Water Salt Balance Model for the Lower Barwon Wetlands

SUMMARY REPORT

December 2022

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Alluvium recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia. We pay our respects to their Cultures, Country and Elders past and present.

Artwork by Vicki Golding. This piece was commissioned by Alluvium and has told our story of water across Country, from catchment to coast, with people from all cultures learning, understanding, sharing stories, walking to and talking at the meeting places as one nation.

This report has been prepared by Alluvium Consulting Australia Pty Ltd for Corangamite CMA under the contract titled Water-Salt Balance Model for the Lower Barwon Wetlands.

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Summary

The Lower Barwon Wetlands complex forms part of the internationally important Port Phillip Bay (Western shoreline) and Bellarine Peninsula Ramsar Site and is highly valued for its ecological significance, supporting a diverse mosaic of freshwater, estuarine and marine vegetated habitats; important for breeding, feeding and refuge requirements of many species of native fish, waterbirds and significant (rare and endangered) flora and fauna. In response to the first recommendation of the Lower Barwon Wetlands Review (Alluvium 2020), Alluvium has been engaged by Corangamite CMA to develop a water-salt balance model for the Lower Barwon wetlands complex. The model was and is intended to consider inter-annual variability, over-bank flows, groundwater interactions, evapotranspiration and risks around climate change and urban development.

Model overview

The model extent focussed on the Lower Barwon system and extended upstream of Geelong to the furthest available downstream gauges along the Moorabool and Barwon Rivers, respectively. These gauges were to be adopted as inflow 'boundary conditions' and used to run the model.

The drivers of hydrologic and salt balance change, principal salt load sources, and their interactions with the key system features were identified following the review of the existing literature and facilitated the development of a conceptual model of the system. This conceptual model provides a high-level overview of the wetland interactions and assisted in the future development of the Source model.

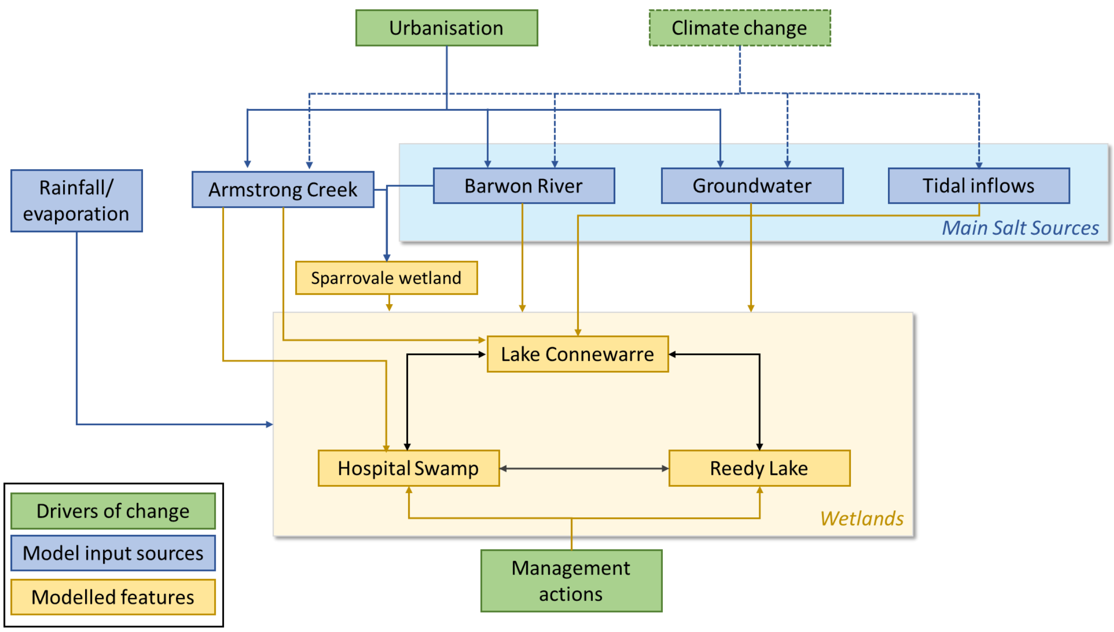

Figure 1. *Key features and drivers of change within the system*

The complete set of model files are provided to the Corangamite CMA with the final version of this report.

Water salt balance scenarios

A series of scenarios were developed to investigate how the salt-water balance responded to broad scale operational, catchment characteristic and climatic changes. These scenarios create a set of best-case and worst-case results that act as 'book-ends' on the likely range of wetland responses. The scenarios were developed through consultation with the LBCAC and project members from Corangamite CMA, City of Greater Gelong and DELWP.

Developing and exploring these scenarios helps to understand the sensitivity of the salt-water balance to changes in variables. This information can be used to explore and design potential management options in the next stages of the project.

Table 1. *Summary information of the scenarios considered in this modelling exercise*

#	Name	Detail
1	Calibration	The conditions built around the layout of the area prior to the inclusion of the Southern Diversion Channel, Sparrovale wetlands and the connection to Lake Connewarre. This is set up to compare pre-Sparrovale outputs to the pre-Sparrovale data from the gauged sources to ensure best fit calibration of the model. The detail of this set up is covered in Section 3 and Section 4
2	Updated conditions	This scenario takes the Calibration scenario (1) and updates the model setup to include Southern Diversion Channel, Sparrovale wetlands, the connection to Lake Connewarre and the associated DRAFT management recommendations
3	Urban development	Using the updated conditions scenario (2) an increase in urban development is applied
4	Permanently full	Using the updated conditions scenario (2) management decisions are applied to maintain filled levels in Reedy Lake and Hospital Swamps
5	2012 Long Term Flows	Based on the updated conditions scenario (2) with the addition of the increased drying in 3rd year
6	Climate Change	Based on the updated conditions scenario (2) with updates based on climate change details discussed in Section 2
7	Higher Drawdown – December start	Based on the updated conditions scenario (2) with drawdown increased to 200% (simulating 14cm per week)
8	Higher Drawdown – February start	Based on the updated conditions scenario (2) with drawdown increased to 200% and started in February (simulating 14 cm per week)
9	Lower Drawdown – December start	Based on the updated conditions scenario (2) with drawdown rate reduced to 50% (simulating 3.5cm per week)
10	Lower Drawdown – February start	Based on the updated conditions scenario (2) with drawdown rate reduced to 50% and started in February (simulating 3.5cm per week)
11	Urban Development + Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 3 and 6
12	2012 Long Term Flows + Climate change	Based on the updated conditions scenario (2) with the combined changes of scenarios 5 and 6
13	Permanently full + Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 4 and 6
14	Expanded Diversion	Based on the updated conditions scenario (2) with management decisions changed case scenario to add in the standard CoGG diversion recommendations for May to December (at reduced capacity) – in addition to the existing December to May diversion
15	Expanded Diversion + Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 6 and 14
16	Expanded Diversion + Urban Development	Based on the updated conditions scenario (2) with the combined changes of scenarios 3 and 14
17	Expanded Diversion + Urban Development + Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 3, 6, and 14
18	50% Diversion	Based on the Expanded Diversion scenario (14) with a reduced capacity to 50% over the whole year
19	Permanent flow through	Based on the updated conditions scenario (2) with management decision changes to attempt to maintain Reedy Lake as a flow through system year-round and Hospital Swamps as a flow through in winter/spring
20	Permanent flow through+ Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 6 and 19
21	Permanent flow through+ Urban Development	Based on the updated conditions scenario (2) with the combined changes of scenarios 3 and 19
22	Permanent flow through + Urban Development + Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 3, 6, and 19

Summary of results

The outcomes of the modelling found clear trends in wetland salinity and the outcomes of different scenarios. Ultimately, the volumes of fresh water held in the wetlands drives the salinity. Higher volumes of fresh water dilute salt in the water and reduce influx of groundwater. Reduction in freshwater as a result of evaporation, outflow or reduced inflow from river or rainfall sources allow saltier groundwater to take over and increase salinity (Figure 2). The results of the modelling showed that the wetlands of Reedy Lake and Hospital Swamps are quite reactive to short term management decisions. The balance between salt and water is shown to be reliant on the balance of inflows and outflows, whether from fresher sources such as the Barwon River and stormwater runoff, or more saline sources such as groundwater.

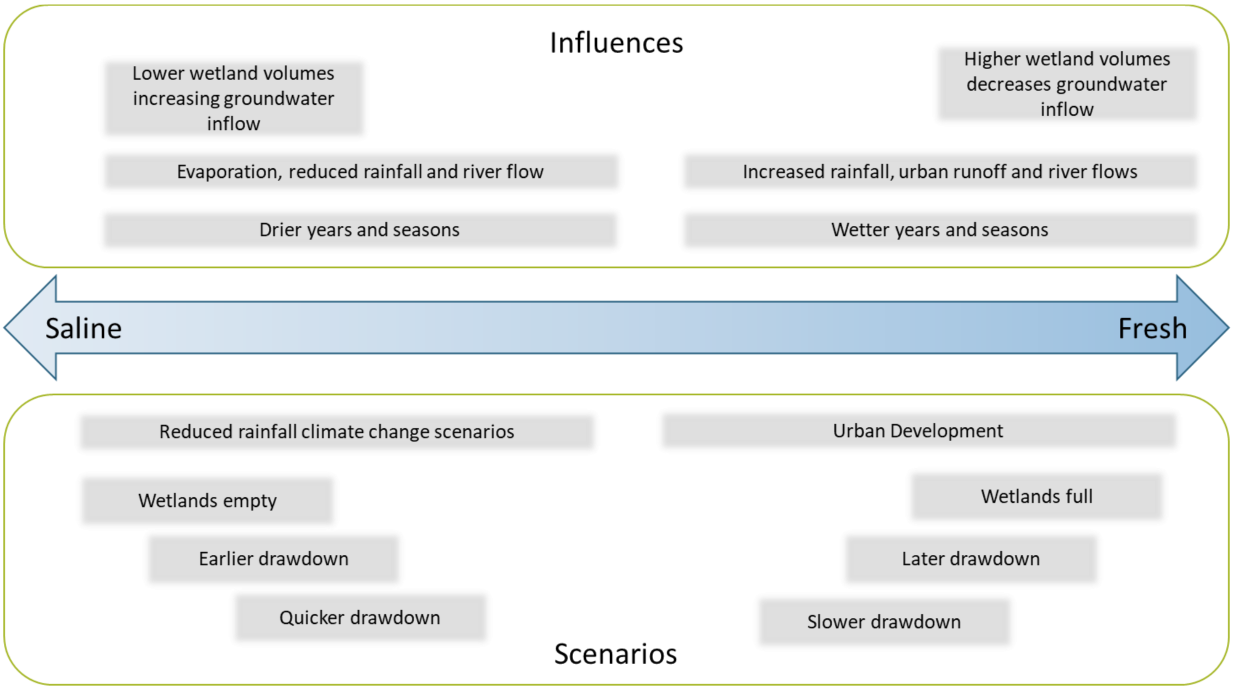

Figure 2 *Salt concentration influences and scenario results*

The individual results of the modelling shows these clear relationships. As each of the parameter changes are made, the scenarios that increase water levels (such as increased urban development and maintaining wetlands permanently full) result in a decrease in concentrations, while those that reduce fresh water inflows and water levels (such as climate change) result in an increase in concentrations (Figure 3, Figure 5). Management actions which led to the largest increases in salinity were those that limited the water levels and flows into the wetlands.

The wetland concentrations were shown to react in the same way to the changes in the timing and rate of drawdown. Earlier start or increased rate reduces wetland volumes which in turn increases concentration, while later start or slower rates have the opposite impact. Increasing the drawdown rate or reducing catchment were the most effective measures for increasing salinity. Decreasing drawdown and maintaining full wetlands worked to reduce concentrations. The rapid impact of changed inflows is shown in the Urban Development scenario (Scenario 3), where runoff increases from the increased imperviousness which in turn is highly reactive to the hydrological conditions of the time.

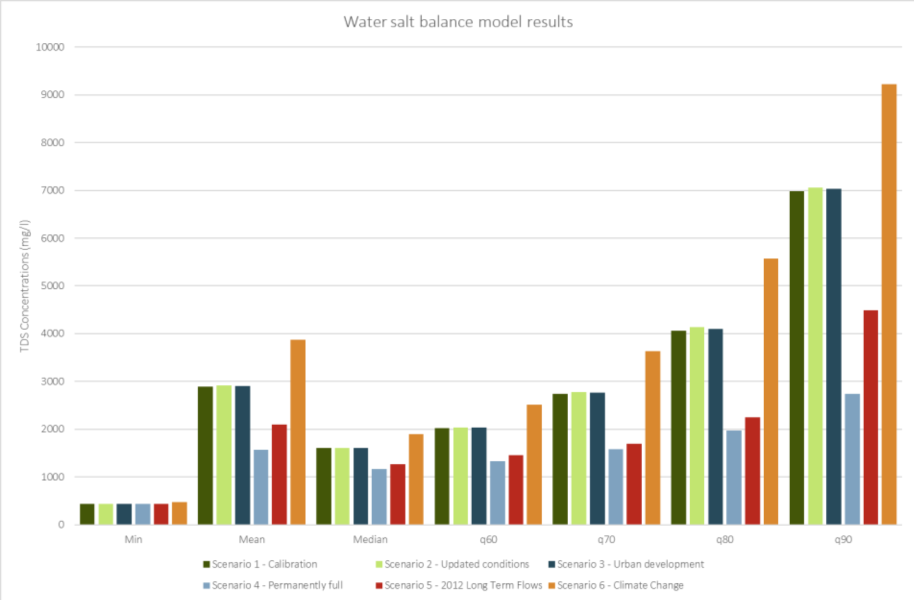

Figure 3 *Water salt balance results. Note the TDS is used as an indicator for salt concentrations*

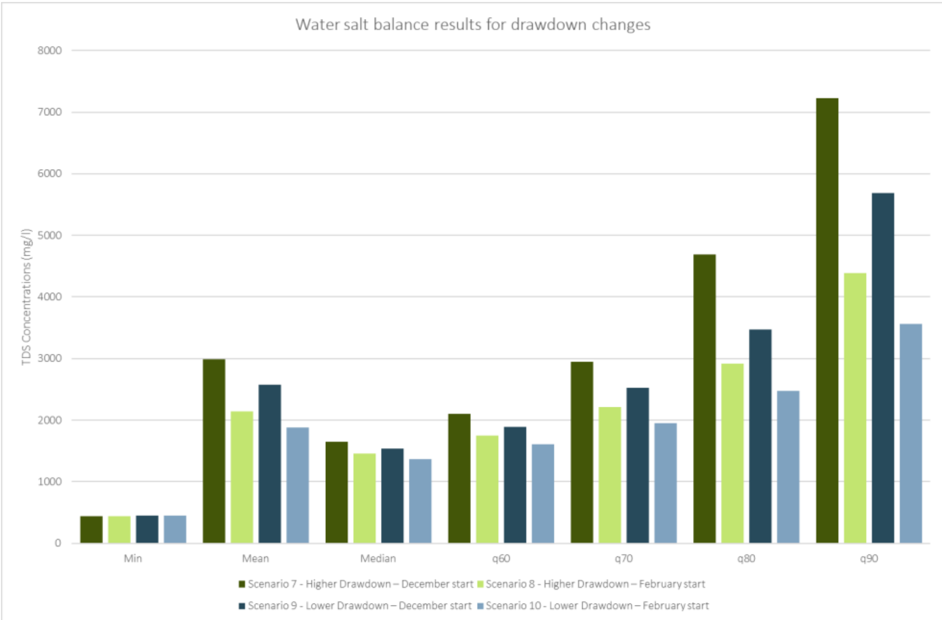

Figure 4 *Water salt balance results for drawdown changes. Note the TDS is used as an indicator for salt concentrations*

When noting scenarios that confine the management changes to the summer period, the wetland showed a capacity to return to the winter averages, showing limited lingering impacts to salinity (Figure 5). As a result, the water-salt balance of the system was largely dependent on the balance of the short term inflows of fresh or saline water. The fresher water sources came primarily from the Barwon River, Armstrong Creek, direct rainfall and direct runoff, which were balanced by the saline groundwater (which in the modelling incorporated a portion of tidal inflows due to the model calibration).

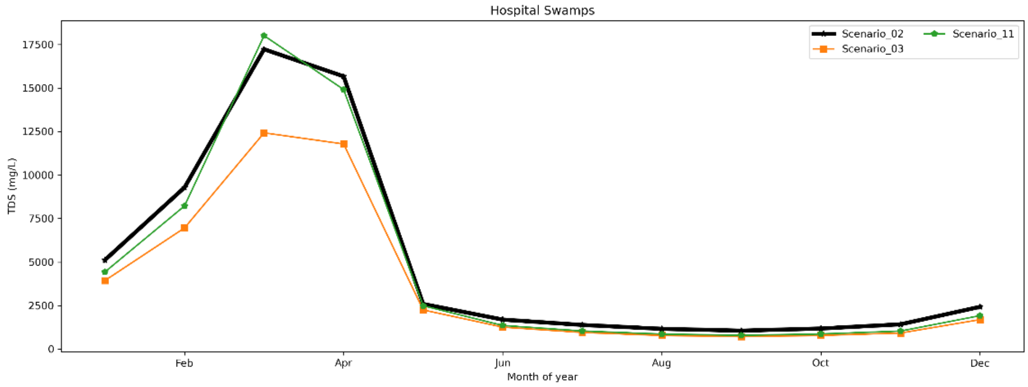

Figure 5 *Water salt balance results for urban development increases. Note the TDS is used as an indicator for salt concentrations. Graph shows calibrated scenario (Scenario 2). Increased urban development (Scenario 3) and combined increased urban development and climate changes (Scenario 11)*

Ecological context assessment

To aid the high-level interpretation of the results in the context of ecological character, a set of indicators have been identified using literature and stakeholder engagement.

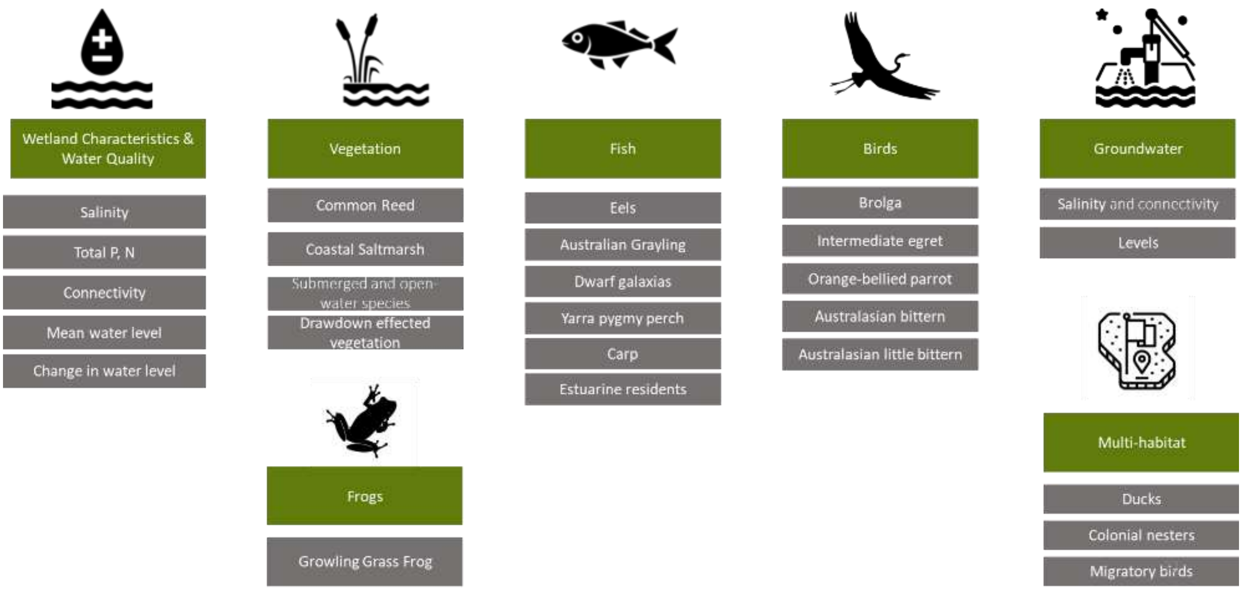

Figure 6 *Selected ecological indicators*

Note that the assessment conducted applies only to the potential role of salinity on each of the indicators and which scenarios are more likely to influence them. This is not intended to be taken as a complete assessment or to replace the FLOWS assessment process, rather to put an ecological lens over the results of the modelling.

While the response from the vegetation is difficult to predict given the interacting factors that influence vegetation community composition and condition, there are some outcomes that would be likely. Scenarios that result in large salinity increases, particularly at higher levels for longer, would be more likely to impact native vegetation. The long-term impact remains uncertain as some species adapt to higher salinity whereas the expectation would be that current vegetation may only persist. Furthermore, at the results show a direct relationship between depth and salinity, highly saline periods are likely to be confined to the lower regions of the wetlands, therefore only impacting a portion of the vegetation community. Water level variation is a critical determinant of species presence and wetland vegetation diversity. Scenarios that maintain deeper levels for longer would likely result in poorer health for much of the vegetation present, and there is a risk that dying vegetation renders sediments inhospitable for species that might otherwise be able to tolerate the salinity regime.

The effects on vegetation are critical for fish species, therefore vegetation changes are an important consideration. As many of them appear tolerant of higher salinity, maintaining vegetation is an import factor for fish species to maintain food sources and habitat.

Impacts on frogs, local waterbirds and multi-habitat birds is more difficult to determine given the increased capacity for movement but some impacts can be anticipated. Growling Grass frogs may be able to tolerate minor increases in salinity but will be sensitive to major increases given their need for water throughout their life cycle. Based on the results of the modelling, annual management may not impact the Growling Grass Frog if the return to winter freshness is able to satisfy the ongoing requirements (in conjunction with the other environmental factors). The biggest impacts on local waterbirds and multi-habitat birds will be through the effects on vegetation that is provides habitat and food sources. The impacts on waterbirds will be determined by the availability of habitat (vegetation, water depth) at the landscape scale, although reductions in the quality or amount of habitat is likely to be associated with declines in regional populations.

It is important to note that the changes in salinity may be positive or negative for the species considered, but the broader context of the whole wetland is important. For example, if the coverage of the Common Reeds were to expand, this would be associated with changes in the number of other types of vegetation and the characteristics of the habitat mosaic that is known to be important in supporting the diversity of plants, invertebrates and fish and birds. This is why the Ramsar Limits of Acceptable Change (LAC's) are framed as specific proportions of different types of freshwater vegetation.

The wetlands are, however, complex systems in which salinity levels and depth fluctuations are just two factors among many that interact to influence their character and condition. Despite the uncertainty associated with managing a complex system, the water-salt balance model that has been developed and calibrated as part of this project will be critical for the update to the FLOWS study.

Contents

Figures

Tables

1 Introduction

Alluvium Consulting Australia Pty Ltd (Alluvium) has been engaged by the Corangamite Catchment Management Authority (CCMA) to model the salt-water balance of the Lower Barwon wetlands (the wetlands).

The project has been undertaken to provide the Corangamite CMA with a purpose-built water/salt balance hydrological model in the E-Water Source modelling platform. It is intended that the model be used for the assessment of wetland management options and to inform a future environmental flow (FLOWS) study.

The project has included the conceptualisation, development, calibration and running of such an E-Water Source, daily timestep hydrologic model incorporating the physical processes that influence salinity in the wetlands, including riverine flows, climate, localised runoff, and groundwater. The project has also included the running of scenarios to identify the influence of these parameters on wetland condition.

The project has been completed in three stages, as shown in Figure 7.

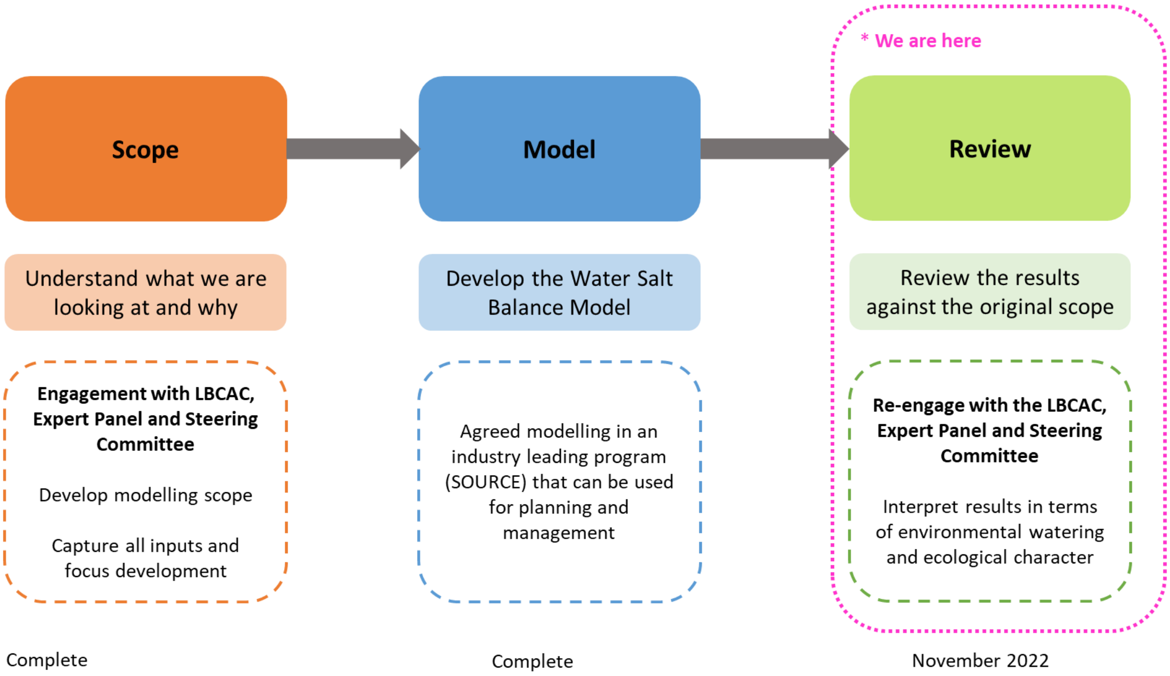

Figure 7 *Project Stages*

This report has been prepared for the review stage. The review stage brings together the information gathered over all previous stages of the project, from scoping, through the initial engagement activities, to the results and implications of the Source model scenarios that have been run. Management actions that control the timing and magnitude of filling and draw-down of these wetlands have been explored, including operations and outcomes under current and future climate conditions, with and without the urbanisation in the catchment. A total of 22 scenarios have been modelled comprising combinations of these factors.

This report outlines the development of the E-Water Source model, the selection of ecological indicators and the selection process for the modelled scenarios. It then describes the results of each of the scenarios in terms of the implications for management of wetland hydrology and salinity and the impacts on the ecological health of the wetlands. The modelling results provide insight into the impacts of management decisions and climate on the condition of the wetlands and will assist in both short-term management decisions and the development of an updated FLOWS study.

1.1 Background

The Lower Barwon comprises a system of wetlands and lakes located in the Barwon River estuary zone upstream of the Barwon Heads, on southern side of the Bellarine Peninsula (Figure 8). The wetlands are a component of the Lake Connewarre complex, which together with adjacent lakes, form the estuary of the Barwon River. The wetland complex consists of Lake Connewarre, Reedy Lake, Hospital Swamps, Murtnaghurt Lagoon and Salt Swamp, as well as the lower reaches of the Barwon River.

The area also includes the recently developed Sparrovale wetlands. The Sparrovale wetlands lie north of the Harriott Armstrong Creek future community. The wetlands are part of the 500 hectares of land that were acquired by the City of Greater Geelong to enable the storage and treatment of stormwater runoff from the residential areas surrounding Armstrong Creek residential area and prevent unseasonable fresh water runoff from discharging into Hospital Swamps.

The Lower Barwon Wetlands complex forms part of the internationally important Port Phillip Bay (Western shoreline) and Bellarine Peninsula Ramsar Site and is highly valued for its ecological significance, supporting a diverse mosaic of freshwater, estuarine and marine vegetated habitats; important for breeding, feeding and refuge requirements of many species of native fish, waterbirds and significant (rare and endangered) flora and fauna.

Figure 8 *The Lower Barwon Wetlands Complex*

Over the past 150 years, land adjacent to the Lower Barwon Wetlands complex has been largely cleared for agriculture development. In recent decades, the area has experienced extensive urban development, particularly in the Armstrong Creek area to the west of Hospital Swamps. Associated with this development is the Sparrovale Wetlands, created to treat stormwater from the expanding urban areas. Further upstream, the Barwon River flows through and receives stormwater and other catchment runoff from the City of Geelong, including, for instance, the long-established urban areas around Belmont.

Key sites within the Lower Barwon wetland complex are Reedy Lake and Hospital Swamps, which form the focus of this study. Water regimes in Reedy Lake and Hospital Swamps are independently managed under the Barwon River Environmental Entitlement 2011, with environmental water being actively managed to improve the ecological character of the sites. The ecological character is defined as the combination of ecosystem components, processes, benefits, and services that characterised the wetland in 1983, the time when the wetlands were Ramsar listed.

For the past decade, environmental water regimes at Reedy Lake and Hospital Swamps have been based on an adapted version of the long-term watering recommendations (and associated ecological objectives) provided in the original flow assessment of 2012 (Lloyd et al, 2012). Water levels in Reedy Lake had traditionally been maintained at relatively high levels, but in 2016/17 a four-year watering cycle was trialled for Reedy Lake, consisting of three years partial drying followed by one year of the lake kept full, to improve ecological condition and to better accommodate the shared benefits of the site. In contrast, Hospital Swamps usually experiences a wetting and drying regime in most years. For Hospital Swamps, this water regime has always remained relatively consistent, even when the water entitlement was created in 2011 and Corangamite Catchment Management Authority (Corangamite CMA) began managing the water.

In 2019/20, an independent review of the Lower Barwon Wetlands was commissioned by the CCMA (facilitated by Alluvium and an expert panel convened by the Department of Environment Land Water and Planning - DELWP) to assess the suitability of the four-year trial watering regime (Alluvium, 2020). The review found that watering regimes involving wetting and drying cycles were the best approach to maximise biodiversity and the overall ecological condition of Reedy Lake and Hospital Swamps. In the review, a series of recommendations were made, which if implemented, would improve watering actions to optimise ecological benefits.

Two of the recommendations included in the review were identified as critical and urgent:

1. Complete a water-salt balance model for the wetlands complex, and
2. Update the 2012 environmental flows investigation in the light of the completed model and other advances in the understanding of environmental watering that have taken place over the intervening decade.

In response to the first recommendation of the Lower Barwon Wetlands Review (Alluvium 2020), Alluvium has been engaged by Corangamite CMA to develop a water-salt balance model for the Lower Barwon wetlands complex. The model was and is intended to consider inter-annual variability, over-bank flows, groundwater interactions, evapotranspiration and risks around climate change and urban development. This model, developed in the Source modelling framework (eWater, 2022) is intended to be used to inform environmental watering actions (management of water regimes) to optimise salinity profiles for the biodiversity and ecological functioning of the wetlands complex, as well as guide the next flows study update.

1.2 Project scope and objectives

The Water Salt Balance Model for the Lower Barwon Wetlands project has two primary aims:

1) Develop a Water-Salt Balance model in Source of the Lower Barwon Wetlands that can be used by Corangamite CMA
2) Link the developed Water-Salt Balance model to current water regimes and maintenance of ecological character, with focus on the following objectives:
    - To determine salinity implications to Reedy Lake and Hospital Swamps when maintaining the wetlands at permanently full
    - To investigate the salinity implications to Reedy Lake and Hospital Swamps of managing them in line with the current FLOWS recommendations
    - To determine the salinity implications to Reedy Lake and Hospital Swamps when increasing or decreasing the rate and frequency of summer draw down, within a draw-down year and over a multi-year period.
    - To understand the potential impacts of climate change and urbanisation
    - To confirm that the impacts of gate management are in line with the Water Regime Advice (Lloyd L. , 2013) requirements for Hospital Swamps and Reedy Lake.

The purpose of this report is to demonstrate the achievement of the project objectives and completion of the key deliverables and tasks. It incorporates the feedback from the steering committee and the LBCAC.

1.3 Study area

The study area is the Lower Barwon wetlands, and all integral and surrounding water bodies, water courses and areas that could serve as a source or receiving environment for water flows and salt. The key areas in focus are Reedy Lake and the Hospital Swamps. Other important areas and aspects included in the study are:

- The Barwon River
- Lake Connewarre
- Sparrovale Wetland
- Local urbanised areas
- Groundwater
- Any other nearby environments/inputs considered relevant to the accuracy of the model.
- Recent and future changes such as the latest changes to lower Barwon infrastructure
- Climate change

The study area encompasses the Lower Barwon catchment which contains the wetlands of interest. While this is the area of interest the model will need to include Barwon River water and salt inputs and therefore must be considered within a broader catchment context. The location of the study area within the wider Barwon River catchment is presented in Figure 9.

Figure 9. *Location of the Lower Barwon wetlands and model study extent within the wider Barwon Basin*

2 Engagement

Engagement activities have occurred over the course of the project with community stakeholders, project stakeholders, the project expert panel, and the CCMA project managers. These stakeholders have helped to guide and refine the project as it progressed through the multiple stages of model development described.

The project engaged with the Lower Barwon Community Advisory Committee (LBCAC) over two stages:

- Session No.1: Presentation on the project aims and scope to gather feedback on scenarios to be modelled and important ecological indicators
- Session No. 2: Summary presentation of findings and review of the Final Project Report (this report)

These consultations were able to provide valuable input into the development of the model, the approach to the assessing the impacts to ecosystem health and the presentation of results.

The LBCAC has also been given an opportunity to provide comment on the Draft report, with feedback considered for the final version.

3 Model development

This project has been based on the adoption of the eWater Source model platform for the water-salt balance modelling.

3.1 Background to Source

Source is a modelling platform and comprises a group of models that can be configured in different combinations to answer specific modelling questions. Within Source, the user has a choice of 'river system' or 'catchment' configuration. These two approaches can theoretically be used interchangeably; however, in most cases, one or the other is typically applied for specific projects. For this project, the catchment configuration was applied to derive daily time series of flows and salinity within both the waterways and the wetlands.

Source has three basic water balance components; generation, delivery, and transport, and each of these can be configured independently for specific catchment land uses, topographies, or processes.

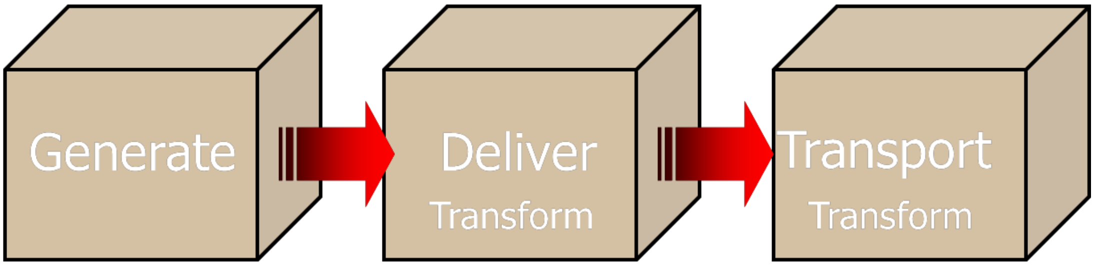

Figure 10. *Source framework concept*

Under each component, there are several models to choose from to best represent catchment processes. The primary driver of Source is rainfall-runoff, and so the accurate configuration, calibration and validation of rainfall-runoff is vital for a robust model. The model generated runoff is then used in a constituent generation model (which can also be a range of different model types) to answer specific questions. Constituents refers to the water quality characteristics associated with different land uses, in this case total dissolved solids to represent salt sediment.

3.2 Modelling process

The modelling process involves six steps.

Step 1 – Subcatchments and streams are delineated using a digital elevation model (DEM) of the region (see Figure 11). At this stage, the resolution of the subcatchments can be specified: The size of each subcatchment is determined by the size of the overall catchment.

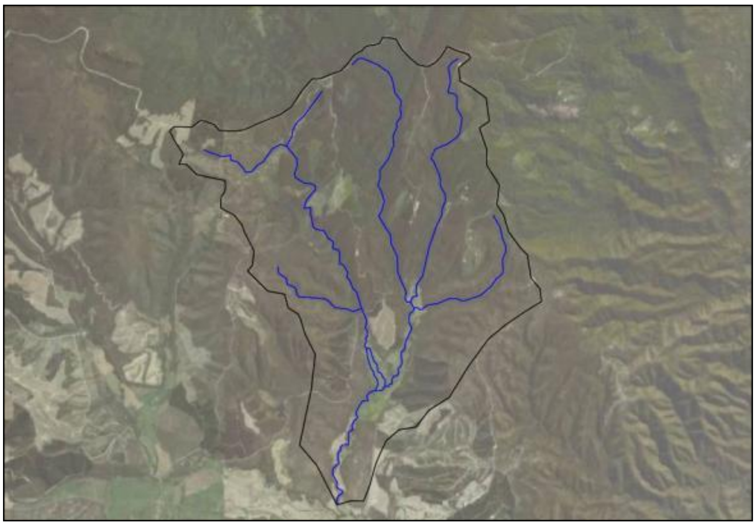

Figure 11. *A spatial description of the catchment (using an example catchment)*

Step 2 – A node-link is then built to connect these subcatchments. This network represents the hydrologic connectivity of the actual system and can be built automatically from the DEM or manually from the data obtained in Step 1 (refer to Figure 12). In most cases the nodes and links are generated automatically from the DEM.

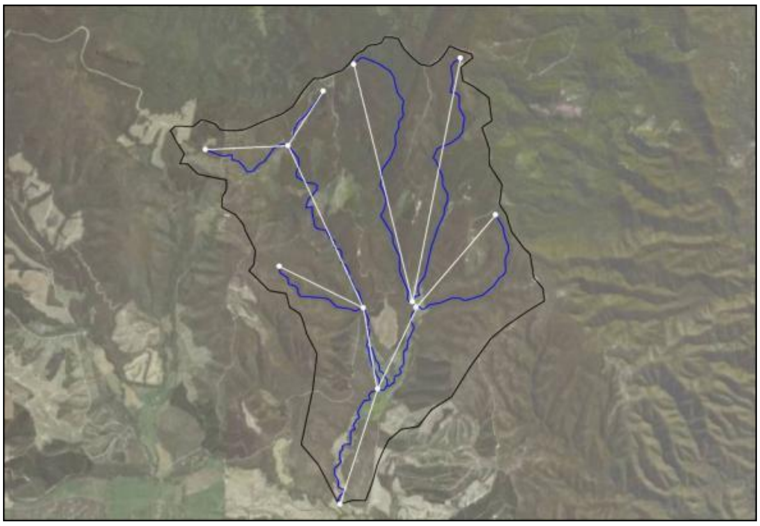

Figure 12. *Construction of a node-link network (using an example network)*

These link models are combined with the subcatchment/node models to describe the whole catchment, as shown in Figure 13.

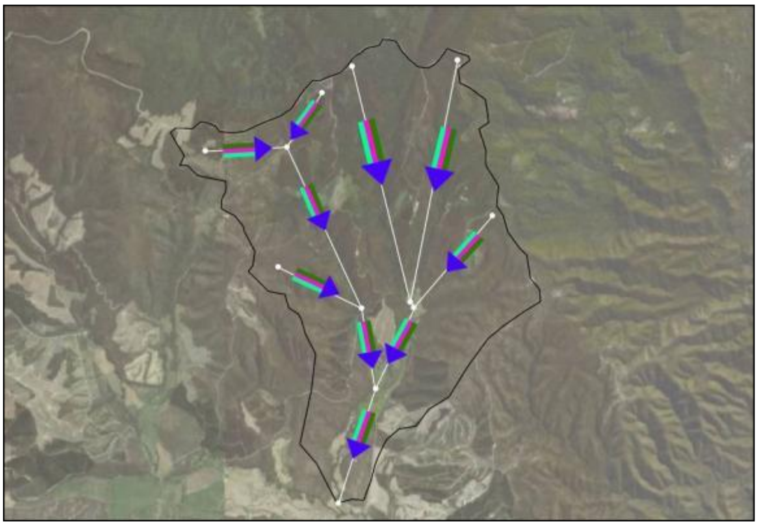

Figure 13. *Node and link models to describe the catchment (using an example network)*

Step 3 – Information about each subcatchment is then described. Land use data is used to describe the 'Functional Units' (FUs) within each subcatchment. Each FU describes a land use with particular runoff and constituent generation characteristics. Typically, a common set of FUs is used for the entire catchment, with the areal extent differing within each subcatchment (see Figure 14).

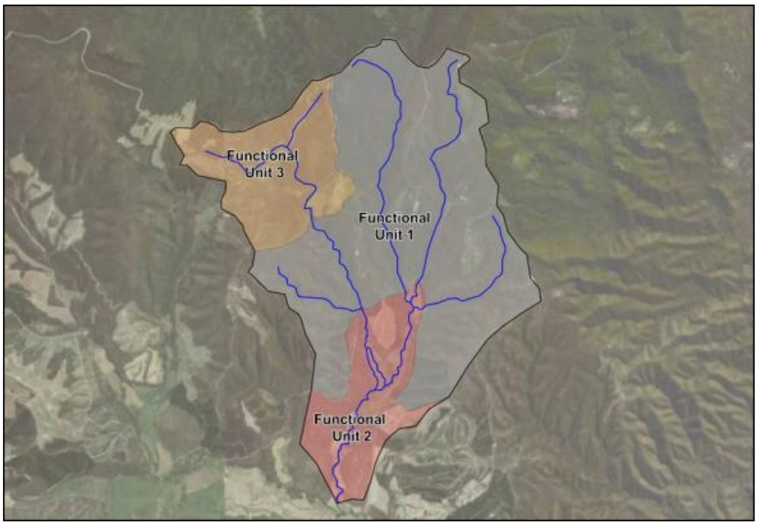

Figure 14. *Definition of function units (using an example network)*

Step 4 – Particular models are then selected, and described, to represent how each FU responds to different climatic and pollutant inputs. (Figure 15).

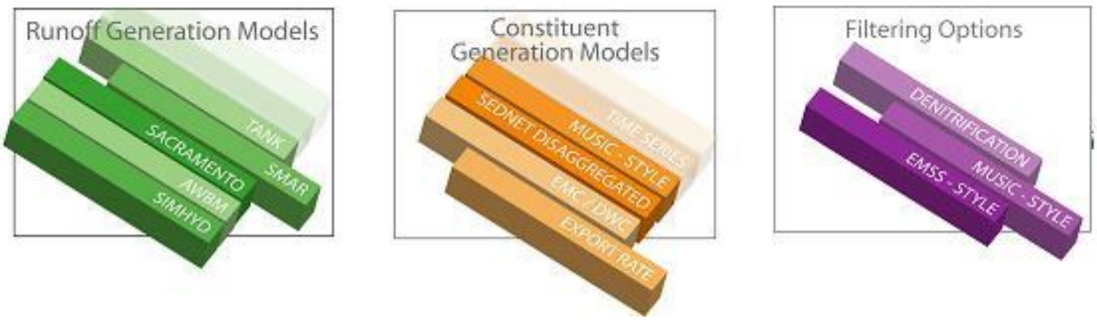

Figure 15. *Selection of node models*

Step 5 – Each link in the stream network is then defined using an appropriate model in a similar way to the subcatchments in Step 4 inputs (Figure 16).

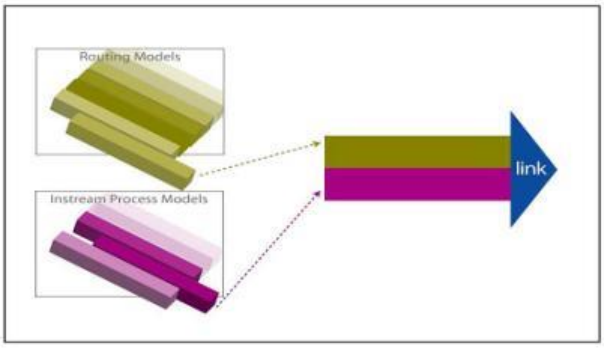

Figure 16. *Selection of link models*

Step 6 – The link models are combined with the subcatchment/node models to describe the overall catchment (Figure 17).

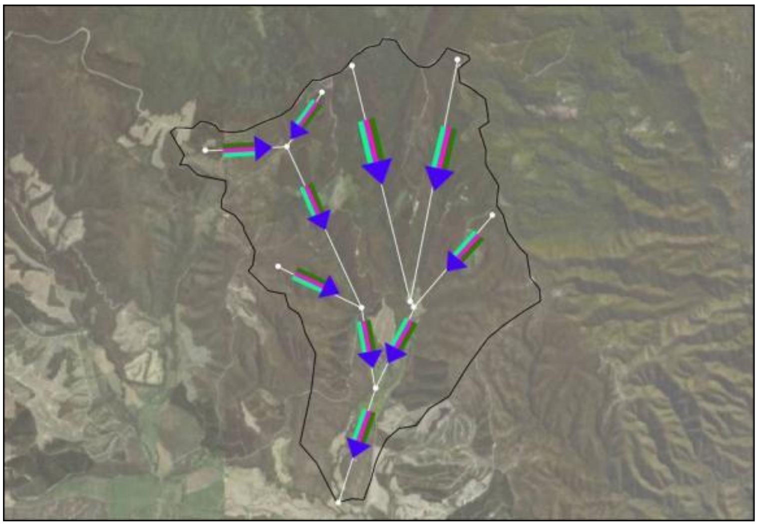

Figure 17. *Node and link models to describe the catchment (using an example network)*

3.3 Model data

The Lower Barwon catchment model was developed using topography, land use, and climate data retrieved from several sources (Table 2).

Table 2. *Data inputs*

Data	Description
Topography	Digital Elevation Model (DEM) data with a spatial resolution of 10 m was retrieved from ELVIS.
Land use	Land use data was retrieved from the Victorian Land Use Information System (VLUIS) for 2016 and categorised into 13 functional units (representing similar land uses that have similar hydrologic and pollutant export responses).
Climate	Daily rainfall and potential evapotranspiration data were obtained from the SILO Long Paddock gridded dataset to capture the daily rainfall surfaces across the catchment area.
Salinity	Lake and stream salinity levels were retrieved from the Victoria Water Measurement Information System *(https://data.water.vic.gov.au/)*.

Data	Description
Stream gauges	Daily stream flow records and water levels were retrieved for several gauges throughout the Lower Barwon catchment from the Victoria Water Measurement Information System *(https://data.water.vic.gov.au/*).

Note that there are existing source models for the upper reaches of the catchment past the stream gauges used here. In order to ensure the most robust inputs were used, observed data from the gauges were taken as the primary input, supplemented by modelled outputs in periods that gauged data was missing.

3.4 Conceptual overview

The drivers of hydrologic and salt balance change, principal salt load sources, and their interactions with the key system features were identified following the review of the existing literature (Figure 18). This facilitated the development of a conceptual model of the system (Figure 19). This conceptual model provides a high-level overview of the wetland interactions and assisted in the future development of the Source model. Important drivers of change were identified as urbanisation, climate change, and management actions, which may act either antagonistically or synergistically. These drivers of change influence incoming flows and salt loads and the interactions between the different modelled features (wetlands). The principal salt load inputs to the system were identified as the Barwon River, Armstrong Creek, groundwater flux, and tidal inflows.

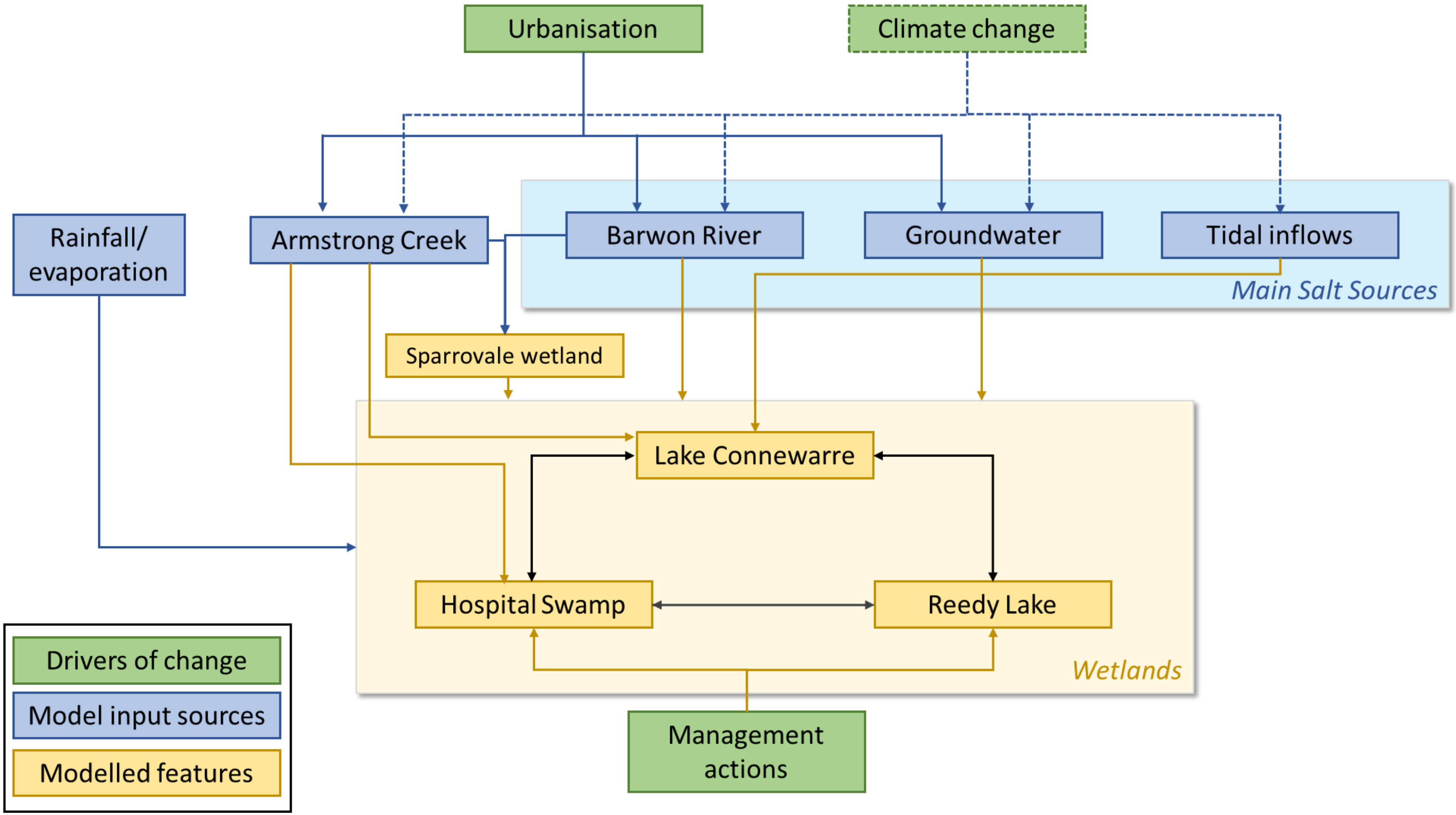

Figure 18. *Key features and drivers of change within the system*

Figure 19. *Conceptual model of the Lower Barwon system*

3.5 Source model setup

This model was built in version 4.11.0 of the Source software. The production of a water-salt balance model is the primary objective of the project, and a fit for purpose, calibrated and representative model has been developed and provided to the Corangamite CMA along with the final version of this report.

Catchment delineation

The model extent focussed on the Lower Barwon system and extended upstream of Geelong to the furthest available downstream gauges along the Moorabool and Barwon Rivers, respectively. These gauges were to be adopted as inflow 'boundary conditions' and used to run the model. The Lower Barwon wetlands were represented as storages in the model as presented in Figure 20.

The 10 m DEM was used to delineate catchment and subcatchment boundaries. These subcatchments are defined by both the shape of the terrain and any confluences between different drainage areas. We note that this process is sensitive to decisions of how the streams themselves are defined (i.e., how much area draining to a point defines a 'stream'). As such, the number of subcatchments in a model is somewhat arbitrary and can be increased or decreased depending on the needs of the model, noting the trade-off between increased resolution and increased catchment complexity (and therefore computational effort). A total of 72 subcatchments were delineated to represent individual areas that generate runoff and constituent loads (Figure 20).

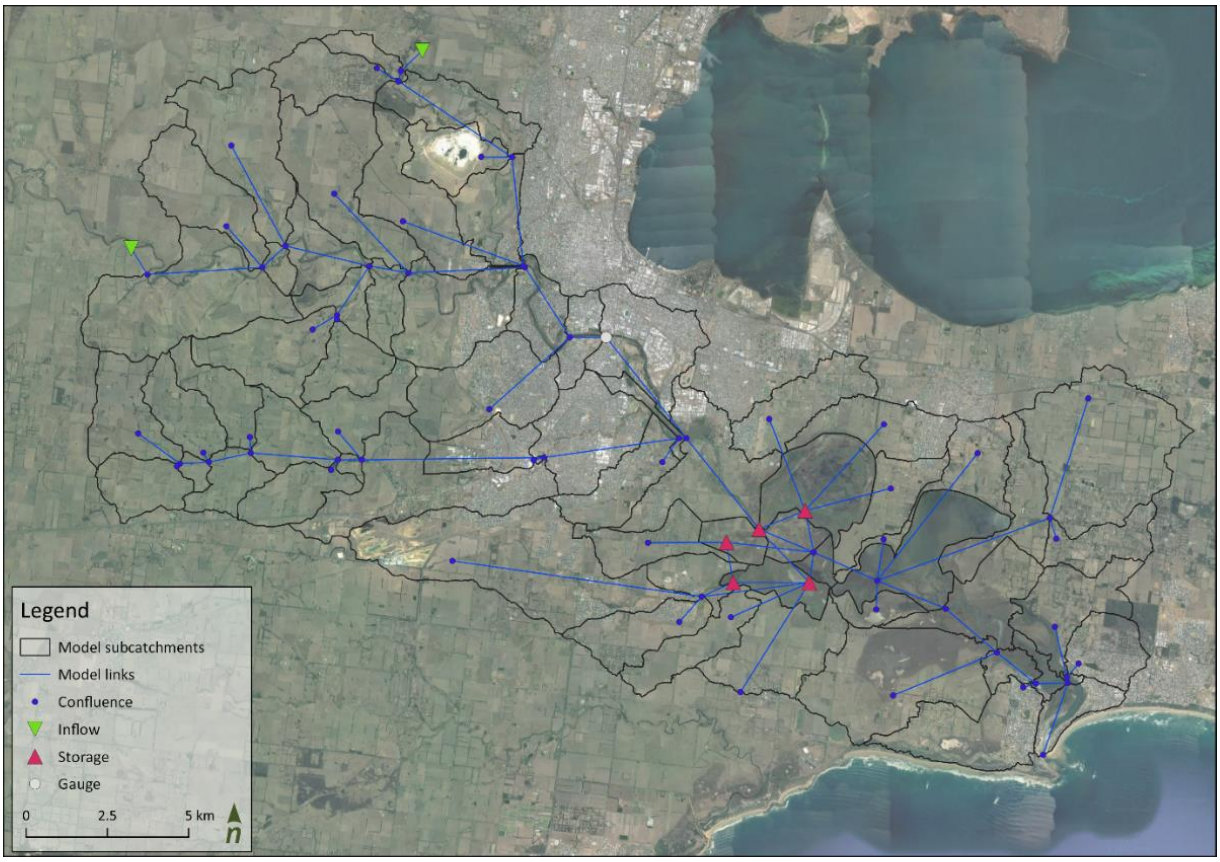

Figure 20. *Subcatchments, links, and nodes derived for the model extent*

Land use

Individual land use types were lumped together to form 13 discrete functional units, based on their similar hydrological and pollutant load characteristics. A list of the functional units adopted in the model is provided in Table 3 and the spatial distribution presented in Figure 21.

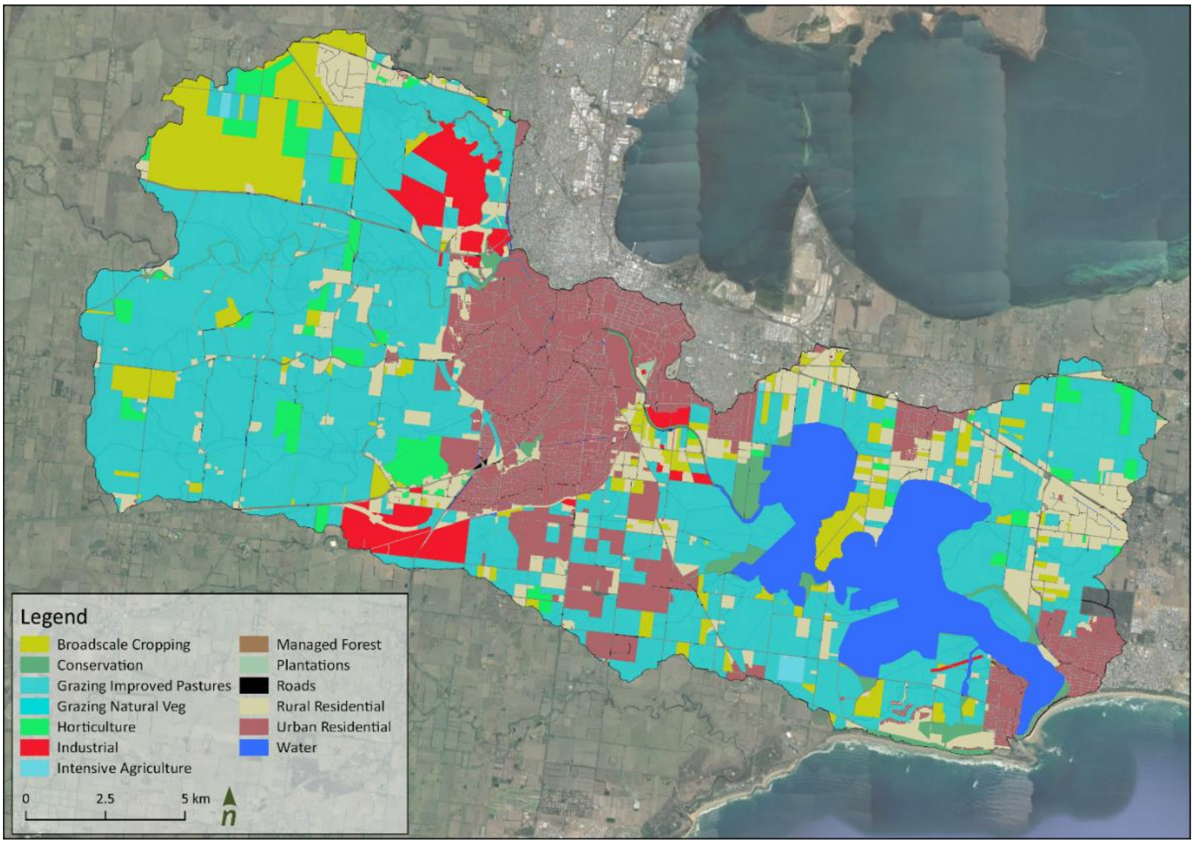

Figure 21. *Spatially distributed functional units across the model extent*

Table 3. *Functional units adopted in the model*

Functional Unit Number	Functional Unit
1	Broadscale Cropping
2	Conservation
3	Grazing Improved Pastures
4	Grazing Natural Veg
5	Horticulture
6	Industrial
7	Intensive Agriculture
8	Managed Forrest
9	Plantations
10	Roads
11	Rural Residential
12	Urban Residential
13	Water

Climate data

Daily rainfall and potential evapotranspiration data for the catchment was retrieved from the gridded SILO (Scientific Information for Landowners) dataset available through the Long Paddock website (https://www.longpaddock.qld.gov.au/). SILO is a database of historical climate records for Australia derived from observed rainfall data and interpolated spatially to daily rainfall surfaces for an area of interest. Climate data was obtained over the period between 1960 and 2021 to ensure a range of climatic conditions were modelled.

The climate change scenarios assessed changes to the study area through using the RCP8.5 emissions scenario for 2065 from the Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria (DELWP, 2020). The climate change factors are shown in table three, with the selected change highlighted in blue.

Table 4 *Climate change factors*

Variable	Projection	Change relative to 1995 (%)					
		Year 2020		Year 2040		Year 2065	
		RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5
Evapotranspiration	Low	1.3	0.9	2.3	1.7	4.8	2.6
	Medium	2.2	1.6	4.0	2.8	7.0	4.8
	High	3.0	2.8	5.4	5.0	9.9	6.2
Rainfall	Low	1.1	2.1	2.0	3.7	1.2	1.5
	Medium	-1.7	-0.5	-3.0	-0.9	-5.2	-3.6
	High	-6.4	-7.5	-11.5	-13.5	-19.6	-13.6

Rainfall-runoff model

The conceptual rainfall-runoff model SimHyd was used to calculate the daily stream flow for each subcatchment. The structure of this rainfall-runoff model is shown in Figure 22 and is used to describe the key rainfall-runoff and constituent/pollutant generation processes occurring within the catchment. The SimHyd parameters used for this model are presented in Table 5 and are based on previous models developed for the region (Alluvium, 2022).

Table 5. *Adopted SimHyd rainfall-runoff model coefficients*

Parameter	Value
Baseflow Coefficient	0.1
Impervious Threshold	4.9
Infiltration Coefficient	350
Infiltration Shape	1
Interflow Coefficient	0.012
Pervious Fraction	0.35 - 1
RISC	4.6
Recharge Coefficient	0.06
SMSC	255 - 400

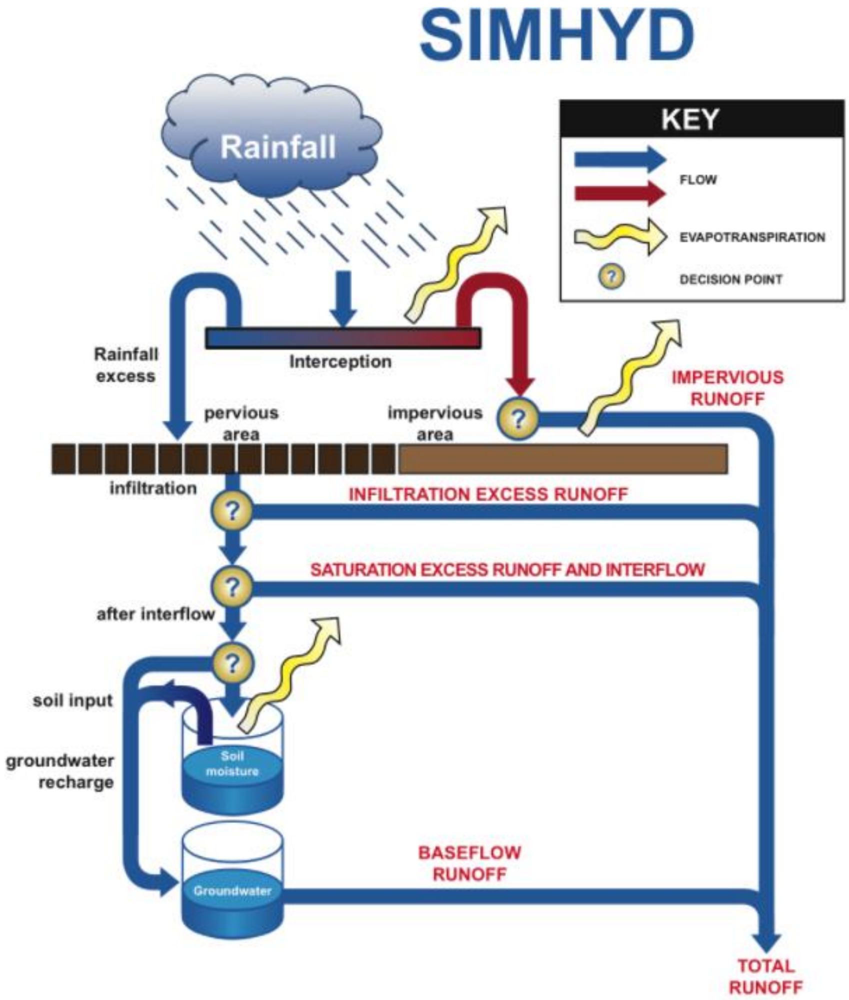

Figure 22. *Structure of the SimHyd rainfall-runoff model*

Salinity

Total dissolved solids (TDS) are a measure of the quantity of dissolved organic and inorganic materials present in the water column. TDS has been applied in the model as a surrogate for salinity, as they are typically highly correlated.

The model aims to show how TDS varies with flows. To do this, Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) were modelled in Source. Here, EMC represents TDS concentrations associated with quick (surface) flows, while DWC is indicative of concentrations associated with slow (base) flows. Different EMC and DWC values can be adopted for different functional unit and sub catchment combinations. Concentrations applied here were based on previous modelling experience in the catchment and were further delineated between rural and urban functional units as seen in Table 6.

Table 6. *Adopted TDS concentrations used in this analysis for different functional units*

Parameter	EMC	DWC
Rural	500	1500
Urban	60	300

Boundary conditions and infilling

Measured flows from the Moorabool River at Batesford (Gauge ID: 232202) and the Barwon River at Pollocksford (Gauge ID: 233200) were used as inflow boundary conditions at the locations shown in Figure 20.

Missing data in the gauged record was filled using a previously developed hydrologic model of the whole Barwon River catchment that was used for an assessment of the regional drainage schemes (Alluvium, 2022).

A timeseries of measured salinity concentrations was also applied at these boundaries. Here, salinity was first converted from electric conductivity (µS/cm) to TDS (mg/L) using a conversion ratio of 0.64 (McNeil and Cox, 2000). There were much larger periods of missing data associated with salinity compared to streamflow. For the Barwon River boundary, we chose to infill missing salinity using the measured relationship between salinity and flow at this gauge (Figure 23). We derived estimates of salinity by separating the flow-salinity relationship for low flows (< 200 ML/d, see Figure 24) and high flows (> 200 ML/day, see Figure 25), respectively. Salinity data was not available at Moorabool River at Batesford (Gauge ID: 232202). Salinity concentrations were instead derived from a calibration process at the downstream gauge (refer to Section 3). This process resulted in a flow-based threshold being applied for salinity at the Moorabool River, whereby a TDS of 2,500 mg/L was used for low flows (< 50 ML/d) and a TDS of 1,000 mg/L was applied for all other flows.

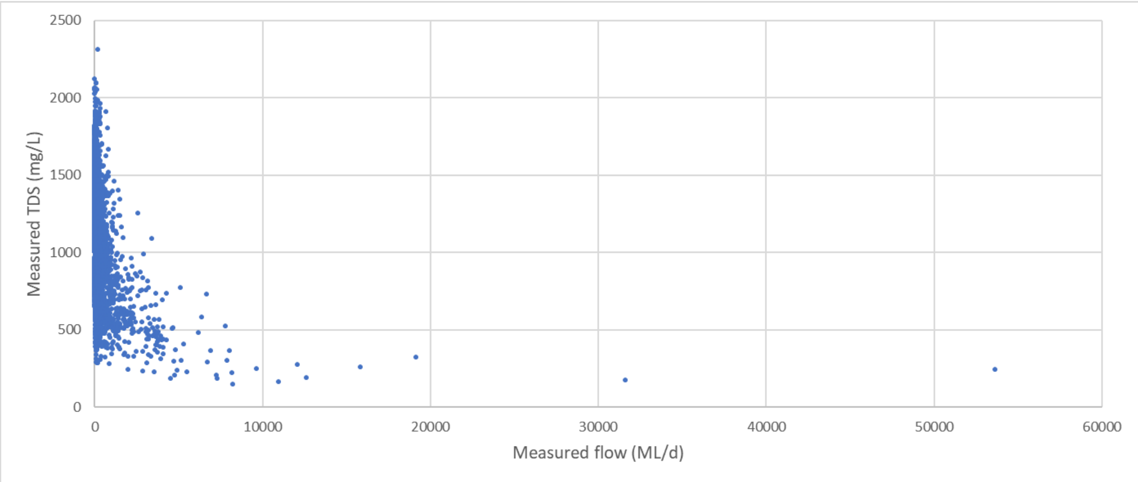

Figure 23. *Relationship between measured flow and salinity at the Barwon River at Pollocksford (Gauge ID: 233200)*

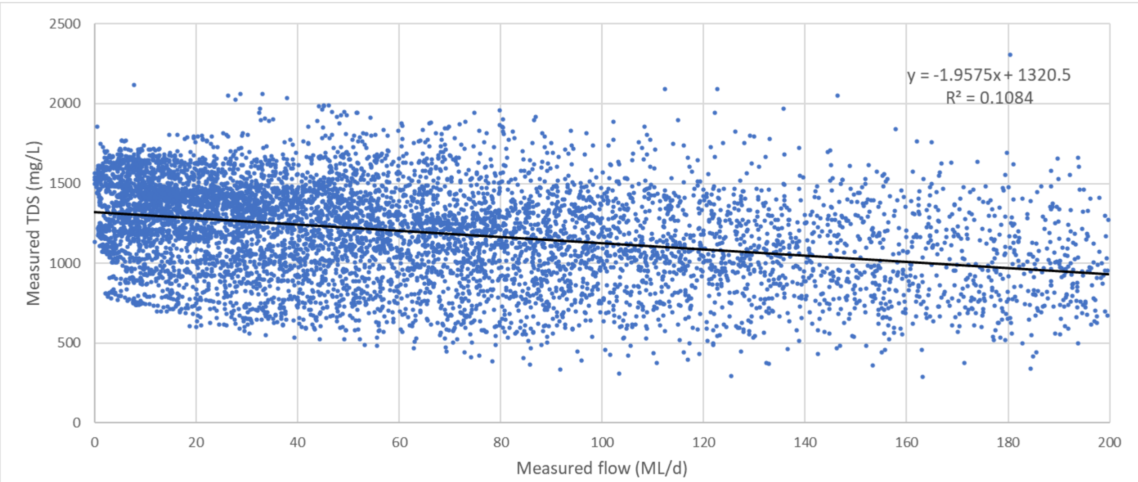

Figure 24. *Relationship used to infill salinity for flows below 200 ML per day at the Barwon River at Pollocksford (Gauge ID: 233200)*

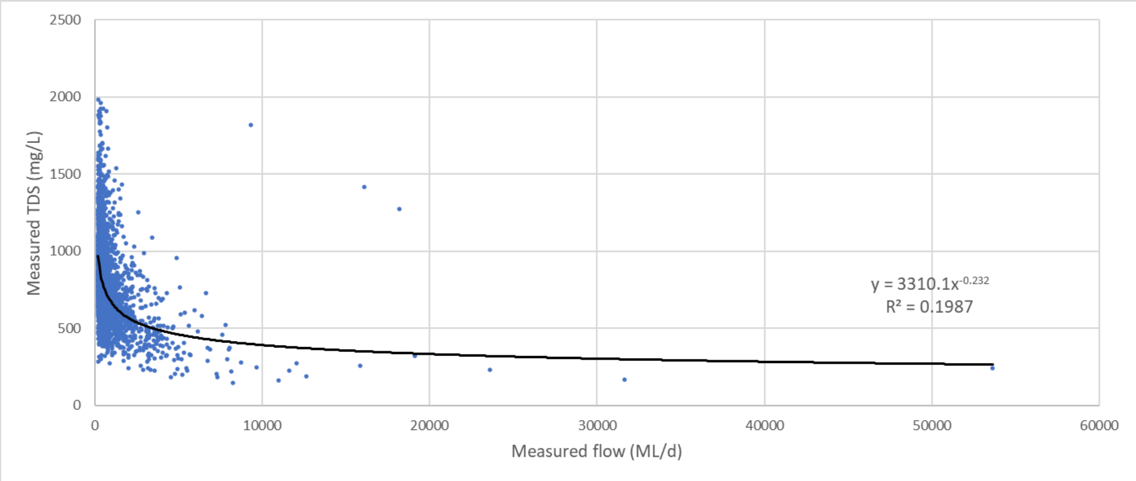

Figure 25. *Relationship used to infill salinity for flows above 200 ML per day at the Barwon River at Pollocksford (Gauge ID: 233200)*

Wetland configuration

The wetlands were represented in the Source model using storages under the historic baseline conditions (i.e. not considering the Sparrovale diversion).

It is important to understand how storages work within the Source model. A conceptual diagram of the storages/wetlands and their operation is presented in Figure 26, using the analogy of a bucket. The storage volume and surface area are specified for a range of storage depths. Inflows, rainfall, and potential groundwater interactions contribute to the filling of the bucket as well as bringing in quantities of salt. Water is lost through evaporation, and evaporation depends on the surface area of water. When the bucket is full, excess water spills over and into the downstream system.

The relationship between the wetland depth and the spillway discharge volume is required to operate this model. Additionally, management actions can be reflected through the operation of conceptual structures in the model such as a valve for the inlet or outlet channel. The volume of water that can be discharged from this valve can be defined in the model depending on the water level within the wetland. Similarly, management decisions can be implemented to open valves depending on the time of year or wetland levels.

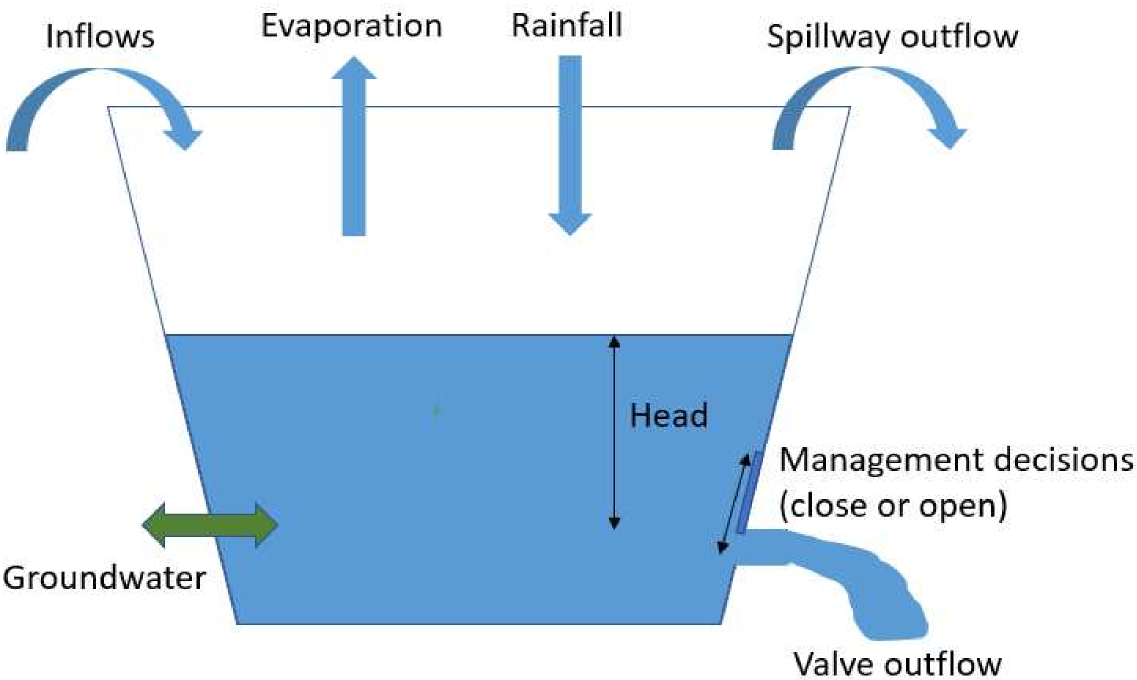

Figure 26. *Conceptual diagram of storage operation within the Source model*

The Barwon model included the “Barwon Weir” corresponding to the Barwon River upstream of the tidal barrage, which allowed for the managed diversion of water into both Reedy Lake and Hospital Swamp when river levels reach a suitable height (~0.7 m AHD). During large flow events, when river levels rise excessively high, uncontrolled spills into the wetlands and into downstream Lake Connewarre may occur. The wetlands can be managed through controlled releases, and likewise may spill downstream, when levels become excessively high. The make-up of this configuration is represented spatially in Figure 27.
Details of the stage-storage (depth, volume, and surface area) relationship for these wetlands was not readily available. To resolve this, we adopted LiDAR taken in the area to estimate the volumes and surface areas for the wetlands up to a level of 0.7 m AHD. We estimated the volume and surface area of the wetlands below this level up to the maximum depth of the wetlands, which was based on available literature. The derived stage-storage relationships for these wetlands are shown in Table 7, Table 8, and Table 9.

Information regarding the overflow characteristics of these wetlands is sparse and had to be inferred from the available river level and lake level data. Available water level data was utilised to infer the channel capacities into and out of Reedy Lake and Hospital Swamps, with reference made to the available literature (ALS, 2020). A description of this process is outlined in the model calibration.

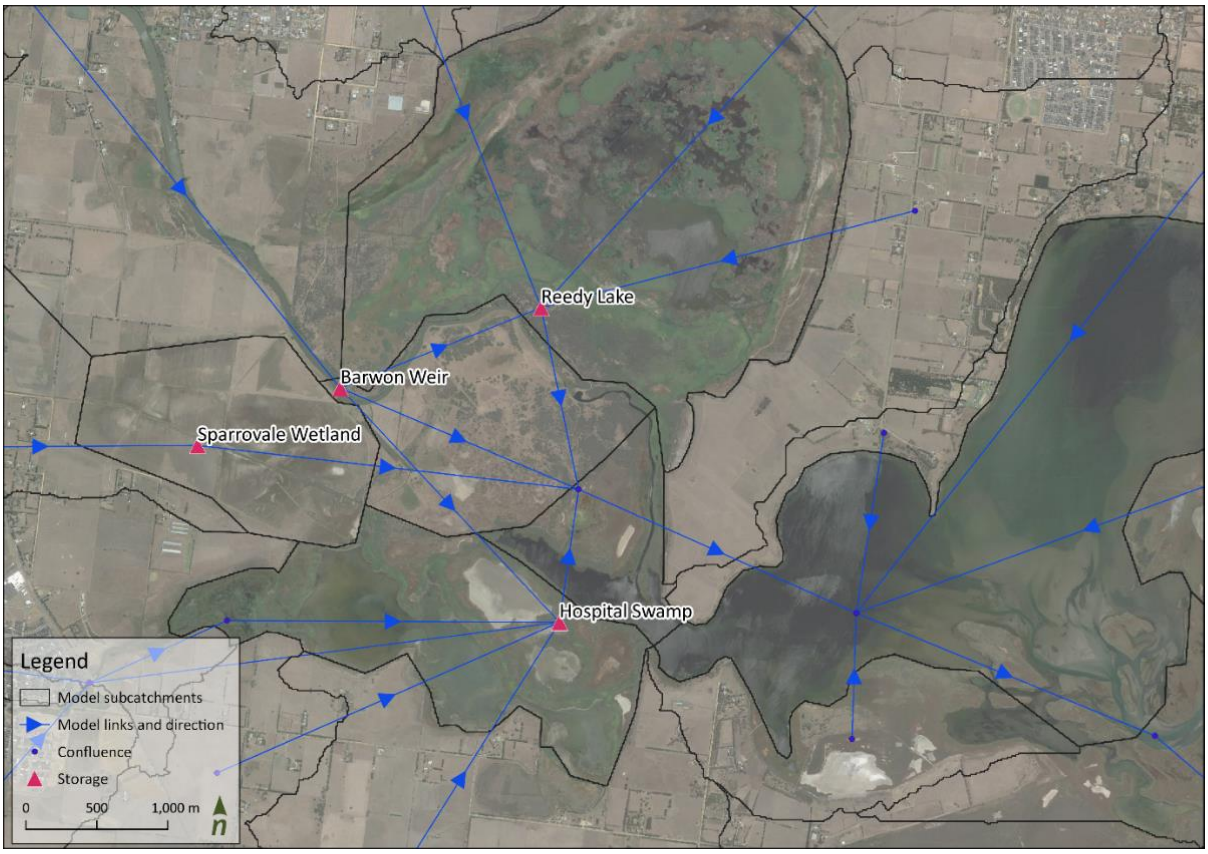

Figure 27. *Configuration of the wetlands under the baseline modelling case used in calibration*

Table 7. *Derived Reedy Lake stage-storage relationship*

Level (m AHD)	Volume (ML)	Surface Area (km^2)
0	0.0	0.00
0.1	142.8	1.46
0.2	340.5	2.02
0.3	593.1	2.58
0.4	900.7	3.14
0.5	1263.3	3.70
0.6	1680.8	4.26
0.7	2149.9	4.82
0.8	2673.1	5.39
0.9	3253.6	5.96
1	3887.1	6.50
1.1	4792.3	9.05

Table 8. *Derived Hospital Swamps stage-storage relationship*

Level (m AHD)	Volume (ML)	Surface Area (km^2)
0.2	0.0	0.10
0.3	126.6	0.30
0.4	276.7	0.90
0.5	450.3	1.77
0.6	647.5	2.01
0.7	868.2	2.25
0.8	1106.4	2.49
0.9	1376.5	2.79
1	1669.0	2.98
1.1	1976.8	3.12

Table 9. *Derived Sparrovale Wetland stage-storage relationship*

Level (m AHD)	Volume (ML)	Surface Area (km^2)
0.4	0.0	0.00
0.5	105.0	1.07
0.6	229.1	1.26
0.7	372.2	1.46
0.8	531.3	1.65
0.9	709.1	1.83
1	904.5	1.99
1.1	1112.4	2.11

Groundwater

As detailed below, CDM Smith provided information regarding the groundwater salinity concentration and the range of probable fluxes (groundwater flow rates) between the wetlands and the groundwater. Groundwater inflows to the wetlands were assigned a TDS value of 19,500 mg/L based on this advice.

The first step in evaluating the potential groundwater flux (in and out) of the wetlands was to review the existing geo-spatial and hydrological spatial data. This information was screened for features which can be related qualitatively and quantitatively to groundwater-surface water interaction. Surface features were extracted from satellite and areal images including vegetation and landform pattern, topography, the extent of the surface water in the wetlands, natural and artificial water courses and infrastructure (for example channels, weirs, drainages). The hydrogeology of the sites was identified through existing Victorian Aquifer Framework layers and groundwater data extracted from Visualising Victoria's Groundwater website, where available the sediments of the lake beds were defined through lithological logs of adjacent groundwater bores.

A calculation tool was setup in Excel to calculate a vertical Darcy based volumetric flux from the aquifer to each of the investigated wetlands, Reedy Lake, Hospital Swamp and Sparrovale Wetland (Figure 28). As shown in Figure 28, the calculation tool results in either a gaining wetland, where the surface water level is below the groundwater level, or a losing wetland, where the surface water is above the groundwater level.

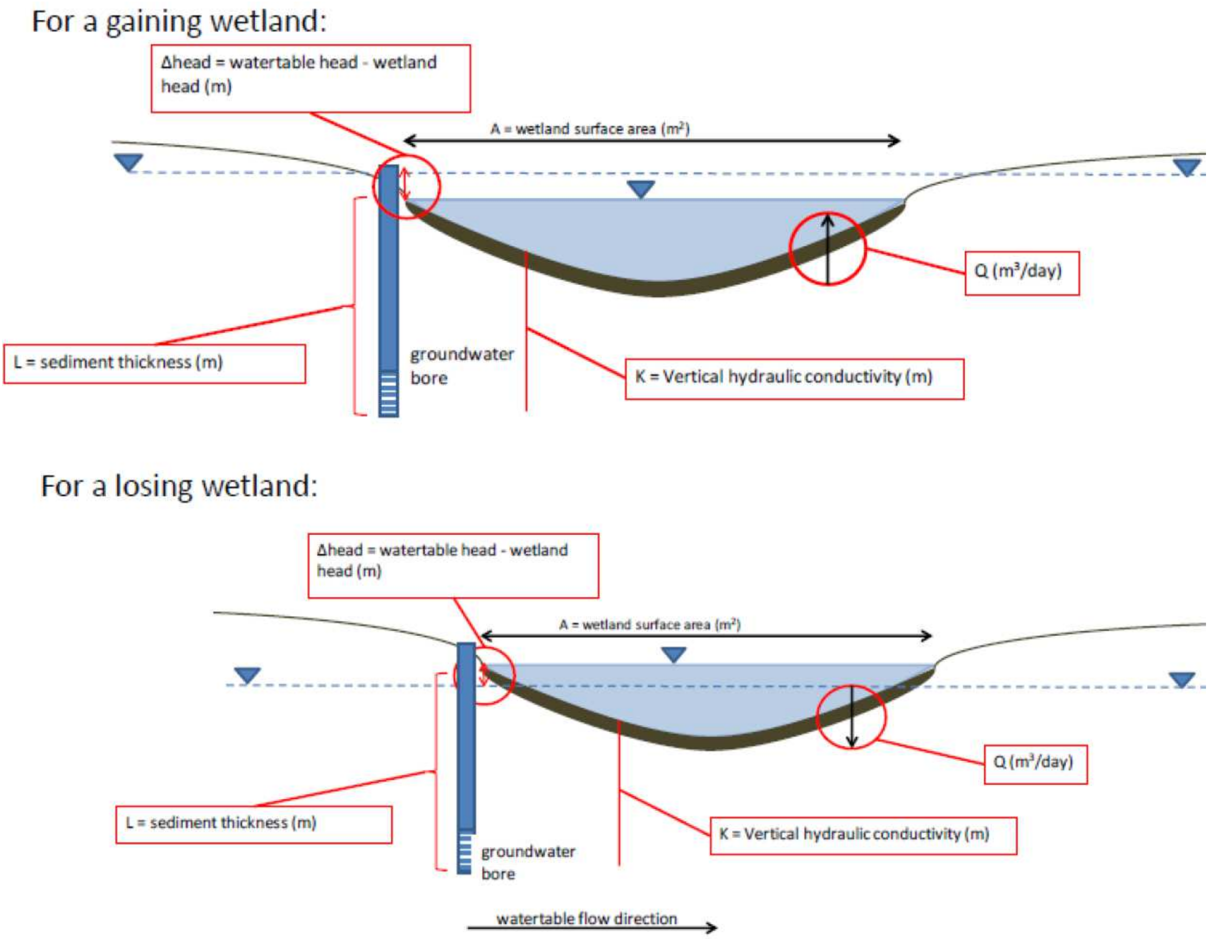

Figure 28 *Schematic view of the applied Darcy based vertical flux estimate between an aquifer and wetland as a vertical section.*

Horizontal hydraulic conductivity values were not readily available and were typically chosen through expert opinion based upon literature values. Where field measurements were available in a comparable hydrogeological setting and relative spatial proximity, those values where used. All adopted values are in line with published values for silty soils, the predominant classification in the area. Since vertical hydraulic conductivities are required for the calculation, an anisotropy factor of 10 was applied for piezometers placed in sedimentary conditions. No anisotropy was applied for those placed in Basalt.

For Reedy Lake and Hospital Swamps groundwater level data from several piezometers were available, many of them spatial spread around the wetland. Based on its location within the wetland, hydrogeology, assumed regional groundwater flow, behaviour of the groundwater time series and proximity to the Barwon River, 'areas of influence' on groundwater-surface water interaction on the wetland where delineated for each piezometer in relation to the total area covered by the wetland. Using Google Earth Pro for Reedy Lake, five areas were established in that way, while for Hospital Swamps two areas were delineated. This delineation was based on the wetted area with water levels of about 1.1m AHD. The areas were kept constant during the calculation of scenarios with different surface water levels. While this approach has the tendency to overestimate volumetric flows and hence the groundwater-surface water interaction, it is assumed that this error is small in comparison to extrapolation errors and the very limited knowledge of vertical hydraulic conductivities.

4 Salt-water balance modelling

4.1 Model Calibration

Model calibration is the process of fine tuning the accuracy of a predictive model. It is done by comparing modelled outputs (such as modelled streamflows) against real world data (such as data from a streamflow gauge) to see how closely they compare.

For this project, the salt-water balance was calibrated for water levels, streamflow, and salinity at several river and wetland locations. The calibration involved graphing a time series of streamflows (etc) to see how closely the modelled and observed results match, as well as statistical analysis such as calculating the coefficient of determination (R^2).

4.2 River flows

Most of the flows and salt loads in the lower river reaches of the Barwon River come from the upstream reaches. Only a minor portion of the flows and salt come from the river's subcatchments. This means that flows in the Barwon River at Geelong (Streamflow gauge ID: 233217; Figure 29) are largely determined by river flows in the upstream reaches of the Barwon (Gauge ID: 233200) and Moorabool Rivers (Gauge ID: 232202). Modelled stream flows were calibrated to gauge 233217 (Figure 30, Figure 31) and achieved a very close match.

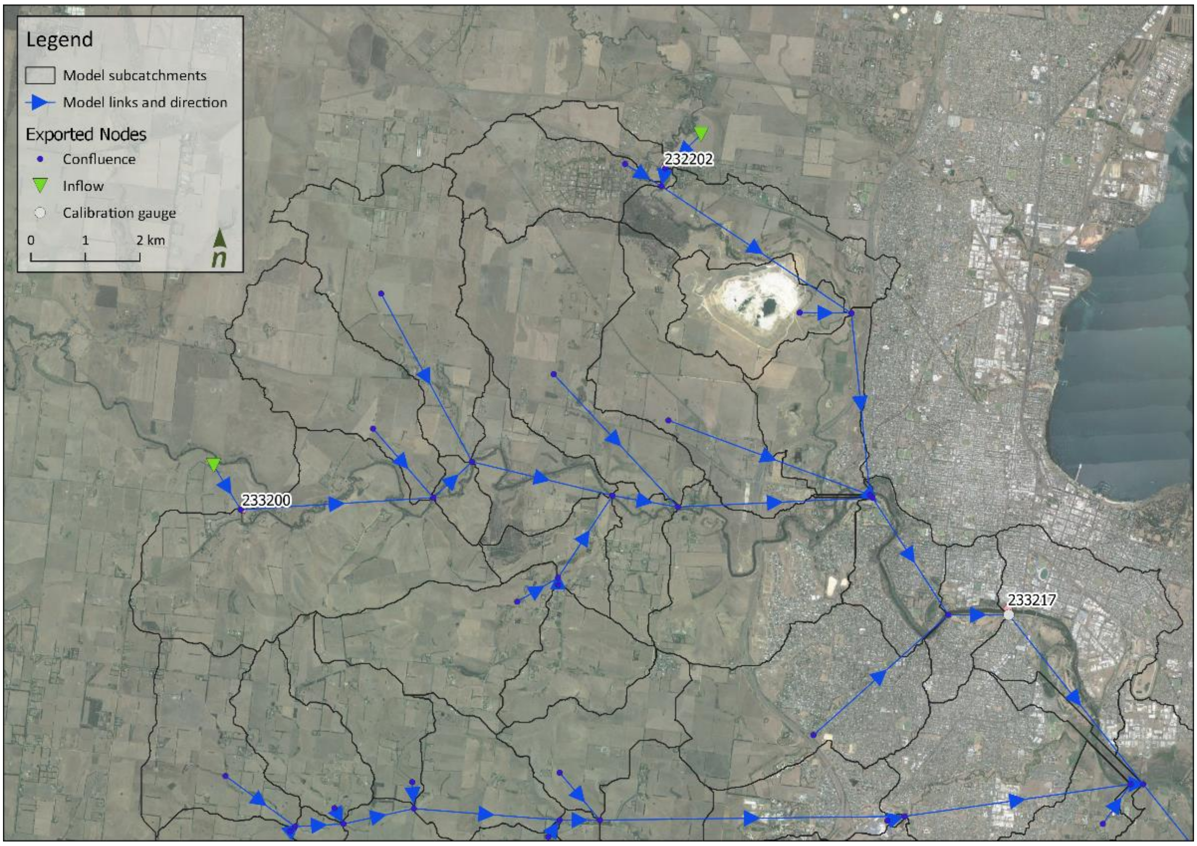

Figure 29. *Location of the model boundary inflows and the Geelong River gauge used for calibration*

To model salinity concentrations we developed a mathematical relationship between river flows and salt loads in the Barwon River at Geelong (Figure 31). We then used this relationship to calculate salinity concentrations for the Moorabool River, for which there was no available monitoring data. Using this process, we determined that the Moorabool River's salinity was 2,500 mg/L during low flows (< 50 ML/d), dropping to 1,000 mg/L as flows increase above this level. These calibration results also showed a good fit with measured data (Figure 31).

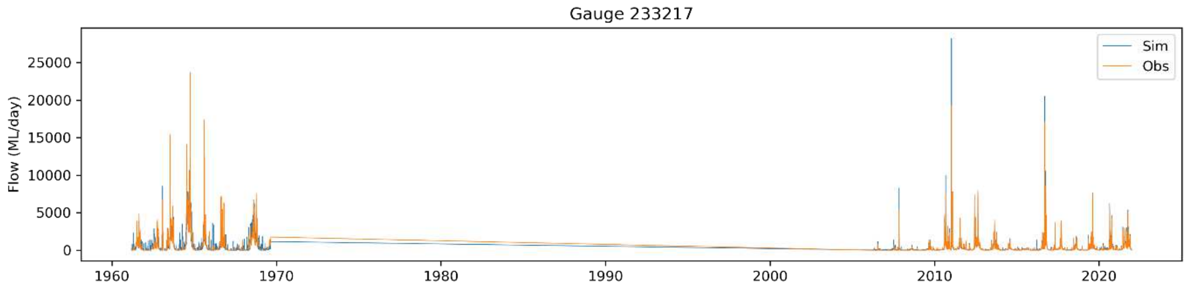

Figure 30. *Streamflow calibration for the Barwon River at Geelong (Gauge ID: 233217)*

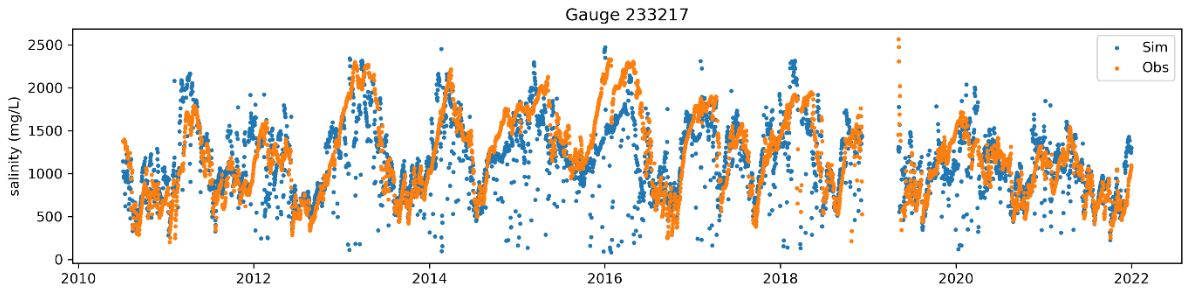

Figure 31. *Salinity calibration for the Barwon River at Geelong (Gauge ID: 233217)*

4.3 Barwon River upstream of the lower Barwon tidal barrage

The Barwon River upstream of the lower Barwon tidal barrage plays an important role in the functioning of the river-wetland system. It separates the fresh water reaches of the Barwon River from the saline, tidal waters of Lake Connewarre. Water can begin to flow into the wetlands when it reaches a level of 0.7 m AHD upstream of the barrage. The volume of water flowing into the wetlands is then driven by the head of the water behind the weir. Accurately representing this in the model was imperative for modelling the river flows into the wetlands.

To achieve this, we modelled the weir as a water storage filled from streamflow and emptied as water was released through the weir. As there was no recent bathymetry data for the weir pool, we iteratively adjusted the storage volume and the weir spillway volumes until we achieved a satisfactory calibration. We also assumed a linear relationship between water level and volume in the weir (Table 10). The calibration results show that the model is suitable for determining the volume of river flows that could be diverted to the wetlands (Figure 32, Table 10).

Table 10. *Calibrated stage storage relationship for the Barwon River at the weir*

Level (m AHD)	Volume (ML)
0	0
0.7	5400
0.86	6400
1.45	13100
1.8	18000

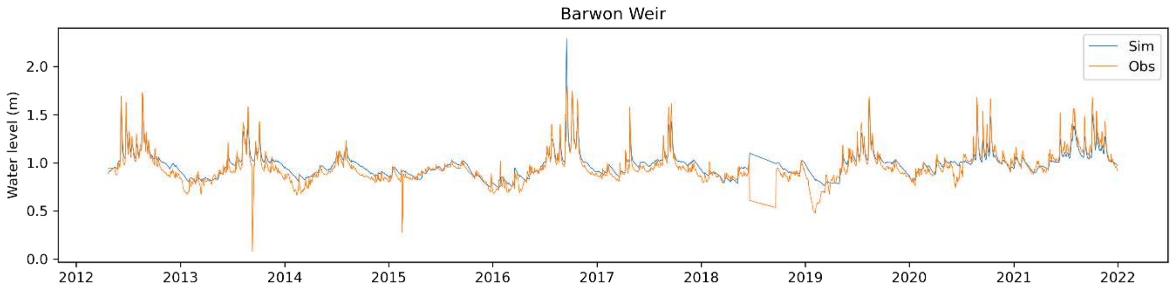

Figure 32. *Water level calibration at the Barwon Weir (Gauge ID: 233269)*

4.4 Wetlands

The wetlands were also modelled as storages. Wetland volumes were calculated using existing LiDAR, and the capacities of the inlet and outlet channels were estimated in consultation with water managers and using available literature (e.g. ALS, 2020).

Water can normally enter these wetlands via the inlet channels, however during floods, water overtops the Barwon River banks and flows directly into the wetlands. In the absence of information on the level of connectivity between the river and the wetlands, we calibrated the flood flows to observed increases in wetland water levels during flooding. When wetland water levels are very high, water also spills into Lake Connewarre. The flows into Lake Connewarre were estimated from the observed water level drawdowns after flooding.

The model also incorporated the local management recommendations for the operating structures on the inlet and outlet channels. In some years, water managers deviate from the recommended water regime to accommodate local weather or environmental conditions. For instance, 2019/20 was a planned 'full year' for Reedy Lake and the water level was kept elevated over summer. Over this period there was a good match between the observed and modelled data (Figure 33). Because 2020/21 was a wet year hydrologically, Reedy Lake could not be drawn down and water levels remained high over the following summer, which is an exception to the planned water regime. This operational flexibility could not easily be codified in the model, and instead we defaulted to an assumption that the 'typical' water regime applied in all years (Table 11).

Table 11. *Wetland watering regime adopted in the model*

	Reedy Lake	Hospital Swamp
Month of filling	May	May
Month of drawdowns	Dec - Feb	Dec - Feb
Desired full level (m)	0.8	0.5
Wet year every	4 years	10 years

The model was found to do a good job of matching the seasonal filling and drawdown patterns in both Reedy Lake and Hospital Swamps (Figure 33 and Figure 34), except when there is a change in the planned watering regime such as in 2021 (Reedy Lake) and 2020 (Hospital Swamps).

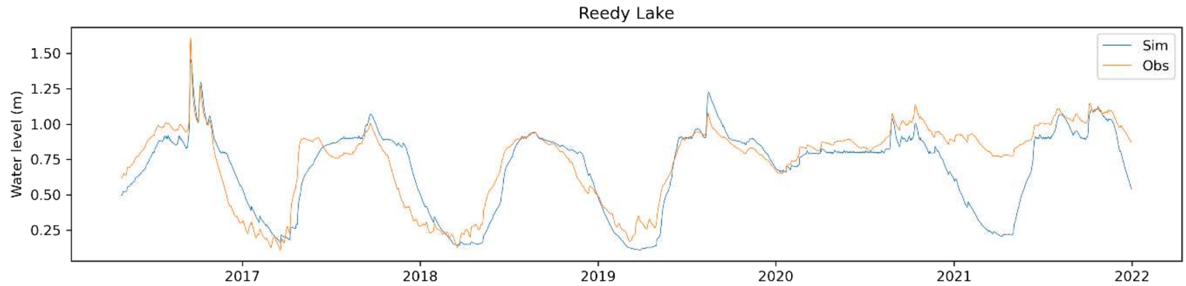

Figure 33. *Water level calibration at Reedy Lake (Gauge ID: 233603)*

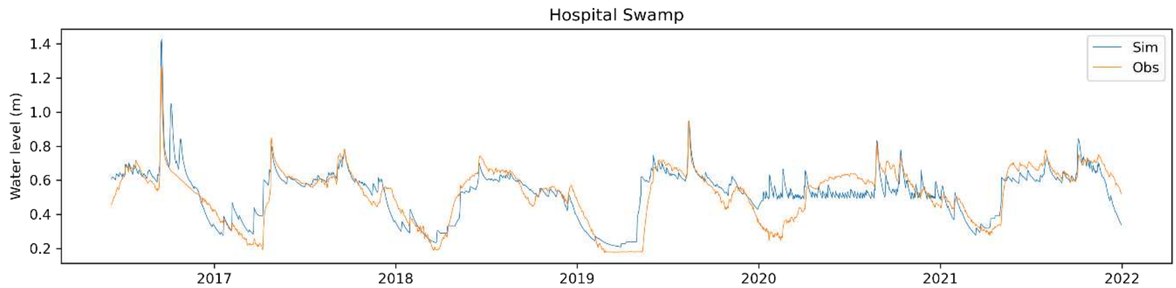

Figure 34. *Water level calibration at Hospital Swamps (Gauge ID: 233604)*

The process of water level calibration also allowed the drawdown process of the lakes to be applied to the model, with Source relying on water levels and channel capacities to guide the process. Due to the limitations on the Source model platform, the target drawdown of 7 cm per week (as per the advice in long-term watering recommendations of Lloyd et al. (2012)) is not able to be added directly into the models but are rather inferred during the calibration process. The inferred drawdowns are then represented through an inbuilt relationship that is able to be used to be amended to test changes to drawdown rates.

Salinity concentrations within the wetlands were calibrated next (Figure 31). During summer, salinity increases as water levels decrease (Figure 34 and Figure 35). This occurs because of:

- evaporation (which removes water but leaves salt behind),
- saline groundwater inflow (saline groundwater is a source of salt to the wetlands)
- tidal intrusion to the wetlands.

We developed a groundwater flux for a range of wetland water levels and calibrated it to wetland salinity concentrations over different seasons (Figure 35 and Figure 36). As the model was calibrated to wetland salinity levels that already incorporate the impacts of tidal intrusion on salinity, the model implicitly includes both sources of inflows. The only caveat is that the impacts of each source cannot be separated from one another in the model. Although the inflow of saline water has a large effect on the salinity of the wetland, we were unable to differentiate between groundwater inflows or tidal inflows in the model but ultimately this did not matter.

Note that the incorporation of tidal inflows in order to differentiate from groundwater and model the impacts from changes such as sea level rise requires a much higher level of complexity in the model that was out of scope for this project.

In summary, we are confident that the model accurately represents the salt-water balance of the Reedy Lake and Hospital Swamps, and their connections to the river system.

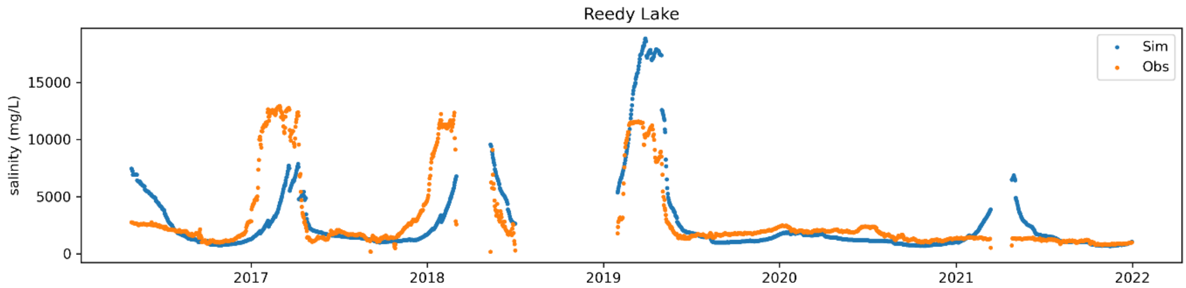

Figure 35. *Salinity concentration calibration at Reedy Lake (Gauge ID: 233603)*

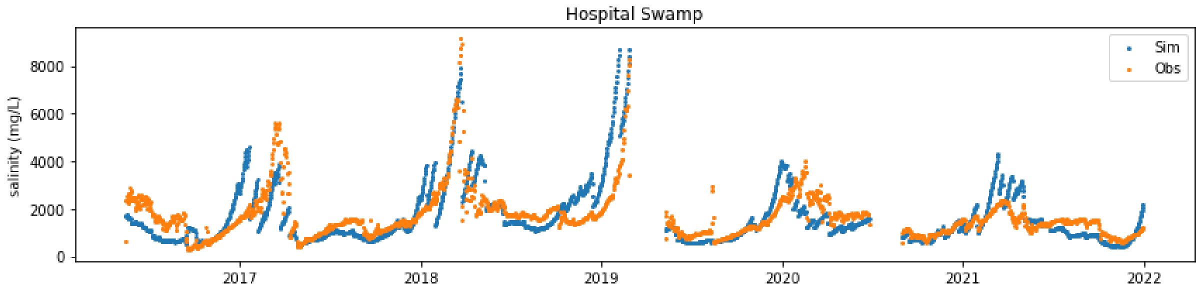

Figure 36. *Salinity concentration calibration at Hospital Swamps (Gauge ID: 233604)*

4.5 Salt-water balance scenarios

A series of scenarios were developed to investigate how the salt-water balance responded to broad scale operational, catchment characteristic and climatic changes. These scenarios create a set of best-case and worst-case results that act as 'book-ends' on the likely range of wetland responses. The scenarios were developed through consultation with the LBCAC and project members from Corangamite CMA, City of Greater Gelong and DELWP.

Developing and exploring these scenarios helps to understand the sensitivity of the salt-water balance to changes in variables. This information can be used to explore and design potential management options in the next stages of the project. The full set of scenarios is listed in Table 12.

Table 12. *Summary information of the scenarios considered in this modelling exercise*

#	Name	Detail	Additional assumptions
1	Calibration	The conditions built around the layout of the area prior to the inclusion of the Southern Diversion Channel, Sparrovale wetlands and the connection to Lake Connewarre. This is set up to compare pre-Sparrovale outputs to the pre-Sparrovale data from the gauged sources to ensure best fit calibration of the model. The detail of this set up is covered in Section 3 and Section 4	• Land use applied from the 2016 spatial distribution • Daily rainfall and evapotranspiration taken from SILO database • Rainfall-runoff model SimHyd used to generate expected daily inflow from within the catchment boundary • Boundary inflows for streamflow and salinity from the Moorabool River at Batesford (Gauge ID: 232202) and the Barwon River at Pollocksford (Gauge ID: 233200) supplemented by existing modelling for gaps in data • Details of the stage-storage (depth, volume, and surface area) relationship developed from LiDAR • Groundwater inflow relationship developed from local piezometers • Model was calibrated to gauge 2332017 (Barwon River at Geelong) • Fill from May, drawdown Dec – Feb (based on calibrated relationship), 4- and ten-year cycles based on the updated recommendations of the Lower Barwon Review 2020 (Alluvium, 2020) More information is available in Section 3 and Section 4 of this report
2	Updated conditions	This scenario takes the Calibration scenario (1) and updates the model setup to include Southern Diversion Channel, Sparrovale wetlands, the connection to Lake Connewarre and the associated DRAFT management recommendations	• Southern Diversion Channel capacity assumed equal to 110 ML/day • Addition of the Diversion through to Sparrovale • Diversion occurs from Dec – May and diverts all water up to the channel capacity • Excess flows from Armstrong Creek discharged to Hospital Swamps

#	Name	Detail	Additional assumptions
3	Urban development	Using the updated conditions scenario (2) an increase in urban development is applied	• Change in the urban footprint of Armstrong Creek from approximately 31% urban to 83% urban
4	Permanently full	Using the updated conditions scenario (2) management decisions are applied to maintain filled levels in Reedy Lake and Hospital Swamps	• Wetland drawdowns no longer occur, with the goal of maintaining full wetlands year round • Outlet from wetlands to Lake Connewarre no longer operated in the model
5	2012 Long Term Flows	Based on the updated conditions scenario (2) with the addition of the increased drying in 3rd year	• Water levels were reduced to 0 m AHD every fourth year in Reedy Lake
6	Climate Change	Based on the updated conditions scenario (2) with updates based on climate change details discussed in Section 2	• Median changes predicted for evaporation, rainfall, and streamflow under the RCP8.5 scenario for 2065 were incorporated in the model • Resulted in a 7% increase to evaporation and 5.2% decrease in rainfall
7	Higher Drawdown – December start	Based on the updated conditions scenario (2) with drawdown increased to 200% (simulating 14cm per week)	• The modelled drawdown rate (volume of water) was doubled and began in December • The change in drawdown was applied through a proportionate amendment to the drawdown relationship developed through calibration • The relationship was increased to 200% based on the inverse of the reduced drawdown of Scenario 9 and 10. The lower drawdown of 50% in Scenario 9 and 10 was the application of the recommended 3.5 cm per week taken from the Technical Memorandum for the Waterbird Monitoring at Lower Barwon Wetlands (Weller, 2022), being half the existing 7cm per week
8	Higher Drawdown – February start	Based on the updated conditions scenario (2) with drawdown increased to 200% and started in February (simulating 14 cm per week)	• The modelled drawdown rate (volume of water) was doubled and began in February • The change in drawdown was applied through a proportionate amendment to the drawdown relationship developed through calibration • The relationship was increased to 200% based on the inverse of the reduced drawdown of Scenario 9 and 10. The lower drawdown of 50% in Scenario 9 and 10 was the application of the recommended 3.5 cm per week taken from the Technical Memorandum for the Waterbird Monitoring at Lower Barwon Wetlands (Weller, 2022), being half the existing 7cm per week

#	Name	Detail	Additional assumptions
9	Lower Drawdown – December start	Based on the updated conditions scenario (2) with drawdown rate reduced to 50% (simulating 3.5cm per week)	• The modelled drawdown rate (volume of water) was halved and began in December • The change in drawdown was applied through a proportionate amendment to the drawdown relationship developed through calibration • The relationship was reduced by 50% of the existing 7cm per week drawdown (taken from the recommendations of Lance Lloyd et al (2012)). 50% is based on the application of the of the recommended 3.5 cm per week taken from the Technical Memorandum for the Waterbird Monitoring at Lower Barwon Wetlands (Weller, 2022).
10	Lower Drawdown – February start	Based on the updated conditions scenario (2) with drawdown rate reduced to 50% and started in February (simulating 3.5cm per week)	• The modelled drawdown rate (volume of water) was halved and began in February • The change in drawdown was applied through a proportionate amendment to the drawdown relationship developed through calibration • The relationship was reduced by 50% of the existing 7cm per week drawdown (taken from the recommendations of Lance Lloyd et al (2012)). 50% is based on the application of the of the recommended 3.5 cm per week taken from the Technical Memorandum for the Waterbird Monitoring at Lower Barwon Wetlands (Weller, 2022).
11	Urban Development + Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 3 and 6	• Combination of the changes to urban area in Armstrong Creek and climate change • The modelled drawdown rate (volume of water) was doubled and began in December. The change in drawdown was applied through a proportionate amendment to the drawdown relationship developed through calibration • The relationship was increased to 200% based on the inverse application of the of the recommended 3.5 cm per week taken from the Technical Memorandum for the Waterbird Monitoring at Lower Barwon Wetlands (Weller, 2022). 200% was used as it represents the opposite change to the change made for Scenario 7 and Scenario 8 (i.e., 3.5/3.5 rather than 7/3.5) to show the range of potential impacts
12	2012 Long Term Flows + Climate change	Based on the updated conditions scenario (2) with the combined changes of scenarios 5 and 6	• Combination of the changes made to adhere to the flow recommendations and climate change

#	Name	Detail	Additional assumptions
13	Permanently full + Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 4 and 6	• Combination of the changes made to keep the wetland permanently full and climate change
14	Expanded Diversion	Based on the updated conditions scenario (2) with management decisions changed case scenario to add in the standard CoGG diversion recommendations for May to December (at reduced capacity) – in addition to the existing December to May diversion	• The DRAFT management recommendations for the Armstrong Creek diversion were revised so that 50% of the flow capacity were diverted to Sparrovale Wetlands from May to December. This was in addition to 100% of the flow capacity being diverted from December to May.
15	Expanded Diversion + Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 6 and 14	• Consists of the updated diversion management with the impacts of climate change considered
16	Expanded Diversion + Urban Development	Based on the updated conditions scenario (2) with the combined changes of scenarios 3 and 14	• Consists of the updated diversion management with the impacts of urbanisation considered
17	Expanded Diversion + Urban Development + Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 3, 6, and 14	• Consists of the updated diversion management with the impacts of urbanisation and climate change considered
18	50% Diversion	Based on the Expanded Diversion scenario (14) with a reduced capacity to 50% over the whole year	• 50% of the flows down Armstrong Creek were diverted to Sparrovale Wetlands through the Southern Diversion Channel (providing channel capacity was not exceeded) all year round
19	Permanent flow through	Based on the updated conditions scenario (2) with management decision changes to attempt to maintain Reedy Lake as a flow through system year-round and Hospital Swamps as a flow through in winter/spring	• Inflow and outflow channels to and from the wetlands were left open in the model between May and December in Hospital Swamps and year-round Reedy Lake with no additional management changes
20	Permanent flow through+ Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 6 and 19	• Flow through system was modelled with the impacts of climate change considered

#	Name	Detail	Additional assumptions
21	Permanent flow through+ Urban Development	Based on the updated conditions scenario (2) with the combined changes of scenarios 3 and 19	• Flow through system was modelled with the impacts of urbanisation considered
22	Permanent flow through + Urban Development + Climate Change	Based on the updated conditions scenario (2) with the combined changes of scenarios 3, 6, and 19	• Flow through system was modelled with the impacts of urbanisation and climate change considered

5 Hydrologic conditions

To aid the analysis of the modelling results, periods of wet, dry, and average hydrological conditions were identified to isolate periods of specific interest. This identification was undertaken through two methods: one to isolate single years, and the second to isolate longer windows of time.

5.1 Single year assessment

The single year assessment involved splitting the period of modelling into individual water years (1 July to 30 June). The total river discharge from each water year was calculated and the threshold for the lowest and highest 20% of years determined. These years were then delineated as 'dry' and 'wet' years, respectively, with the remaining 60% of water years delineated as 'average' (Figure 37). We then compiled modelled run data into their respective bins of different hydrologic conditions, which were used to determine summary statistical measures.

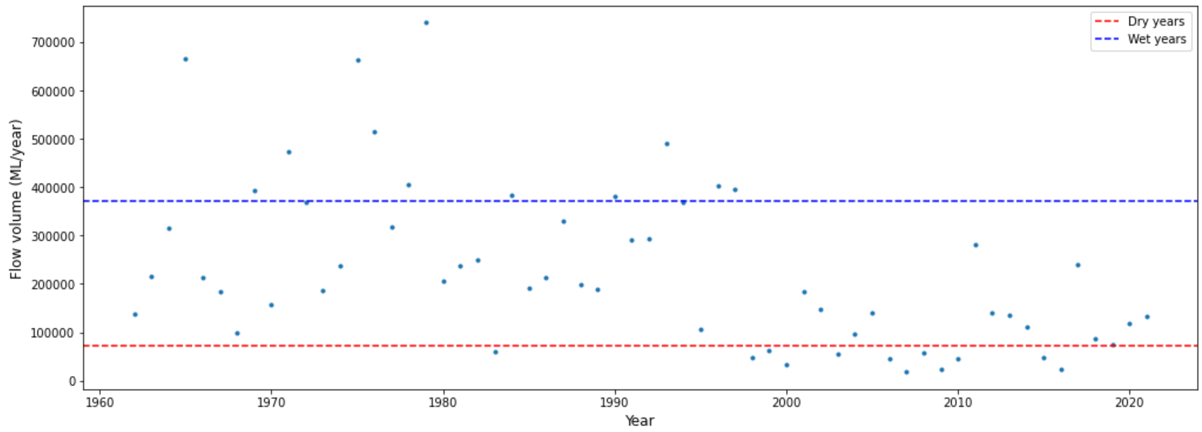

Figure 37. *Delineation between 'wet' and 'dry' water years using the modelled river flows at Geelong, with years falling above the blue line constituting a wet year, and years below the red line constituting a dry year*

5.2 Multi-year assessment

The second method of assessment identified wet, dry and average periods based on the gauged flow data for the Barwon River at Geelong (Gauge 233217) (DEWLP, 2022). The annual flows at Geelong were used to determine the total flow for each water year from July 1960 to June 2020 to compare yearly volumes.

Using an 8-year rolling average of flows, the highest and lowest average flow period, along with the period that was closest to the total average, were isolated and used for further analysis (see Table 13). Using this method, the hydrological periods are shown in Figure 38 were defined.

Table 13. *Hydrological period definitions*

Hydrologic period	Start date	End date
Wet years	1 July 1971	30 June 1979
Average years	1 July 1981	30 June 1989
Dry years	1 July 2002	30 June 2010

Based on this assessment, the identified windows of wet, dry, and average conditions have been used to assess the results of the various scenarios.

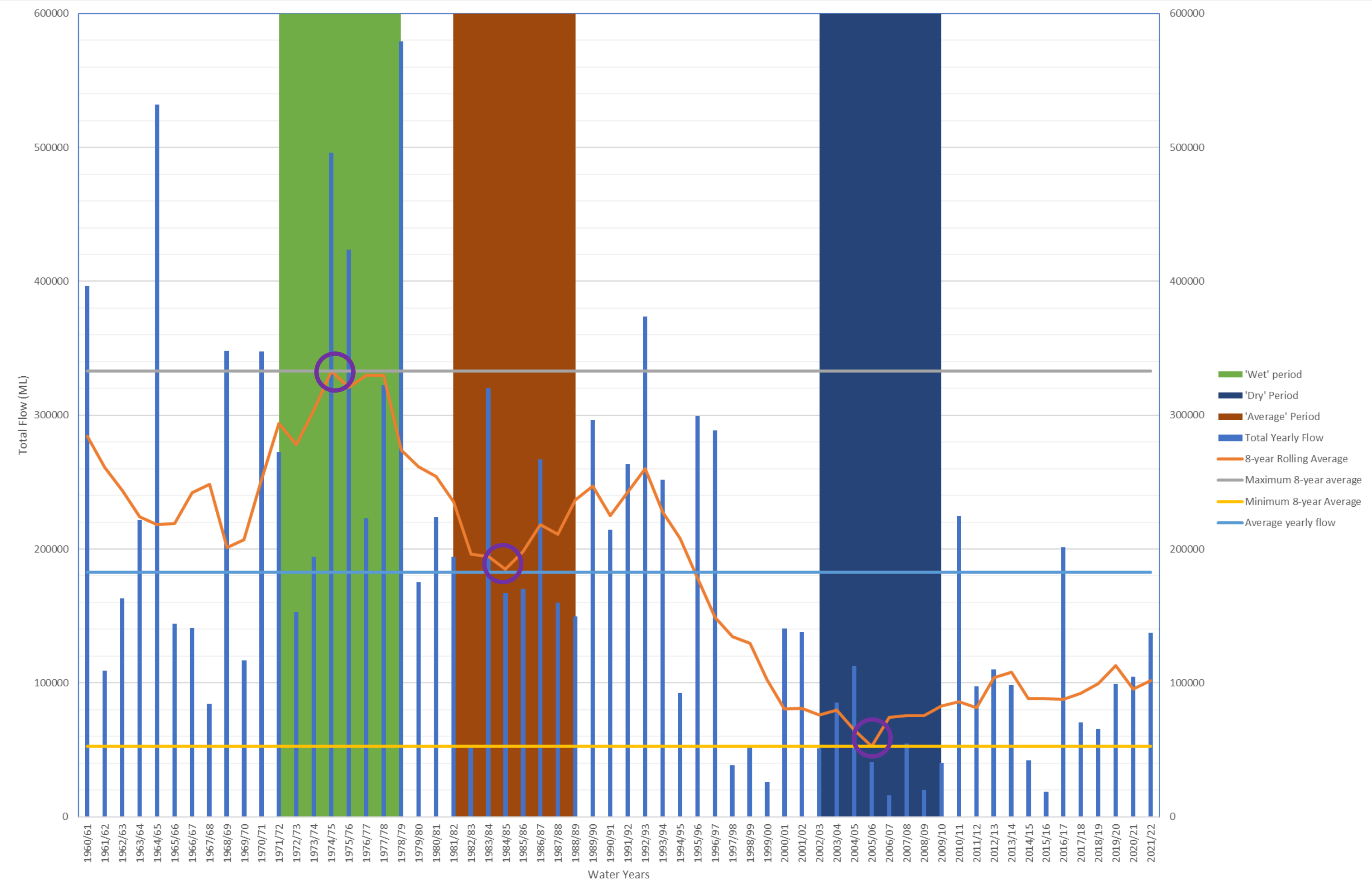

Figure 38. *Display of hydrological year selection, using average yearly inflows and 8-year rolling average. Purple circles indicate the point in the rolling average that resulted in the wet, dry and average period identification*

6 Modelling results

Note that further detail on the modelling results is provided in Attachment 1.

6.1 Summary of results

The results of the modelling showed that the wetlands of Reedy Lake and Hospital Swamps are quite reactive to short term management decisions. The balance between salt and water is shown to be reliant on the balance of inflows and outflows, whether from fresher sources such as the Barwon River and stormwater runoff, or more saline sources such as groundwater.

The rapid impact of changed inflows is shown in the Urban Development scenario (Scenario 3), where runoff increases from the increased imperviousness which in turn is highly reactive to the hydrological conditions of the time. Management actions which led to the largest increases in salinity were those that limited the water levels and flows into the wetlands. Increasing the drawdown rate or reducing catchment inflows (Hospital Swamp due to the Sparrovale diversion scheme) were the most effective measures for increasing salinity. Decreasing drawdown and maintaining full wetlands worked to reduce concentrations. Depending on the prevailing weather conditions and desired salinity levels within the wetlands, a combination of the management actions described in this report could be adopted.

6.2 Calibration comparison

For this analysis the baseline case (Scenario 1 - Calibration) has been compared to the Updated Conditions scenario (Scenario 2), which involved the implementation of the Armstrong Creek diversion into Sparrovale Wetlands. The results of implementing this Southern Diversion Channel on TDS is presented in Figure 70. Implementing the diversion results in a considerable increase in the range of TDS concentrations within Hospital Swamps because of receiving reduced freshwater inflows from Armstrong Creek. With less catchment inflows occurring, the influence of the saline groundwater becomes more apparent. Significantly higher concentrations are noted during the summer months (December to May) during which the diversions take place (Figure 39).

Results are not presented for Reedy Lake under this scenario as the Armstrong Creek diversion channel had no influence on the operation or TDS within Reedy Lake.

All additional scenarios assessed involved the implementation of the Southern Diversion Channel and as such, this scenario was adopted as the baseline against which the additional scenarios have been compared and reported below.

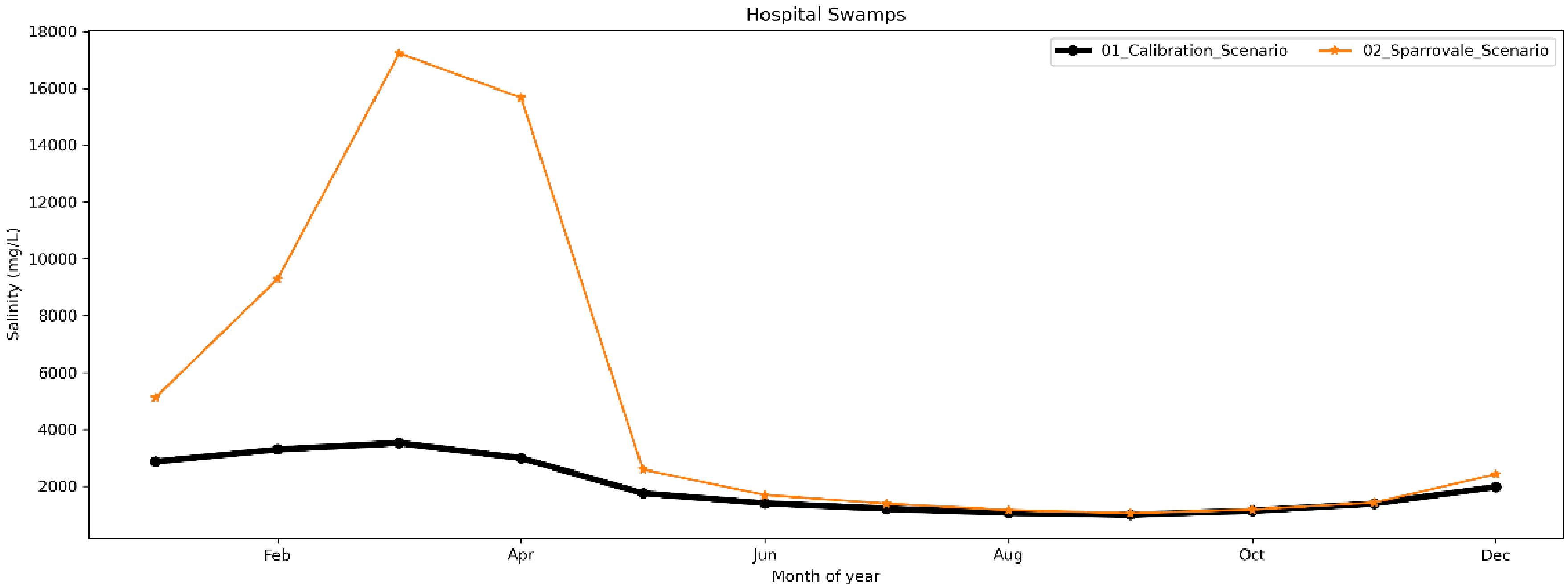

Figure 39. *Comparison of average monthly TDS concentrations within Hospital Swamps between the calibration and Armstrong Creek diversion channel scenarios*

6.3 Scenario comparison

Note that 'fiddle plot' representations of the distribution of results are in Attachment 1.

Urban development within the Armstrong Creek catchment was found to decrease TDS concentrations within Hospital Swamps and especially in Sparrovale Wetlands, but not within Reedy Lake, which does not receive inflows from the Armstrong Creek catchment (see Attachment 1). The impacts of climate change have an opposing impact due to decreased catchment runoff, which leads to a reduction in dilution. Maintaining full wetlands leads to a reduction in TDS concentration in both wetlands. The impacts of changes to the timing and magnitude of drawdowns was found to have variable results, as discussed below.

The expanded diversion scheme scenario (Scenario 14) involved diverting an additional 50% of all flow from Armstrong Creek outside the typical diversion period considered (Dec to May). This increased TDS concentrations in Hospital Swamps (Figure 72), which would be expected given the reduction of inflows to the wetland. The impacts of climate change and urbanisation with this revised operation scheme are likewise shown, with climate change resulting in an increase in TDS, whereas urbanisation decreases TDS.

Changing the wetlands to operate as flow-through systems leads to a much larger range of TDS concentrations within the wetlands. In this change the inlet and outlet channels to and from the wetlands were left open in the model between May and December in Hospital Swamps and year-round Reedy Lake with no additional operating rules set. The change was likely due to the wetlands constantly filling and draining, which resulted in lower river levels. When river levels dropped (notably during the dry season), filling of the wetland was not possible due to the lessoned water availability. However due to the flow-through setup the wetlands still drained so that water levels decreased. This then generated a build-up of salinity due to groundwater inflows and evaporative losses. These results are considered in more detail below.

We note here that the scenarios that have been modelled are not intended to act as recommendations or be considered likely future management scenarios. The intention of the scenarios run as part of this project are to test the sensitivity of the wetland TDS concentrations to various changes. These tests are often through running more extreme scenarios to exaggerate the change to ensure a substantial impact can be assessed. We note that the key outcome of the project is the water salt balance model that is able to be used in future work such as the planned FLOWS study.

Table 14. *Summary statistics for TDS (mg/L) at Hospital Swamps from each of the model scenario runs*

	Scenario	Max	Min	Mean	Median	q60	q70	q80	q90
1	Calibration	20810	331	1958	1450	1753	2153	2740	3858
2	Updated conditions	147750	370	4986	1934	2447	3507	6526	12472
3	Urban development	98143	206	3680	1316	1785	2499	4283	8927
4	Permanently full	15931	379	2542	2174	2588	3041	3601	4711
5	2012 Long Term Flows	243751	370	5327	2062	2660	3926	7081	12907
6	Climate Change	1287149	396	6507	2131	2710	3992	7588	14446
7	Higher Drawdown – December start	31662041	0	13486	1662	2121	3037	6209	14771
8	Higher Drawdown – February start	38744	367	3411	1744	2187	2895	4452	8648
9	Lower Drawdown – December start	31945	380	4076	2351	2968	3803	6276	10720
10	Lower Drawdown – February start	21398	380	3440	2474	3194	3914	5044	7883

	Scenario	Max	Min	Mean	Median	q60	q70	q80	q90
11	Urban Development + Climate Change	311553	226	4635	1464	1983	2831	4933	10380
12	2012 Long Term Flows + Climate change	1287149	396	6505	2131	2710	3990	7588	14437
13	Permanently full + Climate Change	21172	396	3039	2532	3010	3540	4292	5645
14	Expanded Diversion	186972	383	5579	2413	2980	4240	7249	13243
15	Expanded Diversion + Climate Change	1191751	0	7153	2694	3329	4888	8432	15387
16	Expanded Diversion + Urban Development	157638	248	4216	1789	2300	3026	4774	9540
17	Expanded Diversion + Urban Development + Climate Change	2334035	243	5671	1998	2567	3468	5618	11202
18	50% Diversion	15150	383	2385	1994	2326	2710	3287	4534
19	Permanent flow through	21479	380	3110	1287	1898	3203	5360	8549
20	Permanent flow through+ Climate Change	20814	364	2576	1141	1559	2510	4034	6780
21	Permanent flow through+ Urban Development	24312	396	3528	1386	2154	3701	6253	9793
21	Permanent flow through + Urban Development + Climate Change	23377	376	2935	1213	1775	2914	4724	7907

Table 15. *Summary statistics for TDS (mg/L) at Reedy Lake from each of the model scenario runs*

	Scenario	Max	Min	Mean	Median	q60	q70	q80	q90
1	Calibration	38633	442	2886	1602	2022	2737	4064	6987
2	Updated conditions	39589	442	2910	1610	2035	2773	4135	7060
3	Urban development	39385	442	2900	1607	2031	2759	4104	7029
4	Permanently full	15642	442	1565	1171	1326	1581	1973	2736
5	2012 Long Term Flows	32100	442	2099	1270	1451	1696	2247	4492
6	Climate Change	84519	471	3873	1899	2515	3634	5577	9220
7	Higher Drawdown – December start	39997	439	2992	1649	2104	2946	4692	7224
8	Higher Drawdown – February start	22340	439	2140	1453	1752	2212	2922	4383
9	Lower Drawdown – December start	31380	445	2578	1539	1894	2521	3474	5691
10	Lower Drawdown – February start	23537	445	1880	1364	1604	1952	2470	3563
11	Urban Development + Climate Change	84024	471	3857	1894	2503	3605	5539	9203
12	2012 Long Term Flows + Climate change	156322	471	4270	1894	2515	3638	5607	9526
13	Permanently full + Climate Change	30870	472	2114	1316	1543	1931	2667	4019
14	Expanded Diversion	39867	442	2917	1611	2036	2781	4153	7073
15	Expanded Diversion + Climate Change	85086	471	3889	1901	2521	3652	5609	9246
16	Expanded Diversion + Urban Development	39638	442	2907	1609	2032	2764	4117	7043
17	Expanded Diversion + Urban Development + Climate Change	84637	471	3866	1895	2504	3618	5553	9219
18	50% Diversion	31575	442	2515	1516	1859	2422	3386	5592
19	Permanent flow through	1074148	452	23374	2364	3474	5920	12273	38224
20	Permanent flow through+ Climate Change	1074148	452	23374	2364	3474	5920	12273	38224
21	Permanent flow through+ Urban Development	5882186	503	61537	4054	6209	11803	27487	104257
21	Permanent flow through + Urban Development + Climate Change	5882186	503	61537	4054	6209	11803	27487	104257

Initial scenarios

An initial grouping of scenarios consisted of scenarios with little to no management change occurring. The scenarios considered included Scenario 2 (Updated Conditions), Scenario 6 (Climate Change), and Scenario 18 (50% Diversion) model runs and were evaluated on a monthly basis in Figure 40 and Figure 41 for Reedy Lake and Hospital Swamps, respectively.

Scenario 2 acts as the baseline for comparison, with the climate change scenario (Scenario 6) highlighting the likely future conditions with no change in approach.

The reduced capacity scenario (Scenario 18) demonstrates the impact of an alternate diversion arrangement for Armstrong Creek, whereby 50% of all flows from the creek (within channel capacity) are diverted year-round to Sparrovale instead of all flows from December to May (noting that Scenario 14 allows 50% of the flow capacity were diverted to Sparrovale Wetlands from May to December in addition to 100% of the flow capacity being diverted from December to May). Scenario 18 resulted in a decrease in TDS concentrations within Hospital Swamps in summer (due to reduced diversion of flows) and increase in winter (due to an increase in diverted flows), though the decrease in summer was appeared more substantial. No changes were seen in Reedy Lake due to this change being focused on the Southern Diversion Channel operation .

Climate change resulted in increased TDS concentrations throughout all months of the year as a result of reduced streamflow and catchment runoff.

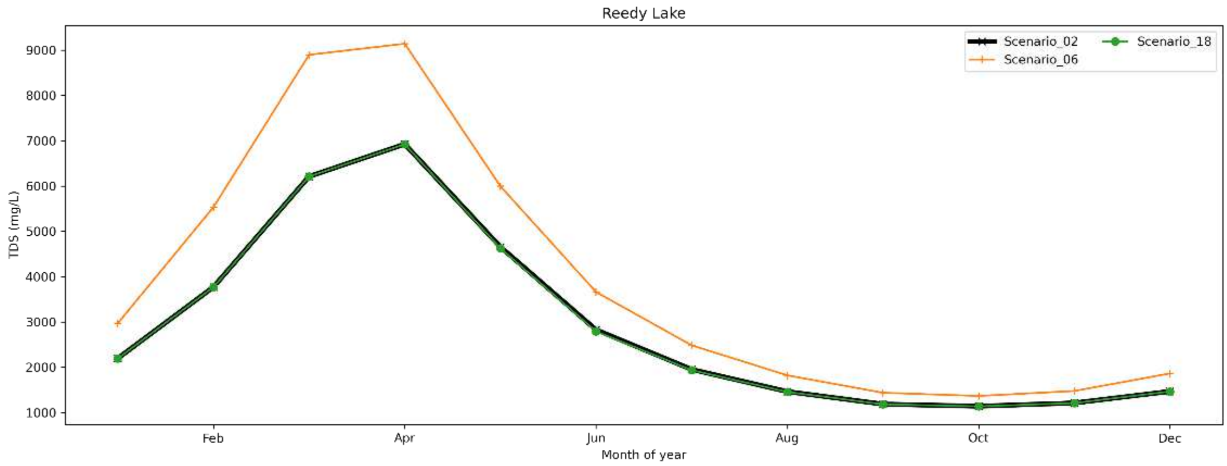

Figure 40. *Average monthly TDS concentration at Reedy Lake under scenarios 2, 6, and 18*

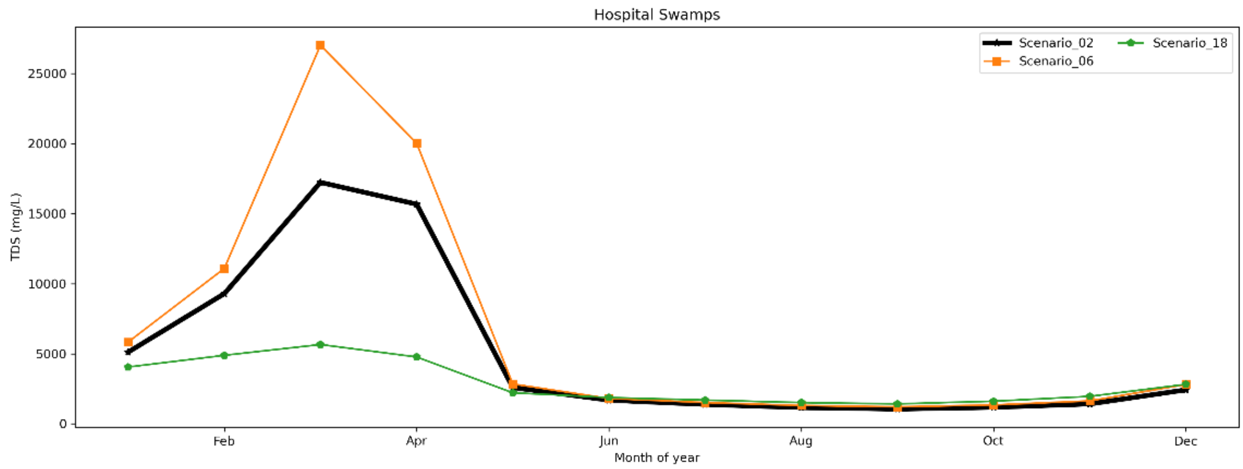

Figure 41. *Average monthly TDS concentration at Hospital Swamps under scenarios 2, 6, and 18*

Urban development scenarios

The urban development scenarios (Scenarios 3 and Scenario 11) are grouped in Figure 42 to show changes to mean monthly TDS concentrations resulting from increased urbanisation in the Armstrong Creek catchment under current and predicted future climatic conditions. It is important to note that the urban development scenario is focussed on the Armstrong Creek catchment and as such the results did not impact on Reedy Lake. Due to this, only the results for Hospital Swamps are discussed.

TDS concentrations decreased in all months of the year with increased urban development This was due to larger volumes of stormwater runoff from the catchment owing to increased impervious areas from urbanisation. The relatively fresh water dilutes the saltier water of Hospital Swamps, lowering salinity concentrations in the wetland. As previously noted, the impacts of climate change have an antagonistic impact, resulting in an increase in salinity concentrations due to reduced runoff and by extension reduced dilution. When urbanisation and climate change are considered in combination, there are minor changes relative to the baseline scenario, indicating that they have potential to cancel each other out.

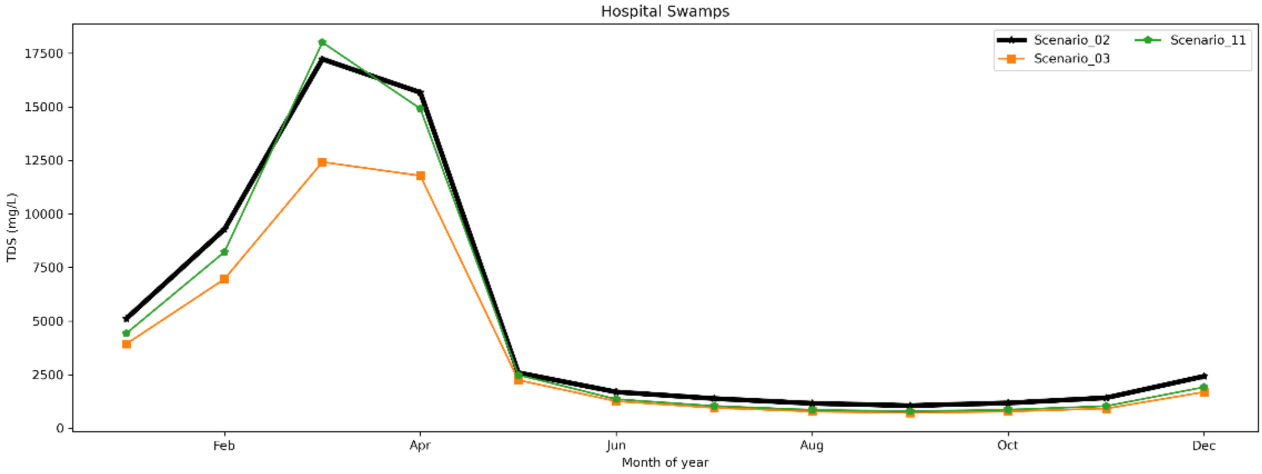

Figure 42. *Average monthly TDS concentration at Hospital Swamps under scenarios 2, 3 and 11*

Permanently full scenarios

The permanently full scenario grouping (Scenario 4 and Scenario 13) shows the changes resulting from attempting to maintain Reedy Lake and Hospital Swamps permanently full under current (Scenario 4) and future climatic conditions (Scenario 13). The results indicate a reduction in overall salinity at Reedy Lake, where the summer/autumn peaks don't occur to the same degree as they do under the updated conditions of Scenario 2, with the relatively fresh inflows from the Barwon River reducing the TDS concentration of the lake (Figure 43).

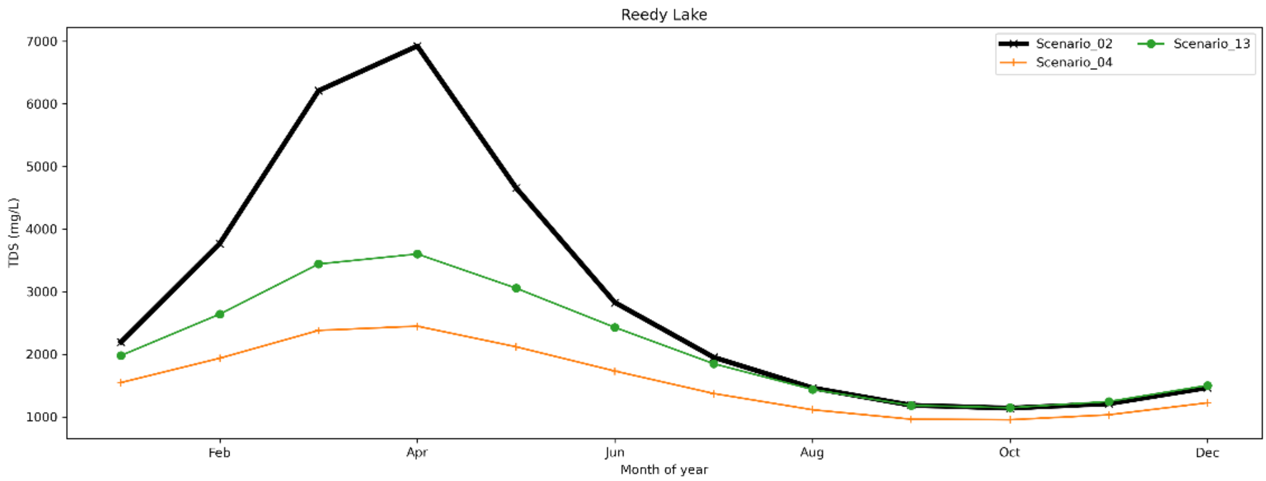

Figure 43. *Average monthly TDS concentration at Hospital Swamps under scenarios 2, 4, and 13*

The monthly results at Hospital Swamps shows a similar change in TDS to Reedy Lake, with a considerable decrease in salinity over the summer months when drawdowns typically occur, and an increase over the winter months, which did not occur at Reedy Lake.

The slightly different responses of the two wetlands to these scenarios relates to differences in how they were considered in the model. When attempting to maintain full levels, inflows are made to the wetlands when the water levels drop below a target level (0.8 m AHD in Reedy Lake and 0.5 m AHD in Hospital Swamps), providing water levels are sufficient in the Barwon River. Outflows from the wetlands are effectively cut off unless the wetlands overtop. In calibrating the model, it was assumed that there was some degree of water movement between Reedy Lake and Lake Connewarre starting from 0.8 m AHD. As such, water levels tended to equalise at this level (Figure 45 and Figure 46) with regular inflows and outflows moving water and salt through the system. By contrast, there was no connectivity between Hospital Swamps and Lake Connewarre until levels passed 0.5 m AHD, which was the target level for this wetland, and therefore more limited water movement through the wetland. We assumed that flushing of Hospital Swamps only occurred during large streamflow events. This effectively led to a slight build-up of salt over time due to evaporation, although this build up was negligible when compared to the baseline conditions in the summer months, when groundwater inflows become an important driver of concentrations.

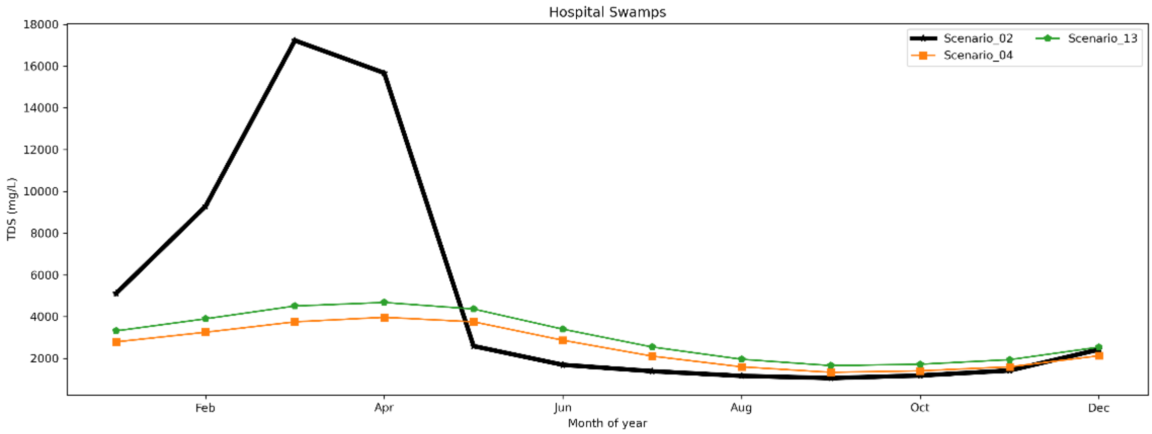

Figure 44. *Average monthly TDS concentration at Hospital Swamps under scenarios 2, 4, and 13*

Water within Reedy Lake remains at low TDS concentrations during periods when fresh river water flows to the system, however during periods of scarcer water supply, TDS increases as a result of evaporative losses and limited flushing. This trend becomes visible when comparing the wet periods of 1971/72 - 1978/79 (Figure 45) against the dry period of 2002/03 – 2009/10 (Figure 46). In the wet periods the depth at Reedy Lake is maintained at a higher level, with only a few brief periods when the storage drops below 0.8 m AHD (that coincided with increases in salinity). When this is compared to drier periods, the residual salt mass is able to play an increased role in overall salt concentration of the water body. The dry periods show the impact that evaporative loss has on TDS concentrations, with larger drops in water level resulting in greater TDS peaks. This is particularly evident in 2006, 2008, and 2009 (marked with arrows).

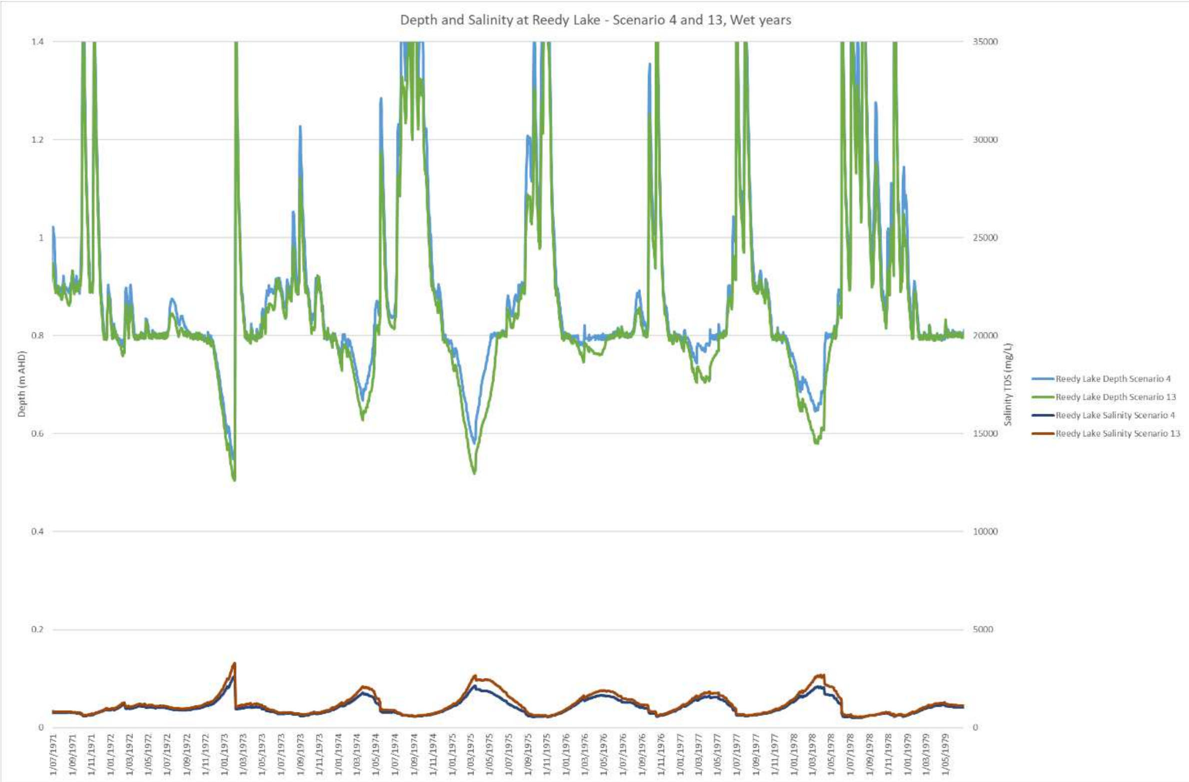

Figure 45. *Depth and Salinity at Reedy Lake - Scenario 4 and 13, Wet years*

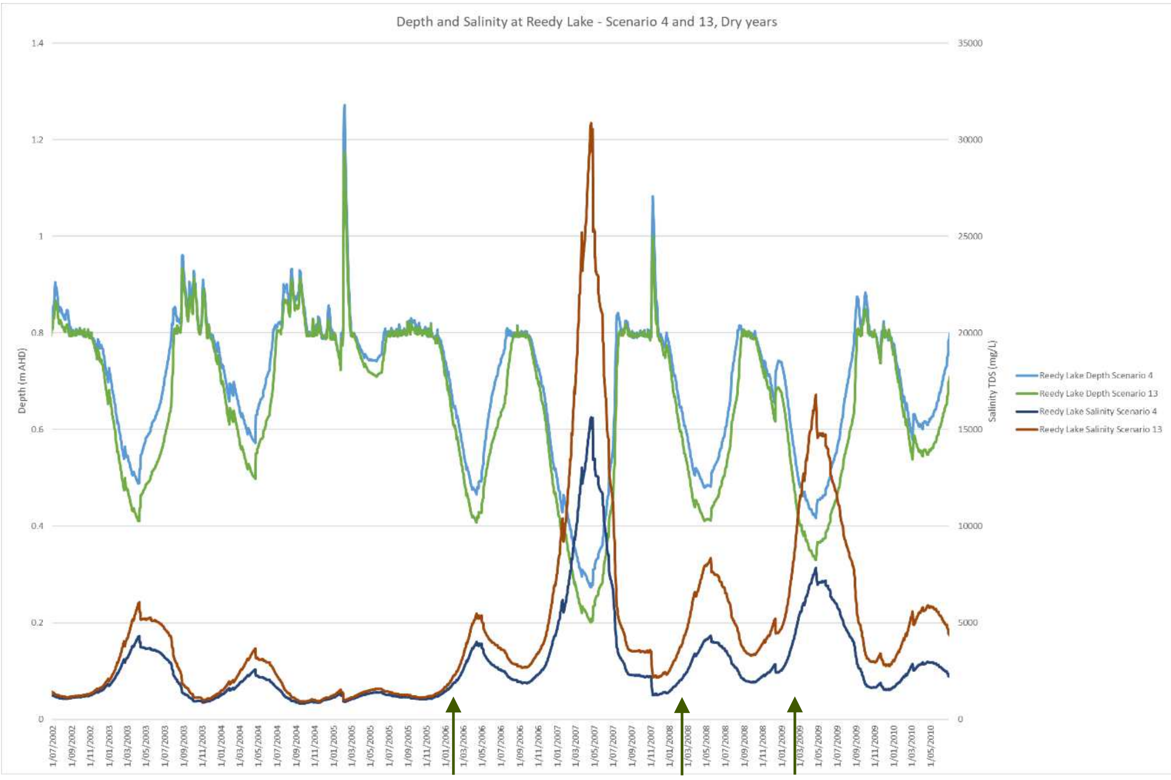

Figure 46. *Depth and Salinity at Reedy Lake - Scenario 4 and 13, Dry Years. Arrows show a build up of TDS over time – refer to report main body for detail*

The change at Hospital Swamps is a product of the lessened prospect of spills from the wetland. The reduced spilling means there is a reduced 'flushing' of the wetland, resulting in a build-up of salt quantities over time. The different influence is most pronounced in the wet years (Figure 47) when levels are maintained at 0.5 m AHD. With no outflows occurring from spills, the periods of constant depth (with inflows that include TDS quantities topping up evaporative loss) results in steady increases in salinity. Periodic flushing from natural sources acts as the flush salt from the system, though this impact is reduced in the climate change scenario where rainfall is reduced. In the drier years the impact becomes even more pronounced (Figure 48).

The trend identified in the Hospital Swamps outputs is mirrored in the statistical outputs shown in the violin plots of Attachment 1 (Figure 71) and the outputs shown in **Table 14**. Both of these outputs show a trending to a higher average TDS, with the current climate showing a minor shift in the maximum TDS but a more noticeable shift in the mean, and the climate change scenario (where rainfall is reduced) moved to become of one of the most saline scenarios for Hospital Swamps.

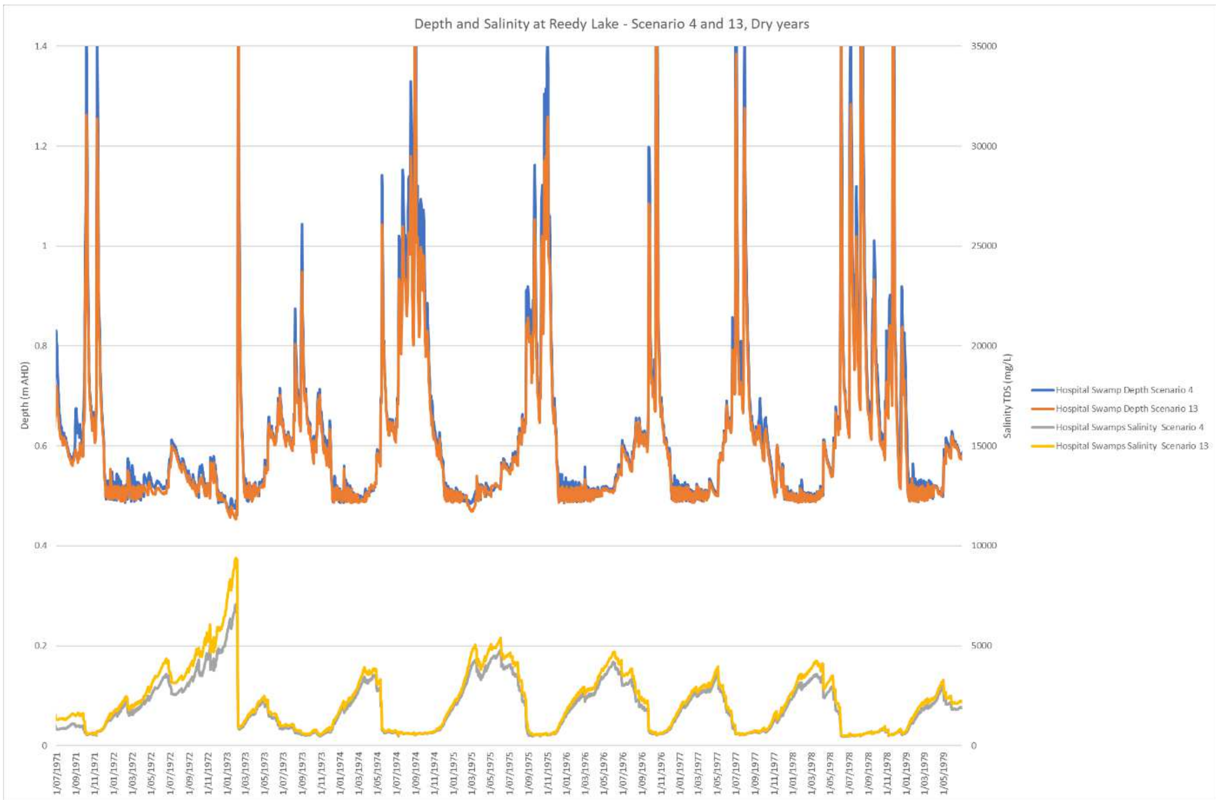

Figure 47. *Depth and Salinity at Hospital Swamps - Scenario 4 and 13, Wet Years*

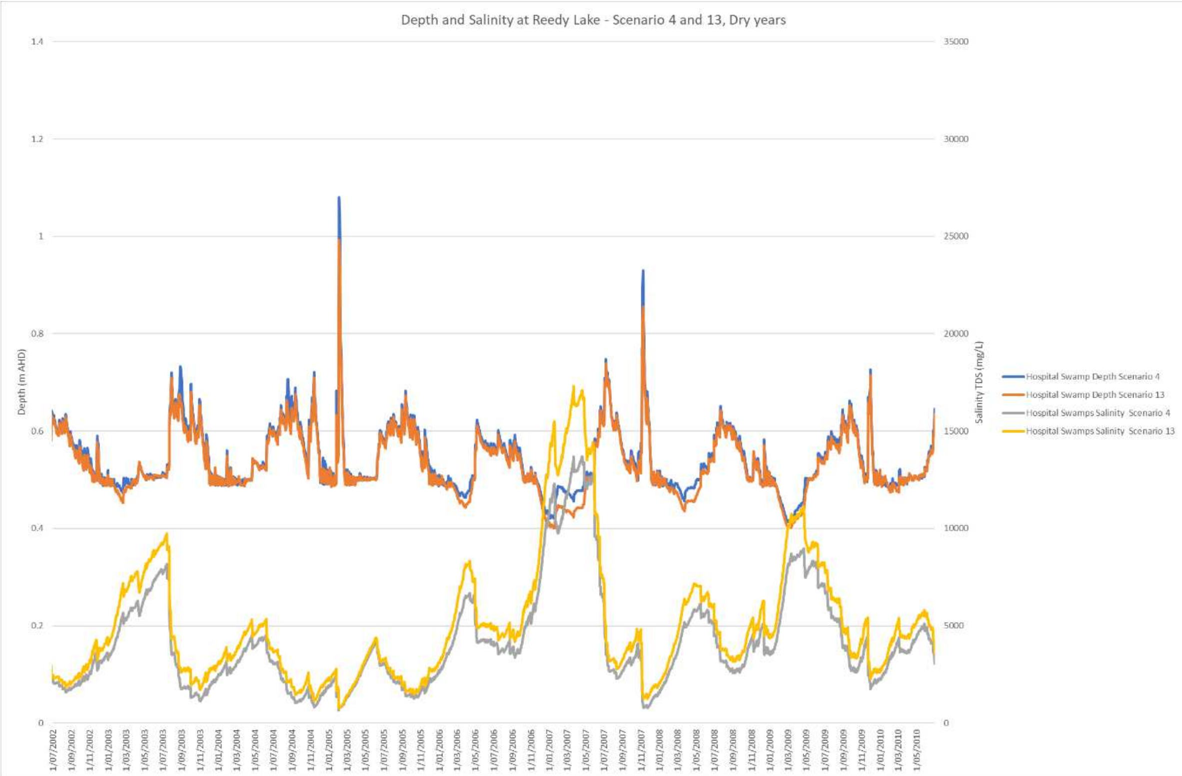

Figure 48. *Depth and Salinity at Hospital Swamps - Scenario 4 and 13, Dry Years*

2012 Long Term FLOWS recommendations

The 2012 Long Term FLOWS recommendations scenarios (Scenario 5 and Scenario 12) sought to test the 2012 FLOWS Study target of including a full drawdown year in the 4-year cycle in (Lloyd et al, 2012), and then tested this under climate change conditions. Implementation of the 2012 Long Term FLOWS recommendations increased average TDS concentrations within Reedy Lake over summer and spring when drawdowns occur (Figure 49), due to the drying out of the lake every fourth year, resulting in increased salinity. Climate change had an opposing impact, leading to increased TDS throughout the year in both wetlands.

Note that the 2012 Long Term FLOWS changes only applied to Reedy Lake, and therefore there was no change to the results for Hospital Swamps (see Figure 50).

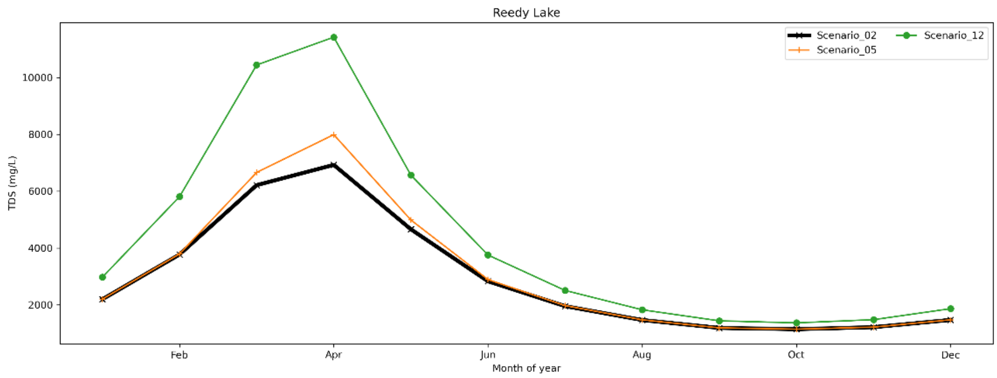

Figure 49. *Average monthly concentration at Reedy Lake under scenarios 2, 5, and 12*

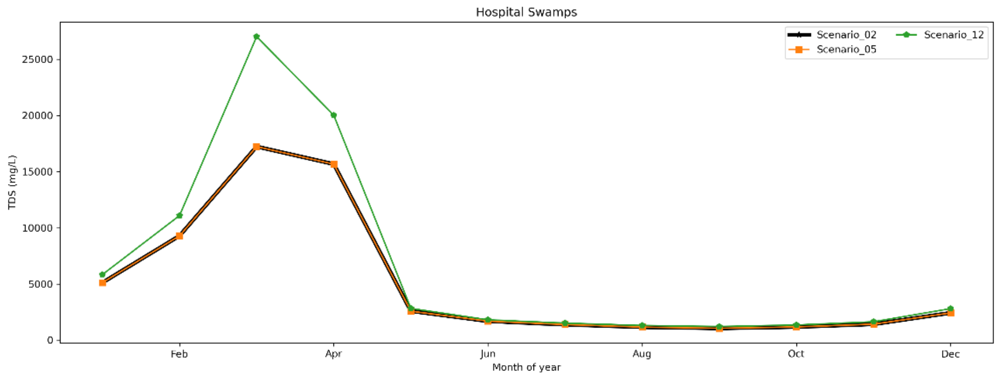

Figure 50. *Average monthly concentration at Hospital Swamps under scenarios 2, 5, and 12*

Changed drawdown conditions

Variations in the drawdown targets incorporated in the model were tested, using variations of increased and decreased drawdown rate (200% and 50% of the calibrated drawdown relationship respectively), in combination with changes to the timing of the drawdown start date (starting in December or February). These changes resulted in 4 unique combinations that were tested;

- Higher Drawdown (200% simulating 14cm per week) – December start (Scenario 7)
- Higher Drawdown (200% simulating 14cm per week) – February start (Scenario 8)
- Lower Drawdown (50% simulating 3.5cm per week) – December start (Scenario 9)
- Lower Drawdown (50% simulating 3.5cm per week) – February start (Scenario 10)

Average monthly TDS concentrations for each scenario are shown in Figure 51 (Reedy Lake) and Figure 52 (Hospital Swamps), while the seasonal variations in water level are shown in Figure 53 and Figure 54.

As a result:

- Scenario 7 has a higher drawdown from December, so concentrations are able to increase immediately, and remain higher until May
- Scenario 8 has a higher drawdown rate, so concentrations are higher than Scenario 10, but are not able to catch the Scenario 2 comparison
- Scenario 9 has a lower drawdown rate so even though the start time is the same, TDS is not able to rise as high as Scenario 2
- Scenario 10 combines the late start and the slow drawdown and as a result maintains the lowest TDS concentration
- All scenarios appear to return to the average over winter

Within Reedy Lake and Hospital Swamps, decreasing the drawdown rate relationship led to decreased TDS concentrations (when compared to the same start time), particularly during the drawdown period. Ultimately the actions that move water out of the wetlands, through drawing down earlier or faster, reduces the water levels and increases TDS concentrations. Starting the drawdown earlier appears to have a greater impact on the TDS concentration as the wetlands are emptier sooner.

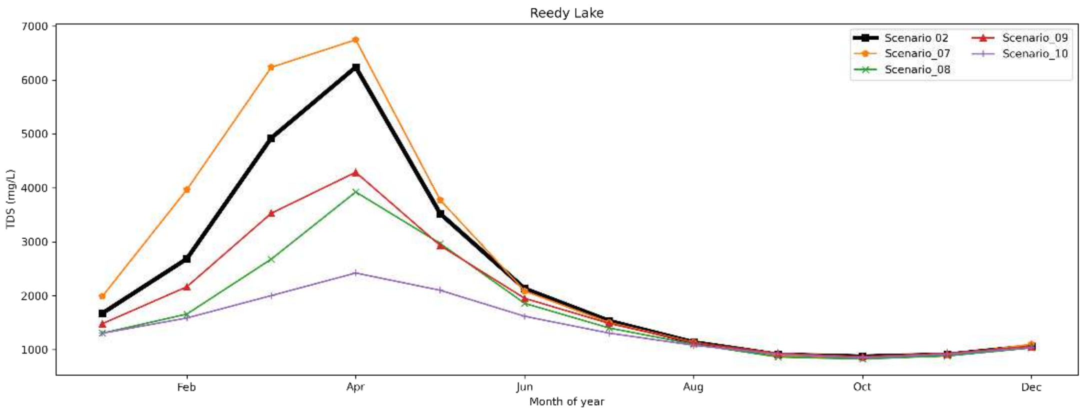

Figure 51. *Average monthly TDS concentration at Reedy Lake under scenarios 2, 7, 8, 9, and 10*

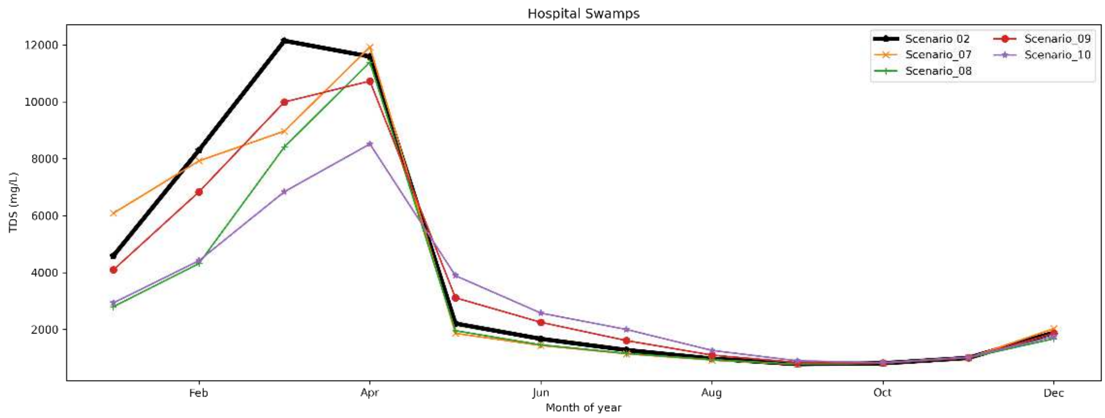

Figure 52. *Median monthly TDS concentration at Hospital Swamps under scenarios 2, 7, 8, 9, and 10*

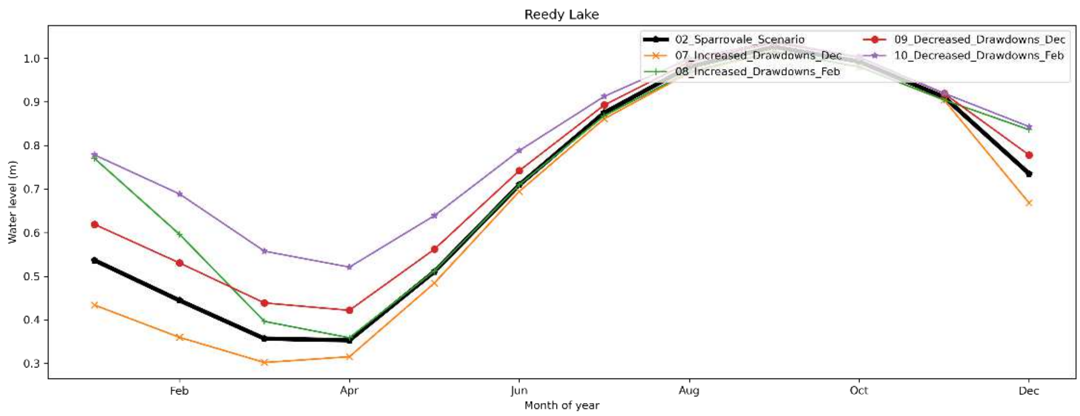

Figure 53. *Average monthly water levels at Reedy Lake under scenarios 2, 7, 8, 9, and 10*

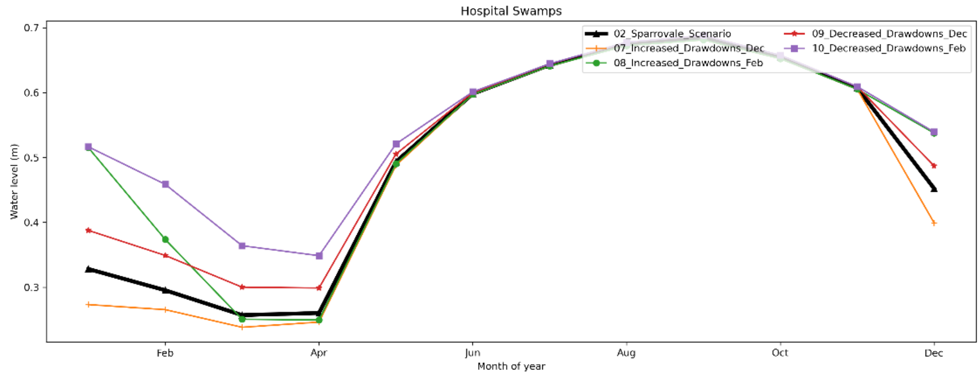

Figure 54. *Average monthly water levels at Hospital Swamps under scenarios 2, 7, 8, 9, and 10*

Expanded Sparrovale operation

An alternate Sparrovale diversion scheme was evaluated in Scenario 14. In this scenario, 50% of flows between May and December from Armstrong Creek were diverted to Sparrovale (provided channel had capacity) and 50% flowed to Hospital Swamps. All the flows were diverted for the remainder of the year. The impacts of climate change (Scenario 15), urbanisation (Scenario 16) and combined urbanisation and climate change (Scenario 17) with this scheme are presented in Figure 55. As previously noted, climate change results in an increase in TDS concentrations due to reduced runoff, while urbanisation has the opposite impact. When assessed in combination, these two factors go some way to cancelling each other out.

The direct comparison of Scenario 2 and Scenario 14 indicate a shift in salinity to a higher average in the overall salinity at Hospital Swamps. While the change to the upper and lower bound concentrations (using minimum and q90 due to in Scenario 14 shown in Table 14) indicate a slight shift in the extreme concentrations, the median and q60 results show a more significant shift. This indicates that the shift to higher salinity in Scenario 14 is particularly prominent when hydrological conditions are not in the extremes (neither extremely dry limiting inflow capacity or extremely wet causing spills), and management decisions are the primary influence.

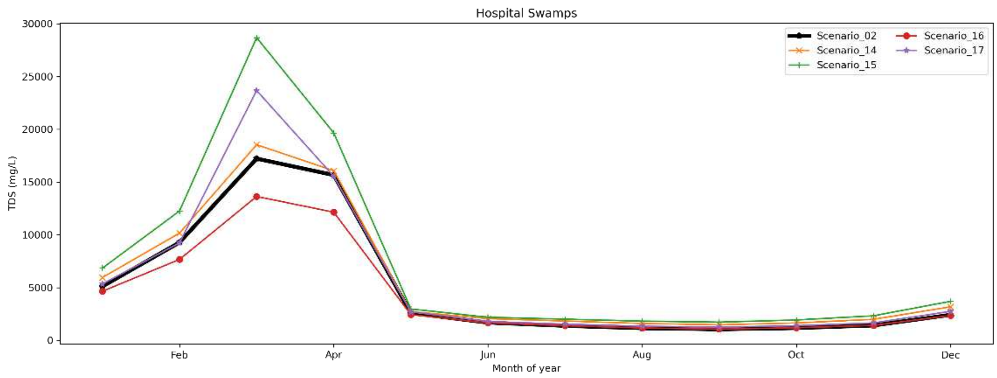

Figure 55. *Average monthly TDS concentration at Hospital Swamps under scenarios 14, 15, 16, and 17*

Permanent flow-through scenarios

Lastly, several permanent flow-through scenarios were assessed. For Reedy Lake this involved opening the inlet and outlet channels year-round to allow water to travel through the system constantly. By contrast, in Hospital Swamps, the inlet and outlet channels were opened between May and December and shut for the remainder of the year.

The results of these scenarios show that this causes markedly different results for the two wetlands. Maintenance of the permanent flows through Reedy Lake leads to a marked decrease in water levels during winter but an increase in summer (Figure 56). Likewise, median[1] TDS concentrations increase throughout winter but decrease over summer (Figure 57). Under this management scenario, anytime there were extended periods of low river flows, Reedy Lake would effectively dry out due to a combination of outflows to Lake Connewarre and evaporation.

Hospital Swamps differed to Reedy Lake in that it was maintained as flow-through only during winter, which resulted in decreased TDS concentrations throughout the year, which became more prominent as while water levels increased (Figure 58 and Figure 59). Under this management scenario, as the system was only operated as flow through during the wet season and the wetland did not dry out, as occurred with Reedy Lake. During the dry season the wetland was shut off from inflows and outflows. The shut off of the channels to and from the Hospital Swamps in summer and flow through in winter highlights the change in depth and salinity that the two management decisions can make. Note that this is not intended to reflect any anticipated management decisions or plans, rather acts as a sensitivity test as described.

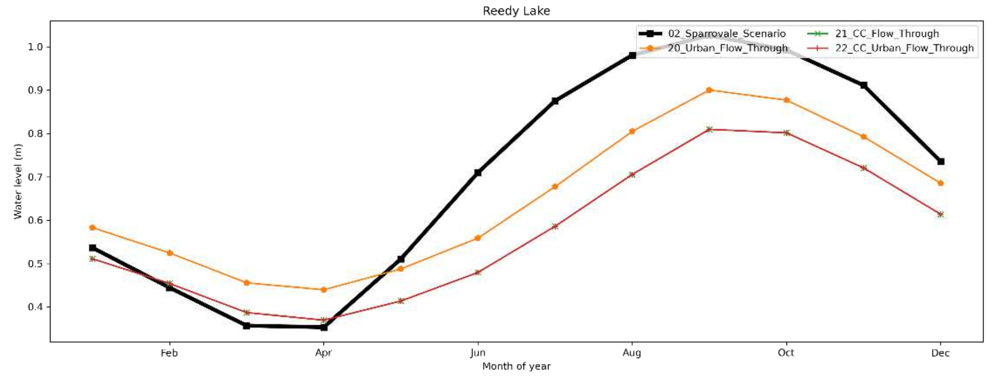

Figure 56. *Average monthly water levels at Reedy Lake under scenarios 2, 20, 21, and 22*

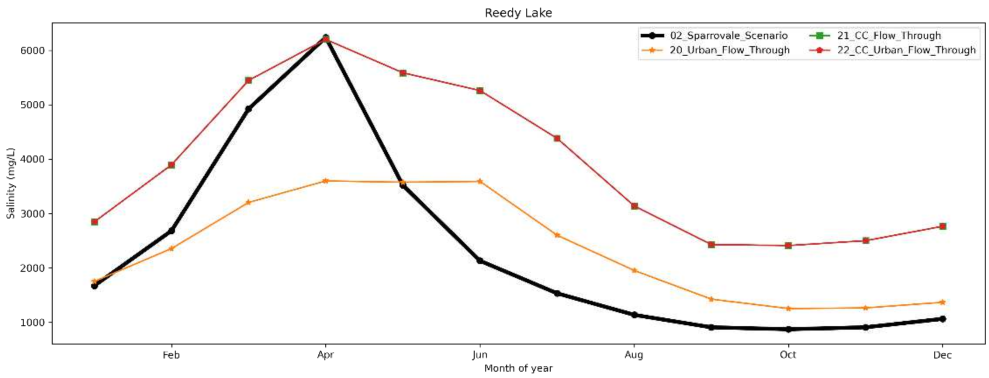

Figure 57. *Median monthly TDS concentration at Reedy Lake under scenarios 2, 20, 21, and 22*

[1] The median was adopted here as there were instances in which the wetlands dried up over this period due to a lack of inflows, which resulted in exceedingly high salinity concentrations that skewed the average.

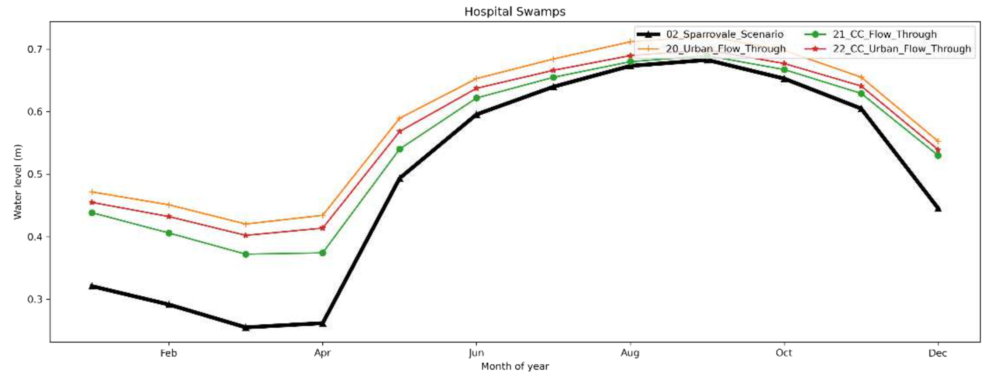

Figure 58. *Average monthly water levels at Hospital under scenarios 2, 20, 21, and 22*

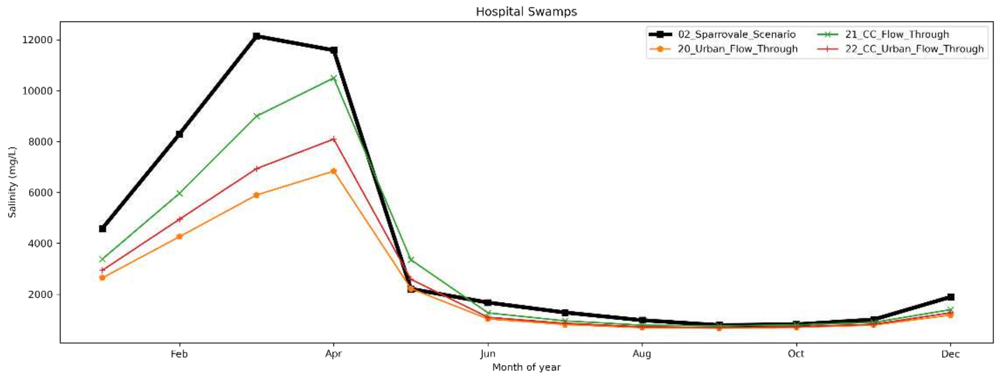

Figure 59. *Median monthly TDS concentration at Hospital Swamps under scenarios 2, 20, 21, and 22*

6.4 Influence of hydrological conditions

In order to differentiate the results of the climate change scenario from the existing variations in conditions, and to align the assessment with the initial scope of the project. This has been done in 2 ways:

- An assessment based on the single year's conditions
- An assessment based on the long-term trend of conditions

Single year condition assessment

Differences between wet and dry years have been considered based on the hydrological conditions within each of the water years (1 July to 30 June) to delineate between different climatic conditions (refer to Section 5.1).

Due to the significant number of results generated by this analysis (22 scenarios, 3 hydrological conditions, 2 wetlands, and a range of statistical measures), we have only evaluated the variations in TDS under the Sparrovale diversion scenario. The results for other scenarios generally followed this same pattern.

Marked TDS increases are seen in 'dry' years for all statistical measures considered in both Reedy Lake and Hospital Swamps (Figure 60 and Figure 61), which would be expected, as catchment runoff and river inflows are diminished during dry years, leading to lower dilution and greater influence of groundwater and evaporation.

'Wet' years lead to a reduction in salinity concentrations, though this effect is only minor at Hospital Swamps, and more considerable at Reedy Lake. The influence of dry years is much more significant than that of wet years on TDS concentrations, suggesting that management actions may be more critical in dryer years than in wetter years.

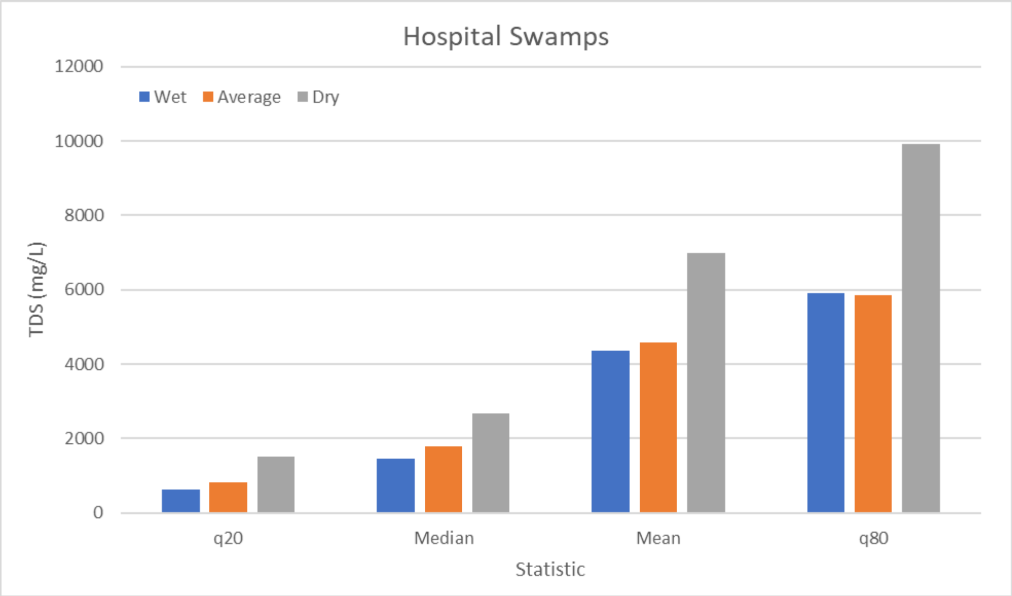

Figure 60. *Summary statistics at Hospital Swamps under Scenario 2 (baseline) for 'wet', 'average', and 'dry' conditions*

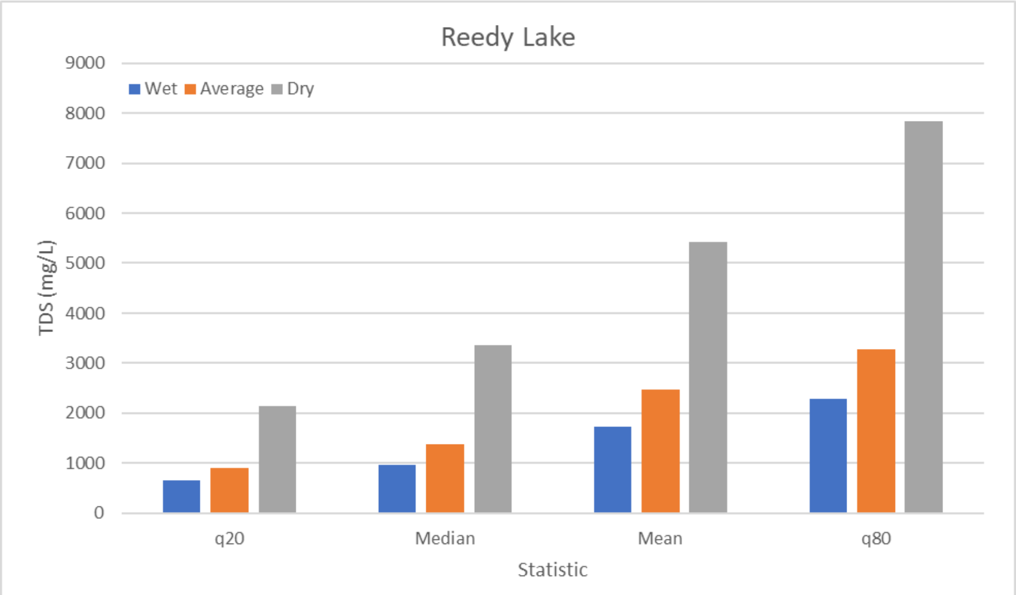

Figure 61. *Summary statistics at Reedy Lake under the Scenario 2 (baseline) for 'wet', 'average', and 'dry' conditions*

Wet, dry and average conditions

Using the method described in Section 5.2, periods of wet, dry and average conditions were isolated for each scenario. The average and maximum TDS concentration during these periods is shown in Table 16 for Hospital Swamps and Table 17 for Reedy Lake. Note that the 90th percentile results have been used in place of the maximum concentration. This is due to some of the lakes completely drying but continuing to have groundwater inflows. These inflows would in turn evaporate immediately, in effect creating extremely high concentrations. Though the TDS mass was not extremely high, the near absence of water creates a concentration that is not useful for the analysis. The 90th percentile is used to show the extremes of the TDS concentration while ensuring the presence of water in the wetlands.

Table 16. *Hospital Swamps hydrologic condition TDS comparisons*

Scenario		Wet Years (1971-1979)		Average Years (1981-1989)		Dry Years (2002-2010)	
		Average	90th percentile	Average	90th percentile	Average	90th percentile
1	Calibration	1974	3820	2044	3956	2236	4258
2	Updated conditions	3958	11024	4225	11610	5016	14394
3	Urban development	2907	7492	3143	8152	3706	9907
4	Permanently full	2619	4772	2790	5149	3295	6382
5	2012 Long Term Flows	4131	11268	4421	11877	5320	14971
6	Climate Change	4214	11929	4486	12527	5335	14814
7	Higher Drawdown – December start	3668	10616	3948	11571	4587	13498
8	Higher Drawdown – February start	3324	8471	3521	8943	3967	10374
9	Lower Drawdown – December start	4070	10732	4284	11158	4822	13299
10	Lower Drawdown – February start	3485	8021	3650	8343	4108	9555
11	Urban Development + Climate Change	3115	8139	3322	8713	3895	10655
12	2012 Long Term Flows + Climate change	4213	11937	4487	12526	5333	14814
13	Permanently full + Climate Change	3123	5722	3342	6249	3978	7595
14	Expanded Diversion	4393	11538	4707	12176	5716	15506
15	Expanded Diversion + Climate Change	4739	12570	5105	13327	6172	16516
16	Expanded Diversion + Urban Development	3295	7989	3559	8710	4195	10500
17	Expanded Diversion + Urban Development + Climate Change	3592	8788	3828	9364	4583	11515
18	50% Diversion	2430	4608	2539	4782	2835	5288
19	Permanent flow through	3114	8625	3241	8846	3496	9867

Scenario		Wet Years (1971-1979)		Average Years (1981-1989)		Dry Years (2002-2010)	
		Average	90th percentile	Average	90th percentile	Average	90th percentile
20	Permanent flow through+ Climate Change	2544	6641	2675	7122	2902	8043
21	Permanent flow through+ Urban Development	3527	9880	3672	10146	3936	11264
22	Permanent flow through + Urban Development + Climate Change	2899	7755	3048	8287	3285	9407
Average		3424	8743	3638	9252	4214	11019

Table 17. *Reedy Lake hydrologic condition TDS comparisons*

Scenario		Wet Years (1971-1979)		Average Years (1981-1989)		Dry Years (2002-2010)	
		Average	90th percentile	Average	90th percentile	Average	90th percentile
1	Calibration	2908	7081	3225	7774	3847	9843
2	Updated conditions	2929	7165	3250	7870	3882	9881
3	Urban development	2921	7129	3238	7851	3863	9868
4	Permanently full	1613	2853	1754	3132	2129	3924
5	2012 Long Term Flows	2110	4640	2284	5057	2519	5581
6	Climate Change	3593	9018	4034	10076	5002	12292
7	Higher Drawdown – December start	2973	7265	3234	7778	3770	8955
8	Higher Drawdown – February start	2178	4398	2390	4932	2849	6147
9	Lower Drawdown – December start	2623	5756	2947	6580	3612	8235
10	Lower Drawdown – February start	1936	3718	2134	4117	2609	5040
11	Urban Development + Climate Change	3579	8994	4016	10054	4977	12217
12	2012 Long Term Flows + Climate change	3609	9072	4061	10144	5018	12344

Scenario		Wet Years (1971-1979)		Average Years (1981-1989)		Dry Years (2002-2010)	
		Average	90th percentile	Average	90th percentile	Average	90th percentile
13	Permanently full + Climate Change	2181	4258	2452	4854	3205	6348
14	Expanded Diversion	2934	7188	3256	7879	3899	9912
15	Expanded Diversion + Climate Change	3603	9037	4040	10076	5028	12331
16	Expanded Diversion + Urban Development	2925	7139	3244	7860	3877	9874
17	Expanded Diversion + Urban Development + Climate Change	3586	9003	4026	10063	4996	12261
18	50% Diversion	1926	3689	2121	4078	2590	4996
19	Permanent flow through	4477	11192	5974	19344	10057	29507
20	Permanent flow through+ Climate Change	4439	10723	6027	19279	10067	29939
21	Permanent flow through+ Urban Development	5593	16325	7187	18741	12612	25670
22	Permanent flow through + Urban Development + Climate Change	5593	16325	7187	18741	12612	25670
Average		3192	7817	3731	9376	5137	12311

The isolation of the wet, dry and average periods reinforces the trends that are seen in the other modelling results. The wetter years are characterised by higher inflows of fresh water from upstream, increasing water availability and spills, which in turn produces lower salinity. Drier years have less fresh water available to flow from the rivers to the wetlands, resulting in evaporation of saline water and inflows of saline groundwater, both of which produce saltier water in Reedy Lake and Hospital Swamps.

These results show a general consistency toward higher TDS concentration in the drier years, and lower concentrations in the wet years. This is consistent with the previous results that show a flushing of the system when there are high enough water levels in the Barwon River or Armstrong Creek to induce spills, as well as greater capacity to divert water through the inlet channels. In drier years there is less water available to fill the wetlands, allowing evaporation and groundwater to take over and increase TDS concentrations.

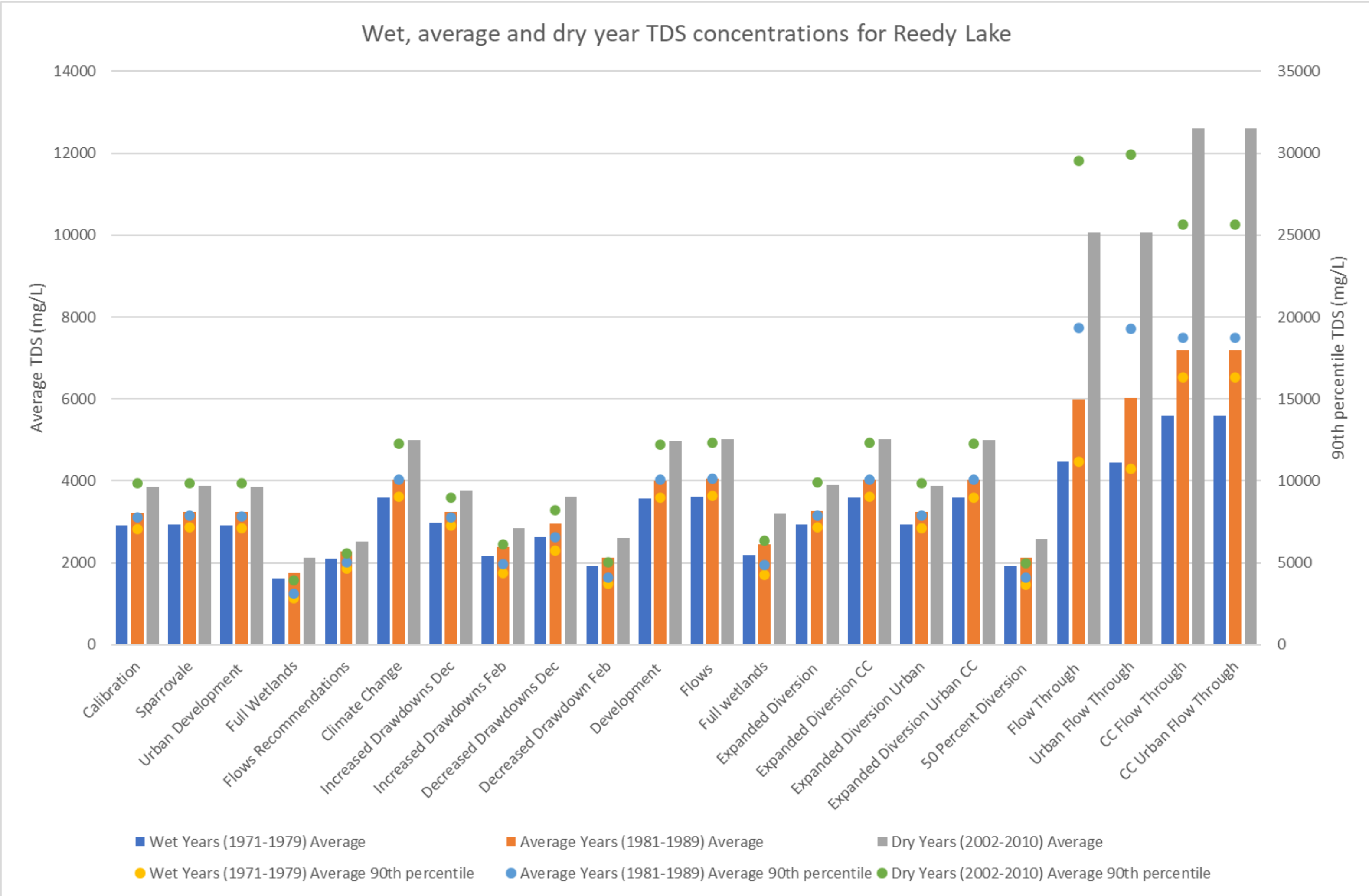

Figure 62 *Wet, average, and dry year TDS concentrations for Reedy Lake*

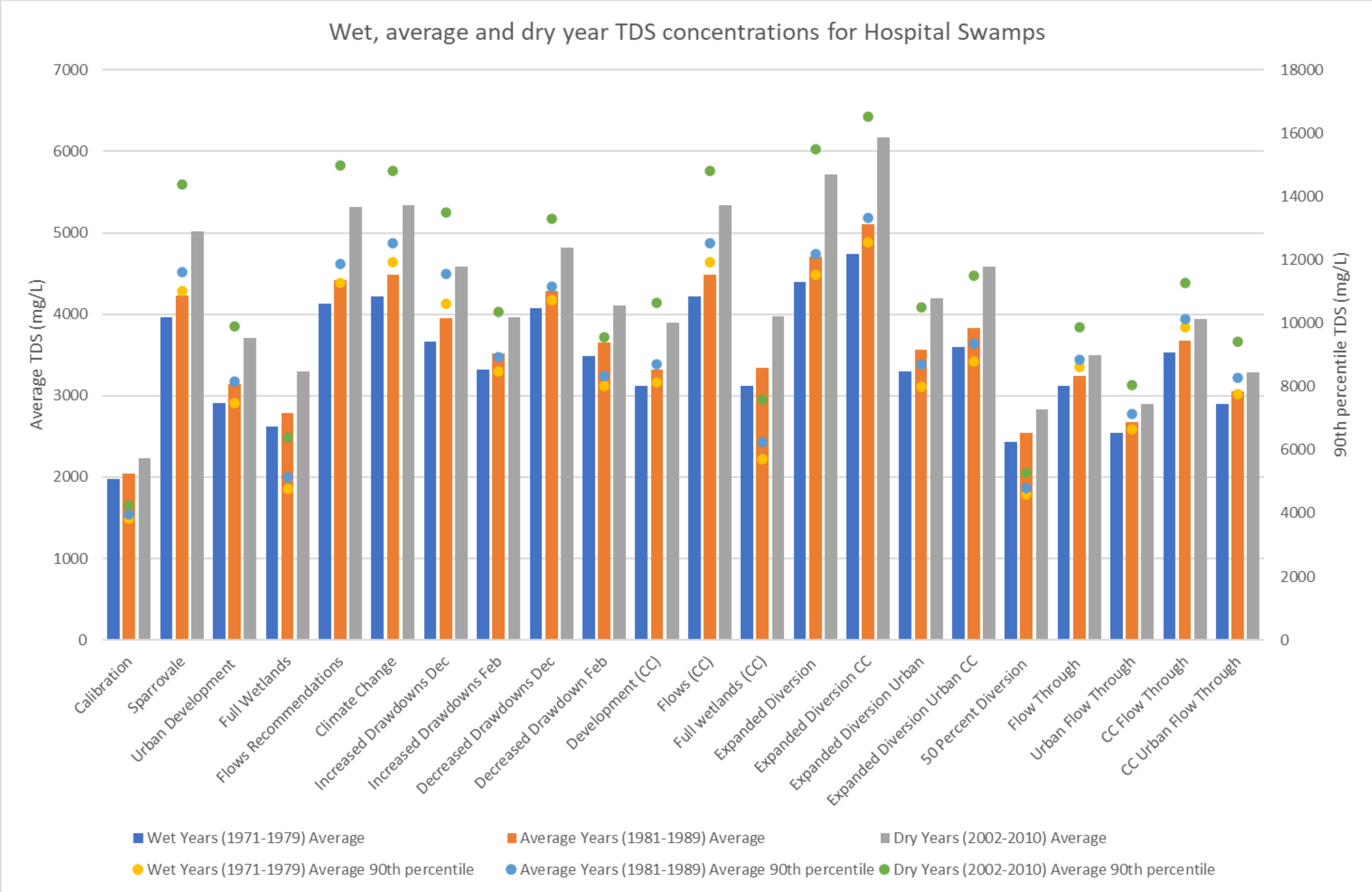

Figure 63 *Wet, average, and dry year TDS concentrations for Hospital Swamps*

The trend of these results continued when management decisions took over, for example the flow through option created higher salinity in Reedy Lake as water was able to freely flow through the outflow channel year-round, causing groundwater to become the dominant input (noting that this was not an anticipated management decision rather a sensitivity test as described). The link to fresher inflows is evident here as well as the wet periods allow a more constant inflow to wash away the salty deposits. These scenarios in the wet and dry years demonstrate the sensitivity in the model of the wetlands to changes in inflows and outflows, with the holding of water in the wetlands to maintain water levels higher ensures salinity decreases. The monthly average shown in Figure 56 supports this, as any of the scenarios that held gates open over winter to allow flows out of the lake or swamps resulted in a drop in level compared to the 'winter full' management which in turn created an increase in salinity.

When comparing each of the scenarios over the various hydrological conditions (Figure 62 and Figure 63), each showed a consistent trend of step increases in average TDS concentration from wet to average to dry. This is an important note when considered in the context of the yearly comparisons shown for each of the scenarios shown earlier. With the exception of the Reedy Lake permanent flow through scenario, each showed the variation of the concentrations occurring in the managed periods of summer and autumn before trending back to the 'baseline' Sparrovale scenario.

6.5 Influence of inputs

As each of the scenarios has demonstrated, changes in the catchment will be important to identify and understand to ensure that management decisions can be adapted accordingly. Influences on the water flows into the wetlands will change through time, whether through direct change to the catchment or indirect through the climate. Increases in fresh water through urban runoff, rainfall intensity bursts, or through overflows of infrastructure will dilute the wetlands and lower salinity, whereas reductions in inflows due to drought or decisions to extend periods of low water levels allows the current salt mass to play a larger role and allow higher salt intrusion from groundwater and tidal flow.

By isolating scenarios with singular changes to the model parameters, the impacts of the change can be seen. Figure 64 shows the Update Conditions scenario that is used as the basis for comparison (Scenario 2) compared to urban development (Scenario 3), permanently full (Scenario 4), climate change (Scenario 6), and the reduced capacity of the Sparrovale diversion (Scenario 18). The results have been sorted to demonstrate the probability of each scenario exceeding the scaled concentration levels, allowing the more saline scenarios to become visible (higher lines means more saline over the 60 years modelled). This shows how changes may occur in the system in the longer term, even if the extremes in high and low remain similar.

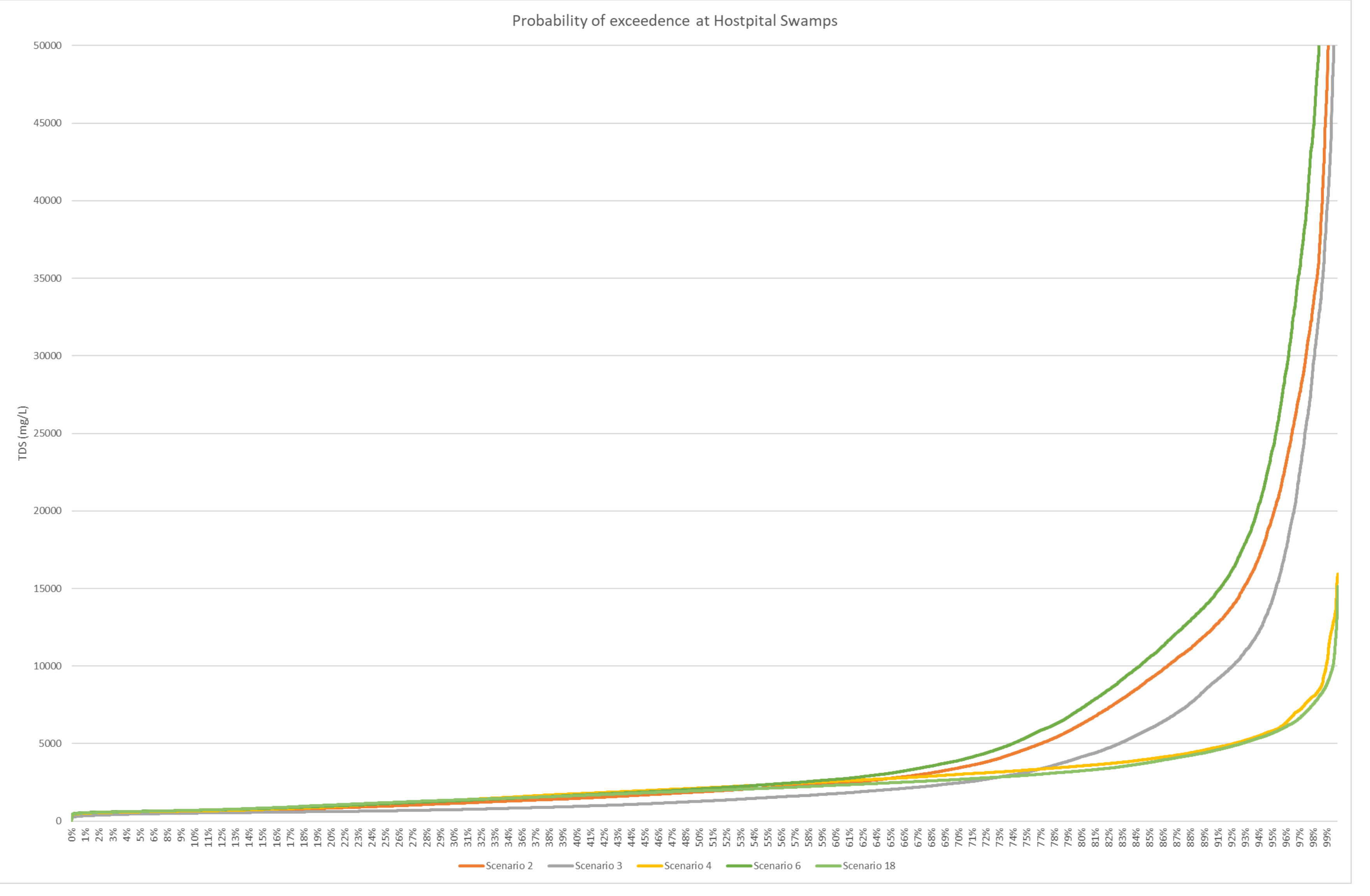

Figure 64 *Probability of exceedance at Hospital Swamps*

Using Scenario 2 as the benchmark, the items that are shifted higher and lower, or more saline and less saline, are easily linked to the changes in the system. The climate change scenario with reduced rainfall results in less fresh water (through direct rainfall, or overflows from the Barwon River, Armstrong Creek and Sparrovale when at capacity) results in a general shift of results to a higher likelihood of saline conditions. Increases in runoff from urban development has the opposite influence, resulting in a shift to a lowering in saline probabilities. This change in inflow can be linked to the increased runoff directly into Hospital Swamps from Armstrong Creek and the overtopping of Sparrovale when it reaches capacity. Management decision can have similar implications, through deliberate mechanisms such as the permanently full scenario maintaining high levels that minimise groundwater inflows and ensure the salt remains extremely diluted, or inadvertent mechanisms such as the reduced flow through the diversion that maintains higher levels in Sparrovale wetlands that causes increased frequency and intensity of flows back through Hospital Swamps.

6.6 Implications of climate change

As outlined in Section 3, most of the scenarios were tested under potential future climate conditions based on the RCP8.5 emissions scenario for 2065 taken from the Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria (DELWP, 2020). The change in climatic conditions taken result in a change in the rainfall and evapotranspiration, with rainfall reduced by 5.2% and evapotranspiration increased by 7%. The practical implications of this change are that the rainfall inputs used in the modelling are reduced to 94.8% of the prior input, and the systems evaporative losses increase to 107% of the existing values. When each of the scenarios were compared to the climate change version of the change, the results indicated a relatively uniform increase across scenarios.

These results are based on the emission scenario recommendations from DELWP as described, however these climate change scenarios apply the changes to the annual average. This provides an important long-term snapshot of potential changes, however, the potential variations in rainfall are likely to become increasingly erratic. Shorter term implications of climate change are likely to cause the increased frequency, severity and duration of extreme events such as heavy rainfalls induced flooding and periods of extreme drought (IPCC, 2022) and while these are not the scenarios that have been modelled here, it is possible to infer the resultant implications. For example:

- Periods of heavy rainfall induced flooding: the increased runoff from heavy rainfall will cause an increase in fresh water runoff into to wetlands through either direct flows or overtopping of banks. The influx of fresh water will lower the salt concentrations, offsetting any inflows from tidal or groundwater sources. This was demonstrated in the Urban Development scenario (Scenario 3) and the wet year periods
- Periods of extreme drought: The reduced rainfall such as that seen in the dry year periods results in lower availability for managed flows into the wetlands (and by implication overtopping events). The lower inflows should be expected to result in increased salt concentrations, as the reduced freshwater inflows allows a larger influence from the more saline groundwater and tidal water sources.

These inferences are based on the rest of the model remaining static, such as groundwater and tidal pressures, however as with the items above it is possible to make assumptions based on the key drivers in each of the results. If groundwater and/or tidal flows become a stronger influence on the system (through processes such as sea level rise), periods or scenarios when the levels in the wetlands are lower will potentially be prone to larger salt water ingress from these sources.

6.7 Key questions

As part of the scope for the assessment as series of key question were developed by Corangamite CMA in order to investigate areas of importance or interest.

What are the salinity implications to Reedy Lake and Hospital Swamps of maintaining the wetlands permanently full?

The implications to salinity in the permanently full scenarios are primarily linked to the influx of freshwater into the wetlands to maintain high water levels. The fresh water acts to dilute the water in the wetlands, vastly reducing the salinity over the majority of the model period. This is particularly true in Reedy Lake, where the full level results in some spilling over bank into lake Connewarre. This inadvertently created a flow through scenario where slightly saline water in the lake water being removed into Lake Connewarre and replaced by fresher river water, further reducing salinity. Higher water levels also reduced the inputs from groundwater, with the wetlands providing freshwater to groundwater rather than taking on the saltier groundwater. It is noted that the implications on groundwater from this were likely to be minimal, due to the larger amount of water stored in the aquifer

The only periods where this was not the case was the periods where water levels in the Barwon River and Armstrong Creek were not sufficient to provide inflows into the Lakes. With the outlets closed to maintain water levels, salt mass in the water remains in the wetlands and as the water evaporates the salt load creates increased salinity. The inability of the wetland to flush the salt out means that a build-up can occur, something that was even more prevalent in the drier climate change conditions. Some of the salt would leach out to groundwater during higher water level periods but this process is much slower than outflows through the channel.

It is important to note however that there are other water quality implications from maintaining the wetlands permanently full which will be discussed further below. In addition to the water quality implications, continued water flow to maintain levels, particularly into Reedy Lake, result in lowered water levels in the Barwon River behind the barrage potentially causing water supply implications for water users upstream.

What are the salinity implications to Reedy Lake and Hospital Swamps of managing them in line with the current FLOWS recommendations?

The change to manage the wetlands in line with the current flows recommendations was conducted in Scenario 5. The results of the model indicated a minor change in the salinity implications as a result of the addition of the full dry year. The full dry year replaced a partial dry year in the model cycle, which acts as a more saline period over the 4-year period. As is shown in Figure 65, the peak in salinity is noticeably higher than the comparison. The peak occurs periodically in line with the changes to the management decisions. The third year that attempts the full drawdown is the noticeable change in salinity, with Scenario 5 rising above the comparison Scenario 2, however it is noted that the change is not every 3 in four. This implies that the natural conditions limit the ability for the full drawdown to occur.

Importantly the salinity then returns to the trend over the winter period (as is present in most scenarios), allowing the cycle to resume until the next full dry year, and no lingering impacts on salinity seen.

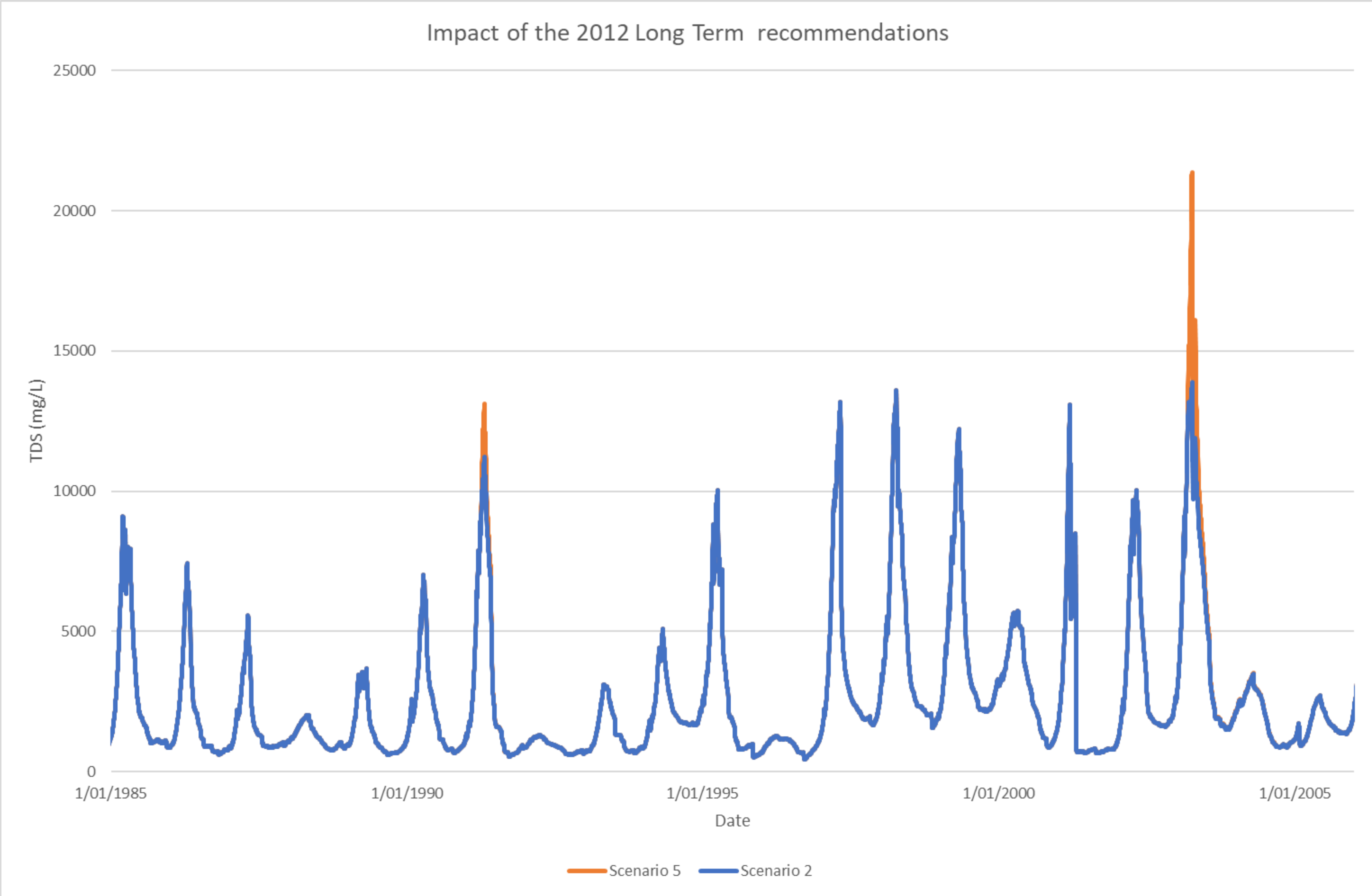

Figure 65 *Impact of the original FLOWS recommendations*

What are the salinity implications to Reedy Lake and Hospital Swamps of increasing or decreasing the rate and frequency of summer draw down, within a draw-down year and over a multi-year period?

The implications on salinity for Reedy Lake and Hospital Swamps relates directly to the volumes of water held to dilute the salt loads held, and to reduce groundwater inflow. The balance of water volume is compounded by these two influences, simultaneously allowing the existing salt loads to have a greater impact and for groundwater intrusion to draw more salt into the surface water.

Given the salinity in the wetlands is directly linked to water levels, the decisions within a single drawdown year will have a direct impact. Decisions that maintain water levels higher for longer, such as delaying the start of drawdown of decreasing the rate, with likely result in reduced salinity. Decisions to reduce water levels, through earlier starts to drawdown or increasing the rate, will likely increase the salinity. This is due to the relative fresh water that inflows to the wetlands have a higher influence and deeper levels, where as as the levels reduce, groundwater inflows are able to start moving salt load in to the water, increasing salinity.

It is noted in the results that this relationship appears to be annual. In the changed drawdown scenarios, the salinity in the model returned to the values of the Scenario 2 comparison, before reacting to the change in a similar way the following year. This would imply that the lasting effects on salinity of the change do not linger, with the winter flows flushing the system to create a fresh canvas for salt water management. Therefore, it indicates that multi-year changes to the management would result in impacts isolated to the year of change. For example, if the 4-year cycle were expanded to a 6- or 8-year cycle, it seems reasonable to predict a cycle that has a similar trend to the 4-year cycle, with higher salinity in years of lowered levels and lower salinity in years with higher levels. For most scenarios, the salinity of the wetlands appears highly dependent on that years choice and the hydrological conditions of the time rather than the management of the year preceding.

7 Ecological context assessment

As part of the project planning, we have assembled a panel that is able to provide technical expertise as part of the examination of the modelling outcomes. The advice provided is summarised below. Note that the assessment conducted applies only to the potential role of salinity on each of the indicators and which scenarios are more likely to influence them. This is not intended to be taken as a complete assessment or to replace the FLOWS assessment process, rather to put an ecological lens over the results of the modelling.

7.1 Assessment themes

Vegetation

Figure 66 below shows the distribution of various types of coastal saltmarsh and mangroves, plus some other estuarine wetland types, taken from a 2011 State-wide saltmarsh study. It is noted that under the LACs limits of acceptable change to the Ramsar site (noting that the below apply to the whole Ramsar site, with the third directly linked to Reedy Lake) (DELWP, 2018):

- saltmarsh extent should not fall below 900 ha (currently around 1,200 ha)
- protection of rare saltmarsh plant species is required (e.g. *Wilsonia herblands* and *Distichlis* grasslands)
- protection of freshwater vegetation is required, specifically reeds and sedges, milfoils and Lignum. A habitat mosaic is to be maintained at Reedy Lake, with no habitat comprising more than 70% of the total wetland area for more than 5 successive years

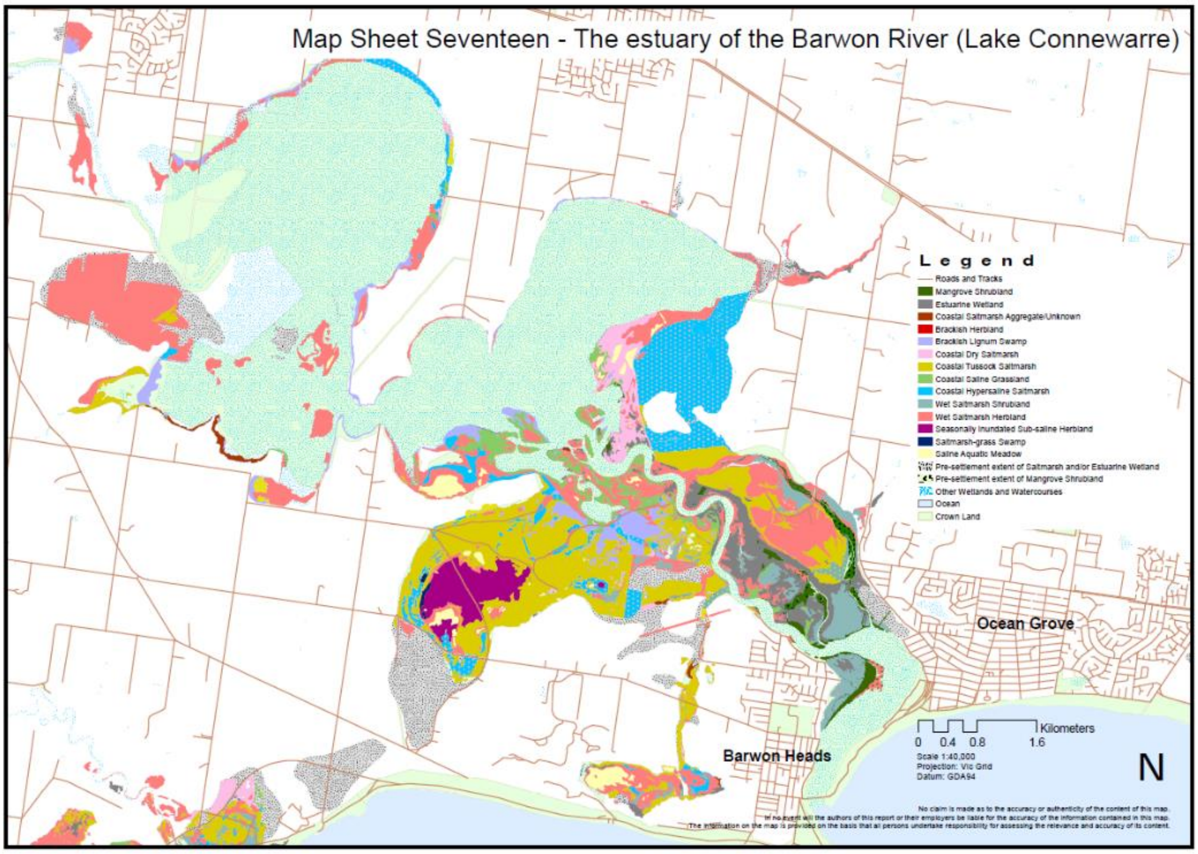

Figure 66 *Vegetation distribution in the Lower Barwon wetlands (Boon et al, 2011)*

The key vegetation considerations that will form the basis of the high-level review include:

- Coastal saltmarsh: It is noted that Coastal saltmarsh is listed as a vulnerable ecological community under the *Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth).*
- Seagrass: Some seagrass has been noted to be in the area, but is not considered relevant to this project as seagrass occurs mainly in Swan Bay, not in the geographical area covered by this investigation. Note, however, that some plant taxa such as *Ruppia* are considered by many botanists to be bona fide seagrasses.
- Mangroves: There is a large area (40 ha) of the Grey Mangrove *Avicennia marina* in the Barwon estuary but is again outside our spatial scope (as confirmed by the 2011 mapping reproduced above).
- Freshwater vegetation: Mostly occurs in Reedy Lake. Dominant species are Common Reed (*Phragmites australis*) and Cumbungi (*Typha spp.*)
- Threatened wetland species: No threatened wetland plant species have been noted, however there is concern about the Cumbungi, Common Reed, and open water plant species in Reedy Lake. It was noted however that there is a high level of confidence in the information availability for the Cumbungi, Common Reed, Lignum and Bolboschoenus species in Reedy Lake. To perform a high level yet informed assessment of the impacts on the vegetation, a series of output requirements from the modelling have been identified.
- Water depth (m AHD): This is an important factor for plant distributions in the system. Modelling requires to be at a maximum weekly time step, especially in any periods when a water body dried out completely. It is noted that the results will provide volume outputs for the lakes and wetlands. A volume to depth relationship will be developed to provide average depths. This information will be used to map the inundation areas at key depths in order to assist the assessment but will be limited by data quality
- Salinity (EC or gravimetric): No more than a weekly timestep, but lower for tidal reaches. Ideally a daily timestep. Similar issues regarding shallower fringes. . Indications of hypersaline conditions will require careful scrutiny because of problems with measurement (Williams and Sherwood 1994).

- Total P (mg/L), Total N (mg/L): This is a controlling factor for algal blooms and eutrophication more generally. Timestep requirements are consistent with the above.

Hydrological and hydrodynamic considerations

The hydrological/hydrodynamic considerations identified were drawn largely from the findings of the review conducted in 2020 (Alluvium, 2020), noting the common members from that study and this investigation. The items that were highlighted by the panel included:

- The potential threat to the Ramsar listed values of Hospital Swamps resulting from the Urban development within the Armstrong Creek catchment
- Influences of the Sparrovale wetland and the Southern Diversion Channel on flow regimes
- the relative volumes of Armstrong Creek winter runoff and Barwon River winter inflows to Hospital Swamp
- Shallow water and mudflats are important to water birds as shorebirds are only found at either wetland when there is plenty of exposed mud or shallow-water habitats
- Consideration should be given to filling Reedy Lake in dry years to allow the Lower Barwon to act as a refuge during drought
- The importance of investigating the impacts of water quality and increases to stormwater inflow resulting from increased urban runoff and impacts of increased runoff on the Hospital Swamp watering cycle
- Inclusion of groundwater in the modelling

Groundwater

Groundwater is not an aspect of system health like the ecosystem elements are, but it can be used as an indirect indicator of system health. The key aspect of groundwater with regard to the Lower Barwon wetland system is the groundwater flux to and from the surface water bodies. The relevant hydrogeological parameters here are elevation and salinity of the groundwater. The location of the data is key, as local groundwater-surface water interactions and the complexity of local aquifer systems can mean each lake and wetland interacts with groundwater differently with different salinity profiles. The temporal spread of data is also important, as the season or a flood event can mean the gradient between the groundwater and the lake or wetland can shift completely, from groundwater seeping into the base of a wetland during summer, and the lake recharging the groundwater during peak flow conditions after a flood.

Groundwater data may be used as an indicator for ecosystem health in the following way: if the range of groundwater salinities suitable to maintain a key element of the ecosystem is known (for example, key vegetation species), and the interaction of groundwater and the surface water body is understood (for example, through relative water elevations), then managers of the system can track when a change to the wetland system pushes the bounds of acceptable ecosystem health.

Geomorphology

Salinity and water influence geomorphology directly and indirectly, by altering rates and patterns of erosion, deposition, and sediment transport. Change in geomorphology of the wetlands may first occur via a sequence of changes in other parts of the system, such as vegetation cover or groundwater levels. Geomorphic change via an indirect pathway such as vegetation has been well documented in the Gippsland Lakes, where increased salinity first lead to a loss of shoreline vegetation, and then an increase in shoreline erosion (Victorian Resources Online, Undated). The indirect influence of system inputs in geomorphology leads to the following general points:

- There may be a considerable time lag between changes in water level or salinity and changes in geomorphology.
- Early indications of geomorphic change may fist be expressed as changes in vegetation health, distribution and type.
- Geomorphic processes (such as shoreline erosion) may be non-linear, occurring slowly at first but becoming more rapid with time.

To predict how changes in salinity or water level will impact geomorphology, and by what pathway, it helps to conceptualise whether changes in water level or salinity alter the balance between erosive forces and resistance forces. Resistance forces are those that prevent or limit the rate of geomorphic change. Erosive forces are those that perform geomorphic work, and cause a change in physical form. Both forces vary across time and space, but for a geomorphic change to occur (e.g. shoreline erosion) erosive forces must exceed resistance forces.

7.2 Indicator Selection

In order to aid the high-level interpretation of the results in the context of ecological character, a set of indicators have been identified using literature and stakeholder engagement.

The indicators have been chosen because they fulfil at least one of four roles:

1. They are a key determinant of wetland character and condition (e.g. hydraulics, salinity).
2. They are a value (e.g. listed species, community value) that needs to be sustained
3. They provide an indication of a threat (e.g. nutrients, carp). These are important because flow and salinity changes may affect the system indirectly through their impacts on other threats.
4. They integrate information about the overall condition of the system and are predictably sensitive to anticipated changes/management interventions.

As the Barwon wetlands support many environmental values, assessing impacts on all these species is not feasible due to the large number, but also because our understanding of many species habitat preferences are limited. The selection of a suite of complementary indicators will ensure that we will be able to assess the likely impacts on the whole system and from this infer outcomes for each of the values, particularly those that we identify as vulnerable to changes in habitat quality or availability.

The final list of indicators is shown in Figure 67.

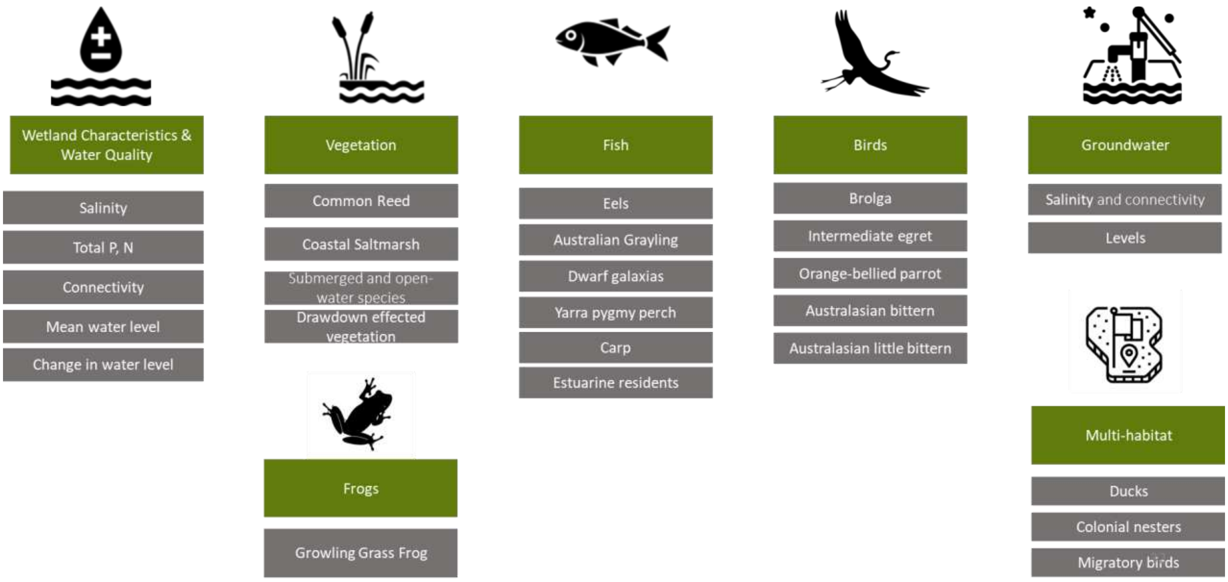

Figure 67 *Selected ecological indicators*

7.3 Water quality assessment

As outlined in Figure 67 the selected water quality indicators are:

- Salinity
- Total P, Total N, total suspended solids, dissolved oxygen
- Connectivity between the Lower Barwon River, the wetlands and Lake Connewarre
- Mean water level
- Change in mean depth

Note that the implications for salinity are not reviewed any further here. For information on salinity see Section 6.

Total Phosphorus, Total Nitrogen

While the levels of total phosphorus and total nitrogen loads into the system and their distributions have not been modelled as part of the water-salt balance modelling, it is an important consideration to understand the implications of the results.

The changes that are likely to change the phosphorus and nitrogen load into the wetlands are those that change the inflows and their sources. In the context of the water-salt balance model, this change comes in the form of the increases in urbanisation modelled in Scenario 3. The implications from this scenario and by extension other changes to land use in the catchment are the quality of the stormwater runoff, that can result in an increase or decrease in loads depending on the change.

As the results of Scenario 2 indicated a decline in salinity due to increases in runoff, then there is a reasonable assumption that the runoff is likely to carry an increase in phosphorus and nitrogen load, as well as a range of other pollutants that are common from urban runoff that will result in a decline in water quality in water quality in Armstrong Creek and by extension Hospital Swamps. The degree of impact is variable however, as developed areas (both currently planned and future planning) are likely to require stormwater management inclusions that may lower the impacts, and the addition of Sparrovale may act as a water treatment area, reducing the loads on the wetlands.

There is a potential that the urbanisation will result in a decrease in total phosphorus and nitrogen loads, in the event that the area being urbanised is currently supplying high nutrient runoff. Areas of irrigation and agriculture that use fertilisers, and confined grazing that results in high concentrations of faeces or fertiliser in the runoff may have higher nutrient concentrations than urban areas.

As the sources and loads of phosphorus and nitrogen have not been quantified as part of this study it is recommended that they are considered as part of the development of the FLOWS study upgrade that this project proceeds.

Connectivity between the Lower Barwon River, the wetlands and Lake Connewarre

The key connectivity considerations that appeared in the modelling results were the implications to wetland salinity by reducing outflows, the forced connectivity from uncontrolled spills into the system, and the connection through the in and out flow channels.

The impact of closing the outlets from the wetlands in the permanently full scenario (Scenario 4) showed the dual impacts of this reduced connectivity. The more dramatic, and more common impact was the reduced capacity of fresh water to leave the system. The accumulation of freshwater in the wetlands resulted in a shift in the balance between water and salt, lowering the long-term salinity of the wetlands. The secondary impact is the reduced capacity of salt and other dissolved or suspended solids to leave the system. While the impact of this is negligible over the majority of the model period, during the periods of extended drought such as those isolated in the millennium drought shows that as inflows reduce, the higher salt load has a greater influence. Inflows are reduced in periods of lower rainfall and lower water levels in the Barwon River that reduce the water managers capacity to fill the wetlands. As a result, as the salt is not able to be flushed from the system, during extended periods of extreme dry, the salinity rises. This impact in the model is greater in Hospital Swamps, as Reedy Lake has a higher likelihood of spills at a full level acting as a flush of dissolved solids.

Spills into the system were present in changes in the catchment that increased runoff from local areas, in this case most prominently in the urban development scenario of Scenario 3, and during periods classified as wet due to increased rainfall and river flows. These increased spills (and direct flows) into the wetlands were noted as being functions of a relatively natural system, however it does present a reduced control over the system.

The regulation of gate infrastructure for the inlet and outlet channels of the wetlands is also an important connectivity consideration. Scenarios that hold the gates open, such as the flow through scenarios, allow connection between the wetlands that can be vital for fish species, sediment transfer and water movement. This can become a problem in cases such as the permanently full scenarios where gates are kept closed. In this occasion if a fish species in the wetlands either required movement between salinity concentrations over a life cycle, or needed to move on as salinity dropped, then the closed channel would greatly hinder this movement (depending on access to fish passage infrastructure).

Flow variation and the associated inundation and drying of habitats has been identified as the most important determinant of vegetation community dynamics in rivers and wetlands (Raulings et al, 2010). Different species of plant are adapted to thrive in habitats that vary in terms of the depth and duration of the aquatic and dry phases. For many species, inundation represents a disturbance, while of others extended dry periods may be detrimental. The disturbance created by fluctuating water levels also creates areas of open habitat that provide opportunities for species to become established. One of the consequences of this dynamic is that species tend to occur within specific bands between areas that are permanently inundated and completely dry.

Regulation of systems is often associated with reductions or loss of depth variation which eliminates the intermediate habitats that alternate between wet and dry and overall, this leads to a loss of species in the system. The construction of regulatory structures has also been associated with the death and subsequent decomposition of vegetation as plants tolerances for submergence are exceeded (Park et al, 2018). In many cases, the loss of vegetation diversity will have cascading effects on the animals that rely on plants for food and habitat.

Mean and rate of change in water level

The mean and rate of change of water level in the lakes is an important consideration for the geomorphology and vegetation assessment. As is shown in Figure 68 the changes in the maximum rate of change in the wetlands (in this case Reedy Lake) shows variability across the years that were modelled, however the maximum rates of change across the scenarios did not show any dramatic changes. Importantly, there were no outliers in the rates of change, with no Scenario indicating that the depth change would differ from the others.

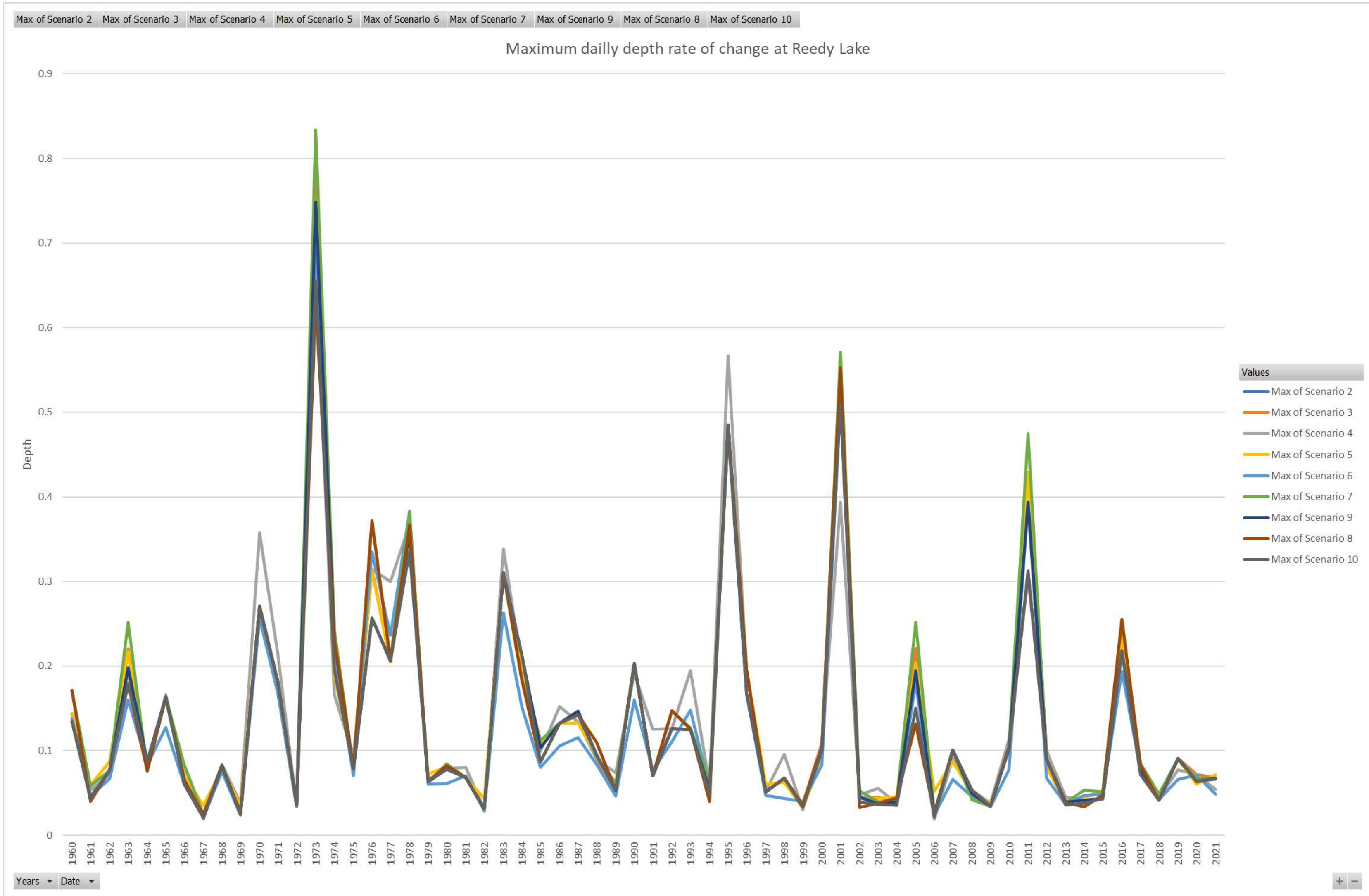

Figure 68 *Depth Rate of change at Reedy Lake*

7.4 Vegetation

As outlined in Figure 67 the selected vegetation indicators are:

- Common reed
- Coastal Saltmarsh
- Submerged and open-water species
- Drawdown impacted vegetation

An important note on the indicator species being assessed is the very wide 'preference' envelope of most of the indicative EVCs. Presumably this envelope refers to the fundamental niche of the individual taxa (sensu Hutchinson 1957) and the realised niche will be considerably narrower, owing to competition between and among individual species (e.g. Bertness & Pennings 2000; Crain et al. 2004).

In other words, the spatial distribution of a given plant species or vegetation type is determined not only by its physiological requirements and the extant physico-chemical conditions but also by biotic interactions with other organisms, especially competition with other species. Many saltmarsh species, for example, can grow in freshwater conditions but only in the absence of competitive glycophytic (i.e. salt-intolerant) species such as Cumbungi (Typha spp.). In such habitats saltmarsh taxa are quickly suppressed when freshwater taxa are present because they cannot compete in terms of growth rate or reproductive success under non-saline (i.e. freshwater) conditions. In contrast, freshwater taxa such Typha spp or Eelgrass (Vallisneria australis) as cannot survive in saline sites because they lack the physiological adaptations required for these stressful environments.

What this means in practical terms is that the distribution of different types of water-dependent plants and vegetation types in the Lower Barwon Wetlands is controlled by a large number of factors, of which salinity and water regime are only two. Moreover, as described later, salinity and water regime interact in very complex ways to confound any simple analysis made on the basis of each in isolation.

Note that due to the limitations on the data availability and the scope of the review, it has not been possible to assess drawdown impacted vegetation. Assessment of this indicator would require accurate and agreed-to mapping of all water-dependent vegetation types in the study area overlaid by inundation mapping, involving resources beyond the scope of this investigation.

A summary of the salinity and water regime preferences for the three target vegetation types, *Phragmites australis*, coastal saltmarsh, and submerged or open-water species, is included in Attachment 2. Table 18 shows selected salinity values (median and Q90) for Scenarios 5 (implementation of existing flow recommendations), 3 (increase in urban development), 6 (climate change) and 17 (expanded diversion plus urban development plus climate change) with an accompanying commentary on likely vegetation responses, based on the summaries outlined in Attachment 1. These scenarios were chosen to provide a snapshot of the impacts of the specific changes, and how the extremities of the changes may impact vegetation in the wetlands.

Table 18 *Selected salinity values for Scenarios 5, 3, 6 and 17 and likely vegetation responses for three target vegetation types*

Scenario	Salinity (g/L)		Likely vegetation responses		
	Median	Q90	Common Reed	Coastal saltmarsh	Submerged and open-water species
5 (2012 Long Term FLOWS recommendation)	2.1	13	Unlikely to suffer if the vegetation type is EVC 952 Estuarine Reedbed but inhibition of growth rates and a decrease in plant stature at the higher salinities is possible if the community is EVC 821 Tall Marsh.	If coastal saltmarsh is present in areas with this salinity regime, it is highly likely to be replaced by faster-growing glycophytic vegetation types such as those dominated by Common Reed (*Phragmites australis*) or Cumbungi (*Typha* spp.) etc.	Responses depend on whether the taxa of submerged plants are glycophytic or halophytic. If the former, they will be lost at the higher salinities indicated by Q90 values. More salt-tolerant taxa such as *Ruppia* and *Lepilaena* can probably survive under the salinity range envisaged (i.e. 2–13 g/L) under this scenario.
3 (Urban development)	1.3	8.9	Broadly speaking, as per the response to Scenario 5 above. The lower Q90 projections than for Scenario 5 suggest that even EVC 821 is likely to persist under Scenario 3. Glycophytic species, however, will likely be advantaged by the lower Q90 salinities.	Likely loss of large areas of coastal saltmarsh and their replacement with either (a) other forms of coastal saltmarsh with a different spectrum of species, mostly those not requiring high salinities, or (b) glycophytic plant assemblages.	Broadly speaking, as per the response to Scenario 5 above. The highest salinities of ~9 g/L are likely to be too high for the persistence of salt-intolerant species such as *Vallisneria australis* and many species of *Myriophyllum*.
6 (Climate change)	2.1	14.4	Broadly speaking, as per the response to Scenario 5 above as neither the median nor the Q90 salinities vary greatly from the Scenario 5 projections.	Broadly speaking, as per the response to Scenario 5 above as neither the median nor the Q90 salinities vary greatly from the Scenario 5 projections.	Broadly speaking, as per the response to Scenario 5 above as neither the median nor the Q90 salinities vary greatly from the Scenario 5 projections.
17 (Expanded diversion plus urban development plus climate change)	2.0	11.2	Broadly speaking, as per the response to Scenario 5 above as neither the median nor the Q90 salinities vary greatly from the Scenario 5 projections.	Broadly speaking, as per the response to Scenario 5 above as neither the median nor the Q90 salinities vary greatly from the Scenario 5 projections.	Broadly speaking, as per the response to Scenario 5 above as neither the median nor the Q90 salinities vary greatly from the Scenario 5 projections.

Common Reed

The first of the target species, Phragmites australis, is the dominant emergent macrophyte in EVC 952 Estuarine Reedbed. It has among the widest hydrological niche of any tall emergent rhizomatous plant in Australia (Rogers & Ralph 2011), but it is not clear whether specimens established under a given water regime (e.g. permanent inundation) can easily adapt to an altered one (e.g. seasonal inundation). With regard to salinity tolerance, it was believed formerly that Phragmites australis in near-coastal sites was limited to areas with average salinities of <10 g/L but it is now known that Phragmites australis can persist in water at least as saline as two-thirds seawater, or ~20 g/L (Holmes et al. 2016; Boon et al. 2019). It is highly likely that distinct ecotypes exist, with corresponding variation in salinity tolerance according to prior salinity regimes.

Cumbungi (Typha spp.) can be an important component of EVC 821 Tall Marsh (as can Phragmites australis). The two species co-occur in the tall reedbed communities of the Lower Barwon Wetlands and many non-specialists fail to distinguish between the two. It is generally though that Cumbungi has a more narrow hydrological niche than Common Reed (Roberts & Marston 2011; Rogers & Ralph 2011), typically requiring shallow inundation over summer. Salinity tolerance is not well known for the species of Typha that occur in Australia, but a preliminary threshold may be set at ~3−5 g/L before severe inhibition of growth sets in (e.g. Glenn et al. 1995) until more detailed research and interrogation of the published literature establishes a revised value.

Coastal Saltmarsh

Detailed information on the hydrological and salinity preferences for species typical of coastal saltmarsh, including even for very common species such *as Sarcocornia quinqueflora*, is largely not available or is very old. One recent study using Tasmanian plants indicated optimal growth at a salinity of ~12 g/L but with growth continuing up to seawater salinities of ~35 g/L (Ahmed *et al*. 2021).

Sainty *et al*. (2012) showed the saltmarsh species in south-eastern Australia more generally as highly tolerant of water-logging and salinity. Sexual reproduction, however, is likely to require periods of low salinity for seeds to germinate and young plants to establish (Ungar 1962, 1978; Adam 1994). Information on other taxa of small halophytic plants in south-eastern Australia (e.g. *Samolus repens*) is almost completely lacking. Frood & Papas (2016) give a typical salinity range of 10−50 g/L (Table 18).

Submerged and open-water species

The assessment of open-water taxa was based on indicator species rather than a comprehensive examination of individual taxa, in part due to the scope of the assessment and some uncertainty about community composition in the Lower Barwon Wetlands. There is WetMAP data that can be used to undertake a more specific assessment as part of the upcoming FLOWS study.

If the waters are brackish, Ruppia species and Lepilaena species, the dominant taxa in EVC 842 Saline Aquatic Meadow, are probably present. Both genera are highly tolerant of inundation at moderate salinities, at least on the basis of studies undertaken in Tasmanian saltmarshes (Kirkpatrick & Harris 2005). Research in South Australia and Western Australia indicates the two genera are tolerant of inundation regimes varying from intermittent to permanent, and of salinity regimes extending well into the hypersaline (Brock 1982; Brock & Lane 1982; Frahn et al. 2012).

If, however, the waters are fresh, Vallisneria australis or various species of milfoil (Myriophyllum spp.) are more likely to be present. Typical of glycophytic submerged angiosperms, most are unlikely to grow well at water-column salinities >3 g/L (Hart et al. 1991). Hart et al. (2003) concluded that many riverine aquatic plants (meaning here submerged and semi-emergent aquatic plants) were salt-intolerant and that salt concentrations of 1−2 g/L could prove lethal. Non-lethal effects may be obvious at lower salinities. Nielsen et al. (2003) reported similar threshold values for native open-water species of aquatic angiosperms.

For EVC 918 Aquatic Herbland, one of the possible EVCs present in freshwater open-water areas of the Lower Barwon Wetlands, Frood & Papas (2016) provided a very wide range of hydrological preferences, ranging from permanent inundation to episodic inundation of <3 years in every 10. Duration of inundation is also highly variable, too variable to be used to identify thresholds. The same holds for water depths, which can vary from <30 cm to >2 m. The salinity preference is shown as <3 g/L, broadly consistent with the limits proposed by Hart et al. (1991) over 30 years ago.

7.5 Fish

As outlined in Table 11 the selected water quality indicators are:

- Eels
- Australian Grayling
- Dwarf galaxias
- Yarra pygmy perch
- Carp
- Estuarine residents

Living in the water means that fish have greater exposure to salinity levels, so some species will be directly affected. There are two indirect pathways by which changes in salinity may influence species. The first is through effects of salinity on vegetation communities that provide habitat for fish and their food and can be important for breeding. The second is that freshwater flows may provide cues for the movement of species and loss of these cues would likely have an impact on species completing their life cycles.

Depth variations may also be important as they influence both the amount of habitat and vulnerability to predation. Depth impacts on vegetation may also have a big impact on habitat availability for both the fish and their food.

Short-finned Eels

Short-finned eels mature in freshwater waterbodies, preferably still-water, before migrating to the ocean to breed. Young eels (glass eels) migrate back through the estuary in search of freshwater habitat. River flows are thought to attract and direct migrating eels through a combination of odours, salinity, and water current. Survival of glass eels is influenced by food availability and so if glass eels are moving through a system, it will be important that there is access to abundant high-quality food.

The transition from the ocean into freshwater habitats requires metabolic changes in Eels, so it is unlikely that changes in the salinity levels envisaged in this assessment will act as a threat to Eels. There is a risk that changes to salinity gradients through the estuary and wetlands may disrupt glass Eel migration with possible consequences for populations. As eels will chase fresh water, the change in salinity of the flows from the wetlands into Lake Connewarre will likely lead to shift in eel distribution as eels choose to swim towards the fresher water of the Barwon River as opposed to the more saline water from Reedy Lake and Hospital Swamps. It would likely be expected to be a temporary change however, with eels likely to return as the outflows that provide migratory triggers become fresher.

The other consideration for eel movement is connectivity when water is becoming more saline. Eels would require passage options out of the wetlands as water becomes more saline, so open connection to the Barwon River either upstream or downstream of the tidal barrage is vital. It is important to note as well however, that adult eels are relatively resilient and may be able to overcome barriers through overland movement.

Changes in cycles of inundation and drying have the capacity to influence both food abundance and exposure to predators. As noted, vegetation responses to changes in salinity can be complex and their interaction with depth variation are not well understood. The effects of changes in depth on vegetation is, however, better understood and maintaining constant depths is known to impact vegetation communities. The extent which this represents a threat to glass eels remains uncertain.

Australian Grayling

To complete their life cycle Australian grayling requires access to a range of freshwater, estuarine and marine habitats. Adults spend most of their lives in cool, clear freshwater rivers and streams with a gravel substrate and alternating pool and riffle zones. Adults are cued to move downstream to spawn by increased flows. Larvae and juveniles inhabit estuaries and coastal seas, and there appears to be an obligatory marine stage, although their precise habitat requirements are not known. Movements of juveniles into freshwater systems is cued by increases in discharge, it is not clear what the specific cue for this movement is, whether it is current, salinity, or odour. There is therefore a risk that migration may be affected by changes in wetland salinity levels, despite their being fish passage through the entire system.

Australian Grayling also undertakes movements between freshwater and marine systems so it is unlikely that changes in the salinity levels envisaged in this assessment will act as a threat to grayling. There is a risk that changes to salinity gradients through the estuary and wetlands may disrupt migration from the ocean back into freshwater systems. This risk is similar to the one discussed in the Eel assessment, where as the outflow from the wetlands becomes more saline, then the Australian Grayling would be more likely to use the Barwon River over the more saline wetlands. The connectivity out of the wetlands is also an important consideration due to the reliance on passage between areas.

Dwarf Galaxias

Dwarf galaxias (DG) live in shallow (<30cm) freshwater with abundant aquatic vegetation. Populations can survive in areas that partially or completely dry by aestivating beneath rocks or logs. DGs are good at moving between waterbodies through very shallow water (2mm). They are vulnerable to invasion by gambusia and are now found mostly in swamps or isolated ponds, some distance from rivers. DG feed mostly on aquatic invertebrates such as copepods, chironomid larvae etc and a variety of small terrestrial arthropods.

Changes in salinity are likely to impact Dwarf galaxias. While no threshold was found, it would be reasonable to assume exceeding 1,000 mg/L would be detrimental. It is likely that they may be able to survive short periods of time in water with greater salinity.

Dwarf galaxias are able to avoid periods of drying, however, changing cycles of inundation and drying will affect vegetation which will have adverse impacts on their habitat.

Yarra pygmy perch

Yarra pygmy perch preferred habitat is slow-flowing or still freshwater lakes, ponds and slow-flowing rivers with large amounts of aquatic vegetation (particularly emergent vegetation). River regulation is believed to affect them by reducing connectivity that enable them to move between suitable habitats after disturbances (e.g. flood, dry).

Loss of freshwater will represent a loss of habitat for perch.

Changes in patterns of inundation will affect vegetation which will have adverse impacts on their habitat.

Carp

Carp are highly adaptable, occupying a range of habitats but reaching their highest abundances in permanent wetlands. Since being introduced in the 1960s, carp have spread across most of south-eastern Australia. They are now the most abundant large freshwater fish in some areas, including most of the Murray-Darling Basin, and are thought to have contributed to the degradation of our natural aquatic ecosystems through increases in turbidity, loss of aquatic plants and competition with native fish.

Carp are tolerant of a wide variety of water quality conditions but have a lethal concentration for 50% of individuals of 11,715 mg/L although sub-lethal effects have been observed at lower concentrations. Unfortunately increases in salinity are likely to favour carp over native freshwater fish.

Variations in depth will not directly impact carp, although they will move in responses to increasing depth in spring.

Estuarine residents

A range of fish species are resident in estuaries and include broad groupings of estuarine opportunists (freshwater) that includes Big-headed gudgeon and Australian smelt, estuarine residents such as Blue-spot goby and Black bream, estuarine dependent (marine derived) including Tupong and King George Whiting and estuarine opportunists (marine) such as mullet and Greenback flounder. The opportunistic species will utilise estuary habitats when salt levels are within their tolerances. Estuarine residents such as the Blue-spot goby are able to tolerate a wide range of salinities and temperatures.

Species that live in marine habitats and spawn in freshwater or estuaries (anadromous) and those that live in freshwater and require salty water to spawn (catadromous) are more likely to have more specific salinity requirements. The list of these species found within Hospital Swam and Reedy Lake is provided in Table 19.

Table 19. *List of fish species found in Hospital Swam and Reedy Lake dependent on estuaries to complete their life cycle.*

Guild	Common name
Anadromous	Tupong
	Small-mouthed hardyhead
Catadromous	Common galaxias
	Spotted galaxias
	Broad-finned galaxias
	Short-finned eel
	Australian grayling

7.6 Frogs

The Growling Grass Frog (GGF) was selected as an indicator (Figure 67) due to its conservation status and because tadpoles and frogs represent an important food resource for a range of fish and birds.

The GGF is found in large permanent to semi-permanent (6 months) with, moderate to low salinity (less than 5600mg/L). Wetlands with abundant aquatic vegetation, particularly submerged and floating species provide better habitat. These wetlands often have minimal tree canopy cover. The GGF is tolerant of moderately salty water which also appears to provide FFG with refuge from chytrid fungus.

Minor increases in salinity may benefit GGF, but once salinity levels exceed 7.0 mS/cm salinity will become a threat to survival and recruitment. As a result, the scenarios that are more likely to create higher saline conditions (such as the climate change scenario (Scenario 6) or any management decisions that result in lower enough water levels that groundwater and tidal flows can impact salinity will increase the likelihood of poor conditions for the GGF.

GGF are critically dependent on vegetation to survive, so any changes that affect vegetation cover will affect GGF.

7.7 Birds

As outlined in Figure 67 the selected water quality indicators are:

- Brolga
- Great Egret
- Australasian bittern
- Australian little bittern
- Orange-bellied parrot

In general, waterbirds are not affected directly by changes in salinity, however, they are affected indirectly by changes in vegetation and food availability.

Brolga
The main habitat for Brolga in Victoria is freshwater meadows or shallow marshes where they eat a wide variety of food including edible bulbs, roots, shoots and leaves of wetland plants and animals such as insects, molluscs, crustaceans, frogs and lizards. While freshwater wetlands are preferred, brolgas can both forage and nest in brackish or saline (30,000 ppm) habitats as they have the capacity to excrete salt through glands near their eyes.

Brolgas are critically dependent on shallow water to both forage and breed and so any change to the water regime that affects the area of shallow water habitat is likely to be detrimental to Brolga. While Brolga feed on a wide range of freshwater and saline prey, their diet consists of plant material and prey that are dependent on vegetation and while Brolga may adapt to a gradual transition in vegetation, declines or loss of vegetation is likely to affect food resources and lead to declines in population numbers.

Changes to salinity will impact brolgas if their food resources are affected through transition to lower quality or less productive food species. The Brolga's preferred freshwater meadows will be impacted if salinity increases above 1,000 mg/L, however, they may adapt to the more salt tolerant community that succeeds it.

Changes in cycles of inundation and drying will impact Brolgas if the areas of shallow water and associated vegetation are reduced or lost.

Great Egret

Great Egrets are distributed around the world and occur in a wide variety of habitats ranging from damp grasslands through to intertidal mudflats. They feed in shallow water on a wide variety of prey items including molluscs, frogs, aquatic insects, small reptiles, crustaceans with the main prey item being fish. Great egrets usually build a nest of sticks in a tree that over-hangs water.

Increases in salinity above 1000 mg/L are likely to impact obligate freshwater food items including frogs, insects and fish. Egrets are adaptable and will use the more saline habitat and only be impacted if prey abundance or quality decline.

Egrets require shallow water to forage so changes to the water regime that affects the area of shallow water habitat is likely to reduce access to food. While Great egrets feed on diverse aquatic animals, many of these, including insects, frogs and fish are dependent on vegetation so that declines or loss of vegetation is likely to affect food resources and lead to declines in population numbers.

Australasian Bittern

Australasian Bitterns predominantly inhabit freshwater wetlands with occurrences in estuaries or tidal wetlands. Regardless of salinity levels, wetlands need to support a mosaic of dense vegetation to support their foraging either at the edges of pools in water up to 0.3 m deep or from vegetation over deep water. They favour permanent and seasonal freshwater habitats, particularly those dominated by sedges, rushes and/or reeds.

Australian bitterns are able to tolerate changes in water depth and salinity but are critically dependent on vegetation to persist. Significant changes to vegetation associated with changes in salinity or depth variability will mean that they will not forage effectively. The food items available to Australian bitterns may also be affected directly by salinity changes and indirectly through vegetation changes. Frogs would be particularly vulnerable to salinity changes, while other taxa may increase or decline with unknown impacts on Australian bittern populations.

Salinity increases above 3,000 mg/L will affect vegetation communities but as long as the transition leads to replacement by a mosaic of emergent vegetation adjacent to open water, Australasian bitterns will have access to foraging habitat.

Alterations to cycles of inundation and drying that either hold levels constant or exceed emergent species capacity to persist will impact Australasian bitterns

Australian Little Bittern

Like the Australian Bittern, Little bitterns forage among vegetation in freshwater wetlands where they prey on a variety of animals including fishes, frogs and insects. Changes in salinity or patterns of inundation and drying will impact foraging. The food items available to Australian little bitterns may also be affected directly by salinity changes and indirectly through vegetation changes. Frogs would be particularly vulnerable to salinity changes, while other taxa may increase or decline with unknown impacts on Australian little bittern populations.

Effects on Australian little bittern is expected to be the same as for Australasian bitterns.

Orange Bellied Parrot

When on the mainland, Orange-bellied parrots birds inhabit coastal saltmarshes and adjacent pastures, close to open water bodies where they feed on seeds and flowers of low shrubs or prostrate vegetation (Ehmke 2009, Ehmke & Tzaros 2009). Preferred food plants in saltmarshes include Beaded Glasswort, Austral Seablight (*Sueda australis*), and Shrubby Glasswort (*Tecticornia arbuscula*).

Changes in the vegetation community in terms of species or ground-cover are likely to be detrimental to Orange-bellied parrots through effects on their food or susceptibility to predators.

None of the scenarios were associated with increases in salinity that would impact salt marsh communities which can tolerate 10,000 to 50,000 mg/L.

Bird assessment

The overall impact of the changes that impact the bird population are linked to the vegetation condition. The changes that were made in the water salt balance appear to hold not significant impact on the bird indicator species, though a more detailed investigation with a more wholistic assessment is recommended.

7.8 Multi-habitat species

As outlined in Figure 67 the selected water quality indicators are:

- Ducks
- Colonial nesters
- Migratory birds

The multi habitat species were chosen due to their importance to ecological character and community values. The scope of their assessment is a broader consideration of whether the changes to the salinity and watering regimes would affect the species. This is a result of the multi-habitat nature of the indicator groups, that means it is not possible to assess the individual species in a specific manner. While the groups would be supported by other wetland or vegetation areas across the region and the multinational migration paths, this assessment tries to ascertain whether the Lower Barwon Wetlands would remain beneficial.

Among the ducks, Chestnut teal can tolerate higher salinities, Hardhead can be found in estuaries and Australian shelduck utilise saline habitats, but only if they also have ready access to a source of freshwater. Magpie geese and Australian grebes are both freshwater species.

White-faced herons have broad habitat tolerances from freshwater to marine. Royal spoonbills are opportunistic using freshwater and saltwater wetlands, but also will use sewage lagoons, salt-fields, dams, and reservoirs. In contrast, Yellow-billed spoonbills are rarely found in saline habitats being found in freshwater wetlands, dams, lagoons, and swamps, and occasionally pastures. It is likely that White-face herons and Royal spoonbills would continue to utilise the wetlands if salinity increased if their food remained abundant. Yellow-billed spoonbills may use salinized wetlands under extreme conditions, but they would no longer be preferred habitat.

All five migratory species will use habitats that range from freshwater to saline. Latham's and Painted snipe are both dependent on vegetation cover. For all five species food resources are a key determinant of wetland use. Latham's and Painted snipe feed by probing in soft sediments, while the shorter bills of sandpiper and greenshank are used to collect a variety of small animals such as insects and worms.

While there is no defined upper limit for salinity for freshwater birds, Magpie geese and Australian grebes are likely to be most susceptible to increases. Based on vegetation and invertebrate tolerances, exceeding 1000 mg/L should be considered an upper limit. It is possible that both species would move into and out of Hospital swamp and Reedy Lake as salinity levels changed through the year.

7.9 Geomorphology

Reedy lake and Hospital swamp are low energy depositional environments.

Changes in salinity and mean water level have the potential to impact the type, extent and density of vegetation within Reedy Lake and Hospital swamp. Should changes in salinity or mean water level be large (either decreasing or increasing significantly compared to existing conditions), then vegetation die-back may result. Vegetation die-back reduces the resistance of the bed and shorelines which has the potential to trigger erosion.

The larger the change in salinity or mean water level, the greater the potential for vegetation die back and subsequent erosion. If mean water level increases to the point that the unvegetated shorelines of Reedy Lake and Hospital Swamp (approximately 0.9 m AHD), are subject to significantly more wave action, then erosion may occur.

Analysis of likely vegetation response to the modelled changes in salinity and water level (section 7.4) suggest that any loss (die-back) of vegetation is likely to be replaced by a species more suited to the altered water levels or salinity. While a change in the distribution of a particular species or EVC class may have ecological consequences, from a geomorphic perspective the change has little effect. Both Common Reed and Salt Marsh provide ample erosion resistance in this low energy environment and a change in the make-up of species on the shoreline is unlikely trigger widespread erosion. The time lag between die-back of one species and the establishment of another may lead to a temporary decrease in erosion resistance of the bed and shoreline, but any resulting erosions likely to be localised and relatively short-lived.

Large decreases in mean water level may allow vegetation to spread into areas that were previously submerged, and free of emergent vegetation. The larger the decrease in mean water eve the greater the potential for vegetation expansion. The geomorphic impact of such increase in vegetation cover is a potential increase in the trapping of sediment, which may lead to the vertical accretion of sediment. Rates of vertical accretion are likely to be low and would also require water level fluctuation to be large enough that newly established vegetation is frequently but temporarily re-submerged so that stands intercept mobile sediment.

7.10 Groundwater

The results of the model have indicated that where scenarios removed surface water flow into the wetlands, groundwater became a greater contributor to the salinity of the waterbodies, particularly in summer. Some changes could potentially influence the groundwater salinity, at least locally, or encourage saltwater intrusion though it’s noted that the transfers between groundwater and surface water were maintained constant (relative to wetland depth) based on historic data.

The hydrology of the wetlands is shown to be dominated by the fresh surface water inputs, that can maintain or reduce water levels, impacting groundwater flux. With decreasing water levels in the wetland the influence of groundwater hydrology increases. The salinity levels in the wetlands are influenced by groundwater as it is naturally more saline than the surface water. During low water levels in the wetland the combined effect of evaporation, decreasing wetland water volume and groundwater inflow creates steeply rising salinity concentrations.

There are also scenarios that could potentially change the balance of water and salt across the catchment, with implications to groundwater. The increased urbanisation scenarios result in higher volumes of surface runoff from the increased imperviousness which in turn reduces groundwater recharge. This change would increase the surface water component in the wetlands, changing the balance between surface and groundwater resulting in higher groundwater recharge rates in the wetlands. An increase in localised groundwater recharge at the wetlands could decrease groundwater salinity in the area. The full wetlands scenarios would have similar impacts, increasing the localised freshwater intrusion into the groundwater potentially creating localised decreases in salinity of the aquifer.

The climate change scenario would also have implications on the groundwater component of the wetlands. On a shorter time scale, this would mean longer low water levels in the wetlands, increasing the importance of groundwater for the wetlands hydrology. This would also increase the salt concentration and time of exposure of these concentrations in the wetlands. On a longer time scale of lower river levels, lower groundwater recharge would also reduce groundwater inflow in the wetlands, which may lead to increased dry periods. Rising sea water levels in conjunction with decreasing groundwater levels can lead to progressing saltwater intrusion, which in turn may change the salinity levels of the groundwater reaching the wetlands.

8 Discussion and Recommendations

The water-salt balance model project has been able to develop a Source model of the lower reaches of the Barwon River and its wetlands to provide a key input to the upcoming Flows study review. The model investigates impacts from changes to the systems during a range of hydrological conditions over a 60-year period, and incorporates the inputs and outputs including;

- Inflows from the Barwon River and Moorabool River,
- Local catchment runoff,
- Sparrovale wetland connections,
- Groundwater/surface water interactions,
- Evapotranspiration, and
- Direct rainfall

The complete set of model files are provided to the Corangamite CMA with the final version of this report.

The results of the investigation show a system that is relatively reactive to the changes in inflows and outflows of fresh and saline water but demonstrated a capacity to recover over the course of a calendar year. The return to the salinity of the baseline scenario was noted in any change that allowed exit flows during the winter period, before then reacting again to the management over summer. Outside of the permanently full scenario that held the outflow gates closed, the salinity levels in both Reedy Lake and Hospital Swamps appeared to recover from any previous change made to the system, with no observed lingering impacts.

As a result the water-salt balance of the system was largely dependent on the balance of the short term inflows of fresh or saline water. The fresher water sources came primarily from the Barwon River, Armstrong Creek, direct rainfall and direct runoff, which were balanced by the saline groundwater (which in the modelling incorporated a portion of tidal inflows due to the model calibration). As the water levels in the wetlands are the primary factor controlling groundwater inflow, the fresh water inflows to Reedy Lake and Hospital Swamps act as a dual influence of diluting any existing salt load and restricting the inflow of groundwater.

Using these results as a guide, the major challenge that the management decisions are likely to face will be managing the changes out of the CMA's control. This will be difficult in changes that result in higher flows, though actions can be taken such as increasing diversion channel capacity or barrage upgrades that can move water directly to Connewarre to reduce uncontrolled spills into the wetlands and maintain CMA control of the inflows. It is noted however the prevalence of uncontrolled flow into the system under current infrastructure setup, with overtopping from the Barwon River in Reedy Lake and from Armstrong Creek into Hospital Swamps occurring in the model, particularly with increased runoff.

The scenario that will be more difficult to manage will be the increase in length and severity in droughts that are expected to occur due to human induced climate change. While ways can potentially be found to move increased flows through the system to the river mouth and ocean, reduction in water availability in periods of drought will be harder to remedy resulting in reduced control over the system.

Consideration of the results and the potential impact on ecological changes produces a variety of results, mostly linked to the health of the systems vegetation. For example, geomorphic changes are likely to be minimal based on the rate of change of depths in the modelled result, are more likely to be impacted by the vegetation present to hold soils in place.

While the response from the vegetation is difficult to predict given the interacting factors that influence vegetation community composition and condition, there are some outcomes that would be likely. Scenarios that result in large salinity increases, particularly at higher levels for longer, would be more likely to impact native vegetation. The long-term impact remains uncertain as some species adapt to higher salinity whereas our expectation would be that current vegetation may only persist . Furthermore, at the results show a direct relationship between depth and salinity, highly saline periods are likely to be confined to the lower regions of the wetlands, therefore only impacting a portion of the vegetation community.

The effects on vegetation are critical for fish species, therefore vegetation changes is an important consideration. As many of them appear tolerant of higher salinity, maintaining vegetation is an import factor for fish species to maintain food sources and habitat. Movement of fish is also important however, is less likely to be affected given that some species move across salinity ranges throughout the stages of lifecycle.

Water level variation is a critical determinant of species presence and wetland vegetation diversity. Scenarios that maintain deeper levels for longer would likely result in poorer health for much of the vegetation present, and there is a risk that dying vegetation renders sediments inhospitable for species that might otherwise be able to tolerate the salinity regime.

Impacts on frogs, local waterbirds and multi-habitat birds is more difficult to determine given the increased capacity for movement but some impacts can be anticipated. Growling Grass frogs may be able to tolerate minor increases in salinity, but will be sensitive to major increases given their need for water throughout their life cycle. Based on the results of the annual modelling (whether the decision is to wet or dry that year) may not impact the Growling Grass Frog if the return to winter freshness is able to satisfy the 65-month requirement (in conjunction with the other environmental factors).

The biggest impacts on local waterbirds and multi-habitat birds will be through the effects on vegetation that is provides habitat and food sources. The impacts on waterbirds will be determined by the availability of habitat (vegetation, water depth) at the landscape scale, although reductions in the quality or amount of habitat is likely to be associated with declines in regional populations.

It is important to note that the changes in salinity may be positive or negative for the species considered, but the broader context of the whole wetland is important. For example, if the coverage of the Common Reeds were to expand, this would be associated with changes in the number of other types of vegetation and the characteristics of the habitat mosaic that is known to be important in supporting the diversity of plants, invertebrates and fish and birds. This is why the Ramsar LAC’s are framed as specific proportions of different types of freshwater vegetation. The wetlands are, however, complex systems in which salinity levels and depth fluctuations are just two factors among many that interact to influence their character and condition. Despite the uncertainty associated with managing a complex system, the water-salt balance model that has been developed and calibrated as part of this project will be critical for the update to the FLOWS study.

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Attachment 1. Model Results Violin Plots

Attachment 1: Model Results Violin Plots

Violin plots, or fiddle plots, have been applied to show the change in the distribution of typical TDS concentrations within the wetlands under a range of scenarios. Here, larger widths indicate a greater frequency of occurrence compared to smaller widths (Figure 69). The interquartile range and median are represented on the plots with dashed lines.

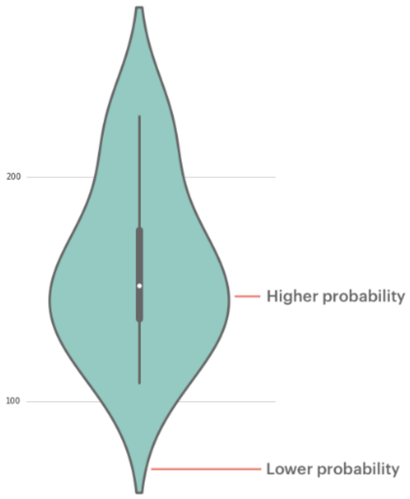


Figure 69. *Violin plot representation of data frequency*

Diversion channel comparisons

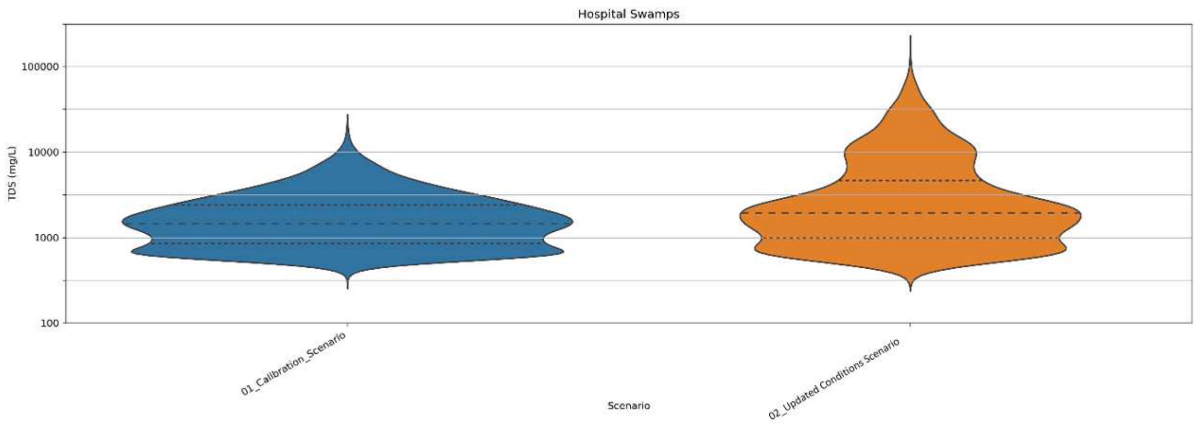


Figure 70. *Comparison of the distribution of TDS concentrations within Hospital Swamps between the calibration and Updated Conditions scenario*

Scenario comparison

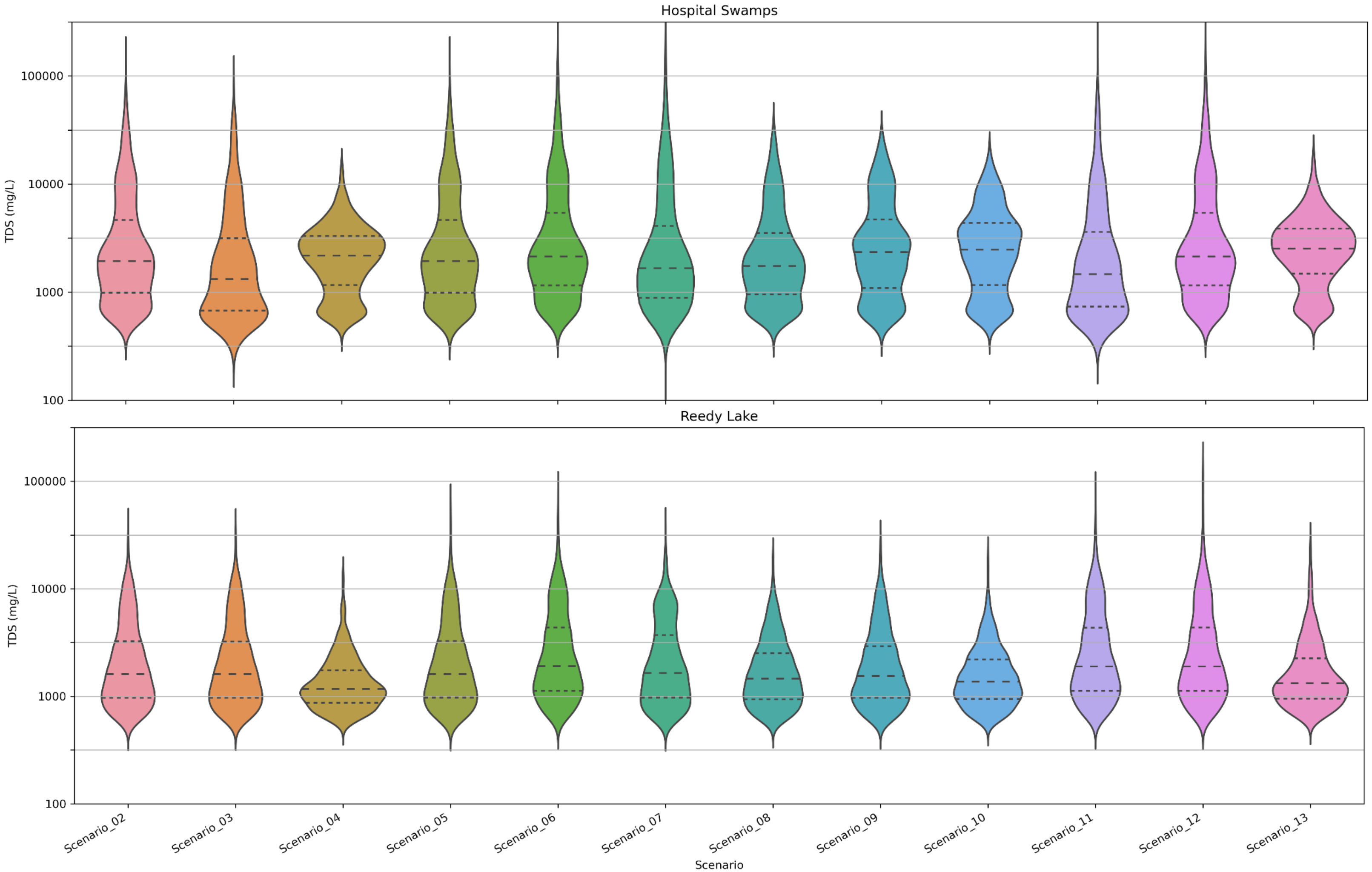


Figure 71. *Comparison of the distribution of TDS concentrations within Hospital Swamps (top) and Reedy Lake (bottom)*

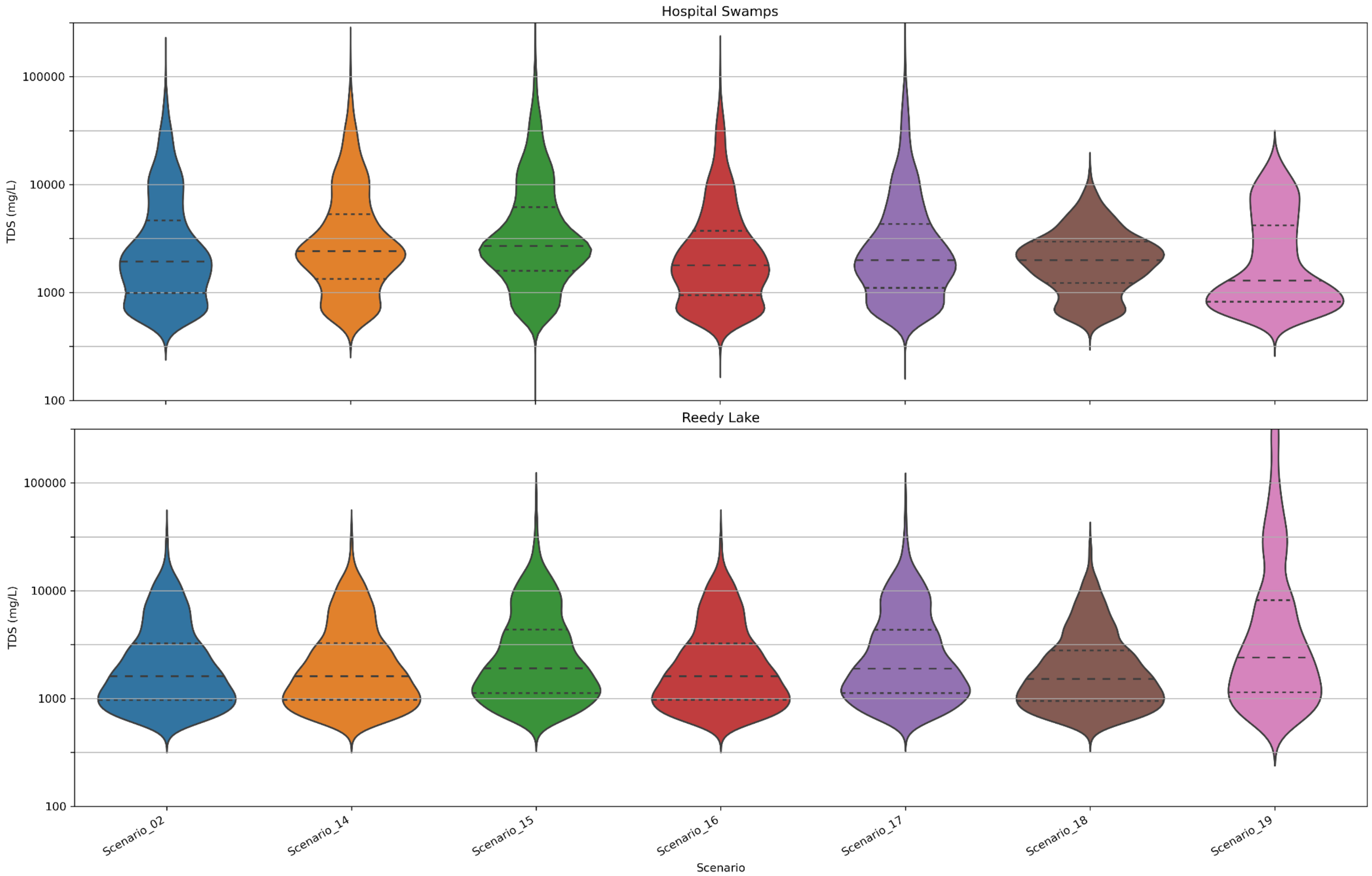
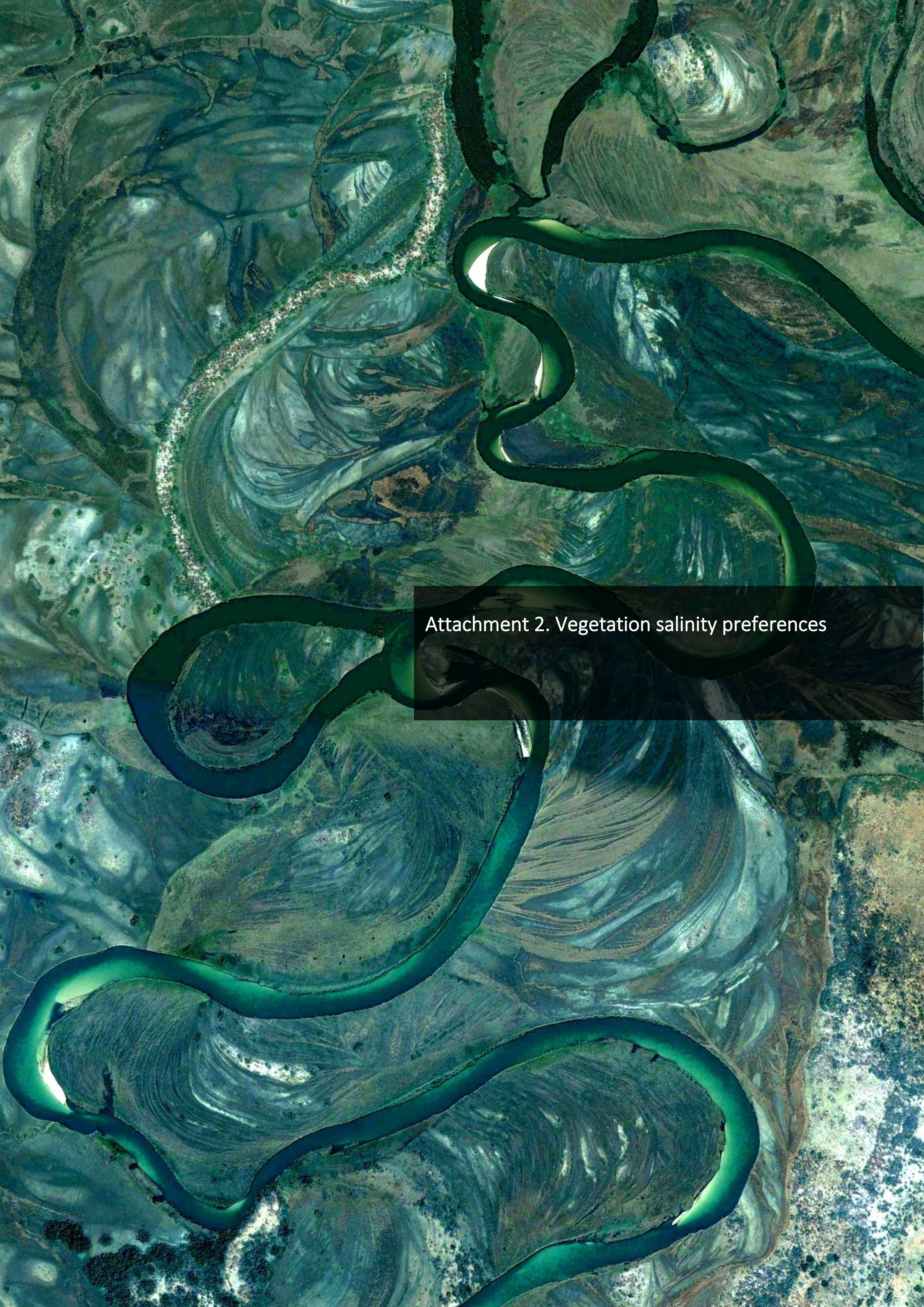


Figure 72. *Comparison of the distribution of TDS concentrations within Hospital Swamps (top) and Reedy Lake (bottom)*



Attachment 2. Vegetation salinity preferences

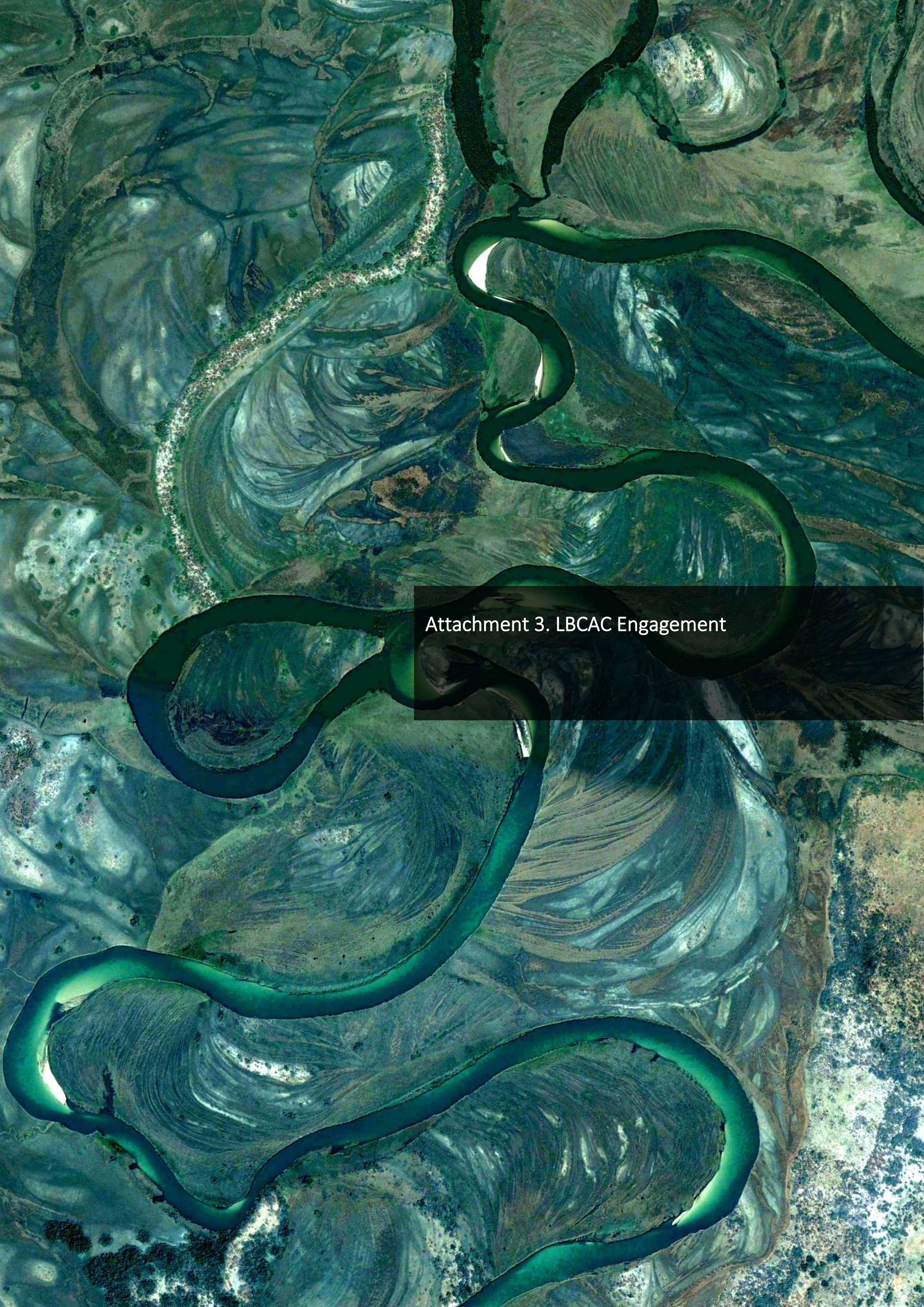
Attachment 2: Vegetation salinity preferences

Table 20 *Hydrological and salinity preferences for selected vegetation types and their presumed EVCs in the Lower Barwon Wetlands. Source: Frood & Papas (2016).*

Vegetation type	Presumed indicative EVC(s)	Hydrological and salinity preferences as per Frood & Papas (2016)		
		Inundation		Salinity
Common Reed	EVC 821 Tall Marsh (If not saline)	Permanent: constant inundation Seasonal: annual or near-annual inundation (e.g. 8–10 years in every 10) Typically <30−100 cm deep		Typically < 3 g/L
	EVC 952 Estuarine Reedbed (If saline)	King tide: several times per year Permanent: constant, annual or less frequently but before wetland dries Seasonal: annual or near-annual inundation (e.g. 8–10 years in every 10) Typically <30−100 cm deep		Typically 3−10 g/L
Coastal saltmarsh	EVC 9 Coastal Saltmarsh Aggregate	Semidiurnal tide: twice daily King tide: several times per year Seasonal: annual or near annual inundation (e.g. 8–10 years in every 10) Intermittent: inundated 3–7 years in every 10 Fringing : inundation periodic but brief	 Common Occasional Occasional Common	10−50 g/L
Submerged and open-water species	EVC 918 Submerged Aquatic Herbland (If not saline)	Permanent: constant, annual or less frequently but before wetland dries Intermittent: inundated 3–7 years in every 10 or <3 years in every 10 Water depth <30−>200 cm		Typically < 3 g/L

Vegetation type	Presumed indicative EVC(s)	Hydrological and salinity preferences as per Frood & Papas (2016)		
		Inundation		Salinity
	EVC 842 Saline Aquatic Meadow (If saline)	King tide: several times per year Permanent: constant, annual or less frequently but before wetland dries Seasonal: annual or near annual inundation (e.g. 8–10 years in every 10) Intermittent: inundated 3–7 years in every 10 Water depth <30–>200 cm	Common Occasional Occasional Common	10–50 g/L

Attachment 3. LBCAC Engagement



Attachment 3: Lower Barwon Wetlands Community Advisory Committee (LBCAC) Engagement

The Lower Barwon Wetlands Community Advisory Committee (LBCAC) was engaged in two stages over the course of the project:

- Session No.1: Presentation on the project aims and scope to gather feedback on scenarios to be modelled and important ecological indicators
- Session No. 2: Summary presentation of findings and review of the Final Project Report (this report

Project scoping

At the first session, the LBCAC were presented with the projects plans and aims, and were invited to provide feedback to help guide the project. At that session, we received feedback on the important considerations for the modelling, and for the indicators used to assess the results. The feedback included:

- Investigating the balances during the millennium drought
- Inclusion of groundwater
- Inclusion of the connection between Sparrovale and Lake Connewarre
- Consideration of the northern and western growth corridor
- Assessment of the impacts to the Growling Grass Frogs in Reedy Lake
- Preservation of the freshwater marsh in Reedy Lake
- Assessment of the historic watering regimes
- Consideration of eels as a representative species

Following the session, we received one (1) submission. The submission identified;

- Importance of maintaining lower saline concentrations in Reedy Lake to preserve fresher water dependant inhabitants
- Assessment of the impacts to the Growling Grass Frogs in Reedy Lake
- Assessment of the impacts to the Brolga populations

Results

Following the completion of the modelling, the results were presented to the LBCAC at Session No. 2, to discuss the range of outcomes found and the sensitivity of the modelled system. This session was conducted via video conference, with the session recorded and provided to members of the LBCAC.

During the session we received feedback regarding the assessment parameters and the presentation of results. The feedback included:

- Provide clarity in the measure used for results, and consistency in the use of TDS (Total Dissolved Solids) rather than salinity
- As the extreme salinity values that occur when the lakes are close to empty (due to the very small water volume in the mg/L calculation) it is suggested to use the median results rather than the average
- Wherever possible use consistent axis scales
- Ensure that the assumptions in the model are clearly articulated in the reporting

- Clarity was sought that the CMA does not allow complete drying (CMA policy is to not allow complete drying until after flow recommendations have been updated. It is noted that some scenarios are included to test responses to a range of conditions including the unlikely extreme).
- There was endorsement of the concept of 'too fresh' (though it was noted that the threshold of 'too fresh' will vary across vegetation and animal species)
- Change of indicator from the Intermediate Egret to the Great Egret
- Update of indicator: Change Australasian little bittern to Australian little bittern

Committee members were also invited to provide feedback on the presentation following the circulation of the recording. The feedback following the session included:

- Due to the complexity of some of the information it is recommended to include a schematic of the system to aide understanding