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Our Ref: RMH: L.N1347.022.CoorongSalinityModelling_3yearFinalToNRM_PPT.doc

3rd August 2009

SA MDB NRM Board
Level 4, 111 Gawler Place
ADELAIDE SA 5001

Attention: Glynn Ricketts

Dear Glynn

RE: COORONG SALINTY MODELLING (Update six out of six scenarios modelled)

1 Introduction

Due to extended drought conditions in south eastern Australia, River Murray flows are at their lowest levels on record. No water has passed the Barrages between Lake Alexandrina and the Coorong since late 2006. A lack of freshwater input and high evaporation rates have resulted in hyper-marine conditions along the length of the Coorong. In the South Lagoon, salinities of well above 150,000 us/cm (> 100 g/L) have been recorded. These high salinities have greatly altered the ecology of this internationally significant Ramsar wetland. The South Australian (SA) NRM Board (through the SA Department of Environment and Heritage (DEH)) has commissioned investigations into management strategies that could be used to reduce the salinity of the Coorong and allow recovery of the ecological health of the Coorong. Initial management strategies to be investigated include pumping water from the South Lagoon into Encounter Bay and dredging (deepening and widening) the constriction between the North and South Lagoons to encourage better exchange and mixing of water.

This letter details model investigations into salinity levels in the Coorong. The letter covers:

- the available data for model setup and calibration;
- the status of model calibration achieved;
- the predicted performance of management strategies aimed at reducing salinity levels in the Coorong; and
- a discussion of model limitations and potential improvements.

This letter contains results already presented in previous draft letters (May 1st and May 24th) but adds results for a sixth scenario (the letter of May 24th detailed five scenarios). A scenario where Hells Gate was more significantly dredged (120m wide – to be in better agreement with what is used in the CSIRO 1D model) was discussed in the May 24th letter but has been removed from this final report as the increased width of dredging showed insignificant difference to the scenario where a 20m wide channel was dredged.

2 Model Setup and Available Data

An RMA10s finite element numerical model was developed to simulate hydrodynamics and salinities within the Coorong. Development of the model and the data used to drive and calibrate the model is described below. The model calibration period was 1/1/2008 to 31/12/2008.

<u>Model Mesh</u>

The model mesh was developed based on a bathymetric data set (described below), aerial photography (taken in 2000) for the upper part of the North Lagoon provided by DEH and Google Earth Imagery (2008) where no other data was available.

Bed elevations within the model mesh are based on a digital elevation model (DEM) of Coorong bathymetry created using hydro survey collected in 2002 for the North Lagoon and some 22 cross-sections of the Southern Lagoon (unknown date of survey). LiDAR data collected in 2008 was used on the fringing areas of the Lagoons for levels above ~0.1 m AHD. Bathymetric data for the constriction between the North and South Lagoon (referred to in this document as the Hells Gate area) was generally inadequate and assumptions based on Google Earth Imagery were required.

It is also possible that the Hells Gate area undergoes morphological change due to waves and currents. This morphological change would subsequently impact on hydrodynamics and the resultant exchange of salt between the North and South Lagoons. It is recommended that an assessment of bathymetric change be undertaken either using a desktop study or morphological modelling.

The resolution of the flexible model mesh varies between element sizes of 20 to 500 m. The model mesh and model bathymetry is shown in Figure 2.1.

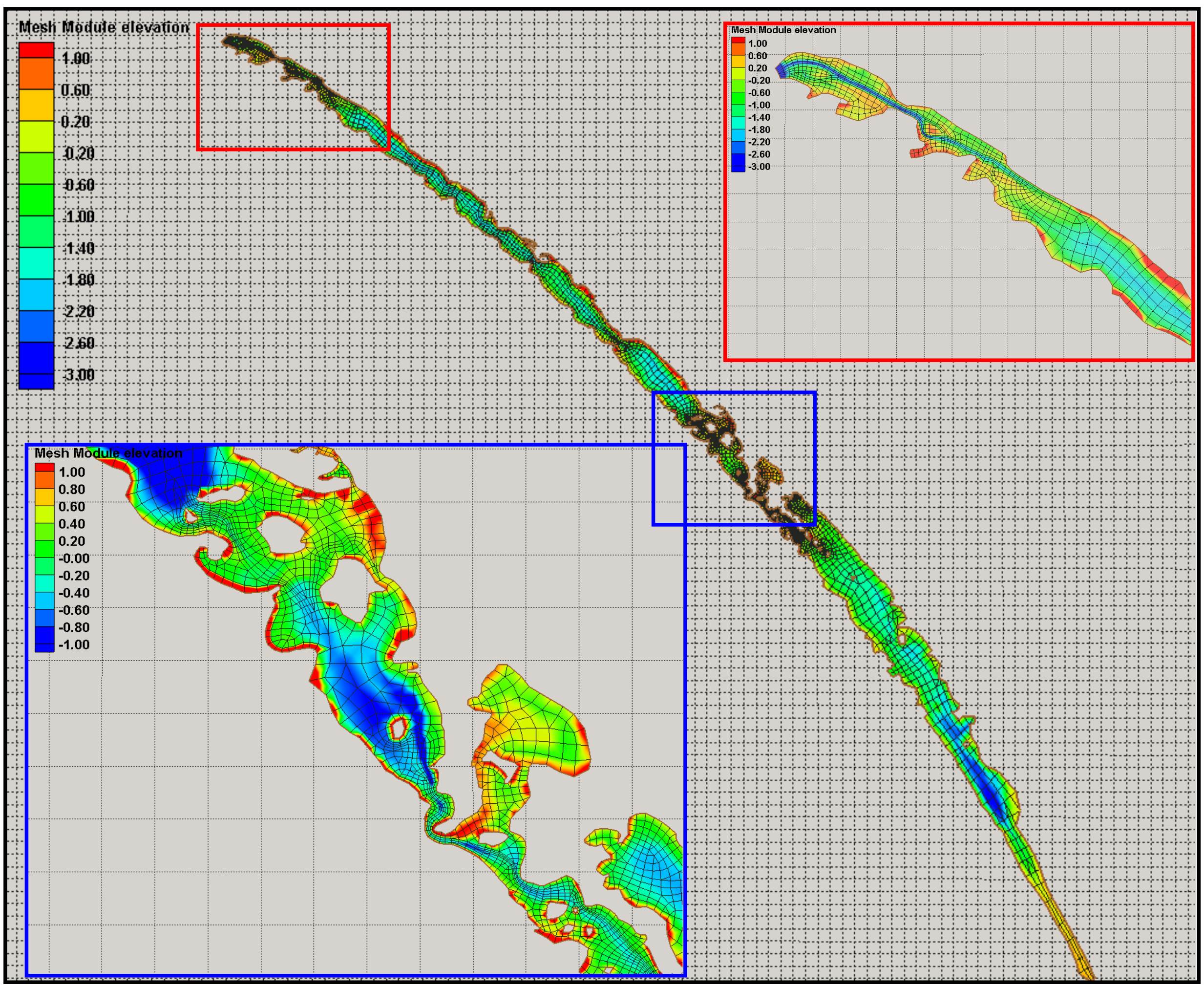

Figure 2.1: Model Mesh and Model Bathymetry showing detail around Hells Gate and near Ewe Island Shacks (Grid Lines in all three images are at 1000m spacing's)

Model Boundaries and Calibration Data Sets

Model Boundaries

The model boundary conditions used to drive the RMA10s numerical model include:

- A water level (and salinity) boundary at Ewe Island Shacks;
- Surface wind shear using wind data collected at Narrung;
- Direct net evaporation (and rainfall) applied to the water surface;
- Discharge into the South Lagoon at the Morella Salt Drain (between Snipe Island and Sand Spit Point)
- For the pumping scenarios, water was extracted from the model in the vicinity of Policeman Point

These locations are shown in Figure 2.2. The boundaries and data sets are further described below.

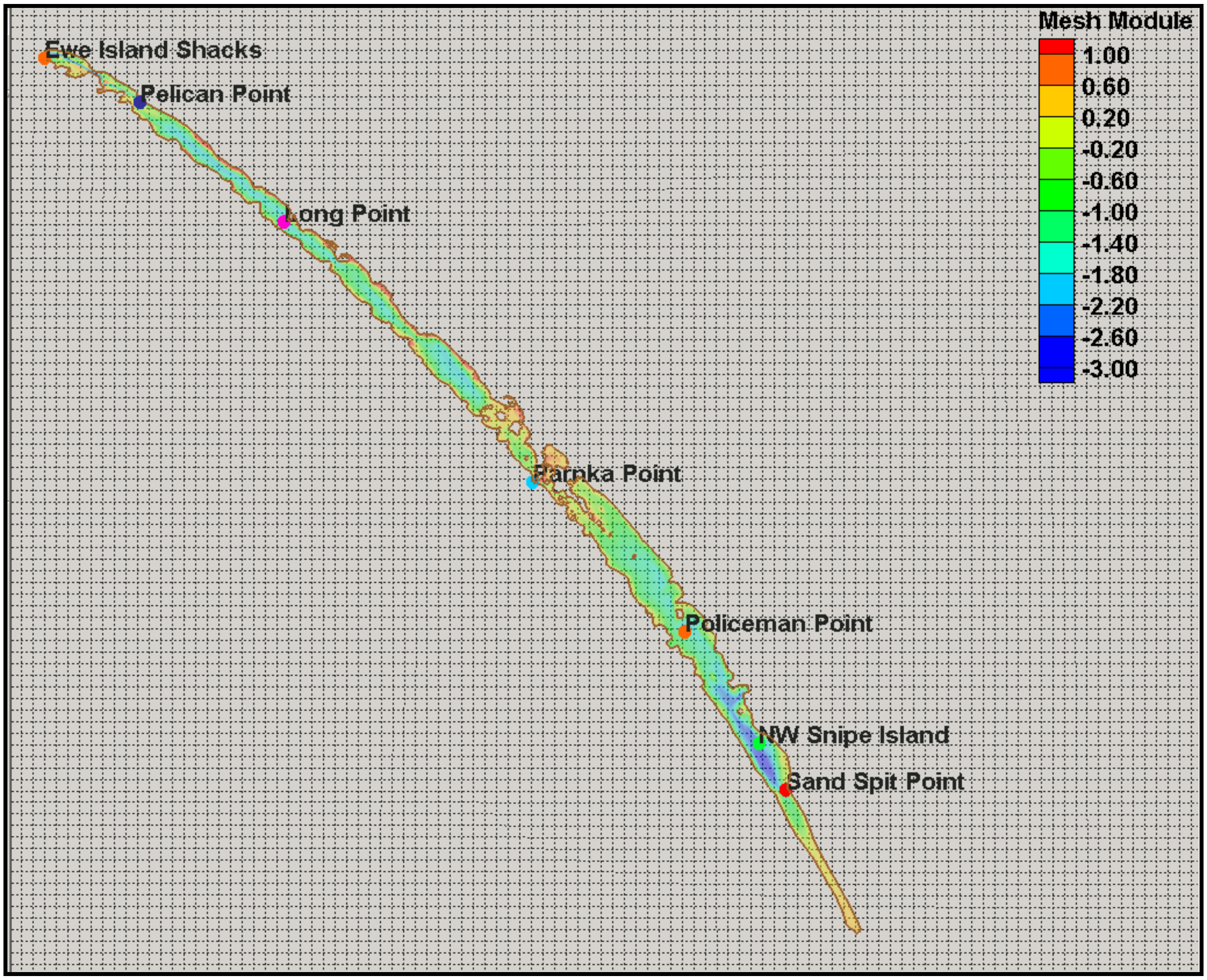

Figure 2.2: Location of Model Boundaries and Calibration Data

Water Level and Salinity Boundary at Ewe Island Shacks

A water level and salinity boundary was applied at Ewe Island Shacks using data collected by DLWBC. In order to remove uncertainty over the bathymetry of the Murray Mouth and the impact of waves on the hydrodynamics, it was decided that the model should be driven by water levels within the North Lagoon to increase our ability to reliably validate hydrodynamics and mixing within and between the North and South lagoons. The data recorder at Ewe Island Shacks was not working properly before 9/5/2008 so recorded data from Mundoo Channel was used between 1/1/2008 – 9/5/2008. A comparison of Mundoo Channel and Ewe Island water levels show that they are comparable though do differ slightly.

Wind Data

Wind data collected by the NRM at Narrung was applied to the model as a surface wind shear which alters the hydrodynamics of the model and allows the simulation of wind driven currents and setup. While the Narrung AWS which collects the wind data is quite close to the Coorong, it is 15-20km further inland and hence may record lighter sea-breezes than occur on the Coorong. However, the Coorong is also sheltered from sea breezes by the beach barrier separating the waterway from the Southern Ocean.

Evaporation and Rainfall Data

The Bureau of Meteorology (BOM) SILO database which uses interpolated data from meteorological stations was used to source rainfall and evaporation data for the Coorong.

Morella Salt Drain Discharge

Inflows (volume and salinity) from the Morella Salt Drain into the South Lagoon were obtained from a DLWBC recorder.

Initial Salinity Conditions

The model required an estimate of initial salinity for the model run. This estimate is reasonably important as it defines the distribution and quantity of salt contained within the system at the start of the simulation.

At the start of the simulation salinity data was only available at the Mouth of the Murray / Mundoo Channel (55,000 µS/cm (33 g/L)), Parnka Point (153,300 µS/cm (92 g/L)) and at the end of the South Lagoon / Sand Spit Point (161,600 µS/cm (97 g/L)). Salinity between these three points was linearly interpolated and applied to the model mesh. However, spatially varying salinity data collected by DLWBC on the 21-22 April 2009 suggests that a linear distribution of salinity is not an accurate assumption. Increasing the length of model calibration from the start of 2007 to the end of April 2009 may reduce the impact of the initial conditions on model results and assist in comparing the model's predicted salinity distribution with recorded data.

Calibration Data Sets

The water level and salinity calibration data sets were collected by a number of DLWBC recorders and are detailed below. The location of the data recorders is shown in Figure 2.2. The measured data is shown in the calibration section of this letter.

Table 1.1: Summary of the Availability of Water Level and Salinity Data in the Coorong

	Tide/Estuary Level		EC corrected	
Site Name	Start	Finish	Start	Finish
Sand Spit Point	19/12/1990	13/11/2008	13/08/1998	13/11/2008
NW Snipe Island	21/10/2008	11/02/2009	21/10/2008*3	11/02/2009
Parnka Point	17/12/1990*1	11/02/2009	13/03/1998*1	11/02/2009
Long Point	27/09/2007	11/02/2009	not available	not available
Pelican Point	09/05/2008	11/02/2009	09/05/2008	11/02/2009
Ewe Island Shacks	20/09/2002*2	11/02/2009	08/05/2008	11/02/2009
Barker Knoll[4]	20/09/2002	11/02/2009	20/09/2002	11/02/2009
Mundoo Channel[4]	20/07/2007	19/02/2009	20/07/2007	19/02/2009

1) For 2008 at Parnka Point there was no level data before 20/5/2008 and there was no salinity data between 27/2 and 20/5.

2) There was no level data for Ewe Island Shacks in 2008 before 9/5/2008.

3) The measured EC data does not look correct when compared to the DLWBC spatial salinity data set collected on the 22/4/2009. It appears to under-predict salinity by 20,000 uS/cm (12 g/L).

4) This site is downstream of the model domain, and is not shown on Figure 2.2

3 Model Calibration

The calibration simulation was established and run with the boundary conditions described in Section 2 and compared to the calibration data sets also previously described. The model was able to reproduce observed water levels and salinities in the North Lagoon by using default parameters. The main effort in achieving a reasonable calibration of water level and salinity in the South Lagoon, involved changes to the channel though the Hells Gate area. This was required as there were insufficient existing bathymetric data to describe this important part of the model.

Graphs comparing modelled water levels to measured water levels are shown in Figures 3.1 to 3.4 at four locations along the Coorong, where suitable data were available. At Pelican Point and Long Point the model is able to very closely reproduce observed water levels (Figure 3.1 and 3.2). The differences in water levels at Long Point between 1/1/2008 and 9/5/2008 are due to the lack of data at Ewe Island Shacks (water levels from Mundoo Channel were used to drive the model before 9/5/2008). During July, the model slightly under-predicts observed water levels which may be due to slight differences in the wind field between the anemometer (at Narrung) and the Coorong.

At Parnka Point (Figure 3.3.) the model is able to closely simulate trends in water level changes. The model slightly under-predicts water level from mid-September which may be due to inaccuracies in the model bathymetry (due to lack of suitable bathymetric data) or morphological change in the Hells Gate area which may have a seasonal pattern.

Water levels in the South Lagoon (Figure 3.4) are again reasonably closely predicted by the model. The differences are likely due to inaccuracies in the calculation of water flux through the Hells Gate area as discussed in the preceding paragraph.

The model's ability to reproduce observed salinity is shown in Figures 3.5 to 3.7. At Pelican Point in the North Lagoon there are a number of significant changes in salinity over time. Here, ambient salinity levels are dominated by exchange from the Mouth of the Murray. The models inability to closely match the sharp changes in salinity observed between August and December may be due to the coarse mesh through the North Lagoon that tends to over-estimate mixing and reduce spatial salinity gradients, but it is difficult to determine the exact cause, given limitations of the bathymetric data. Salinity behaviour at Parnka Point (Figure 3.6) is highly variable and depends on whether water is flowing from the North Lagoon (lower salinity) or from the South Lagoon (higher salinity). The figure shows that the model is able to predict significant features of the observed data. As previously mentioned, more accurate bathymetry data in this area would lead to improved calibration of both hydrodynamics and salt transport. Once there is confidence in the hydrodynamics further improvements in mixing parameters within both lagoons could be made to fine tune the modelled salt transport processes.

The ability of the model to reproduce salt behaviour in the South Lagoon is shown in Figure 3.7. The model appears to slightly over-predict salinity which may be due to a lack of conveyance through Parnka Point, an over-estimation of net evaporation or an underestimation of mixing in the South Lagoon. Once there is confidence in the simulated hydrodynamics at Hells Gate, further refinements could be made.

No model is ever perfect, and with the model that we presently have available, we consider a reasonable assessment of impacts resulting from different management options for the southern lagoon can be achieved.

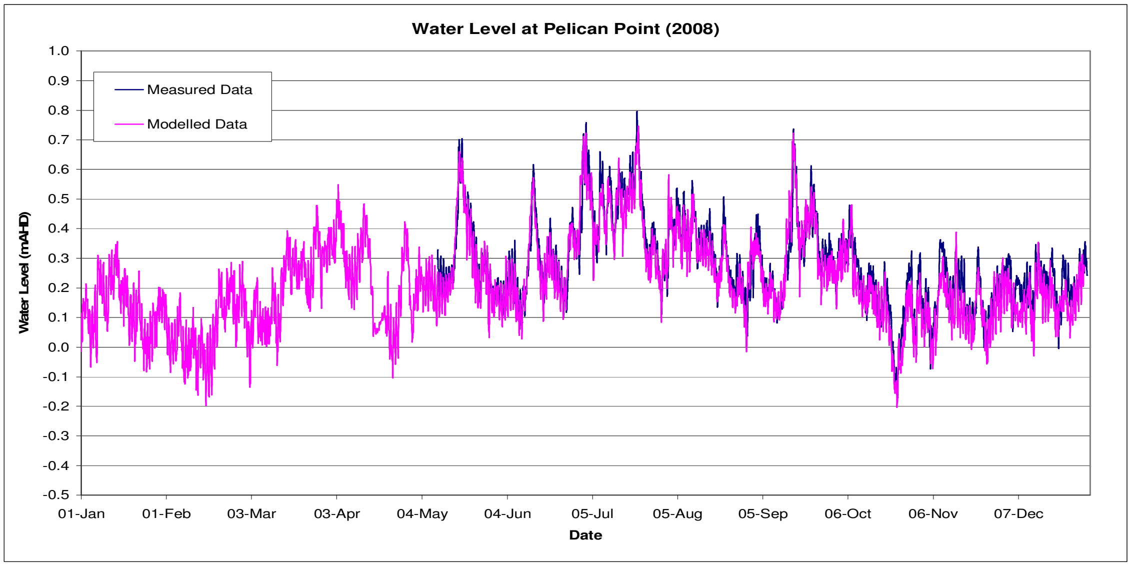

Figure 3.1: Measured and Modelled Water Levels - Pelican Point (North Lagoon)

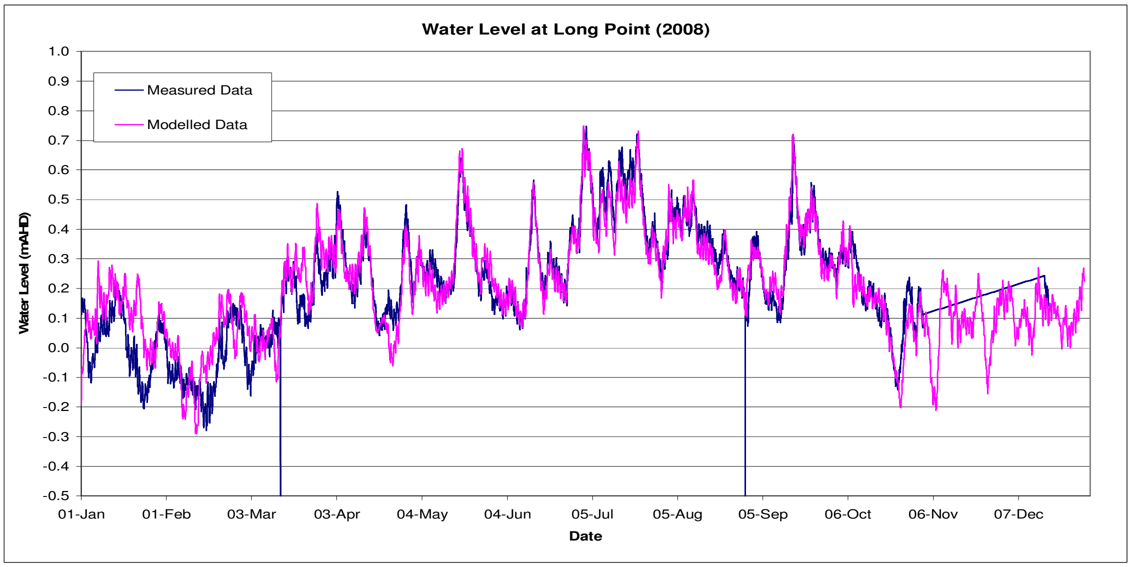

Figure 3.2: Measured and Modelled Water Levels - Long Point (North Lagoon)

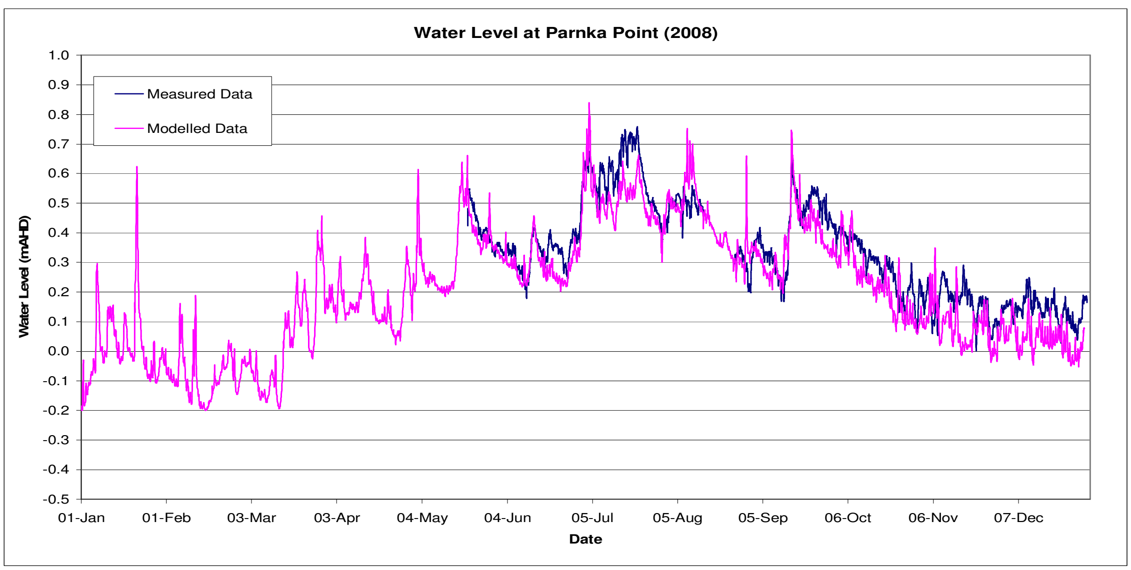

Figure 3.3: Measured and Modelled Water Levels - Parnka Point

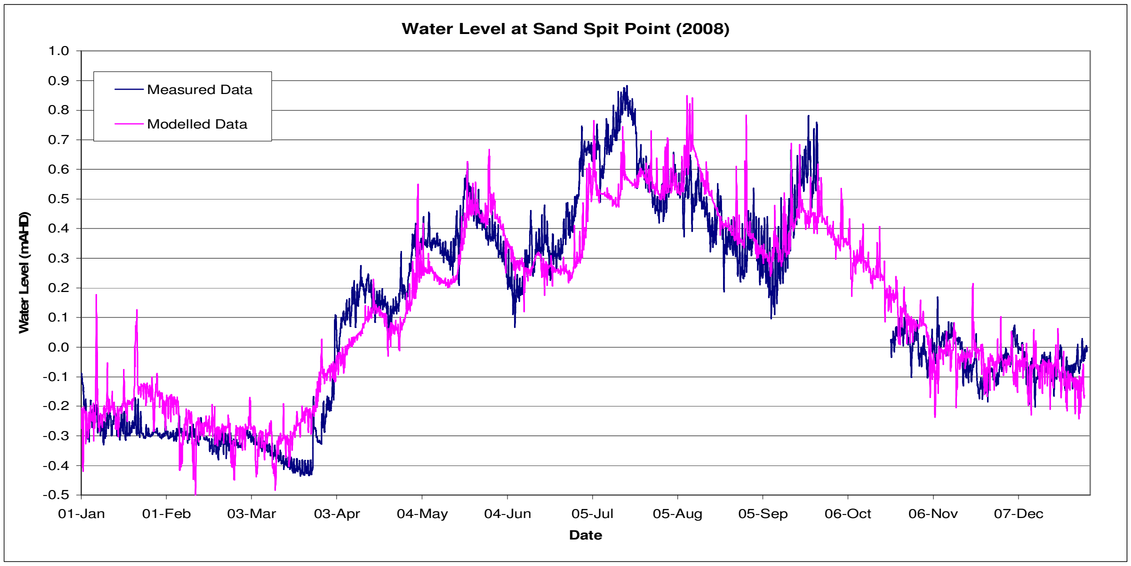

Figure 3.4: Measured and Modelled Water Levels – Sand Spit Point (End South Lagoon)

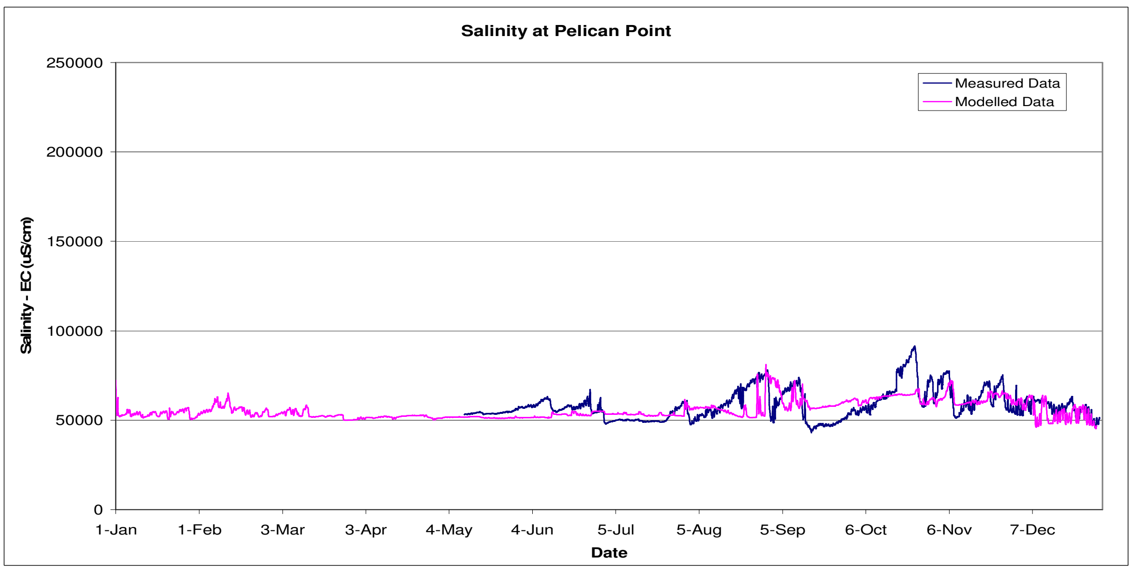

Figure 3.5: Measured and Modelled Salinity (µS/cm) - Pelican Point (North Lagoon)

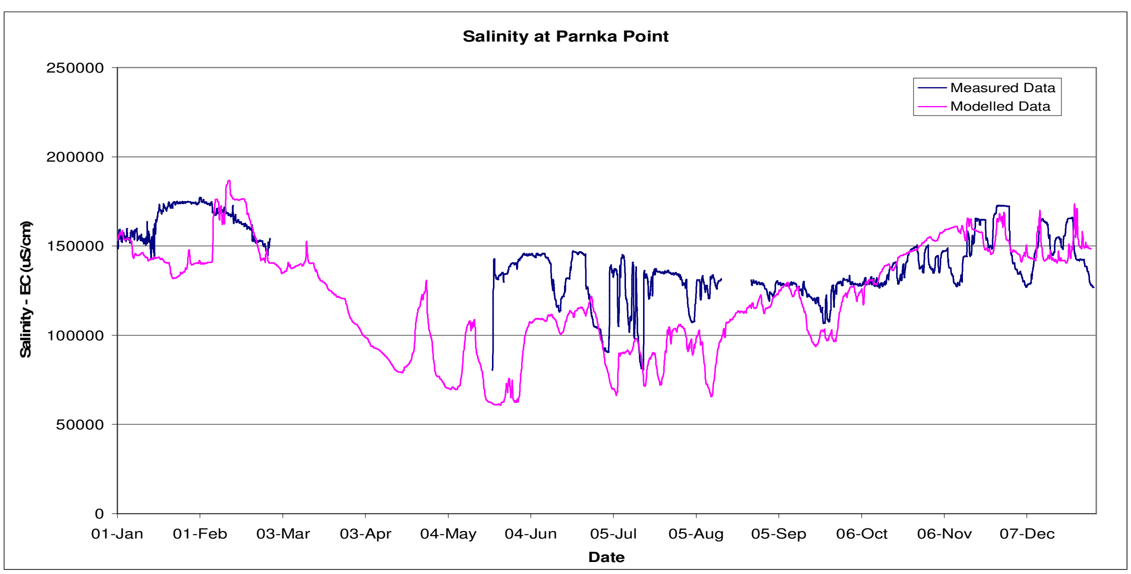

Figure 3.6: Measured and Modelled Salinity (µS/cm) - Parnka Point

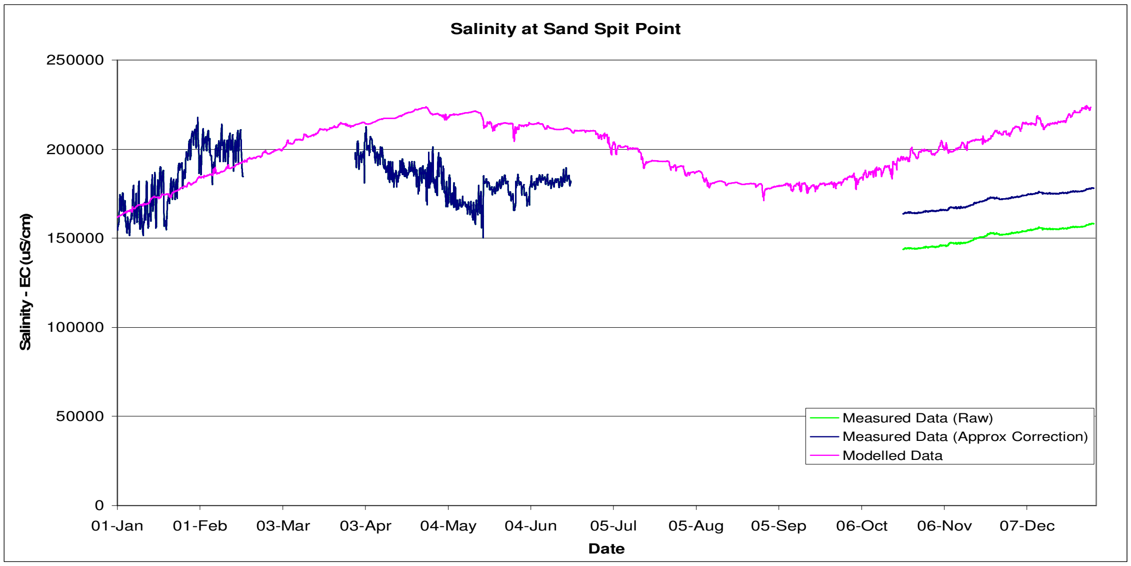

Figure 3.7: Measured and Modelled Salinity (µS/cm) – Sand Spit Point (End South Lagoon)

4 Scenario Runs

A range of management scenarios to reduce salinity in the Coorong have been suggested. The target salinity guidelines are 60 g/L (~100,000 µS/cm) in winter and 100 g/L (~170,000 µS/cm) in summer. Management options suggested so far include:

- Dredging a deeper and wider channel through the constriction (Hells Gate area) between the North and South Lagoon to increase the mixing of salt between the Lagoons;
- Pumping salty water from the South Lagoon (near Policeman Point) into Encounter Bay. This would remove a mass of salt from the South Lagoon and allow less salty water from the North Lagoon to enter and cause further dilution. The most effective and efficient timing of pumping is to be investigated.
- Construction of a regulator at Parnka Point. This would allow a degree of water level control in the South Lagoon which could be used to optimise natural mixing or to enhance the effectiveness of a pumping strategy.
- A combination of the above.

Six scenarios have been modelled to date. They Include:

1) Base case - do nothing option;
2) Dredging a deeper and wider channel through Hells Gate (see Appendix A);
3) Pumping 150 ML/day 1/1/2008 – 31/12/2010;
4) Pumping 150 ML/day (Winter) 1/6/2008 – 31/12/2010;
5) Combined Dredging at Hells Gate and Pumping 150 ML/day 1/1/2008 – 31/12/2010;
6) Pumping 250 ML/day 1/1/2008 – 31/12/2010;

The scenarios have been modelled for 3 years. Model boundary condition (water level & salinity at Ewe Island Shacks, wind and evaporation) data for 2008 were repeated for each year of simulation. Model predictions for salinity at four locations along the Coorong are shown in Figures 4.1 to 4.4. Water level predictions for the South Lagoon are shown in Figure 4.5.

Figure 4.1 shows that, in the absence of any intervention (Base Case) salinity at the end of the South Lagoon (Snipe Island) could reach 170 g/L (~280,000 µS/cm) in summer. Figure 4.2 shows that, in the middle of the South Lagoon (Policeman Point), the salinity could reach 130 g/L (220,000 µS/cm) in summer. The model shows that while dredging a channel through Hells Gate is able to slightly reduce summer salinity levels, in winter there is minimal benefit. The figures show that pumping water from the South Lagoon results in a significant reduction in both summer and winter salinity levels, and starting the pumping in summer brings about the greatest benefit. A combination of dredging Hells Gate and pumping from the South Lagoon compared to pumping with no dredging, slightly increases salinity in winter but reduces the peak summer salinity levels. Pumping at 250 ML/Day results in the greatest reduction in salinity of all the six options. At Policeman Point, summer peaks for the third year are only 105 g/L and in winter they are 60 g/L which is very close to the target guidelines. However, salinities at the end of the South Lagoon (Snipe Island) are slightly above the target guidelines with the model predicting 120 g/L and 80 g/L for summer peak and winter low salinities.

Another point worth noting is that the 250 ML/day pumping scenario is the only simulation undertaken which demonstrates decrease in the summer peak salinity level with time.

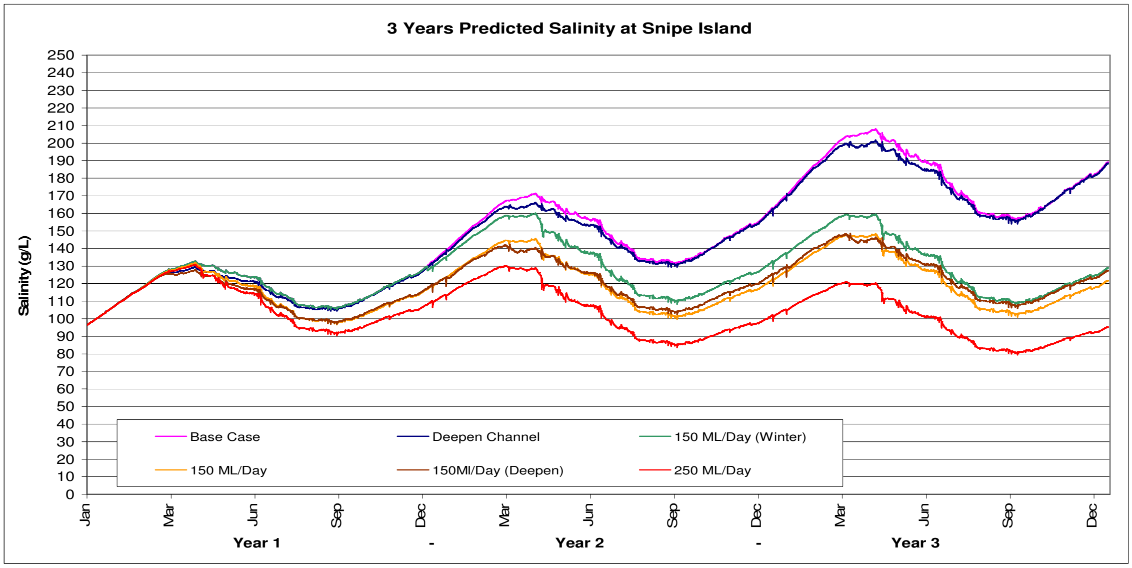

Figure 4.1: Predicted Salinity (g/L) – Snipe Island (End South Lagoon)

The results of the model runs show that these strategies have a negligible impact on salinity levels in the northern end of the North Lagoon (Figure 4.4) which remain fairly constant between 30 g/L and 40 g/L (~50,000 and 70,000 µS/cm) and hence below the target levels for both summer and winter.

Salinity levels at the southern end of the North Lagoon are more variable. While the pumping scenarios help to further reduce salinity in this area, the dredging scenario can increase salinity above the base case in this area (Figure 4.5).

The management options have an insignificant impact on water levels within the North Lagoon though water levels in the South Lagoon during summer have been altered by several of the management strategies tested. Figure 4.6 shows a comparison of water levels predicted to occur in the South Lagoon. The figure shows that dredging a channel through Hells Gate prevents a significant drop in water level which occurs in the Base Case and pumping simulations where the constriction at Hell's Gate presently causes a hydraulic disconnection to occur between the lagoons when water levels fall below approximately -0.05 mAHD. Pumping at 150 ML/Day results in a decrease in summer time minimum water levels from - 0.3 m AHD to -0.4 m AHD. Pumping at 250 ML/Day results in a decrease in summer time minimum water levels from -0.3 mAHD to -0.5 mAHD. A combination of dredging Hells Gate and pumping from the South Lagoon (at 150 ML/day) is able to maintain water levels in the South Lagoon above -0.2 mAHD in Summer. During winter time when water levels in the South Lagoon are greater than 0.2 mAHD, there is less difference in water levels between the six scenarios.

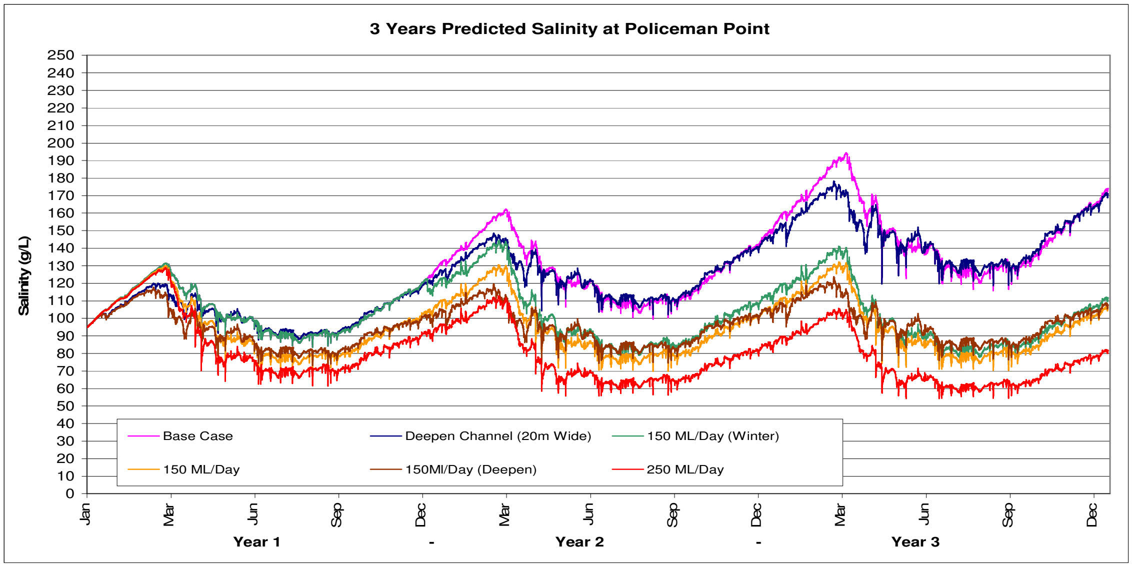

Figure 4.2: Predicted Salinity (g/L) – Policeman Point (South Lagoon)

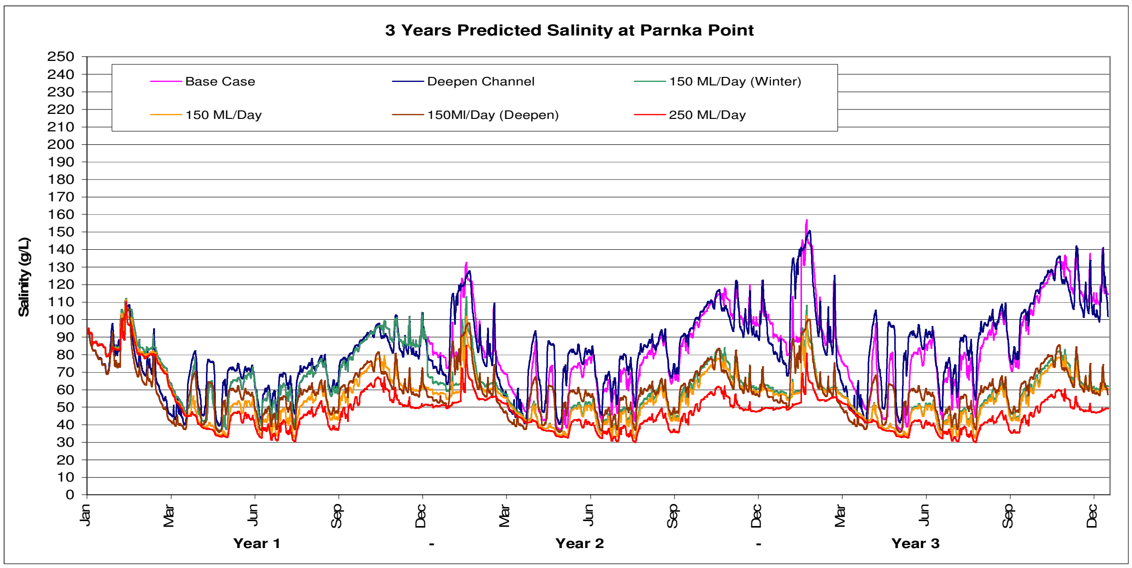

Figure 4.3: Predicted Salinity (g/L) – Parnka Point

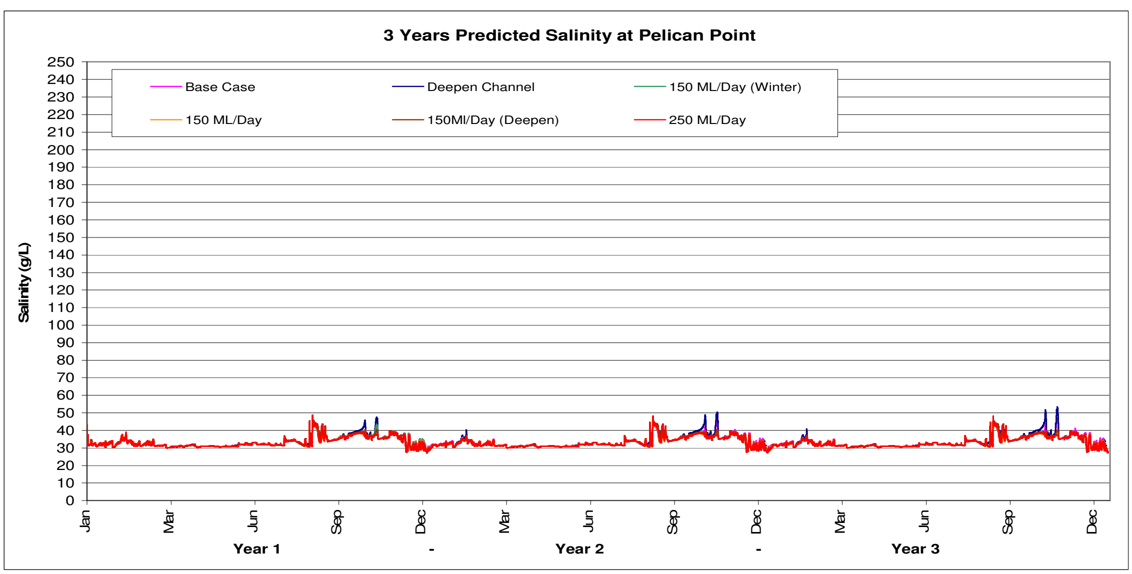

Figure 4.4: Predicted Salinity (g/L) – Pelican Point (North Lagoon)

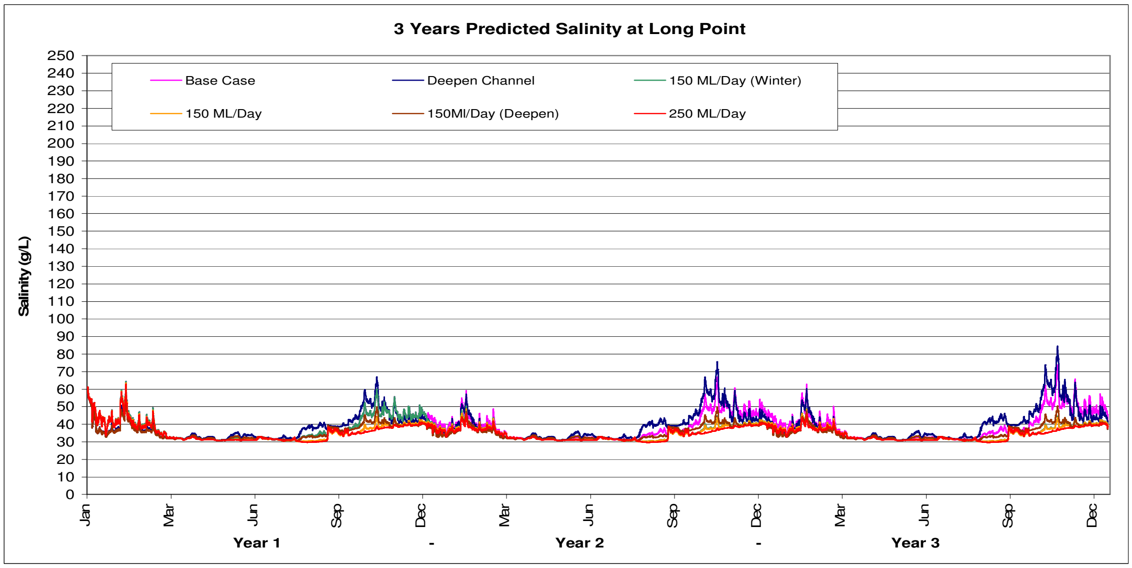

Figure 4.5: Predicted Salinity (g/L) – Long Point (North Lagoon)

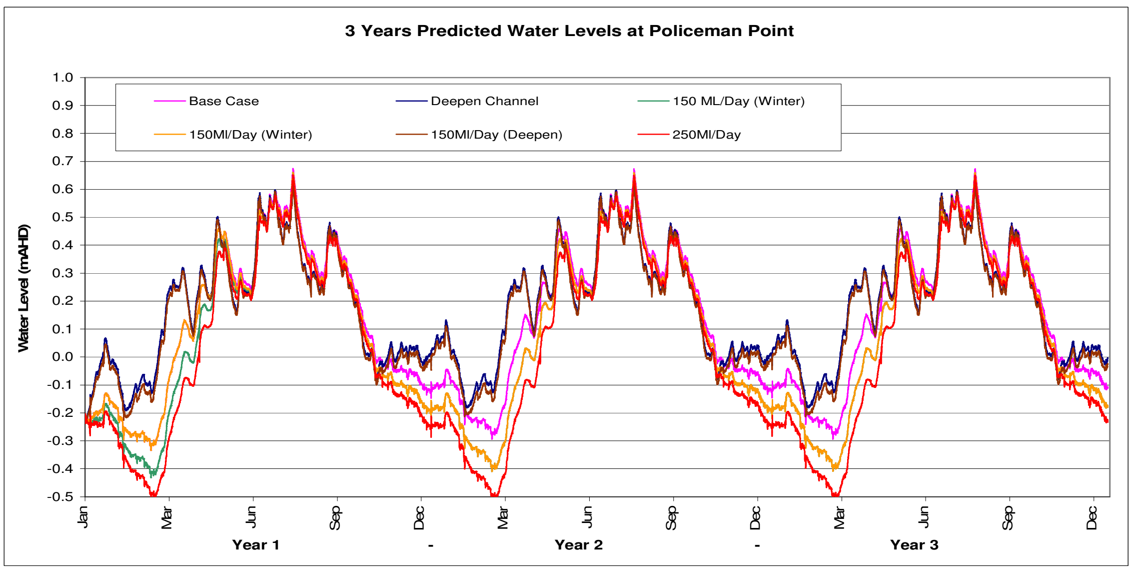

Figure 4.6: Predicted Water Levels (mAHD) – Policeman Point (South Lagoon)

5 Discussion and Conclusion

A reasonable calibration of the RMA10s Coorong model has been achieved with the model being able to predict the changes of both water level and salinity in both the North and South Lagoons. An absence of suitable bathymetric data along the Hells Gate area meant significant engineering judgement was required to achieve the current state of calibration. As uncertainties in bathymetry in this area still exist, further calibration of the model by fine tuning friction and mixing parameters are yet to be justified. While an updated bathymetric data set was collected in July 2009, it was confined to a 200m wide corridor and missed some important areas, which mean a large number of assumptions regarding bed levels would still be required. Given that the model was calibrated to the previous data set, it was considered unwise to run any new management scenarios using the new bathymetry as they would not be comparable to previous model scenarios. The new bathymetry data could be improved with the collection of a small amount of additional survey in some key area. If the new bathymetry data can be successfully merged with existing data sets, recalibration of the model to the new bathymetry is recommended.

It is also recommended to extend the calibration period from 1/1/2009 to 31/4/2009 which would increase confidence in model results and allow a comparison to the spatial salinity data set collected on the 21-22/4/2009.

The state of the model's calibration is adequate to test the relative performance of a range of the suggested management scenarios. The model predictions show that, while dredging a deeper (-0.8 mAHD) and wider (20 m) channel through the Hells Gate area does reduce the salinity of the South Lagoon during summer, there is minimal benefit over the Base Case during winter.

Pumping at 150 ML/Day from the South Lagoon (near Policeman Point) is able to significantly reduce (and almost stabilise) the salinity of the South Lagoon. However, the modelling shows that, at this pumping rate, salinities are still above the required target salinity levels, and while salinity levels appear stable and increasing only slightly during successive years, there appears to be no long term reduction in salinity at this pumping rate.

Simulations of pumping at 250 ML/Day is indicate a long term reduction in salinity levels within the South Lagoon. In the third year of pumping the target salinity levels at Policeman Point are achieved however, at Snipe Island they are still slightly exceeded.

Beginning pumping in Summer is likely to bring about the greatest reduction in salinity as the water is more concentrated, resulting in a greater mass of salt being removed for a given pumping rate. Pumping over summer may result in an increased reduction in water levels from -0.3mAHD (Base Case) to -0.4 mAHD (150 ML/Day) or -0.5 mAHD (250 ML/Day). A combined scenario of dredging at Hells Gate and pumping is able to mitigate somewhat against these lower water levels while still producing significant reductions in salinity.

The use of a regulator (adjustable weir or gate structure) at Parnka Point may help manipulate water levels to enhance flushing and could also be used to increase the effectiveness of a pumping strategy. Such a structure could be modelled using RMA10s.

Peak salinity levels are affected by the increase in water levels that occur in Autumn. The sensitivity of peak salinity levels for a range of different annual water level time series is likely to be significant and may warrant further investigation.

We trust that this information meets the requirements of the NRM Board and DEH. We look forward to discussing any further modelling needs and are happy to discuss the possibility of further simulations and investigations. Should you require any further information or clarification of the above, please contact the undersigned on (02) 4940 8882.

Yours Faithfully
BMT WBM Pty Ltd

Rohan Hudson
Senior Engineer

Appendix A: Dredged Channel Profile Through Hells Gate

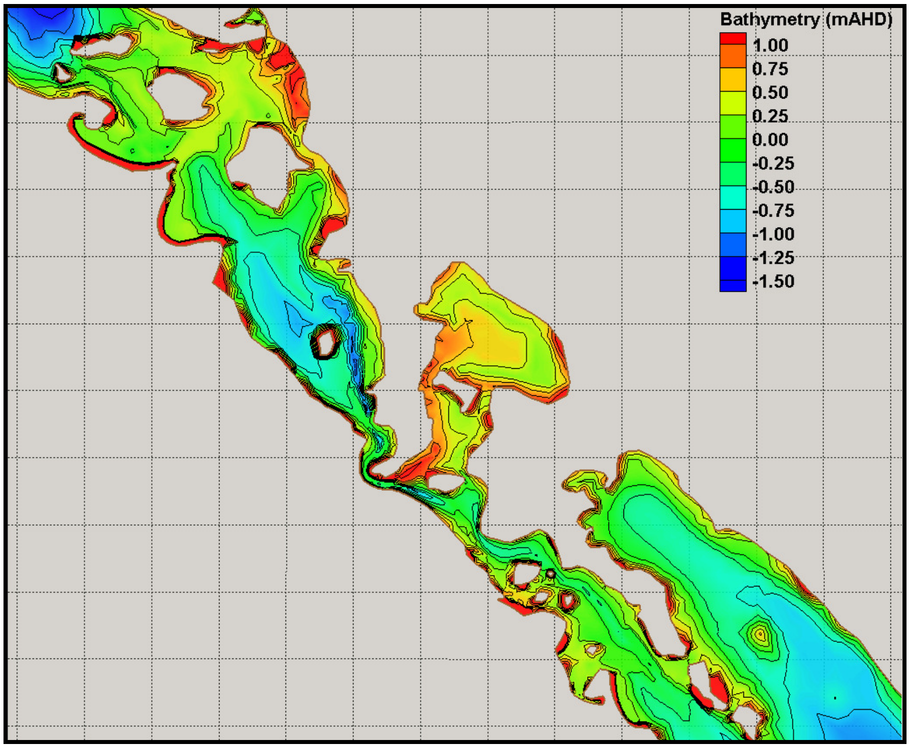

Figure A.1: Existing Bathymetry through Hells Gate Area (Base Case), Grid Size = 1000m

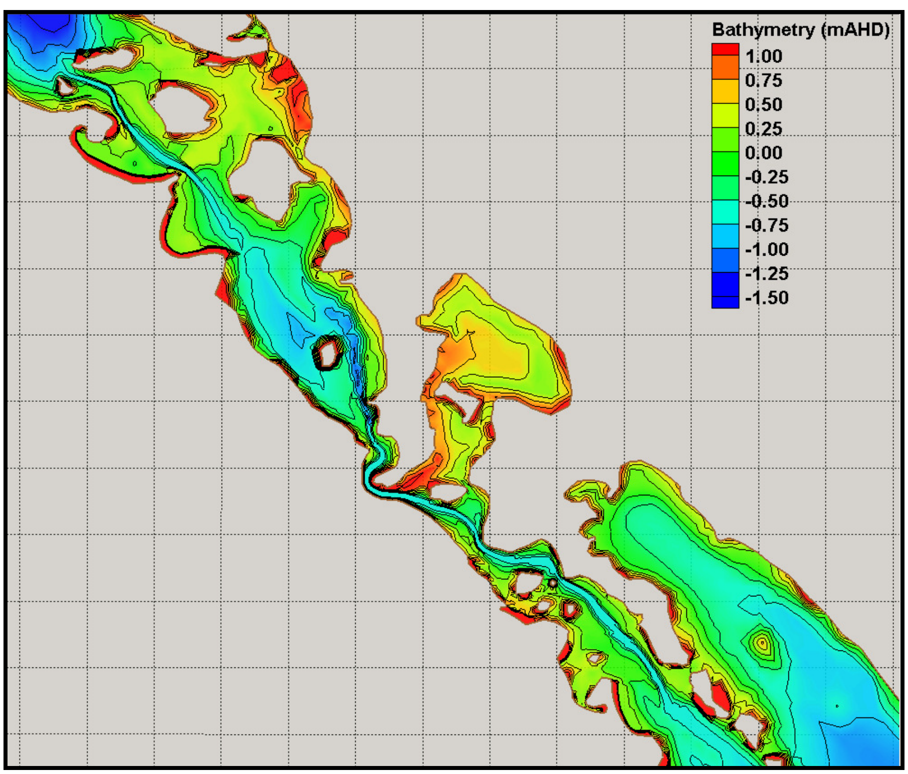

Figure A.2: Dredge Scenario Bathymetry through Hells Gate Area (Channel is typically 20m wide at -0.8 mAHD), Grid Size = 1000m

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Our Ref: DJW: L.N1792.001_SouthLagoonPumpingSimulations_Final.docx

10 December 2009

LLCMM Icon Site Coordinator
SA MDB NRM Board
Level 4, 111 Gawler Place
ADELAIDE
SA 5001

Attention: Glynn Ricketts

Dear Glynn

RE: Coorong Model Upgrade and Simulations of Proposed Pumping from the Southern Lagoon

I refer to my email to yourself on October 9, 2009, which outlines our proposed scope of works for the above project and subsequent correspondence. This letter provides a summary of our methodology, findings and advice relating to this project.

Scope of Works

The project scope can be broadly divided into two separate components as follows:

- Model Upgrade: this involved the inclusion of new, improved data into our digital elevation model of the Coorong, and subsequent upgrading of the model mesh to match the new digital elevation model.
- Model Simulations: Two model simulations were requested by the South Australian Murray Darling Basin Natural Resources Management Board (*NRM Board*) for this project. As the model has been modified from that used in our previous work (*L.N N1347.022.CoorongSalinityModelling_3yearFinal.doc, dated August 3, 2009*) we have also re-executed a "base simulation" for comparison. We advise that results from simulations presented below are therefore not directly comparable to that previous work, as the model has been improved.

The following discusses these two components in detail.

Model Upgrade

Digital Elevation Model Upgrade

Our previous work indentified the importance of bathymetry at Parnka Point and surrounding areas to the exchange of water between the Northern and Southern Lagoons. We also identified a lack of existing reliable survey data in this area.

Additional data was collated within this area from the following sources:

- An aerial photograph covering the Southern Lagoon and Parnka Point from February 2008, and an aerial photograph of the Northern Lagoon and Murray Mouth from March 2008, which were provided to us by the Department for Environment and Heritage (DEH);

- A bathymetric model of the entire Coorong, originally prepared as part of habitat mapping work undertaken by the CLLAMMecology Research Cluster, and derived from satellite reflectance data. This data was provided to us by the NRM board
- Additional hydrosurvey data, as provided by the NRM Board from the following dates:
    - July 2009, comprising a dense set of cross sections, typically around 100-200 m long and covering almost the entire length of this complex area;
    - September 2009, comprising survey data additional to that from July, in order to make the data set more complete for use in our model.
- Fringing LiDAR Data from the area, collected in early 2008, and provided to us by DEH.

Overall, cross checks between the different sources of information have indicated that the satellite derived data differed significantly from the other data sets in a number of locations, it was not used in the refinement of our digital elevation model.

For the Parnka Point area, the hydrosurveyed data set was adopted as the preferred data source, and breaklines of approximately equal elevation were digitised between the surveyed points using the underlying aerial photography as a guide. The breaklines and surveyed points were then used to train an algorithm within ArcGIS to interpolate a reasonable DEM of the areas shown as wetted within the aerial photograph.

The DEM thus derived was subsequently merged with the fringing LIDAR information. The resulting merged DEM was then checked for consistency against the aerial photography, with some adjustments made where the resulting product was notably deficient. In those areas, we have normally reverted back to previous digital elevation models, which were based upon sparse cross section survey from 2002.

The resulting DEM is shown on **Figure 1.**

In addition to the DEM at Parnka Point, we also upgraded our DEM in the vicinity of the Murray Mouth. This happened in conjunction with parallel projects being undertaken by BMT WBM for SA Water and the Murray Darling Basin Authority. Previously, the model was being driven by measured water levels along the Coorong at “Ewe Island Shacks” just downstream of the Ewe Island Barrage. By extending the model to include the entrance compartment, and the channel between the Murray Mouth and Goolwa Barrage, we have achieved a more consistent response of the overall system to wind set up. Initially, we had concern that this would be problematic, because it is not feasible to accurately model the effects of present dredging operations at the Murray Mouth, and these could have been significant. However, we have found that a water level calibration equivalent to that from our previous study was achieved for period of our calibration (January 2008, through to August 2009). This is probably reflective of the Murray Mouth dredging program consistently achieving the target tidal ratio at Tauwitchere Barrage, although it should be noted that the dredging works do affect water levels all the way along the Coorong.

A monitoring hydrosurvey undertaken by SA Water during January 2008 was used as the basis for our mesh modifications and bathymetric changes within the entrance compartment. This survey data is shown on **Figure 2.** The elevations of the entrance bar at the Mouth were estimated on the basis of wave breaking patterns and other features present in the March 2008 aerial photograph.

<u>Improvements to Model Mesh and Revalidation</u>

Following adjustments to the digital elevation models, the model mesh was modified to better represent the bed elevations. The resulting model mesh in the areas of interest is shown on **Figure 1** and **Figure 2** for Parnka Point and the Murray Mouth respectively.

Furthermore, the spatial variation of initial salinity was modified to better represent measured longitudinal salinity gradients along the length of the Coorong. This was a potential deficiency noted in our previous modelling. Assisting in this regard was a longitudinal “Run of the River” survey of the entire Coorong undertaken by DWLBC in April, 2009. This illustrated a sharp increase in salinity across the Parnka Point area, commensurate with disconnection of the two lagoons during the summer months. The spatial pattern of variation was scaled in accordance with measurements at and around early January 2008. The data that we have used for this purpose is provided on **Figure 13.** The resulting longitudinal variation across Parnka Point and into the Southern Lagoon is shown on **Figure 3.**

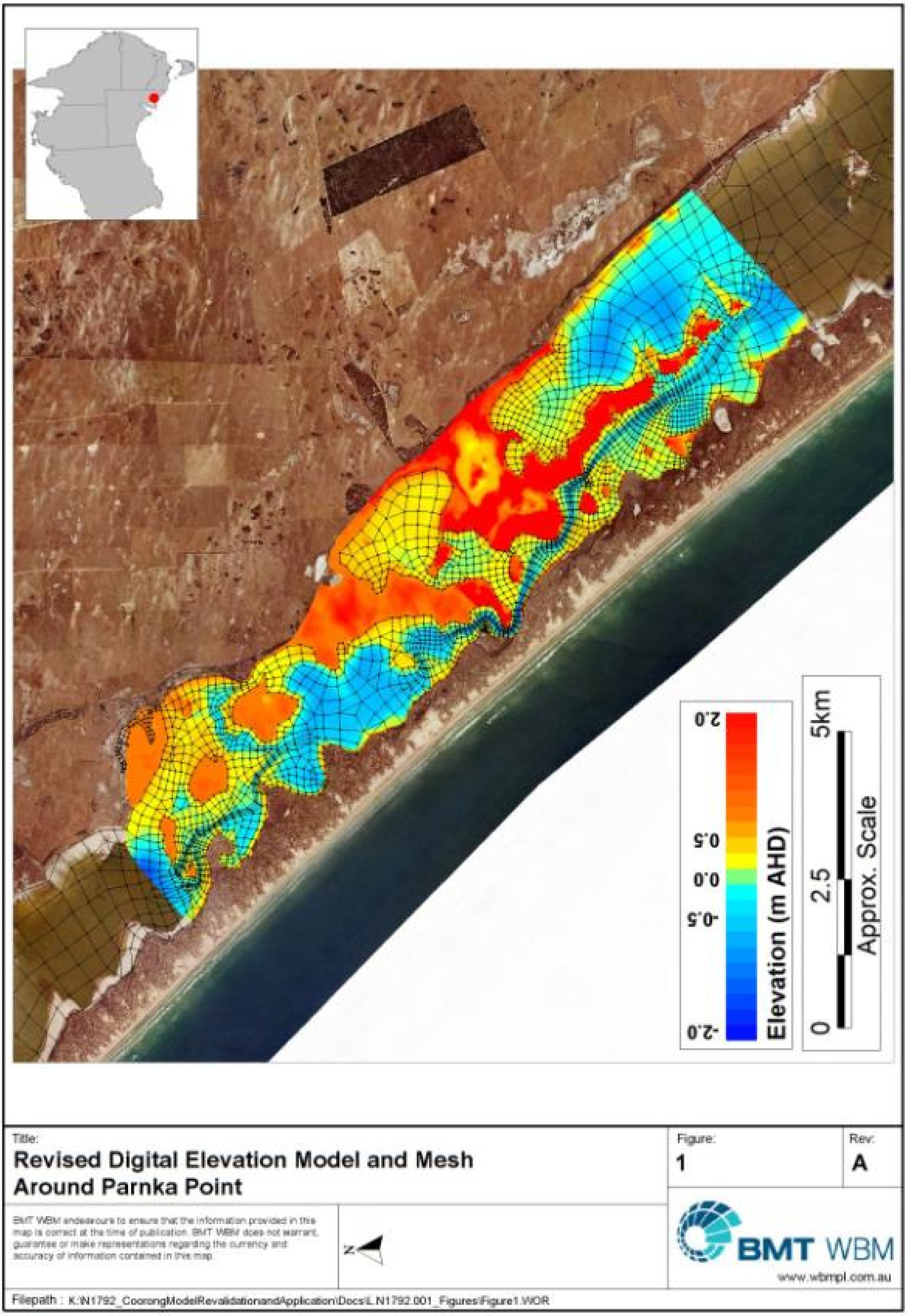

Figure 1 **Revised Digital Elevation Model and Mesh around Parnka Point**

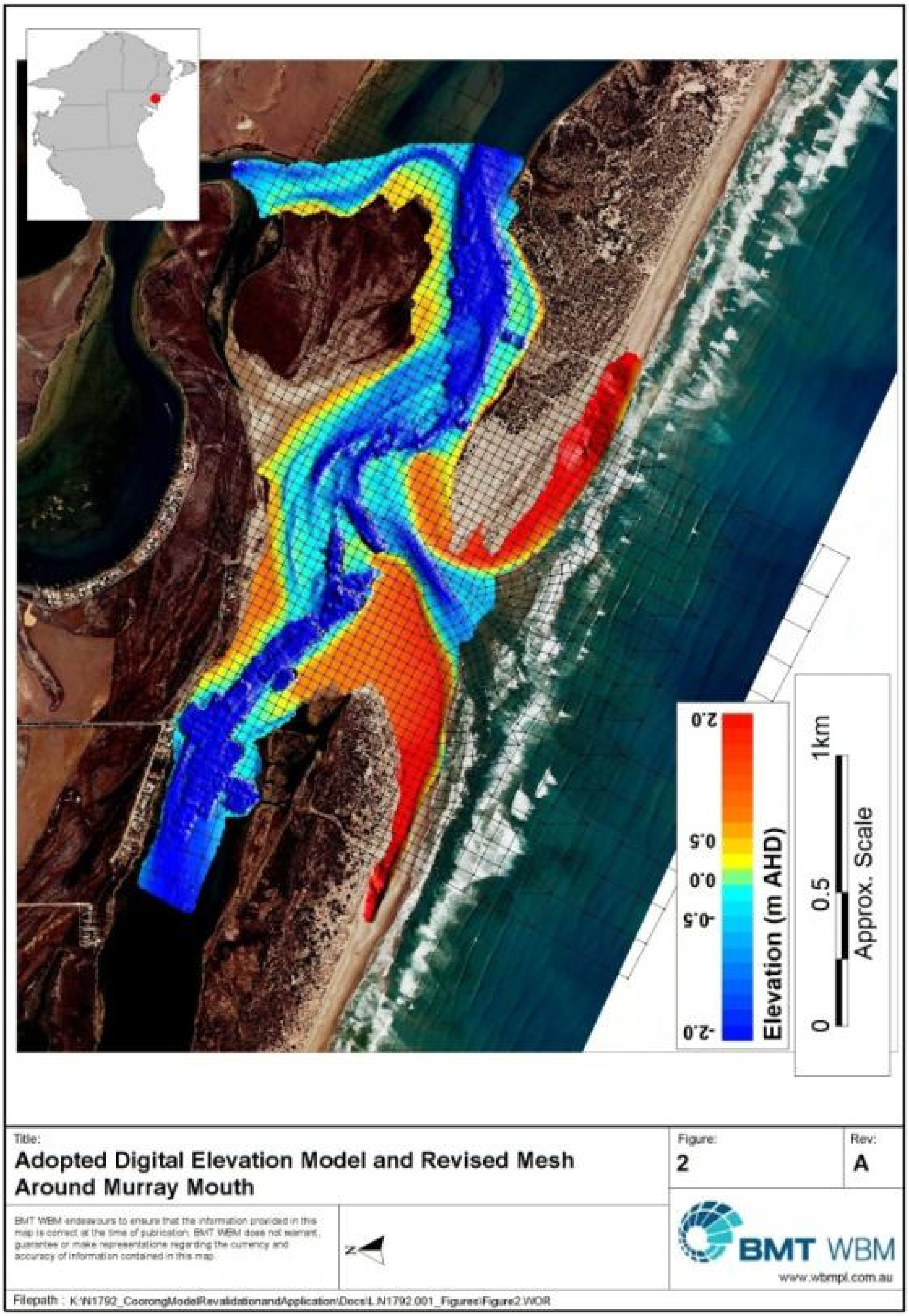

Figure 2 **Adopted Digital Elevation Model and Revised Mesh at Murray Mouth**

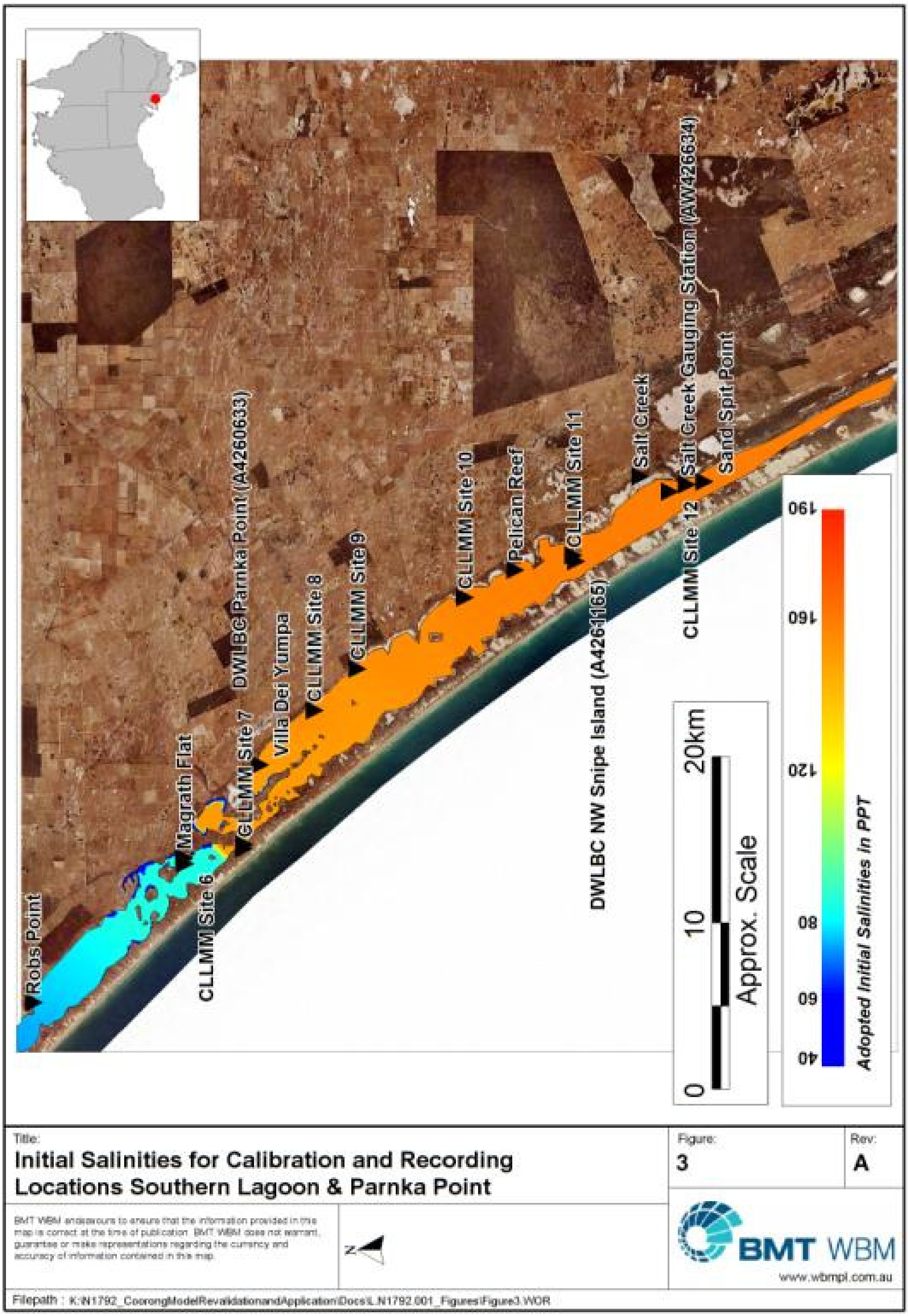

Figure 3 Initial Salinities for Calibration and Recording locations, Southern Lagoon and Parnka Point

The calibration simulation was then executed for the revised mesh. Due to the additional time that has elapsed since the last modelling exercise, we have also extended the calibration through to August, 2009, using data that we had readily available, to improve our confidence in the model's long term predictive capabilities.

As the model now extends through the Murray Mouth, it was necessary to adopt a tidal water level as the downstream boundary. Tide levels are available from Victor Harbour. Previous analysis by CSIRO (pers. comm. Ian Webster) has identified through analysis of time series at Victor Harbour, Goolwa Barrage and Tauwitchere Barrage that measurements of tide at Victor Harbour need to be raised by approximately 0.14 m to bring them in line with the recorded water levels in the Coorong. Webster indicates that this could be due to wave set-up at the Murray Mouth, but concludes that the actual mechanism for this difference is not known.

We tested our model using the both the recorded and adjusted water levels at Victor Harbour and found that the adjustment resulted in a marked improvement in predicted water levels within the entire system. Accordingly, we have concluded that the adjustment proposed by Webster is reasonable and have adopted it for this modelling exercise.

In our first attempts to validate the revised model, salinity at the Murray Mouth was set at a standard value of 35 ppt. However, it quickly became apparent that this would not result in appropriate measured values within the entrance, particularly in the vicinity of Ewe Island Shacks and Beacon 17, where salinities lower than 35 ppt are present in the record. We have found that application of salinities measured inside the estuary as the actual ocean boundary values results in much better prediction of salinities throughout the Northern Lagoon. For the calibration exercise, we have considered salinities measured at the three automatic stations closest to the entrance (Beacon 1, Beacon 17 and Barker Knoll). From these three sites, we have considered those that seem to provide the most appropriate salinity values (i.e. quality of the record seems reasonable) at any given time and have compiled these into a representative time series for use in the modelling.

We are uncertain why the recorders seem to provide salinity values that are relatively fresh, when compared to the Ocean, particularly given that there are no significant freshwater discharges at the present time. Whether or not there is some freshwater contribution from another source, which may be accentuated at different times in different areas as the mouth changes between being relatively shoaled and opened again by dredging remains uncertain. Nevertheless, the approach we have taken results in a good response to salinity, particularly within the Northern Lagoon and we consider it reasonable for our present assessment.

The wind record used for the present study was acquired from the gauge at Pelican Point. Where data was unavailable from this record, data from the wind gauge at Narrung was used to infill the gaps. The wind stress coefficients used have been scaled up within the bounds of literature values, as presented in Williams (2006).

Evaporation and rainfall data was acquired from the SILO database (QNRM, 2009), using information that had previously been acquired for Lake Alexandrina covering the period of calibration. We consider this reasonable because the SILO data is less reliable closer to the coast.

We have also considered the impact that high salinity levels have on evaporation. This is of particular importance in the Southern Lagoon, where the impact of high salinities is potentially very important during the summer months, when the Northern and Southern Lagoons are disconnected and there is limited chance for equilibration of water levels between the two.

As salinity increases, the vapour pressure at the water surface is reduced, resulting in a lower rate of evaporation from the water surface. Furthermore, the degree to which this impact is felt is moderated by temperature, because evaporation also has a cooling effect on the water body. So, although higher salinities lower the evaporation rate, higher temperatures reduce increase the tendency for evaporation. There is therefore a seasonal variation in the *evaporation reduction factor*. We have relied upon data provided in Salhotra et. al (1985), taken from evaporation pans comprising mixtures of water from the Dead and Mediterranean Seas. We limited the data used in our assessment to those pans with a concentration of around 200 ppt, which were among the lowest salinity concentrations considered by Salhotra et. al. (1985), but is close to the peak salinities presently experienced during summer in the Southern Lagoon.

Using these data, we have found that evaporation from the water body could realistically be decreased by 15% during the middle of summer and 30% during the middle of winter. It should be recognised that this approach is an approximation, and methods involving a more rigorous treatment of the heat budget at the water surface (including wind, solar radiation, humidity and the impact of salinity) could give different results. The capability of a more rigorous heat budget assessment is not presently available in TUFLOW-FV. The approach we have taken has resulted in a significant improvement in the models capability to replicate measured data in the southern lagoon.

Calibration Results

Our resulting calibration is discussed within this section.

The quality of the water level calibration is shown in **Figures 4** through **7** for NW Snipe Island/Sand Spit Point, Parnka Point, Long Point and Pelican Point respectively.

Overall, the model is replicating seasonal trends well. Water levels at the southern end of the Southern Lagoon show a good seasonal trend, but typically sit below levels measured at Sand Spit Point and above the recorded levels at NW Snipe Island. The simulated level is typically within 0.1m of the measured levels and is considered good.

At Parnka Point, the water level apparently fits measured data well during the late winter and spring months, but sits between 0.1 to 0.2 m too high during summer. This is consistent with the Parnka Point recorder being affected to a greater extent by the northern lagoon, which also has relatively high simulated water levels, than it should be during the summer. This is likely due to changes in the mouth bathymetry arising from dredging.

Both Long Point and Pelican Point illustrate patterns that are higher than measured in summer (~ 0.1 m) and lower than measured in winter (0.1 to 0.2 m).

Where the previous and present calibration periods overlap (i.e. 2008), the model can be seen to produce a similar level of calibration to water levels, with the exception of Parnka Point, where predictions used to sit lower than measured, but are now typically higher during Summer.

The model validation period has been extended and shown to replicate conditions reasonably but not perfectly over a longer time period. Given the level of uncertainty associated with other parameters such as the ocean boundary and mouth conditions, we consider the calibration to be suitable for the present assessment.

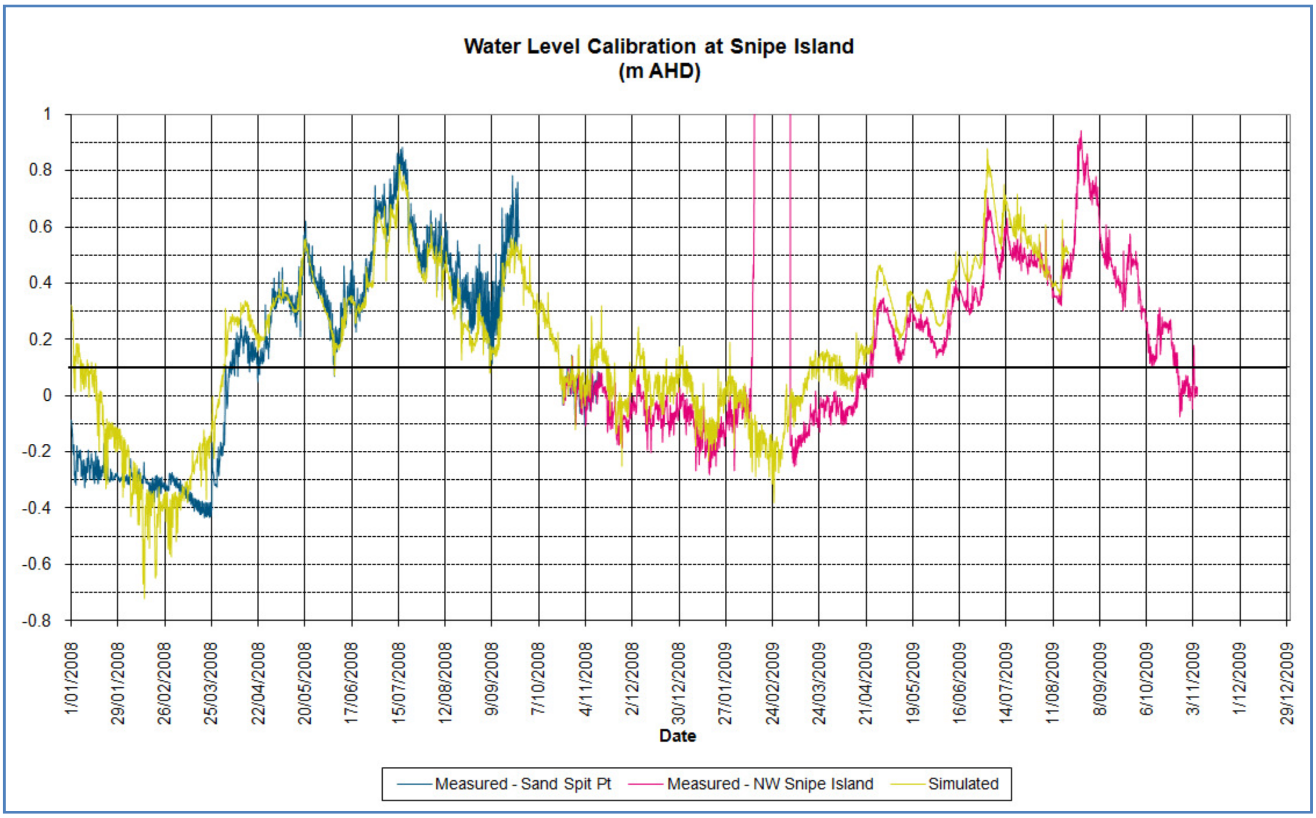

Figure 4: Water Level Calibration at NW Snipe Island/Sand Spit Point

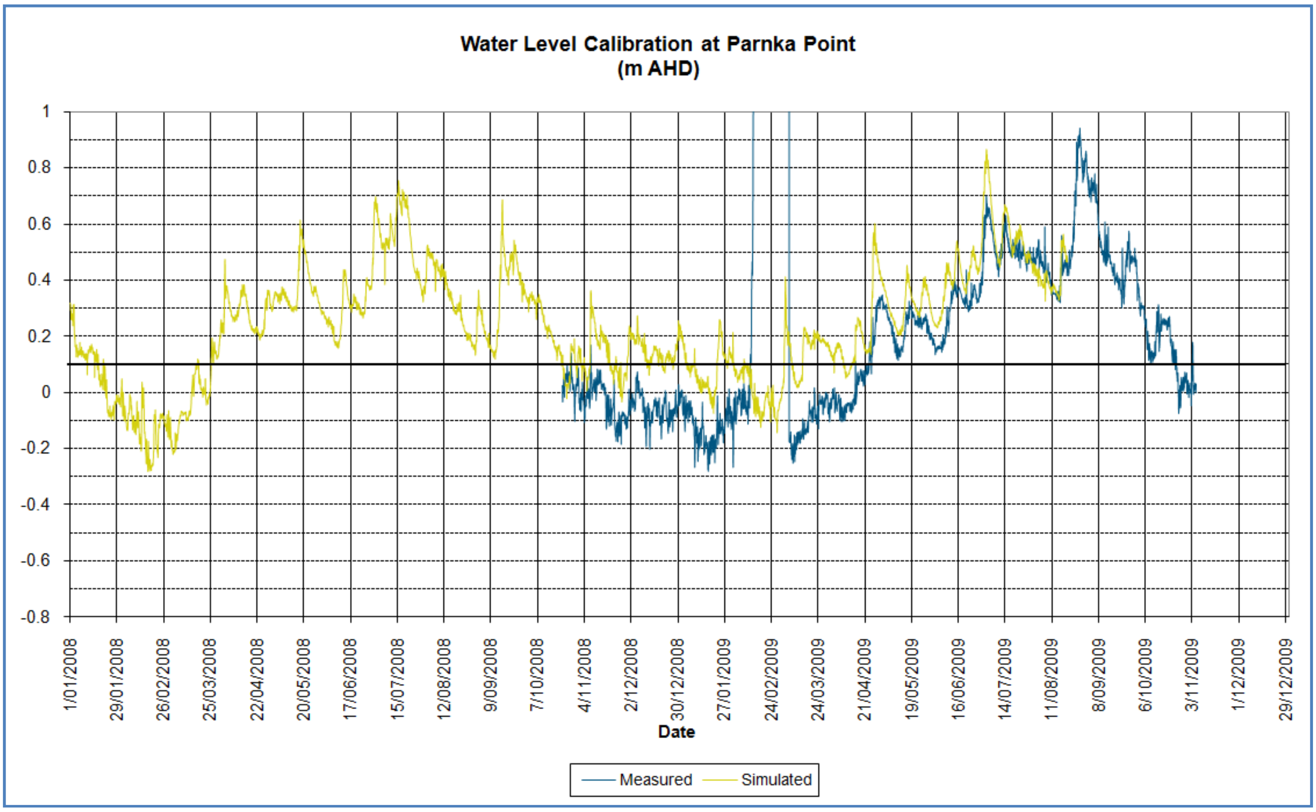

Figure 5: Water Level Calibration at Parnka Point

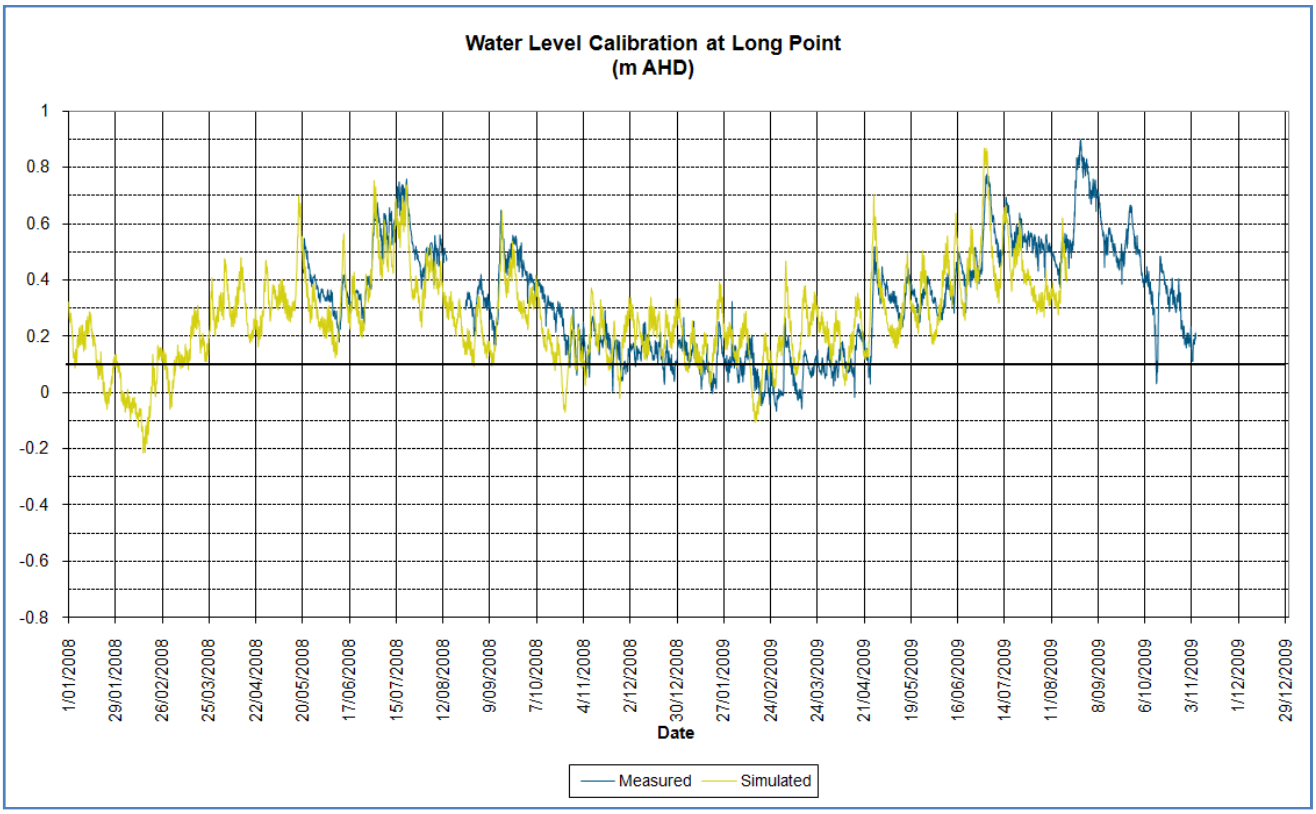

Figure 6: Water Level Calibration at Long Point

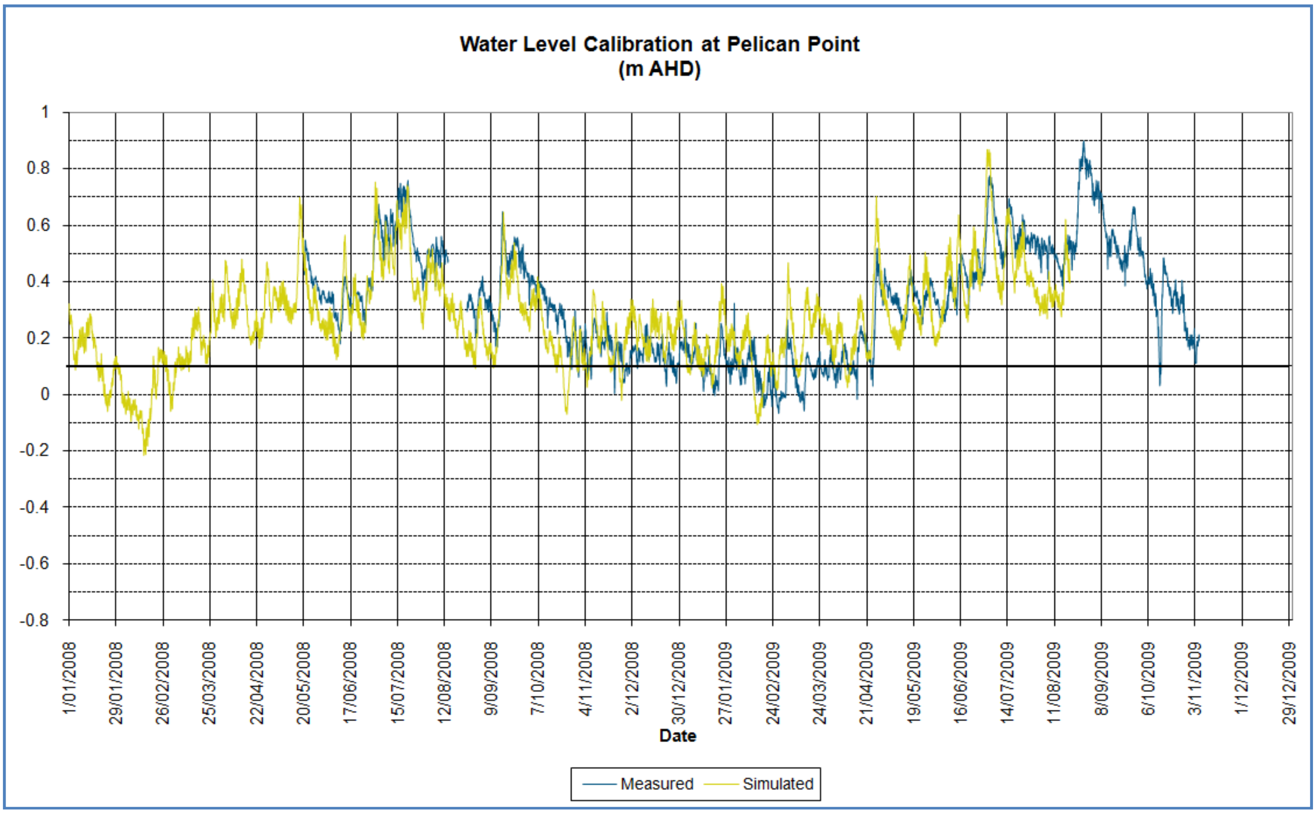

Figure 7: Water Level Calibration at Pelican Point

The quality of salinity calibration is shown in **Figure 8** through **11** for NW Snipe Island/Sand Spit Point, Parnka Point, Long Point and Pelican Point respectively.

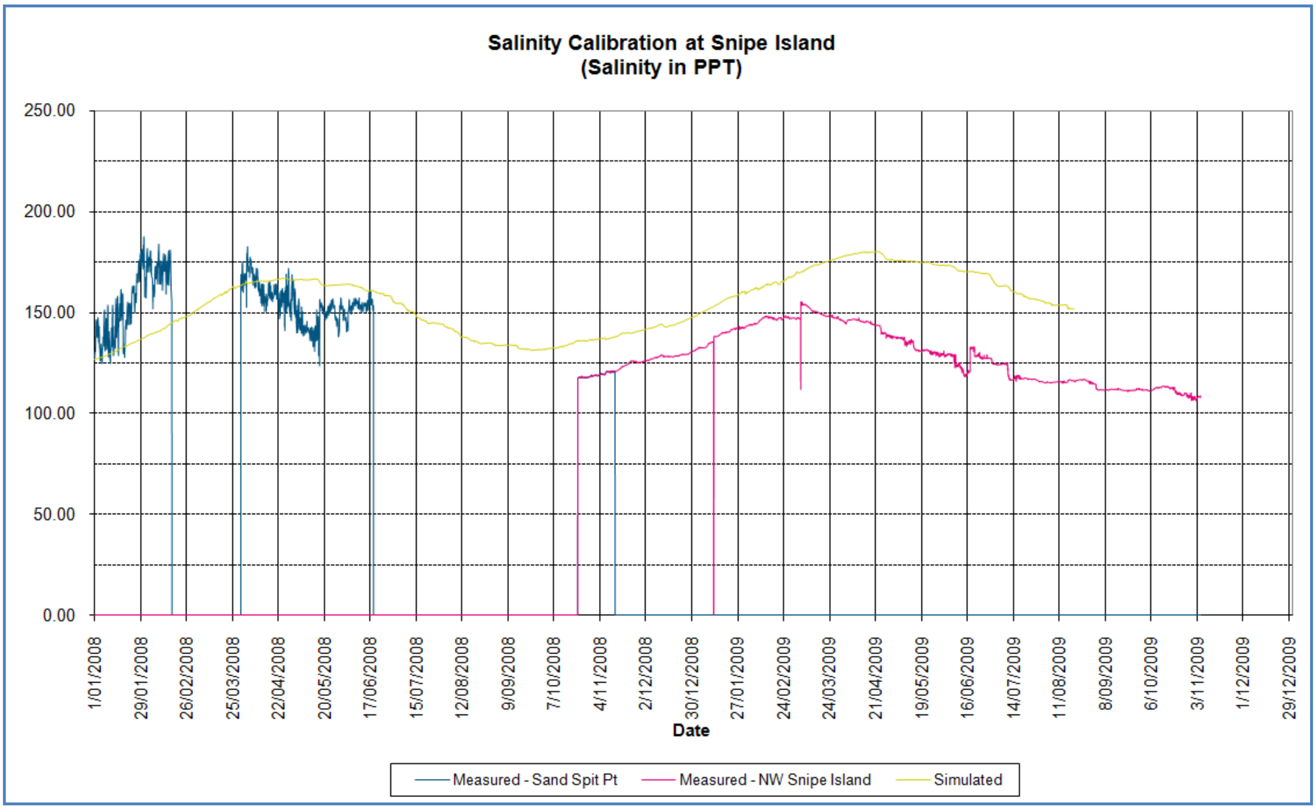

Figure 8: Salinity Calibration at NW Snipe Island/Sand Spit Point

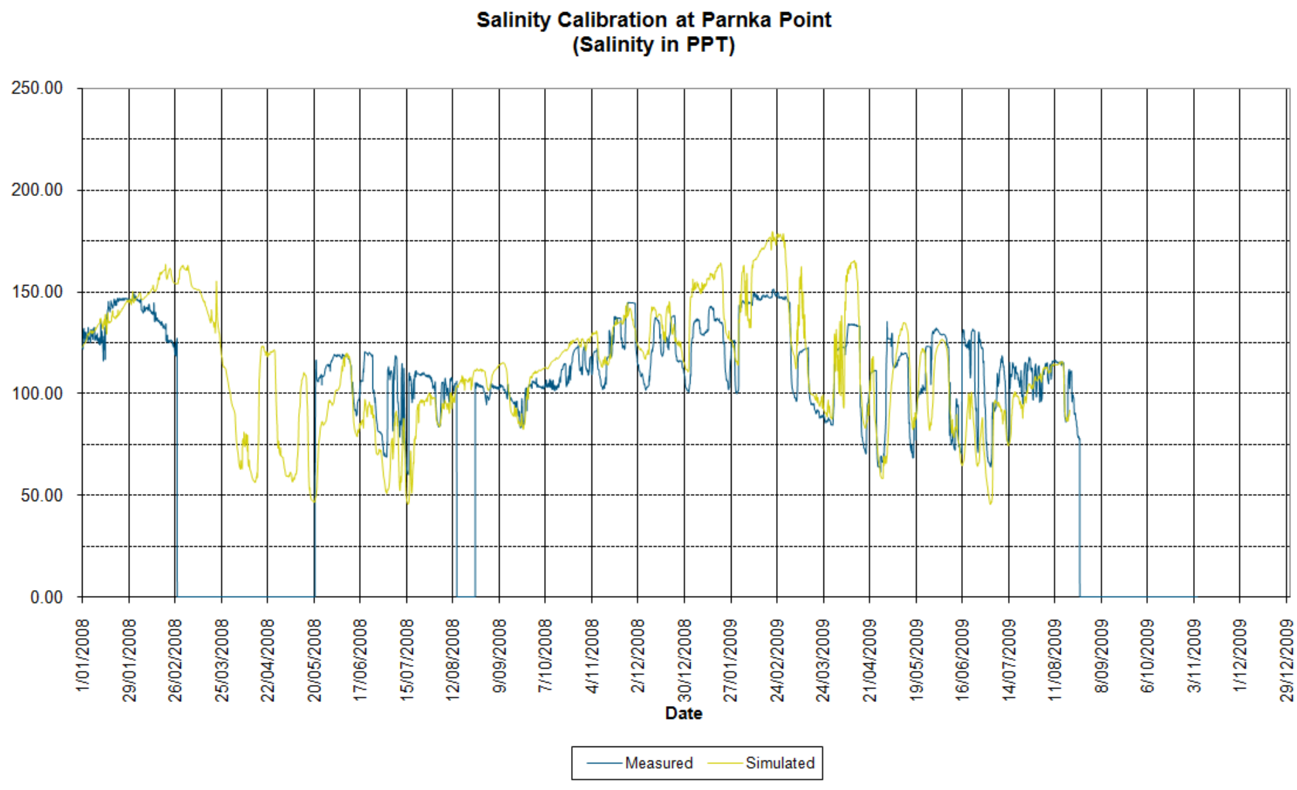

Figure 9: Salinity Calibration at Parnka Point

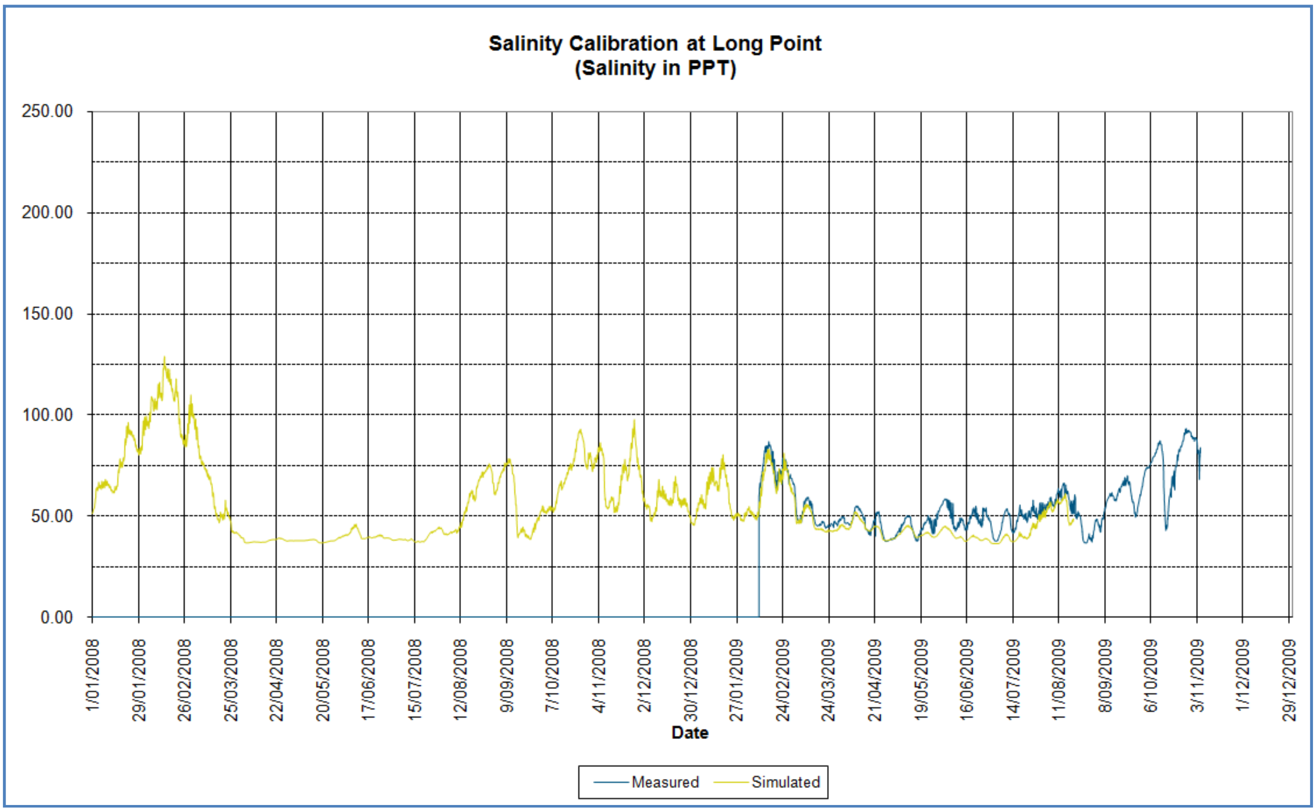

Figure 10 Salinity Calibration at Long Point

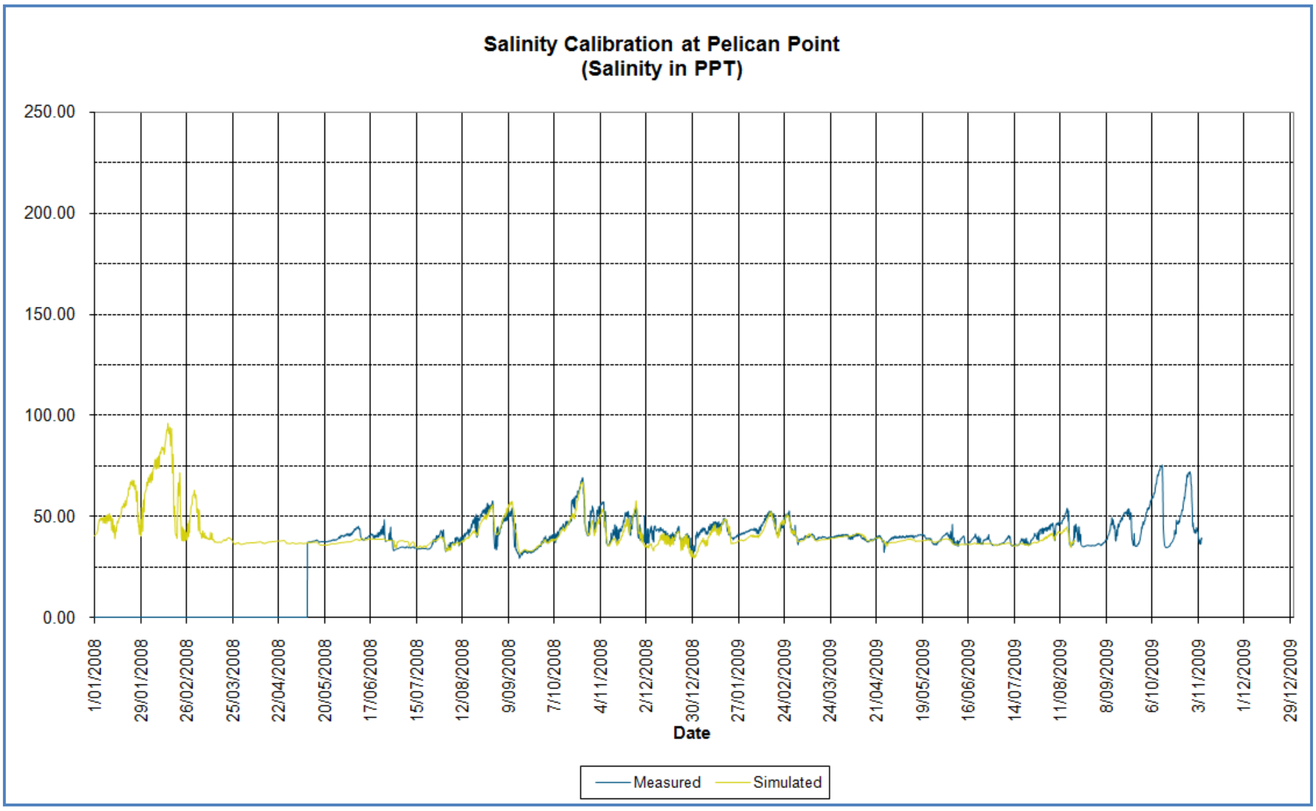

Figure 11: Salinity Calibration at Pelican Point

Overall the magnitude of salinity variation and general trends at the end of the Southern Lagoon are considered to be good. The absolute magnitude of salinity has not been matched and there appears to be a discrepancy between the values measured at Sand Spit Point and NW Snipe Island. This is discussed in detail below. Furthermore, the peak in salinity throughout the year appears to occur in the middle of March at the end of the Southern Lagoon (when considering the permanent recorders) whereas, our simulation indicates a peak that is typically around the middle of April. We note that separate grab samples that were tested for salinity in the southern lagoon (**Figure 13)** also indicate that high salinities are sustained at the end of the Southern Lagoon through April.

At Parnka Point, salinities are well matched during the late winter and spring months. During the middle of summer, when the two lagoons are typically disconnected, there are a series of events where water is pushed back from the Southern Lagoon, past Parnka Point, apparently under the influence of wind. The salinities measured at Parnka Point may be too low, as suspected for the Snipe Island recorder. However we note that the water levels during summer are high compared to measured values and it may be that the movement of water backwards through Parnka Point during summer is also slightly overestimated by the model as well.

This degree of exchange results in a very good response to salinities in the Northern Lagoon, via this "backwash" process, during the summer months. Unfortunately, the response during the winter months is not as pronounced as measured during the winter months (see June through August at Long Point in particular) where the measured data indicates it should be more responsive to water exchange from the Southern Lagoon.

Overall, the salinity calibration is superior to that presented in our previous modelling report. In addition, the calibration period has been extended and shown to produce reasonable results over this longer period.

With additional data and effort, a more robust calibration could be achieved. The model is considered to be an improvement on that presented previously and therefore also better at assessing the different managing strategies for the reduction of salinity in the Southern Lagoon required by this exercise.

The issue of salinity has been considered in great detail during this particular assessment, and this is discussed in the following section. In addition to those issues highlighted below, we also consider that the following may warrant further investigation:

- **Spatial Variation of Wind:** We have applied a single wind field across the entire model domain. It is likely that there are significant variations in wind along the length of the Coorong, and consideration of this point may be warranted in the future;
- **Bathymetry in the Southern Lagoon:** We have assessed bathymetric data that give significantly varied measurements of bathymetry in the Southern Lagoon. We have compared data collected from cross sectional survey in 2002, satellite imagery interpretation by SARDI and depth measurements taken by DWLBC during a longitudinal survey of the Coorong in April, 2009. At some locations, the bed elevation varies by as much as 1.5 m between the different sources. A robust and more complete hydrosurvey would allow us to improve our simulation of storage and flow characteristics, and hence the degree of mixing throughout the Southern Lagoon;

Discussion of Salinity Data and Validation in the Southern Lagoon

Following improvement of the model bathymetry, particularly in the vicinity of Parnka Point, we were able to easily achieve good calibration to water levels and salinities throughout the system. In addition, the improvements to the mesh have resulted in the model more successfully replicating the different "backflow" events whereby wind drives salt from the Southern Lagoon to the Northern Lagoon. However, calibrating to salinities in Southern Lagoon has proved more problematic. We have identified two potential reasons for this:

- Potential errors introduced in converting the measured EC values to PPT. This is required because almost all recordings of salinity in the Southern Lagoon are in EC units and measure of mass (i.e. PPT) is required for the equations that the model solves. There are a variety of equations available for converting between the two units.
- Apparent discrepancies between measured EC values in the Southern Lagoon from different sources.

Our previous report also illustrated similar issues with the model predicting salinities in the order of 220,000 µS/cm at the end of the Southern Lagoon, compared to measured values of around 150,000 to 160,000 µS/cm at Snipe Island. It was assessed that that recorder was likely predicting salinities that were around 20,000 µS/cm too low.

Conversion of EC to PPT

We are now aware of numerous relationships that have been applied in the vicinity of the Coorong and Lower Lakes for salinity. These are (EC in µS/cm):

- Straight scaling, where PPT = EC/1667, this is a commonly applied "rule of thumb" in the Lower Lakes, but is apparently not appropriate for higher salinities;
- A relationship supplied to us by DWLBC in 2007, for application within the Lower Lakes, but tabulated for salinities up to 200,000 EC:

$$Concentration\ (\mathrm{g/L}) = \ (0.548 \times EC)\frac{+\ (2.2 \times 10^{-6} \times EC^2) - \ (2.06 \times 10^{-13} \times EC^3)}{1000}$$

- A relationship documented in Williams (1986) which has been used by the University of Adelaide during the CLLAMM project, but is not considered appropriate for EC values above 100,000

$$Concentration\ (\mathrm{g/L}) = \ 0.4465 \times \left[\frac{EC}{1000}\right]^{1.0878}$$

- A relationship proposed by Thomas and Lang (2003) for the Coorong and provided to us by Ian Webster (CSIRO):

$$Concentration\ (\mathrm{g/L}) = \frac{\left[[(0.5865 \times \mathrm{EC}) + (3 \times 10^{-6} \times \mathrm{EC}^2)] - [7 \times 10^{-12} \times \mathrm{EC}^3]\right]}{1000}$$

- A revised relationship, derived by Ian Webster, and based on combined data from DWLBC and DEH.

$$Concentration\ (\mathrm{g/L}) = \frac{[0.295 \times EC \times (1 + (0.000238\ \times EC^{0.67}))] \times 1.8055)}{1000}$$

Overall, this final relationship appears to better match our attempts to validate salinities in the Southern Lagoon, and has been used within the modelling provided within this report to derive values of PPT from EC readings. However, as Webster notes (pers. comm., 2009), there is presently a real paucity of available data in the Coorong for the high salinities presently being experienced in the Southern Lagoon during summer.

It should be clear from **Figure 12** that, for higher salinities (i.e. > 100 ppt) the relationships deviate substantially and are significantly non-linear. Within **Figure 12,** the relationships of DWLBC, Williams, Thomas & Lang and Webster have been converted to an equivalent value in PPT.

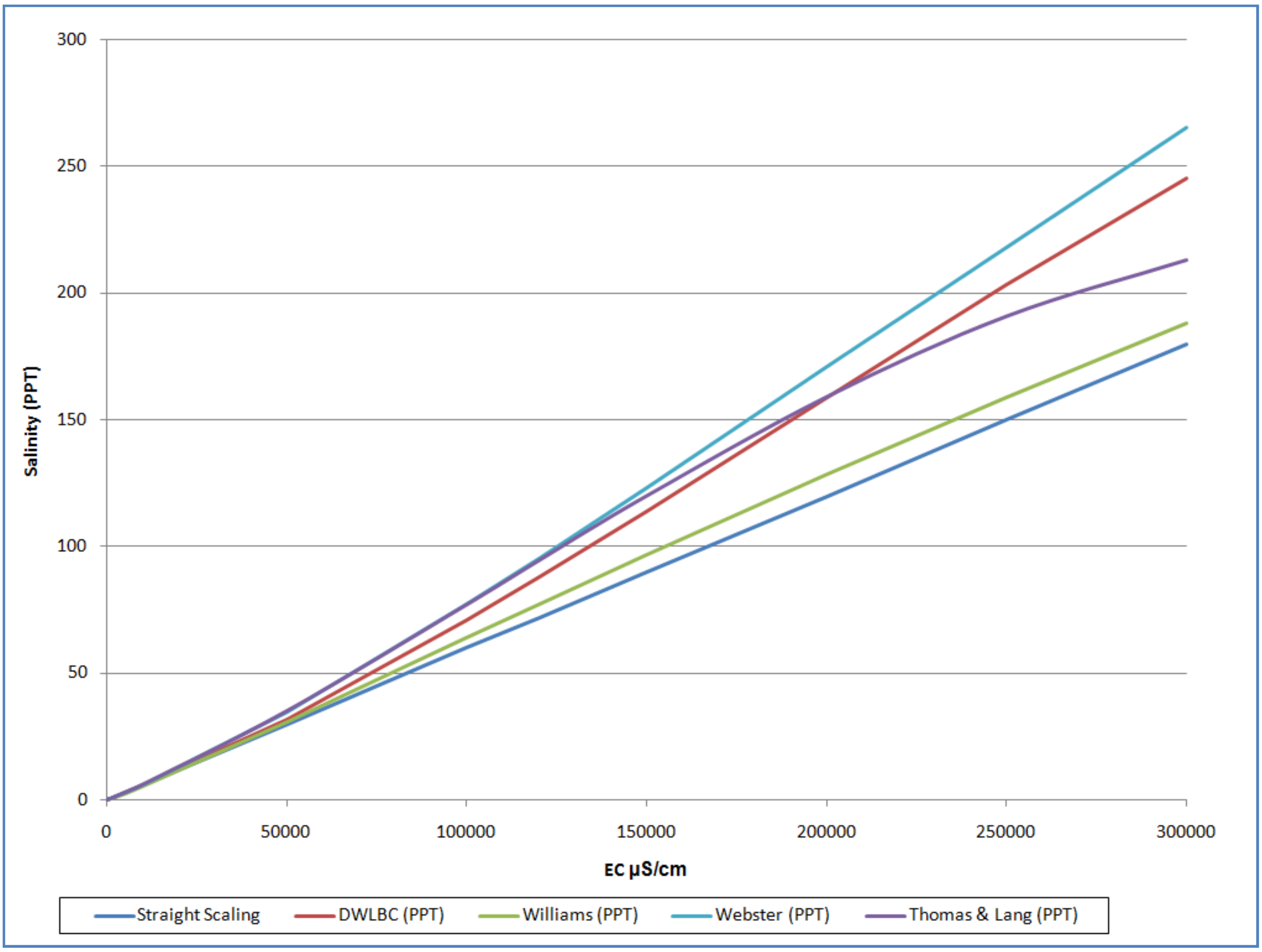

Figure 12 Various Relationships of Salinity in PPT vs. EC in µS/cm

Discrepancies between Field Measurements

We have compiled all salinity measurements we could find from the Southern Lagoon since the summer of 2007/2008 and have charted them. Prior to charting, we have converted them to PPT. The locations can be discerned from **Figure 3** and the resulting data is shown on **Figure 13.**

The data considered here comes from the following sources:

- Water quality assessment data from the SA EPA's web site: (http://www.epa.sa.gov.au/environmental_info/water_quality/water_quality_monitoring_sites/coorong)
- Data provided to use by the NRM Board, comprising monthly (approximately) grab samples taken by DWLBC staff
- Records from the permanent recorders managed by DWLBC in the Southern Lagoon and around Parnka Point.

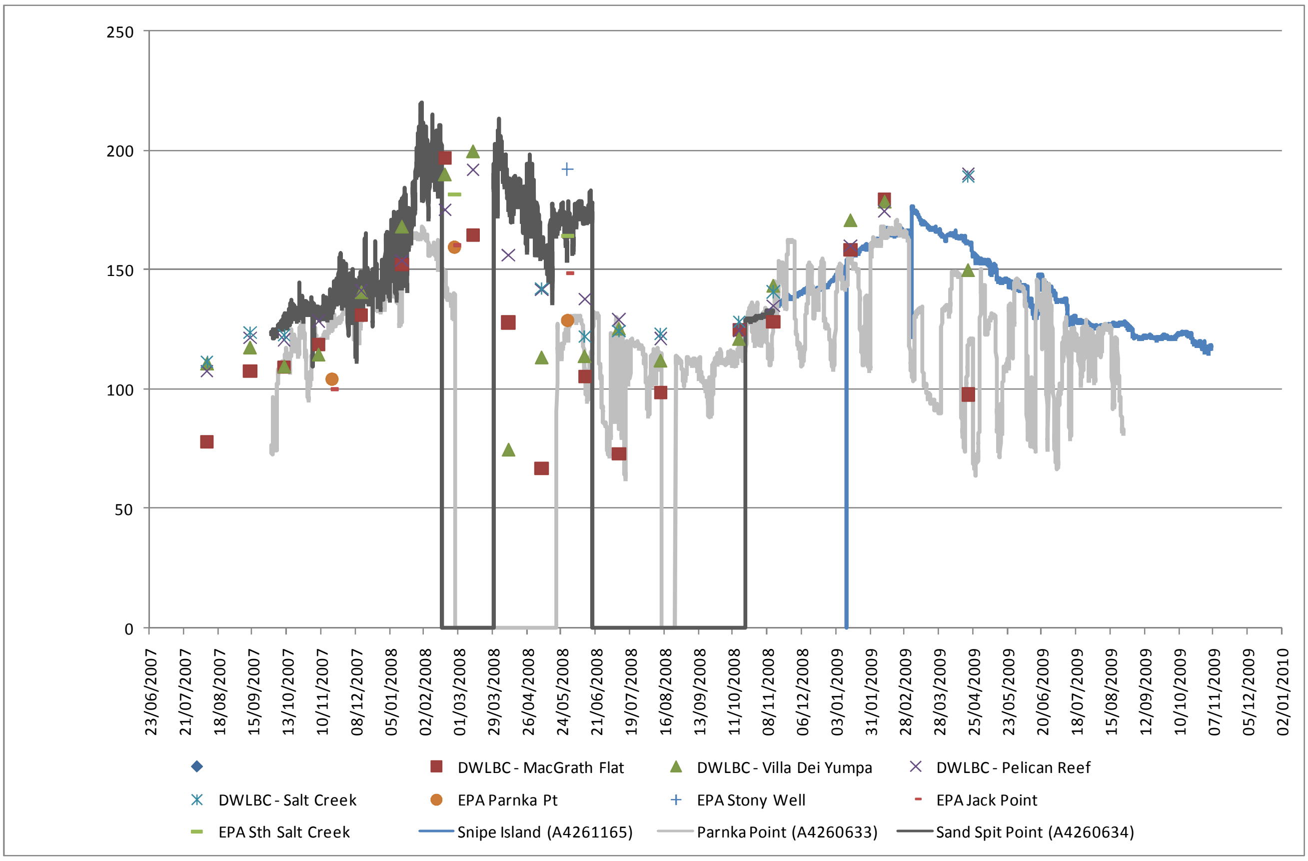

Figure 13 Combined Salinity Measurements in the Southern Lagoon
(Salinities in grams/Litre)

A few things can be discerned from the plotted data.

- The Villa Dei Yumpa and MacGrath Flat sites illustrate unusually high salinities during the post summer annual peak in salinity. While these sites aren't at the end of the Southern Lagoon, they are likely within backwater areas that are relatively poorly flushed, and may form evaporation pans during summer, prior to reconnection during autumn and winter.
- The permanent water level recorder at Sand Spit Point (apparently discontinued in June 2008) measured salinity levels that appeared to trend higher than the recorder subsequently installed at (NW) Snipe Island in October, 2008. The short available record at Sand Spit Point starting in October, 2008 has identical values to the record reported for NW Snipe Island over the same period. Accordingly, we consider that this short period of record has been erroneously recorded against Sand Spit Point. However, it should be noted that the Sand Spit Point site is probably prone to (at least partial) disconnection during summer.

- The Sand Spit Point record reaches the peak measured salinities of grab samples by the EPA (see Stony Well) and DWLBC (see Pelican Reef) during February – April 2008. These months correspond to the highest salinity levels measured in the Southern Lagoon during the year (i.e. prior to reconnection of the two lagoons during the winter Months.
- Conversely, the Snipe Island Recorder does not record the same peak levels as the grab samples from Stony Well or Pelican Reef, indicating that the record at Snipe Island may be too low.

Although there is not enough evidence to make a definitive conclusion, we consider it likely that the salinity record at (NW) Snipe Island is recording unusually low values.

Future Scenario Simulations

The model simulations undertaken as part of this assessment cover a period stretching from April 2009 and March, 2013. We chose April 2009 as the starting time, because this coincides with a longitudinal salinity survey in the Coorong and we therefore have a reliable initial salinity condition throughout the length of the waterway.

Real data has been utilised in the model simulations until the end of the calibration period (i.e. to August 20, 2009). Beyond this time, we have utilised the following:

- Evaporation and Rainfall conditions as used to represent 2008 in the calibration simulation (repeated on a year by year basis);
- The Morella UPSE flow release pattern as present in the record during the summer of 2007/2008. We considered this flow release pattern to be reasonably representative of the historical flow rates over the last 5 years. This pattern was repeated at the appropriate time each year;
- The wind record from 2008, which was repeated;
- The tidal signal from 2008, as used in the calibration simulation, and repeated over the remaining years of the future simulations. The astronomical tide level does not vary significantly in the context of this assessment from year to year, and it is reasonable to adopt similar water levels on a repeating basis. The salinities used at the boundary in the calibration simulation were also repeated, given that they appear to represent a reasonable variation over the course of a year;

We have run three future model simulations as part of this assessment, these are:

1. The base simulation, using the boundary conditions listed above;
2. An identical simulation to (1), with the exception that pumping begins on March 1st 2010 and continues until the end of the simulation at a constant rate of 250 ML/day;
3. An identical simulation to (2) with the exception that the model simulation has been stopped a the end of Summer 2011 (i.e. beginning of March) and a 50 m wide channel cut through the connection between the two lagoons with a bed elevation of no higher than -0.8 m AHD, before recommencing the simulation through to the end of March, 2013.

We have provided a plot of salinity simulated near Policemans Point (i.e. representative of salinity levels along the southern lagoon) and to the south of Robs Point (i.e. representative of the southern end of the Northern Lagoon. We consider that these two sites are representative of those locations of most interest to the management of salinity within the Coorong at the present time. The results are shown in **Figure 14** and **Figure 15** respectively.

In addition to the simulated salinity values, we have also examined the changes to water level that could be expected. Overall, we have found that for simulations where pumping is undertaken, the water levels in the Southern Lagoon can be up to 0.1 m lower in the southern lagoon towards the end of Summer.

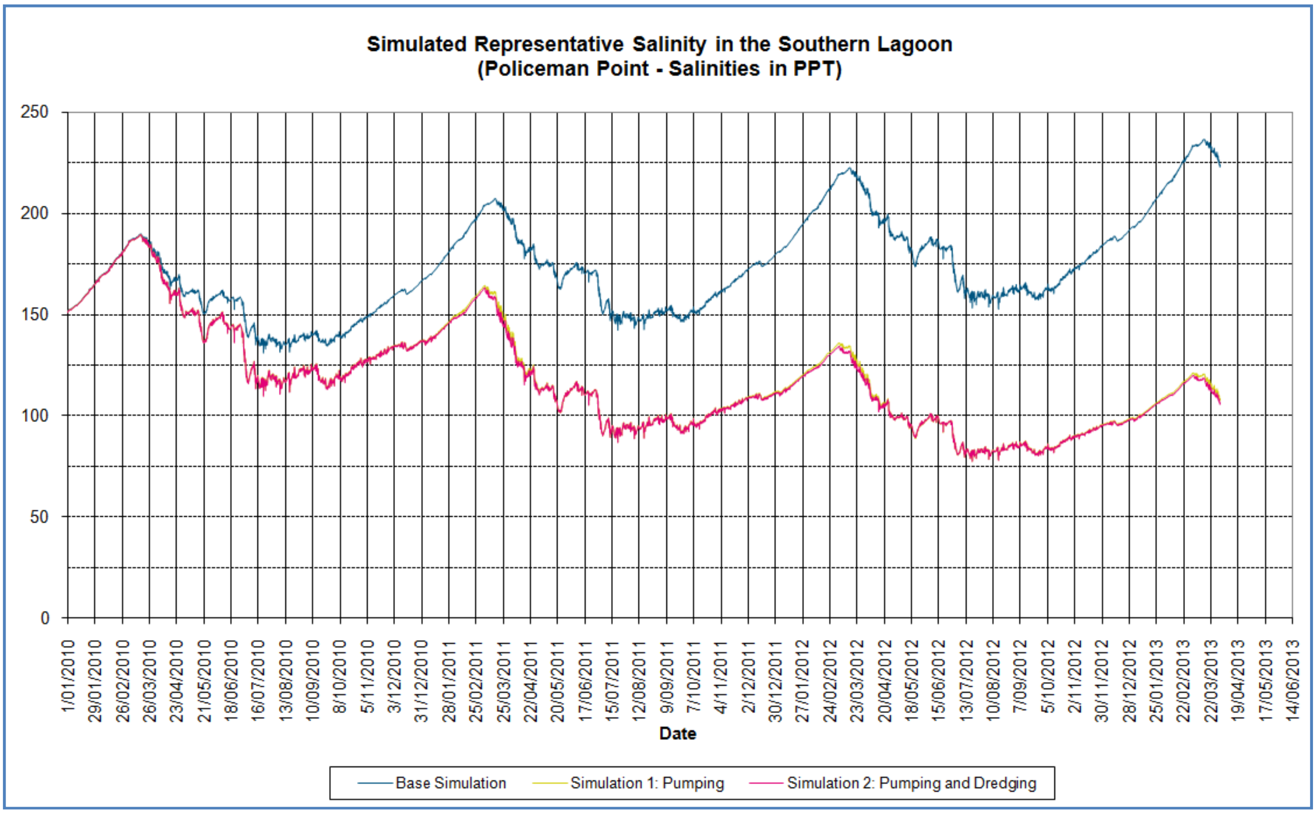

Figure 14: Simulated Salinities at Policeman's Point for the Three "Future" Simulations

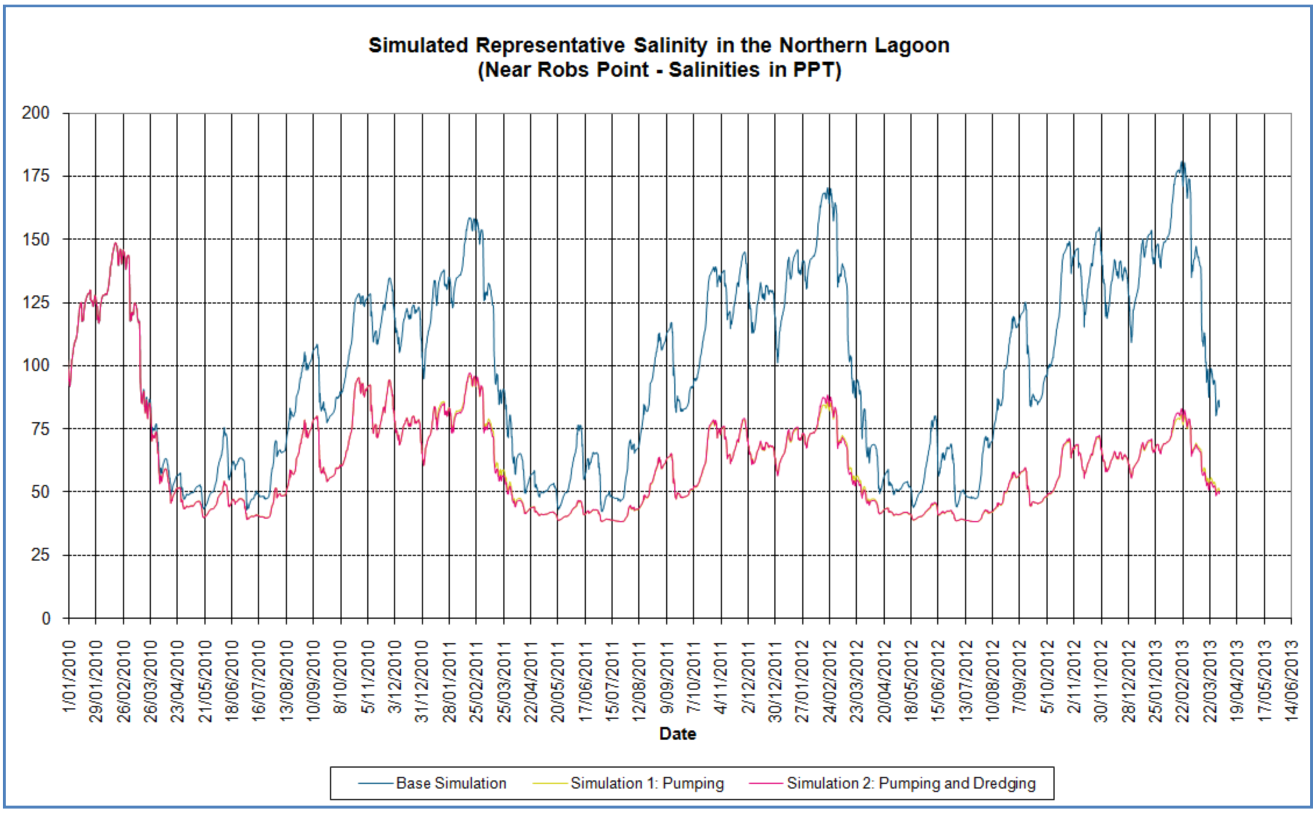

Figure 15: Simulated Salinities near Robs Point for the Three "Future" Simulations

Conclusions

We have managed to improve the model of the Coorong using upgraded bathymetry in the Parnka Point area, additional data and analysis which has provided further insight on the processes that affect salinity within the Northern and Southern Lagoon of the Coorong. We have also extended our validation period beyond the end of 2008, including the period up to August, 2009.

One major difference between present modelling and that undertaken in the past is the starting salinity adopted at the beginning of the scenarios being used to predict potential future conditions. While the previous simulation adopted values of around 95 ppt for the starting condition in the Southern Lagoon, the present work adopts salinities of closer to 150 ppt. This represents an increase in the amount of salt in the system at the beginning, and the effects are felt through to the end of the simulation. The reason this change was made to the model was to bring it into context with an actual time frame (i.e. pumping is to start March 2010) and the identification of better relationships to convert field measurements of salinity into values in parts per thousand.

Our calibration simulation appears to predict values that are too high during the summer of 2008/2009, when compared to values measured at the NW Snipe Island. We consider that this is probably related to both the relationship used for conversion between EC and PPT, and potentially problems related to the instrument or the location where it is installed. Overall, we consider that our predicted salinities for the base case err conservatively (i.e. are too high) and, should the environmental conditions of rainfall, evaporation and tidal forcing eventuate in the way they have been modelled, it is likely to overpredict salinities, particularly in the Southern Lagoon.

We also point out that there is limited data available to validate these relationships at the high salinity levels presently being experienced in the Southern Lagoon during summer, and have recommended that additional data be collected to provide validation or improvement of the relationships used. In the absence of more definitive data to convert between EC and PPT in the Southern Lagoon, we cannot quantify the proportion of discrepancy between measured data and modelled values that can be attributed to model overprediction.

The model simulations indicate that the peak salinity in summer would be around 115 -120 ppt, with the low in winter being around 75 -80 ppt. These are somewhat higher than the targets of 100 and 60 ppt respectively but, as noted above, we consider our models to be conservative in this regard.

As per our previous model simulations, we do not predict any significant benefit arising from dredging a channel to -0.8 m AHD through this area, even if the channel is 50 m wide. We understand that this conclusion differs somewhat from that drawn previously by CSIRO, but have not investigated this issue further at the present time.

We advise that we have not yet made any assessment regarding the impact of management options upon additional sediment influx through the Murray Mouth.

Recommendations

We consider that the following are advisable if further insight is to be gained within the Coorong:

- In conjunction with the routine measurement of salinity within the Coorong, we consider it wise to obtain laboratory measurements of total dissolved solids, to enable more confidence to be gained around the relationship between field measurements (in EC) and the mass concentration measures required for hydrodynamic modelling (i.e. g/L or PPT), particularly for the higher salinities experienced in the Coorong at the present time.
- In addition to the routine measurements of salinity, we consider it prudent to undertake regular longitudinal surveys of salinity, the likes of which were undertaken by DWLBC in April, 2009, on a more regular basis (say every 2 months) in order to better capture the gradients of salinity along the length of the Coorong during all seasons.
- We consider that a permanent recorder should be installed midway along the Southern Lagoon.

We trust that the above details meet the requirements of the NRM Board. Should you require any further information, please contact the undersigned on (02) 4940 8882.

Yours Faithfully
BMT WBM Pty Ltd

David Wainwright
Associate

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