Development of a fine-scale salinity model for the Avon Heathcote Estuary Ihutai

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List of Abbreviations

CCC	Christchurch City Council
DOC	Department of Conservation
ECan	Environment Canterbury
IPCC	Intergovernmental Panel on Climate Change
MBIE	Ministry of Business, Innovation and Employment
MFE	Ministry for the Environment
NIWA	National Institute of Water and Atmospheric Research
PCE	Parliamentary Commissioner for the Environment
RMA	Resource Management Act 1991
SLR	Sea level rise
UC	University of Canterbury

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1. Introduction

The Resilient Shorelines study at University of Canterbury (UC) is using the Avon Heathcote Estuary Ihutai to investigate ecosystem-based approaches to conservation planning and adaptation in response to environmental change. In particular, the study is using a novel opportunity to understand effects of the Canterbury earthquakes that may be similar to impacts of sea level rise. These result from topographic and bathymetry changes in and around the estuary and associated waterways (Beaven et al., 2012; Cochran et al., 2014) that have driven changes in hydrodynamics (Measures et al., 2011).

Therefore the wider context for the work reported here is to develop methodologies for modelling the impacts of sea level rise on estuaries and coastal river mouths using the Avon-Heathcote Estuary/Ihutai as a case study. Initial objectives have included establishing the magnitude of earthquake-induced changes. Subsequent steps will include establishing the relationships between strong physical drivers such as water levels and salinity, and the spatial pattern of estuarine ecosystems.

There is particular focus on understanding salinity changes in the upper estuarine ecosystem in the vicinity of the freshwater-saltwater interface. In these areas, species, habitats and ecosystems that are adapted to brackish conditions are expected to migrate in response to the inland penetration of salt water under sea level rise. An example is the location of īnanga spawning habitat that is associated with the inland extent of salt water intrusion on spring tides (Taylor, 2002). It is expected to be strongly affected by sea level rise.

To facilitate the development of ecosystem-based scenario models for sea level rise, a salinity model with resolution at ecological meaningful scales was required. An existing fine scale hydrodynamic model was available using Delft3D software (Deltares, 2012) that had been developed for ECan and MBIE following the earthquakes (Measures & Bind, 2013). However, it had not been calibrated for salinity. A collaborative project was designed between UC and NIWA to calibrate the model and develop a scenario modelling approach for sea level rise at a level of resolution sufficient for understanding sea level rise impacts on īnanga (whitebait) spawning habitat.

The project was allocated funding from Brian Mason Scientific and Technical Trust and commenced in late 2015. The purpose of this report is to provide a description of the model development process and an illustration of model outputs from an initial set of modelled scenarios for sea level rise.

2. Objectives

The key objectives for this report are to

- describe the salinity model and calibration process;
- provide examples of the modelled effects of sea level rise on spring tide salinity regimes in the upper estuary;
- discuss applications of the model for management; and
- provide recommendations for future research.

3. Methods

3.1 Study site

The Avon Heathcote Estuary Ihutai located at the city of Christchurch on the South Island's east coast (Figure 1). The estuary is located between the Waimakariri River and the southern end of a large sandy bay (Pegasus Bay) where it is a prominent local feature (Kirk, 1979). It is a barrier enclosed tidal lagoon type estuary (Hume et al., 2007) of high socio-ecological importance for the people of Christchurch (Jones & Marsden, 2007; Owen, 1992) and of high cultural importance for manawhenua and wider Ngāi Tahu whānui (Jolly et al., 2013; Lang et al., 2012).

The existing Delft3D hydrodynamic model extent covers the Avon River/Ōtākaro and Heathcote River/Ōpāwaho main stems, the lower estuary, and an area of open ocean in the vicinity of the estuary entrance to assist the modelling of boundary conditions (Figure 1).

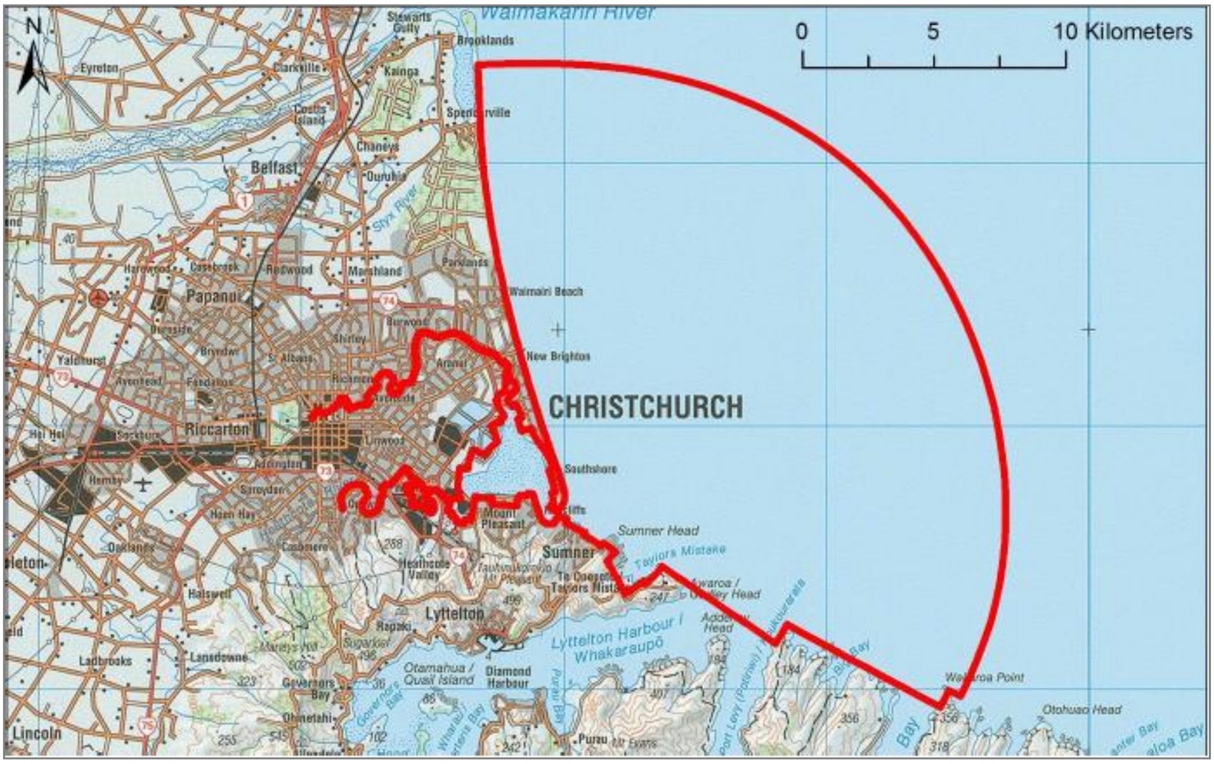

Figure 1. Estuarine extent covered by the NIWA Delft 3D hydrodynamics model (Measures & Bind, 2013).

3.2 Salinity measurements

Calibration dataset

Time series measurements were taken using Odyssey conductivity/temperature loggers deployed over various time intervals in different parts of the catchment. The loggers were secured on a concrete base with the probe positioned 10 cm from the bottom to reduce the likelihood of sediment accumulating around and potentially blocking the probe. A float was attached to aid retrieval. In some cases loggers malfunctioned due to water ingress or were lost in the field. In these cases additional deployments with new loggers were undertaken to provide data from a range of sites including in the main estuary, major channels, and mainstems of the two major rivers. The location of deployment sites are marked in red in Figure 2 and the dates of the deployments are listed in Table 1. Deployment sites were located as close to the channel centreline as practicable on relatively straight sections of waterway to reduce the likelihood of noisy salinity signals from local mixing effects due to complex bathymetry.

Figure 2. Location of salinity measurements.

Table 1. Details of salinity logger deployments

Easting (NZTM)	Northing (NZTM)	Location name used in model	Start Date	End Date	Notes
1573198	5177757	Heath_131Clarendon	14/01/2015	27/01/2015	
1574069	5178300	Heath_40mDsRadleySt	14/01/2015	27/01/2015	
1573776	5178198	Heath_41Clarendon	14/01/2015	27/01/2015	
1573559	5177949	Heath_81Clarendon	14/01/2015	27/01/2015	
1573095	5177664	Heath_OpawaRdSpawn	14/01/2015	27/01/2015	
1575327	5183399	Avon_Chardale	1/02/2015	23/02/2015	
1575661	5183517	Avon_Flapgate	1/02/2015	23/02/2015	
1575020	5183425	Avon_OlgiviePlace	1/02/2015	23/02/2015	
1575924	5183513	Avon_OutsideLKS	1/02/2015	23/02/2015	
1573909	5178364	Heath_21Clarendon	22/02/2015	12/03/2015	
1574069	5178300	Heath_40mDsRadleySt	22/02/2015	12/03/2015	
1574117	5178134	Heath_MidRchNrCulTRB	22/02/2015	12/03/2015	
1574291	5177968	Heath_OpDavisPl	22/02/2015	12/03/2015	
1574435	5177858	Heath_WoolstonCut	22/02/2015	12/03/2015	
1574069	5178300	Heath_40mDsRadleySt	13/03/2015	11/04/2015	
1574053	5177738	Heath_RaupoSite	13/03/2015	11/04/2015	Logger malfunctioned
1577742	5180785	Avon_BridgeSt(Sal)	10/09/2015	21/10/2015	Logger malfunctioned
1578853	5177346	BeachvilleRdSeawall	10/09/2015	21/10/2015	Logger lost
1576511	5176939	Heath_FerrymeadUs	10/09/2015	21/10/2015	
1577742	5180785	Avon_BridgeSt(Sal)	16/11/2015	24/11/2015	
1578687	5177431	BeachvillePrvtJetty	24/11/2015	8/12/2015	
1578547	5177493	BeachvilleBoatRamp	8/12/2015	16/12/2015	

Validation dataset

Spot measurements of bottom and near-surface salinities (10 cm from the top of the water column) were taken on spring tides over four months (March – June) in 2015 using YSI 30 handheld conductivity/salinity/temperature meters. In these surveys the progression of the flood tide was followed upstream to establish the maximum upstream extent of saltwater intrusion following the methods of Richardson & Taylor (2002) except using kayaks. In each catchment two tides were surveyed on consecutive days each month. The surveys focused on locations near the upstream limit of the saline intrusion and were timed to occur during spring tides of a similar size (based on predicted tide levels at the Port of Lyttelton). Additional measurements were also taken from bridges, seawalls and jetty structures at various times and places throughout the estuarine system. The locations of spot measurements are shown in green on the map in Figure 2.

Salinity data processing

The raw conductivity and temperature data collected for both the calibration and validation datasets was converted to salinity using the procedure described by the Intergovernmental Oceanographic Commission (IOC et al., 2010). It should be noted that there is greater uncertainty in this conversion at very low salinity values due to other influences on conductivity.

3.3 Model calibration and validation

Overview

The existing model of the Avon Heathcote Estuary Ihutai was calibrated for the simulation of tidally varying water levels but it was not possible to calibrate the model for salinity due to the lack of suitable data sets (Measures & Bind, 2013). For this study the salinity datasets described in Section 3.2 were used to calibrate and validate the model.

The process of model calibration involves setting up simulations representing periods of time for which observed salinity data was available. By comparing observed and modelled salinity the errors present in the model can be investigated and the model parameters adjusted iteratively to improve performance. As some of the model parameters influencing salinity also influence the tidal variations in water level it was necessary to maintain a check on the model hydraulics as well as the salinity.

After completing the iterative calibration process, the residual differences between the observed and modelled data are reported in order to communicate the level of accuracy the model achieves. A further check on model performance is undertaken by validating the model against a separate data set, in this case spot measurement of top and bottom salinity measured near high spring tides.

Model setup

In order to calibrate the model, simulations were undertaken for two periods, coinciding with the greatest density of available data, a further simulation was set up for model validation:

- Calibration simulation A: 11 January 2015 to 13 March 2015: During this period there were time-series data available from the Avon and Heathcote Rivers.
- Calibration simulation B: 12 November 2015 to 14 December 2015: During this period there were time-series data collected available from the main body of the estuary.
- Validation simulation C: 13 March to 8 May 2015.

The boundary conditions for the calibration and validation models were based on:

- River flows time-series data recorded at Buxton Terrace (Heathcote) and Gloucester Street (Avon) monitoring sites were used directly to specify freshwater inflows into the model at these locations.
- Sea-levels outside the estuary recorded at the Sumner sea-level recorder were used to set the offshore (tidal) boundary for the models.
- Wind speed and direction recorded at Brighton Pier climate station were used to set winds in the model domain. A temporally-varying but spatially-uniform wind was assumed across the whole estuary.

Calibration adjustments

During the calibration process several aspects of the model were adjusted:

- Model bathymetry – 'noise' in the model bathymetry was found to be causing excessive vertical mixing within the model so a volume-conserving smoothing algorithm was developed to smooth the bathymetry in the direction of flow along the main channels.
- Background horizontal eddy viscosity and diffusivity – these parameters influence the mixing processes in the model. In order to improve calibration they were reduced from their default values. The final values used in the calibrated model were: Horizontal Eddy Viscosity = 0.01 m^2/s, Horizontal Eddy Diffusivity = 0.01 m^2/s.
- Vertical layering – different vertical layering schemes were investigated to achieve a balance between accuracy and speed the final layering scheme selected used a depth-proportional (sigma-layer) scheme with five layers of equal thickness.

- Roughness – roughness was simulated using a spatially varying Manning's n coefficient. The final values were unchanged from those selected during the hydraulic calibration (Measures & Bind, 2013).

Validation

To validate the model the location of furthest salinity intrusion was extracted from the validation dataset and compared to the modelled value. To make a consistent comparison this was taken to be the location of tidal flow reversal (as observed in the field). The model results were then interrogated to identify the modelled location at which the salinity peak was the closest to this value and the difference between modelled and observed locations compared in terms of distance along the channel centreline.

3.4 Scenario modelling

Aim

The aim of the scenario modelling was to use the calibrated model to assess the effect of sea level rise (SLR) on salinity. In particular the scenario modelling focussed on the location of saline intrusion up the Avon and Heathcote Rivers during spring tides due to its potential relevance to the spatial distribution of īnanga spawning habitat (see Section 5.3).

As well as sea level height it was recognised that river flow has a strong influence on salinity so when investigating SLR it was important to also investigate the effect of river flow.

Scenario setup

Each scenario model simulated a period from eight days before a spring tide through to three days after (Figure 3). This period was selected to give the model a chance to equilibrate before the period of interest, and also to simulate long enough after the spring tide to ensure we captured the peak salinity. The offshore tidal boundary conditions for the scenario models used astronomic tides (ie. no tidal surge/anomaly) and were based on the forecast astronomic tides from 12 February 2015 to 24 February 2015 from the EEZ Tide model (Stanton et al., 2001).

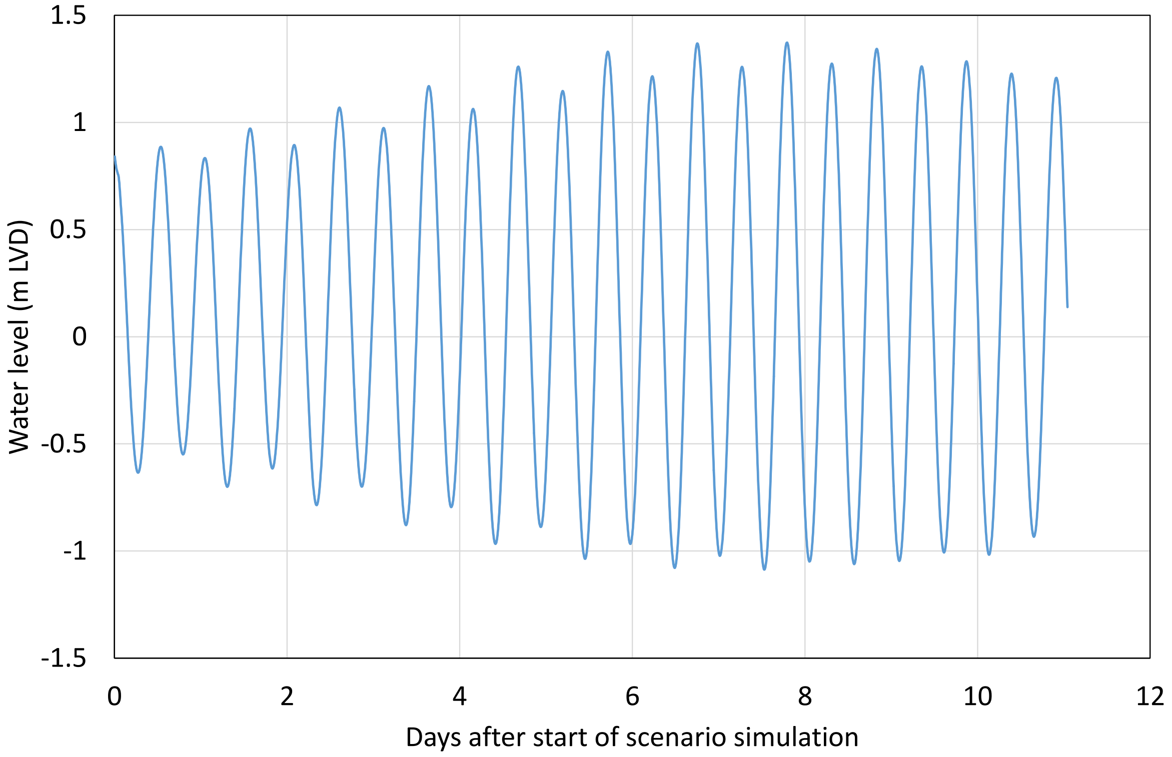

Figure 3. Offshore tidal boundary for scenario modelling.

Three different sea levels were simulated: current sea level, 0.5 m SLR and 1.0 m SLR. These scenarios were chosen for relevance to current planning processes. The 1.0 m SLR climate change scenario is of particular interest for the assessment of potential climate change impacts over a planning horizon of approximately 100 years. This is a key planning horizon to be taken into account under national policy for coastal hazards (DOC, 2010). It should be noted that the science of SLR estimation over various time frames is constantly changing (eg. IPCC, 2013) and must be contextualised to the specific adaptation context (MFE, 2008). A 1.0 m SLR scenario has been adopted by recent climate change studies in consideration of a 100 year time frame (eg. Tonkin & Taylor, 2015) and can be regarded as a pragmatic scenario for informing longer term planning based on current data. The 0.5 m SLR scenario represents an intermediate scenario of interest. In practice, contemporary planning for sea level rise has become focused on 50 and 100 year time horizons as a means to facilitate the assessment of plausible future impacts and workable responses within current resource management processes (PCE, 2015).

Five different river flow scenarios were simulated for each of the three SLR scenarios (15 scenarios in total). The river flow scenarios were designed to cover the range of flows typically found in the Avon and Heathcote rivers based on flow duration curves calculated from the observed flow records (Figure 4). The five scenarios represented river flows which were exceeded 2%, 20%, 50%, 80% and 98% of the time respectively (Table 3). Flow rates were kept constant for the duration of each scenario simulation.

For simplicity no wind was included in any of the scenario models.

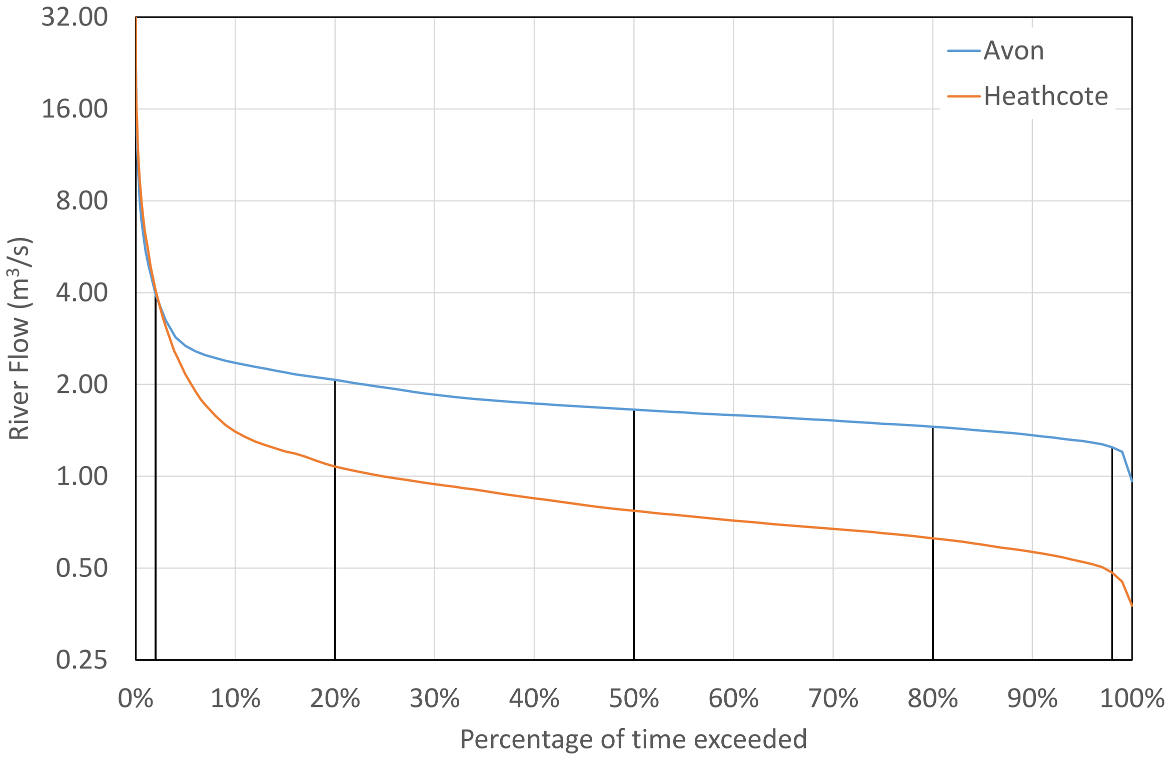

Figure 4. Observed flow duration curves for Avon and Heathcote Rivers.

Table 3. River flow for scenario modelling.

Flow scenario (% of time flow exceeded)	Avon River flow (m3/s)	Heathcote River flow (m3/s)
2%	3.96	4.08
20%	2.07	1.08
50%	1.65	0.77
80%	1.45	0.63
98%	1.24	0.48

4. Results

4.1 Calibration and Validation

Main estuary

The model calibrates well for salinity in the main body of the estuary. Figure 5 shows a comparison of observed and modelled salinity on the Avon River at Bridge Street Bridge. The maximum and minimum salinity on each tide as well as the shape of the tidal variation in salinity matches very well.

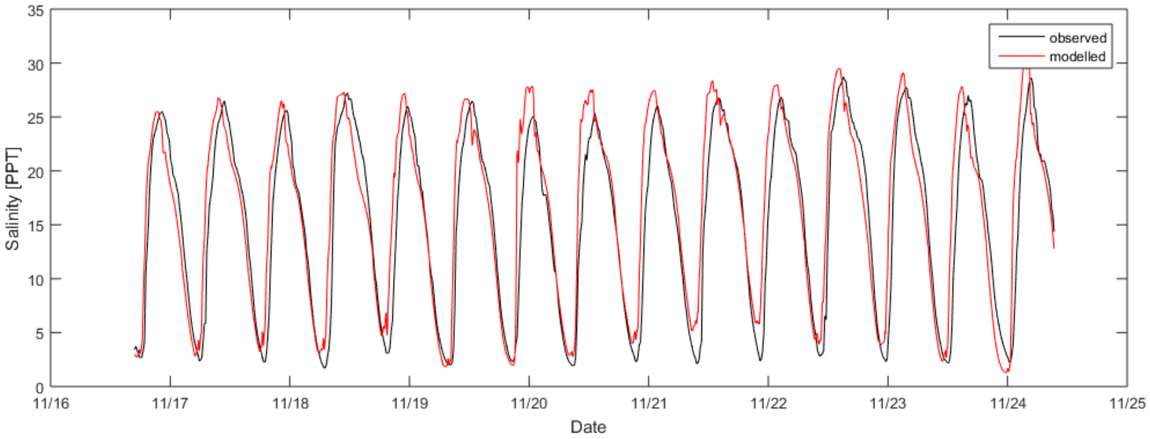

Figure 5. Observed and modelled salinity at the downstream end of the Avon River (Bridge Street).

Further comparisons from the monitoring undertaken at Beachville Road are shown in Appendix A. These sites also match well although at the BeachvillePrvtJetty site there are some periods in the observed record where the observed salinity appears depressed below normal levels for 1-3 tides but this is not replicated in the model record. It is possible that this difference is caused by wave driven mixing of freshwater plumes in the estuary (waves are not represented in the model) but there is no obvious correlation with observed wind speed or direction. At the BeachvilleBoatRamp site the pattern of observed and modelled data matches very well but the observed data declines slowly over the monitoring period. This decline is difficult to account for with the data available. It could due to freshwater plume effects or to drift in the calibration of the sensor.

Overall the model performs well for salinity in the main body of the estuary.

Avon River

The model correctly predicts the timing and relative magnitude of salinity peaks in the Avon River but consistently under-predicts the peak salinity values compared to the observed data. Various changes were tested during model calibration to try and improve this result but it was not possible to fully close the gap between observed and modelled salinity. An example of this is shown in Figure 6 and further plots comparing observed and modelled salinity are shown in Appendix A.

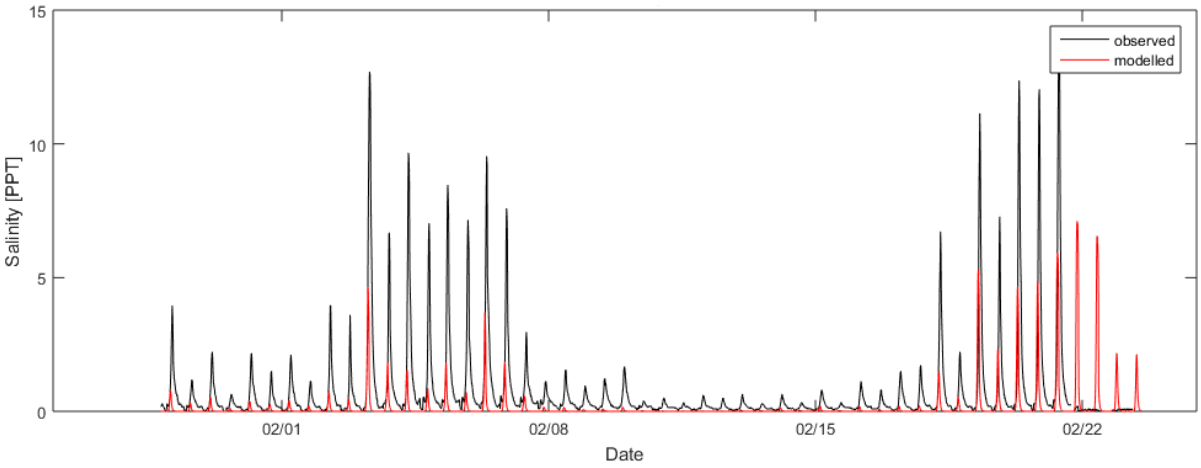

Figure 6. Observed and modelled salinity in the Avon River outside Lake Kate Sheppard (site identified as "Avon_Flapgate" in Figure 2 and Table 1).

Heathcote River

The model significantly under predicts salinity in the Heathcote River. This can be seen clearly in Figure 7 where observed salinity peaks as high as 11 ppt but model salinity never exceeds 1 ppt.

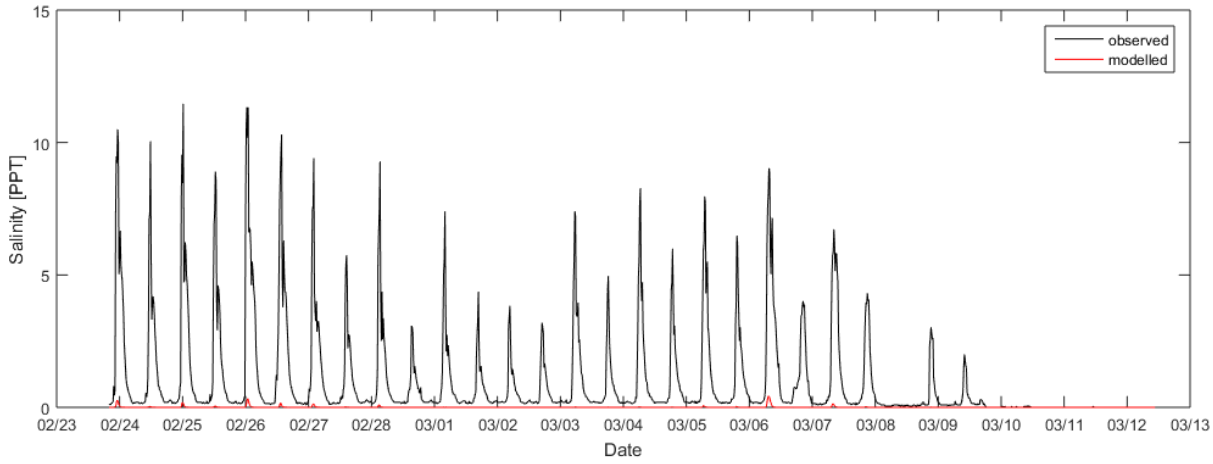

Figure 7. Observed and modelled salinity in the Heathcote River at the upstream confluence of the Woolston Loop and Cut (site identified as "Heath_WoolstonCut" in Figure 2 and Table 1).

Lots of time and effort was spent exploring potential reasons for the differences between the modelled and observed salinity in the Heathcote River. Potential causes of variation include effects of the CCC macrophyte control program and bed changes related to post-quake siltation not accommodated in the modelled bathymetry. In addition, further salinity measurements taken over the 2016 īnanga spawning season (not reported here) suggested that salt water ingress was occurring through the Woolston Cut tidal barrage on incoming tides. This was investigated with CCC stormwater engineers who confirmed that the barrage was designed to be fully sealing with rubber seals to prevent leakage (J. Walter, pers. comm.). However further observations confirmed that leakage was occurring and the two north gates were sitting about 100mm higher than the two south gates (Figure 7). The time period over which leakage was occurring is unknown and could have affected the modelling in several ways. Significant leakage appears to be visible as a plume of lighter coloured estuarine water in Google Earth aerial imagery from 11 April 2015 (Figure 8) suggesting that significant leakage was likely occurring during the data collection in February to March 2015.

Leakage through the barrage is likely to be the primary reason for differences between the modelled and observed salinity in the Heathcote River. Leakage through the cut on incoming tides would significantly increase upstream salinity. The model represents the barrier in a fully closed position so does not replicate this leakage.

Figure 7. Observed leakage through the tidal barrage at the Woolston Cut on an outgoing tide (April 2016).

Figure 8. Aerial photo appearing to show leakage of lighter coloured estuarine water upstream through Woolston Barrage on incoming tide in April 2015.

Validation

For model validation the furthest extent of the saline propagation upstream was measured for specific spring tides by following the salinity upstream using a kayak. The validation results were consistent with the calibration results in showing that salinity did not propagate as far up the rivers in the model as in reality, particularly for the Heathcote River.

4.2 Scenario modelling

15 scenarios were simulated representing combinations of five different river flows and three different sea levels. The results can be interpreted in a number of different ways. Figure 9 shows how increasing sea levels drive salinity further up the Avon River for a single example flow rate and Figure 10 shows how salinity propagation is influenced by river flow under current sea levels. Alternatively the results can be mapped spatially as in Figure 11 which shows that under high flow conditions (2% exceedance flow) there is little saline intrusion up the Heathcote River at spring tide, in fact the river maintains a freshwater plume out into the estuary at all times.

As well as the salinity outputs the model results also contain useful data on flow velocities and depths under the different SLR and river flow scenarios.

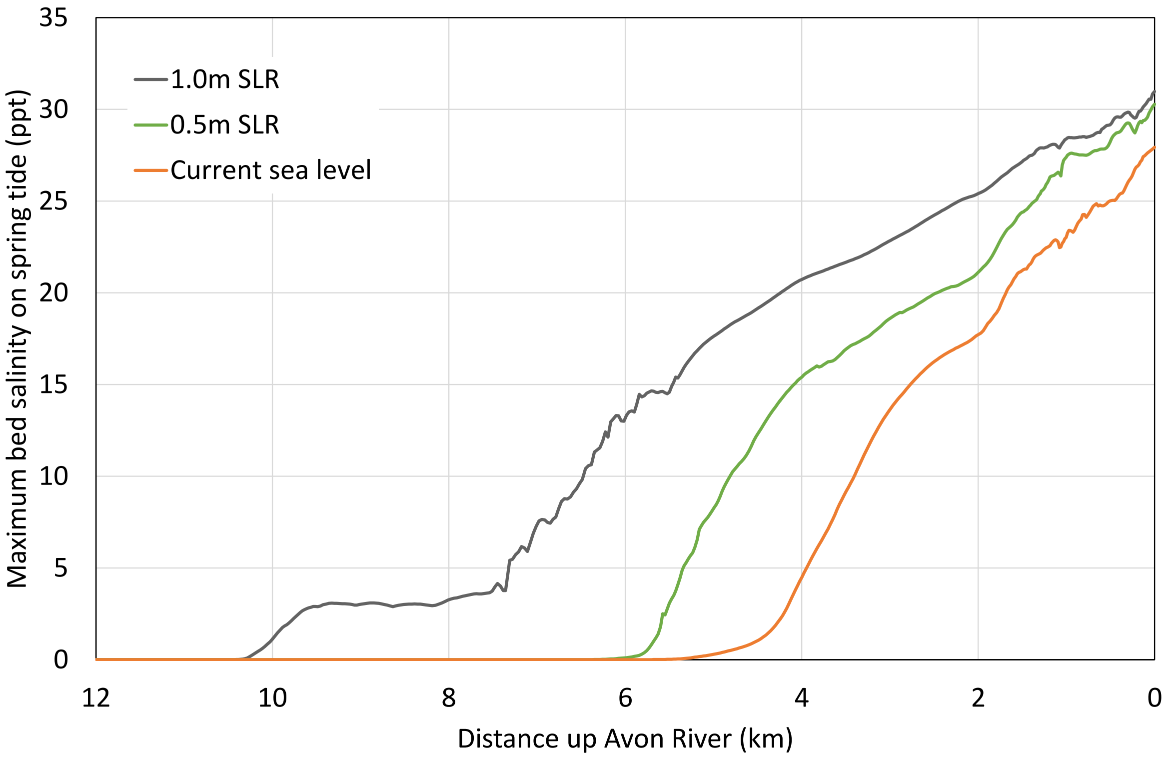

Figure 9. Effect of SLR on peak bed salinity in the Avon River with river flow of 2.07m^3/s (flow exceeded 20% of the time under current conditions).

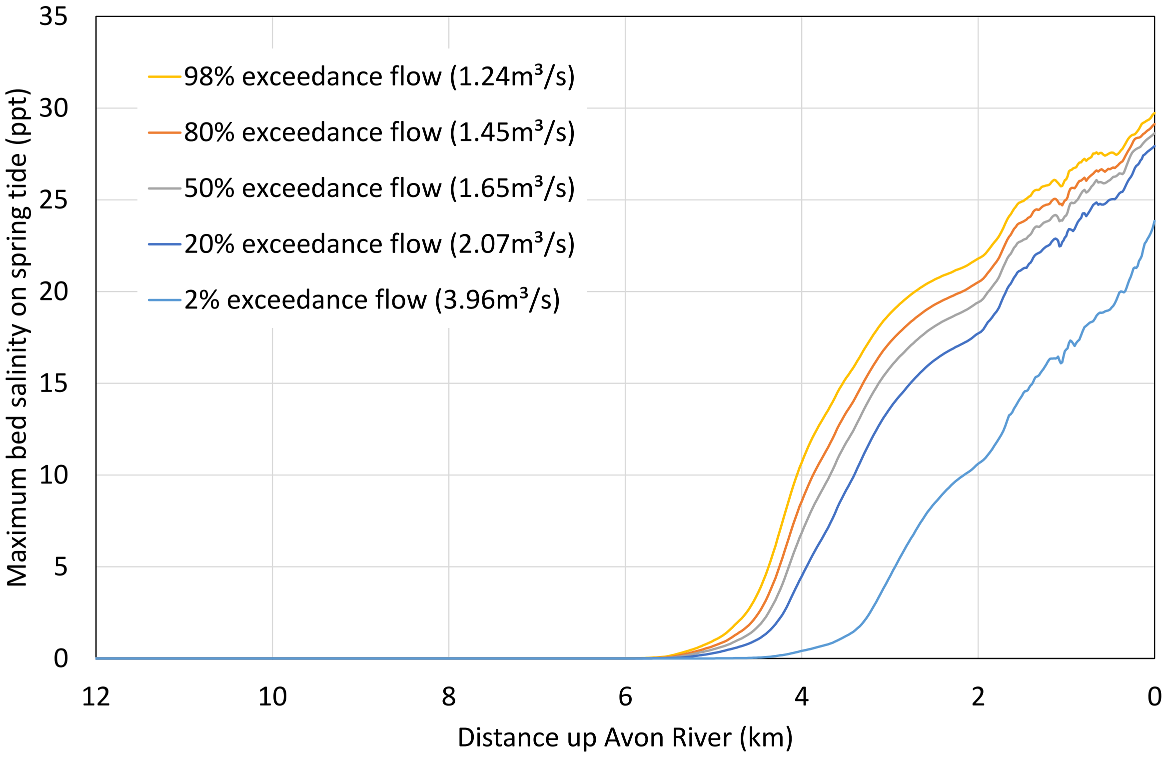

Figure 10. Effect of river flow on peak bed salinity in the Avon River (current sea level).

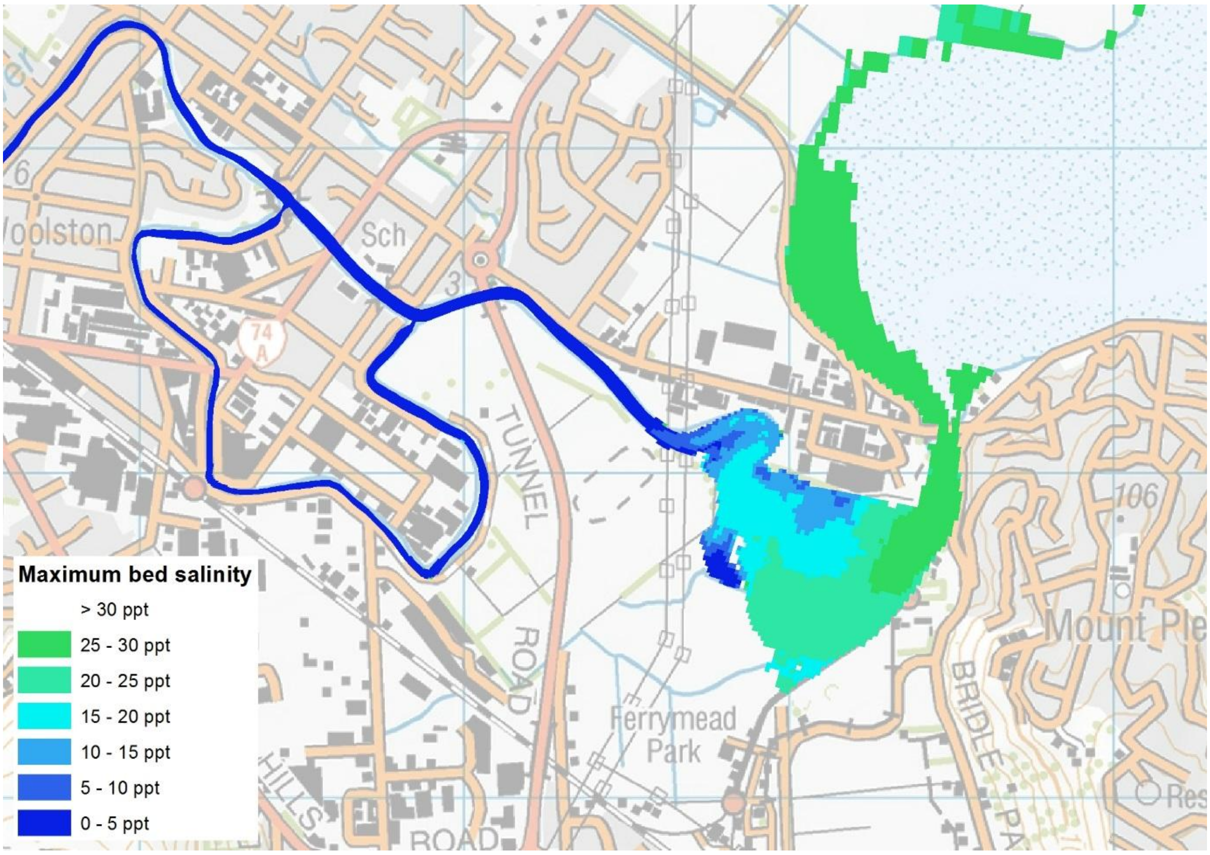

Figure 11. Peak bed salinity in the Heathcote River at spring tide under high flow conditions (2% exceedance flow (4.08m^3/s) and current sea level scenario shown).

5. Discussion

5.1 Interpretation of scenario modelling

The scenario models provide powerful data on the effects of changes in sea level and river flow on spring tide salinity, flows and water levels. The model generates a large amount of data that can be analysed and interpreted in a number of different ways. Some examples of this are shown in Section 4.2. Interpretation of the scenario modelling is ongoing.

The initial interpretation is focussing on identifying and mapping different metrics which can potentially be linked to riparian habitat, in particular īnanga spawning habitat. This is likely to include various salinity metrics and thresholds (eg. locations where peak bed salinity exceeds a threshold), as well as hydrodynamic metrics (eg. locations which experience flow reversals, locations which have a tidally varying water level). Simplifying model results down to the spatial extent of these different thresholds then allows the effect of river flows and sea level rise on each of these thresholds to be quantified. Mapping the changes in extent of each of these thresholds will provide improved understanding of changes likely to happen in response to sea level rise.

5.2 Limitations

The scenario modelling has a number of limitations which must be remembered when interpreting the results:

Residual errors after calibration

The salinity calibration and validation process undertaken highlights that while the model performs well for salinity in the main estuary, salinity does not propagate as far up the Avon and Heathcote Rivers in the model as in reality. The model does however reproduce the patterns of salinity observed in the rivers, just not as far upstream. It is important to remember this consistent difference between the model and reality when interpreting the results of salinity modelling in the rivers. Focussing on the relative change between different scenarios is one way of interpreting the results to take this residual error into account.

Morphological change

As sea levels rise it is likely that there will be some response in the bed levels of the estuary and rivers as deeper water encourages settlement of sediment or greater tidal flows (due to increased tidal prism volumes) or causes erosion. The SLR scenarios modelled as part of this study use fixed bathymetry for all scenarios based on the surveyed post-earthquake bathymetry.

Effects of wind and waves

The scenario modelling does not include any wind or wave effects. Waves in particular can cause additional mixing within the estuary, potentially having a significant effect on salinity. These effects have not been considered in the modelling.

Model extent

The model extent focuses on the areas which are currently inundated at high spring tides. However, with sea level rise there is the potential to inundate areas outside the current estuary and river margins. The model extent limits the area of inundation to the current model boundaries, even for a sea level rise of 1 m. This effectively means that the scenario modelling is representative of what would happen if stop-banks were constructed to prevent new areas becoming tidally inundated as a result of sea level rise. Without stop-banks the tidal prism volume (volume of water moving in and out on each tide) would be slightly larger, tending to push salinity slightly further up the rivers.

5.3 Applications of the model for management

As part of the Resilient Shorelines project, the model contributes to a vulnerability assessment methodology being developed to support an ecosystem-based approach to riparian management. Within this approach the model provides a means to investigate salinity effects at an ecologically relevant scale.

Applications of the model within the current project include:

- investigating the effects of salinity changes on riparian habitats and ecosystems in the estuarine environment; and
- a particular focus on vulnerability assessment methodology for the spawning habitat of īnanga (*Galaxias maculatus*). This is a species of high cultural and recreational value with a current conservation status of ‘At Risk - Declining’ under the New Zealand Threat Classification System (Goodman et al., 2014). The protection of īnanga spawning habitat is an objective specifically identified in a range of policies and plans (Orchard, 2016). This recognises the widespread occurrence of degraded riparian margins in lowland waterways that is thought to be a major contributor to īnanga population decline (Jowett et al., 2009). Recent work in the Avon Heathcote Estuary Ihutai has identified spatial shifts in the distribution of habitat in relation to the Canterbury earthquakes with consequential changes in the vulnerability of the

habitat to both current and future threats (Orchard & Hickford, 2016). The model will be used to further explore these changes and consider specific vulnerabilities associated with sea level rise to inform conservation planning and adaptation to climate change.

Additionally the salinity model described here will be useful for a wide range of other applications. Examples include:

- hydrodynamics studies including further research on earthquake changes;
- investigation of relationships between salinity and other components (both biotic and abiotic) of the estuarine system;
- ecological impact assessments for aquatic and riparian species, habitats and ecosystems for which salinity is a factor, and by extension, cultural impact assessments and similar that involve values that are supported by or depend upon attributes of the estuarine ecosystem; and
- the development of further scenario modelling approaches to inform climate risk assessment and adaptation initiatives.

5.4 Recommendations and future research

Key recommendations building on the work described here are:

- conduct further validation of model to comprehensively describe and document model performance for other users;
- obtain a further validation dataset for the Heathcote River/Ōpāwaho, in connection with above, to reflect system conditions once the Woolston Cut tidal barrage is reinstated to its normal (fully sealing) operation; and
- use the model to determine salinity changes relative to the pre-quake estuary configuration. This can be investigated within the modelling approach described here since two versions of the base model were originally built to reflect the pre-quake and post-quake bathymetries.

Some opportunities to explore for further research utilising this model include:

- improving the understanding of ecological succession processes driven by the earthquake changes which may have yet to reach stable end-points. Model results can assist in determining the likelihood of further responses;
- understanding the potential effects of infrastructure or development proposals affecting the bed or estuary margins. This is important for the assessment of ecological impacts and related values. This could be particular useful in connection with reconfiguration of the stop-bank system in the lower Avon and Heathcote Rivers and/or other proposals for flood and natural hazard management; and
- Development of further scenario models to investigate salinity and salt water intrusion effects associated with SLR and the influence of other parameters that may be affected by climate change. This approach has the potential to contribute useful decision support for contemporary environmental planning and could assist with the identification of beneficial climate change strategies.

6. Acknowledgements

Flow, level and wind time-series data used for model boundary conditions was collected by or on behalf of ECan, CCC, NIWA and MetService. Development of the original Avon Heathcote Estuary hydrodynamic model which was used and further developed by this study was funded by ECan and the New Zealand Ministry of Business, Innovation and Employment (MBIE contract UOCX0902). NIWA core funding provided co-funding to this project to support the model calibration.

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Lastly we acknowledge the support of the Brian Mason Scientific and Technical Trust for supporting the work described here.

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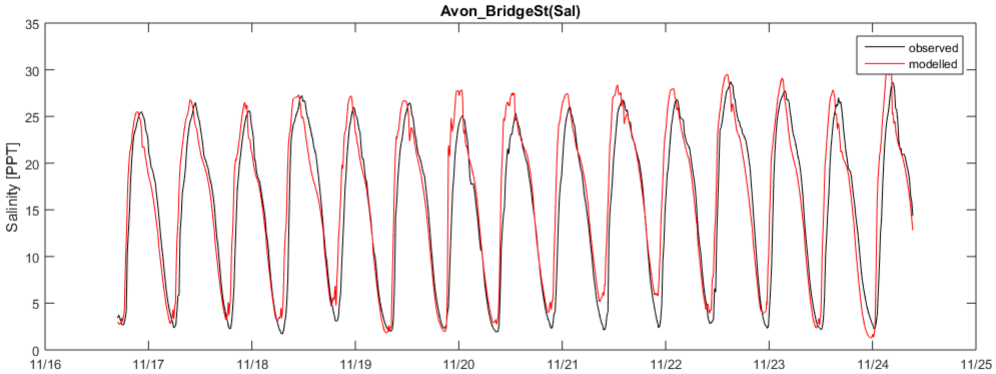
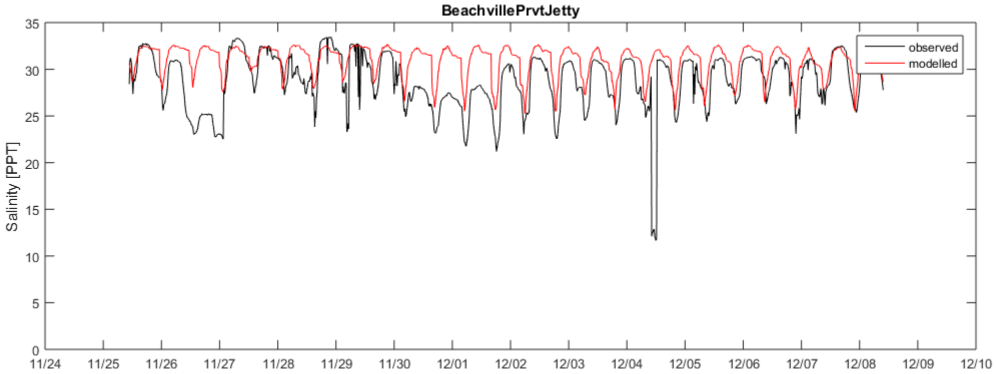
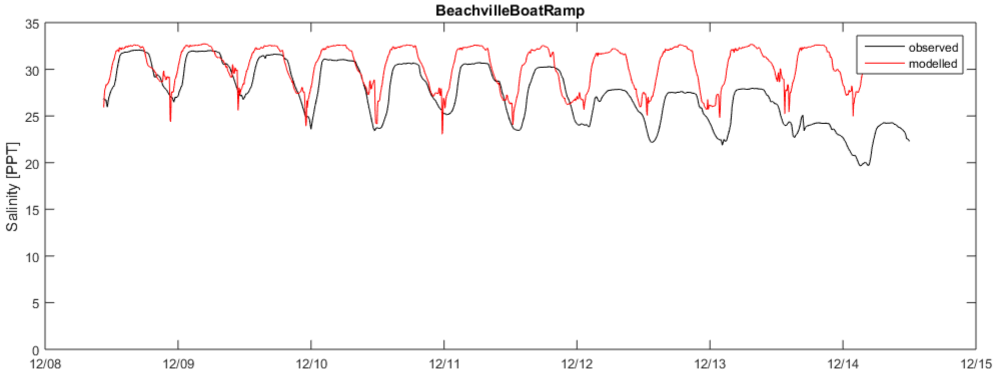
Appendix A: Salinity Calibration Plots

Each of the below plots shows a comparison between coincident timeseries of observed and modelled salinity data for a specific site. The black line shows observed data and the red line shows the model data. Plot titles indicate site location as shown in Figure 2 and Table 1 in the main report. Note that the plots only compare periods for which both modelled and observed data are available. As such the date range shown on the x-axis varies between sites.

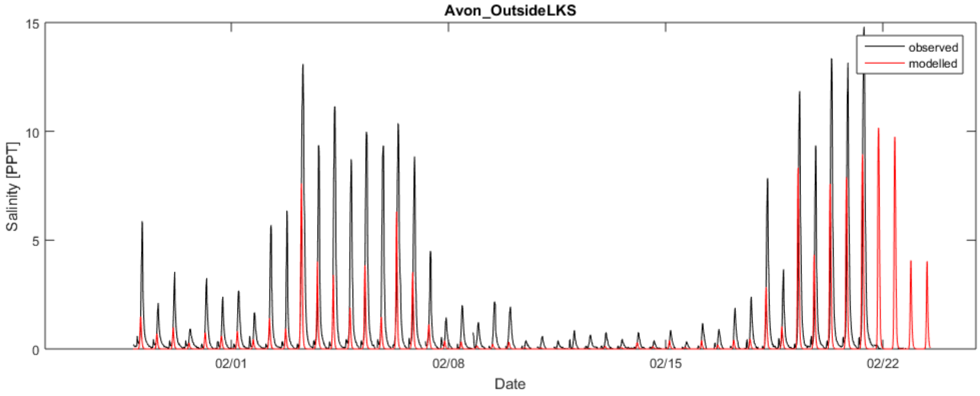
Main estuary

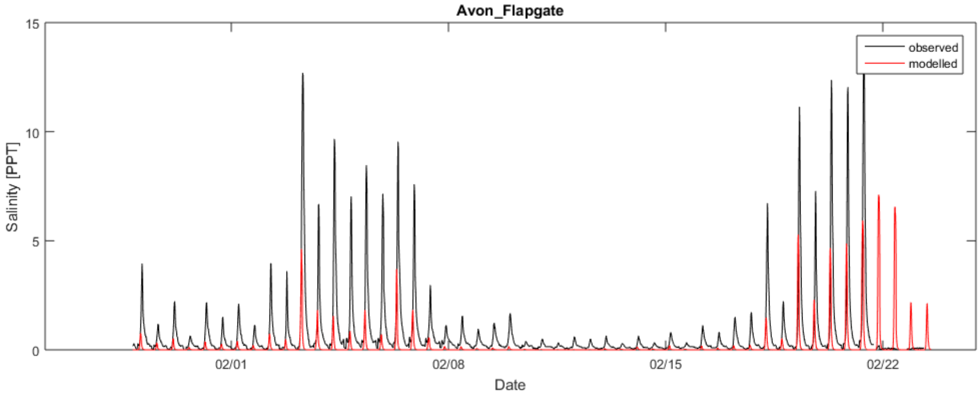


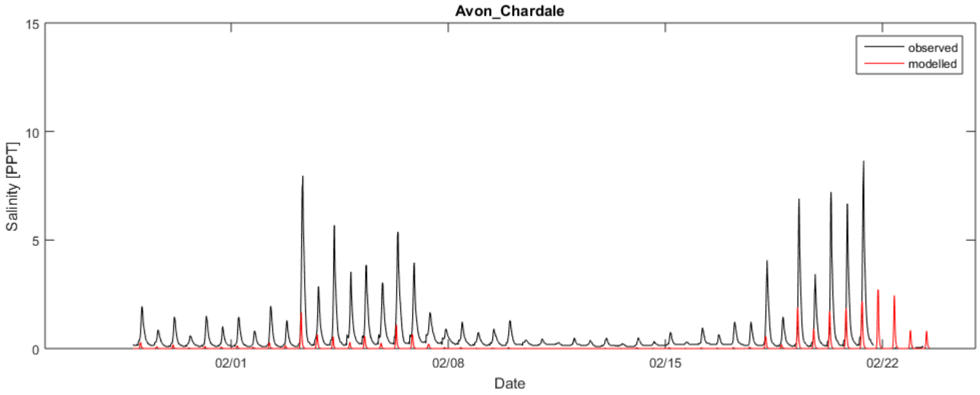


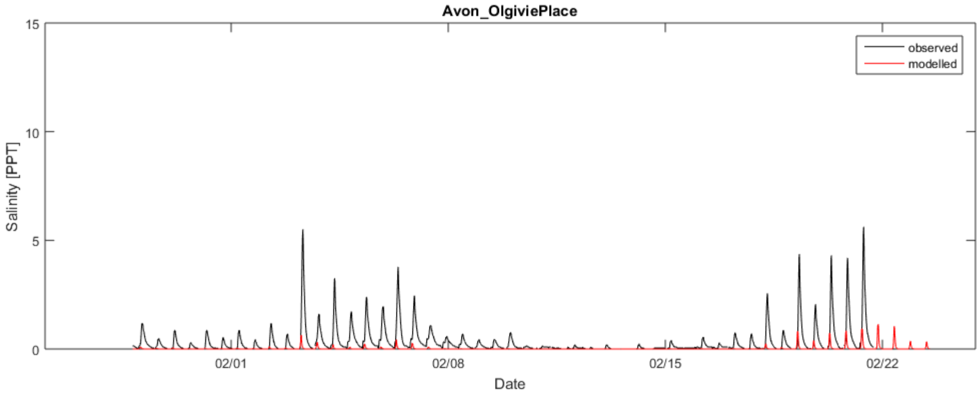


Avon River

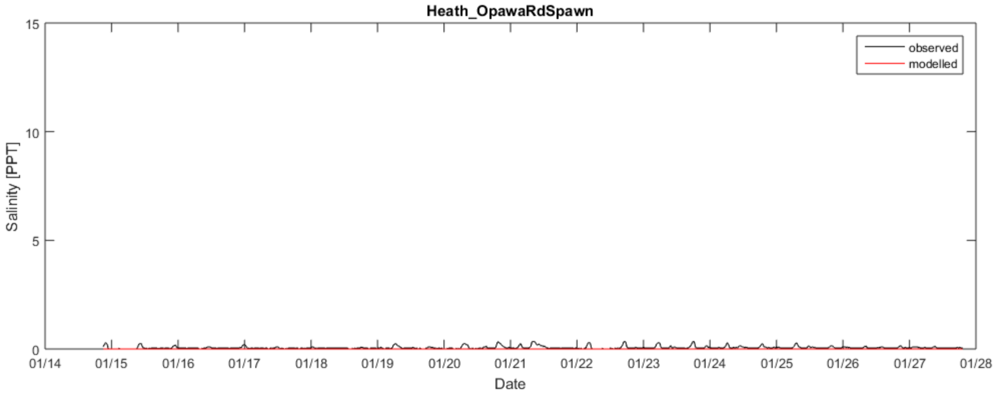

Avon_OutsideLKS

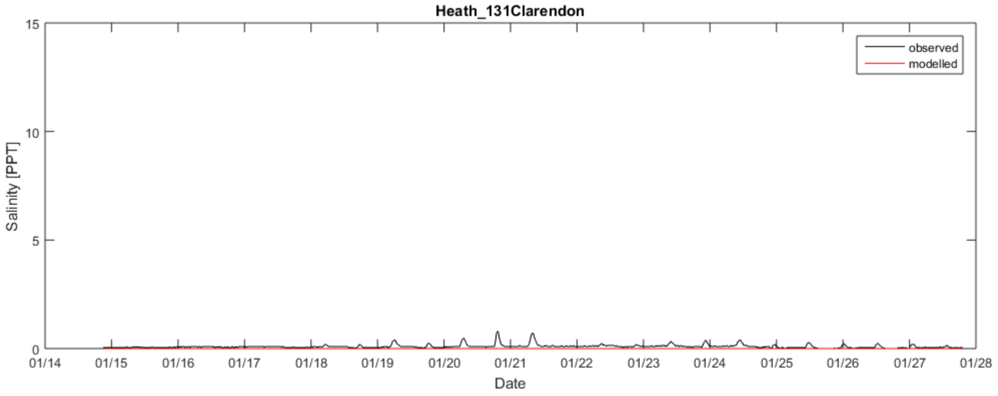

Avon_Flapgate

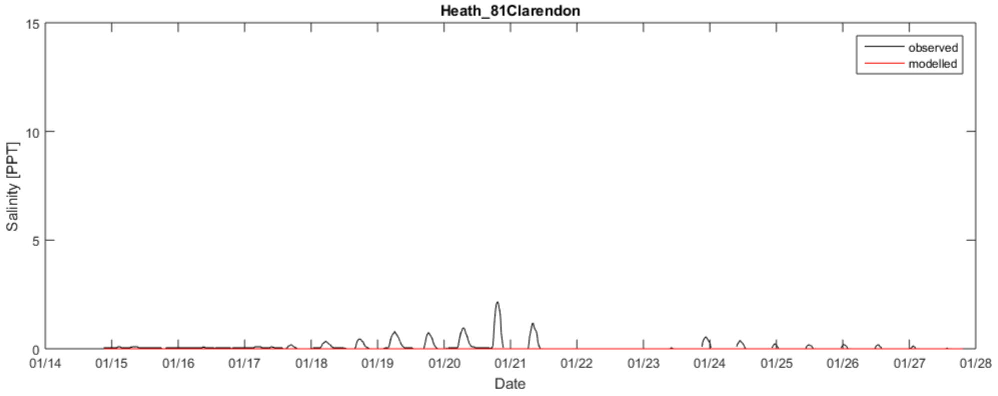

Avon_Chardale

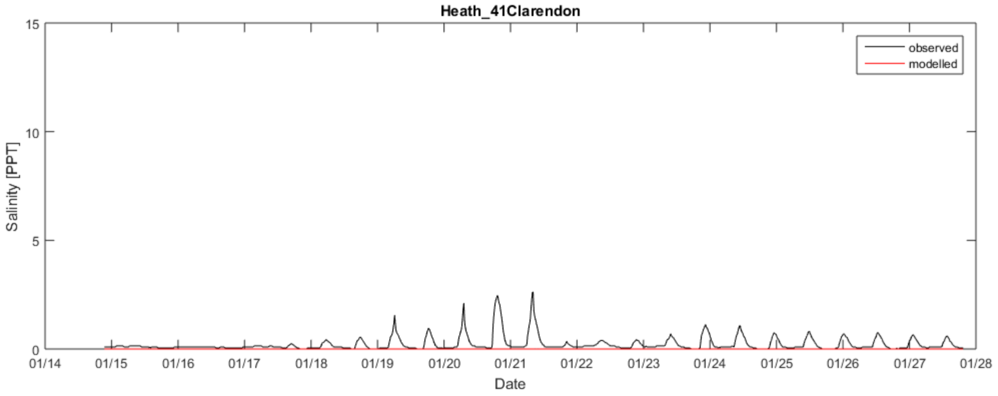

Avon_OlgiviePlace

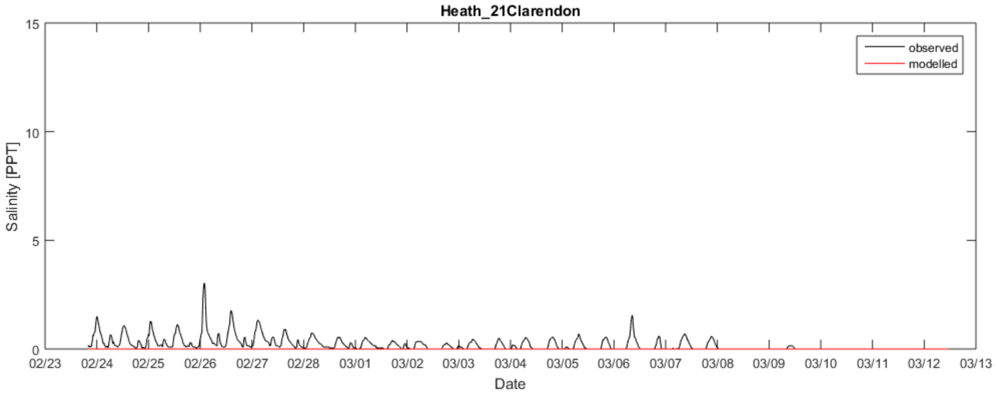
Heathcote River



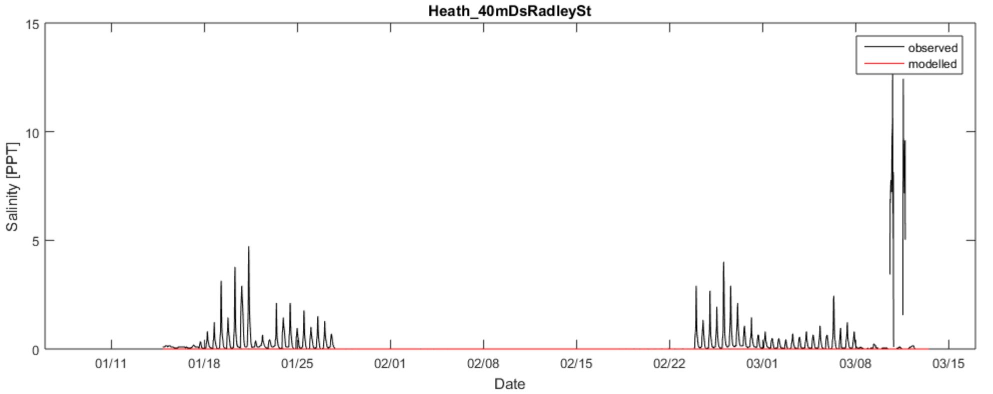




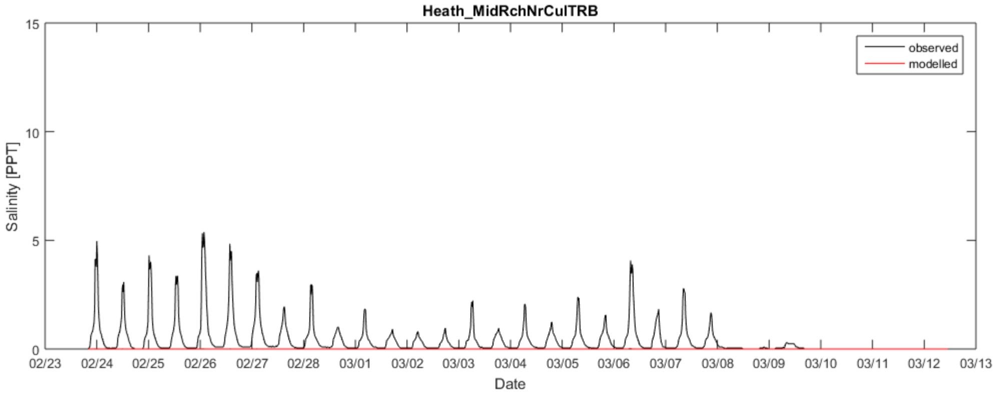




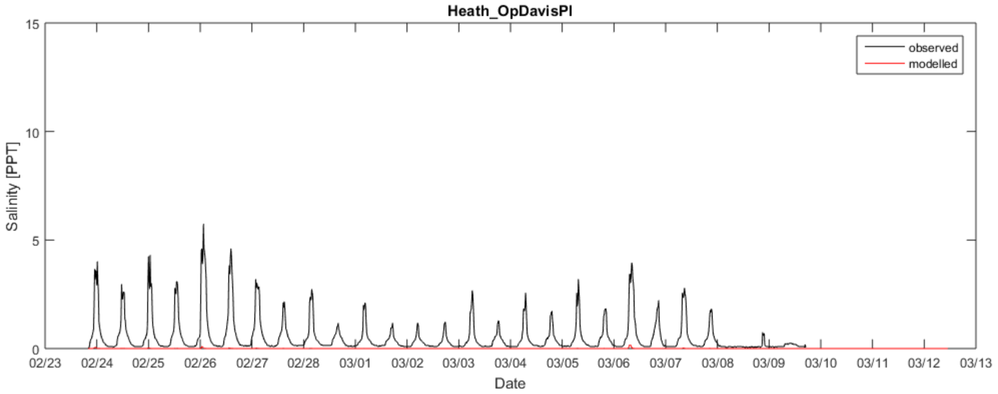
Heath_21Clarendon



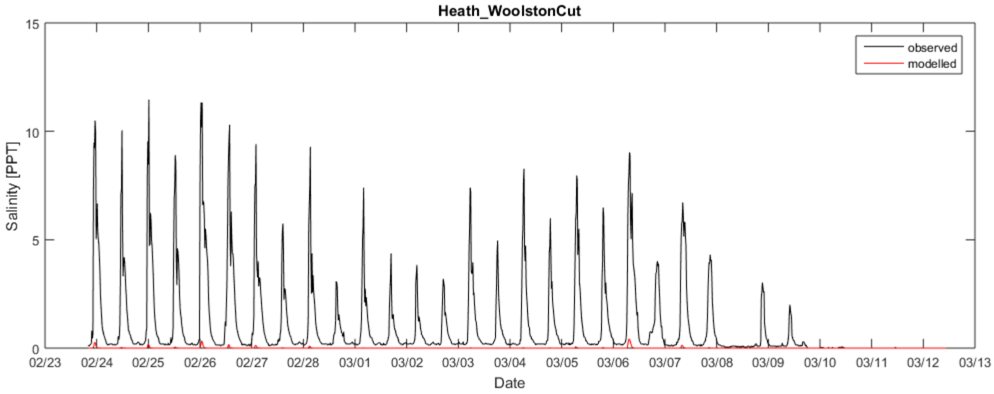
Heath_40mDsRadleySt



Heath_MidRchNrCulTRB



Heath_OpDavisPl


Heath_WoolstonCut
Salinity [PPT]
15
10
5
0
02/23
02/24
02/25
02/26
02/27
02/28
03/01
03/02
03/03
03/04
03/05
03/06
03/07
03/08
03/09
03/10
03/11
03/12
03/13
Date
observed
modelled