IMPLICATIONS OF CLIMATE CHANGE ON THE HYDRODYNAMIC BEHAVIOUR AND ECOLOGICAL FUNCTIONS OF THE SNOWY RIVER ESTUARY

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Abstract

Water Technology was engaged by the East Gippsland Catchment Management Authority to assess the implications of climate change on the hydrodynamic behaviour and ecological functions of the Snowy River estuary and floodplain. This multi-disciplinary project had three main components; a comprehensive field data monitoring program was undertaken involving the deployment of a large number of instruments within the estuary to capture a continuous and up to date, baseline data set of the hydrodynamic, temperature and salinity conditions of the estuary, a three dimensional hydrodynamic model of the estuary was calibrated to this data set and was able to provide detailed salinity, stratification, inundation and sediment transport information for a range of estuary entrance configurations and future conditions; and a flora and fauna investigation that identified the current vegetation and fauna extents and conditions that affect vegetation distribution in the estuary.

This information has provided a holistic assessment of the current condition of the estuary and the implications associated with climate change. The modeling of the climate change scenarios, within the management timeframe of 25 years, identified that there was an observed salinisation of the estuary and the potential for a significant increase in the frequency and duration of entrance closures and therefore inundation of the floodplain.

It was found that there were clear relationships between floodplain inundation duration, salinity and vegetation assemblage. These vegetation associations were utilised in conjunction with the outputs of the hydrodynamic model to develop predictions of vegetation change across the 5,000Ha floodplain.

The information developed form this study will assist the East Gippsland Catchment Management Authority in the development of management plans that maximize ecological outcomes for the estuary during changing climatic conditions.

Introduction

This paper outlines the methods to determine the current hydrodynamic behavior and ecological condition of the Snowy River estuary floodplain and how it may change based upon modifications to inflows and sea level. The project utilised a multidiscipline approach drawing upon skills in hydrodynamic modelling and ecology.

The Snowy River estuary has undergone significant historical changes from its natural state due largely to changes in land use and the significant reduction in catchment inflows from the Snowy Mountains Hydroelectric Scheme (SMHS). Over the next 20-30 years, the Snowy River estuary faces additional changes due to the predicted further reduction in catchment yields due to post wildfire eucalypt forest regeneration, the potential return of environmental flows and the impact of reduced rainfall and sea level rise.

To improve the understanding of the complex physical processes which occur in the Snowy River estuary, and to inform longer term strategic management directions for the estuary, a detailed study of the hydrodynamic, salinity, ecology and sediment transport processes occurring was undertaken. To assist with the study, a sophisticated numerical modelling tool capable of predicting the fundamental hydrodynamic, salinity and sediment transport processes of the estuary was developed. This modelling tool has been used to assist in integrating the various forcing variables that act upon the estuary. The modelling tool provides a means to extend the understanding of the existing hydrodynamic behaviour of the estuary and to predict the potential response of the estuary to changes in key forcing variables in the future.

Current condition

The ecological character of the Snowy River floodplain has undergone significant changes since European settlement due to the clearing and draining of the floodplain for agriculture, reduced catchment inflows, and rising sea levels.

Catchment inflows have been affected by the SMHS, on-going drought conditions, and the bushfires of 2003 and 2007. These reduced freshwater inflows contribute to the increasing salinisation of the estuary, and the increased frequency of estuary closures.

All of these factors significantly affect the ecological values of the floodplain. Increasing salinity in the estuary has impacted on the plant assemblage within and surrounding the estuary. Non salt tolerant species are being lost and replaced by saline tolerant species. Species that are not tolerant of flooding are also lost when estuary closures inundate vegetation for extended periods. Increasing sea level is thought to have raised the levels of saline groundwater, placing further pressures on the existing vegetation.

Two reserves on the floodplain are managed by Parks Victoria (Curlip and Corringle State Game Reserves). 2,500ha of the total floodplain area of 5,500ha is used for cattle grazing.

Expected Changes to Estuary Forcing Variables

This study has considered the magnitude of the expected changes to the key forcing variables acting upon the estuary over a timeframe that extends 25 years from present. The predictions of the changes expected by 2035 have been derived from relevant scientific publications and other applicable studies and are summarized as follows:

Over the 20th Century, global average sea levels are estimated to have increased by approximately 0.17 meters (Church & White, 2006). The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPPC, 2007) provides a predicted increase in mean sea levels, following the upper rough estimates above late 20th Century levels, of approximately 0.2

meters by 2035. This estimate of sea level rise is considered consistent with the policy of the Victorian Coastal Strategy (2008) to consider a sea level rise of not less than 0.8m by 2100.

Predicted changes to the quantity of water available to downstream users following the 2003 alpine bushfires in the Snowy River catchment, were estimated by the Murray Darling Basin Commission (SKM, 2007). The total maximum reduction in streamflows is predicted to occur approximately 25 years after bushfires, and provides an estimate in line with the 20-30 year timeframe considered in this study. The predicted maximum reduction in streamflows was estimated at 24%. The Brodribb River catchment has not been extensively burnt in recent history and it is has been assumed that no significant changes to streamflows will occur in this catchment.

The Climate Change in Australia Technical Report (CSIRO, 2007) estimates the magnitude of predicted climate change in Australia for various timeframes including 2030. These estimates have been adopted as representative of the 20-30 year timeframe considered in this study. By 2035, annual rainfall in East Gippsland is predicted to reduce by between 2-5%. Annual temperatures are predicted to increase by between 0.6-1.00C, and potential evaporation rates are projected to increase by 2-4%. No detailed assessment of the impact of these climate change predictions on streamflows into the Snowy estuary is understood to exist. Therefore to test the sensitivity of potential climate change related impacts on streamflows into the estuary 2035, an additional reduction of 5% of the historical streamflow yields in the Snowy and Brodribb River has been adopted. This provides a total potential reduction in Snowy River streamflows, due to wildfire regeneration and climate change, of approximately 30% by 2035.

Entrance Condition

The condition of the estuary entrance is one of the most critical variables controlling the hydrodynamics and broader environmental processes of the estuary. Historically the entrance has shown significant dynamics in terms of its location and dimensions however, post SMHS and in particular following the drought conditions experienced over the last 15 years, the entrance location has remained relatively static and its condition has tended towards a constricted state with relatively frequent entrance closures.

Analysis of the historical streamflow record incorporating the predicted 30% reduction in streamflow yields by 2035 has identified that the number of 30 day periods with Snowy River streamflows below $3m^3/s$ (260ML/d) (identified as the minimum threshold required to maintain the constricted entrance opening), could increase by somewhere between 30-50% on average over the long term.

Based on the observed historical behaviour of the estuary entrance, the potential for entrance closures to occur increases significantly when Snowy River streamflows are less than this minimum streamflow threshold for approximately 30 days or longer, and the entrance has not been scoured by flood flows exceeding approximately $200m^3/s$ (17,300ML/d) over the preceding two years.

In response to the rate of sea level rise predicted over the next 20-30 years, the Snowy River estuary entrance would be expected to be translated shoreward and upward, as sediment is eroded from the beach face and transported over the entrance berm via washovers. On average, this is likely to increase the height of the entrance berm by a similar magnitude as the predicted increase in mean sea level. Over the long term, the estuary pool level that must be achieved to enable successful artificial openings of the closed entrance will therefore potentially increase from the current 0.9metres AHD to 1.1metres AHD by 2035.

Hydrodynamic Modelling

Model Overview

Numerical modelling is the process of creating an equation or system of equations that describes or predicts, with an appropriate degree of accuracy, some physical situation. The Danish Hydraulic Institute's (DHI) MIKE 3 flexible mesh flow model has been utilised for this study. MIKE3 is based on the numerical solution of the three-dimensional incompressible Reynolds average Navier-Stokes equations invoking the assumptions of Boussinesq and hydrostatic pressure. The governing equations therefore consists of continuity and momentum equations for the flow and advection diffusion equations for salinity and temperature and equations of state relating water density to salinity and temperature.

The spatial discretisation is performed using a cell-centered finite volume method. The horizontal domain is discretised as triangular and quadrilateral elements of sufficiently varying resolution to adequately represent the topography and provide computational stability in areas of flooding and drying and high hydraulic or water quality gradients. The vertical domain is discretised as a combination of fixed z coordinate layers and varying sigma layers.

Model Topography

The horizontal spatial domain of the model is comprised of quadrilateral and triangular elements. Linear features such as the Snowy and Brodribb River channels were resolved as quadrilateral elements to improve computational efficiency and numerical resolution of the hydrodynamics of these features. The floodplain and remaining channels are resolved as triangular elements of varying size to adequately resolve areas of high hydraulic gradients and minimise unnecessary computational points in other areas. The computational mesh of the entire model is displayed in Figure -1.
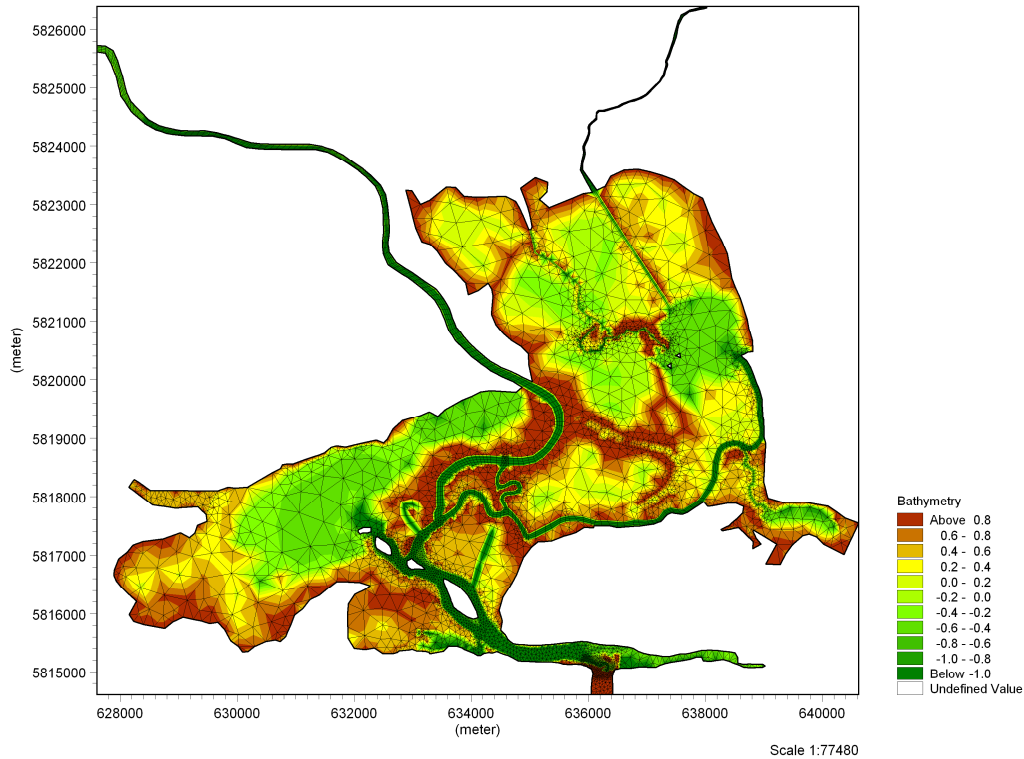
Figure - 1   Model Computational Mesh

Vertical Layering

The vertical domain was discretised as a combination of fixed z coordinate layers and varying sigma layers. A total of 10 layers in the vertical were required to resolve the strong stratification and associated interface that develops in the Snowy River.

Hydraulic Structures

Sub elements structures such such as levees and culverts on the floodplain not readily resolved in the computational mesh were incoporated implicity within the model schematisation. Levees were modelled as weirs with elevations extracted from the DTM to control the level at which floodwaters could inundate adjacent floodplain areas. A simple culvert routine was employed to simulate flows through culverts on the floodplain.

Eddy Viscosity and Dispersion

The transfer of momentum through sub-grid scale turbulence is modelled through the inclusion of eddy viscosity in both the horizontal and vertical.

The horizontal eddy viscosity is given by a "Smagorinsky-type" formulation. This expresses the effects of sub-grid scale turbulence by an effective eddy viscosity related to a characteristic length scale and the local spatial current variations.

The vertical eddy viscosity is modelled using a standard k-ε formulation, as described for example by Rodi (1980). The turbulence model solves two additional transport equations for the turbulent kinetic energy (k), and the dissipation (ε) of turbulent kinetic energy. The damping effect of stratification on vertical mixing is included through a Richardson number dependent damping coefficient.

The horizontal and vertical dispersion coefficients used in the computations are directly linked to the eddy viscosity through a scaling factor such that the amount of dispersion is governed by the turbulence in the flow.

Hydrodynamic Model Calibration

The development of a hydrodynamic model of the Snowy River estuary required a rigorous calibration process to ensure the model accurately reproduces observed hydrodynamic behaviour within the study area. The calibration process consisted of systematically comparing observed hydrodynamic behaviour within the study area against the hydrodynamic models reproduction of that behaviour. This process generally incorporates comparisons between observed water level variations, current velocity observations and other available water quality measurements i.e. salinity. Where the model does not adequately represent the observed behaviour, reasons for the discrepancies are identified and inputs to the model adjusted. This process is repeated until a satisfactory result is achieved.

A number of environmental forcing sequence scenarios were utilised for calibration of the model considered representative of various dynamic estuary states.

The three calibration scenarios were as follows:

- Low flow constricted entrance
- Flood flow scouring of constricted entrance
- Closed entrance flooding

The three scenarios were simulated in the hydrodynamic model and the model results were compared to available hydrodynamic information including:

- Instantaneous water level data
- Instantaneous salinity data
- Inundation extent data

Calibration Results – Low Flow Constricted Entrance

Water Levels

Figure 2 through to Figure 6 shows the final comparison between observed and simulated water levels at the six monitoring locations following calibration of the model. The following observations are made regarding the level of agreement achieved between the modelled and observed water level variations in the estuary:

- The significant attenuation of the ocean tide and impact on mean water levels in the estuary associated with the propagation of the tide across entrance and associated flood tide delta is considered to be well reproduced by the model.

- The attenuation of the tide and shift in phase along the length of the Snowy River is considered to be well resolved in the model.

- The influence of the surge events in Bass Strait around the 1st July on mean water levels in the estuary is accurately reproduced by the model.

- The level of agreement between the observed and simulated water levels at the Upper Snowy monitoring location are somewhat less well reproduced than the other locations. This is considered primarily due to the lack of accurate bathymetric data at the upstream end of the Snowy River and the channel cross section therefore had to be estimated at this location.
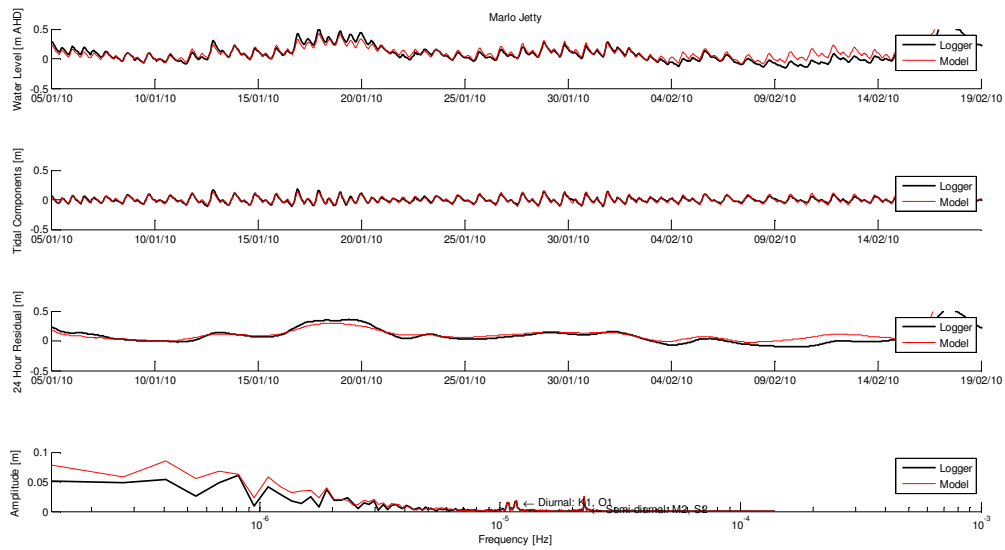

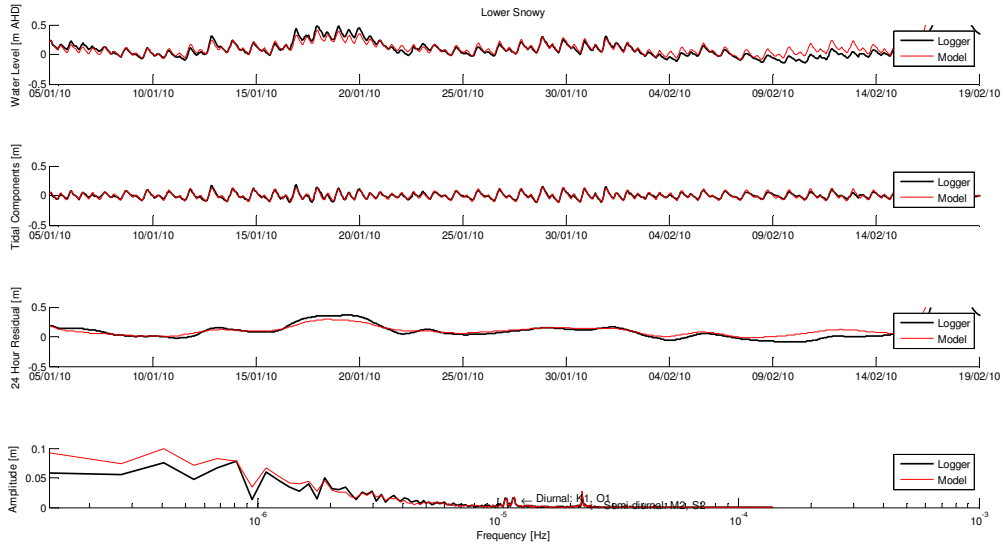**Figure 2   Marlo Jetty Low Flow Constricted Entrance Water Level Calibration Results**

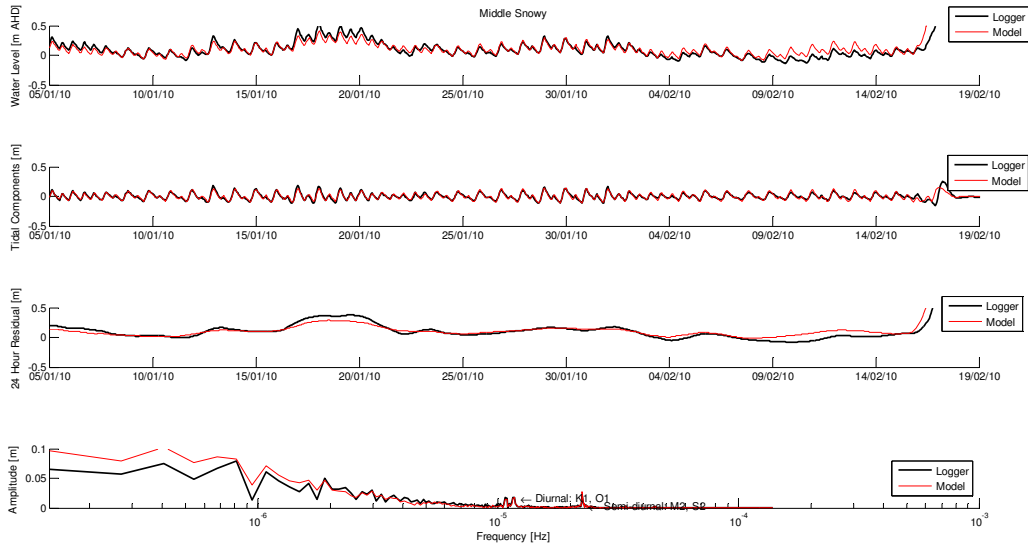**Figure 3   Lower Snowy Low Flow Constricted Entrance Water Level Calibration Results**

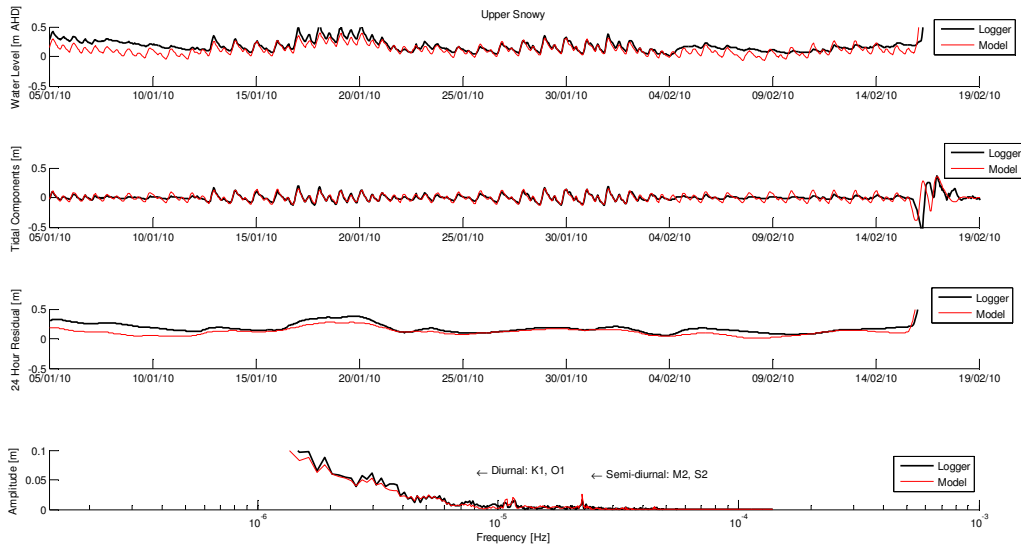**Figure 4   Middle Snowy Low Flow Constricted Entrance Water Level Calibration Results**

Figure 5 **Upper Snowy Low Flow Constricted Entrance Water Level Calibration Results**
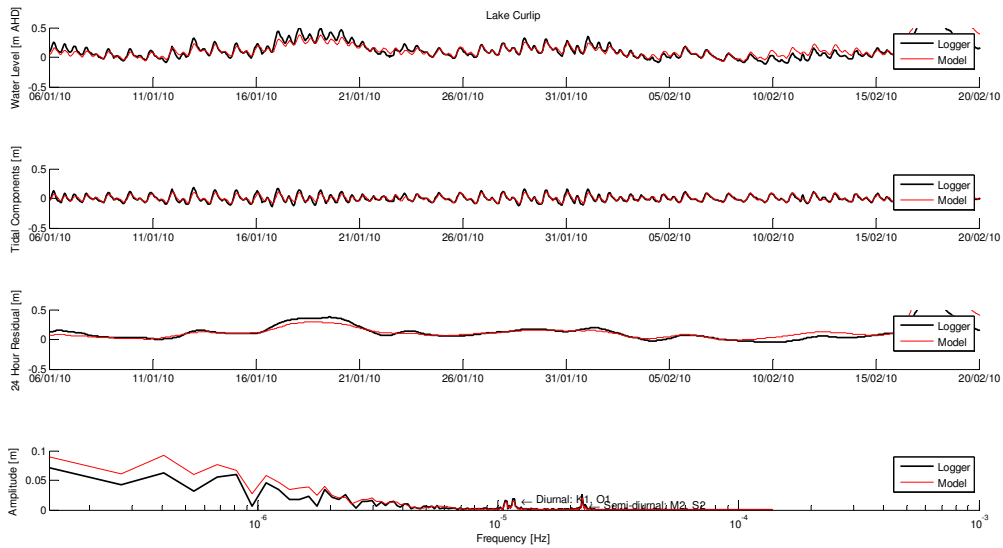

Figure 6 **Lake Curlip Low Flow Constricted Entrance Water Level Calibration Results**

Salinity

Figure 7 through to Figure 8 shows the final comparison between observed and simulated water levels at the six monitoring locations following calibration of the model. The following observations are made regarding the level of agreement achieved between the modelled and observed salinity in the estuary:

- The magnitude and variation of the modelled salinity in the lower depths of the Snowy River over the period of record is considered to be in good agreement with the observed records.

- Due to the use of sigma vertical coordinates in the upper layers of the model, it is difficult to produce a direct comparison of salinity at the same depth as the logger was deployed. Therefore the closest sigma coordinate to the depth of the logger was extracted and compared to the observed salinity. Despite some differences in the detail, the relative magnitude and variation in the salinity close to the interface of the salt wedge is considered to be reasonably well produced by the model.
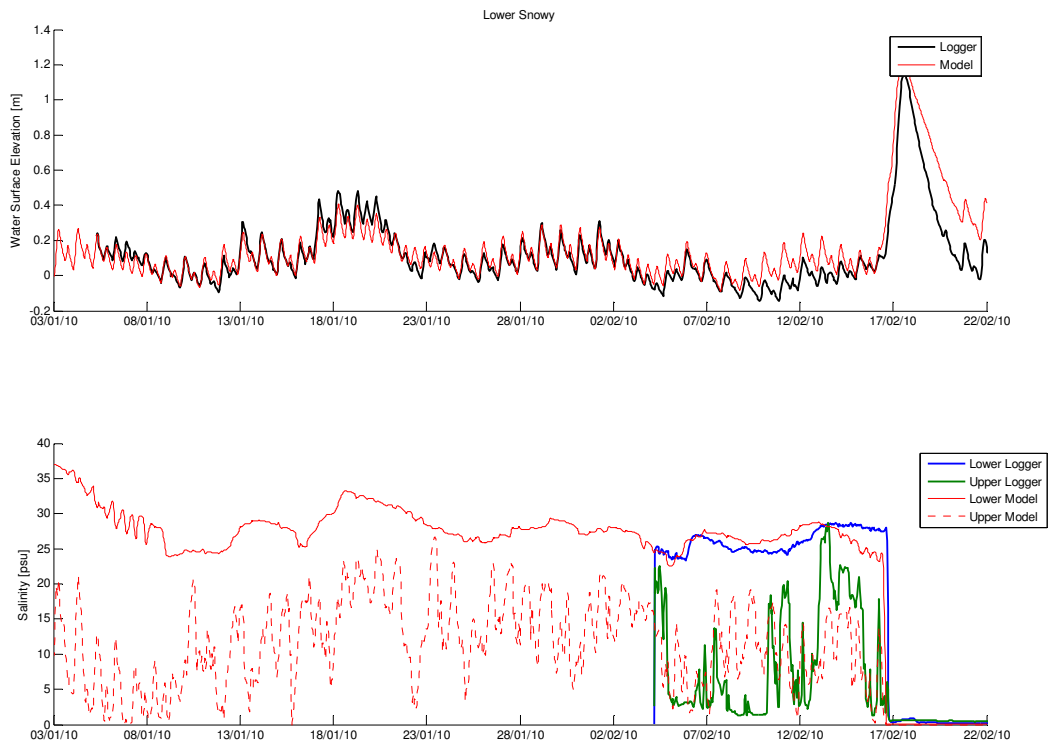

Figure 7   Lower Snowy Low Flow Constricted Entrance Salinity Calibration Results
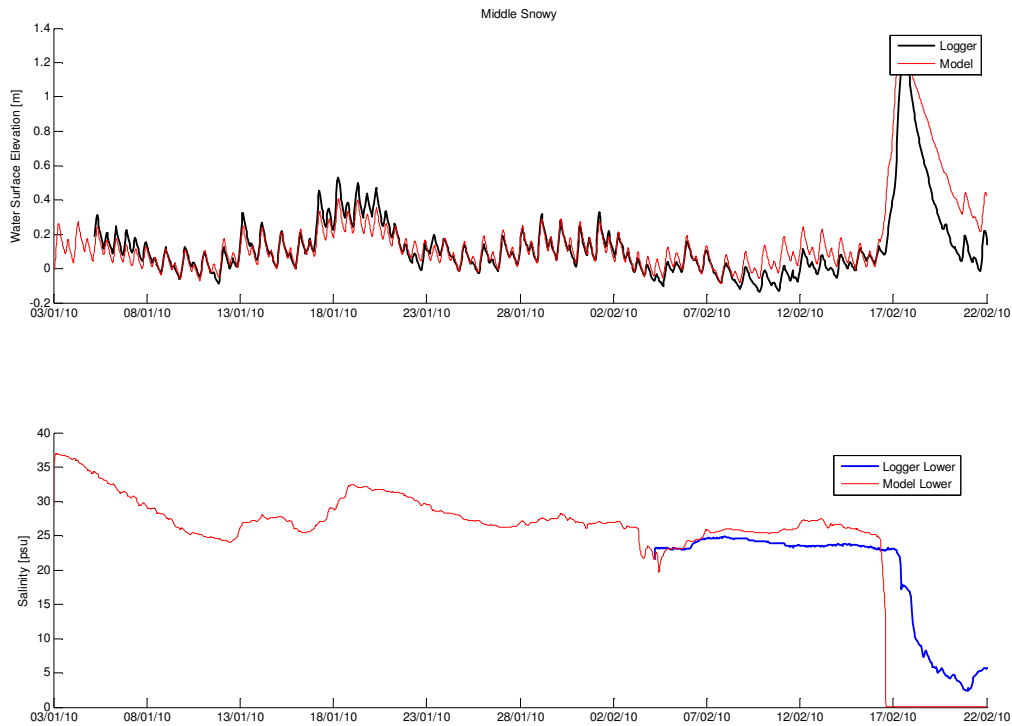
Figure 8   Middle Snowy Low Flow Constricted Entrance Salinity Calibration Results

Calibration Results - Flood Flow Scouring of Constricted Entrance

Figure 9 displays the bed level change predicted by the sediment transport model of the entrance channel. The following observations are made regarding the level of agreement between the modelled and observed water levels variations in the estuary:

- The flood peak and general shape of the flood hydrograph are considered to be well produced by the model, along with the tidal range after the flood event.

- The ability of the model to accurate describe the scouring of the entrance associated with the flood event is dependent upon the hydraulic roughness of the entrance. During a flood event the bed-forms (ripples/dunes) that are formed by the sand bed are changed in form, most likely flattening out under the higher flows. The result is a reduction in hydraulic roughness along the entrance channel, and increased scouring. As the flow subsides after the flood, the sediment reforms the various bed features and the hydraulic roughness increases. This type of effect has been noted by authors such as Knight (1981) and in Morvan et. al (2008).

- The impact of waves on the transport of sediment into the estuary after the flood event was investigated during the calibration by including the wave field to the ocean levels over the calibration period and including wave transport in the sediment transport equations. It was found that the effect of waves was predominantly limited to the ocean

side of the entrance, where the shape of the ebb tide delta altered depending on the wave magnitude and direction.
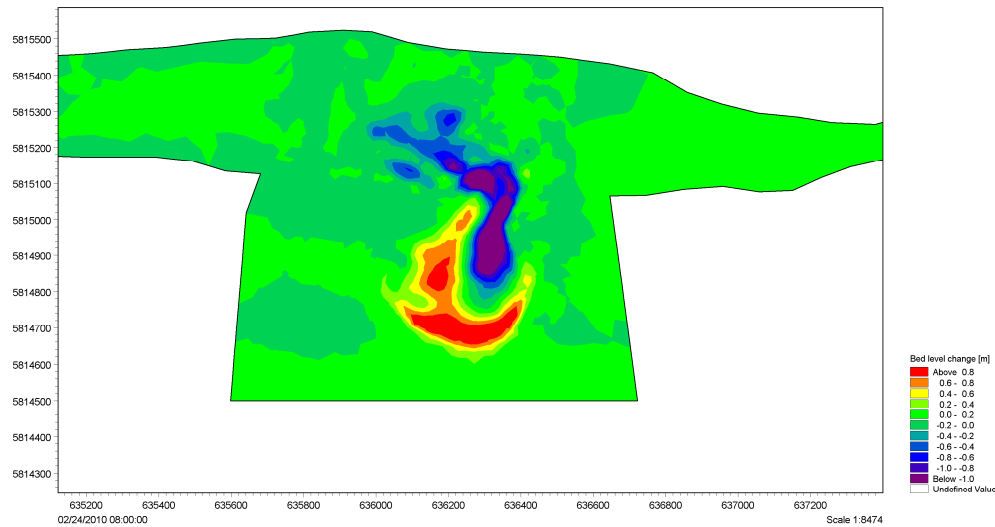

Figure 9   Flood Flow Scouring Bed Level Change Calibration Result

Calibration Results - Closed Entrance Flooding

Water Levels

Figure 10 shows the final comparison between the available observed and simulated water levels within Lake Corringle during the closed entrance flooding event. The observed water level record in Lake Corringle is considered representative of the pool level in the lower part of the estuary. The following observations are made regarding the level of agreement achieved between the modelled and observed water level increase in the estuary during the closed entrance flooding event.

- The modelled slope of the increase in the water level is in very good agreement with the observed record indicating that the flooding behaviour and floodplain storage activation of the model is in good agreement with the observed behaviour

- The maximum floodplain water level achieved prior to artificial opening of the entrance is in very close agreement with the observed level.
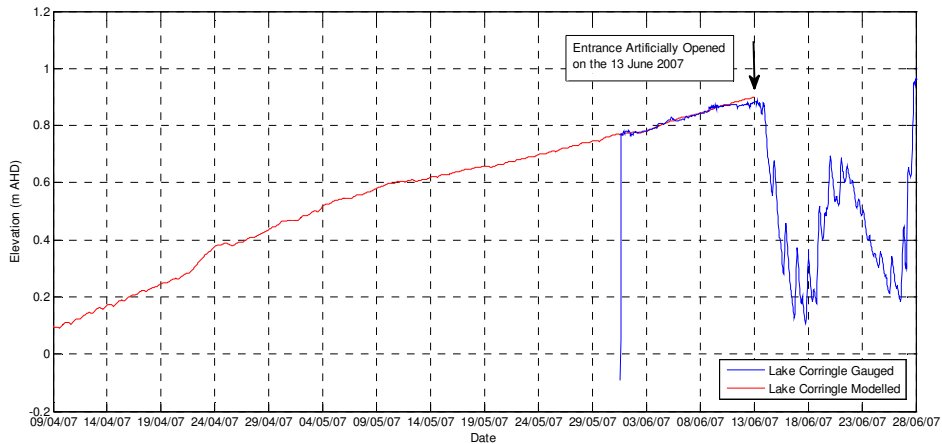
Figure 10   Lake Corringle Water Level Calibration Results

Flooding Extent

Figure 11 displays the comparison of the predicted flood extent from the model at a pool level of 0.9m AHD, i.e. immediately prior to artificial opening of the entrance, and the 0.9m AHD contour of the study area derived from the LiDAR survey. Figure 11 is considered to show that the model is capable of predicting flood extents on the floodplain in very high agreement with the flood extents expected from analysis of the survey.
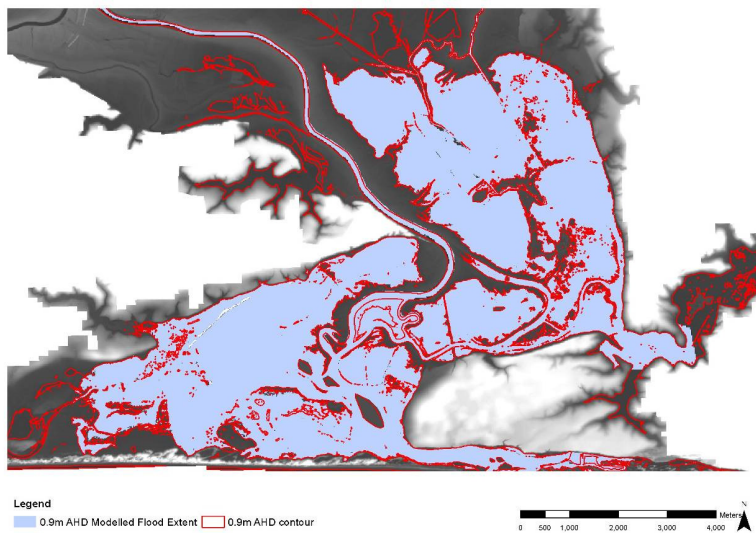

Figure 11   Comparison of Modelled Closed Entrance Flooding at 0.9m AHD

Assessment of Vegetation Extent and Change

Overview

The assessment of vegetation and vegetation change used a range of methods to determine the spatial extent of vegetation classes and their associated habitat values, including:

- a review of all available databases, previous studies and community observations;

- mapping vegetation Ecological Vegetation Class (EVC is a standard Victorian vegetation classification method) using aerial imagery and ground truthing;

- measurement of field variables that may influence the vegetation classes;

- assessment of the conditions that the vegetation classes occupy; and

- analysis of changes modelled changes of hydrodynamic conditions and their influence on vegetation distribution.

The project team determined that the most efficient method to map the vegetation classes of over 5,600 ha of land is through the interpretation of high resolution aerial imagery supplemented by the use of an Aerial Laser Survey (LiDAR) generated topographical surface then selectively ground truthed to ensure categorisation reflected the field validated observations.

The colour and texture contrast of the vegetation enabled the delineation of vegetation types (Figure 15). Polygons within a geo database were manually digitised around these vegetation types and attributed to an EVC. Field validation was then undertaken to confirm the desktop analysis.
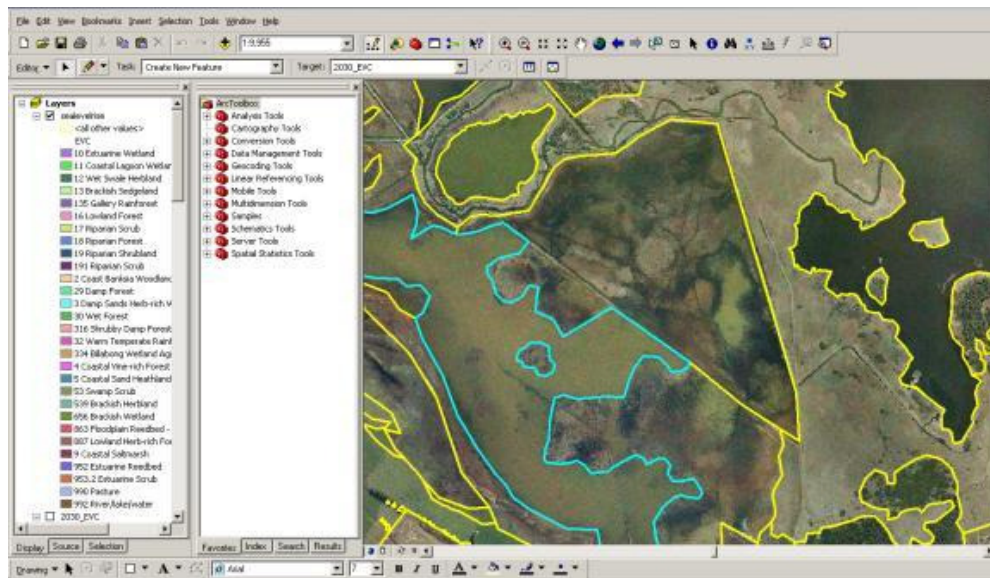

Figure 15 Yellow lines are an example of manual digitising of vegetation classes around colour contrasted areas in the aerial image (Aerial supplied by DSE)

The vegetation polygons required classification to enable interpretation. Following an initial field visit, the vegetation in each of the polygons was attributed to an EVC based on the observed vegetation composition and lifeform cover in reference to the pertinent EVC benchmarks (DSE 2010). The EVCs to which areas have been attributed are a 'best fit' for the vegetation observed: not all areas fitted conveniently into an established EVC based on the benchmark description. This variation is based on (1) the benchmark statements being generic for a Bioregion, and not specifically for the area being observed, and (2), changes in vegetation from the benchmark composition and structure due to land use impacts.

Field validation of vegetation

Field validation was undertaken in the weeks of 1st and 15th of March 2010. The field validation process was targeted towards the conformation of the location of ecological classes and, importantly, presence of character species, or evidence of dieback or class change. This information was collected to assist in the determination of the conditions that species currently occupy and whether, if hydrological conditions change, a class change may occur.

At each of the validation sites an assessment was undertaken to establish the vegetation class and the factors that may be affecting its position in the landscape. This included:

- key species list;
- surface water salinity and pH (YeoKal water quality multi probe);
- condition of vegetation;
- site photography;
- EVC type;
- potential factors impacting upon vegetation; and
- elevation information with a Differential GPS (DGPS) at the location of changes in vegetation class.

Determination of elevations of the vegetation classes

The median elevation of each of the EVC polygons was calculated to ascertain if there is a relationship between the mapped vegetation class and its elevation above sea level. This was undertaken with the interpretation of the LiDAR data generated 2m grid. Using the Arc GIS Spatial Analyst package each 2m point in the grid that fell within a polygon was collated and the median determined. This median elevation of the vegetation shapefile was then attributed to a separate shape file to enable an elevation map to be produced. This attribute data was then exported to MS Excel where the median elevation range that each EVC occupied could be calculated.

Whilst this technique provides valuable information to assist in the determination of association between elevation and vegetation, its limitations have been recognised. A constraint of LiDAR is its inability to accurately represent the ground surface elevation in areas of very dense vegetation. This is particularly problematic for areas vegetated by *Phragmites.* As such, the *Phragmites* located from ground and aerial interpretation appears to inhabit the higher elevation land. This is incorrect, as the survey has registered returns from the top of the vegetation not the ground surface. The results for the Phragmites have been corrected based on the data gathered with the dGPS during the field investigation.

Interpretation of the data from the hydrodynamic model

The outputs of the hydrodynamic model investigation were supplied as a series of GIS outputs from MIKE3 software. These GIS outputs were overlain onto the EVC GIS data layer enabling

the values associated with inundation duration (days) and salinity (Parts per Thousand, PPT) to be attributed to the individual vegetation polygons.

The attribute table of this layer was then exported to an Excel spreadsheet where the data on the relative inundation durations and salinities were calculated.

Revised vegetation maps were then prepared taking into account the changed hydrological conditions and elevation in relation to sea level at a particular vegetation polygon.

Conclusions

Estuary Hydrodynamics

Under the prevailing constricted entrance condition of the estuary and due to the increase in mean sea levels and associated tidal entrance response predicted by 2035, the estuary area was not predicted to change materially and minimal changes to the tidal range and tidal penetration within the estuary are expected.

By 2035, the reduction in stream flows and the increase in the entrance berm height and mean water levels in the estuary due to sea level are however predicted to increase the average durations in which various parts of the estuary and floodplain are inundated during future entrance closures. This results in some parts of the floodplain potentially being inundated on average for between 10-20 days longer during future entrance closures. The total additional area of the floodplain that is likely to be inundated during future entrance closures by 2035 compared to existing closures is however only expected to increase by approximately 100 hectares to approximately 4648 hectares.

Estuary Salinity Regime

The reduction in streamflows and the increase in mean sea levels predicted by 2035 are predicted to result in some modest changes to the salinity regime of the estuary. Under prevailing constricted entrance condition of the estuary, it is likely that the salt wedge will penetrate further into the upper reaches of the Snowy River below Orbost than generally occurs under existing conditions. The salinity of Lake Corringle and Lake Curlip are also predicted to increase in the order of 5ppt on average during low streamflow conditions.

The salinity of pooled floodwaters on the floodplain during entrance closures by 2035 is not predicted to increase significantly above those expected under existing entrance closure events.

Periodic flushing of the salt wedge from the Snowy River channel is considered an important process for maintaining good water quality and habitat in this reach of the estuary. It is estimated that flows in excess of approximately 30m3/s (2,750ML/d), sustained for a number of days, are required to flush the salt wedge from the Snowy River channel.

Combined fresh flows of 20,000ML/d are considered sufficient to flush salt water from the majority of the estuary. Periodic flushing of salt water from the lower sections of the estuary is considered important to maintain the estuarine character and ecology of the lower section of the estuary.

Vegetation

The dominant existing native vegetation classes on the floodplain were found to be Estuarine Scrub, Coastal Saltmarsh, Estuarine Reedbed and Estuarine wetland occupying 1265, 780, 235 & 280ha respectively. These areas include vegetation classes described as 'degraded dieback' and 'monoculture'.

The area of pasture within the study area below 1.3mAHD was mapped at 650ha with an additional 270ha classified as 'dead pasture'.

Clear impacts of the frequent estuary closures were noted. The loss of pasture grass from areas subject to inundation was clearly identifiable as was the dieback of *Melaleuca ericifolia*, believed to be brought about by a combination of inundation, salinity and groundwater.

Estimated Conditions in 2035

With the hydrodynamic model results it was possible to estimate the distribution of vegetation assemblage in 2035.

Based on the salinity concentration outputs of the hydrodynamic model during an estuary closure, the observations in the field, and the background literature review, it is unlikely that the closures are the sole cause of the dieback of *Melaleucas* and the transition to alternate vegetation classes. The process appears to be more closely aligned to the influences associated with increasing salinisation of the estuary, brought about by reduced in-flows, and an reduction in groundwater depth. This groundwater influence has not been measured in detail but field observations did correlate dieback with saline shallow groundwater and pooled saline surface water isolated from the main body of the estuary.

The hydrodynamic modelling shows that the depth, extent and duration of inundation during estuary closures will increase. This will decrease the extent of available grazing land, with areas of pasture expected to decrease by up to 400ha. A further loss of 288Ha of Estuarine Scrub vegetation is also likely; unless significant freshwater flows in the Snowy River became available.

Whilst the results indicate a move towards a changed vegetation assemblage surrounding the estuary management recommendations were prepared to enable the transition to be managed in such a way that provides positive outcomes.

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