CASE STUDIES IN THE APPLICATION OF MODELLING TO MANAGING ESTUARIES

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Abstract

The estuarine environment is a zone of great significance ecologically, socially and economically, but is also a zone of great complexity. Issues such as climate change may potentially have a significant impact in an estuary that can affect not only sensitive ecology but critical infrastructure as well. A key tool in being able to assess the impacts of climate change in the estuarine zone is to employ numerical simulations of the behaviour and response of an estuary under a range of scenarios. A numerical model can provide an insight into processes and behaviour that is anticipated in the future or cannot be measured effectively. Once the model is established the simulations can then provide a valuable basis for further assessment.

Current generation numerical models provide a means to not only simulate the physical hydrodynamics, but also a complex range of other non physical parameters. A number of conclusions can nevertheless be related to changes in water level and salinity, or other relatively simple physical parameters. For example, much infrastructure in an estuary has the potential to be affected by inundation due to rising water levels. Salinity can be related to the complex processes within an estuary which affects the ecology, recreational use or infrastructure such as water extraction.

This paper discusses some case studies in which numerical models have been used on the Hastings, Nambucca and Hawkesbury Rivers and the type of results that can be achieved. Each has used a slightly different modelling approach and analysis to provide water way managers with the understanding of the processes they need. For example, Port Macquarie Hastings Council required an assessment of sea level rise on the efficacy of potable water extraction. On the Nambucca River, the impacts of sea level rise and the significance of entrance condition were assessed in terms of salinity migration. With the Hawkesbury River, the focus has been on setting up a real-time system that can be used to aid recreation and aquaculture management.

For Lake Conjola and Manly Lagoon, real-time data is used to assess and help manage lake entrance conditions for flood mitigation purposes. These represent earlier systems using a simplified modelling approach that parameterises the system in accordance with specific management objectives.

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Introduction

In the management of estuaries, Councils face a range of issues and concerns. Each is a unique combination of local issues, including environmental, legal, political and social issues. The specifics are unique to each council or government area.

MHL has recently undertaken a number of projects designed to aid councils and other government bodies' to provide greater insight into the key physical processes operating.

Case Studies

Below are selected case studies that MHL has undertaken on the behalf of local government and NSW state government (DECCW).

Nambucca

MHL has conducted a number of studies into the Nambucca River on the Northern NSW Coast (Figure 1). These have been to investigate Salinity migration under a range of Scenarios. In the 2008 Study (Manly Hydraulics Laboratory, 2008) the focus was on the security of the Shire's water supply and the effects on biota that augmenting this with water drawn from the Nambucca River would have.

In the 2009 study, the changes that could be expected in water levels and salinity concentrations along the length of the Nambucca River under a range of climate change scenarios was investigated.

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Figure 1: Location of the Nambucca River on the NSW Coast

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Hastings

For the Hastings River study, the long term security of the water supply drawn from the Hastings River, also located on the Northern NSW Coast (Figure 2), was the issue. Port Macquarie-Hastings Council (PMHC) draws water from the river as part of their urban water supply at Koree Island (Shown Figure 3).

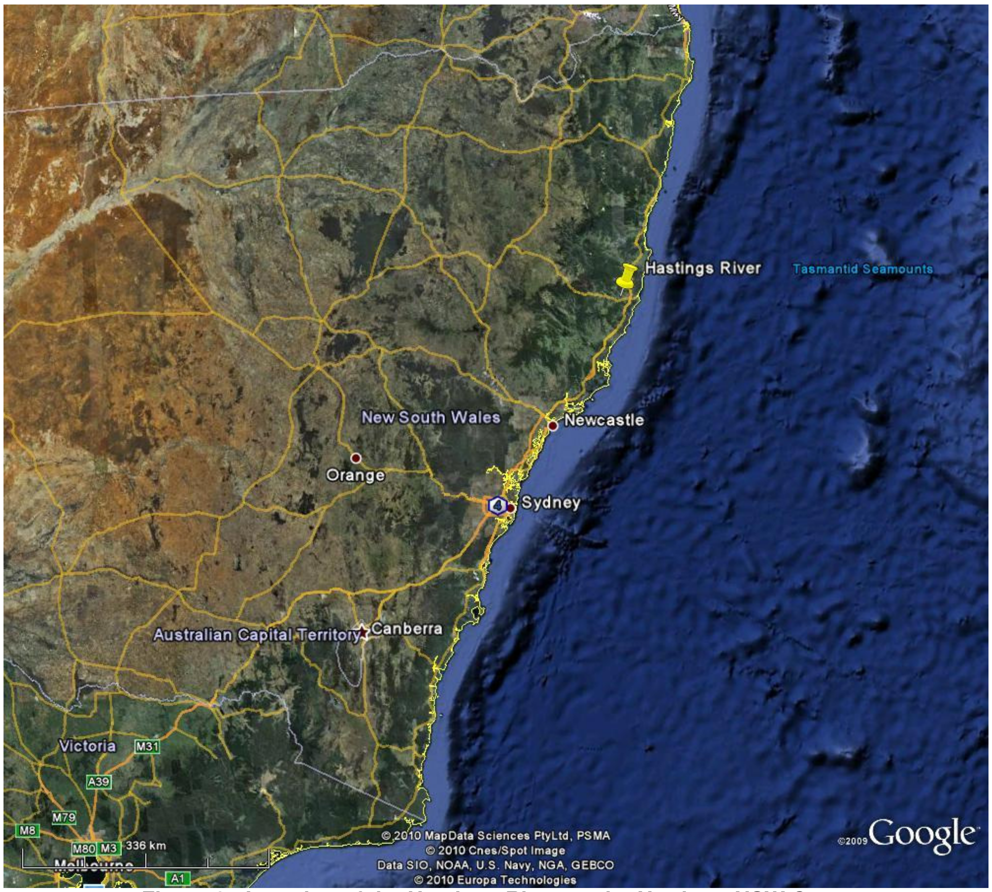

Figure 2: Location of the Hastings River on the Northern NSW Coast

Due to concerns regarding the potential for salt water to migrate up to the pump stations intake point, MHL was commissioned to undertake a modelling exercise to compare the potential for salt to migrate up river.

These scenarios were chosen because the effects of future sea level rise were identified as being a risk to the water supply at Koree Island, but also as periods of low flows are already subject to flow restrictions based on ecological concerns.

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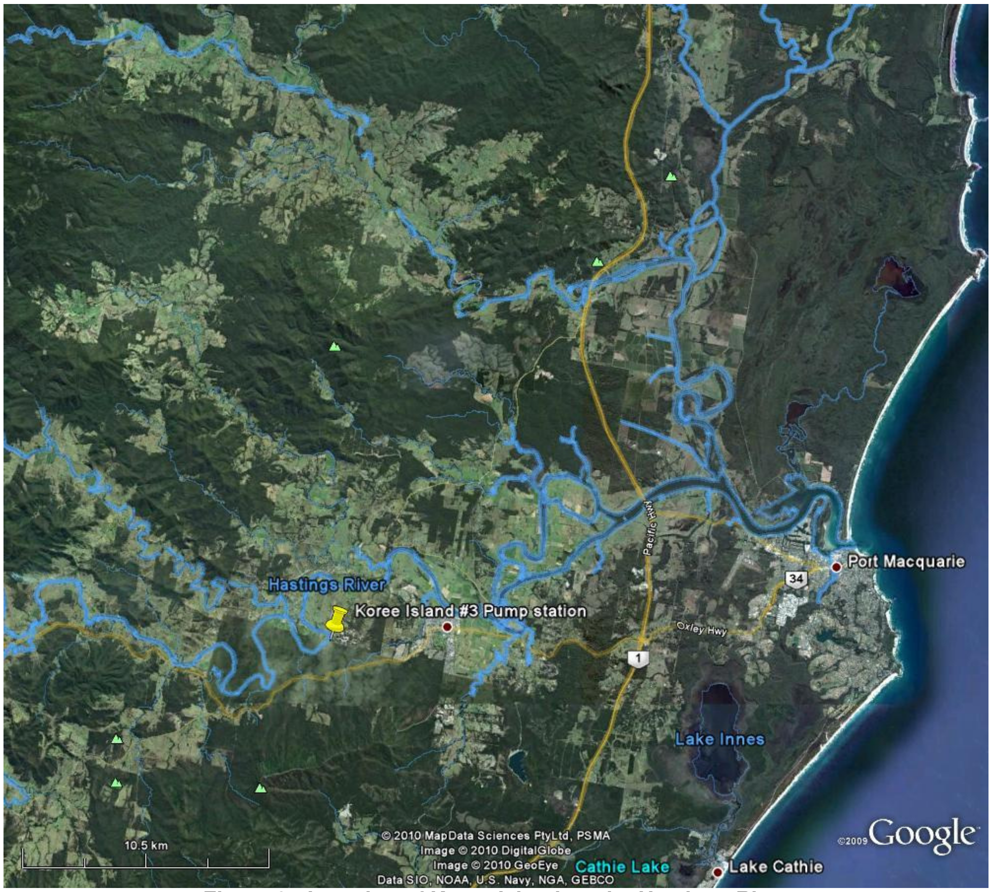

Figure 3: Location of Koree Island on the Hastings River

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Hawkesbury River

Hornsby Shire Council (HSC) has a number of concerns regarding water quality in the lower Hawkesbury River as well as its tributaries such as Berowra Creek. Water quality for recreation, as well as aquaculture, are of concern as there are a number of recreations sites, as well as oyster leases and prawn fisherman in the estuary. The location of the Hawkesbury River in relation to Sydney is shown in Figure 4.

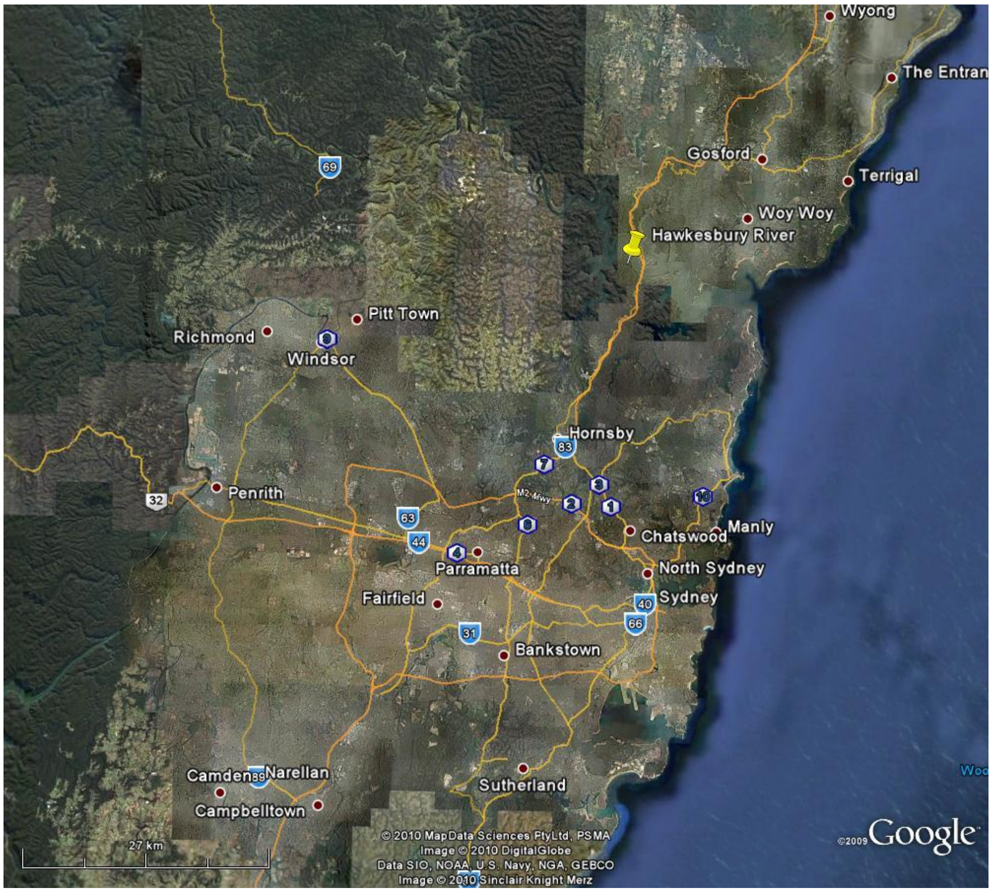

Figure 4: Location of Hawkesbury River

To investigate the coupled hydrodynamic and water quality processes, HSC commissioned DECCW to develop a computer model of the entire estuary. This model was developed using ELCOM (Hodges and Dallimore, 2010), and had to incorporating 58 input data streams from across Sydney and from as far away as Penrith or Prospect.

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Lake Conjola

Located on the South Coast, in the Shoalhaven (Figure 5), Lake Conjola is an intermittently closed and open lake or lagoon (ICOLL). A more detailed view of the entrance can be seen in Figure 6. A decision support system has been developed for Lake Conjola. This system records the water levels and performs a tidal analysis on the recorded data to obtain the tidal components. A reduction in the tidal components, and specifically the M2 component indicates that the entrance is becoming more heavily shoaled, while an increase indicates that it is becoming more open (Manly Hydraulics Laboratory, 2001).

Figure 5: Location of Lake Conjola on the NSW Coast

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Figure 6: Entrance Shoals at Lake Conjola Entrance as well as the site of the water level recorder.

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Manly Lagoon Watch

Manly Lagoon is located close to the Sydney CBD (Figure 7). Manly Lagoonwatch is a system developed for Manly Council to perform a real-time analysis of the flood risk presented to the community. To do this measurements of water level in the lagoon as well as rainfall in the catchment are collected, with the locations of these recording sites shown in Figure 7 and details around the entrance shown in Figure 8.

Figure 7: Location of Manly Lagoon

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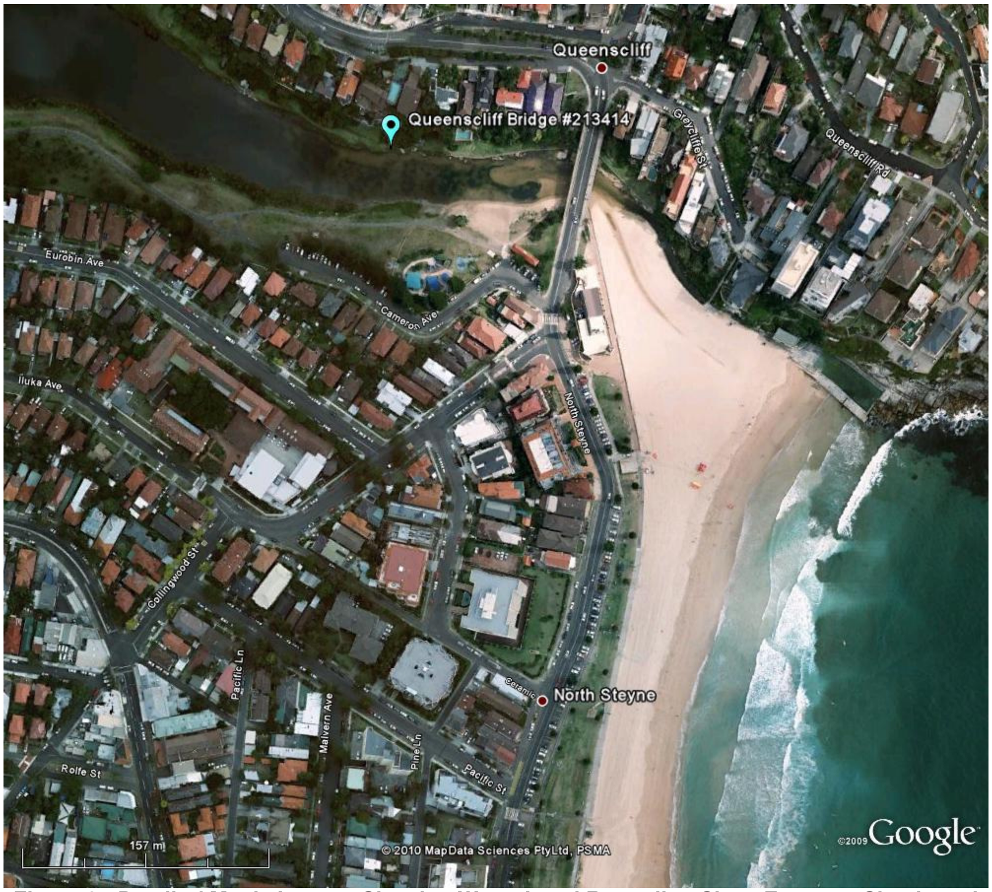

Figure 8: Detail of Manly Lagoon Showing Water Level Recording Sites, Entrance Shoals and Urban Development.

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Estuary Process Modelling

Nambucca River

DECCW in conjunction with Nambucca Shire Council raised concerns regarding the potential for sea level rise to alter the migration of salt upstream from the ocean. Some hypothetical sea level rise scenarios were modelled in order to examine the sensitivity of the system to various assumptions regarding the effects of sea level rise.

A one dimensional model was used to simulate the hydrodynamics, and the results of this compared to infer the behaviour of the salinity. The entrance morphology was considered especially important, and several scenarios considering different entrance morphology schemes were set up and compared.

Nambucca River is some what unusual in that there is a heavy throttling of the entrance, and then relatively little response after this. This can be seen from the extracted M2 tidal constituent (Figure 9, Manly Hydraulics Laboratory, 2009). The M2 amplitude is representative of the tidal range. After a relatively quick drop off, the M2 amplitude remained almost constant, apart from a small increase of the order of 10%, moving upstream through the rest of the River's tidal domain This small increase in the tidal amplitude upstream was attributed to the mechanics of the wave propagation along the estuary, and was observed to be consistent between all scenarios modelled. This occurred even in cases that included sea level rise.

Salinity migration provided contradictory results. Running the model with a constant diffusion coefficient that was calibrated against previous recorded results indicated that salt would intrude further into the estuary under sea level rise Figure 10 (Manly Hydraulics Laboratory, 2009). However, the advective transport potential was shown to be reduced under climate change (Figure 11). This is consistent with diffusion theory, such as that explained by Fisher et al (1979), whereby the net advection would be a function of the cumulative flood and ebb tidal velocity integrated over time. Because of this salinity should intrude less under climate change. This presents one of the limitations of one dimensional modelling for climate change studies. Contemporary diffusion theory in a one dimensional model does not account for the variations that might be expected with changes in flow velocity, hence salinity intrusion is underestimated in a one dimensional model, and hence any study of the effects of sea level rise must consider at least a two dimensional model or re-calculate diffusion coefficients for the one dimensional model based on the altered depths and circulation pattern.

The analysis of the model results from this project showed how an estuary could be sensitive to changes in the entrance morphology. This could have consequences upstream that are otherwise difficult to foresee. The difference between the salinity and net advection potential plots illustrates one of the limitations of one dimensional modelling. The calculated salinity suggests that salinity would increase upstream with sea level rise regardless of any changes

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in entrance morphology. However, the calculated advection potential shows that if sea level rise occurs and the entrance shoals remain in their current position, salinity will increase upstream. On the other hand, if the entrance shoals were to rise in an attempt to maintain the current dynamic equilibrium with the tides, then the salinity will likely decrease upstream and the results of the model confirmed this to be the case.

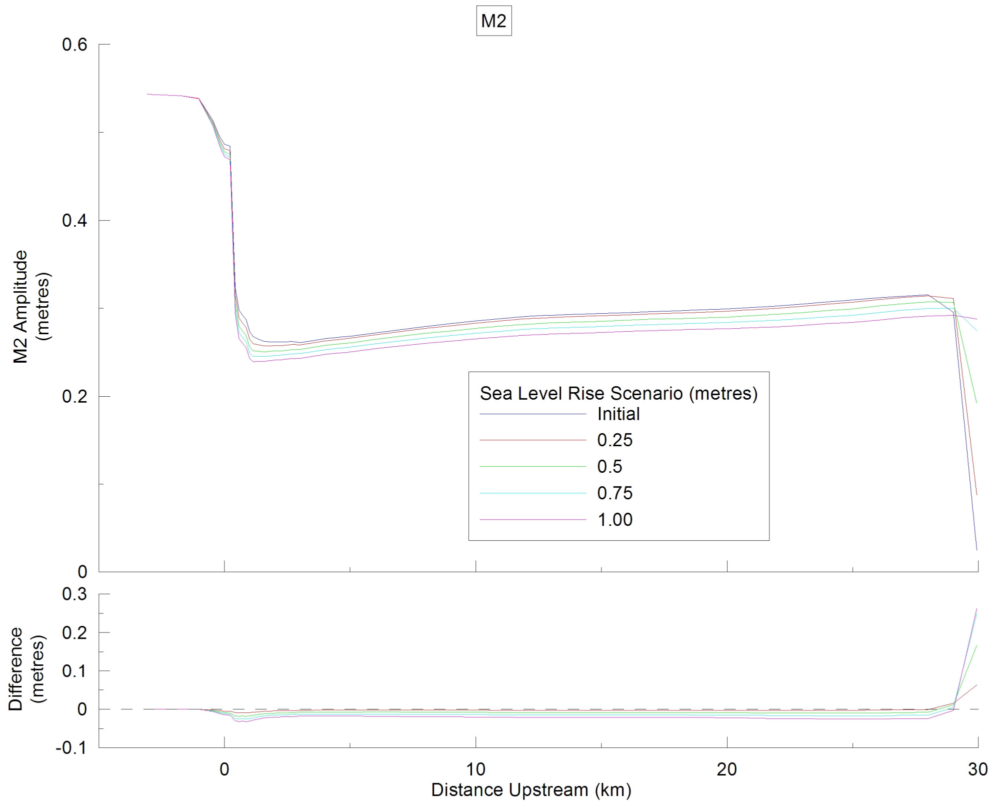

Figure 9: Extracted M2 Tidal Constituent along the Nambucca River

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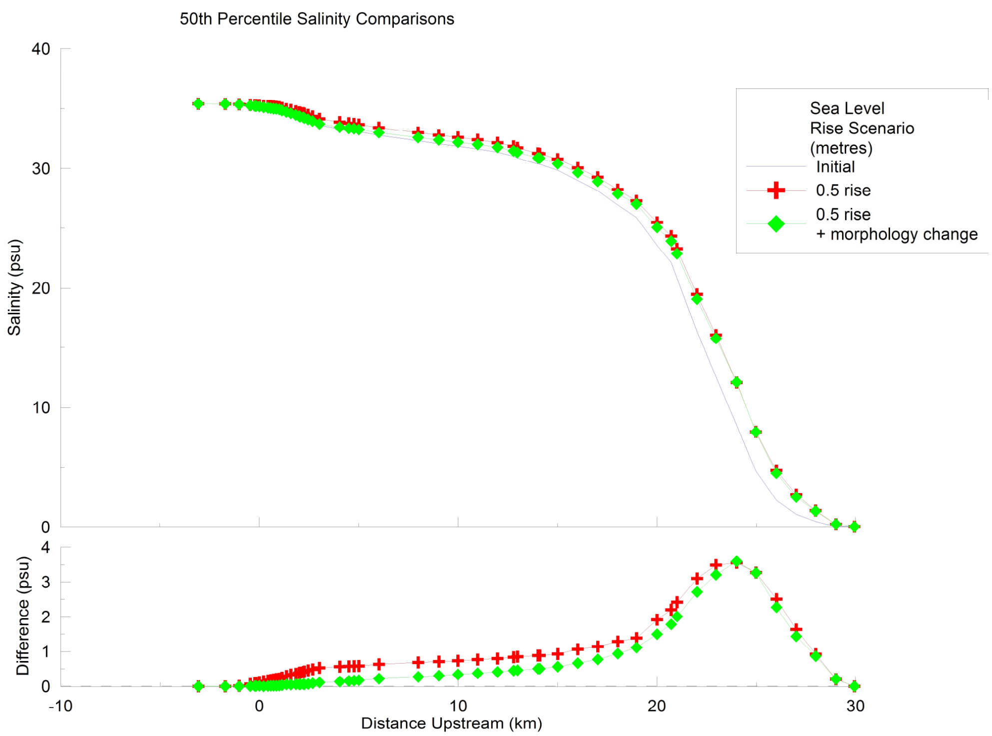

Figure 10: Salinity at the 50th Percentile along the Nambucca River

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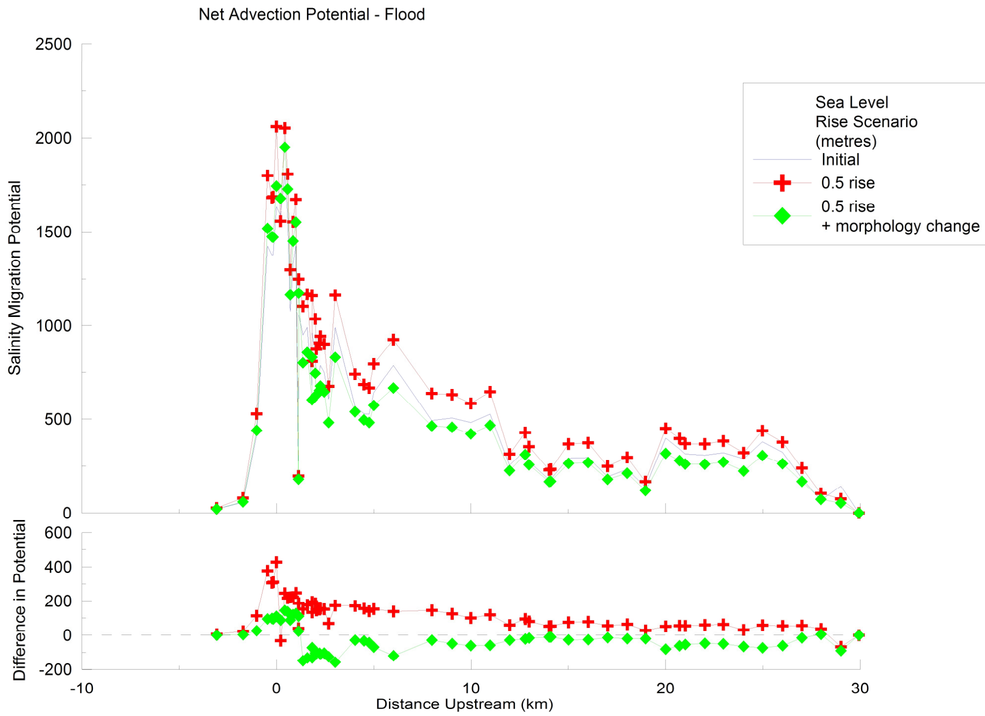

Figure 11: Advective Transport Potential along the Nambucca River

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Hastings River

One of the major sources of urban water supply for .PMHC is drawn from the Hastings River at Koree Island. This has been upgraded with the Koree Island #3 pump station and it can now draw up to 1300 L s^{-1} from the river (Port Macquarie Hastings Council & Australian Water Association, 2004). While there are other sources of potable water available to the Council, the loss of this source would be problematic in the long term.

A two dimensional hydrodynamic and water quality model was set up using RMA. Extensive data was available in the lower and mid estuary from a flood study undertaken by Patterson Britton (2006). The initial model mesh was taken from this study, though it had to be extensively modified to undertake a water quality study.

Modelling results showed that the estuary was most sensitive to changes in the upstream catchment inflows with respect to salinity and water quality, with the greatest differences in salinity concentration being related to variations in the inflow percentiles. For example, if the isohaline contours (lines of equal salinity) are compared between Figures 12 and 13, it can be seen that salinity isohalines have moved further upstream with a reduction in the catchment runoff flows. The estuary was also sensitive, though to a lesser extent, to rises in sea level.

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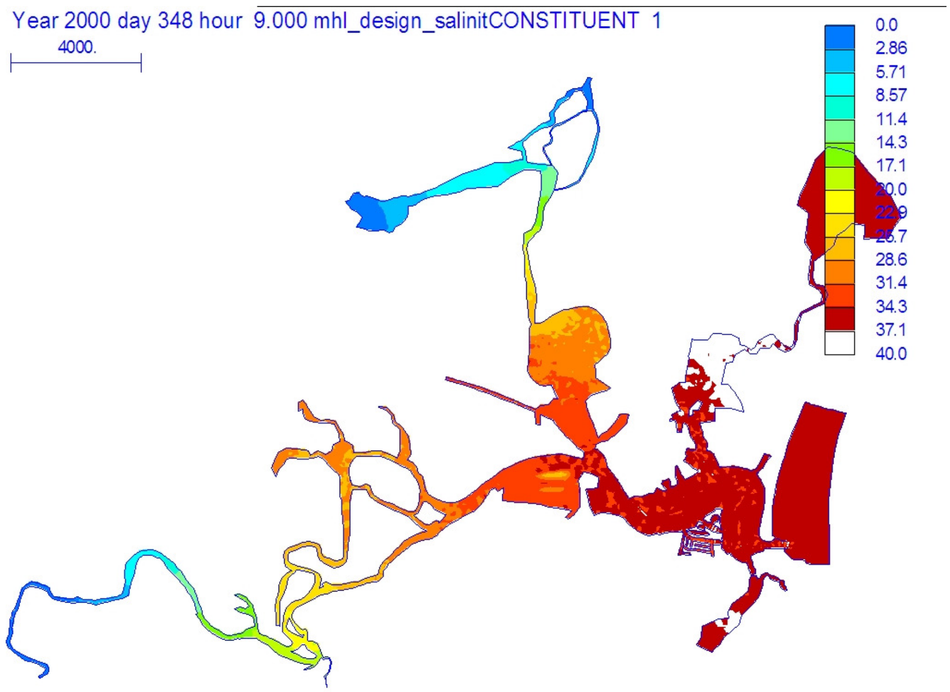

Figure 12: Low flow salinity isohalines without sea level rise

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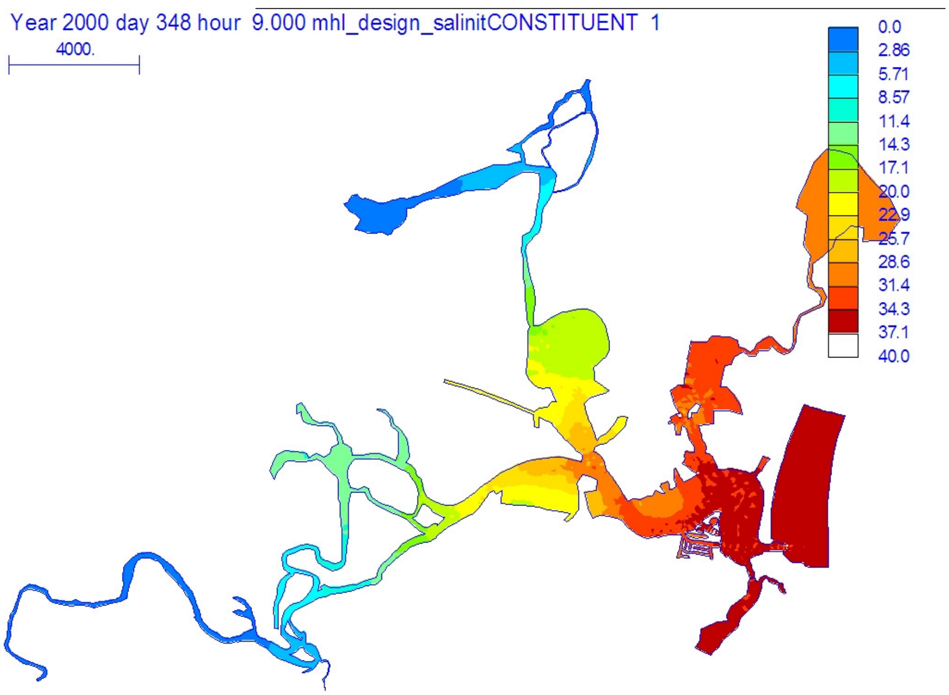

Figure 13: Median flow salinity isohalines

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Hawkesbury River

Hornsby Shire Council has a number of water quality concerns the parts of the estuary for which they are responsible. Specifically, concerns were raised about the suitability of water for recreation as well as aquaculture. It has been noted by the council that the water quality is often related to the salinity.

To model the estuary, a three dimensional hydrodynamic and water quality model was built using ELCOM by DECCW (Loveless, 2009). In this model the simulation of salinity and temperature were included, as these not only have a feed back on the hydrodynamics due to differences in density, but can also be related to other water quality processes such as discharge from sewer overflows. While ELCOM has more sophisticated options for conducting water quality simulations, these were not used as the objective was to create a dataset that could be related to analyses that are readily measurable. Real-time data is being collected by MHL on behalf of Hornsby Shire Council (www.estuary.hornsby.nsw.gov.au), and these measurements were used to verify the model. However, a model that could enhance the understanding of estuary processes was sought by Council, so modelling analytes that related to the existing data collection program were of most value.

Modelling results to date have focussed on reproducing the hydrodynamic processes and relating these to key water quality concerns. Isohalines such as those in Figure 14 are produced. Council has been able to identify salinity thresholds which represent a hazard to bathers and recreational users, and the model is able to reproduce these events.

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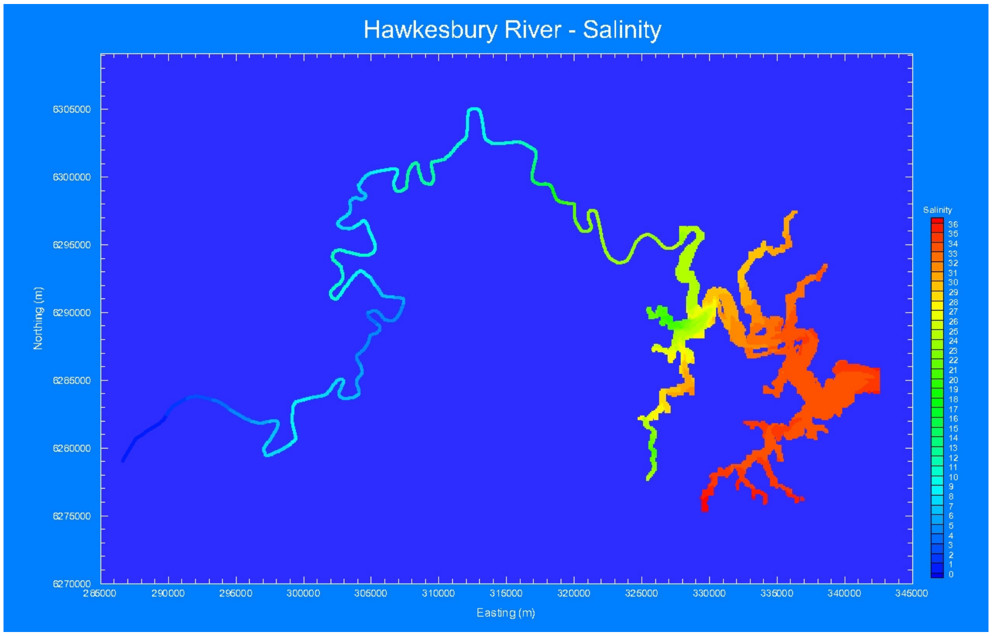

Figure 14: Overview of modelled salinity for the Hawkesbury River

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Real Time Modelling

Hawkesbury River

A significant extension of the modelling exercise is to run the model in real-time using automatically recorded data. Running a model in real-time in this fashion extends it as a management tool, allowing decisions to be based on the best understanding of the physical processes as they evolve.

In the case of the Hawkesbury River, HSC has identified that various water quality parameters are related to the salinity. In addition, MHL operates a number of salinity, temperature and water quality gauges in the estuary in addition to the Council's data collection program. MHL is able to combine the information received from the water quality gauges and use this to inform the results of the ELCOM model to obtain values for the salinity and temperature anywhere in the model domain. From this the risk to bathers and aquaculture can be inferred using relationships the Council has developed. This can be communicated to the public on a daily basis or more frequently.

A marine algal bloom at Calabash Bay (Berowra Waters) was identified by MHL's monitoring system between the second and fourth of October, 2010. Hornsby Council were notified of the potential bloom preceding the event which triggered water quality analysis that showed the bloom contains the potentially toxic species of Prorcentrum cordatum which has been associated with diarrheic shellfish poisoning. Signs were erected and notices issued for people to avoid contact with the water, not to harvest shellfish off the rocks or eat fish collected in the vicinity of the bloom until further notice.

Lake Conjola and Manly Lagoonwatch

In simplified real-time systems such as the Lake Conjola Entrance Decision Support System or the Manly Lagoonwatch System, data is collected and processed in near real-time. These data can then be related to physical processes using computer algorithms. These data processes and related presentation can then assist local authorities in managing the estuaries, in the above cases by giving them time to commission dredging works at the entrances and/or mechanically open an entrance before significant flooding occurs.

Conclusions

From the experience that MHL has to date, a sophisticated model that captures the hydrodynamics is paramount in understanding estuarine processes in the face of challenges such as climate change and sea level rise. The changes in the dynamics expected in these scenarios require that the main physical processes be more explicitly simulated, at least in two dimensions. This is primarily because the assumptions about the response to various processes have very significant consequences that may be difficult to predict.

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In the course of modelling the various case study projects described above, problems have arisen, particularly with respect to modelling expected sea level rise impacts associated with climate change. Previously these challenges could be addressed in a modelling study with reference to recorded data. Various calibration parameters could be adjusted, or features added or removed until the model reproduced the observed physics, and this was verified with the reproduction of recorded data to within acceptable tolerances.

However, by definition, scenarios involving climate change have not yet occurred, and so data regarding these events is not available. It may be possible to use recorded data from exceptionally high tides, prolonged wet or dry events to infer what the effects under climate change may be, though these may not fully describe the anticipated climate change scenarios.

Entrance morphology is another area in which there is the potential for very significant effects under climate change. Depending on the entrance, and any stabilisation works that have taken place, sand in the entrance may or may not be mobile. While in cases of stabilised entrances, the geometry may not vary significantly with climate change, for unestablished entrances or semi-stabilised entrances; significant changes in geometry may take place in order to establish a new equilibrium with the tides, wave climate and hydrology. Geometry changes in the entrance may have significant effects further upstream with respect to the tidal prism, inundation levels and water quality. Further, these changes may have effects on land use, water extraction and ecology which need to be anticipated.

If salinity intrusion is to be included in climate change studies, then one dimensional modelling has been shown to be inadequate. The diffusion coefficients (measured for existing hydrodynamic forcing) parameterise several processes that create mixing. Where there is sufficient data to calibrate a one dimensional model, this may be an adequate approach. Under a climate change scenario, there will be no data to establish a representative parameterisation of diffusion and no data to verify model performance against. Using at least a two dimensional hydrodynamic model will better represent the major mixing processes.

As computing capability has grown, and the automated collection of data has increased, this has enabled modelling the complexity of real time systems to increase. The Hawkesbury River has shown a system that has a greatly enhanced capability by incorporating all the significant physical processes. This gives the council not only a tool for managing water quality, but also a platform from which future concerns can be analysed.

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Acknowledgments

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