.[2], Bishop, W.[1], Mawer, J.[1]

[1]Water Technology, Melbourne, VIC
[2]Bureau of Meteorology, VIC

Abstract

Flooding of the Gippsland Lakes occurs due to the complex interaction of catchment streamflows, coastal-ocean levels and wind setup, and present a significant challenge for operational flood forecasting. The Bureau of Meteorology (the Bureau) engaged Water Technology to undertake a proof-of-concept development of hydrodynamic model incorporating the integration of marine and atmospheric forecast data suitable for operational flood forecasting in the Gippsland Lakes.

As well as forecasting streamflows into the Gippsland Lakes, the Bureau routinely produces a range of atmospheric and marine forecast products that are relevant for predicting the magnitude and timing of elevated water level conditions in the Gippsland Lakes. These products include the ACCESS (Australian Community Climate and Earth-System Simulator), for atmospheric forecasts of surface pressure and wind, the OceanMAPS, for ocean forecasts of sea level anomaly (SLA) and Tidal Analysis for tide predictions.

In order to integrate the range of streamflow, atmospheric and marine forecast data produced by the Bureau for the Gippsland Lakes, a one-dimensional (1D) MIKE11 hydrodynamic model of the Gippsland Lakes was developed and calibrated to a range of historical flood events. The hydrodynamic model was then simulated in an offline forecast mode over two historical flood events in the Gippsland Lakes, incorporating the integration of the Bureau's streamflow, atmospheric and marine forecast data for those flood events

Introduction

The Gippsland Lakes system consists of a network of lakes in Gippsland region in southeast Victoria. Lake Wellington, Lake Victoria and Lake King are the three primary lakes in the system, covering an area of approximately 400 km^2. Six large rivers (Latrobe, Thomson, Avon, Mitchell, Tambo and Nicholson Rivers) feed into the lakes (Figure 1) which have a total catchment area of over 20,000 km^2. The waters of the lakes flow into Bass Strait through an artificial permanent opening at Lakes Entrance.

Townships located around the Gippsland Lakes can be affected by high water levels in the lakes. Elevated lake water levels may be caused by high river flows, high coastal ocean levels (impacted by atmospheric pressure, storm surge and tides), strong winds or a combination of these factors. The hydrodynamic characteristics of the Gippsland Lakes are fundamentally complex and model calibration is difficult due to the paucity of measured historical information available, in particular the limited number of flood events.

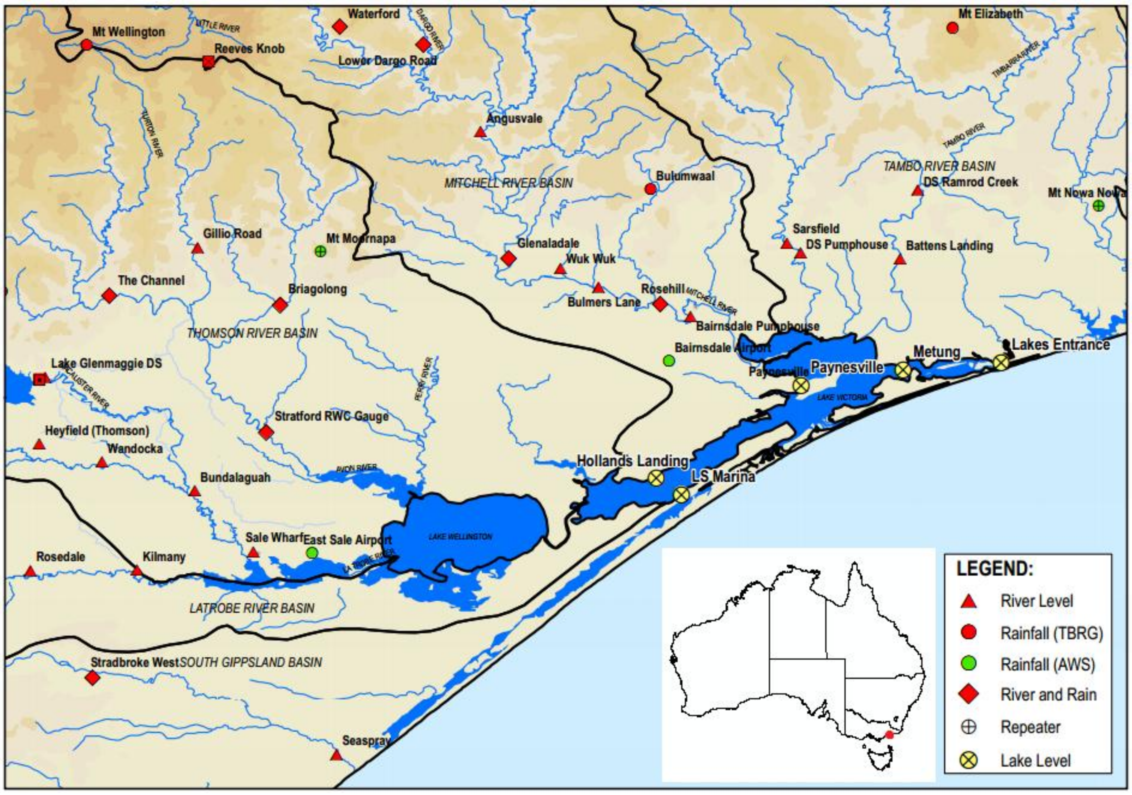

Figure 1 Gippsland Lakes Locality Map

In June 2007, major floods in river systems throughout Gippsland resulted in significant flooding in the Gippsland Lakes. High coastal ocean levels and strong winds also influenced peak lake levels during the event. This event was estimated (based on Grayson et al., 2004) as having an Average Recurrence Interval (ARI) of between 20 and 30 years. Other significant floods are known to have occurred in 1998, 1978, 1952 and 1893.

Following the June 2007 event, the Victoria Government provided funding to develop a flood warning system for the Gippsland Lakes and install associated monitoring equipment. In the years following the 2007 event, six new sites were installed: five lake level gauges at Hollands Landing, Loch Sport, Paynesville, Metung and Lakes Entrance and one river level gauge at Downstream Pumphouse on Nicholson River. In addition, the following sites were upgraded to radio telemetry; Rosedale on the Latrobe River, Ramrod Creek and Battens Landing on the Tambo River, Bundalaguah on the Thomson River and a rain gauge at Mt Elizabeth (Figure 1).

The Bureau developed two operational tools for the purpose of forecasting water levels in the Gippsland Lakes (Bureau of Meteorology, 2013). The first is a hydrologic model using the URBS software (Carroll, 1992) run using near real-time observed and predicted river inflows and ocean level data within the HyModel framework (Malone, 1999) to predict lake levels at 5 forecast locations as a result of rainfall over the catchment area. The second tool is a Linear Model that predicts lake level peaks at two locations, Paynesville and Lakes Entrance. This model is based on the research reported in the GLFLMP (Grayson et al., 2004) and the FLAGL (SKM, 2011) projects. It uses river inflows, ocean levels, initial lake levels and can provide estimates of wind impacts. Both tools are fully integrated with the near-real-time data feeds from the Bureau systems. These represent the best available tools for operational use by the Bureau for flood forecasting given the available level of data and the requirements of an operational flood forecasting system, which must use robust and simple methods.

However, there remains a significant level of uncertainty in lake level forecasts due to the limited number of calibration events and the inherent limitations of these tools.

The Bureau is in the process of implementing a new hydrological forecasting system, HyFS, based on the Delft-FEWS software platform developed by the Dutch water research organisation, Deltares. The implementation of this system will enable the Bureau to investigate and use new types of flood forecasting tools into the future, including hydrodynamic models which can better represent complex hydrodynamic situations such as those experienced in the Gippsland Lakes.

To inform future directions and feasibility of a hydraulic model for the Gippsland Lakes, the Bureau commissioned Water Technology to develop a proof-of-concept hydrodynamic flood forecast model. Water Technology previously developed and calibrated a sophisticated two-dimensional (2D) hydrodynamic model of the Gippsland Lakes that included a significant focus on flood behaviour as part of the Gippsland Lakes/90 Mile Beach Local Coastal Hazard Assessment Project (in preparation). The proof-of-concept 1D model was developed from the existing complex 2D model with simplifications. Specific objectives included ensuring operational suitability by reducing complexity and model run-times, while maintaining predictive performance at lake forecast locations compared to the more complex 2D model.

Proof-of-Concept Hydrodynamic Model Development

In response to the Bureau's request, Water Technology proposed to develop a proof-of-concept, operational flood forecasting model of the Gippsland Lakes that would enable the Bureau to evaluate the following:

- the ability of a 1D hydrodynamic schematisation to reproduce the hydrodynamic behaviour, in particular the characteristics of floods, in complex estuary systems (such as the Gippsland Lakes)
- the ability for hydrodynamic simulations to be run in forecast mode with appropriate levels of accuracy, numerical stability and computational times to support their potential application as part of operational flood forecasting systems;
- the ability to integrate real-time water level data into the hydrodynamic model simulations to improve operational flood forecasts;
- the ability to integrate existing Bureau operational atmospheric and ocean numerical forecast data into an operational flood forecasting model.

The following provides an overview of the proof-of-concept model development undertaken and demonstration of the potential forecast ability of the proof-of-concept model for two recent flood events in the Gippsland Lakes.

One-Dimensional Hydrodynamic Model

MIKE 11 is a 1D hydrodynamic model which uses an implicit, finite-difference scheme to solve unsteady flows in rivers and estuaries. The cross-section elevations were interpolated from a detailed Digital Elevation Model (DEM) of the Gippsland Lakes generated from a combination of bathymetric survey data and topographic LiDAR survey (Water Technology, 2013). The model schematisation includes all the major water bodies and tidal channels required to ensure the key hydrodynamic and flooding behaviour of the Gippsland Lakes could be reproduced.

The 1D hydrodynamic model was developed using valuable experience gained during the development of the existing 2D hydrodynamic model. The main advantage gained in developing a 1D hydrodynamic model over using the previously developed 2D hydrodynamic model is the significant decrease in model simulation time. The 1D model was demonstrated to be able to simulate a 10 day period within approximately 2 to 4 minutes, whereas the 2D model required approximately 14 hours to simulate a similar duration.

As part of the model development and refinement, particular attention was paid to ensuring the placement and schematisation of the cross-sections representing the major water bodies in the model. The cross-sections were located to produce an elevation-volume relationship that closely approximated the relationships established from the detailed bathymetric and topographic survey data sets.

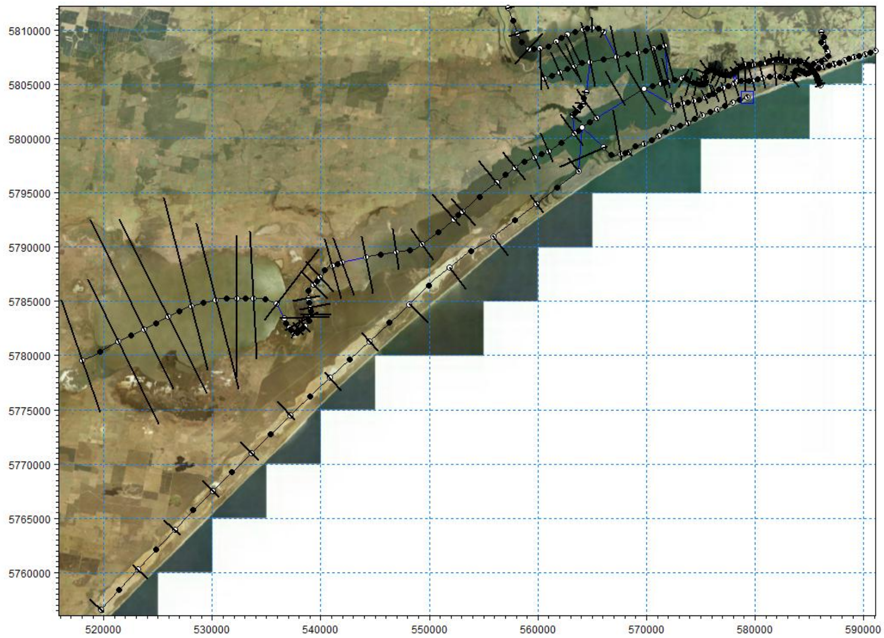

Figure 2 MIKE 11 Gippsland Lakes Cross Section Schematisation

Model calibration

Three historical hydrodynamic scenarios were selected to calibrate the MIKE 11 Gippsland Lakes mode, based on the extent of available data. These were: June-July 2011, which represented typical ambient conditions and June 2007 and 2012 which represented large and small flood events respectively. The calibration process consisted of simulating the historic hydrodynamic scenarios and where discrepancies existed between simulated and observed water level data, the cause of the discrepancy was identified and the model configuration and parameterisation adjusted until a satisfactory level of agreement was achieved.

For the 2012 calibration event the root-mean-square error (RMSE) ranged from 0.07 to 0.17 m over the four sites. Similar statistics for the 2007 calibration event were not calculated due to a number of gaps in the measured data. Differences in measured and modelled peak water levels for the 2012 calibration event ranged from -0.02 to 0.10 m (Table 1).

Figure 3 shows examples of water level calibration plots at four locations, including 3 forecast locations, within the Gippsland Lakes for the June 2012 flood event for the operational flood forecast 1-dimensional hydrodynamic model.

Based on the three historical hydrodynamic calibration scenarios the model was considered to accurately simulate the propagation of the astronomical tide and its attenuation through the entrance and further into the lakes, and the propagation of catchment generated flood flows through the Gippsland Lakes.

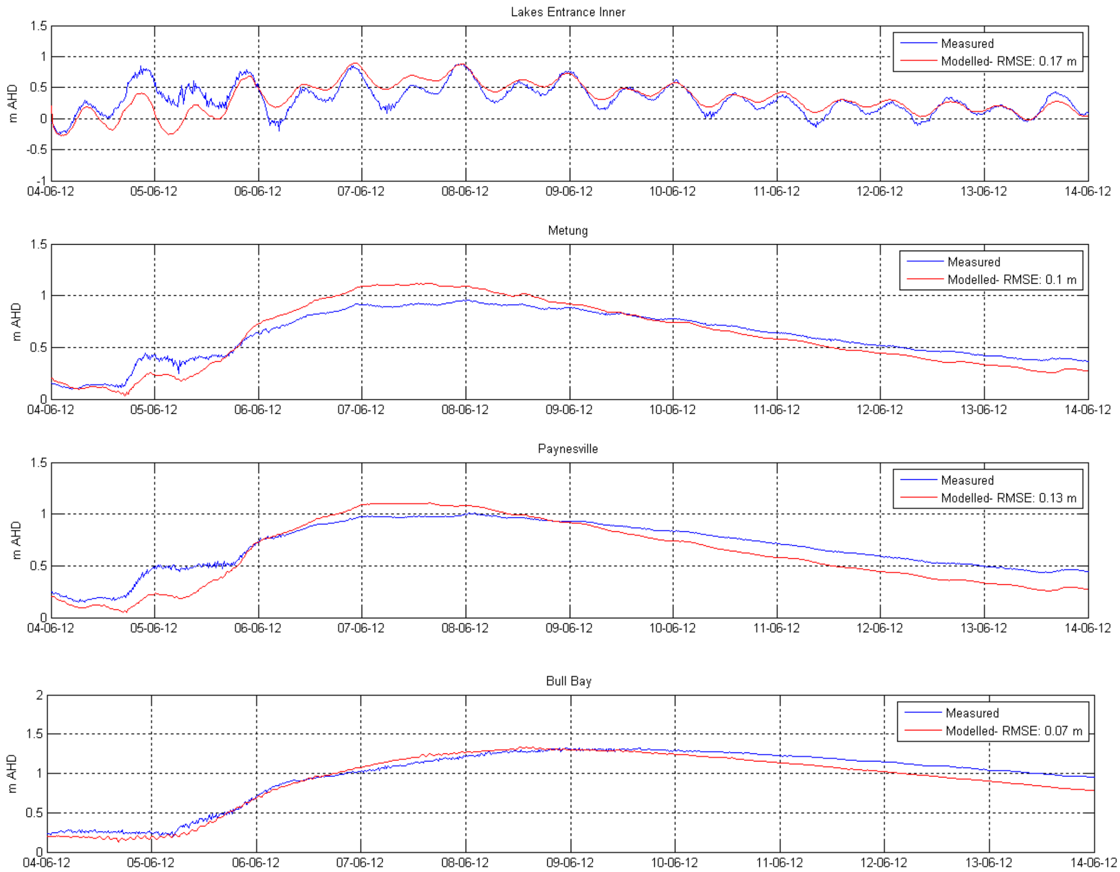

Figure 3 June 2012 Flood Event Calibration – Comparisons of Measured and Modelled Water Levels

Table 1 Measured and Modelled (1-D) Peak Water Levels at Four Locations for the June 2012 Flood Event

Location	Measured Peak Water Level (m AHD)	1-D Modelled Peak Water Level (m AHD)	Difference in Peak Water Level (m)
Lakes Entrance Inner	0.90	0.88	-0.02
Metung	0.96	1.13	0.07
Paynesville	1.01	1.11	0.10
Bull Bay	1.31	1.34	0.03

Data Integration

A critical aspect of the proof-of-concept was the evaluation of the ability to integrate real-time measured water level data and Bureau coastal water level anomalies, atmospheric pressure and wind numerical forecast model data into the hydrodynamic model flood forecasts of the Gippsland Lakes. The following sub-sections describe the characteristics of the data and method used to integrate the data into the hydrodynamic model flood forecasts.

Real-time water level updating

The establishment of five telemetered Gippsland Lakes water level monitoring stations, as part of the Gippsland Lakes Flood Forecasting Project (GLFFP) (SKM, 2011), provides the potential opportunity to incorporate real-time water level data into flood forecast simulations with the proof-of-concept hydrodynamic model.

By integrating the real-time water level data into the initial water level conditions in the forecast model simulations, the flood volumes in the Gippsland Lakes can be corrected quite precisely to those observed in near real-time.

A simple routine for integrating available real-time water level data into the hydrodynamic model initial water level conditions was developed. The routine applies real-time water levels to the initial water level conditions of various reaches within the hydrodynamic model, in order to approximate the water surface slope through the Gippsland Lakes at an instantaneous point in time. The routine includes prediction of the astronomical tide and incorporation of coastal water level residuals to approximate the coastally driven water surface slope through the entrance and lower reaches of Reeves Channel.

Figure 4 illustrates schematically how the real-time water level data was applied to the initial water level conditions in the hydrodynamic model to approximate the real-time water surface slope throughout the Gippsland Lakes.

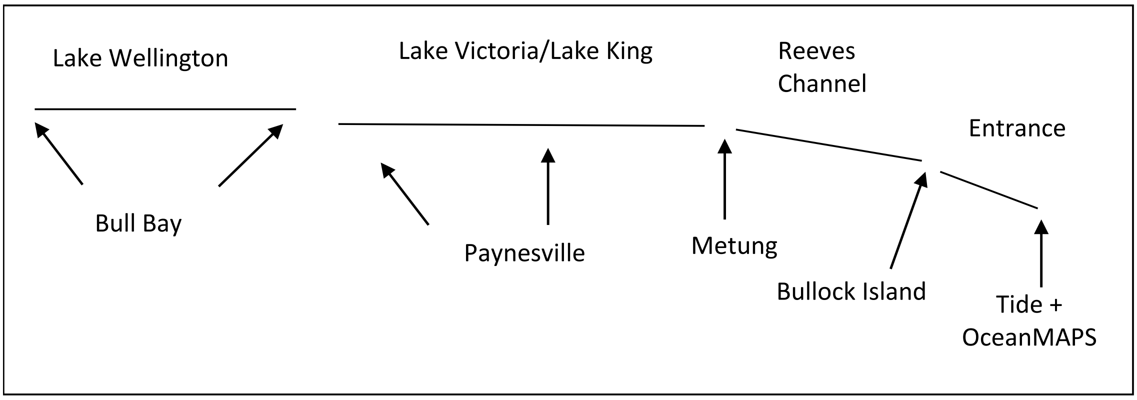

Figure 4: Schematic illustrating how initial water levels were defined throughout the Gippsland Lakes flood forecast simulations

Forecast streamflows

The Bureau undertakes streamflow flood forecasts using URBS models for the five major catchments that discharge into the Gippsland Lakes. The streamflow forecasts are provided at 6 hourly intervals, or more frequently as required during the particular flood event in question. Figure 5 displays an example of the Bureau streamflow forecasts for the major catchments for the June 2012 flood event. During an event, the streamflow forecasts improve as more observed rainfall and water level data becomes available.

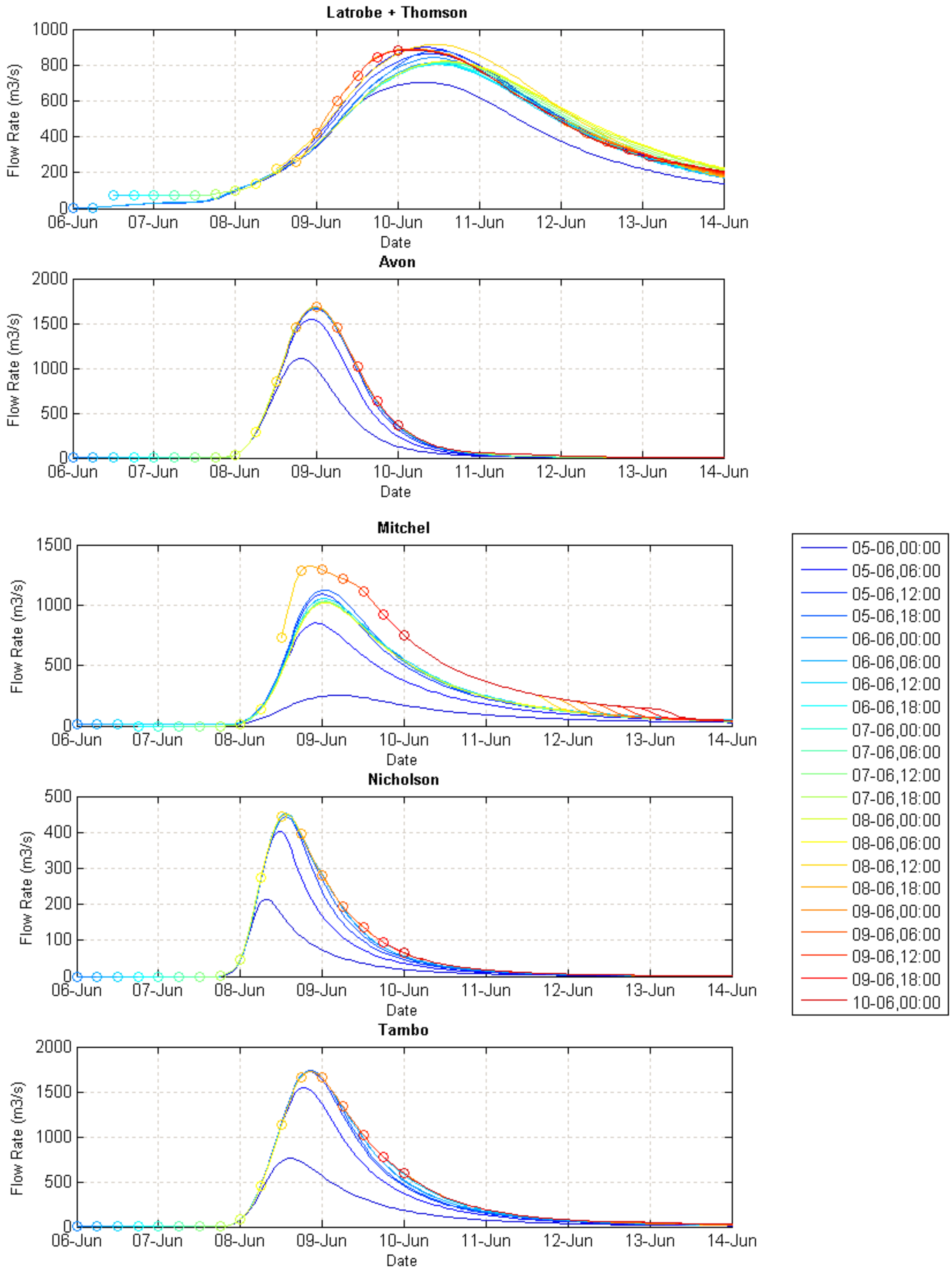

Figure 5 June 2012 Bureau URBS Streamflow Forecasts

Forecast coastal water level residuals

The Ocean Model, Analysis and Prediction System (OceanMAPS) is an operational ocean forecasting model for the Australian region established in 2007 as part of the BLUElink project (The Centre for Australian Weather and Climate Research, 2012).

The OceanMAPS provides forecasts of sea level anomalies (SLA). The SLA is an estimate of the deviation from mean sea level primarily due to mesoscale, geostrophic turbulence phenomena including eddies associated with oceanic currents and coastally trapped waves.

The forecast system incorporates four independent 7 day forecast cycles that are each time-lagged by one day over four consecutive days. This forecast design effectively results in an ensemble of SLA forecasts. For the purposes of the proof-of-concept modelling, the daily SLA forecasts from the OceanMAPS forecast ensemble were used to update the coastal water level boundary for the ‘off-line’ flood forecast simulations.

Additional variations in coastal water levels due to the inverse barometric effect are not accounted for in the OceanMaps SLA forecasts. To account for this additional component of coastal water level variations, the atmospheric pressure forecasts from the ACCESS-G model were converted to an equivalent hydrostatic pressure head difference. This was then interpolated onto the OceanMaps SLA forecasts to provide a total coastal water level residual forecast. This total coastal water level residual forecast was then interpolated onto the astronomical tide to provide a daily, 7 day total coastal water level forecast for the entrance to the Gippsland Lakes.

Figure 6 displays an example of the OceanMaps SLA forecasts and processed total coastal water level forecast for the entrance to the Gippsland Lakes during the June 2012 flood event.

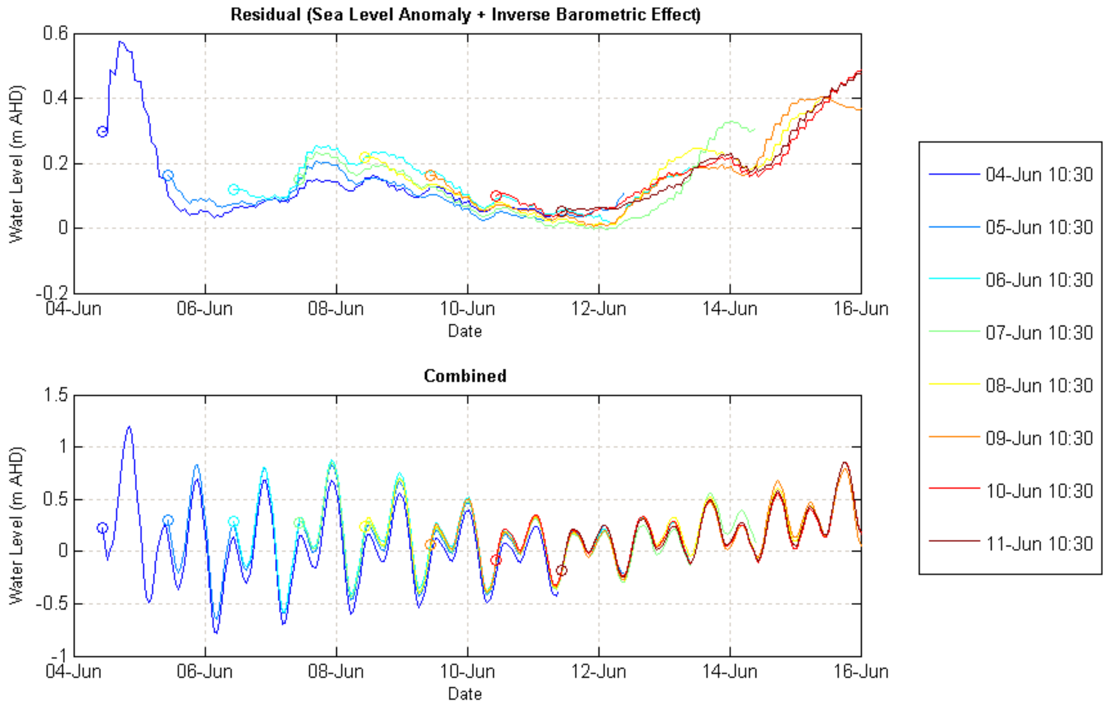

Figure 6 **June 2012 Bureau OceanMaps SLA & Pressure Forecasts**

Forecast winds

For the purposes of the proof-of-concept demonstration, ten day forecast wind speeds and directions from the ACCESS-G model were incorporated into the MIKE 11 model boundary conditions for the ‘off-line’ flood forecast simulations. The surface wind speed and direction forecasts from the ACCESS-G model are updated every 12 hours, and provide forecast wind conditions for the following 10 days.

Proof-of-Concept Operational Flood Forecast Simulations

To evaluate the proof-of-concept, the calibrated hydrodynamic model was simulated in an 'off-line' flood forecast scenario for the June 2012 flood event and the June to July 2013 flood event.

To provide a means of evaluating the relative improvement in forecast accuracy that could potentially be achieved by the real time and forecast data integration, a 'base case' forecast scenario was first simulated. The base case forecast scenario consisted of off-line flood forecasts during the 2012 and 2013 flood events that only included the Bureau's streamflow forecasts and the predicted astronomical tide, with the Gippsland Lakes initial water levels set to mean sea level (0 m AHD) at the start of each forecast simulation. These results provide a basic set of flood forecast results that enable the relative improvement in forecast accuracy due to integration of real-time water levels and atmospheric and ocean forecast data to be quantified.

A second flood forecast scenario was then simulated for the 2012 and 2013 flood events including the integration of real-time water level data throughout the Gippsland Lakes as well as the integration of forecast coastal water levels (sea level anomaly, inverse barometric pressure effects and astronomical tides) and wind forecasts.

Figure 7 and Figure 9 display the 'base case' scenario flood forecast results for the June 2012 and June–July 2013 flood events respectively.

Figure 8 and Figure 10 display the proof of concept real-time and atmospheric and ocean forecast data integration scenario flood forecast results for the June 2012 and June–July 2013 flood events respectively.

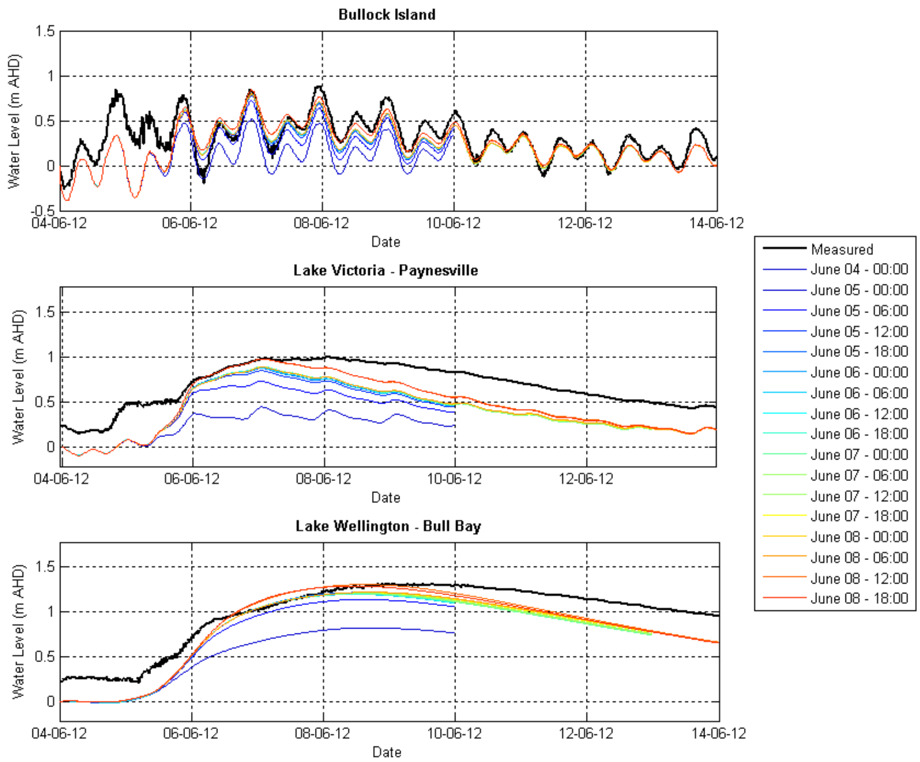

Figure 7 'Base Case' Lake Water Level Forecasts (June 2012 Event)

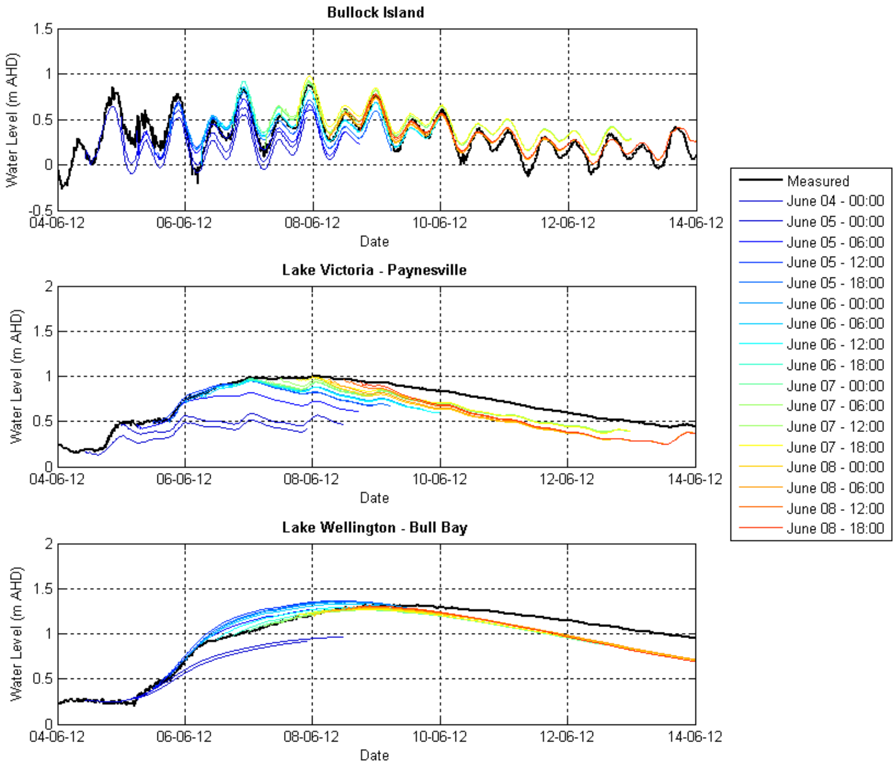

Figure 8 **Real-time and Forecast Data Integration Lake Water Level Forecasts (June 2012 Event)**

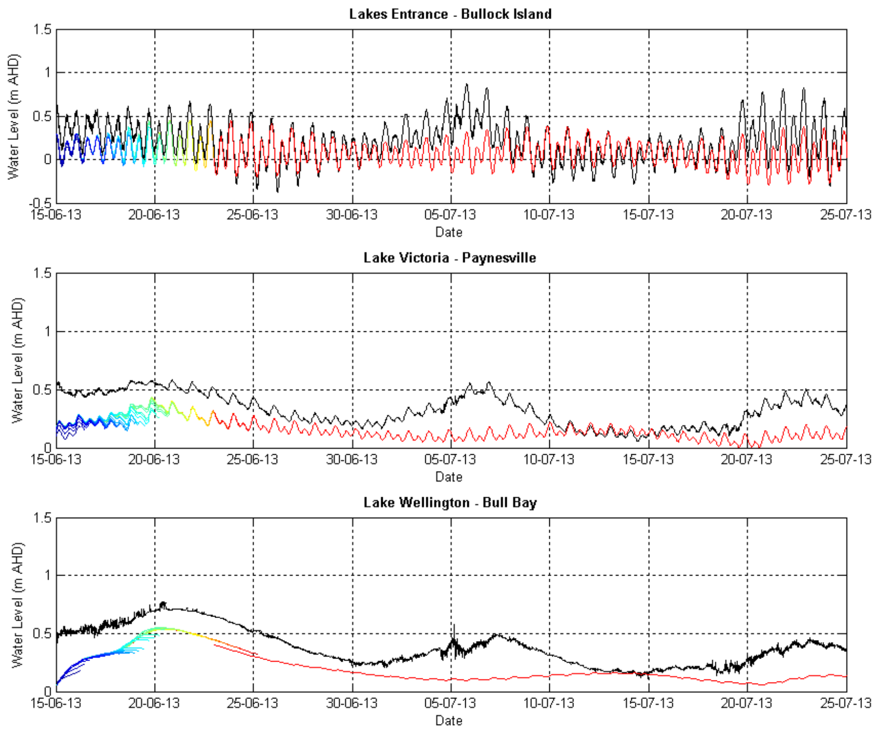

Figure 9 **'Base Case' Forecast Comparisons to Measured Water Levels (June-July 2013 Event)**

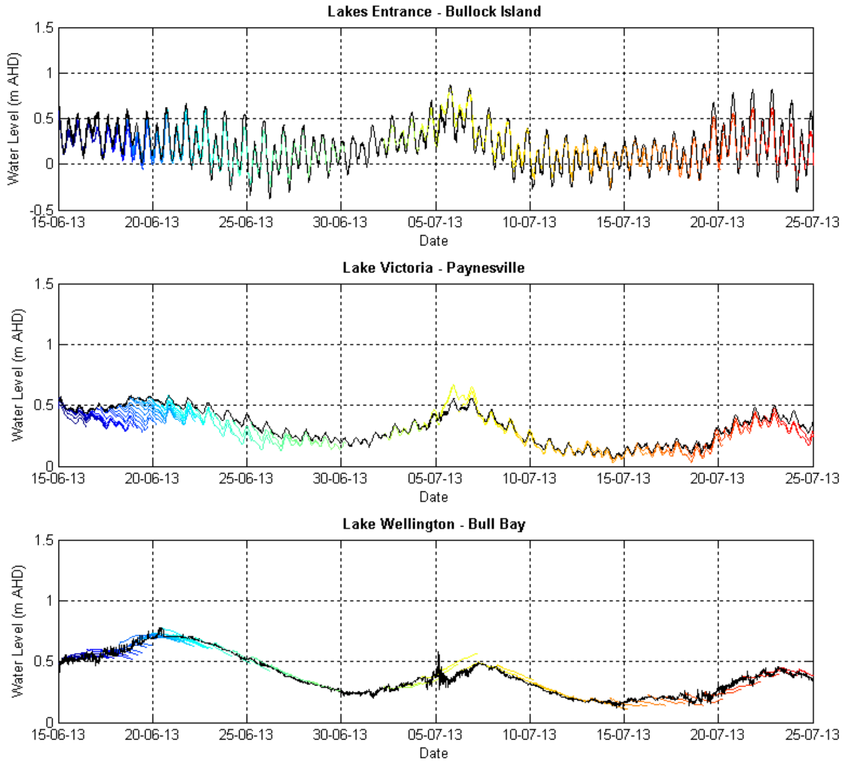

Figure 10 **Real Time and Forecast Data Integration Forecast Comparisons to Measure Water Levels (June-July 2013 Event)**

The potential benefits of the integration of real-time water level and forecast meteorological and oceanographic data was particularly evident in the June–July 2013 event forecast simulations. The base case scenario for this event consistently underestimated forecast water levels at each of the three forecast locations, particularly between the 3rd and 8th of July when a relatively large coast ocean level event occurred, resulting in higher water levels at Lakes Entrance than the late June streamflow event itself. In comparison, the real-time and forecast data integration scenario demonstrated significant improvements over the base case scenario for this period, reflecting how increased coastal ocean levels contributed significantly to the total lakes water level relative to catchment inflows.

In addition to the qualitative improvements to flood forecast accuracy presented by the time-series comparisons above, further analysis and comparison of the proof-of-concept flood forecasts scenarios and the measured water levels at three key locations in the Gippsland Lakes has been undertaken for the two historical flood events simulated.

The absolute (modelled-measured) forecast water level errors are presented at 6 hour intervals, out to 48 hours at each location. These error plots demonstrate that the integration of real-time and forecast meteorological and oceanographic data assisted in removing forecast bias (errors centred closer to zero), and typically decreased the error range over the two flood events assessed.

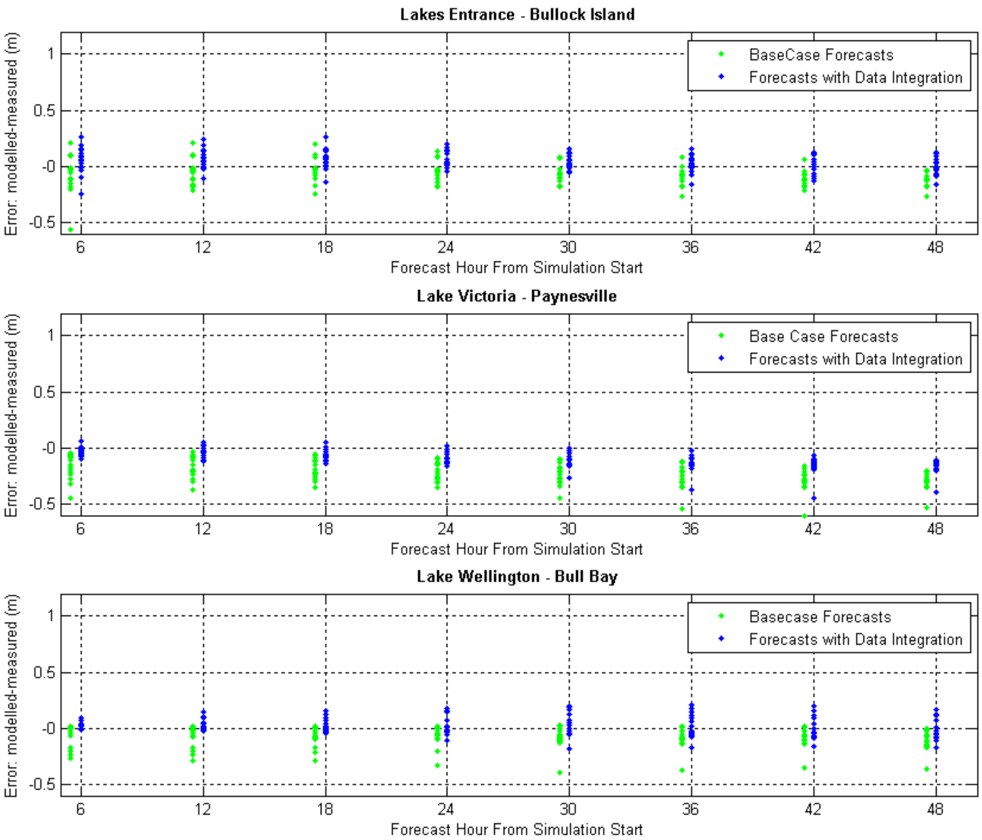

Figure 11 **Absolute Forecast Error with Increasing Forecast Time for the June 2012 Flood Event**

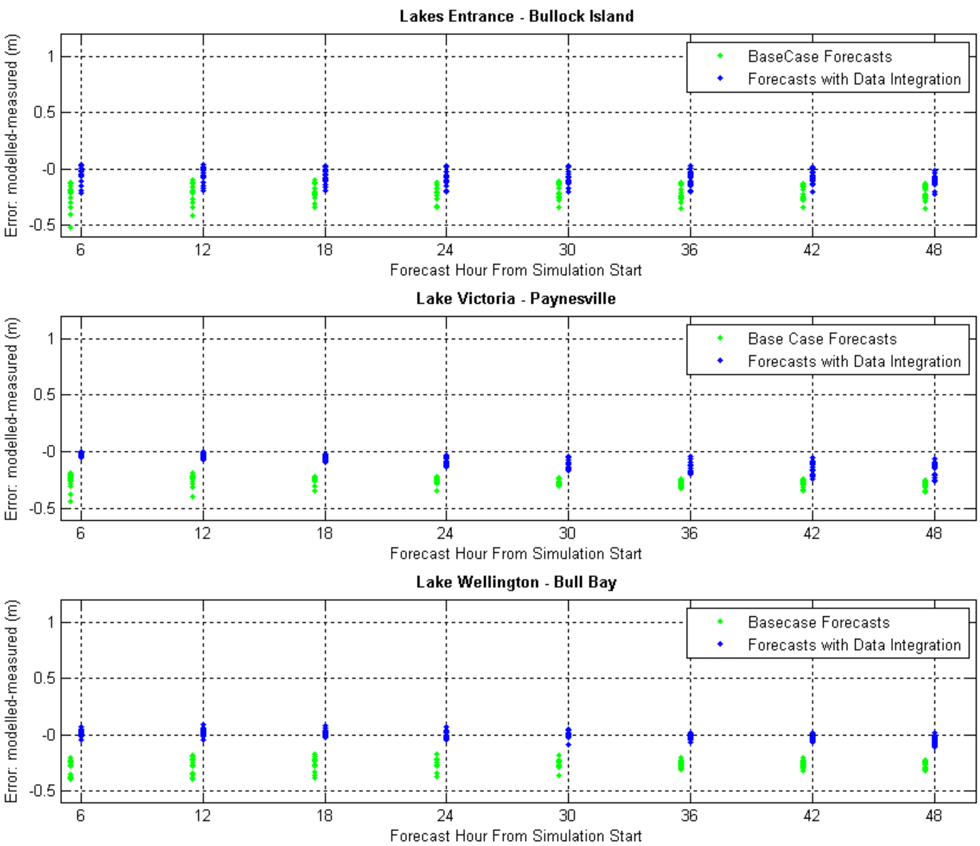

Figure 12 **Absolute Forecast Error with Increasing Forecast Time for the June–July 2013 Event**

Summary and Future Considerations

The proof of concept work presented in this paper shows that hydrodynamic modelling has the potential to be used for real time flood forecasting for complicated hydrodynamic systems. The simplified 1D hydrodynamic model performed well at predicting elevated lake levels, while still meeting the run-time requirements of a real-time flood forecasting model. Integration of Bureau oceanographic and atmospheric forecasts and observed river level data can further improve the forecasting performance of the hydrodynamic model.

HyFS provides a platform that is capable of running a range of hydrodynamic models, alongside and for comparison with existing methods, and can integrate these models seamlessly with other forecast data and real-time water level observations. HyFS will be the operational flood forecasting platform for the Bureau from mid-2015 onwards.

Before hydrodynamic models can be implemented for operational use at the Bureau, a number of steps would need to be undertaken. Firstly, and most importantly, the development of a national hydrodynamic modelling strategy to provide clear guidelines on situations where hydrodynamic modelling should be considered for flood forecasting use, including associated data requirements and likely development costs. Subsequent steps include selection of a preferred modelling package, integration of the modelling package within HyFS and training of flood forecasting staff in the background, limitations and real-time use of these models. This will then give the Bureau the capability to develop and run real-time hydrodynamic models in situations where they offer significant advantages over currently used methods.

References

Bureau of Meteorology (2013) Gippsland Lakes Forecasting Tools Model Development (Revised)

Carroll, 1992 URBS A Catchment Management and Flood Forecasting Rainfall Runoff Routing Model, Version 3.9

The Centre for Australian Weather and Climate Research (2012) Ocean Model, Analysis and Prediction System: Version 2. Melbourne: Centre for Australian Weather and Climate Research

Grayson, R., Candy, R., Tan, K., McMaster, M., Chiew, F., Provis, D., & Zhou, S. (2004). *Gippsland Lakes Flood Level Modelling Project - CEAH Report 01/04.* Melbourne: Centre for Environmental Applied Hydrology, University of Melbourne.

Malone (1999) Using URBS for Real Time Flood Modelling, 25th Hydrology na Water Resources Symposium

Sinclair Knight Merz. (2011). Gippsland Lakes Flood Forecasting, Report 9: Routing Inflows to the Gippsland Lakes. Melbourne: Sinclair Knight Merz.

Water Technology (2013) Proof-of-Concept Development of a Hydrodynamic Model for Operational Flood Forecast in the Gippsland Lakes. Report Prepared for the Bureau of Meteorology.

Water Technology (in preparation) Gippsland Lakes/90 Mile Beach Local Coastal Hazard Assessment Project – Report 2: Inundation Hazards.