NATIONAL RESEARCH FLAGSHIPS




## Water for a Healthy Country

# Predicting the future ecological condition of the Coorong

## The effect of management actions & climate change scenarios

Rebecca E Lester, Ian T Webster, Peter G Fairweather & Rebecca A Langley

April 2009

DRAFT

The University of Adelaide Australia
SARDI South Australian Research and Development Institute
Government of South Australia
Flinders University Adelaide Australia
CSIRO

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The Water for a Healthy Country National Research Flagship is a research partnership between CSIRO, state and Australian governments, private and public industry and other research providers. The Flagship aims to achieve a tenfold increase in the economic, social and environmental benefits from water by 2025.

The Australian Government, through the Collaboration Fund, provides $97M over seven years to the National Research Flagships to further enhance collaboration between CSIRO, Australian universities and other publicly funded research agencies, enabling the skills of the wider research community to be applied to the major national challenges targeted by the Flagships initiative.



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# Foreword

The environmental assets of the Coorong, Lower Lakes and Murray Mouth (CLLAMM) region in South Australia are currently under threat as a result of ongoing changes in the hydrological regime of the River Murray, at the end of the Murray-Darling Basin. While a number of initiatives are underway to halt or reverse this environmental decline, rehabilitation efforts are hampered by the lack of knowledge about the links between flows and ecological responses in the system.

The CLLAMM program is a collaborative research effort that aims to produce a decision-support framework for environmental flow management for the CLLAMM region. This involves research to understand the links between the key ecosystem drivers for the region (such as water level and salinity) and key ecological processes (generation of bird habitat, fish recruitment, etc). A second step involves the development of tools to predict how ecological communities will respond to manipulations of the "management levers" for environmental flows in the region. These levers include flow releases from upstream reservoirs, the Lower Lakes barrages, and the Upper South-East Drainage scheme, and dredging of the Murray Mouth. The framework aims to evaluate the environmental trade-offs for different scenarios of manipulation of management levers, as well as different future climate scenarios for the Murray-Darling Basin.

One of the most challenging tasks in the development of the framework is predicting the response of ecological communities to future changes in environmental conditions in the CLLAMM region. The CLLAMMecology Research Cluster is a partnership between CSIRO, the University of Adelaide, Flinders University and SARDI Aquatic Sciences that is supported through CSIRO's Flagship Collaboration Fund. CLLAMMecology brings together a range in skills in theoretical and applied ecology with the aim to produce a new generation of ecological response models for the CLLAMM region.

This report is part of a series summarising the output from the CLLAMMecology Research Cluster. Previous reports and additional information about the program can be found at http://www.csiro.au/partnerships/CLLAMMecologyCluster.html

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# Acknowledgements

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We also acknowledge the contribution of several other funding agencies to the CLLAMM program and the CLLAMMecology Research Cluster, including Land & Water Australia, the Fisheries Research and Development Corporation, SA Water, the Murray-Darling Basin Commission’s (now the Murray-Darling Basin Authority) Living Murray program and the SA Murray-Darling Basin Natural Resources Management Board. Other research partners include Geoscience Australia, the WA Centre for Water Research, and the Flinders Research Centre for Coastal and Catchment Environments. The objectives of this program have been endorsed by the SA Department of Environment and Heritage, SA Department of Water, Land and Biodiversity Conservation, SA Murray-Darling Basin NRM Board and Murray-Darling Basin Commission.

We would like to thank the members of the CLLAMMecology Research Cluster for their ongoing contributions to the development of these models and scenarios, and the CLLAMMecology Management Committee for their overall encouragement. The participants of the CLLAMM Futures workshops, and the third workshop in particular, also contributed useful suggestions and criticisms of the model development process. Constructive criticism and suggestions regarding model development, evaluation and verification were also offered by Gene Likens and Peter Petraitis. Participants of the three CLLAMM Futures workshops, along with other managers and stakeholders also provided critical advice regarding the development of the scenario set presented here, with Glynn Ricketts from the SA Murray-Darling Basin NRM Board and Russell Seaman from DEH making significant contributions.

Data and assistance in interpretation of those data were provided by David Paton and Daniel Rogers from the University of Adelaide, Sabine Dittmann and Alec Rolston from Flinders University, Qifeng Ye and Craig Noell from SARDI Aquatic Sciences, Joseph Davis from the Murray-Darling Basin Authority and the Australian Wader Study Group. The generosity of these contributors in sharing their valuable datasets is gratefully acknowledged. The foresight of these scientists in collecting these datasets is exemplary. Funding bodies contributing to the original collection of these data include the South Australian Department for Environment and Heritage, Earthwatch and the Fisheries Research and Development Corporation. Additional data was supplied by the South Australian Department for Environment and Heritage, Primary Industries and Resources South Australia and the Australian Bureau of Meteorology Climate & Consultative Services, the National Tidal Facility and Flinders Ports.

We also gratefully acknowledge the research assistance provided by Stephanie Duong and assistance with map-making from Craig Noell at SARDI Aquatic Sciences.

# Executive Summary

Management of large-scale ecosystems like the Coorong is complex, and it can be difficult to objectively assess the likely ecological consequences of management decision.  This is particularly the case with the added uncertainty of climate change and sea level rise.

We used a hydrodynamic model and an ecosystem state model for the Coorong in sequence to assess the likely consequences of 20 possible future scenarios for the Coorong.  The hydrodynamic model uses forcing data for climate, tides, winds and flows over the barrages to provide hourly predictions of water levels and salinity along the length of the Coorong for a 114-year model run.  The ecosystem state model uses these simulations together with flows over the barrages as inputs to a scheme for predicting the extant mix of ecosystem states along the length of the Coorong.

The scenarios investigated here include a mixture of climate change, sea level rise and various management options.  We investigated the effect of current extraction levels, The Living Murray initiative, dredging at the Murray Mouth and a proposed increase in the flow volumes at Salt Creek via the Upper South East Drainage scheme.

From our investigation of a Baseline scenario (with a historic climate and current extraction levels), it was evident that the current condition in the Coorong is exceptional, even with 114 years of variation.  No other drought in the sequence produced conditions as poor as are currently observed in the Coorong.

Extraction levels had a significant impact on both the hydrology and the ecosystem states of the Coorong.  Under natural flows (i.e. no storages and no extractions in the Murray-Darling Basin), there would be substantiative changes in the ecosystem states of the Coorong and the ecosystem was predicted to be in a much healthier mix of states than is currently the case.

Under current extraction levels, climate change has the potential to be devastating for the ecology of the Coorong.  Salinities under a dry future climate projection are predicted to rise to an unrealistic 400 g $L^{-1}$ and higher, with the number of days without flow over the barrages peaking in the thousands (i.e. up to eight years).  The effect of this on the ecosystem states of the Coorong was dramatic, with sites predicted to be in a degraded ecosystem state for almost half of all years.  On the other hand, the effect of climate change was much smaller under natural flow conditions, indicating that it was the combination of climate change and current extraction levels that were driving the dire predicted mix of ecosystem states, rather than climate change alone.

Sea level changes had a mixed impact on the hydrodynamics and ecosystem states of the Coorong.  Estimates for the broader region including the Coorong at the lower end actually include a decrease in sea level of up to 10 cm.  Such a decrease exacerbated the effect of climate change by decreasing the connectivity in the system.  This resulted in a small increase in the proportion of degraded ecosystem states in the Coorong.  Sea level rise, either at a moderate or high level (i.e. +20 or 40 cm by 2030), increased the hydrodynamic connectivity in the Coorong, and thus alleviated some of the more severe effects of climate change at current extraction levels.  These predictions do assume that the current Murray Mouth is the only connection between the Coorong and Encounter Bay.  Any breaches of either peninsula would likely change the overall effect on the system.

Relatively small amounts of additional environmental water delivered to the Coorong, via The Living Murray initiative had a large impact on the ecosystem states in the Coorong.  By providing additional flows at times of drought, TLM had the capacity to alleviate many of the effects of prolonged drought, and resulted in a decline in the proportion of site-years in a degraded ecosystem state of up to half.  There was a note of caution, however, with the inclusion of TLM infrastructure without the delivery of environmental water actually causing a slight deterioration in the condition of the Coorong.  This emphasised the need to actually deliver the environmental water as planned once the necessary infrastructure was in place.

Murray Mouth dredging had quite a limited effect on the connectivity and the ecosystem states of the Coorong. The intervention was only modelled during dry years, using a depth of -2 m AHD, but seemed to affect hydrodynamic variables at only the Murray Mouth sites, without affecting sites further along the Coorong. This resulted in a relatively limited impact on the distribution of ecosystem states either in the entire 114 years, or in the last 20 years of the model run.

The proposed augmentation of the USED scheme had a greater impact. The effect of additional water through Salt Creek affected the ecosystem states in the South Lagoon regularly, and affected sites as far north as the Murray Mouth occasionally. This scenario was based on a hypothetical maximum possible volume of water thought to be available from the Upper South East, and additional work is needed to investigate the effect of more realistic volumes, but this option had the potential to buffer the Coorong in times of drought, if the water was available. However, the overall message from the engineering options was that there was no effective substitute for barrage flows.

There are a number of uncertainties inherent in the current ecosystem state model, particularly surrounding any recovery within the system. This is due to a lack of data covering time periods in which the ecosystem of the Coorong was recovering. As such, potential recovery pathways and time lags are not able to be quantified by the model. Further monitoring work, focused on the biological and environmental parameters used by the model is recommended.

Nonetheless, these models have the potential to assist managers in the development of more rigorous management targets and monitoring programs. The ecosystem state model simplifies the task of quantifying ecosystem condition, and the range of values for each variable that define each ecosystem state could provide the basis for limits of acceptable change. This model and the associated scenario analyses, represent a robust, data-derived attempt to quantify the ecological condition of the Coorong and objectively assess the various management options available. Its predictive capacity is provided by its direct link to the hydrodynamic model. This approach has significant promise and could be applied to other estuaries and other ecosystem types.

# 1. Introduction

## 1.1. Coorong

The Coorong is a long, shallow, lagoonal system that stretches approximately 110 kilometres in a south-easterly direction (Figure 1.1). It is separated from the ocean by a narrow sand peninsula and is artificially divided from the freshwater Lakes Alexandrina and Albert to the north by a series of barrages. These barrages were constructed between 1935 and 1940 in order to prevent saline intrusion up the River Murray as extraction levels increased (Newman, 2000). The barrages include a series of gates that can be opened to allow the passage of fresh water from the Lakes into the Coorong. The Coorong has a single connection to the Southern Ocean near its northern end called the Murray Mouth. Having its freshwater inflows through the barrages located towards the same end as the Murray Mouth makes the Coorong an inverse estuary (Wolanski, 1987) rather than the more-usual configuration of fresh inflows at one end and connection to the sea at the other. The Coorong can be divided into three regions. The section to the north of the Murray Mouth extending to the southern limit of the barrages at Pelican Point (Site 5, shown in Figure 1.1) is the Murray Mouth region. From Pelican Point (Site 5, Figure 1.1) to the constriction at Parnka Point (Site 9, Figure 1.1) is known as the North Lagoon. From Parnka Point (Site 9, Figure 1.1) towards the south, past Salt Creek (Site 12, Figure 1.1), is the South Lagoon. Environmental conditions thus form a natural gradient from estuarine conditions around the Murray Mouth through to hypersaline conditions in the South Lagoon.

The Coorong is a Ramsar Convention-listed Wetland of International Importance, and is one of six identified Icon Sites in the Murray-Darling Basin as determined by the then Murray-Darling Basin Commission (MDBC) (Department for Environment and Heritage, 2000; Murray-Darling Basin Commission, 2006). The region has substantial cultural, economic, recreation and environmental values. It supports both commercial and recreational fisheries, has a significant tourism industry and is in close proximity to beef and dairy farming nearby (for example, on Ewe Island; Site 4, Figure 1.1). The local indigenous Australian community, the Ngarrindjeri nation, has a long-standing spiritual connection with the land, and many culturally-significant species are supported by the Coorong (Phillips and Muller, 2006). In addition, the Coorong meets eight of the nine criteria specified by the Ramsar Convention for determining internationally-important wetlands. In particular, it regularly exceeds the criterion of supporting more than 20 000 waterbirds and supports more than the designated 1% of individuals in a single species or subspecies for a total of nine species (Paton *et al.*, in press). In the past, the South Lagoon alone has supported in excess of 150 000 waterbirds in a single year (Paton *et al.*, in press) but, by 2008, the number of waterbirds for the South Lagoon had declined to 62 000 (Dan Rogers, University of Adelaide, pers. comm., 2008). According to the most recent South Australian State of the Environment report (Mudge and Moss, 2008), the current condition of the Coorong is the worst ever recorded.

The observed decline in condition and the desire to provide a good scientific basis to guide the management of the system prompted the formation of the CLLAMMecology Research Cluster (Lamontagne *et al.*, 2004). CLLAMM is an acronym for ‘Coorong, Lower Lakes and Murray Mouth’, thereby describing the region within which the Cluster was to operate. The Cluster included researchers from the University of Adelaide, Flinders University, the South Australian Research & Development Institute Aquatic Sciences (SARDI Aquatic Sciences) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Water for a Healthy Country Flagship. Management agencies responsible for the Coorong were also involved, including the South Australian Department for Environment and Heritage (DEH) and the South Australian Department of Water, Land and Biodiversity Conservation (DWLBC). The aim of the Research Cluster was to develop an ecosystem-level understanding of the Coorong, Lower Lakes and Murray Mouth. The four Cluster themes developed to achieve this aim focussed on: 1) targeting the response of key species; 2) quantifying productivity and trophodynamics in the system; 3) mapping dynamic habitat availability; and 4) assessing likely ecological responses to a range of alternative futures. This final theme, named CLLAMM Futures, was an integrating theme that combined existing knowledge and knowledge derived from the other themes during CLLAMMecology to develop an ecosystem response model for the Coorong, in the form of an ecosystem state model (Lester *et al.*, 2009).

This report describes outcomes from the application of this ecosystem state model to predict future ecological responses to management actions and climate change via a series of scenarios. Fundamentally, the ecosystem model was based on relationships between the physical environment within the Coorong and its biotic assemblages. The physical variables that are associated with ecological responses appear to be related to salinities and water regimes. In exploring a number of scenarios, water levels and salinities were modelled using a hydrodynamic model. Ecological responses were then assessed by predicting the ecosystem states likely to occur under each of the simulated salinity and water level regimes.

This report introduces the hydrodynamic and ecosystem state models and defines each of the 20 scenarios that were explored. These are linked to a number of research questions. Results are presented for both the hydrodynamics and the ecosystem states, comparing scenarios relating to each research question in turn. These are then discussed and the management implications of the findings are summarised.

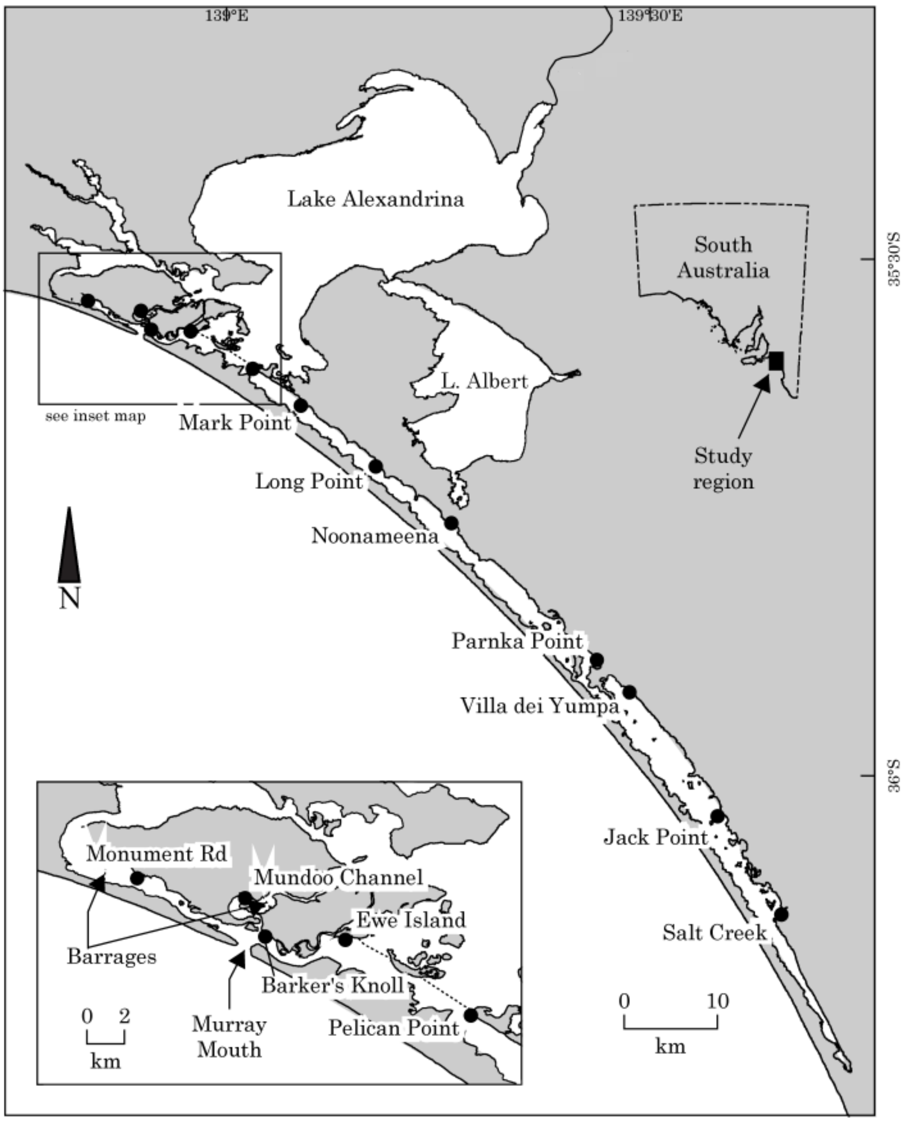



***Figure 1.1. Map of the Coorong showing the twelve study sites used as focal locations during CLLAMMecology and forming the basis of our ecosystem response modelling***

*(Source: Craig Noell, SARDI Aquatic Sciences, South Australia)*

# 2. Hydrodynamic model

## *2.1.* Model description

Here we provide a brief description of the hydrodynamic model applied to investigate the impacts of management interventions on water levels and salinities within the North and South Lagoons of the Coorong. The model structure, calibration and validation have been described in more detail by Webster, 2006.

The base hydrodynamic model simulated water motions and water levels along the Coorong from the Mouth to the southern end of the South Lagoon as these responded to the driving forces associated with water level variations in Encounter Bay (including tidal, weather band, and seasonal variations), the wind blowing over the water surface, barrage inflows, flows through Salt Creek (via the Upper South East Drainage scheme), and evaporation from the water surface. The model domain extended from the Mouth to the southern end of the South Lagoon (~5 km past Salt Creek) and is shown in Figure 2.1 with the major inflows. This domain was divided into 102 cells each 1 km long in which a momentum equation and an equation describing conservation of mass were solved. Major channel constrictions occurred at the Mouth and in the channel connecting the two lagoons past Parnka Point (Parnka channel).

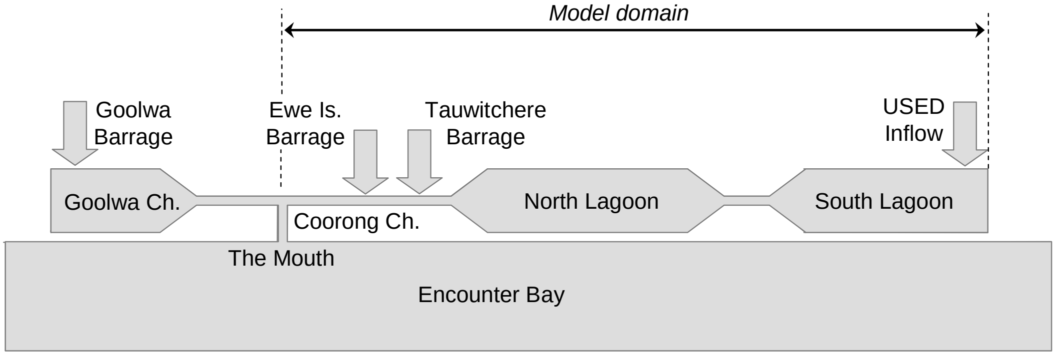



***Figure 2.1. Coorong connectedness including major inflows and model domain***

The depth of the Mouth was highly dynamic, increasing during times of significant outflows and tending to infill when flows were small or zero. The last six years resulted in very small barrage flows, so it has been necessary to maintain the Mouth in an open condition by dredging. As part of the calibration procedure, the Mouth depth in the model was adjusted every week to an elevation that allowed the model to simulate correctly the tidal attenuation between tides measured at Victor Harbor and at Tauwitchere Barrage inside the Coorong. We were able to develop a relationship between flow through the Mouth and its depth. This relationship was used to define the Mouth depths during the long-term scenarios described in this report.

Parnka channel, which connects the two lagoons, was highly complicated and convoluted. Rather than attempting to resolve the details of the channel shape, the model assumed that the section of severely constricted channel was 100 m wide and 1000 m long, dimensions approximately consistent with satellite images of the region. The optimal elevation of the Parnka channel was determined to be -0.19 m AHD through calibration.

The currents, water levels, and mixing regimes simulated by the basic hydrodynamic model were used to drive a module representing the salinity dynamics. Salinity was modelled in the 14 cells shown in Figure 2.2, which extended across groups of cells used in the base hydrodynamic model. The salinity module solved equations for the conservation of the mass of salt in each cell and required the prescription of the salinity of sea water and of the Upper South East Drainage scheme (USED). The salinity of the sea in Encounter Bay was set at 36.7 g $L^{-1}$.

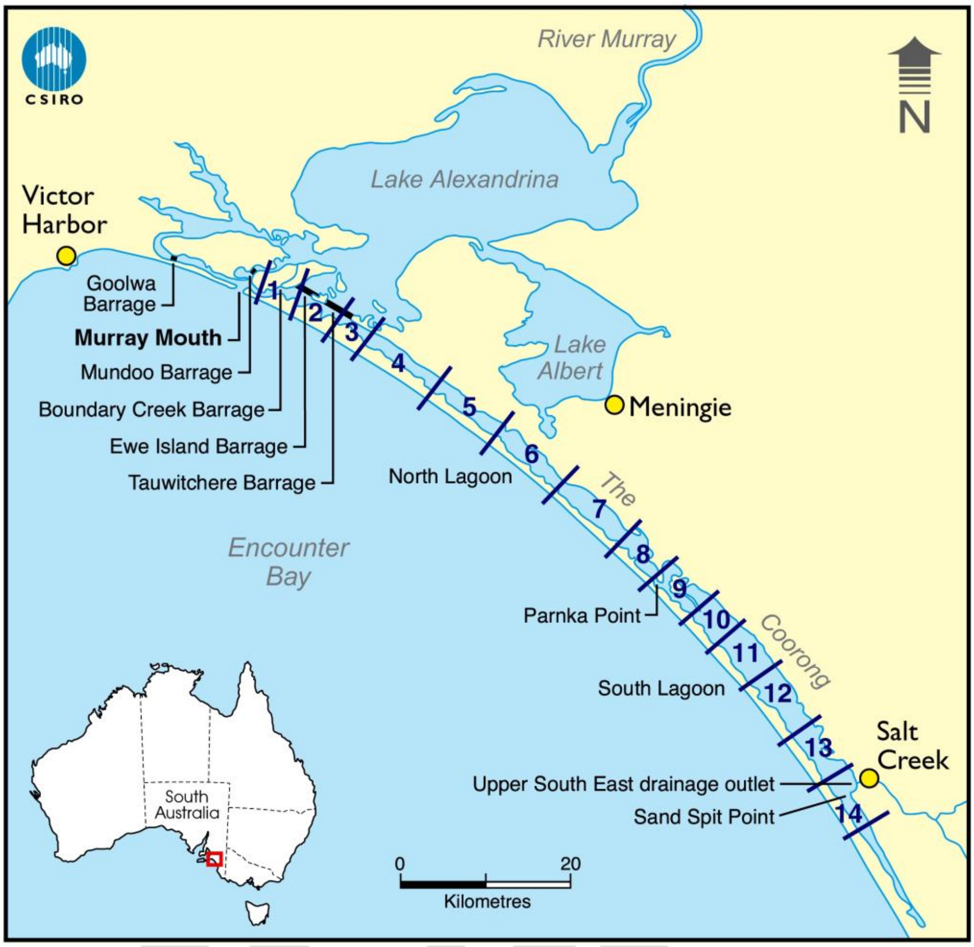



***Figure 2.2. Map of the Coorong showing boundaries of cells used in the salinity module***

## 2.2. Model application

The model was used to simulate water levels and salinity along both lagoons of the Coorong between 1895 and 2008 with the exception of the scenario investigating the impact of changing USED inflows. Required Input data were time series of forcing for the simulation period including wind, sea levels, evaporation, precipitation, USED inflows, and barrage inflows. These data included hourly water levels measured at Victor Harbor (Flinders Ports), twice-daily wind observations from Meningie (BOM), precipitation and evaporation from Mundoo (BOM) and USED inflows (Surface Water Archive, SA Government).

Daily barrage flows obtained from the Murray-Darling Basin Authority (MDBA) were available for the 1895-2008 simulation period, but the other forcing data required were available only since 1982. The available forcing data were divided into 8-year segments starting in 1982, 1990, and 1998. As input to the model, these data sequences were repeated cyclically starting with the use of the 1990 segment to provide forcing time series from 1894 to 1902. The 1998 segment was used to force the model from 1902 to 1910 followed by the 1982 segment being used to force the model during the period 1910 to 1918 and so on up to 2006. An additional segment of 4-year duration was used to start the model in 1890 and provide a spin-up time for the model of five years at the beginning of each simulation. An additional 2-year forcing segment was used to extend the model simulation from 2006 to 2008 at its end.

The barrage flows were provided by MDBA as totals across all the barrages for each day. An analysis of the relative flows between the main barrages between 1982 and 2007 showed that an average of 58% of the total flow was released through Tauwitchere barrage and 19%

through Ewe Island barrage. These proportions were applied to the whole of the barrage flow time series to obtain the estimated daily flows through Tauwitchere and Ewe Island barrages.

For all but the special USED scenario, the daily USED inflow was taken to be the average of measured flows on each day of the year between 2001 and 2008 and the salinity of the inflow taken to be 16.1 g $L^{-1}$. The latter was the calculated flow-weighted average of salinity in the Salt Creek discharge between 2001 and 2008. For the special USED scenario, flow and salinity were calculated from the modelled flows and salinities in the drains discharging to Salt Creek.

The 20 scenarios considered later in this report assumed one of three possible climates for considering river run-off and barrage discharge. These climates were historic climate, a median future climate, and a dry future climate. The latter two climates were based on the simulations of climate models used for estimating the median climate and a possible dry extreme climate for 2030. CSIRO and the Bureau of Meteorology developed climate change projections for Australia that estimated changes in meteorological parameters as a result of climate change (Pearce *et al.*, 2007). Temperature, evapotranspiration, rainfall, wind speed, relative humidity, and solar radiation were all expected to change to some degree. For the median future climate the temperature was expected to increase by 0.8 $^{o}$C for the Coorong region, whereas, for the 10th percentile dry future climate, the temperature increase was expected to be 1.2 $^{o}$C. These temperature increases were expected to increase the evaporation rate in the Coorong by 7% and 10%, respectively, so these increases were incorporated into the scenarios as appropriate.

Model runs commenced on 1/7/1890 and water level and salinity output from 1/7/1895 following the 5-year spin-up period. Simulated time series were available at hourly intervals at 101 locations along the Coorong for water level and at 14 locations for salinity. These time series were then processed to provide suitable input to the ecological model.

# 3. Ecosystem state models

Assessing ecological condition at an ecosystem scale is a difficult task. Typically, there are some aspects of an ecosystem that are well-studied and understood (e.g. birds and fish) and others that are less well understood (e.g. groundwater inputs and microbes). In order to assess ecological condition in the Coorong, we developed an ecosystem response model based on what we term “ecosystem states”.

Unlike the hydrodynamic model described above, the ecosystem states model is not based on a deterministic understanding of how ecosystems behave. That is, it is not based on equations describing the interactions among each species, their environment, and their competitors and predators. Instead, it is a statistical model, where existing data for the region has been statistically analysed and modelled to identify relationships between the biota that occur within the system at any one point in time and the environmental conditions under which these biota occur.

The ecosystem state model developed for the Coorong under CLLAMMecology identified eight distinct ecosystem states (Figure 3.1). The environmental parameters that differentiated amongst the various states were a combination of water quality, quantity and flow variables. They included the average daily tidal range, maximum number of days since flow had crossed the barrages, average water level and salinity at the location, and average depth of water in the previous year. The appearance of average tidal range as the first split variable effectively divided the Coorong into two basins, with four states possible within each basin. The marine basin existed within the calibration dataset (1999 to 2007) around the Murray Mouth estuary and down to the northern part of the North Lagoon, to about Noonameena (see Figure 1.1), where the states were essentially marine in character (on the right side of Figure 3.1). Within the calibration dataset, the hypersaline basin included the southernmost part of the North Lagoon and the entire South Lagoon, and had four hypersaline states (shown on the left side of Figure 3.1). The biota and conditions characterizing each of these states are given in Appendix B. Additional information regarding the development and testing of the model is given in Lester *et al.* (in prep); Lester *et al.* (2009).

We have given each of the eight states a name for ease of interpretation (Figure 3.1). The names chosen were based on the environmental conditions under which each state exists, and the biota that is supported by each. The trend of declining biotic richness and the variables for which thresholds were significant (e.g. length of time since flow over the barrages) led us to believe that the states represent a continuum from a healthy ecosystem to a more degraded ecosystem in each basin. We have named the states accordingly. However, these names do not imply that a single state (e.g. the ‘healthy’ state) should, or even could, necessarily exist in each region. Finally, despite the labelling of ‘unhealthy’ and ‘degraded’ for several states, this is not to say that no biota exists. As is described in Appendix B, each state continues to support some range of biota that is available as food and habitat resources for other species in the system.

The association of biota with a subset of environmental conditions implies turnover of species across the ecosystem states, so that taxonomic composition and relative abundances were distinct. The ecosystem state model uses environmental data as modelled by the hydrodynamic model to predict transitions between the states and hence is a state-and-transition model.

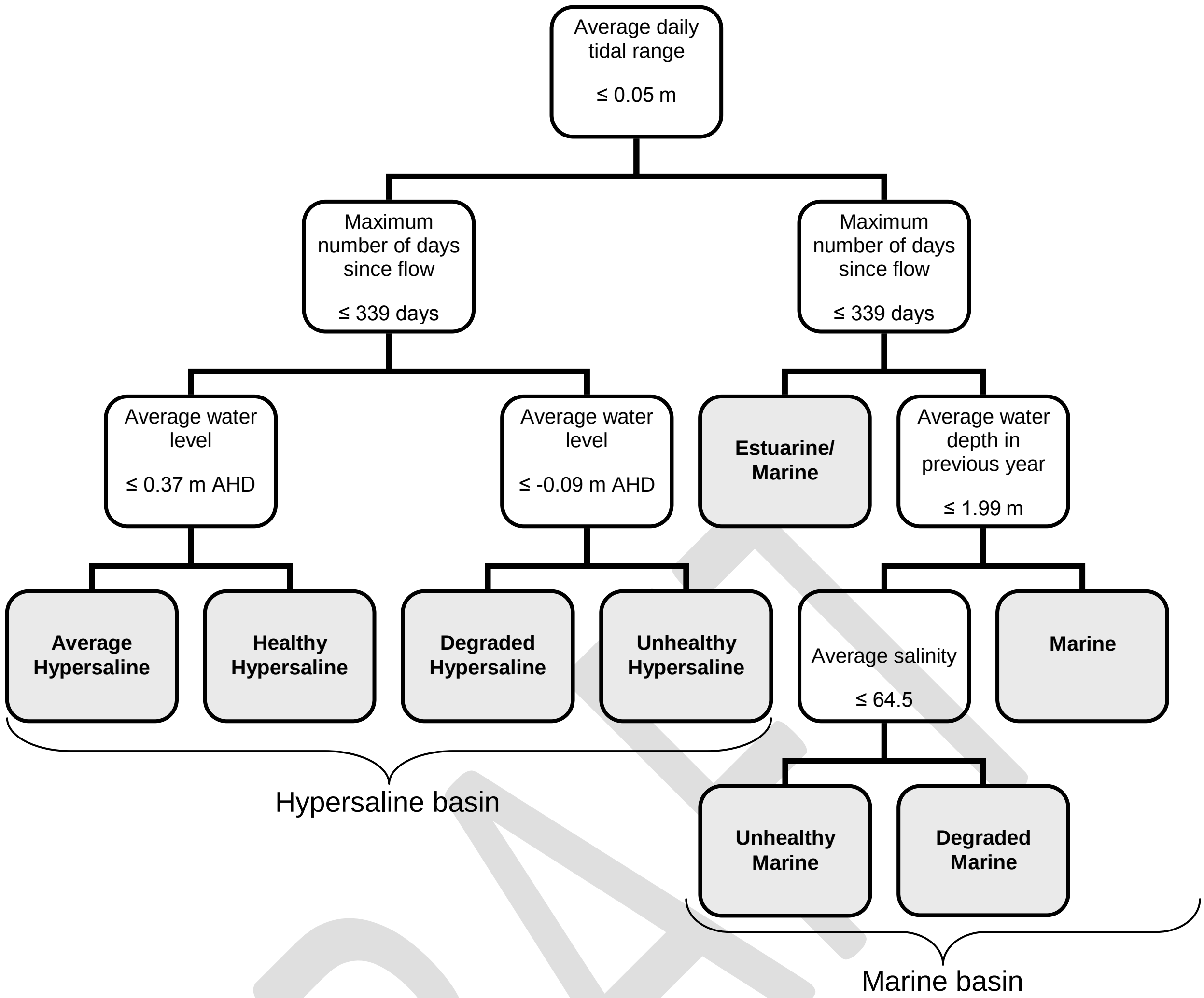



***Figure 3.1. Ecosystem states model for the Coorong as a whole***

This figure presents a logic tree which can be followed to identify the ecosystem state for a given location and time in the Coorong. Each white box contains a splitting parameter and a threshold value. Where the value for the parameter is less than or equal to the threshold value, then the tree should be followed to the left. Where it is higher, the tree should be followed to the right. When a grey terminal node box is reached, the state has been identified.

One of the key driving parameters for the ecosystem state model described above was the occurrence of freshwater flows over the barrages. This meant that only limited changes in ecological conditions could be modelled unless such flows were present. Given that two of the management actions investigated here are designed to be alternatives to having freshwater flows in the short term (i.e. dredging of the Murray Mouth and flows from the USED), we developed a second set of models (one in each basin) to describe the behaviour of the system without reference to the flows over the barrages. The development of this second model is given in Lester *et al.* (2009), along with a discussion relating the results of this model to the original ecosystem state model given in Figure 3.1. The second model was constructed for each basin separately. The model for the marine basin (assumed to occur in the North Lagoon under the current conditions) is shown in Figure 3.2. It describes the ecosystem state of the Coorong relative to the water level, the previous year's water level and depth from two years ago. The hypersaline basin model (used to describe current South Lagoon states) identified a combination of average water level, water level from the previous year, the range in water levels over the year (i.e. change between the maximum and minimum water level over the year) and the maximum salinity for the year as driving the ecosystem state of the basin (Figure 3.3). Both models showed a high capacity for correctly classifying sites in the calibration dataset to the same state identified by the original ecosystem state model.

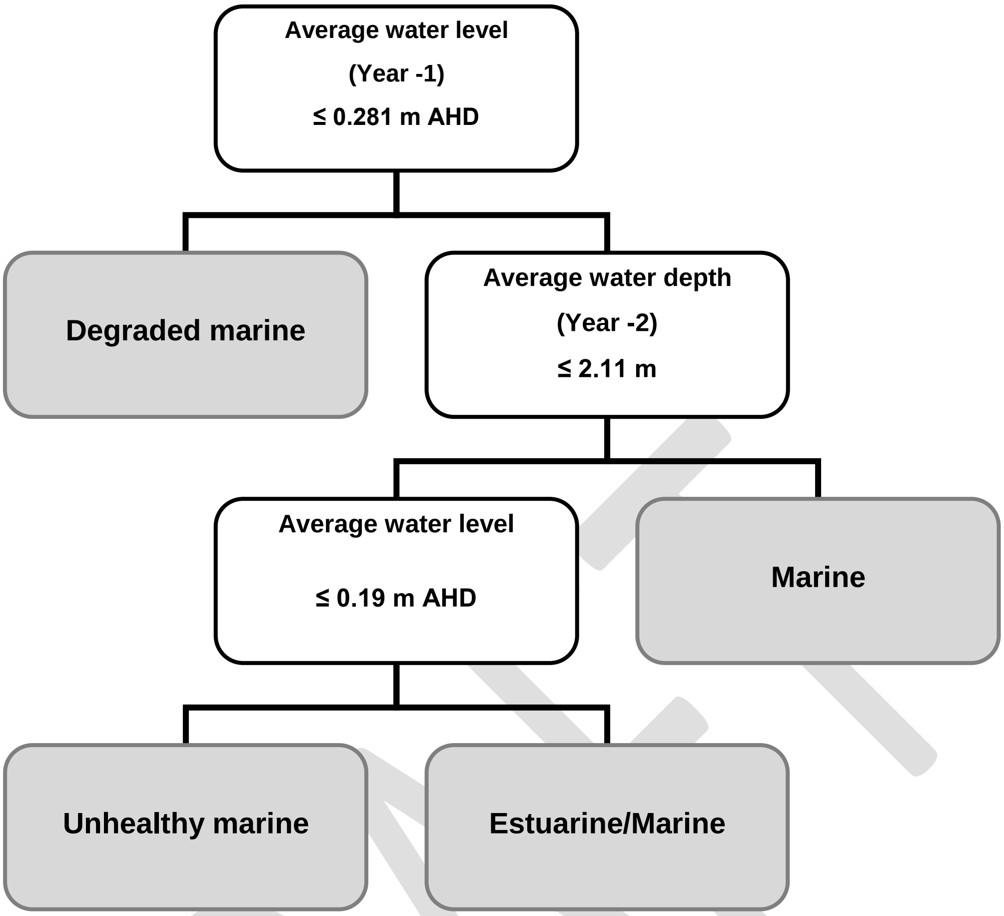



***Figure 3.2 Marine (or northern) basin model for the Coorong excluding flow parameters as predictive variables***

The major area of uncertainty inherent in the ecosystem response model is in its ability to correctly predict the recovery of the system. The model was developed using data from 1999 to 2007, which was a particularly dry period, and one during which the ecological condition of the Coorong was deteriorating throughout. Therefore, the model behaves as though the trajectory of decline is the same as the trajectory of recovery and that both occur over the same length of time. This is unlikely to be true, and represents a major uncertainty of the model but, until data describing the recovery of the system are available, there is no way to quantify the scale of this uncertainty. This uncertainty will be quantified over time, should additional monitoring and research be undertaken for the Coorong. In particular, any interventions that occur within the system should involve data collection both during and after the intervention. This could then be used to refine the model to address this uncertainty about recovery trajectories and any hysteresis inherent in the system.

All of the parameters identified as driving the ecosystem states of the Coorong (in both the original and alternative models) could be calculated from output from the hydrodynamic model, or from the input data used for the hydrodynamic modelling (i.e. flows over the barrages). The hydrodynamic model simulated hourly water levels and salinities along the length of the Coorong for each scenario. These data were then used to calculate the average water levels, depths and salinities as required by the ecosystem response models (Figures 3.1, 3.2, 3.3). By using these parameters as input for the ecosystem response model, we were able to predict the mixture of ecosystem states present in the Coorong each year for the duration of the model run at each of the 12 focal sites identified during CLLAMMecology (Figure 1.1).

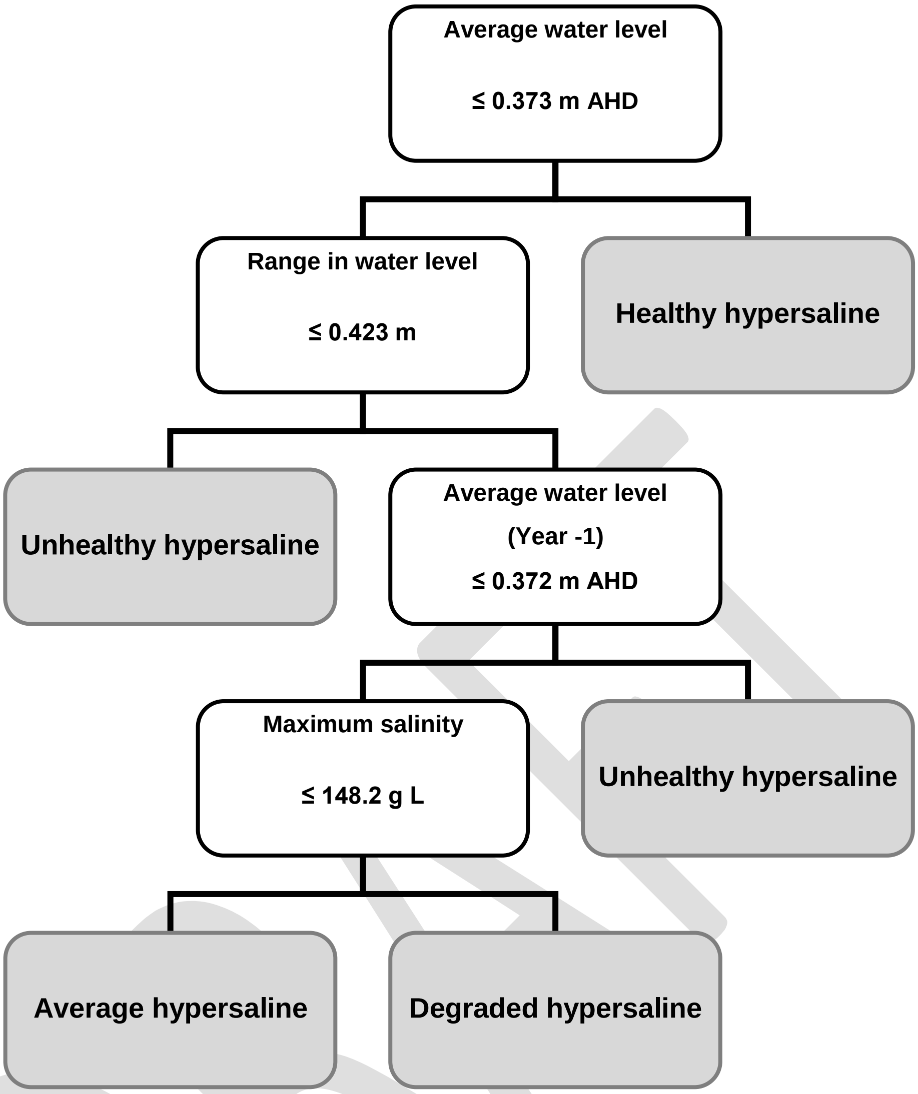



***Figure 3.3. Hypersaline (southern) basin model for the Coorong excluding flow parameters as predictive variables***

Note: The Unhealthy hypersaline state appears in the model twice, indicating there are two distinct pathways to reach that state.

Detailed methods on the analysis of the time series of predicted ecosystem states for each scenario are given in Lester *et al.* (2009).

# 4. Research questions and scenarios investigated

## 4.1. Research questions

The scenarios selected for investigation and the subsequent analyses were designed to answer the following research questions:

1. What are the current ecosystem states in the Coorong?
2. What effect do current extraction levels have on the ecosystem states of the Coorong?
3. What effect will climate change have on the ecosystem states of the Coorong?
4. What effect will sea level rise have on the ecosystem states of the Coorong?
5. What effect will The Living Murray initiative have on the ecosystem states of the Coorong?
6. What effect does dredging of the Murray Mouth currently have on the ecosystem states of the Coorong?
7. What effect could the augmentation of the USED scheme have on the ecosystem states of the Coorong?

## 4.2. Scenarios investigated

A series of workshops, meetings and discussions were held with natural resource managers and other stakeholders to develop the set of scenarios to be investigated for the management of the Coorong. These stakeholders included representatives from DEH, DWLBC, South Australian Murray-Darling Basin Natural Resource Management Board (SA MDB NRM Board), SA Water, Murray Darling Basin Commission (MDBC) and Department of Primary Industries and Resources of South Australia (PIRSA) (Lester and Fairweather, 2008). Based on this consultation process, we identified that predicting the effects of climate change (including sea level rise), extraction levels, The Living Murray initiative, dredging at the Murray Mouth and flows from the USED program were of primary interest for the Coorong.

All scenarios are based on one of three future climate scenarios that have been prescribed by the Sustainable Yield Project of CSIRO (Chiew *et al.*, 2008). The first scenario (A) develops a flow time series using the historical climate sequence. Scenario B assumes a climate which is the median climate predicted for 2030 derived using the climate sequence for 1891-2008 modified by expected climate change, whereas scenario C represents a tenth percentile future dry condition. For each of these scenarios, synthetic time series of flows through the barrages were constructed by analysing the daily time series of climatic data for the period 1891-2008 in combination with inflow models run using the current state of agricultural development and various water management rules, including The Living Murray (TLM) scenarios for water allocation. These flows were made available by the MDBA and are based on SY simulations that have been modified by the Victorian 2030 climate approach. The flows are based on the MDBA modelling benchmark 0811 (November 2008).

We developed a set of 20 distinct scenarios which are investigated here, and are summarised in Table 4.1. These scenarios can be grouped into sets, and are defined as:

Scenarios investigating benchmark conditions:

1. Benchmark conditions (hereafter called 'Baseline')

   This scenario included historic climate conditions (MDB SY Scenario A), current levels of extraction from the Basin (and so current flows over the barrages), and average inflows from the USED scheme. This scenario did not include dredging of the Murray Mouth.

2. 'Natural' flow conditions ('Historic Natural')

This scenario included historic climate conditions with no extractions from the Basin and none of the current infrastructure (with the exception of the barrages).

Scenarios investigating the effect of climate change:

3. Median climate change with current extraction levels ('Median Future')

   This scenario included a median 2030 climate (MDB SY Scenario B), current levels of extraction from the Basin, and average inflows from the USED scheme. This scenario did not include dredging of the Murray Mouth.

4. Dry climate change with current extraction levels ('Dry Future')

   This scenario included a dry 2030 climate (MDB SY Scenario C), current levels of extraction from the Basin, and average inflows from the USED scheme. This scenario did not include dredging of the Murray Mouth.

5. Median climate change with 'natural' flow conditions ('Median Natural')

   This scenario included a median 2030 climate with no extractions from the Basin and none of the current infrastructure (with the exception of the barrages) and average inflows from the USED scheme.

6. Dry climate change with 'natural' flow conditions ('Dry Natural')

   This scenario included a dry 2030 climate with no extractions from the Basin and none of the current infrastructure (with the exception of the barrages) and average inflows from the USED scheme.

Scenarios investigating the effect of sea level rise (SLR):

7. Low sea level rise under a median 2030 climate ('Median Future, -10 cm SLR')

   This scenario included median 2030 climate conditions, current levels of extraction from the Basin, average inflows from the USED scheme, and the low CSIRO estimate for sea level rise, which was actually a 10 cm decrease in sea level (CSIRO Marine and Atmospheric Research, 2008).

8. Medium sea level rise under a median 2030 climate ('Median Future, +20 cm SLR')

   This scenario was as per Median future, -10 cm SLR, but included a median prediction of sea level rise for the region by the CSIRO, of a 20 cm increase by 2030 (CSIRO Marine and Atmospheric Research, 2008).

9. High sea level rise under a median 2030 climate ('Median Future, +40 cm SLR')

   This scenario was as per Median future, -10 cm SLR, but included a high prediction of sea level rise for the region by the CSIRO, of a 40 cm increase by 2030 (CSIRO Marine and Atmospheric Research, 2008).

10. Low sea level rise under a dry 2030 climate ('Dry Future, -10 cm SLR')

    This scenario was as per Median Future, -10 cm SLR scenario but with dry 2030 climate conditions.

11. Medium sea level rise under a dry 2030 climate ('Dry Future, +20 cm SLR')

    This scenario was as per Median Future, +20 cm SLR scenario but with dry 2030 climate conditions.

12. High sea level rise under a dry 2030 climate ('Dry Future, +40 cm SLR')

    This scenario was as per Median future, +40 cm SLR scenario but with dry 2030 climate conditions.

Scenarios investigating the effect of The Living Murray (TLM) initiative

13. TLM infrastructure under historic climate ('Historic TLM off')

    This scenario included the construction of proposed TLM infrastructure in the Basin (MDBA), without the addition of the 500 GL of additional water, under historic climatic conditions.

14. TLM infrastructure and additional water under historic climate ('Historic TLM on')

    This scenario included the construction of proposed TLM infrastructure in the Basin and the addition of the 500 GL of additional water, under historic climatic conditions.

15. TLM infrastructure under median 2030 climate ('Median TLM off')

    This scenario was as per Historic TLM off, using a median 2030 climate.

16. TLM infrastructure and additional water under median 2030 climate ('Median TLM on')

    This scenario was as per Historic TLM on, using a median 2030 climate.

17. TLM infrastructure under dry 2030 climate ('Dry TLM off')

    This scenario was as per Historic TLM off, using a dry 2030 climate.

18. TLM infrastructure and additional water under dry 2030 climate ('Dry TLM on')

    This scenario was as per Historic TLM on, using a dry 2030 climate.

Scenarios investigating the effect of other management interventions

19. Mouth dredging under historic climate ('MM Dredging')

    This scenario was as per 'Benchmark' with an imposed minimum Murray Mouth depth (set at -2 m AHD in accordance with the current dredging operation; as determined through model calibration).

20. Additional flows from the USED scheme under historic climate ('Max USED Flows')

    This scenario was as per 'Benchmark' with additional USED flows, as per the maximum possible flows suggested by Way and Heneker (2007) during a preliminary assessment of augmented diversions from the Upper South-East. This was used as a 'best case' scenario for additional water from the USED.

In constructing these scenarios, several decisions were taken to ensure that the modelling was as up-to-date and relevant as possible, but also practical. For example, Murray Mouth dredging was excluded from all scenarios except for MM Dredging (Scenario 19) because the dredging operation was seen as a short-term strategy for times of drought and low River Murray inflows (Murray-Darling Basin Commission, 2006). It is quite common for the Murray Mouth to close more than the minimum currently imposed on a seasonal basis with lower summer and autumn flows. This natural cycling should not be excluded from the assessment of all scenarios for future Coorong ecosystem states.

Also, when modelling the 'natural' flows for the Coorong, the barrages were included when all other structures and extractions within the Basin were removed. This was an operational decision to enable the hydrodynamic model to be applied appropriately. Effectively, including the barrages allowed all flows from the Lakes to the Coorong, but blocked return flows from the Coorong to the Lakes in times of low flow. This greatly simplified the calculation of the mass balance equations for water and salt within the system.

| No. | Scenario | Climate | Extraction levels | Flow over barrages | USED inflows | Mouth dredging | Sea level rise | TLM infrastructure |
|---|---|---|---|---|---|---|---|---|
| **Benchmark conditions** | | | | | | | | |
| 1 | Baseline | historic (MDB SY Scenario A) | + | + | + | - | - | - |
| 2 | Historic Natural | historic | - | + | + | - | - | - |
| **Effects of climate change to 2030** | | | | | | | | |
| 3 | Median Future | median (MDB SY Scenario B) | + | possible | + | - | - | - |
| 4 | Dry Future | dry (MDB SY Scenario C) | + | possible | + | - | - | - |
| 5 | Median Natural | median | - | possible | + | - | - | - |
| 6 | Dry Natural | dry | - | possible | + | - | - | - |
| **Effects of sea level rise** | | | | | | | | |
| 7 | Median future, -10 cm SLR | median | + | possible | + | - | minimum (10 cm decrease) | - |
| 8 | Medium future, +20 cm SLR | median | + | possible | + | - | median (20 cm rise) | - |
| 9 | Median future, +40 cm SLR | median | + | possible | + | - | high (40 cm rise) | - |
| 10 | Dry future, -10 cm SLR | dry | + | possible | + | - | minimum (10 cm decrease) | - |
| 11 | Dry future, +20 cm SLR | dry | + | possible | + | - | median (20 cm rise) | - |
| 12 | Dry future, +40 cm SLR | dry | + | possible | + | - | high (40 cm rise) | - |

***Table 4.1. Summary of scenarios investigated as a part of CLLAMM Futures and presented in this report***

Note: '+' denotes current levels or present in the scenario and '-' indicates none or not present in the scenario

| No. | Scenario | Climate | Extraction levels | Flow over barrages | USED inflows | Mouth dredging | Sea level rise | TLM infrastructure |
|---|---|---|---|---|---|---|---|---|
| **Effects of TLM initiative** | | | | | | | | |
| 13 | Historic TLM off | historic | + | + | + | - | - | present but no added 500 GL |
| 14 | Historic TLM on | historic | + | + | + | - | - | present, 500 GL flows |
| 15 | Median TLM off | median | + | possible | + | - | - | present but no added 500 GL |
| 16 | Median TLM on | median | + | possible | + | - | - | present, 500 GL flows |
| 17 | Dry TLM off | dry | + | possible | + | - | - | present but no added 500 GL |
| 18 | Dry TLM on | dry | + | possible | + | - | - | present, 500 GL flows |
| **Effects of other management interventions** | | | | | | | | |
| 19 | MM Dredging | historic | + | + | + | + (-2m depth) | - | - |
| 20 | Max USED Flows | historic | + | + | maximum possible | + | - | - |

***Table 4.1 cont. Summary of scenarios investigated as a part of CLLAMM Futures and presented in this report***

Note: '+' denotes current levels or present in the scenario and '-' indicates none or not present in the scenario

# 5. Results

The results section focuses on comparisons between the groups of scenarios in order to answer the specific research questions identified above. Additional analyses and summaries for each of the states individually can be found in Langley *et al.*, 2009.

## 5.1. Hydrodynamic

Figure 5.1 shows daily average salinity in the North and South Lagoons for the model simulation that uses historic climate and current water extraction rules (Baseline, scenario 1). It is presented as an example of the output from the hydrodynamic model and is used to illustrate features of the salinity response of the Coorong to environmental drivers over the last century. The average salinity in both lagoons showed pronounced variation at timescales ranging from seasonal to decadal. The South Lagoon showed average salinity to range from over 200 g $L^{-1}$ to less than 25 g $L^{-1}$ which is approximately the salinity of seawater. Average salinities in the North Lagoon mostly lay in the range between ~80 g $L^{-1}$ to less than 5 g $L^{-1}$. Generally, low salinity in both lagoons corresponded to years of high barrage discharge (Figure 5.2). The Federation drought which commenced near the end of the 19$^{th}$ Century was clearly seen as a period in which average salinity in the South Lagoon would often have exceeded 150 g $L^{-1}$. Similar periods of high salinity were predicted to commence during the late 1930s and, during the last 10 years of low barrage flows, salinity in both lagoons was particularly high. A series of wet years through the 1950s with high barrage discharges resulted in dramatic reductions in salinity in both lagoons through this period.

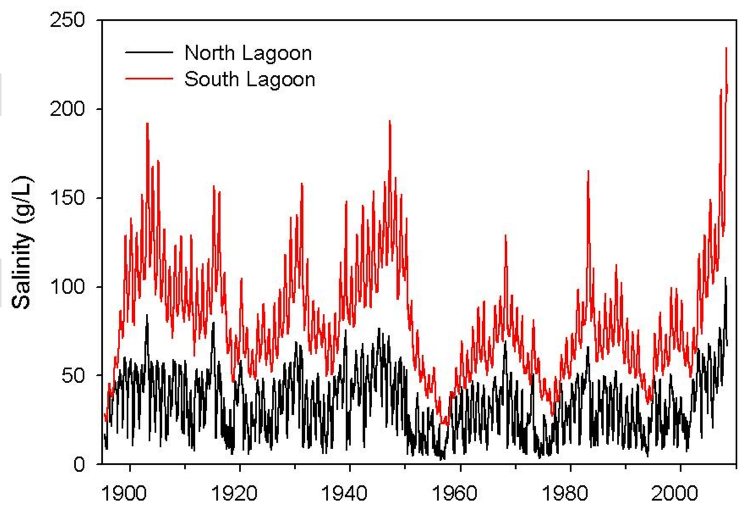



***Figure 5.1. Daily averaged salinity in the North and South Lagoons***

Results are shown for historic climate, current extractions and average USED flows (Baseline, Scenario 1).

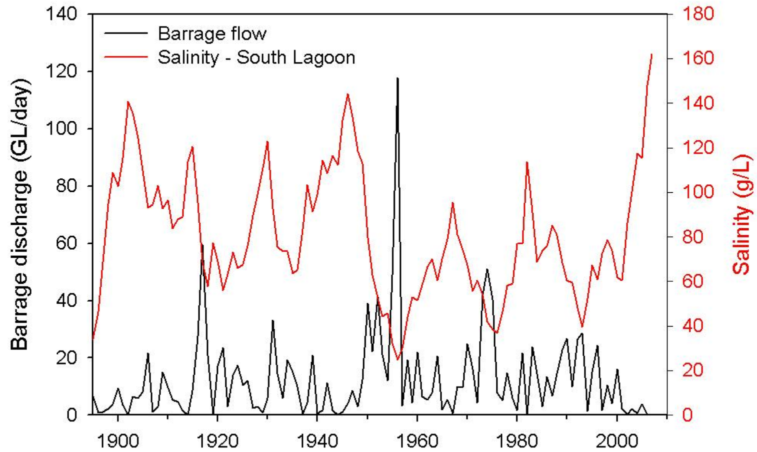



***Figure 5.2. Yearly averaged barrage flow and salinity in the South Lagoon***

Results are shown for historic climate, current extractions and average USED flows (Baseline, Scenario 1).

The salinity in both lagoons underwent a pronounced seasonal cycle. This variation arose as a consequence of the interplay between several factors, including the seasonal cycles of sea level rise and fall, barrage flows, precipitation rates, and evaporation rates. High barrage flows tended to occur in spring and this was a time of relatively low salinity in both lagoons. Maximum salinity in the South Lagoon occurred after the end of summer when evaporation had concentrated the salt in the basin, whereas maximum North Lagoon salinity typically occurred a few months earlier.

### 5.1.1. Current Coorong condition

Investigating the Baseline scenario (Scenario 1) gives us an understanding of the current conditions within the Coorong, and provides a benchmark against which to compare the other scenarios.

Figure 5.3 shows the distributions of each of the variables driving the ecosystem states of the Coorong under the Baseline conditions. The distributions are presented as boxplots (Appendix C gives an overview of how to read each type of figure presented). Median water level was 0.30 m AHD, falling between 0.24 and 0.34 m for 50% of the time (Figure 5.3). Median water depth under baseline conditions along the length of the Coorong was 1.41 m, falling between 1.2 and 1.6 m for 50% of the time. Median salinity was around that of seawater along the length of the Coorong over the 114-year model run, at 35.5 g $L^{-1}$, although there were a number of outliers at extremely high salinities. The median for the maximum number of days since flow over the barrages (i.e. the median number of days of zero flow per year; MaxDSF) for the Baseline scenario was 135 days, while the median tidal range was small, at 0.10 m (although note that the tidal range also includes water level changes due to wind).

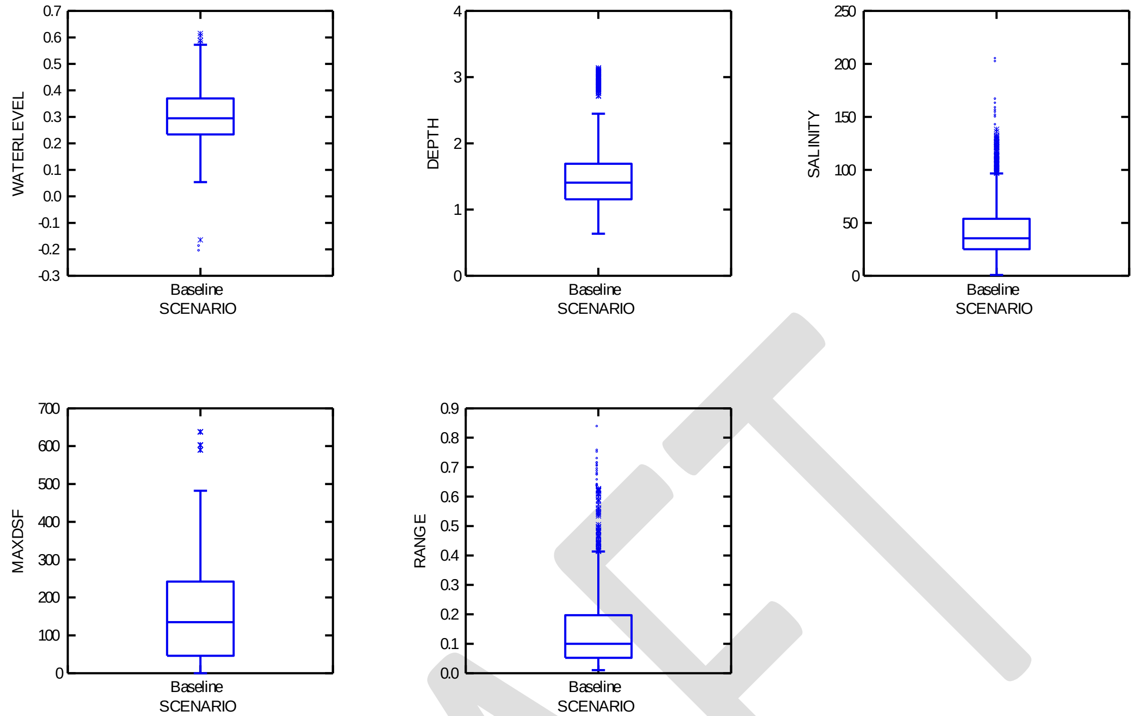



***Figure 5.3. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Baseline scenario.***

a) Water levels (m AHD), b) water depths from the previous year (m), c) salinities (g $L^{-1}$), d) Maximum number of days since flow (MaxDSF, days) and e) tidal range (m)



We undertook an analysis of all thresholds in the ecosystem state model (Figure 3.1). Within the model, there were thresholds for tidal range, maximum number of days without flow, water level, depth from the previous year and salinity. These thresholds governed the prediction of ecosystem state for each site in each year (referred to as a 'site-year'), for the modelling run.

All sites north of Noonameena exceeded the threshold for tidal range for all site-years, as did the Parnka Point site. The remainder of the North Lagoon sites exceeded the threshold for an average of 13.8 years with a return time of 2.6 years. South Lagoon sites exceeded the threshold for 4.6 years on average, returning every 20.5 years.

The threshold for the maximum number of days without flow over the barrages was exceeded for an average of 1.8 years at a return interval of 34.3 years.

The water level threshold of 0.37 m AHD was exceeded for an average of between one and two years across the various sites along the Coorong. For the Murray Mouth region, the return time for exceeding this threshold was 8.2 years. This dropped to 5.0 years for the North Lagoon sites, but was 10.2 years for the South Lagoon. The second water level threshold of -0.09 m AHD was always exceeded for all sites, except for the South Lagoon sites in 2008, the last year of simulation.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point every 15.0 years for 1.7 years, on average.

In the North Lagoon, Long Point was the only site to cross the salinity threshold more than once. This occurred in two separate years, with a return time of 62 years. In the South Lagoon, the salinity threshold was exceeded for an average of 7.3 years with a return time of 10.3 years.

The Gini coefficient was calculated for each variable driving ecosystem states. The Gini coefficient varies between 0 and 1 and gives an indication of how evenly spread a data set is between its highest and lowest values, with 0 representing a perfectly evenly-dispersed distribution and 1 representing a completely unevenly-dispersed distribution. For the Baseline scenario, depth and water level were the most evenly distributed variables (Gini = 0.04 and 0.07, respectively). This suggests that they were relatively likely to occupy any value within their range, rather than being skewed to either end of the distribution. Tidal range and salinity were moderately well-dispersed (Gini = 0.16 and 0.21, respectively), but the maximum number of days without flow was unevenly dispersed, tending to remain low on most occasions, but with occasional large deviations towards the high end of the spectrum (Gini = 0.46).

### 5.1.2. Effect of current extraction levels

The effect of current extraction levels was evident when comparing the Historic Natural scenario (Scenario 2) to the Baseline (Scenario 1). Unsurprisingly, median water levels were higher without the current level of extractions, and remained higher under all fluctuations in weather conditions (Figure 5.4). Maximum water levels did not change appreciably, however. Flows over the barrages tend to cause water to back-up within the Coorong and these water level changes are transmitted along its length (Webster, 2005). Depths under Historic Natural conditions were also similar to those under Baseline conditions. Maximum days since flow, however, varied substantially between the two scenarios with the Historic Natural median of zero days without flow. Salinities along the length of the Coorong also differed significantly under Historic Natural conditions, being lower than the interquartile range observed for the Baseline scenario more than 50% of the time, and with much lower maximum salinity values (78.1 versus 203.9 g $L^{-1}$, respectively). Finally, the tidal range observed under Historic Natural conditions varied substantially more, with a higher proportion of sites experiencing a bigger tidal fluctuation than was observed for the Baseline condition. In effect, the higher discharges through the barrages under Historical Natural conditions maintain the Murray Mouth in a more open state than under Baseline conditions allowing more efficient tidal transmission into the Coorong.

These trends indicate that the extraction of water within the Murray-Darling Basin is having a significant impact on the hydrodynamic properties of the Coorong, and thus affecting variables that drive the ecosystem states of the Coorong.

The tidal prism extended more reliably into the North Lagoon under the Historic Natural scenario. All sites in the Murray Mouth and North Lagoon regions exceeded the threshold for tidal range. In the South Lagoon, the threshold for tidal range was not exceeded often, and had a similar return time to the Baseline scenario.

The threshold for the maximum number of days without flow over the barrages was never exceeded under the Historic Natural scenario. This was also true of the lower water level threshold of -0.09 m AHD. The higher water level threshold (0.37) had a return time for each region that was approximately half that observed under Baseline conditions, of 4.4, 2.8 and 2.7 years for each of the Murray Mouth, North Lagoon and South Lagoon regions, respectively. There was little difference in the sites at which the depth threshold was exceeded, but, under natural flow conditions, it was exceeded more frequently at Mark Point than under the Baseline scenario (average return interval decreasing from 15.0 years to 4.2 years for the Historic Natural and Baseline scenarios, respectively).

The salinity threshold was exceeded under the Historic Natural scenario only for two sites in the South Lagoon, and only for the last year of simulation.

Gini coefficients indicated that tidal ranges, water levels and depths were all very evenly distributed for the Historic Natural scenario compared with the Baseline scenario (Gini = 0.08, 0.05 and 0.03, respectively). Salinity and the maximum length of time without flow were more uneven for Historic Natural conditions than for Baseline conditions (Gini = 0.30 and 0.84, respectively), suggesting that large changes towards high values occurred rarely over the 114-year model run.

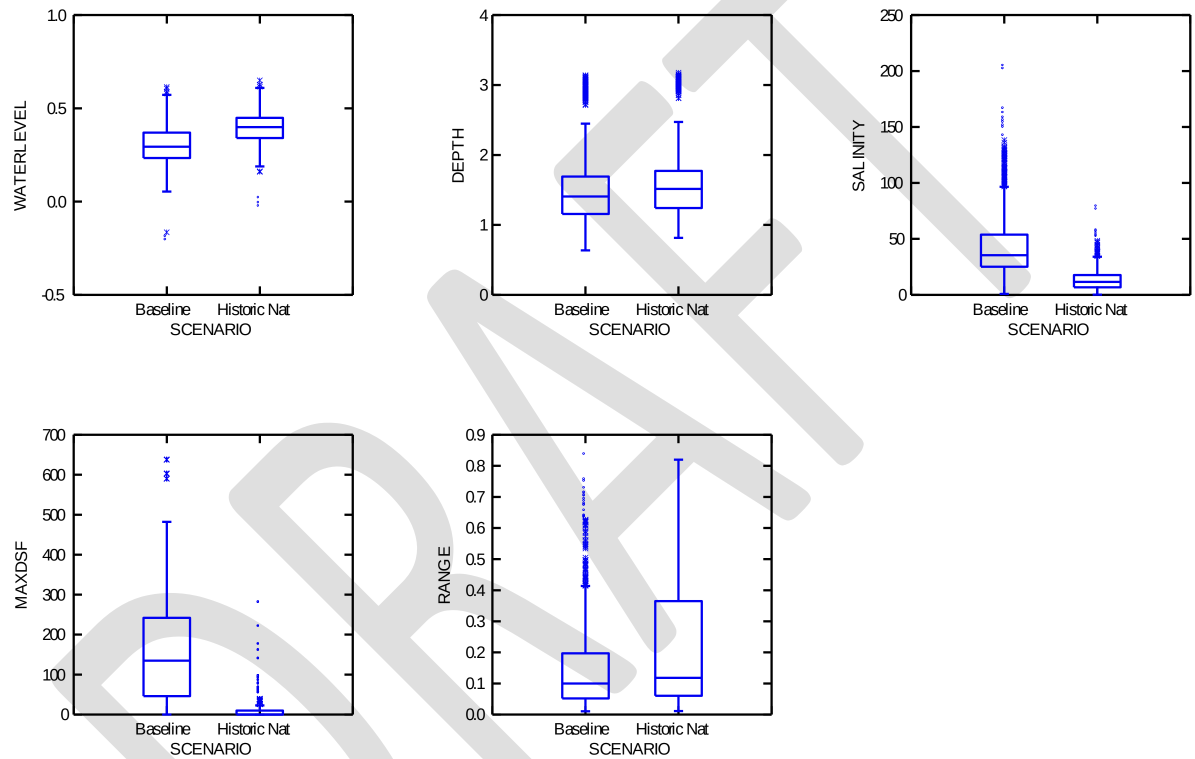



***Figure 5.4. Boxplots showing the comparison between variables driving the ecosystem states of the Coorong for the Baseline scenario (Scenario 1) versus the Historic Natural scenario (Scenario 2)***

a) Water levels (m AHD), b) water depths from the previous year (m), c) salinities (g $L^{-1}$), d) Maximum number of days since flow (MaxDSF, days) and e) tidal range (m)

Note that Historic Nat is the Historic Natural scenario.

The Historic Natural scenario showed a decrease in the number of days without flow compared with the Baseline scenario. It also showed a relative increase in water levels and a decrease in salinities.

### 5.1.3. Effect of climate change

Climate change has the potential to dramatically affect the hydrodynamic drivers of ecosystem states within the Coorong (Figure 5.5). Climate change reduces barrage flows and increases evaporation rates from the Coorong lagoons. Both salinity and the maximum number of days without flow over the barrages will be affected substantially.

The median predictions for a 2030 climate (Median Future, Scenario 3) showed an increase in the median number of days without flow over the barrages relative to the Baseline scenario (186 compared to 135 days, respectively; Figure 5.5). Median salinity was similar between the Baseline and Median Future scenarios (35.5 and 40.4 g $L^{-1}$, respectively), but the observed range of values increased from 203 to 273 g $L^{-1}$ under the Median Future climate. This included salinity predictions of up to 275 g $L^{-1}$ in the South Lagoon of the Coorong under the Median Future climate.

While this may seem extreme, it pales in comparison to predictions made under a dry 2030 climate at current extraction levels (Dry Future, Scenario 4). Under this scenario, the maximum number of days without flows over the barrages ballooned to 2778 days, with a median value of 320 days (or almost 11 months). Median salinity increased to 59.5 g $L^{-1}$ and the maximum modelled salinity for the Dry Future scenario was an unrealistic 460.7 g $L^{-1}$. It should be noted that salinity starts to have a pronounced effect on evaporation rate (i.e. it reduces it) and on the volumetric behaviour of the brine once salinity exceeds ~200 g $L^{-1}$ and these effects are not accommodated within the model. The very high salinities simulated by the model should be taken to be indicative only. While the exact concentration may not be able to be predicted, we are confident that it will be very high, and outside the tolerance limits for the vast majority of taxa in the region.

Comparisons of natural flow conditions under each of the modelled future climates bring these extreme values into perspective. The Median Natural and Dry Natural (Scenarios 5 and 6, respectively) illustrated the degree to which the changes predicted by the Median Future and Dry Future scenarios are reliant on the level of extractions within the Murray-Darling Basin. While there were changes in the variables driving ecosystem states, these were not nearly as substantial as those observed between the Baseline, Median Future and Dry Future scenarios.

The maximum number of days without flow over the barrages under Median Natural conditions remained unchanged at 0 days (Figure 5.5), while the Dry Natural median was 50 days (or just under two months). Median salinities under the Historic Natural scenario were 11.5 g $L^{-1}$. This compared with medians of 13.8 and 20.1 g $L^{-1}$ for the Median Natural and the Dry Natural, respectively. Water levels, depths and the size of tidal fluctuations also changed between scenarios, but differences were relatively slight.

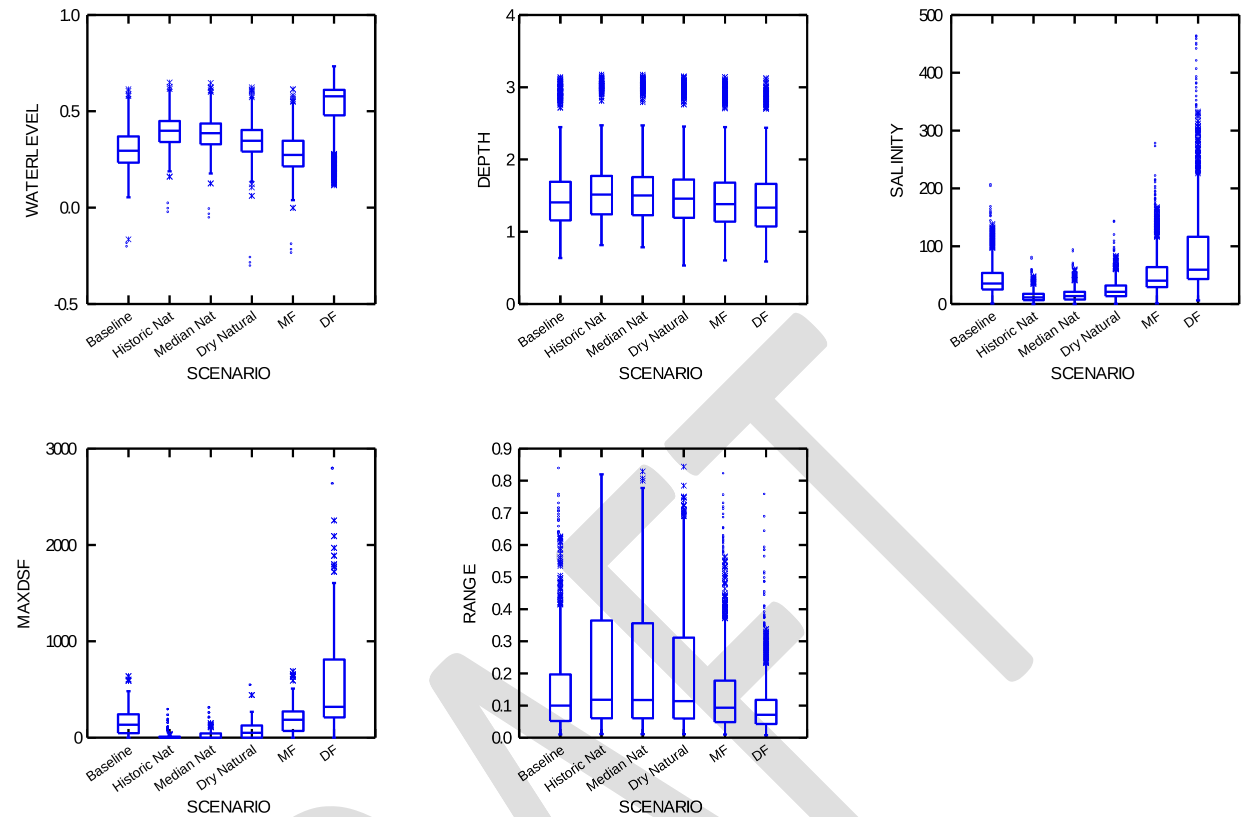



***Figure 5.5. Boxplots showing the comparison between variables driving the ecosystem states of the Coorong for the climate change scenarios***

a) Water levels (m AHD), b) water depths from the previous year (m), c) salinities (g $L^{-1}$), d) Maximum number of days since flow (MaxDSF, days) and e) tidal range (m)

Note that Historic Nat is the Historical Natural scenario, Median Nat is the Median Natural scenario, MF is the Median Future scenario and DF is the Dry Future scenario.

There was little effect of climate change on the frequency of exceeding the threshold for the daily tidal range in the South Lagoon. The tidal prism extended a shorter distance into the North Lagoon under increasing levels of climate change, and remained over the threshold for shorter periods of time, with longer return intervals.

There was a dramatic increase in the length of time the threshold for the maximum number of days without flow was exceeded with climate change, particularly under the Dry Future climate. No difference was observed in the likelihood of crossing the lower water-level threshold (-0.09 m AHD), but return intervals for exceeding the higher threshold increased with the severity of climate change, particularly under the Dry Future scenario.

The effect of climate change on the depth threshold was to increase the return time of threshold exceedance at Mark Point and decrease the duration of that exceedance. There was no impact at the other sites where the threshold was exceeded (i.e. Monument Road and Barkers Knoll, which always exceeded the threshold).

The salinity threshold was only exceeded in the Murray Mouth region under the Dry Future scenario, but it was exceeded at all three sites for an average of 1.5 years with a return interval of 31.1 years. For the same scenario, the South Lagoon always exceeded the threshold (except for the first year of simulation). These were the extremes of a trend of increasing average length of time over the threshold, and decreasing return times comparing the Baseline, Median Future and Dry Future scenarios.

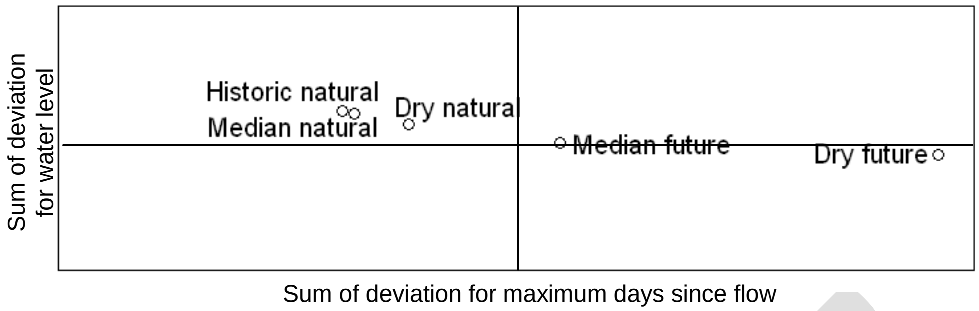
Under natural flow conditions, there was little effect of climate change on the likelihood of crossing the threshold for daily tidal range. Both the Median and Dry Natural scenarios had similar characteristics to the Historic Natural scenario. The same was true for the threshold for the number of days without barrage flow (which was only crossed under the Dry Natural scenario for the last two years of simulation), and the lower water level threshold (which was only exceeded under the Dry Natural scenario for South Lagoon for 2008). The higher water level threshold was influenced by climate change, even under natural flow conditions, with shorter durations over the threshold observed both along the Coorong and with increasing levels of climate change. The opposite was true for the return times (i.e. lowest at the Murray Mouth region under Historic Natural conditions).

Depth was relatively unaffected by climate change under natural flow conditions, but the salinity threshold was exceeded more often in the South Lagoon under the Median Natural scenario, and again under the Dry Natural scenario. It was not crossed elsewhere in the Coorong under any natural flow scenario.

Gini coefficients indicated that variables driving ecosystem states under the Median Future scenario behaved very similarly to the Baseline condition. The largest change was for the maximum number of days without flow, which had a Gini coefficient of 0.46 for the Baseline scenario and 0.43 for the Median Future scenario. Differences in coefficients were slightly larger for the Dry Future scenario, with water levels and salinities becoming more evenly distributed, and tidal ranges and days without flow becoming less even. Under natural flow conditions for either future climate, the dispersion of distributions were very similar to those observed for the Historic Natural scenario. The exception was for the number of days without flow, which had a Gini coefficient of 0.84 under Historic Natural conditions, but 0.78 and 0.60, respectively under the Median and Dry Natural scenarios, indicating that extreme values were more common under the latter two scenarios.

Both climate change scenarios showed an increase in the maximum number of days without flow (Figure 5.6), and an increase in salinity (although this was slight for the Median Future scenario). The Dry Future scenario also showed a slight decrease in water levels, relative to the Baseline scenario. All three natural flow scenarios were an improvement on the Baseline scenario for the number of days without flow, salinity and water levels.

a)




b)

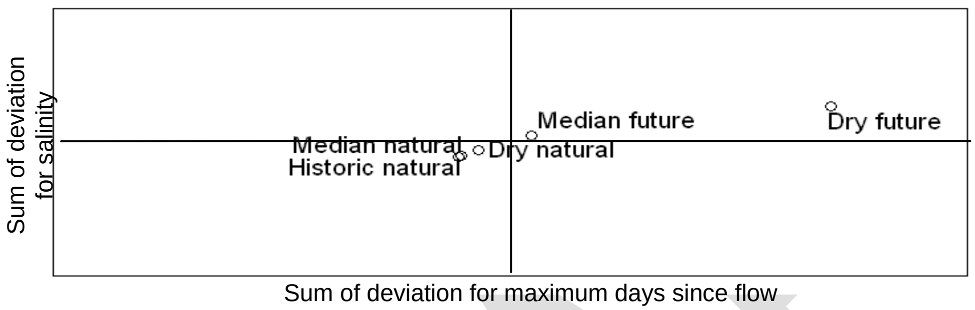



***Figure 5.6. Comparison of climate change scenarios with the Baseline scenario for key variables***

a) Site-years below the tidal range threshold, compared to the Baseline scenario with respect to water level and the maximum number of days without flow. The top-left quadrant represents an improvement in both.

b) Site-years above the tidal range threshold, compared to the Baseline scenario with respect to salinity and the maximum number of days without flow.

### 5.1.4. Effect of sea level rise

Sea level rise is another aspect of climate change that has the potential to affect the hydrodynamic properties of the Coorong (Figure 5.7). Modelling showed that both water levels and water depths would be affected. Salinities and tidal ranges were also slightly affected, but the number of days without flow over the barrages was unchanged.

Water levels were most affected by sea level rise (Figure 5.7). The smallest prediction for change in sea level for the region (a 0.10 m decrease; Median Future -10 cm SLR (Scenario 7) and Dry Future -10 cm SLR (Scenario 10)) resulted in a drop in median and maximum water levels relative to the Median Future and Dry Future predictions. For an increase in sea level of 0.20 or 0.40 m (Median Future +20 cm SLR (Scenario 8), Median Future +40 cm SLR (Scenario 9), Dry Future +20 cm SLR (Scenario 11) and Dry Future +40 cm SLR (Scenario 12)), large increases in water levels were predicted. Median water levels increased from 0.27 m AHD and 0.23 m AHD for the Median Future and Dry Future, respectively, to 0.48 and 0.44 m AHD with a 20 cm sea level rise and 0.68 and 0.64 m AHD with a 40 cm sea level rise. Water depths were affected in a similar manner, with decreases arising from a drop in sea level, and increases proportional to any rise in sea level.

Changes predicted for the salinities and tidal ranges under the various sea level rise scenario were small, varying within a few units of those predicted for the Median Future and Dry Future scenarios. The exception was for a 40 cm rise in sea level under a dry future climate, when median salinity rose from 59.5 g $L^{-1}$ for the Dry Future scenario to 79.3 for the Dry Future +40 cm SLR scenario. At the same time, maximum salinity declined from 460.7 to 307.0 for the same two scenarios.

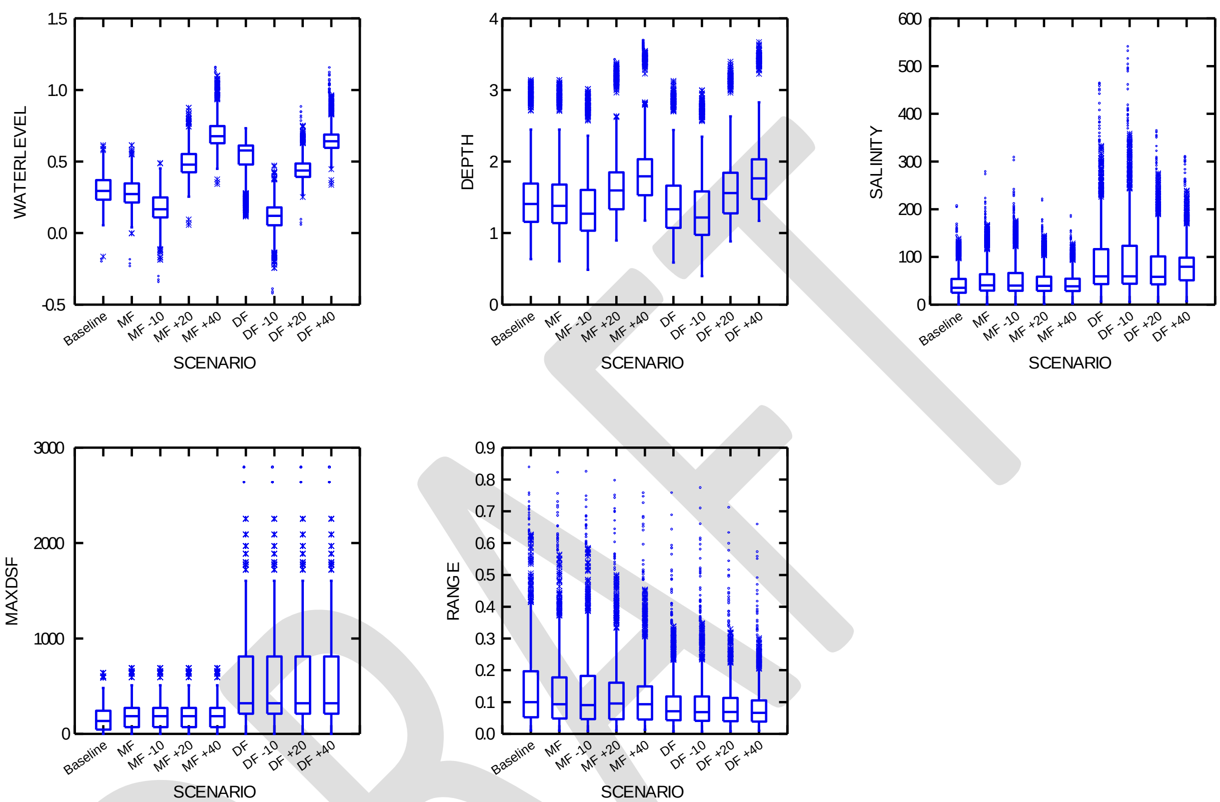



***Figure 5.7. Boxplots showing the comparison between variables driving the ecosystem states of the Coorong for the sea level rise scenarios***

a) Water levels (m AHD), b) water depths from the previous year (m), c) salinities (g $L^{-1}$), d) Maximum number of days since flow (MaxDSF, days) and e) tidal range (m)

Note that MF is the Median Future scenario, MF -10 is the Median Future -10 cm SLR scenario, MF +20 is the Median Future +20 cm SLR scenario, MF +40 is the Median Future +40 cm SLR scenario, DF is the Dry Future scenario, DF -10 is the Dry Future -10 cm SLR scenario, DF +20 is the Dry Future +20 cm SLR scenario and DF +40 is the Dry Future +40 cm SLR scenario.

Increasing sea levels tended to decrease the amount of time that sites in the Coorong exceeded the threshold for daily tidal range, but the differences were relatively small (e.g. 12.7 years over the threshold at a return interval of 3.1 years for the Dry Future +20 cm SLR scenario compared with an average of 10.7 years at a return interval of 3.4 years for the Dry Future +40 cm SLR scenario).

Water levels were influenced, with the likelihood of crossing both thresholds increasing with increased sea level rise, even under the Dry Future climate scenarios. This was to the extent that, under a 40 cm increase in sea level, both the Median and Dry Future scenarios exceeded both thresholds for all bar the last year of simulation and then only in the South Lagoon.

The effect of sea level rise on the depth threshold was mixed. A decrease in sea level increased return times of threshold exceedance at Mark Point, as did an increase of 40 cm, however an increase of 20 cm decreased return times. Monument Road and Barkers Knoll always exceeded the depth threshold. A similar pattern was observed for both future climates investigated.

Increasing sea levels also tended to decrease the proportion of time for which sites were over the salinity threshold. Under a Median Future climate, the higher the degree of sea level rise, the shorter the average exceedance duration and the longer the return times, for all regions in the Coorong. This was less obvious under a Dry Future climate, however, where even under a high degree of sea level rise, most site-years remained above the salinity threshold.

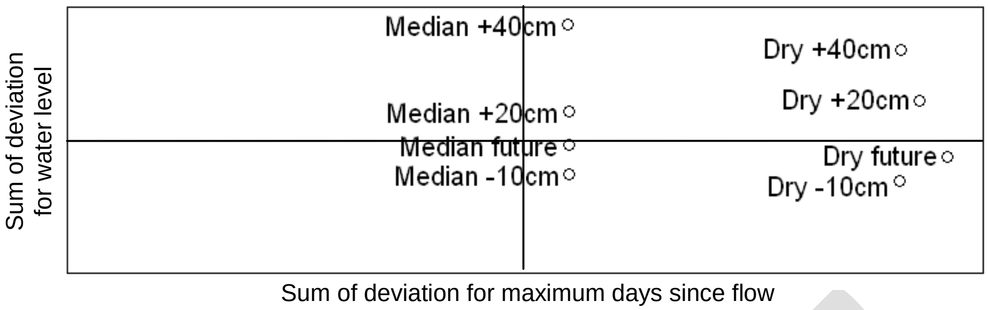
The dispersion of the water level variable showed the largest change between the sea level rise scenarios. A decline in sea level slightly increased the Gini coefficient (0.07 under Median Future compared to 0.09 under Median Future -10 cm SLR, and 0.03 compared with 0.09 under the Dry Future equivalents). Increasing sea level decreased the Gini coefficients for water level under median future climate projections, to 0.03 for Median Future +20 cm SLR and 0.035 for Median Future +40 cm SLR, but did not impact on the coefficients for the Dry Future scenarios. The Gini coefficients for all other variables remained relatively unchanged between the various sea level rise scenarios.

When investigating the deviances in key variables relative to the Baseline scenario, sea level rise scenarios varied slightly with respect to the maximum number of days without flow. While the actual amount of water over the barrages was not affected by sea level rise, the site-years allocated to the marine and hypersaline basin did vary compared to the Baseline scenario, creating a deviation from the Baseline in the proportions allocated to each panel (Figure 5.8a). There was significant deviation in water levels compared to the Baseline scenario, with sea level decreases resulting in lower water levels and sea level rises in higher water levels. No scenarios fell into the top-left quadrant (indicating higher water levels and fewer days without flow than the Baseline scenario).

Neither was any sea level rise scenario located in the bottom-right quadrant of Figure 5.8b, indicating an improvement in both number of days without flow and salinity for site-years above the tidal threshold compared to the Baseline scenario. The scenarios using the median future climate were tightly grouped, and closest to the centre of the plot.

Overall, the effect of sea level rise was less than the effect of climate change on evaporation and rainfall.

a)




b)

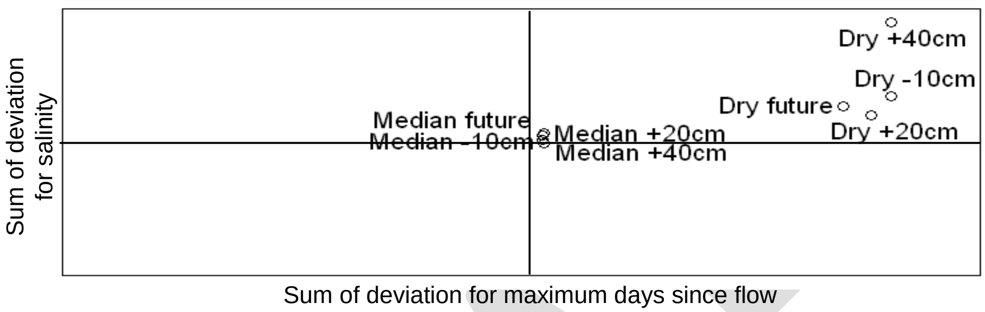



***Figure 5.8. Comparison of sea level rise scenarios to the Baseline scenario for key variables***

a) Site-years below the tidal range threshold, compared to the Baseline scenario with respect to water level and the maximum number of days without flow. The top-left quadrant represents an improvement in both.

b) Site-years above the tidal range threshold, compared to the Baseline scenario with respect to salinity and the maximum number of days without flow.

### 5.1.5. Effect of The Living Murray initiative

The effect of The Living Murray initiative on the hydrodynamic properties of the Coorong was not obvious on all variables driving the ecosystem states (Figure 5.9). Water levels and water depths were largely unchanged by either the inclusion of TLM infrastructure within the basin (Historic TLM off (Scenario 13), Median TLM off (Scenario 15) and Dry TLM off (Scenario 17) scenarios) compared with the baseline scenarios for each climate investigated (Baseline, Median Future and Dry Future scenarios; Figure 5.9). The addition of the recovered water under TLM (Historic TLM on (Scenario 14), Median TLM on (Scenario 16) and Dry TLM on (Scenario 18) scenarios) also made little difference to water levels and depths.

Median salinities also remained largely unchanged under TLM, with either the additional water included or excluded, but maximum salinities were affected. When additional water was added under TLM, maximum salinity under the historic climate declined from 203.9 to 180.9 g $L^{-1}$, and from 275.1 to 236.9 g $L^{-1}$ and 460.7 to 380.7 g $L^{-1}$ under median and dry future climates, respectively.

The largest observed change as a result of TLM was for the maximum number of days without flow over the barrages. The inclusion of TLM infrastructure without the additional water actually slightly increased the median and maximum values for this variable (Historic TLM off, Median TLM off and Dry TLM off). Including the additional environmental water, however, decreased the median length of time without flow over the barrages and dramatically decreased the maximums for this variable. For the historic climate, the maximum modelled number of days without flow over the barrages was 638, while under TLM it was 372. The Median TLM on and Dry TLM on scenarios resulted in decreases of the maximum values for days without flow relative to their baseline conditions of 690 to 616 day and 2778 to 1349 days, respectively.

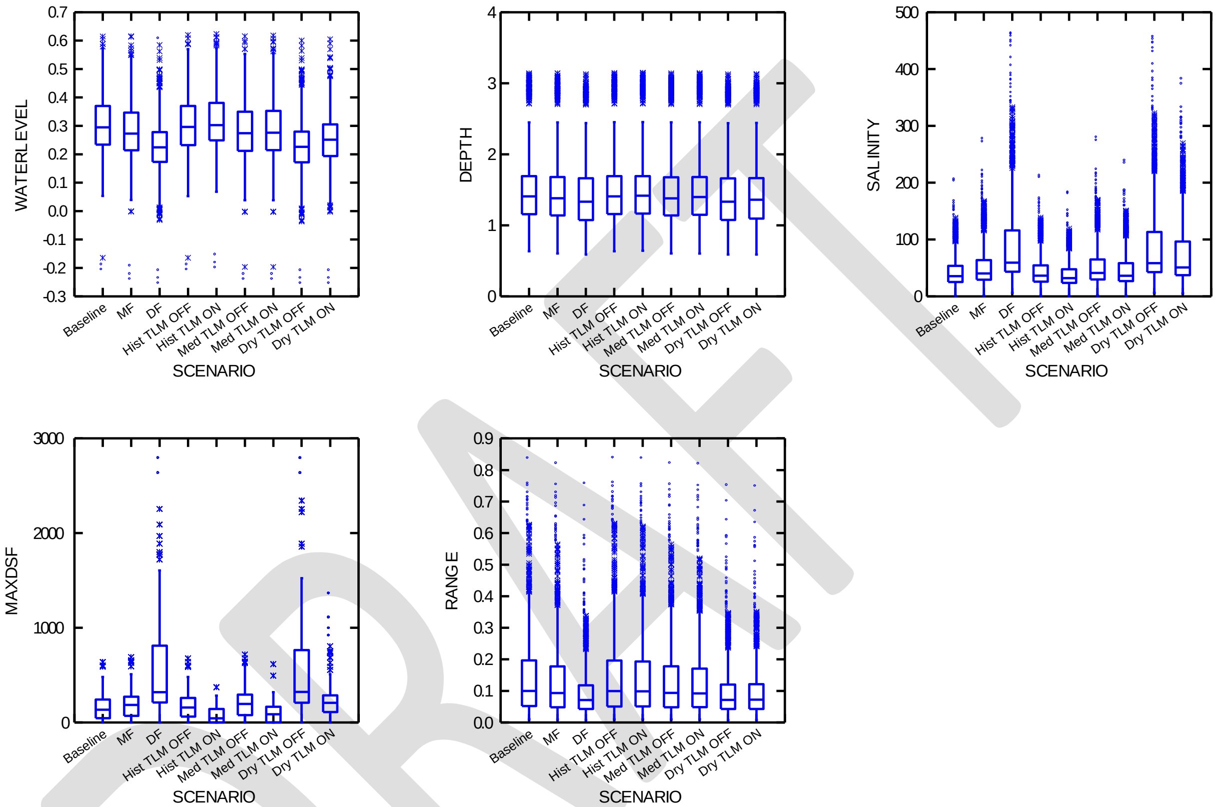





***Figure 5.9. Boxplots showing the comparison between variables driving the ecosystem states of the Coorong for the TLM scenarios***

a) Water levels (m AHD), b) water depths from the previous year (m), c) salinities (g $L^{-1}$), d) Maximum number of days since flow (MaxDSF, days) and e) tidal range (m)

Note that MF is the Median Future scenario, DF is the Dry Future scenario, Hist TLM OFF is the Historic TLM off scenario, Hist TLM ON is the Historic TLM on scenario, Med TLM OFF is the Median TLM off scenario and Med TLM ON is the Median TLM on scenario.

Under a historic climate, the threshold for tidal range was affected by the addition of TLM infrastructure and water. The tidal prism did not extend as far under TLM scenarios, with Mark Point being the northern-most site where the threshold was not always exceeded (compared with Noonameena under the Baseline scenario). The average duration in the North Lagoon over the threshold was slightly shorter for the Historic TLM off and Historic TLM on scenarios, but no change was evident in the South Lagoon sites.

The scenarios investigating the effect of TLM under a median climate showed that the threshold for tidal range was exceeded for fewer years in the North Lagoon once the infrastructure and additional water were taken into account. The average return interval was also slightly longer for both Median TLM off and Median TLM on, compared with the Median Future scenario. No change was evident in the South Lagoon.

Under a dry future climate, the inclusion of TLM infrastructure, without the additional water, increased the length of time sites exceeded the threshold for tidal range, on average. This was also true when the additional TLM water was delivered. The additional TLM water also increased the distance to which sites were above the threshold for all years (from Barkers Knoll to Pelican Point). Sites in the South Lagoon were not affected.

The average time that the threshold for the maximum number of days without flow was exceeded was not affected by the addition of TLM infrastructure, under a historic climate, but the Historic TLM on scenario had fewer years that exceeded the threshold. The Historic TLM off scenario had a lower return time than the Baseline scenario.

For the median future climate, the threshold for the number of days without flow over the barrages was exceeded for slightly more years, on average, under the Median TLM off scenario, compared with the Median Future scenario. The average return time was slightly lower for the Median TLM off scenario. Under the Median TLM on scenario, only the final two years of simulation exceeded the threshold.

Under a dry future climate, the return time for exceeding the threshold for the number of days without flow decreased slightly with the addition of TLM infrastructure, but decreased substantially when the additional water was delivered. The duration of exceedance was approximately the same under the Dry Future and Dry TLM off scenarios, but halved in the Dry TLM on scenario.

Durations for which the first water level threshold (0.37 m AHD) was exceeded were not affected by the introduction of TLM infrastructure or water for any climate investigated in any region. Under the historic climate, the average return times were similar under all scenarios. In the Murray Mouth region, return times were similar between the Median Future and the Median TLM off scenario, but shorter under the Median TLM on scenario. In the North and South Lagoons, return times were slightly lower for the Median TLM off and Median TLM on scenarios, compared to the Median Future scenario. Under the dry future climate, average return times in the Murray Mouth region increased when TLM infrastructure was included, but were similar to the Dry Future scenario under the Dry TLM on scenario.

The second water level threshold (-0.09 m AHD) was not affected by the addition of TLM infrastructure or water under any of the climates investigated.

Under historic climate conditions, the implementation of TLM infrastructure decreased the return time for exceeding the depth threshold at Mark Point, with a further reduction when the additional environmental water was added. For the Median TLM on scenario, the return time for exceeding the depth threshold at Mark Point was slightly shorter than for the Median Future or Median TLM on scenarios. However, under a dry future climate, TLM had no impact on the return times or average exceedance time for depth thresholds. TLM had no impact on the Monument Road and Barkers Knoll sites which were always deeper than the threshold.

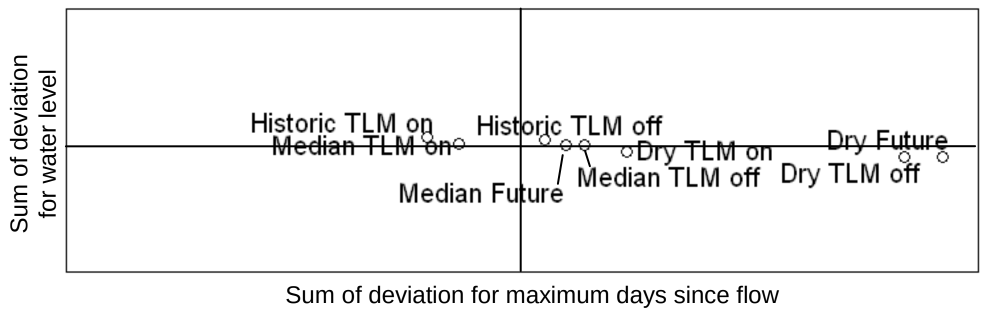
The addition of TLM infrastructure increased the number of sites where the salinity threshold was crossed more than once in the North Lagoon under a historic climate. It also increased the average length of time South Lagoon sites exceeded the threshold and shortened the return interval. This pattern was reversed under the Historic TLM on scenario, with fewer North Lagoon sites exceeding the threshold more than once, and a shorter duration with a longer return interval in the South Lagoon. Exceedance of the salinity threshold was largely unaffected under the median climate TLM scenarios. Under the dry future climate, the addition of TLM water increased the average return time of threshold exceedance in the Murray Mouth region. Return times in the North Lagoon were similar across the Dry Future, Dry TLM off and Dry TLM on, but the average duration over the threshold was halved under the Dry TLM on scenario, compared to the other two. Sites in the South Lagoon were not affected by the addition of TLM infrastructure or water.

For the most part, The Living Murray initiative had little impact on the dispersion of hydrodynamic variables. Tidal ranges, depths and salinities had very similar Gini coefficients under the Historic, Median and Dry Future scenarios, either with the additional TLM water or with TLM infrastructure only. Under Historic climate conditions, the addition of TLM water increased the unevenness of the distribution for the number of days without flow, by making extremely high values less common (Gini = 0.46 for Baseline compared to 0.59 for Historic TLM on) and a similar pattern was observed under the Median TLM on scenario (0.43 for the Median Future versus 0.54 for the Median TLM on scenarios). The Dry Future scenarios showed a slight increase in evenness from 0.51 for the Dry Future scenario to 0.48 for the Dry TLM on scenario.

Compared to the Baseline scenario, the TLM scenarios all showed very small deviations in water levels (Figure 5.10). This can be seen as all scenarios are approximately on the horizontal line, indicating a zero deviation in water level (Figure 5.10a). There was more variability with respect to the duration of zero flow periods compared with the Baseline scenario. Scenarios using the dry future climate had the greatest increases in the number of days without flow. The Median TLM on and Historic TLM on scenarios were the two showing a decrease in the number of days without flow, and therefore an improvement. The Historic TLM on scenario was the only one that fell into the top-left quadrant, indicating an improvement both in water level and number of days without flow.

The TLM scenarios also showed very little variability with respect to salinity compared with the Baseline scenario (Figure 5.10b). Again, scenarios using the dry future climate were somewhat worse, but there was little difference in the others, with all clustered around the horizontal line. No scenarios fell clearly within the bottom-left quadrant, representing an improvement on both variables, but the Historic TLM on scenario came closest.

a)

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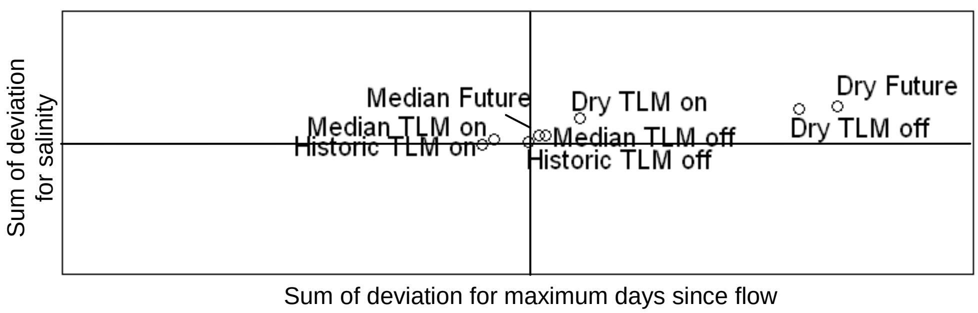



***Figure 5.10. Comparison of The Living Murray scenarios to the Baseline scenario for key variables***

a) Site-years below the tidal range threshold, compared to the Baseline scenario with respect to water level and the maximum number of days without flow. The top-left quadrant represents an improvement in both.

b) Site-years above the tidal range threshold, compared to the Baseline scenario with respect to salinity and the maximum number of days without flow.

### 5.1.6. Effect of dredging

The current dredging activity at the Murray Mouth is represented by the MM Dredging scenario (Scenario 19). As dredging is an intervention that is designed to improve the ecological condition of the Coorong without changing the amount of flow over the barrages, the ecosystem states for this scenario were assessed using the alternative ecosystem state models for the Coorong. The hydrodynamic variables presented here are those that drive the ecosystem states for the alternative models, rather than those presented for the scenarios above (Figure 5.11). In order to allow for comparison, the Baseline scenario is also displayed for the same variables.

The dredging program made very little difference to the modelled water levels or depths across the 114 years (Figure 5.11). The minimum depths were affected, as can be seen by the extent of the lower whisker for that boxplot. The range in water levels experienced across the year (the annual maximum minus the annual minimum level) was the variable most affected, with the median increasing from 1.01 m for the Baseline scenario to 1.11 m when dredging was implemented. The maximum annual range was also predicted to increase from 1.85 m for the Baseline to 2.29 for the MM Dredging scenario.

It needs to be stated that dredging would only be expected to affect the driest years, as the intervention would only be triggered when the transmissivity at the Murray Mouth fell below the threshold level of -2 m equivalent depth.  This means that differences observed in the hydrodynamic properties over 114 years may seem small, but still result in a significant impact on the ecosystem states occurring during drought periods.

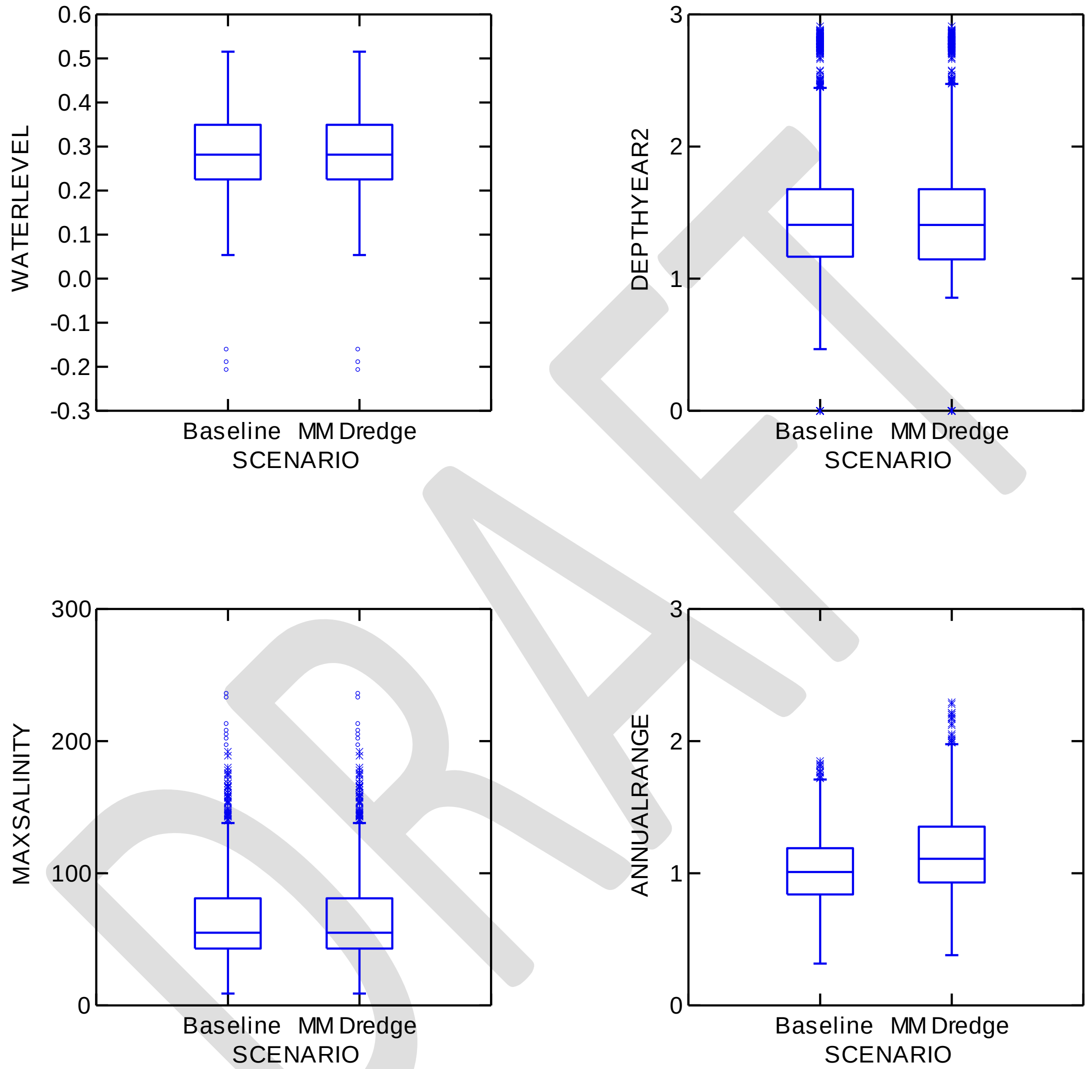





***Figure 5.11. Boxplots showing the comparison between variables driving the ecosystem states of the Coorong for MM Dredging (Scenario 19) compared with the Baseline (Scenario 1)***

a) Water levels (m AHD), b) water depths from two years' previous (m), c) annual change in water level (m)

Note that the Maximum Salinity is only presented for sites 4-12, as no relationship could be calculated for the predicted sites 1-3.

The threshold for water level in the previous year in the marine model was not affected by dredging at the Murray Mouth.  As for the Baseline conditions (investigated using the alternative model), the threshold was exceeded at all sites for all years with the exception of the South

Lagoon sites for the final year of simulation. The threshold for water level in the previous year from the hypersaline model, however, was affected at Mundoo Channel and Barkers Knoll. The Barkers Knoll site did not exceed the threshold under Baseline conditions, but did exceed the threshold with dredging for a single year. At Mundoo Channel, the threshold was exceeded for an average of 1.9 years at a return interval of 8.2 years.

A similar pattern emerged with the water level threshold in the hypersaline model. Return times were not affected, nor were the durations of exceedance in the North and South Lagoons. The average length of time over the threshold was slightly shorter with dredging compared to the Baseline scenario, at 1.4 years, compared to 1.8 years.

The depth threshold (for depth two years' previous) was affected by dredging only at the Monument Road and Mundoo Channel sites. Mundoo Channel never exceeded the threshold in the MM Dredging scenario, and Monument Road exceeded the threshold for an average of 55.0 years with a return interval of 2.0 years.

MM Dredging increased the number of site-years for which the threshold for annual range in water level was exceeded at Monument Road and Mundoo Channel. Under the MM Dredging scenario, only the final year of simulation did not exceed the threshold at those two sites. The durations and return times of exceedance at all other sites were unaffected.

Dredging did not affect the duration or the return time for sites exceeding the threshold for maximum salinity.

There was very little difference between the Gini coefficients for the MM Dredging and Baseline scenarios for all of the variables driving ecosystem states. This indicates that the dredging operation did little to change the occurrence of extreme events within the Coorong over the 112-year model run.

When deviations in key variables were compared between the MM Dredging scenario and the Baseline scenario (assessed using the alternative model), no differences were observed for maximum salinity or water level in the South Lagoon. For the North Lagoon and Murray Mouth region, dredging the Murray Mouth resulted in slightly decreased water levels over the entire model run, and decreased depths. This is likely to be a because, when the Murray Mouth is relatively closed, transmissivity of water into the Coorong is relatively high during high tide and significantly lower during low tide. Consequently, there is a bias towards water level being higher than average sea level at this time (see Webster 2006 for more detail).

### 5.1.7. Effect of augmented USED scheme

As for the MM Dredging scenario, Max USED Flows (Scenario 20) investigated an intervention that was designed to improve the ecological condition of the Coorong by means other than enhanced barrage flows. Accordingly, we used the alternative ecosystem states model, and present the relevant hydrodynamic variables below (Figure 5.12).

Very little difference was evident between the hydrodynamic properties of the Baseline scenario and the Max USED Flows scenario (Figure 5.12). Water levels under the Max USED Flows scenario had a slightly lower maximum and a slightly higher minimum, and there were more extreme annual ranges (represented by crosses) for the Max USED Flows scenario. However, as for the MM Dredging scenario, the largest impact of the Max USED Flows scenario would be expected in drought years and even small amounts of additional freshwater may have been sufficient to improve the ecosystem states occurring under dry conditions for this scenario.

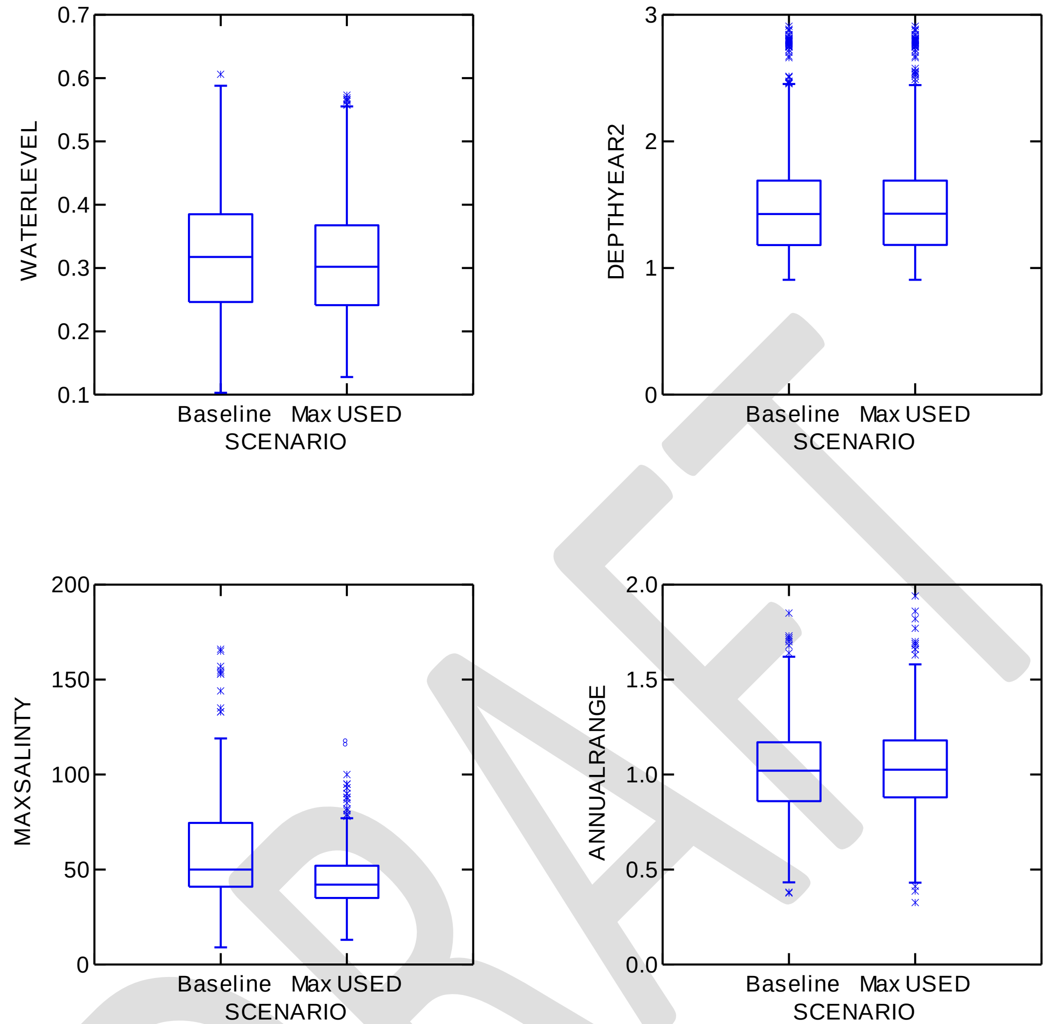



***Figure 5.12. Boxplots showing the comparison between variables driving the ecosystem states of the Coorong for Max USED Flows (Scenario 20) compared with the Baseline (Scenario 1)***

a) Water levels (m AHD), b) water depths from two years' previous (m), c) annual change in water level (m)

Note that Maximum Salinity is only presented for sites 4-12, as no relationship could be calculated for the predicted sites 1-3. Also all variables are for the years 1971-2006 under the Maximum USED Flows Scenario.



The water level threshold for the marine basin model (-0.19 m AHD) were exceeded for approximately twice as long under the Max USED Flows scenario than the Baseline scenario. Return times were relatively unaffected, however, at between 2 and 3 years for all regions in both scenarios.

The water level threshold for the hypersaline basin model (-0.37 m AHD) was exceeded for approximately the same number of years in the Murray Mouth region, but had a return time of almost half for the Max USED Flows scenario, compared with the Baseline scenario. In the

North and South Lagoons, average exceedance times were 1.3 years and 2.6 years, respectively (compared to ~1.5 years for the Baseline), and return intervals were approximately 2 years shorter than those for the Baseline scenario.

The threshold for water levels in the previous year for the marine basin model was always exceeded along the length of the Coorong under the Max USED Flows scenario, compared with the Baseline scenario in which all site-years exceeded the threshold bar the final year of simulation in the South Lagoon sites.

The threshold for water level in the previous year for the hypersaline basin model was never exceeded at Barkers Knoll under either the Max USED Flows or the Baseline scenarios. The other Murray Mouth sites exceeded the threshold for an average of 1.3 years, at a return interval of 4.9 years under the Max USED Flows scenario (compared with 2.2 years every 7.1 years under the Baseline conditions). A similar trend was apparent in the South Lagoon, with slightly shorter return times exceedance times under the Max USED Flows scenario.

The depth threshold was not affected at any site except for the Mundoo Channel site. Under the Baseline scenario, the threshold was exceeded at Mundoo Channel for an average of 14.9 years, with a return interval of 2.2 years. Under the Max USED Flows scenario, this site was never above the depth threshold.

There was no impact of the augmented USED scheme on the likelihood of exceeding the threshold for the annual range in water level.

The maximum salinity threshold was not exceeded for any site in any year under the Max USED Flows threshold, which was an improvement on the Baseline scenario. Under the Baseline scenario, South Lagoon sites exceeded the threshold for an average of 1.7 years at a return interval of 16.3 years. Maximum salinity under maximum USED flow conditions was greater than 100 g $L^{-1}$ in 1% of site-years.

The augmentation of the USED scheme increased the Gini coefficient for the annual range of water levels relative to that observed for the Baseline scenario (Gini = 0.26 for Max USED Flows and 0.10 for Baseline). This indicates that extreme values were less common under the Max USED Flows scenario than for the Baseline scenario.

Compared to the Baseline scenario, the Max USED Flows scenario resulted in a small negative overall deviation in water depths in the North Lagoon and Murray Mouth. This represented a decline in overall depths for the Max USED Flows scenario. Also in the northern section of the Coorong, there was a very small negative deviation in water level, indicating that the augmented USED flows had little impact on Murray Mouth and North Lagoon water levels. In the South Lagoon, however, water levels were somewhat higher than occurred under the Baseline scenario, although again the sum of deviations was relatively small. The largest deviation from the Baseline scenario occurred for maximum salinities, which were substantially lower under the Max USED Flows scenario in the South Lagoon.

## 5.2. Ecosystem states

This section compares the ecosystem states that are predicted to exist under each scenario, in order to answer the research questions outlined above. Additional input for each scenario individually is presented in Langley *et al.* (2009).

Figure 5.13 shows the distribution of ecosystem states at each focal site for each year of the model simulation that uses historic climate and current water extraction rules. It is presented as an example of the spatiotemporal output from the ecosystem state model and is used to illustrate features of the ecological response of the Coorong to environmental drivers over the last century.

Over the 114-year model run, all eight identified ecosystem states were present. The vast majority of site-years were either in the Estuarine/Marine state or the Average Hypersaline state. The effect of the Federation Drought can be seen with a change in ecosystem states in the early years of the $20^{th}$ Century. Other droughts to affect the ecosystem states of the Coorong occurred in 1914-15, 1945 and the present drought, which affected the ecosystem states from 2005 onwards.

In addition to the scenarios that have been investigated as a part of CLLAMM Futures that are reported within this document, we have also undertaken additional modelling focused on the various options to reduce salinities in the South Lagoon of the Coorong, and further investigations of the effect of the proposed increases to diversions from the USED scheme and the effect of Murray Mouth dredging. The findings from these investigations have been, or will shortly be provided to SA MBD NRM Board and DWLBC.

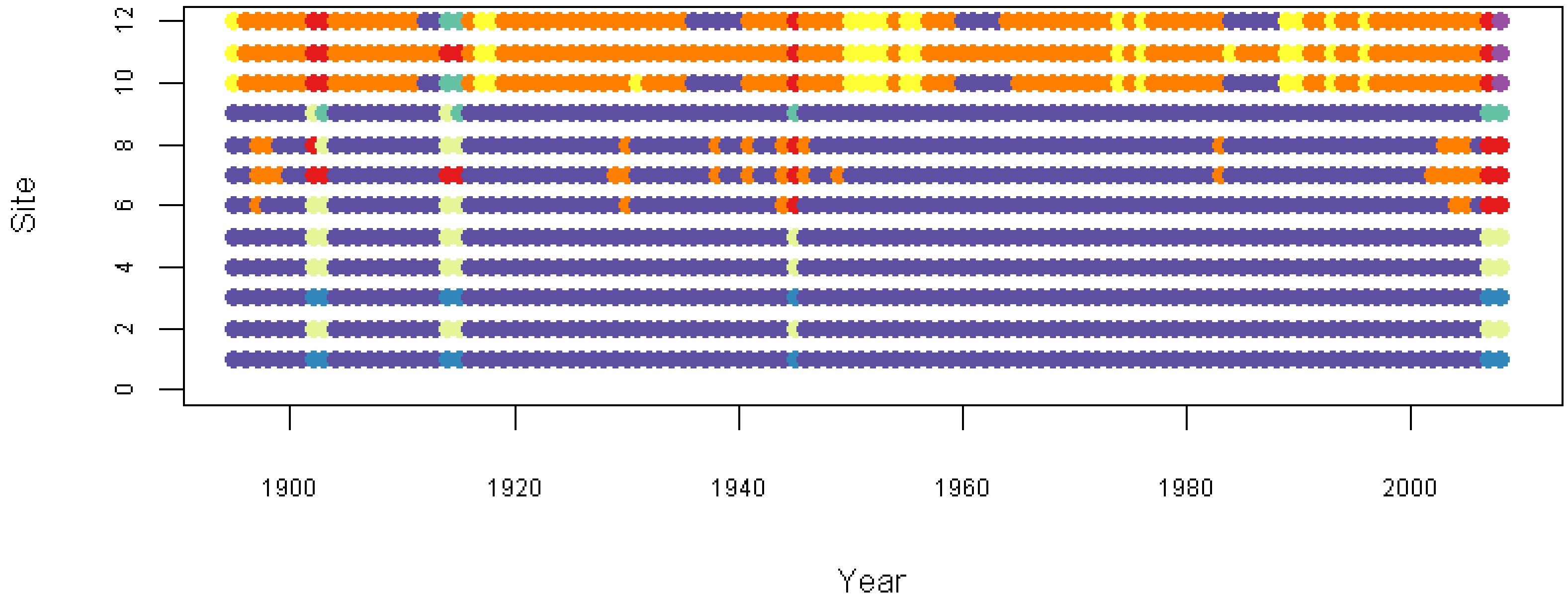



***Figure 5.13. Distribution of states for each site-year under the Baseline scenario***

Each bar shows the distribution of the states within each site across the 114-year model run. Sites are numbered from north to south (e.g. Monument Road = Site 1 and Salt Creek = Site 12). The changes in the bar colours represent the transitions between states. For each bar, colours represent the following states: dark blue = Estuarine/Marine, light blue = Marine, light green = Unhealthy Marine, dark green = Degraded Marine, yellow = Healthy Hypersaline, orange =Average Hypersaline, red = Unhealthy Hypersaline and purple = Degraded Hypersaline.

### 5.2.1. Current Coorong condition

Over the 114-year Baseline scenario model run, the two most common states along the length of the Coorong were the Estuarine/Marine state (70% of site-years) and the Average Hypersaline state (20%; Figure 5.14). Together, these accounted for 90% of the site-years modelled. Healthy Hypersaline (3%), Unhealthy Hypersaline (2%), Unhealthy Marine (2%) and Marine (1%) were all uncommon and the two most-degraded states, Degraded Marine and Degraded Hypersaline appearing in less than 1% of site-years each. This emphasises that the current condition of the Coorong is quite unusual, even over a 114-year time-frame using current extraction levels.

This is also emphasised by the relative proportions of the site-years exceeding the thresholds for tidal range and maximum number of days since flow. Over the 114 years, approximately 75% of site-years have been tidally-influenced, and greater connectivity at the Murray Mouth has resulted in a tidal-prism extending further into the Coorong than is observed currently (extending to Tauwitchere). The number of days since flow has also been lower than is currently the case, with only 6% of site-years exceeding the threshold of 339 days.

When the final 20 years of the model run were compared with the entire 114-years sequence, the Estuarine/Marine state accounted for 3% fewer site-years. There was also a decline in the proportion of site-years predicted to be in the Unhealthy Marine, Degraded Marine and Unhealthy Hypersaline states (1% for all three), with a 1% increase in the proportion of Degraded Hypersaline site-years and no change in the proportion of Healthy Hypersaline site-years. The largest change was in the proportion of site-years predicted to be in the Average Hypersaline state, which increased by 5%.

Transitions occurred between states for 14% of site-years. This means that the state inertia (i.e. the proportion of site-years where the state did not change) in the system for the Baseline scenario was 86%. The sequence in which the states appear at each site across the 114 years is significantly different from a random distribution ($Z_u$ ranges between 3.909 and 7.743 for the 12 sites, $p < 0.0001$ for all sites). When transitions did occur, sites changed basin (i.e. went from a marine state to a hypersaline state or vice versa) in 4% of site-years, indicating a shift in the penetration of the tidal prism. When sites changed within the same basin, they shifted to a more-degraded state 6% of the time and to a less-degraded state 4% of the time.

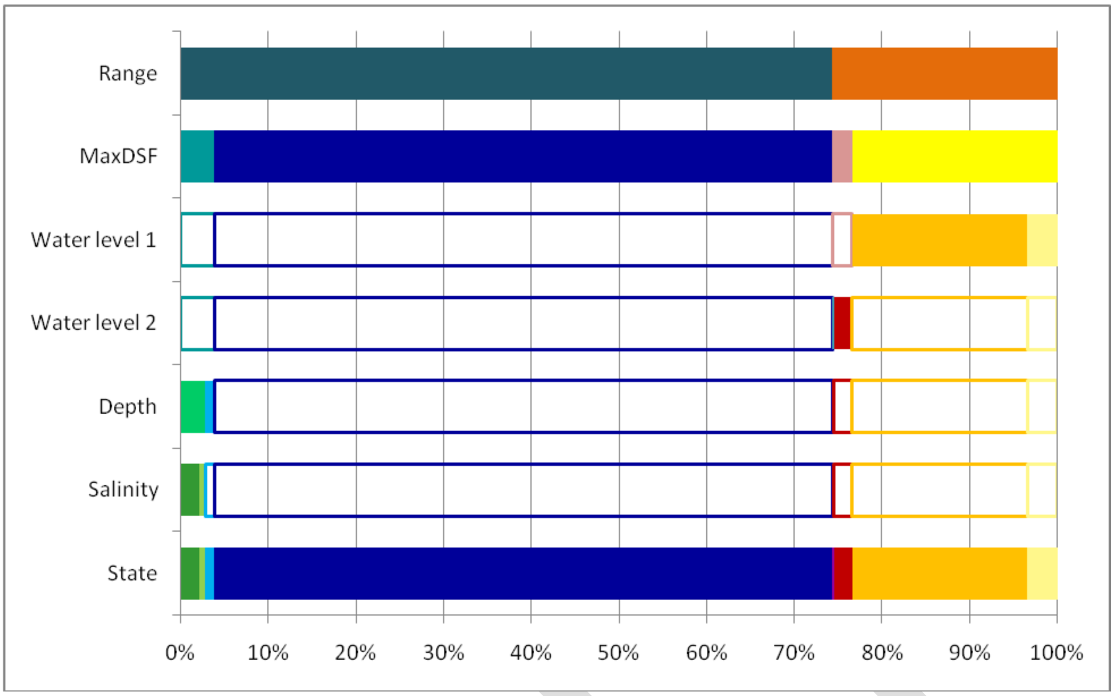



***Figure 5.14. Proportion of site-years in each ecosystem state (bottom bar) and that exceed the thresholds for variables driving them for the Baseline scenario***

Each of the upper six bars shows one threshold for a variable driving ecosystem states in the Coorong. The two solid blocks represent the proportion of site-years that fall below (on the left) and above (on the right) the threshold. Going from top to bottom, each bar builds on the previous until the bottom bar illustrates the distribution of ecosystem states for this scenario. The final bar shows the states with dark green representing the Degraded Marine state, light green is Unhealthy Marine, light blue is Marine, dark blue is Estuarine/Marine, purple is Degraded Hypersaline, red is Unhealthy Hypersaline, orange is Average Hypersaline and yellow is Healthy Hypersaline.

### 5.2.2. Effect of current extraction levels

Current extraction levels within the Murray-Darling Basin are having an effect on the ecosystem states occurring within the Coorong (Figure 5.15).

Under the Historic Natural scenario, only three of the possible eight identified ecosystem states occurred (Figure 5.15). These were the Estuarine/Marine, the Healthy Hypersaline and the Average Hypersaline states. This equated to 100% of the site-years being in states considered healthy, compared with only 94% of site-years under current extractions within the Basin (Baseline scenario). While the overall decline was relatively small (6%), the mix of site-years within each state also changed, with the Healthy Hypersaline state accounting for only 3% of site-years instead of 15% under the Historic Natural conditions. This difference was mostly a result of additional site-years being classified as the Average Hypersaline state under Baseline conditions (8% under Historic Natural compared with 20% under Baseline).

The mixture of marine versus hypersaline basin states was also slightly different between the scenarios, with 77% of site-years occurring within the marine basin under Historic Natural conditions versus 74% under Baseline conditions.

For the final 20 years of the model simulation, site-years in the Estuarine/Marine state were 7% less common under Baseline conditions, compared with 2% less common under Historic Natural conditions. Under Baseline conditions, site-years in the Marine state were 1% more common, as were site-years in the Degraded Hypersaline state, and site-years in the Unhealthy Hypersaline state were 2% more common. All three of these states showed no change in their commonality under Historic Natural conditions. Instead, under Historic Natural conditions, site-years in a Healthy Hypersaline state were 1% less common and site-years in the Average Hypersaline state were 3% more common (compared to 2% more common for both under Baseline conditions).

Under Historic Natural conditions, transitions between states occurred in 11% of site-years, with 8% of the 11% occurring the last decade. During the entire model run, sites between Monument Road and Parnka Point did not vary from the Estuarine/Marine state. This compares with 14% of sites-years changing under Baseline conditions, with 19% changing in the last decade. Runs testing showed that the sequence of state changes (where changes did occur) were not different from a random arrangement for the centre of the South Lagoon (Jack Point, $Z_u = 0.90$, $p = 0.184$), but did have a significant order for both ends of the South Lagoon (i.e. Villa dei Yumpa, $Z_u = 3.67$, $p = 0.001$ and Salt Creek, $Z_u = 3.27$, $p = 0.004$, respectively).

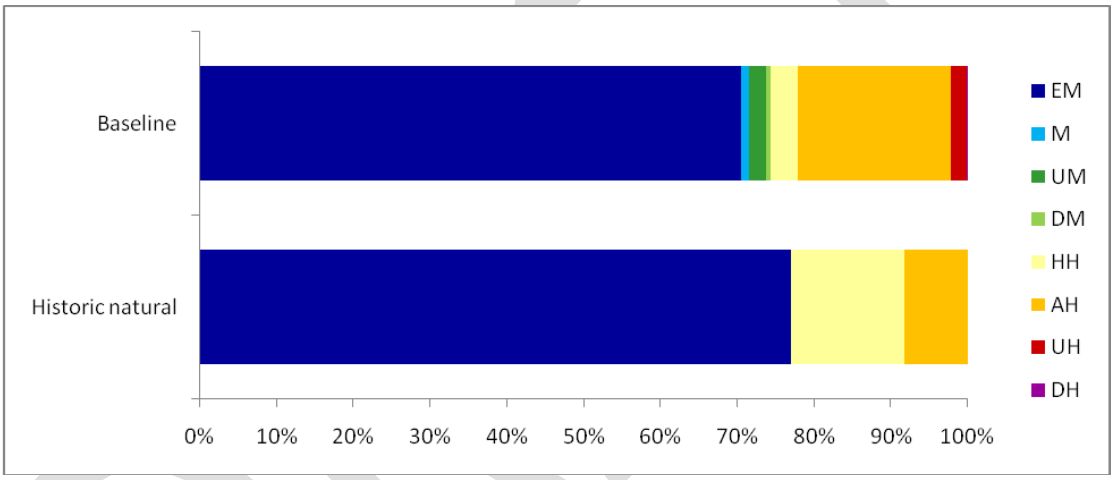



***Figure 5.15. Comparing the proportion of site-years in each ecosystem state for the Baseline versus the Historic Natural scenarios***

Note: EM = Estuarine/Marine, M = Marine, UM = Unhealthy Marine, DM = Degraded Marine, HH = Healthy Hypersaline, AH = Average Hypersaline, UH = Unhealthy Hypersaline, DM = Degraded Hypersaline. States do not appear in the same order as Figure 5.14 to standardise the order of the states, but the colours for each state match across all figures.

### 5.2.3. Effect of climate change

As for the hydrodynamic results, climate change has the potential to dramatically affect the ecosystem states of the Coorong (Figure 5.16). The proportion of degraded states was predicted to increase from 6% under the Baseline scenario, to 11% under the Median Future scenario and 46% under the Dry Future scenario. The proportion of site-years in the hypersaline basin is also predicted to rise, from 26% for the Baseline to 27% and 35% under the Median and Dry Future scenarios, respectively.

The ecosystem states that were most affected were the Estuarine/Marine state and the Average Hypersaline state (Figure 5.16). The Estuarine/Marine state declined from occurring in 70% of site-years under Baseline conditions to 66% under the Median Future and 39% under the Dry Future scenarios. These site-years were replaced by an increase in the occurrence of Marine, Unhealthy Marine and Degraded Marine site-years. Site-years in the Average Hypersaline state fell in occurrence from 20% under the Baseline and Median Future scenarios to 14% under the Dry Future scenario, while site-years in the Unhealthy Hypersaline state rose from 2% under Baseline conditions to 5% and 20% under the Median and Dry Future scenarios, respectively. In all scenarios, the Degraded Hypersaline state accounted for less than 1% of site-years.

Climate change had quite an effect on the proportions of site-years predicted to be in each state when comparing the last 20 years of the model run to the entire 114-year run. The Estuarine/Marine state was predicted for 7% fewer site-years under Baseline conditions in the final 20 years, compared with 4% fewer for the Median Future and 1% more site-years under the Dry Future scenario. While this may seem like an improvement in the Dry Future scenario, it actually indicates that the more-recent conditions (i.e. degraded) were more common over the entire Dry Future run. The other major difference between the three climate change scenarios was in the proportion of site-years predicted to be in the Average Hypersaline state. This was 2% higher for the last 20 years under Baseline conditions, compared to 7% and 6% higher under the Median Future and Dry Future scenarios, respectively.

The proportion of site-years changing over the 114-year model run was also affected by climate change. For the Baseline scenario, 14% of site-years changed, with 6% being changes to a more degraded state within the same basin, and 4% being recovery within the same basin. The final 4% of site-years switched from a state in one basin to a state in the other. For the Median Future scenario, these proportions increased to 18% with 7% degrading and 5% recovering, and for the Dry Future scenario, 26% of site-years changed between states, with 9% degrading, 7% recovering and 10% switching between basins. This indicates that climate change will result in more instability of state for the Coorong. Despite this trend of increasing transitions, runs analysis confirmed that the sequences were significantly different from random sequences for all sites within the Baseline, Median Future and Dry Future scenarios.

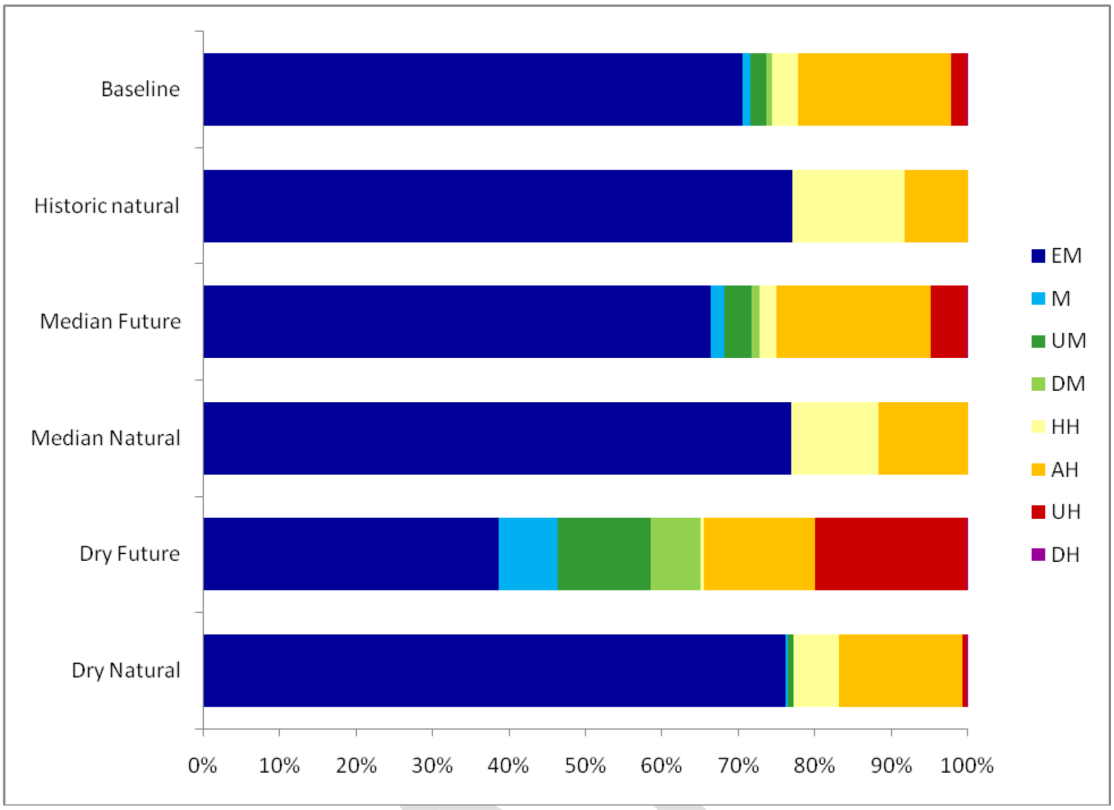



***Figure 5.16. Comparing the proportion of site-years in each ecosystem state for the Baseline versus the climate change scenarios***

Note: EM = Estuarine/Marine, M = Marine, UM = Unhealthy Marine, DM = Degraded Marine, HH = Healthy Hypersaline, AH = Average Hypersaline, UH = Unhealthy Hypersaline, DM = Degraded Hypersaline

The Median Natural and Dry Natural again emphasised the degree to which changes in ecosystem state are largely due to current extraction levels. The Median Natural scenario predicted that no site-years would be in a degraded state (compared with 11% for Median Future) and the Dry Natural scenario predicted that only 2% of site-years would be in degraded states (compared to 46% for Dry Future). The mixture of states was slightly different between the Historic Natural and the Median and Dry Natural scenarios, with more site-years in the Average Hypersaline state for the latter two but, overall, the effect of climate change (whether the median or dry projection) was small compared to the effect of current extraction levels combined with climate change.

Comparing the last 20 years of the model run to the whole 114-years sequence, the biggest difference between the baseline (Baseline, Median Future and Dry Future) scenarios and their natural run counterparts (Historic Natural, Median Natural and Dry Natural) was in the proportion of site-years predicted to be in an Average Hypersaline state (5% under baseline conditions compared with 2% under natural flow conditions). Other states differed within only 2% for the baseline and natural flow scenarios when the last 20 years was compared to the entire run.

For the natural flow scenarios, there was a similar pattern of increasing numbers of transitions between states with the more extreme climate change predictions, as was seen for the scenarios using current extraction levels. The Historic Natural scenario predicted changes in ecosystem state in 11% of site-years, while the Median Natural indicated that 12% of site-years would change state. The Dry Natural scenario showed 26% of site-years altering. However, the proportions of site-years changing were much lower than those observed for the scenarios using current extraction levels (Baseline, Median Future, Dry Future), again indicating that the effect of climate change on the ecosystem states of the Coorong will be heavily influenced by extraction levels within the Murray-Darling Basin. Runs analysis indicated that all sequences of state changes were significantly different from random with the exception of Jack Point for the Historic Natural and Median Natural scenarios.

### 5.2.4. Effect of sea level rise

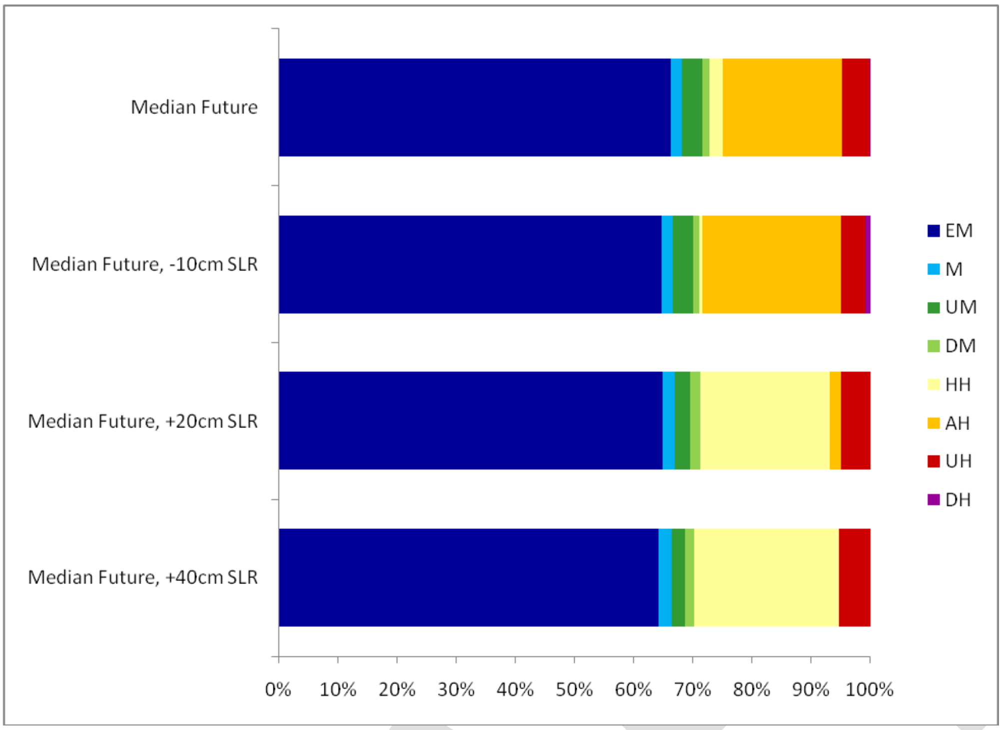
The effect of sea level rise on the ecosystem states was small for the site-years in the marine basin (Figure 5.17). There were small changes in the proportion of site-years that were classified within the marine basin (ranging between 70% and 73% for the Median SLR scenarios and 61% and 65% for the Dry SLR scenarios).

There were larger differences as a result of sea level rise on the proportions of site-years allocated to the various states in the hypersaline basin. A decline in sea level (Median Future, -10 cm SLR and Dry Future, -10 cm SLR) resulted in a more-degraded set of ecosystem states for the hypersaline basin, particularly for the Dry Future SLR scenarios. For the Dry Future, -10 cm SLR scenario, there were slightly more site-years classified as Average Hypersaline, and slightly fewer classified as Unhealthy Hypersaline than the Dry Future baseline scenario. However, there was a substantial decline in the proportion of sites classified as Healthy Hypersaline, and a large increase in the proportion of Degraded Hypersaline site-years. A similar pattern was observed for the equivalent Median Future, -10 cm SLR scenario compared with the Median Future scenario.

A rise in sea level, either by 20 cm or 40 cm, had a different effect on the distribution of states within the Coorong. The most obvious change for all four scenarios (Median Future, +20 cm SLR, Median Future, +40 cm SLR, Dry Future, +20 cm SLR, Dry Future, +40 cm SLR) was the increase in the proportion of site-years in the Healthy Hypersaline state relative to the Median Future or Dry Future scenario, respectively. This was accompanied by a decline in the proportion of site-years predicted to be in the Average Hypersaline state. There was also a slight increase in the proportion of site-year predicted to be in the Unhealthy Hypersaline state for both the Dry Future, +20 cm and +40 cm SLR scenarios.

There was little difference in the proportion of states observed over the whole model run compared with those observed in the final 20 years. Marine basin states declined on average by 1%, as did the Unhealthy Hypersaline state. The Degraded Hypersaline state was present in the same proportion of site-years, but the Healthy Hypersaline and Average Hypersaline states were more common in the last 20 years than in the whole 114-year model run (but only by 2% and 3%, respectively). Across the sea level rise scenarios, the greatest discrepancies occurred for the proportion of Healthy Hypersaline and Average Hypersaline states. Under no sea level rise (so the Median Future and Dry Future scenarios), 1% fewer site-years were in the Healthy Hypersaline state and 7% more were in the Average Hypersaline state over the last 20 years of the model run compared with the whole 114-years. Under a sea level fall of 10 cm, these proportions changed to an average of 0% and 4%, respectively. For either a 20 cm or a 40 cm increase, Healthy Hypersaline states were 5% more common in the last 20 years, and there was no change in the proportion of site-years in the Average Hypersaline state.

a)




b)

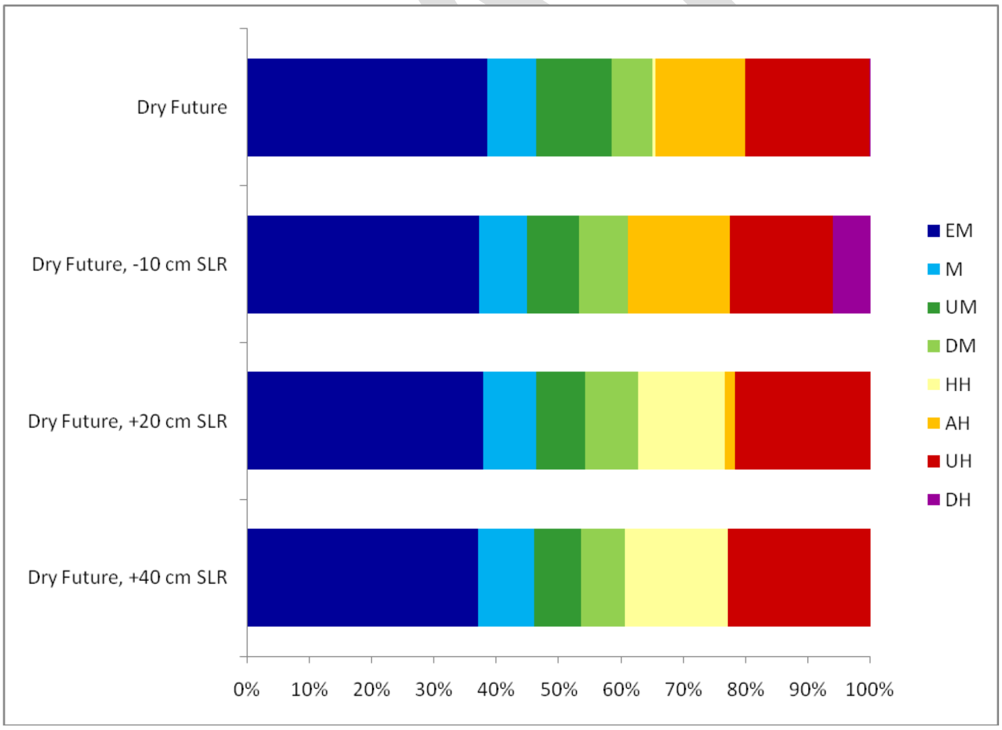



***Figure 5.17. Comparing the proportion of site-years in each ecosystem state for the sea level rise scenarios***

a) Median Future scenarios, b) Dry Future scenarios

Note: EM = Estuarine/Marine, M = Marine, UM = Unhealthy Marine, DM = Degraded Marine, HH = Healthy Hypersaline, AH = Average Hypersaline, UH = Unhealthy Hypersaline, DM = Degraded Hypersaline

Sea level rise had very little impact on the level of state inertia observed during the model run. The proportion of site-years switching between states was quite consistent, with changes of only a few site-years across the six sea level rise scenarios. This was the case both over the entire model run and for just the last decade. Runs analyses confirmed that the sequence of states appearing was significantly different from a random sequence for all sea level rise scenarios under both the Median and Dry Future climates. The exception was the Median Future, +20 cm SLR scenario, where the sequences for Long Point, Noonameena and Villa dei Yumpa were not able to be distinguished from a random sequence.

### 5.2.5. Effect of The Living Murray initiative

The effect of The Living Murray initiative on the ecosystem states of the Coorong was investigated in two stages (Figure 5.18). The first stage investigated the effect of TLM infrastructure, without the additional environmental water allocated under the plan (e.g. Historic TLM off). The second stage included both the infrastructure and the additional 500 GL of environmental water (e.g. Historic TLM on).

Interestingly, under all three climates investigated, the inclusion of TLM infrastructure without the additional environmental water had a slightly negative effect on the mixture of ecosystem states in the Coorong (Figure 5.18). This was most marked for the Historic TLM off scenario, when the proportion of site-years in a degraded state increased from 6% (under Baseline conditions) to 10%. The differences in state were spread along the Coorong, with additional site-years in the Marine, Unhealthy Marine, Degraded Marine and Unhealthy Hypersaline states. For the Median and Dry TLM off scenarios, there was a slight increase in site-years in the Unhealthy Marine state.

Once added, the additional environmental water, however, had a large impact on the distribution of ecosystem states. This effect was greatest under the Dry TLM on scenario, where the proportion of degraded states was only 20% (compared with 46% under the Dry Future scenario). A similar pattern was observed for both the Median TLM on and Historic TLM on scenarios. The majority of the change in states was from states classified as Unhealthy Hypersaline under the TLM off or baseline conditions being classified as Average Hypersaline, and site-years categorised as Marine, Unhealthy Marine or Degraded Marine changing to Estuarine/Marine.

In the last 20 years of the model run, overall the Estuarine/Marine state was less common (-5%) compared to the 114-year model run. The Average Hypersaline state was more common (4%). The proportions of other states either did not change, or changed by ± 1%. The three TLM off scenarios were the most different from this average. For those scenarios, the Estuarine/Marine state was 8% less common in the last 20 years, and the Unhealthy Marine states was 5% more common. The Average Hypersaline state was 2% more common than over the whole model run.

The effect of TLM was also observed in the propensity for site-years to change under each of the scenarios. Including TLM infrastructure only made site-years slightly more likely to shift to a different state, with Historic TLM off having 17% of site-years changing to a new state (compared with 14% for the Baseline scenario), Median TLM off showing 20% of site-years changing (compared with 18% for Median Future) and Dry TLM off having 28% of site-years changing (compared with 26% for Dry Future). The addition of extra environmental water increased the stability of the states occurring in the Coorong, with the state inertia increasing from 84% to 90% under Historic climate conditions (comparing Baseline with Historic TLM on scenarios), 82% to 97% under Median climate conditions and slightly from 84% to 87% under Dry climate conditions.

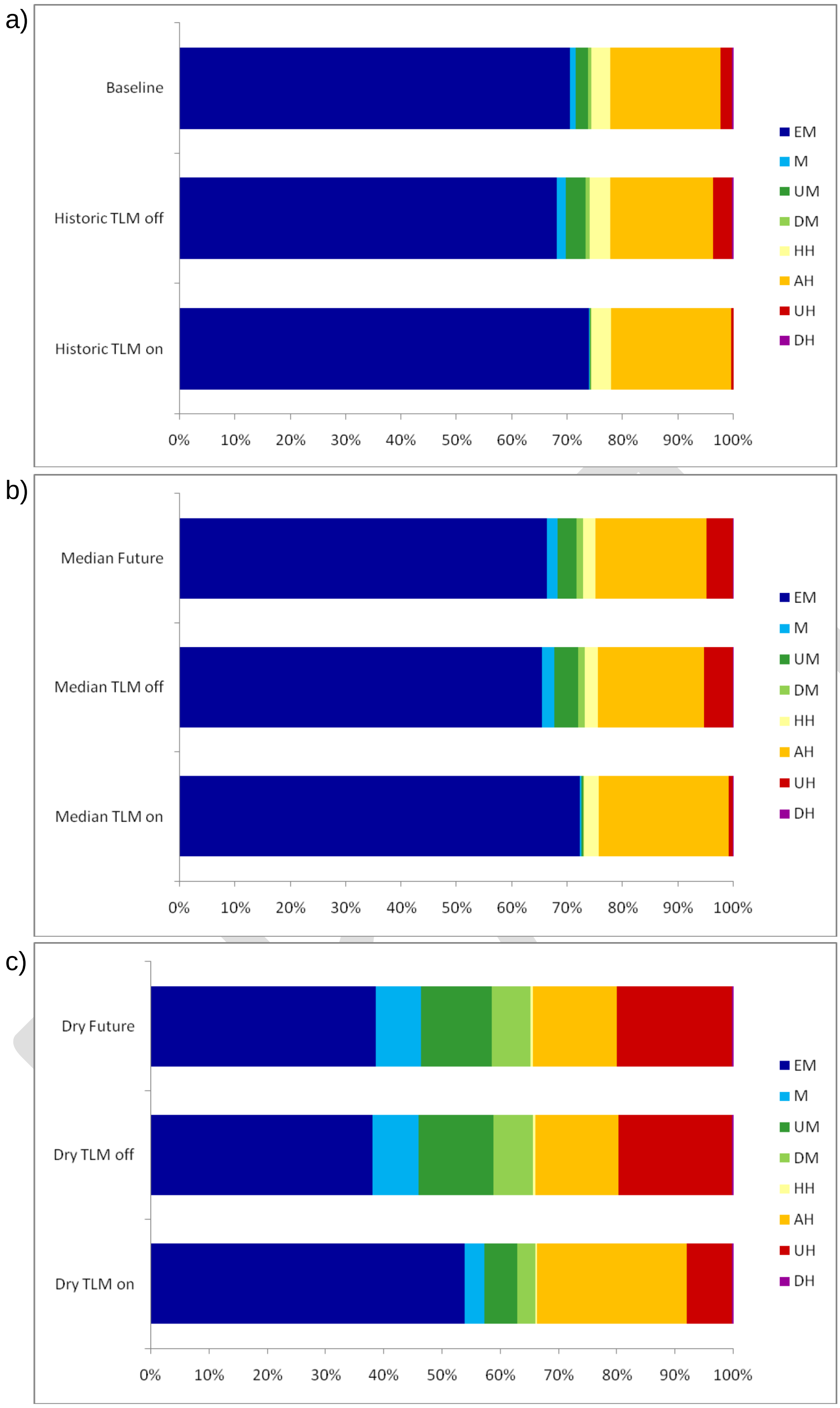



***Figure 5.18. Comparing the proportion of site-years in each ecosystem state for The Living Murray scenarios***

a) Historic scenarios, b) Median Future scenarios, c) Dry Future scenarios

Note: EM = Estuarine/Marine, M = Marine, UM = Unhealthy Marine, DM = Degraded Marine, HH = Healthy Hypersaline, AH = Average Hypersaline, UH = Unhealthy Hypersaline, DM = Degraded Hypersaline

For the Median TLM and Dry TLM scenarios, runs analysis confirmed that the sequence of all sites observed differed from a random sequence. This was also the case for the Baseline and Historic TLM off scenarios, but under the Historic TLM on scenario, many of the North Lagoon sites had sequences of states that were not different from a random assignment of states. This included the sites between Monument Road and Pelican Point as well as the Parnka Point site.

### 5.2.6. Effect of dredging

Because the effect of dredging was intended to be an alternative to flows over the barrages, the alternative ecosystem state model was used to assess its effect on the ecosystem states of the Coorong (Figure 5.19). In order to provide an accurate comparison, the Baseline scenario was also assessed using the alternative model, and this is presented here.

The effect of dredging was most evident for the marine basin states (Figure 5.19). The Baseline scenario (using the alternative model) suggested that 48% of site-years would be in the Estuarine/Marine state and 24% in the Marine state. The proportion in the Marine state dropped with the inclusion of dredging to 17% of site-years, with a corresponding increase of site-years in the Estuarine/Marine state (to 55%).

Over the 112-year model run (fewer years due to lags in the variables required), the effect of dredging had little impact on the level of state inertia within the system with almost the same number of site-years changing states between the two scenarios. This was also the case over the last decade of the model run; however, of those site-year that did change, a higher proportion in the MM Dredging scenario were from healthier states to more-degraded states. While this may seem to suggest that the dredging program at the Murray Mouth resulted in a decline in conditions relative to the Baseline scenario, it is actually a result of a delay in the decline in condition. The Baseline scenario predicted that the marine basin site-years would degrade earlier than the last decade of the model run, thereby masking the effect of the dredging program if the change in the states over the last decade is taken into account.

Over the final 20 years of the model simulation, the Baseline scenario (when assessed using the alternative model) showed a 1% decrease in the proportion of site-years assigned to the Estuarine/Marine state, compared with the whole 112-years run, and there was a corresponding increase in the proportion of site-years allocated to the Unhealthy Marine state. For the MM Dredging scenario, there was a 3% decrease and again, a corresponding increase in the proportion of site-years in the Unhealthy Marine state. Both the Baseline and MM Dredging scenarios had 2% increases in the proportion of site-years in the Healthy Hypersaline and Unhealthy Hypersaline states, compared to the entire model run. The Baseline scenario had a 3% decrease in the proportion of site-years assigned to the Average Hypersaline state, while there was a 4% decrease under the MM Dredging scenario.

Runs analysis confirmed that the sequence of states observed was statistically different from a random assignment of states for sites at either end of the Coorong. Monument Road, Barkers Knoll, Ewe Island, Villa dei Yumpa, Jack Point and Salt Creek were all significantly different from random. Sites in the centre of the Coorong, mostly in the North Lagoon were not able to be distinguished from a random allocation of states. This pattern was also observed for the Baseline scenario when assessed using the alternative model, with the three northern-most and the three southern-most sites having non-random sequences of states over the model run.

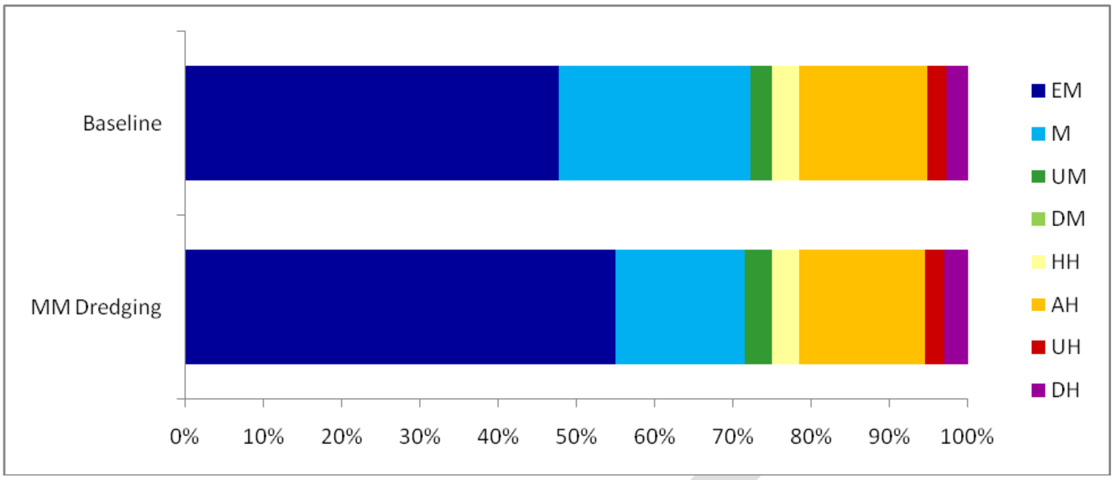



***Figure 5.19. The proportion of site-years in each ecosystem state for the MM Dredging scenario compared with the alternative Baseline scenario***

Note: EM = Estuarine/Marine, M = Marine, UM = Unhealthy Marine, DM = Degraded Marine, HH = Healthy Hypersaline, AH = Average Hypersaline, UH = Unhealthy Hypersaline, DM = Degraded Hypersaline

### 5.2.7. Effect of augmented USED scheme

The effect of the augmented USED scheme was also assessed using the alternative ecosystem state model, and compared with the Baseline scenario investigated using the same model (Figure 5.20). This scenario was only investigated for 1971 to 2006, because this was when data for flows from the USED scheme were available.

The impact that additional flows through Salt Creek from the USED scheme were seen in both the hypersaline and marine basin states (Figure 5.20). In the marine basin, the augmented USED scheme decreased the proportion of site-years classified as Marine compared with the Baseline scenario (assessed with the alternative model) from 25% to 16%. In the hypersaline basin, the proportion of site-years predicted to be in the Average Hypersaline state increased as a result of augmenting the USED scheme from 15% under Baseline conditions to 20% for the Max USED Flows scenario. This was a result of a decrease in the proportion of site-years classified as the Unhealthy Hypersaline and Degraded Hypersaline states, but also a small decrease in the proportion of site-years categorised as the Healthy Hypersaline state.

There was very little change in the proportion of site-years assigned to each state when the last 20 years were compared with the entire 35-years model run. The only differences between the Baseline scenario and the Max USED Flows scenario were that the Baseline showed a 1% decrease in the proportion of site-years in the Degraded Hypersaline state. On the other hand, the Max USED Flows scenario had no change, and the Max USED Flows had a 1% decrease in the proportion of site-years in the Average Hypersaline and Unhealthy Marine states, with a 1% increase in the proportion of Estuarine/Marine site-years, where the Baseline scenario had no change for any of those three states.

The effect of the USED flows was observed throughout the Coorong, although the South Lagoon sites were most commonly affected. The increased flows from the USED scheme appeared to delay the effects of drought conditions in some instances, with changes in ecosystem state occurring several years later than was observed under the Baseline scenario.  There were several instances of changes in the state in the northern states, although, for the most part, these were unchanged. Unfortunately, the effect of augmented USED flows could not be assessed for the most recent decline in condition, as the model run ended in 2006 due to a lack of more-recent data.

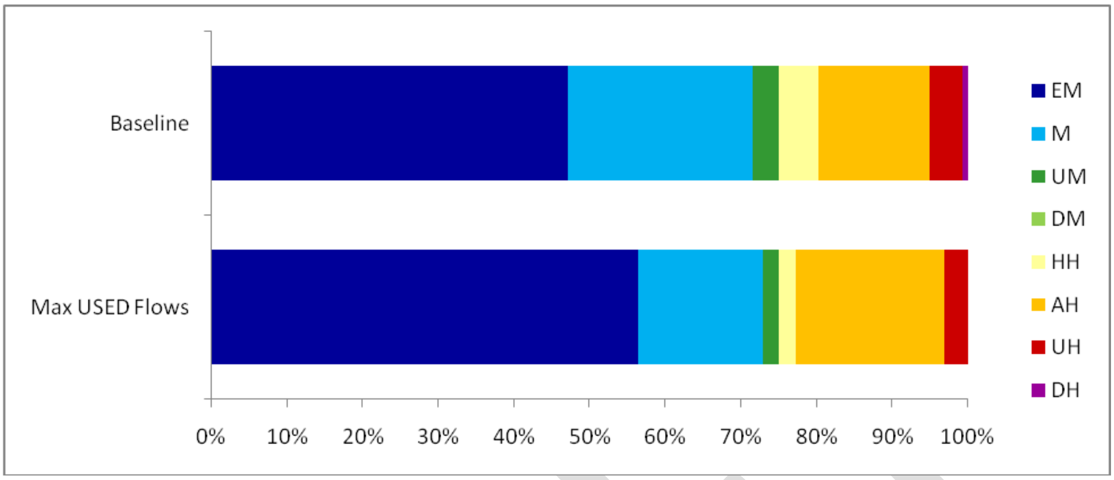



***Figure 5.20. The proportion of site-years in each ecosystem state for the Max USED scenario compared with the alternative Baseline scenario***

Note: EM = Estuarine/Marine, M = Marine, UM = Unhealthy Marine, DM = Degraded Marine, HH = Healthy Hypersaline, AH = Average Hypersaline, UH = Unhealthy Hypersaline, DM = Degraded Hypersaline

Augmenting the USED scheme made very little difference to the state inertia within the system.  Almost the same number of site-years changed from one state to another under the Baseline scenario as for the Max USED Flows scenario.  The properties of the sequences of modelled states for the Max USED Flows scenario differed from those observed for the Baseline conditions.  When assessed using the alternative model, the northern-most and southern-most sites had significant sequences of states over the model run under Baseline conditions.  However, when the Max USED Flows scenario was assessed, the pattern was reversed, with the sites between Mark Point and Parnka Point all having significant sequences, but the South Lagoon sites not being different from random.  The Murray Mouth sites had similar results for the runs analyses between the two scenarios.

# 6. Discussion

The current mix of ecosystem states in the Coorong is unusual when considered against the long-term average under baseline conditions (Baseline scenario). Even assuming that current extraction levels had occurred for the entire 114-year model run, no other droughts (as simulated) result in the same level of degradation amongst ecosystem states. As has been emphasised by the MDB SY project (CSIRO, 2008), the current drought is more extreme than any other predicted for Baseline or for Median or Dry Future scenarios. While we have a significant challenge in ensuring that the Coorong ecosystem is not irreparably damaged in the short term, this is a source of optimism for the long term: that, even under climate change, conditions as bad as the current drought will remain infrequent anomalies.

Comparing the current condition of the Coorong to the conditions expected under natural flows emphasises the effect that current extraction levels are having on the hydrodynamics and ecosystem states of the Coorong. Assuming no extractions or infrastructure within the Basin (Historic Natural scenario) results in a Coorong that remains in healthy ecosystem states for the duration of the model run, including during the current severe drought. The effect of management practices within the Basin have been evident in the Coorong for much longer than the last few years, with as far back as 1999 showing signs of a Coorong lacking freshwater flows (for example see Rogers and Paton (in press). This meant that Coorong ecosystems were already stressed at the onset of the current drought, and have lacked the resilience to cope with the lack of water entering the system over the last three years in particular.

An assessment of the effect of climate change indicates that, in combination with current extraction levels, the impact on the ecosystem states of the Coorong may be disastrous. The hydrodynamics predicted under the Median Future and, in particular, the Dry Future climates are surprisingly bad. Salinities in the South Lagoon under the Dry Future scenario are predicted be well in excess of 300 g $L^{-1}$, and the number of consecutive days without flow may extend to more than 2,500. While this does not include measures such as dredging of the Murray Mouth (given it is intended to be a short-term solution), the effects are startling, and it is unlikely that engineering solutions would be any more effective at maintaining ecological health than they have been during the current. The long periods of drought conditions are predicted to cause extended periods of degraded ecosystem states dominating the Coorong landscape. Also concerning is the rapid switching between healthier and more-degraded states. The increased instability of the ecosystem states within the system may increase the vulnerability of the Coorong to individual species loss and other major changes. This is due to a lack of time between droughts for biota to recover to the point where it has the capacity to survive the next period of unfavourable conditions, with ecosystem recovery after drought known to require considerably more time than recovery after flooding (Lake, 2000). The more often the system fluctuates between favourable and unfavourable, the more likely species loss and invasion by new (possibly introduced) species, for example, are to occur (for example, see Beissinger, 1995).

There is, however, significant scope to minimise the effect of climate change on the Coorong through changes to the level and pattern of extractions within the Murray-Darling Basin. The scenarios modelling future climates under natural flow scenarios illustrate that climate change alone will have a relatively minor effect on the ecosystem states of the Coorong. While we are not suggesting that anything like natural flow conditions can be returned to the system, we believe that this finding alleviates any hopelessness relating to the future condition of the Coorong as being inevitably doomed and so provides the necessary stimulus to find a solution that has better ecological outcomes for the Coorong and other Murray-Darling Basin Icon Sites.

The Living Murray set of scenarios, for example, illustrate that even small increases in the amount of water reaching the Coorong have the potential to have a significant effect on the ecosystem states that are present. Under historic climate conditions, the addition of even an additional 500 GL of water for environmental flows substantially reduces the proportion of site-years that are predicted to be in a degraded ecosystem state. As the effects of climate change are factored in, the efficacy of the allocated 500 GL of water decreases, but the trend is still clear, that relatively small increases in environmental water allocations can have a significant effect, particularly during drier periods within the system. The scenarios investigating the implementation of TLM infrastructure in the system, without the additional water, do offer a cautionary note, however. The simple addition of more infrastructure and additional changes to the water regime did have a negative (but relatively small) impact on the ecosystem states in the Coorong. This suggests that if these initiatives are to be implemented, then it is important to ensure that the environmental water is delivered as intended.

The effect of sea level rise within the Coorong was most obvious on the water levels throughout the system, with flow-on effects to the salinities through increased mixing. Increases in sea level actually appear to mitigate some of the effects of increasing climate change, by increasing the connectivity within the Coorong. This may increase the length of time in which the ecosystem states can be maintained, particularly under low-flow conditions. However, it is important to note that the scenarios investigating sea level rise were only assessing the impact through the existing Murray Mouth. They do not allow for storm surges to breach either peninsula, nor look at over-topping of the barrages. Any breaches in the peninsula would likely affect the ecosystem states of the Coorong, but predicting this effect is difficult with the existing tools.

The impacts of both the Murray Mouth dredging operation and an enhanced USED scheme were minimal on the hydrodynamics of the Coorong, particularly over an extended modelling run. However, both interventions did affect the distribution of ecosystem states in the Coorong. The effect of both was to alleviate some of the worst conditions associated with drought conditions, and prevent the decline of the system to the extent that was observed without the intervention. Dredging of the Murray Mouth had a positive effect at the Murray Mouth sites, but did not have a detectable impact on the ecosystem states further south in the Coorong. The augmented USED flows affected the ecosystem states of sites along the length of the Coorong, most commonly in the South Lagoon. Changes in state also appeared to be off-set by some years, suggesting that the effect of drought may be delayed by increased flows through Salt Creek. Both options are considered worthy of additional scrutiny as short-term strategies for use during extended low-flow conditions, particularly the augmented USED scheme, if flows in the order of those assessed here are, in fact, possible.

In addition to the Murray Mouth dredging and the enhanced USED scheme, the model has also been used to investigate a range of options for lowering the salinity in the South Lagoon. These included management options such as further dredging of the Murray Mouth, channel works at Parnka channel and pumping of saline water in and out of the South Lagoon. It was evident from these scenarios, as well as the ones presented here, that these small engineering options have limited impact on the ecosystem states of the Coorong. While they have the capacity to slow the decline in ecosystem state in the short-term, none of the options were a passable substitute for even moderate flows over the barrages. Of all the management options investigated, here and elsewhere, The Living Murray initiative, including the additional environmental water, showed the mix of ecosystem states most similar to those occurring at the time of Ramsar listing. Of the engineering options, the Max USED Flows scenario was the most similar to the Ramsar benchmark, although there was still a large discrepancy in the overall mix of states. It is notable that both these options involve additional freshwater inputs to the Coorong. In the long-term, securing sufficient freshwater for the Coorong must be the priority to ensure a functional Coorong resembling the Ramsar benchmark.

There are a number of limitations associated with the current modelling and thus areas of uncertainty that should be taken into consideration. A major limitation is that the dataset upon which the ecosystem state model was constructed was limited to a period of ecological decline within the Coorong. While the hydrodynamic model was able to be assessed relative to high flow conditions, insufficient data were available to undertake a similarly-rigorous assessment of the ecosystem state model (but see Lester & Fairweather, 2009). As such, the model is much more reliable in predicting the decline of the system than any recovery of ecological condition. For example, we know very little about the time lags associated with any ecological recovery (e.g. for colonisation of *Ruppia tuberosa* to the South Lagoon), or even whether the system will follow the same trajectory as occurred during the decline. As such, our predictions of the recovery of the Coorong are preliminary, and more data are needed to verify the predictions to gauge any time lags and to adjust the model accordingly. Additional data to test predictions relating to further decline would also increase our confidence regarding the overall predictive capacity of the model, especially for the less-common ecosystem states.

A second and related limitation is that there is likely to be additional ecosystem states that exist within the Coorong under healthier conditions. Many of the scenarios (especially those assessing natural flows) show large tracts of the Coorong existing in the Estuarine/Marine state for the majority of the model run. It is unlikely that the Coorong would be homogenous in this way, and this is also likely to be an effect of the degraded conditions represented by the original calibration dataset. When interpreting those scenarios, it may be more useful to think of the Estuarine/Marine state as a catch-all for a set of states describing truly estuarine, as well as healthy, marine states that we currently do not have the data to adequately capture. As such, the Estuarine/Marine state may be a minimal healthy condition to aim for within the system, rather than be seen as representing a loss of diversity in the system.

Additional data are also needed to resolve differences in the predictions of baseline condition under the alternative model. This would enable us to better assess the effect of interventions that do not involve additional water over the barrages. As for the recovery pathways, verification of the model predictions against observed changes in ecosystem state is needed. Thus, monitoring that can be tailored to detect any changes that are predicted from our modelling is strongly recommended in the coming years.

The need for additional refinement of the models emphasises the need for ongoing monitoring and research within the region. While ecosystem states represent a large change in the manner by which such a diverse ecosystem can be assessed and managed, it is important to continue to refine this assessment, and not assume that the first attempt is able to capture all situations with equal accuracy. We have confidence that the model is able to capture the trends inherent within the system, but further improvement is still possible and desirable, particularly in the areas identified (i.e. recovery and alternative interventions). The ecosystem state technique, however, has significant promise for use in managing large-scale ecological systems, and the concept should be applied to other regions or ecosystems to test its utility more broadly (Lester and Fairweather, in press).

The approach of defining ecosystem states, used here for the scenario analyses, also has significant implications for the management of other estuaries, or indeed, other ecosystem types such as floodplain wetlands. The ecosystem state models have the advantage of greatly simplifying the task of defining ecosystem condition and has the potential to revolutionise the setting of management targets. This approach allows management of a system at an ecosystem scale – aiming for a mix of appropriate ecosystem states, rather than using surrogate variables or indicator species that are often arbitrarily chosen or defined and may lack adequate testing. Our ecosystem states are combinations determined by the data in hand rather than any preconceptions of co-occurring focal variables. By then managing explicitly for a set of states, there is significantly more flexibility in the definitions of acceptable change, allowing for redundancy in an ecosystem (i.e. where multiple species could perform the same function) to be recognised and acknowledged in the management strategy. A deliberately multivariate approach also discourages the temptation to search for a ‘magic bullet’ solution to ecological problems by recognising the interconnectedness of environmental and biotic conditions and the complexity of ecosystems as a whole (Lester and Fairweather, in prep.). Finally, the approach is also flexible enough to provide the basis for simple indices indicating overall condition and likely future condition, as well as the more detailed scenario analyses that are presented here.

# 7. Management implications and Conclusions

The management implications of this work are as follows:

- Current conditions, including the management of the Murray-Darling Basin, are having a significant detrimental effect on both the hydrodynamics and the ecosystem states of the Coorong.
- Climate change, when combined with current extraction levels in the Basin, has the potential to be devastating to the ecosystem states of the Coorong.
- Relatively small changes, such as via the TLM initiative and other increases in freshwater flows to the Coorong, have the potential to have a substantial impact on the health of the Coorong ecology, and are predicted to mitigate the worst effects of dry periods such as the current drought.
- As climate change progresses, however, more water than has been allocated so far will be required to prevent a return to current conditions under any similar dry spell.
- While initiatives such as TLM are critical to the ecological health of the Coorong, follow-through is important, because installing the infrastructure without sourcing the additional water actually has a detrimental effect on the ecosystem states of the Coorong. Thus delivery of environmental flows is paramount.
- Sea level rise, assuming that the peninsula is not breached, may alleviate some of the effects of climate change, by increasing the connectivity within the system, raising water levels and decreasing salinities. This increase in connectivity slows the deterioration of ecosystem states, particularly in the South Lagoon.
- Both the Murray Mouth dredging program and the augmented USED scheme have the capacity to influence the ecosystem states of the Coorong under drought conditions, preventing the degree of degradation that would otherwise occur. As such, both are worthy of further investigations, but both (in particular the dredging) are limited in their capacity to affect the system as a whole.
- Small interventions (and engineering interventions) were able to influence the ecosystem states of the Coorong, and slow the decline of ecological condition in many instances. None of the interventions explored, however, approached the effects of even moderate flows over the barrages and securing adequate freshwater for the system is the only long-term solution likely to result in a functional Coorong that resembles the 1985 benchmark.
- The ecosystem state model used here has the potential to greatly simplify the task of defining and assessing ecosystem condition, and in identifying management targets to maintain that condition. The variables identified, and

the thresholds for each, can be used as the key variables for management and monitoring, with the ranges between ecosystem states setting the limits of acceptable change. This will be a significant improvement in many ecosystems where management targets have been necessarily set by expert opinion in the past.

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# 9. Appendices

## Appendix A - Calibration and accuracy of the hydrodynamic model

Calibration of the model required the specification of four parameters. The first parameter is a factor applied to the wind stress estimated from wind measurements made at Meningie on the southeastern side of Lake Albert. This factor was adjusted so that the modelled water level spectra at Tauwitchere and at Sand Spit Point matched the measured spectra. The optimal factor is 1.6. Wind measurements at the Post Office in Meningie were made twice a day so the value of the factor (above 1.0) is due to a number of reasons including the inability of the wind record to account for gustiness and the separation and terrain differences between Meningie and the Coorong. The second parameter is an evaporation correction factor applied to measured evaporation rates from a Class A pan on Hindmarsh Island. The factor used in modelling has a value of 1.0. The third parameter is the horizontal coefficient of mixing for the two lagoons (61 $m^2$ $s^{-1}$) and the fourth is the effective elevation of the bed of the Parnka channel (-0.19 m AHD). Parameters 2, 3, and 4 were adjusted to obtain the optimal fit in a least-squares sense between measured and modelled salinities in the North and South Lagoons and between measured and modelled water levels at Sand Spit Point in the South Lagoon. The calibration data used for salinity were obtained at 12 sites along both lagoons on 35 occasions by the SA EPA and DEH between 1997 and 2005. The calibration parameters all differ to some extent from the parameters reported by Webster (2006) in an earlier calibration of the model. These differences are due to several factors including a difference in how the effect of wind stress is represented in the model, the addition of two more years of calibration measurements, and differences in the assumed value of the salinities of the sea and of the USED. Overall, the amount of calibration required of the hydrodynamic model is minimal.

All models are imperfect representations of reality. It is necessary to know how credible are hydrodynamic model simulations and particularly how well they are able to represent variation in the system in response to changes in the drivers. In addition to the salinity data used for calibration, there have been additional data obtained by various researchers for the periods 1963-1967, 1976-1979, 1981-1985, 1993, and 2005-2007 that can be used to check the model response to conditions that are quite different from those encountered during the calibration period. In particular, barrage flows prior to 2002 tended to be substantially larger than those after this time.

When modelled and measured salinity values are plotted against one another for sections of each lagoon, the slope of the linear regression is ~0.9 for both the calibration and non-calibration periods. Average modelled salinity and measured salinity differ from one another by an average of 2 g $L^{-1}$ in the North Lagoon and by less than 1 g $L^{-1}$ in the South Lagoon. There is scatter around these regressions, which represents the limitation of the model's ability to simulate the instantaneous salinity at a particular sample collection site. The root mean square (RMS) differences between modelled and measured salinity are 16 and 11 g $L^{-1}$ in the North and South Lagoons, respectively. We have attributed much of this scatter to the incongruity of comparing salinities in cells that are effectively averaged along 5-10 km along the Coorong and across its width of several kilometres with spot measurements that are mostly obtained at the shore. There are certain to be heterogeneities in the salinity structure that are introduced by local evaporation or water input or by swirls in the current that are not resolved by the model. Other errors in the model are certain to be introduced through inaccuracies in prescribing the wind stress, barrage inflows, bathymetry, evaporation rates, and by the neglect of groundwater inputs and losses that are unknown.  Structural simplifications in the model will lead to further error including the simplified bathymetry and the assumption of constant mixing coefficients.

The model does well in simulating both the weather-band response in water level (less than a 10-day period) and the longer-term seasonal fluctuations in both lagoons.  Due to limitations in the form of the meteorological data available, the response of the system to wind fluctuations having periods less than a day is not represented in the model, but for longer periods the measured and modelled level variances differ by 10% or less.  Overall, the model does a credible job of simulating the response of the system in both salinity and in water level.  The model is capable of explaining ~90% of salinity changes in the system in a statistically-averaged sense, but it should be recognised that an individual modelled salinity value is expected to differ from a measurement due to a number of reasons, but that the bias of the modelled salinity is close to zero.

For further information, see Webster (2006).

# Appendix B - Description of the ecosystem states of the Coorong

The ERM model for the Coorong identified eight distinct ecosystem states.  The states are presented as a logic tree (Figure 3.1).

The northern basin consisted of four states, including those named estuarine/marine, marine, unhealthy marine and degraded marine.  These states had greater tidal ranges than those four of the southern basin: healthy, average, unhealthy and degraded hypersaline.  The biological and environmental characteristics of each state are shown in Table B.1.

While the ecosystem state model performs well in describing the ecosystem states that have occurred in the nine years for which we had sufficient data, we acknowledge that other states are likely to (at least potentially) exist that are not adequately represented within this time frame.  One that we have identified as likely to occur is an estuarine state, potentially requiring significant, ongoing freshwater inputs, such as have not occurred during the previous decade.  Another is a state even less speciose than the degraded hypersaline state in the southern basin, or than the degraded marine state in the northern basin.  The existence of both of these states is hinted at in anecdotal accounts of the system, either from the general public or researchers who have worked in the system for many years, and from the trends in data collected during 2008 after the development of these models, particularly in the South Lagoon.  The possible existence of other states that fall outside the bounds of the data set is important to keep in mind when interpreting these results with a view to further management of the system.

| Variable | Estuarine/ Marine | Marine states: Marine | Marine states: Unhealthy Marine | Marine states: Degraded Marine[a] | Hypersaline states: Healthy Hypersaline | Hypersaline states: Average Hypersaline | Hypersaline states: Unhealthy Hypersaline | Hypersaline states: Degraded Hypersaline |
|---|---|---|---|---|---|---|---|---|
| **Biological characteristics** | | | | | | | | |
| Fishing birds | High | Moderate | High | High | Very low | Low | Moderate | Very low |
| Shorebirds | Low | Very low | Low | Moderate | Moderate | Very high | Very high | High |
| Waterfowl | High | Moderate | Moderate | Moderate | Very high | Very high | Moderate | Very low |
| Estuarine fish | High | Very high | High | Low | Very low | Very low | Very low | Very low |
| Marine fish | High | Very high | Very high | Very low | Very low | Low | Moderate | Low |
| Benthic invertebrates | Very high | Moderate | High | Low | NA | Low | Very low | Very low |
| *Ruppia tuberosa*[b] | Very low | Very low | Low | NA | NA | Very high | High | NA |
| **Environmental characteristics** | | | | | | | | |
| Days since flow | Low | High | High | High | High | Low | High | High |
| Flow volume | Moderate | Very low | Very low | Very low | Very low | Moderate | Very low | Very low |
| Salinity | Low | Very low | Moderate | Moderate | High | High | Very high | Very high |
| Tidal influence | High | High | High | High | Very low | Very low | Very low | Very low |
| [TKN] | Low | Very low | Very low | NA | Very high | High | High | High |
| [TP] | Low | Very low | Very low | NA | Moderate | High | High | Very high |
| Turbidity | Low | Very low | Low | NA | Very high | Moderate | High | Moderate |

***Table B.1. Relative biological and environmental characteristics of observed ecosystem states***

Terms within the table are internally standardised from very low to very high. [a] Caution should be used in interpreting these results, as only one case for the degraded marine state exists in each of the long-term (1999-2007) and short-term analyses (2005-2007). [b] *Ruppia tuberosa* was only present in the long-term analyses because it was only monitored annually. NA indicates that no data was available for that state for the specified parameters. [TKN] represents concentration of total Kjeldahl nitrogen and [TP] represents concentration of total phosphate.

# Appendix C – How to read output presented

This appendix provides an introduction to each of the figures that have been presented in this report, and a summary of how to read each. They are presented in the order in which they appear in the report.

## C.1 Boxplots

Boxplot figures were presented for each set of scenarios to represent the hydrodynamic model output for the variables that drive ecosystem states in the Coorong.

In a boxplot, the interquartile range is represented by a box (Figure C.1). That is, the limits of the box show the range for which the variable in question falls for 50% of the time. The whiskers on the box show an interval which is 1.5 times the interquartile range, and more extreme values (outliers) are represented by points. Finally, the median is represented by a line through the box at the relevant height.

Boxplots are presented that compare each group of scenarios, in line with the research questions. Boxplots for individual scenarios are given in Langley *et al.*, 2009).

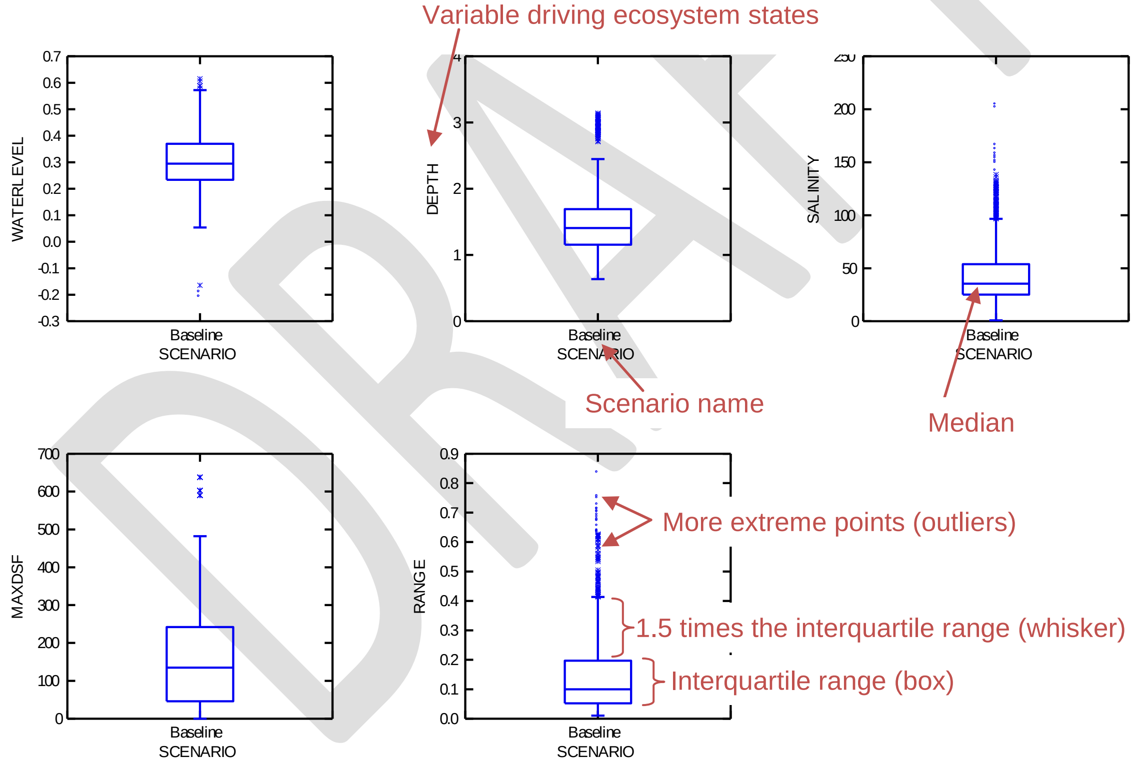



***Figure C.1. Example of boxplots from the Baseline scenario, highlighting points to note in red***

a) Water levels (m AHD), b) water depths from the previous year (m), c) salinities (g $L^{-1}$), d) maximum number of days since flow (MaxDSF, days) and e) tidal range (m)

## C.2 Deviations from Baseline scenario

The second output displaying the hydrodynamic results of the various scenarios compares the deviances of values for key variables from the values obtained in the Baseline scenario (Figure

C.2). This was divided into two panels, one for the two key variables in the hypersaline basin (i.e. maximum days without flow and water level), and one for two key variables in the marine basin of the model (i.e. maximum number of days without flow and salinity). The marine basin also had a third driving variable (i.e. water depth from the previous year) but this threshold was only relevant for a few site-years, and so, in the interests of two-dimensional display, was omitted from this analysis.

In this figure, the vertical and horizontal lines represent the values of each variable seen in the Baseline scenario. That is, scenarios that fall on the lines had a zero sum deviation compared with the Baseline for that variable, and were not different. The first panel plots the sum of deviations for water levels and the number of days without flow for site-years falling below the tidal threshold (Figure C.2a). Here, an increase in water level and a decrease in the number of days without flow could be considered an improvement, compared with the Baseline. Thus, scenarios falling in the top-left quadrant represent an improvement on both variables. Scenarios falling in the opposite quadrant (the bottom-right) represent a deterioration relative to both variables. The other two quadrants are an improvement for one variable, but not the other.

The second panel plots the sum of deviations for salinity and the number of days without flow (Figure C.2b). Here, site-years above the tidal range threshold are included. As for the first panel, scenarios falling on the horizontal and vertical lines indicate no deviation from the Baseline for the variable in question. In this case, a decrease in both salinity and number of days without flow constitutes an improvement. This corresponds to the bottom-left quadrant. Scenarios falling in the opposite quadrant (i.e. the top-right) showed a deterioration with respect to both variables.

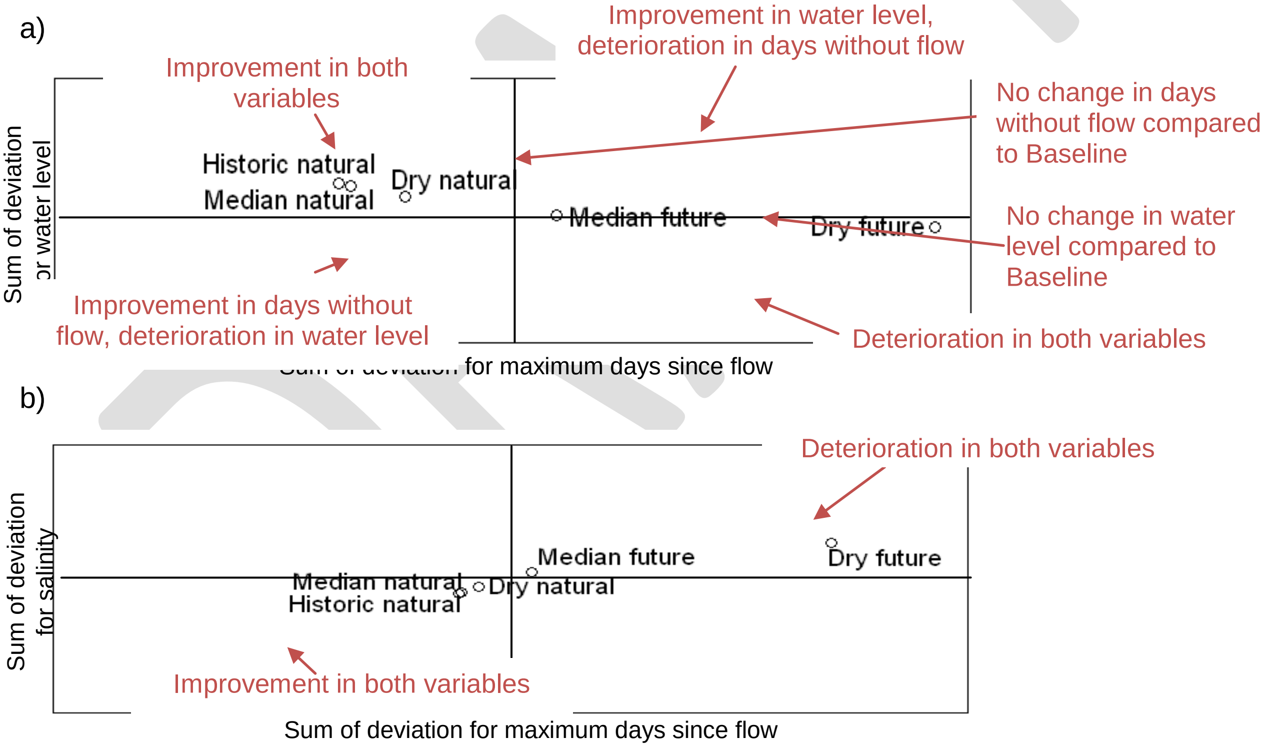



***Figure C.2. Example of comparison of scenarios to the Baseline scenario for key variables, highlighting points to note in red***

a) Site-years below the tidal range threshold, compared to the Baseline scenario with respect to water level and the maximum number of days without flow. The top-left quadrant represents an improvement in both.

b) Site-years above the tidal range threshold, compared to the Baseline scenario with respect to salinity and the maximum number of days without flow.

## C.3 Distribution of ecosystem states in space and time

The distribution of ecosystem states for each site in each year is presented in Figure C.3. Sites are numbered from north to south, with the Monument Road site near Goolwa as Site 1 through to Salt Creek as Site 12 (see Figure 1.1). All 114 years of a simulation run are shown from left to right. Each site-year is represented by a circle, the colour of which indicates the relevant ecosystem state. A key outlining the colour-coding for each of the eight ecosystem states is given below the figure.

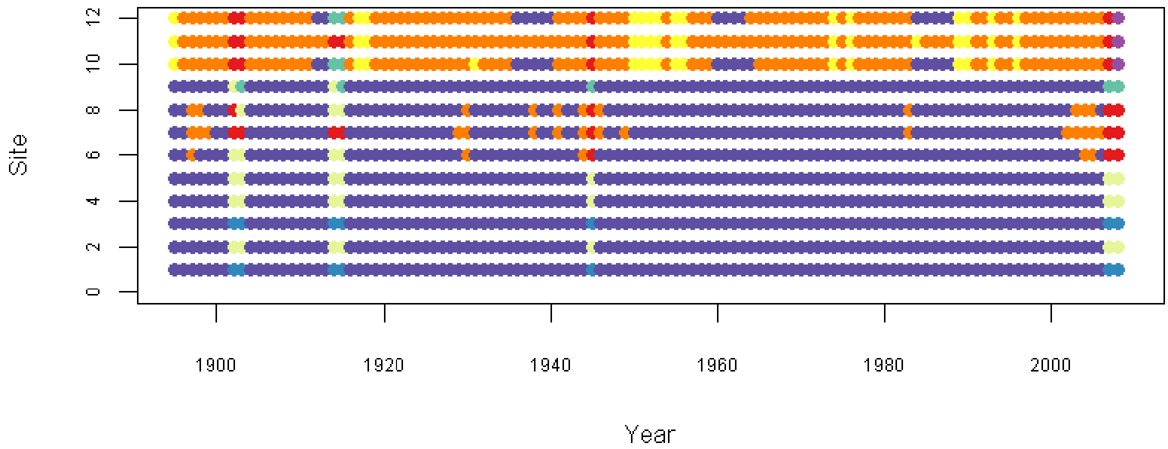



***Figure C.3. Example of distribution of states for each site-year under the Baseline scenario***

Each bar shows the distribution of the states within each site across the 114-year model run. Sites are numbered from north to south (e.g. Monument Road = Site 1 and Salt Creek = Site 12). The changes in the bar colours represent the transitions between states. For each bar, colours represent the following states: dark blue = Estuarine/Marine, light blue = Marine, light green = Unhealthy Marine, dark green = Degraded Marine, yellow = Healthy Hypersaline, orange =Average Hypersaline, red = Unhealthy Hypersaline and purple = Degraded Hypersaline.

## C.4 Proportion of site-years in each ecosystem state with threshold exceedances

The next figure, read from the top, shows a cumulative break-down of the proportion of site-years that exceed each threshold, until the bottom bar shows the proportion of site-years seen in each ecosystem state (Figure C.4). The figure is based on the ecosystem state decision tree (Figure 3.1) and each of the thresholds in the tree is represented. The first splitting variable, the average daily tidal range, is the first (top) bar in the figure. The proportion of site-years that fall below the threshold are shown on the left-hand side of the bar (dark green), and those that exceed the threshold are on the right (dark orange). The second bar builds on the first, using the next splitting variable in the decision tree; the maximum number of days without flow. This time, the bar is split into four, with the left-hand-most segment showing the proportion of site-years below both the days without flow and the tidal range threshold (shown in aqua). The next segment (shown in blue), indicates the proportion of site-years below the threshold for tidal range, but above the threshold for days without flow, thus these first two together add to the same proportion as the dark green bar above (i.e. below the tidal range threshold). This continues along the bar, with the pink segment representing the proportion of site-years above the tidal range threshold but below the days without flow threshold, and the yellow bar showing those site-years above both thresholds.

For the remaining splitting variables, the threshold is only relevant to a subset of the decision tree. For example, the depth threshold is only relevant to site-years that fell below both the tidal range and the days without flow thresholds. The solid colours indicate the subset of the site-years for which each threshold is relevant, with the remainder shown as unfilled outlines. Each bar builds on the divisions in the previous bars.

The final (bottom) bar shows the proportion of site-years in each ecosystem state, after dividing the total according to each splitting variable in the decision tree. Each colour represents one ecosystem state, according to the key given below the figure. This final bar corresponds to the proportion of site-years in each ecosystem state given in the next figure explained below (Section C.5).

In the body of this report, this figure is presented only for the Baseline scenario. Figures for the remaining 19 scenarios can be found in Appendix D.

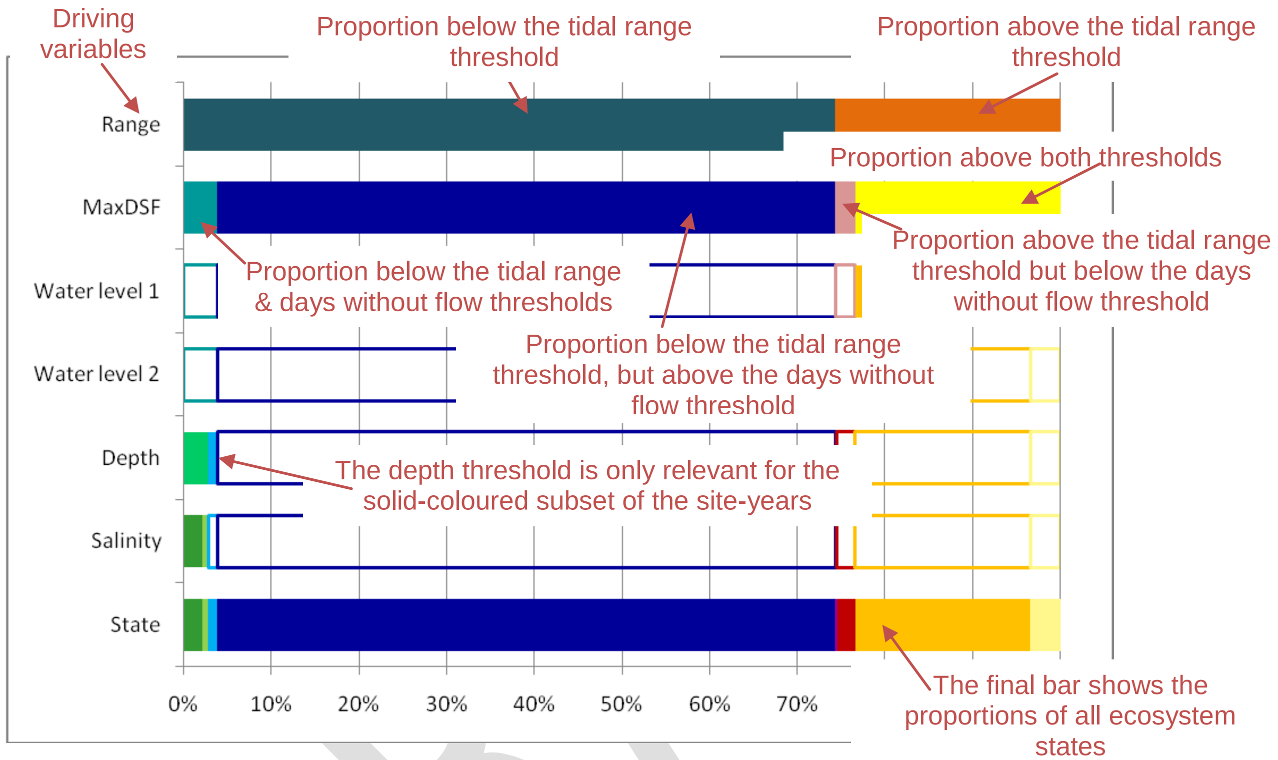



***Figure C.4. Example of proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Baseline scenario, highlighting points to note in red***

Each of the upper six bars shows one threshold for a variable driving ecosystem states in the Coorong. The two solid blocks represent the proportion of site-years that fall below (on the left) and above (on the right) the threshold. Going from top to bottom, each bar builds on the previous until the bottom bar illustrates the distribution of ecosystem states for this scenario. The final bar shows the states with dark green representing the Degraded Marine state, light green is Unhealthy Marine, light blue is Marine, dark blue is Estuarine/Marine, purple is Degraded Hypersaline, red is Unhealthy Hypersaline, orange is Average Hypersaline and yellow is Healthy Hypersaline.

## C.5 Comparison of the proportion of site-years in each ecosystem state among scenarios

The next figure compares the proportion of site-years in each of the ecosystem states amongst groups of scenarios (Figure C.5). This figure shows the same distribution of ecosystem states as the final bar of the previous figure (Figure C.4) for the Baseline scenario, and compares it with the equivalent bar for other scenarios, in combinations according to the research questions. The colour-coding is maintained between the two figures (although the states are in a different, standardised order). Here a legend with abbreviated ecosystem state names is also given, with a key below the figure explaining each of the abbreviations.

This figure gives the total proportion of site-years that were found in each ecosystem state, across the entirety of the model run (usually 114 years). Note that not all states are seen in every scenario. Also the number of colours is not an indicator of 'diversity' because the less-common colours represent degraded states (not necessarily a good thing).

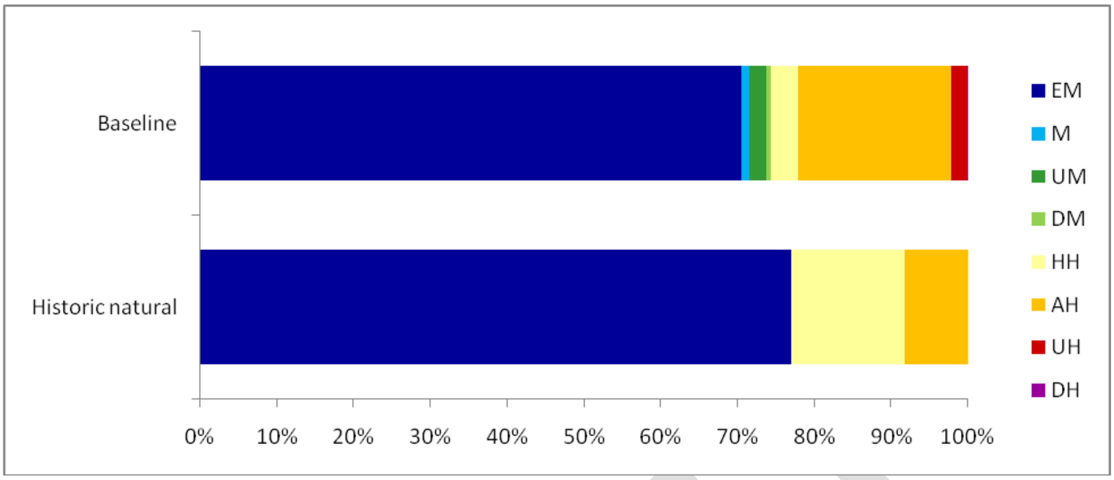



***Figure C.5. Example of comparing the proportion of site-years in each ecosystem state for the Baseline versus the Historic Natural scenarios***

Note: EM = Estuarine/Marine, M = Marine, UM = Unhealthy Marine, DM = Degraded Marine, HH = Healthy Hypersaline, AH = Average Hypersaline, UH = Unhealthy Hypersaline, DM = Degraded Hypersaline

## C.6 Tables presented in Appendix D

Appendix D presents a one-page summary of each of the twenty scenarios. This includes figures such as those described within this appendix, but also several tables summarising other output for each scenario.

The first table summarises the details of each scenario (Table C.1). It gives a list of the various interventions and climates that varied between scenarios and presents the options that was used for the relevant scenario.

Interventions and climates investigated by the scenario analyses

| | |
|---|---|
| Climate | Historic |
| Extraction levels | Current |
| Flow over the barrages | Actual |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | None |
| TLM environmental water | None |

Options included in the relevant scenario

Where an intervention is excluded from a scenario, 'None' is reported

***Table C.1 Example of scenario details for the Baseline scenario***

The second table summarises the hydrodynamic properties of the scenario that are not given by the boxplots (Table C.2). It included the proportion of site-years for which mean salinities are equal to, or over 100 g $L^{-1}$ (although for the MM Dredging and Max USED Flows scenarios, this is the proportion of site-years for which maximum salinity is equal to, or over 100 g $L^{-1}$). The 100 g L-1 threshold is considered by expert opinion to be important for many of the key taxa in the region. The remainder of the table summarises the Gini coefficients for each of the variables from the ecosystem state model (Figure 3.1). The Gini coefficients describe how even the distribution for that variable is, with 0 being perfectly evenly distributed and 1 being completely unevenly distributed.

| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | 6% |
| **Gini coefficients** | |
| Tidal range | 0.16 |
| MaxDSF | 0.46 |
| Water level | 0.07 |
| Water depth | 0.04 |
| Salinity | 0.21 |

***Table C.2 Example of hydrodynamic details for the Baseline scenario***

The next table gives details regarding the frequency of transition between states under each scenario (Table C.3). The overall proportion of transitions gives the proportion of site-years over the entire model run (usually 114 years) for which site-years changed state from the previous year. Of these transitions, three types were possible. Firstly, site-years could change from a state in one basin to the other (e.g. change from a marine-basin state to one in the hypersaline basin or vice versa). Secondly, site-years could change within a basin from one state to another considered to be more degraded than the original state. Finally, site-years could change within a basin from one state to another considered to be less degraded. These three proportions are given in the second to fourth rows of the table, and sum to the overall proportion of transitions between states.

| **Transitions between states** | |
|---|---|
| Overall | 0.14 |
| Between basins | 0.04 |
| More degraded | 0.06 |
| Less degraded | 0.04 |

***Table C.3 Example of frequency of transitions between states for the Baseline scenario***

The final table on the summary sheet provides other characteristics regarding the distribution of states for each scenario (Table C.4). The state richness gives the number of states present in at least one site-year within the scenario (out of a possible 8). The next two rows divide the site-years into those falling within the marine basin and those falling within the hypersaline basin. The final two rows divide the site-years into states considered to be healthy and those considered to be degraded. The definition of a degraded state is any where there has been no flow over the barrages in 339 days (i.e. Marine, Unhealthy Marine, Degraded Marine, Unhealthy Hypersaline and Degraded Hypersaline).

| **State characteristics** | |
|---|---|
| State richness | 8 of 8 present |
| % within marine basin | 0.74 |
| % within hypersaline basin | 0.26 |
| % healthy | 0.94 |
| % degraded | 0.06 |

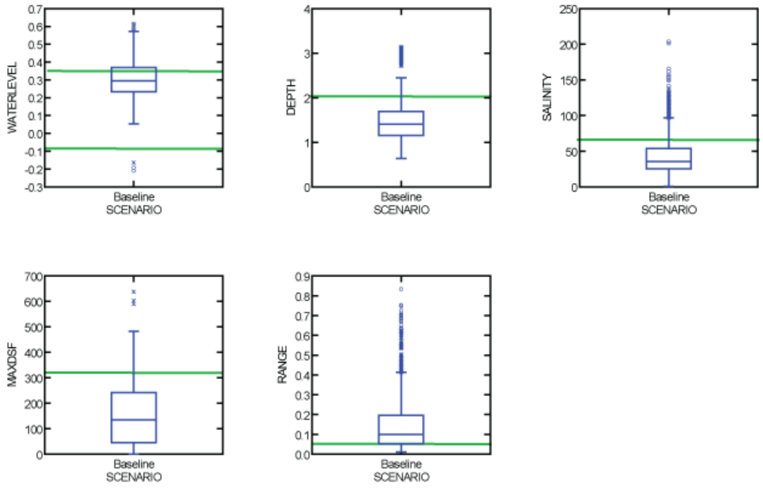
***Table C.4 Example of state characteristics for the Baseline scenario***

# Appendix D - Summary of each scenario

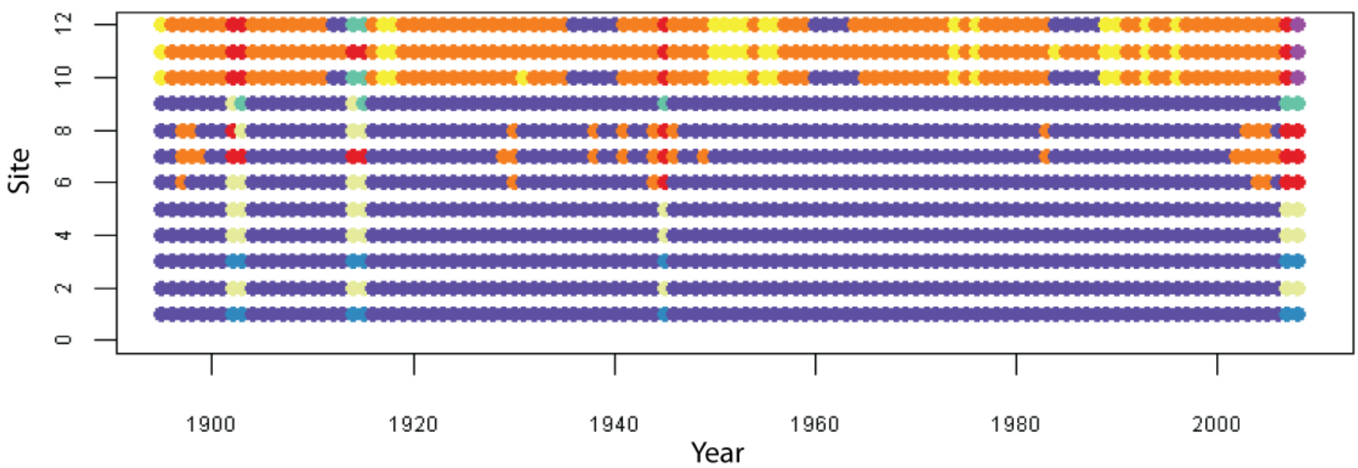
## D.1 Baseline (Scenario 1)

| | |
|---|---|
| Climate | Historic |
| Extraction levels | Current |
| Flow over the barrages | Actual |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | None |
| TLM environmental water | None |

| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | 6.00 |
| **Gini coefficients** | |
| Tidal range | 0.16 |
| MaxDSF | 0.46 |
| Water level | 0.07 |
| Water depth | 0.04 |
| Salinity | 0.21 |



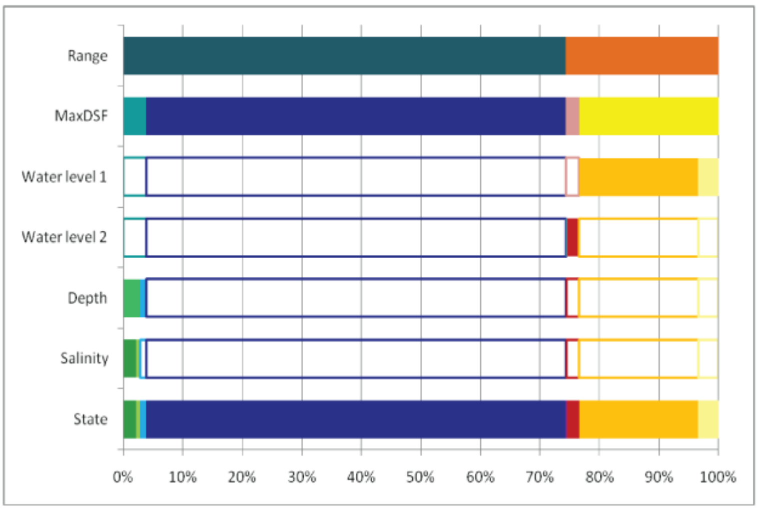

Note: Green lines indicate thresholds




Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 8 of 8 |
| % within marine basin | 0.74 |
| % within hypersaline basin | 0.26 |
| % healthy | 0.94 |
| % degraded | 0.06 |

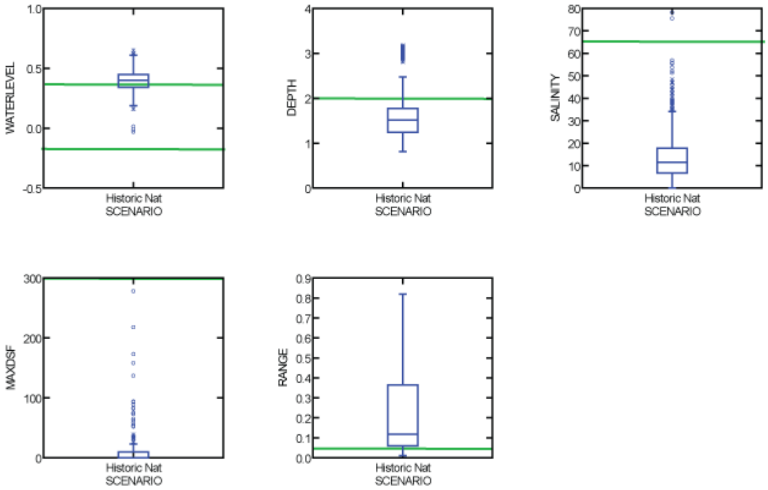
| | |
|---|---|
| **Transitions between states** | |
| Overall | 0.14 |
| Between basins | 0.04 |
| More degraded | 0.06 |
| Less degraded | 0.04 |



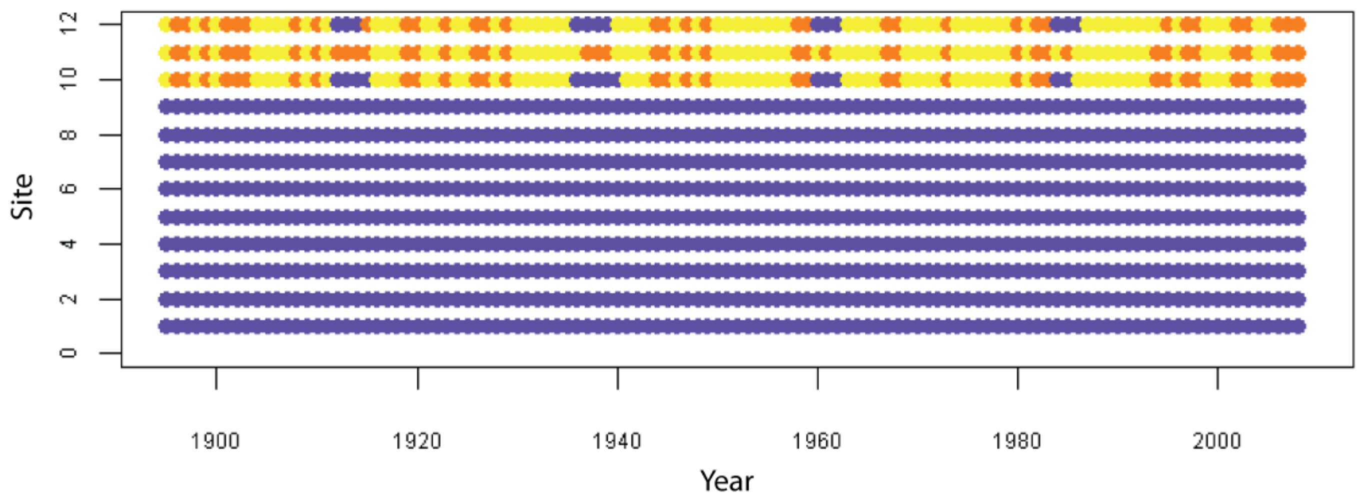
## D.2 Historic Natural (Scenario 2)

| | |
|---|---|
| Climate | Historic |
| Extraction levels | Current |
| Flow over the barrages | Actual |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | None |
| TLM environmental water | None |

| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | None |
| **Gini coefficients** | |
| Tidal range | 0.08 |
| MaxDSF | 0.84 |
| Water level | 0.10 |
| Water depth | 0.03 |
| Salinity | 0.30 |

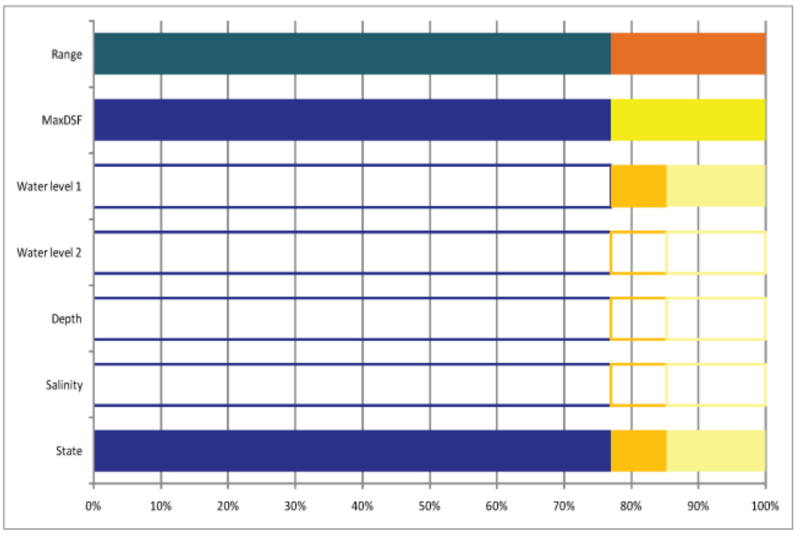



Note: Green lines indicate thresholds, MAXDSF threshold exceeded range of plot



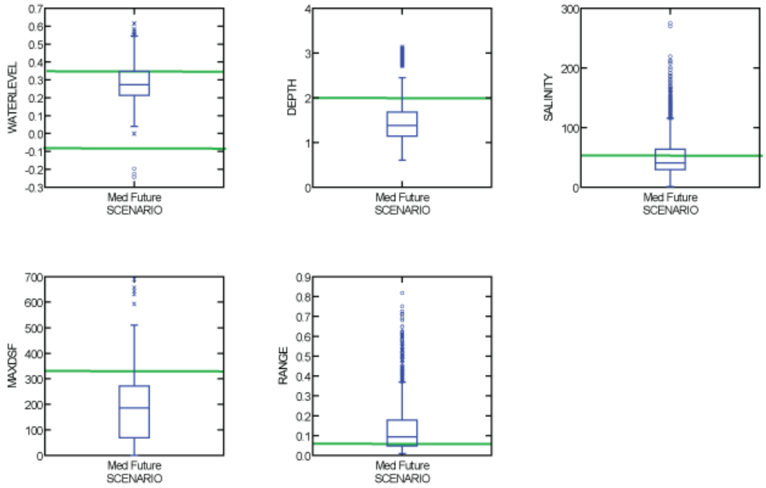

Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 3 of 8 present |
| % within marine basin | 0.77 |
| % within hypersaline basin | 0.23 |
| % healthy | 1.00 |
| % degraded | 0.00 |
| **Transitions between states** | |
| Overall | 0.11 |
| Between basins | 0.01 |
| More degraded | 0.05 |
| Less degraded | 0.04 |

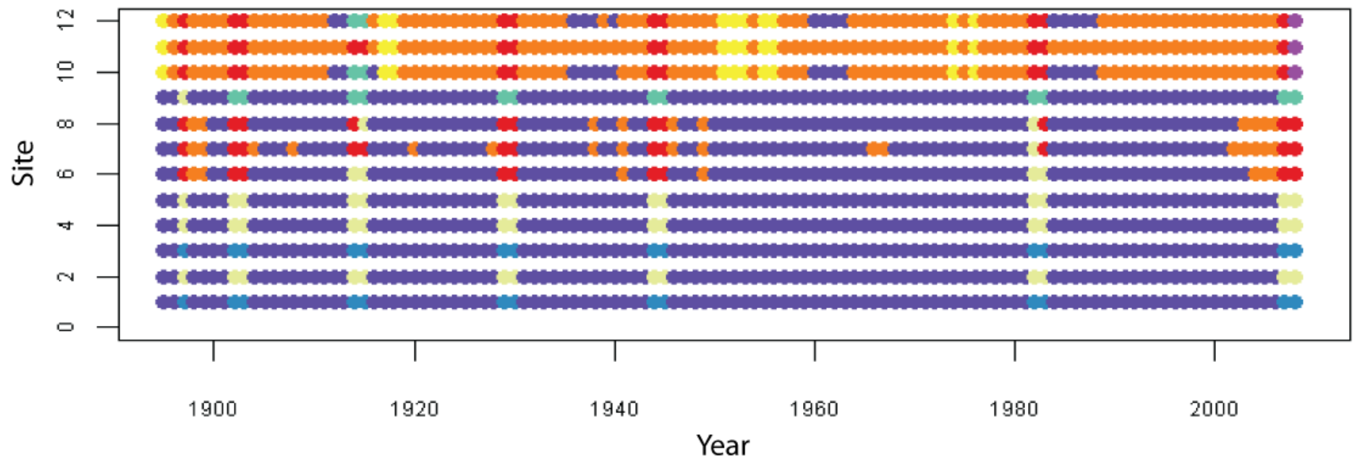


## D.3 Median Future (Scenario 3)

| | |
|---|---|
| Climate | Median (MDB SY B) |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | None |
| TLM environmental water | None |
| % salinity data over 100 g $L^{-1}$ | 13.0 |
| **Gini coefficients** | |
| Tidal range | 0.18 |
| MaxDSF | 0.43 |
| Water level | 0.19 |
| Water depth | 0.03 |
| Salinity | 0.20 |

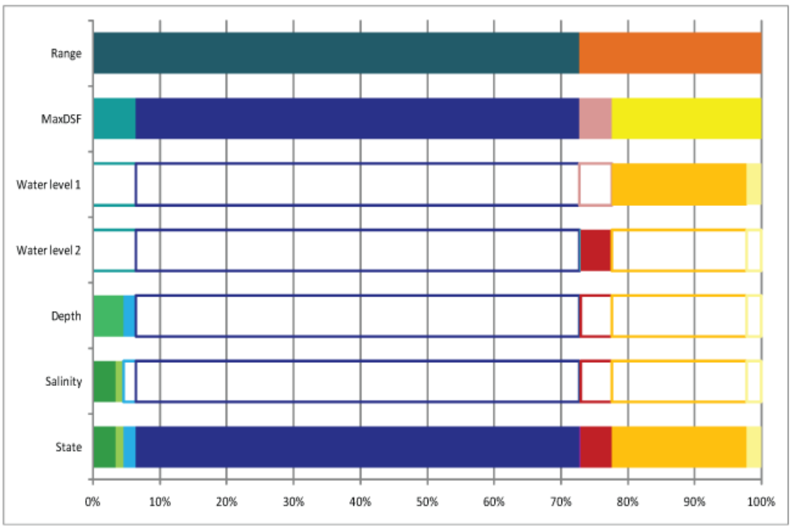



Note: Green lines indicate thresholds



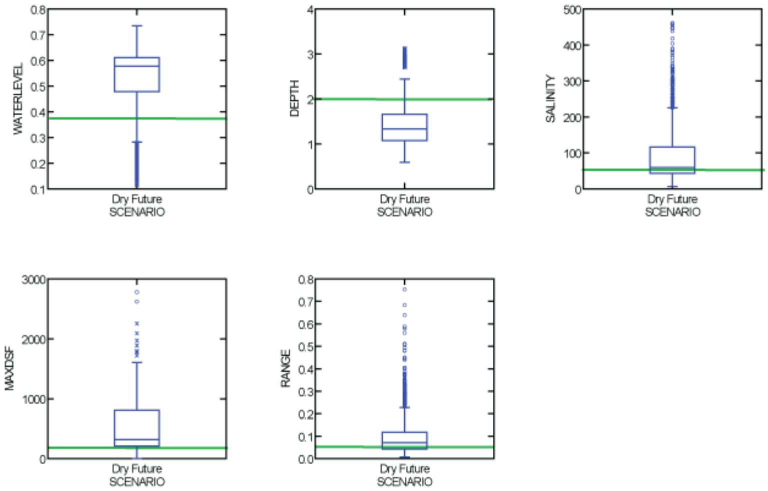

Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 8 of 8 present |
| % within marine basin | 0.74 |
| % within hypersaline basin | 0.27 |
| % healthy | 0.89 |
| % degraded | 0.11 |
| **Transitions between states** | |
| Overall | 0.18 |
| Between basins | 0.06 |
| More degraded | 0.07 |
| Less degraded | 0.04 |

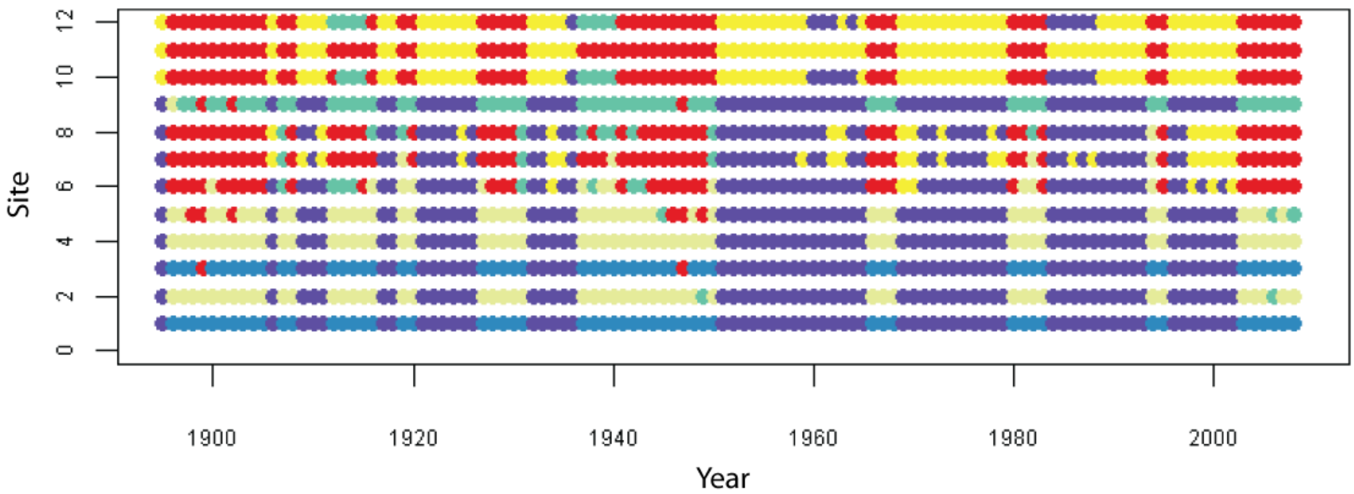


## D.4 Dry Future (Scenario 4)

| | |
|---|---|
| Climate | Dry (MDB SY C) |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | None |
| TLM environmental water | None |
| % salinity data over 100 g $L^{-1}$ | 29.0 |
| **Gini coefficients** | |
| Tidal range | 0.20 |
| MaxDSF | 0.51 |
| Water level | 0.07 |
| Water depth | 0.03 |
| Salinity | 0.17 |

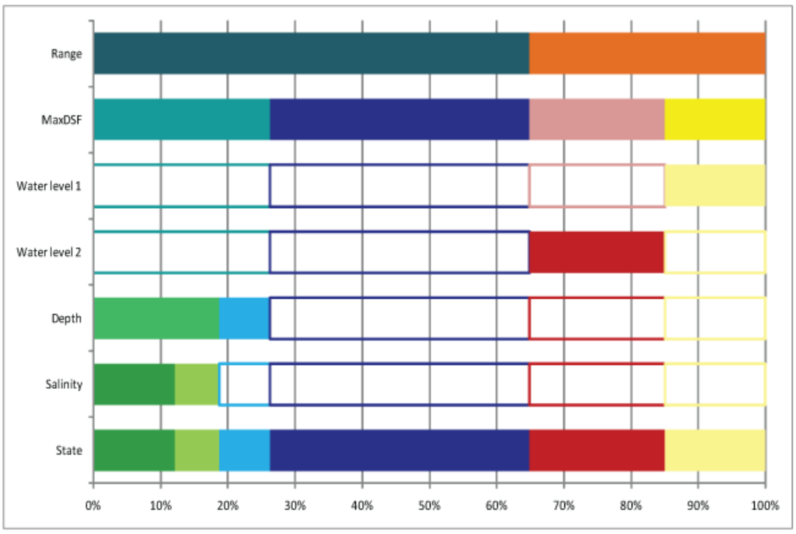



Note: Green lines indicate thresholds, the water level B threshold is lower than the plot range



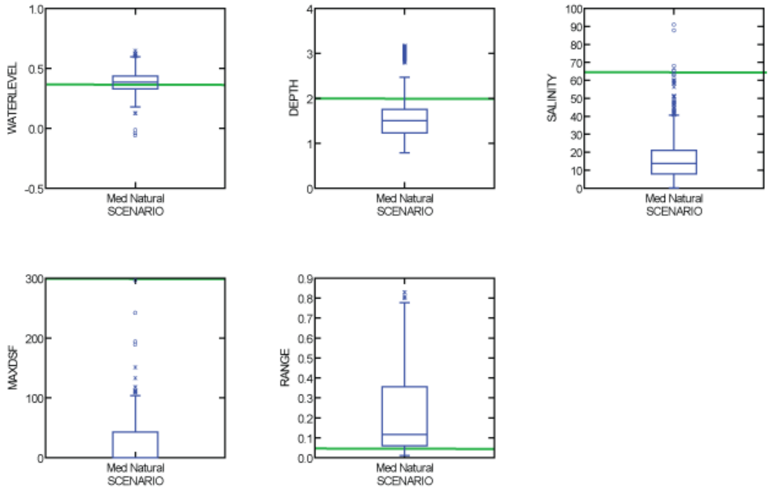

Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 8 of 8 present |
| % within marine basin | 0.65 |
| % within hypersaline basin | 0.35 |
| % healthy | 0.54 |
| % degraded | 0.46 |
| **Transitions between states** | |
| Overall | 0.26 |
| Between basins | 0.10 |
| More degraded | 0.09 |
| Less degraded | 0.07 |



## D.5 Median Natural (Scenario 5)

| | |
|---|---|
| Climate | Median |
| Extraction levels | None |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | None |
| TLM environmental water | None |

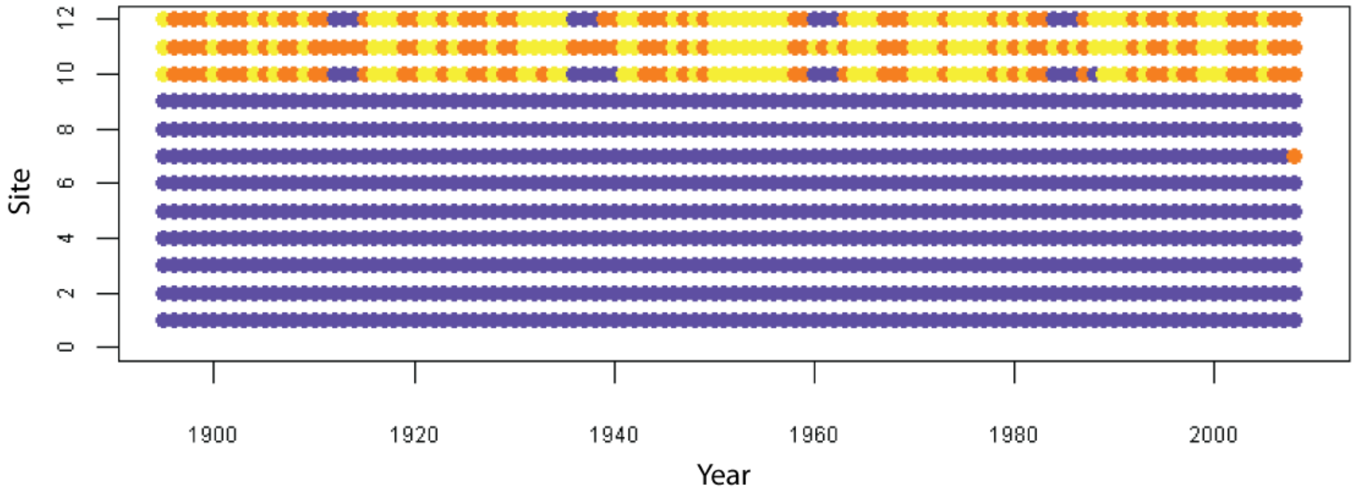



| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | None |

**Gini coefficients**

| | |
|---|---|
| Tidal range | 0.08 |
| MaxDSF | 0.78 |
| Water level | 0.11 |
| Water depth | 0.03 |
| Salinity | 0.30 |

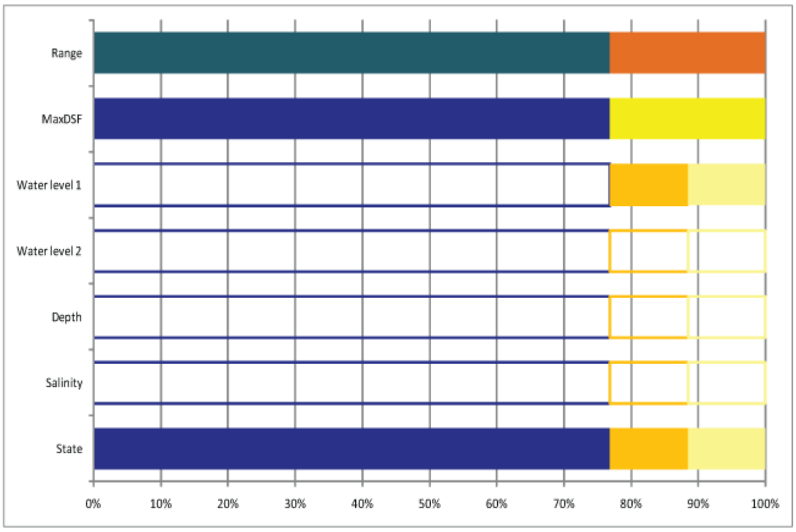
Note: Green lines indicate thresholds, Water Level B threshold is lower and MAXDSF exceeds the range of the plot




Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

**State characteristics**

| | |
|---|---|
| State richness | 3 of 8 present |
| % within marine basin | 0.77 |
| % within hypersaline basin | 0.23 |
| % healthy | 1.00 |
| % degraded | 0.00 |



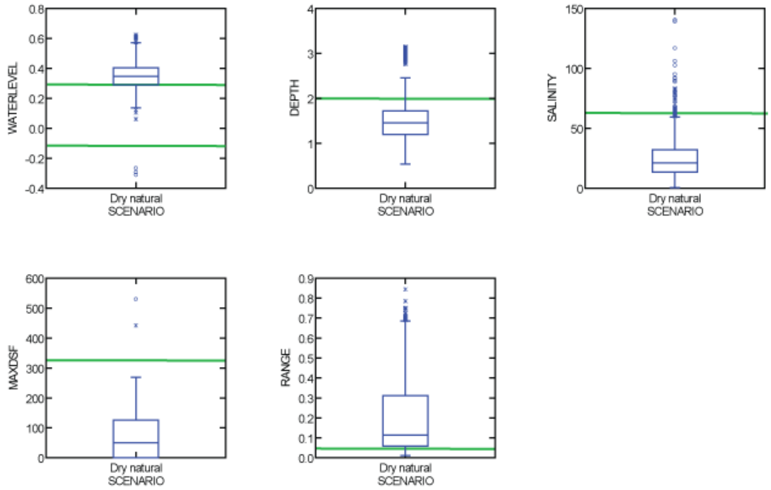

**Transitions between states**

| | |
|---|---|
| Overall | 0.12 |
| Between basins | 0.01 |
| More degraded | 0.06 |
| Less degraded | 0.05 |

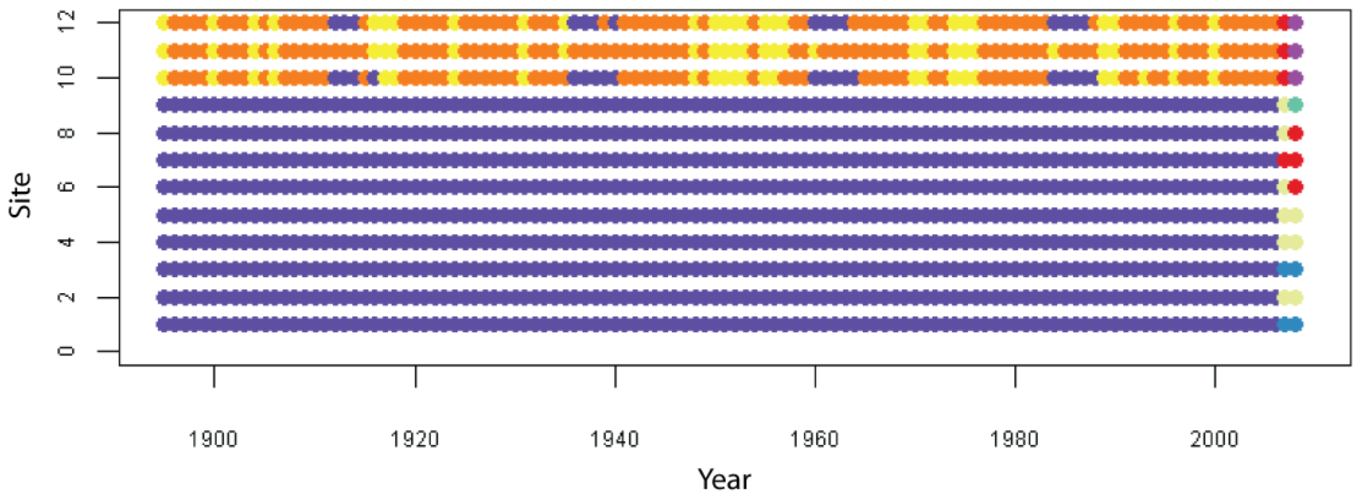
# D.6 Dry Natural (Scenario 6)

| | |
|---|---|
| Climate | Dry |
| Extraction levels | None |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | None |
| TLM environmental water | None |

| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | None |
| **Gini coefficients** | |
| Tidal range | 0.09 |
| MaxDSF | 0.60 |
| Water level | 0.13 |
| Water depth | 0.03 |
| Salinity | 0.25 |

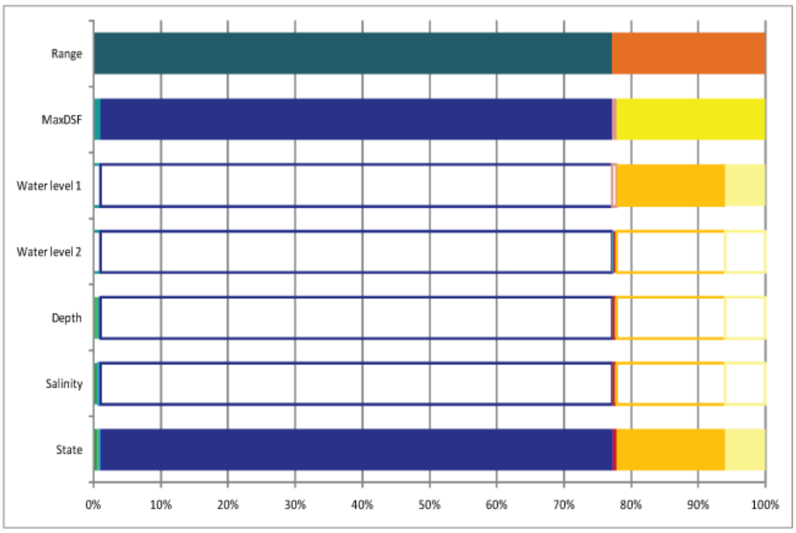



Note: Green lines indicate thresholds



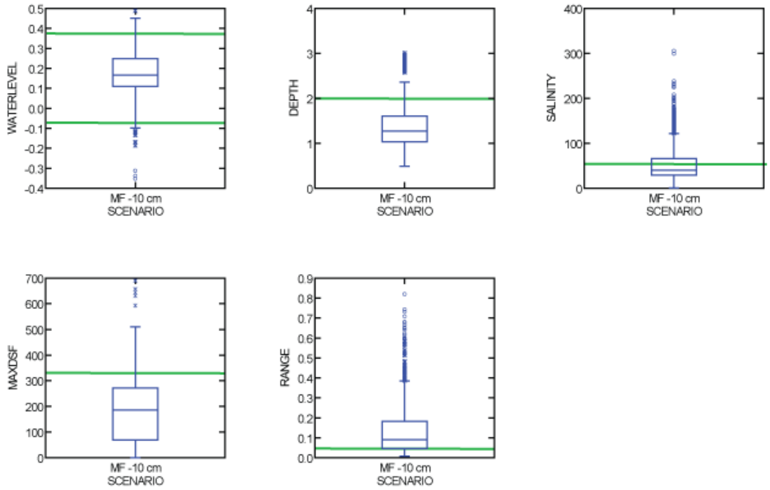

Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 5 of 8 present |
| % within marine basin | 0.77 |
| % within hypersaline basin | 0.23 |
| % healthy | 0.98 |
| % degraded | 0.02 |
| **Transitions between states** | |
| Overall | 0.10 |
| Between basins | 0.02 |
| More degraded | 0.05 |
| Less degraded | 0.03 |

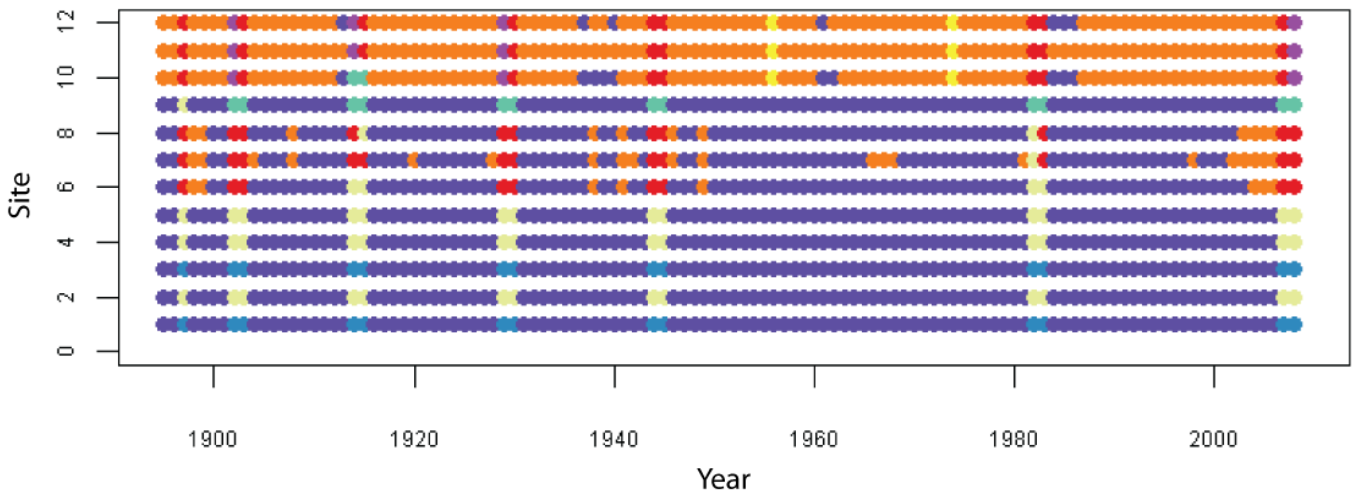


## D.7 Median Future, -10 cm SLR (Scenario 7)

| | |
|---|---|
| Climate | Median |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | Minimum<br>10 cm decrease |
| TLM infrastructure | None |
| TLM environmental water | None |
| | |
| % salinity data over 100 g $L^{-1}$ | 0.14 |
| | |
| **Gini coefficients** | |
| Tidal range | 0.17 |
| MaxDSF | 0.43 |
| Water level | 0.45 |
| Water depth | 0.04 |
| Salinity | 0.20 |

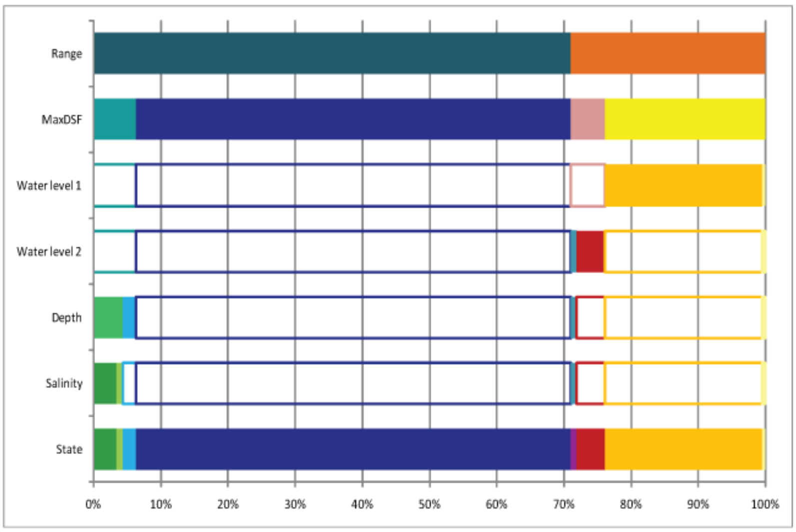



Note: Green lines indicate thresholds




Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 8 of 8 present |
| % within marine basin | 0.71 |
| % within hypersaline basin | 0.29 |
| % healthy | 0.89 |
| % degraded | 0.11 |
| | |
| **Transitions between states** | |
| Overall | 0.17 |
| Between basins | 0.06 |
| More degraded | 0.06 |
| Less degraded | 0.05 |



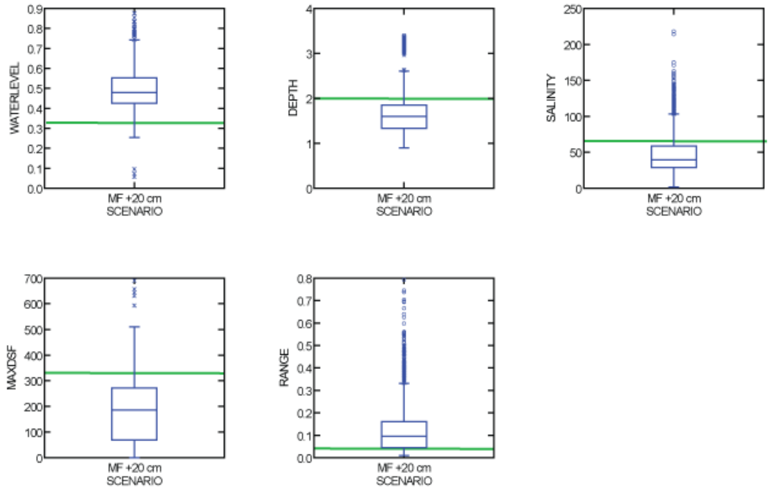
## D.8 Median Future, +20 cm SLR (Scenario 8)

| | |
|---|---|
| Climate | Median |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | Median<br>20 cm rise |
| TLM infrastructure | None |
| TLM environmental water | None |

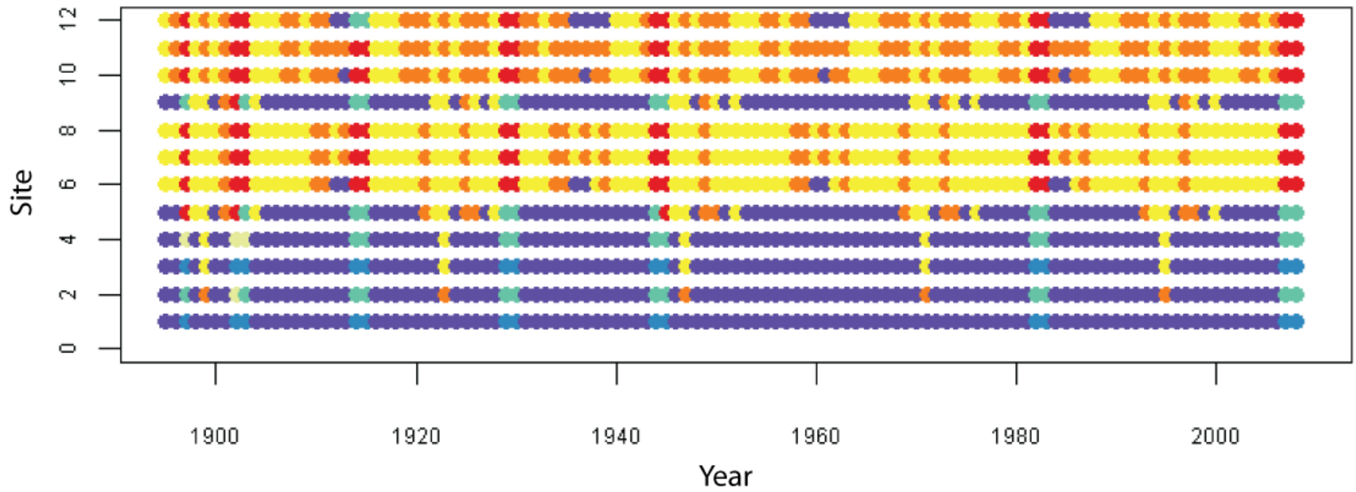
| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | 0.08 |

**Gini coefficients**

| | |
|---|---|
| Tidal range | 0.19 |
| MaxDSF | 0.43 |
| Water level | 0.06 |
| Water depth | 0.03 |
| Salinity | 0.20 |




Note: Green lines indicate thresholds, Water Level B threshold lower than range of plot



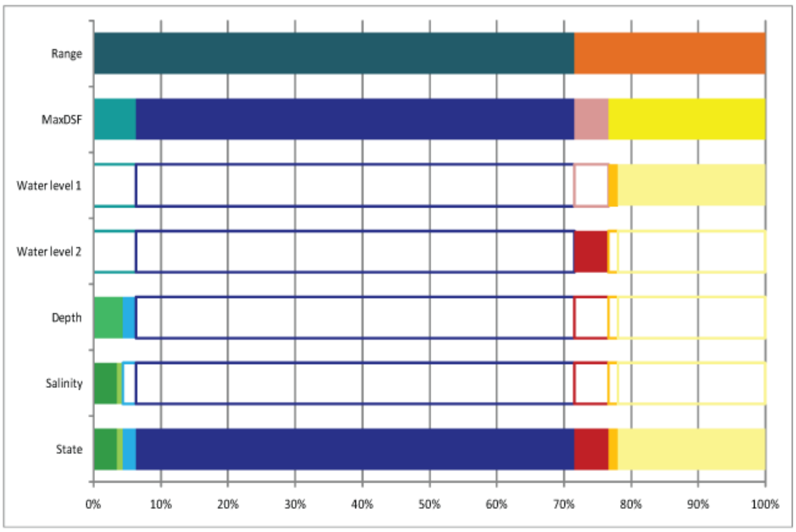

Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

**State characteristics**

| | |
|---|---|
| State richness | 7 of 8 present |
| % within marine basin | 0.71 |
| % within hypersaline basin | 0.29 |
| % healthy | 0.89 |
| % degraded | 0.11 |

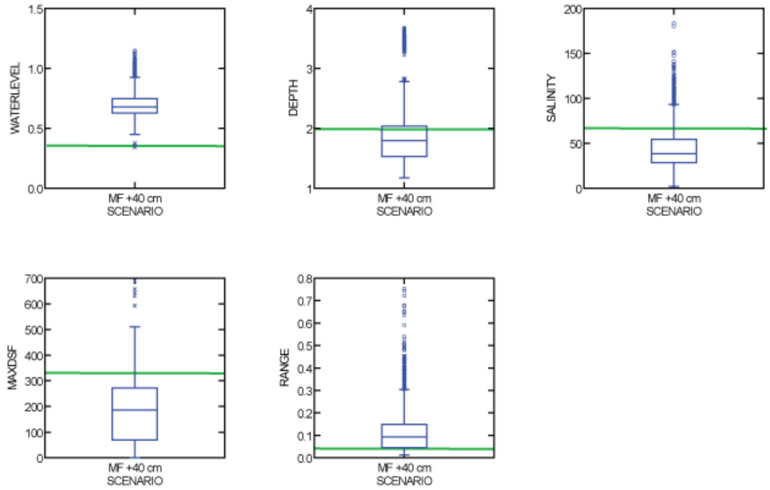
**Transitions between states**

| | |
|---|---|
| Overall | 0.18 |
| Between basins | 0.06 |
| More degraded | 0.07 |
| Less degraded | 0.05 |

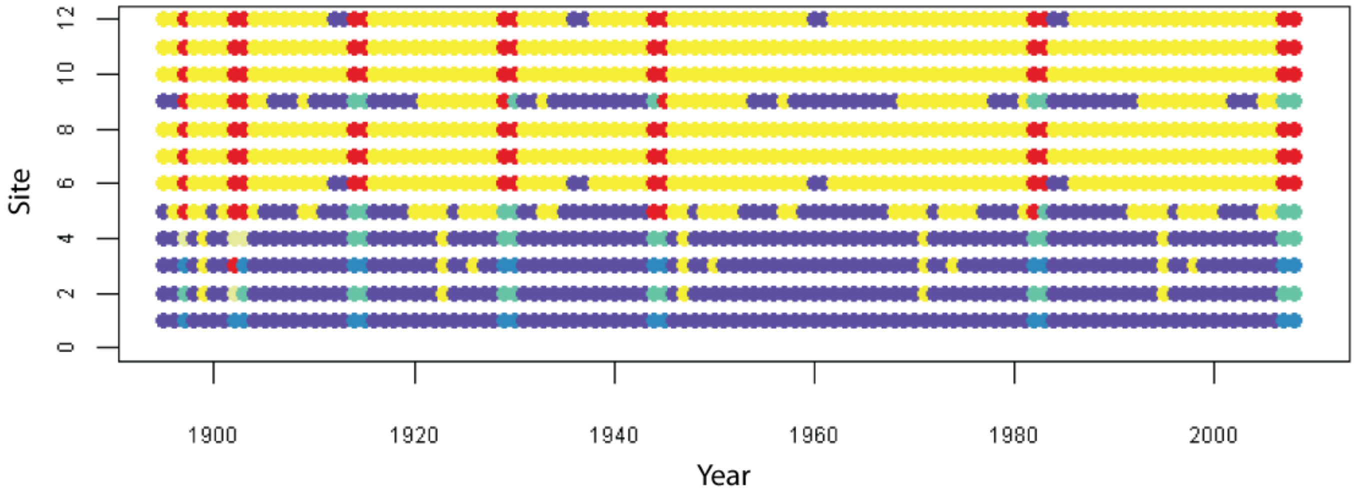


## D.9 Median Future, +40 cm SLR (Scenario 9)

| | |
|---|---|
| Climate | Median |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | High |
| | 40 cm rise |
| TLM infrastructure | None |
| TLM environmental water | None |
| | |
| % salinity data over 100 g $L^{-1}$ | 0.085 |
| | |
| **Gini coefficients** | |
| Tidal range | 0.20 |
| MaxDSF | 0.43 |
| Water level | 0.06 |
| Water depth | 0.02 |
| Salinity | 0.19 |

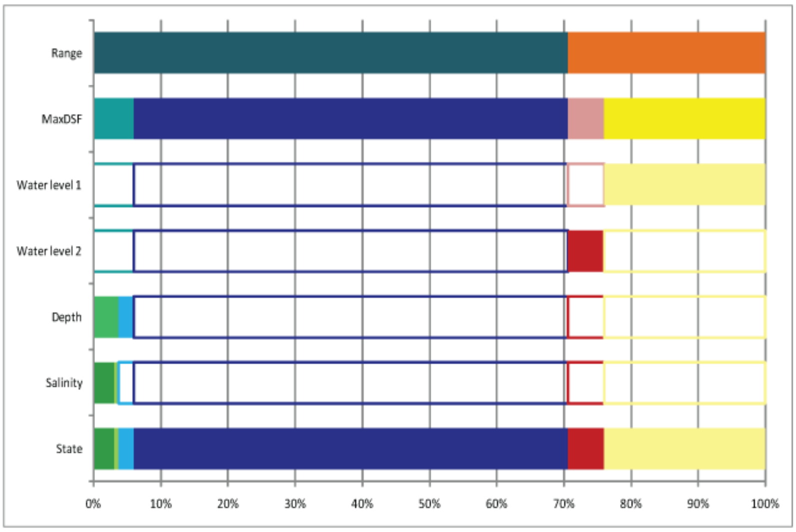



Note: Green lines indicate thresholds, Water Level B threshold lower than range of plot




Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

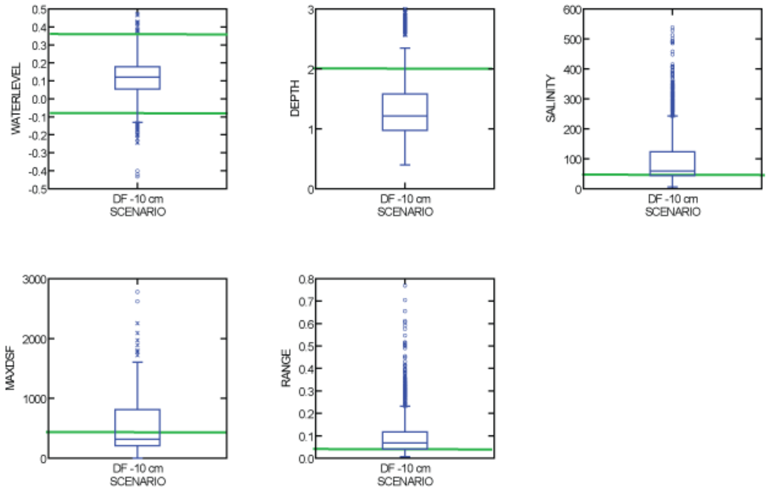
| | |
|---|---|
| **State characteristics** | |
| State richness | 6 of 8 present |
| % within marine basin | 0.70 |
| % within hypersaline basin | 0.30 |
| % healthy | 0.89 |
| % degraded | 0.11 |
| | |
| **Transitions between states** | |
| Overall | 0.16 |
| Between basins | 0.07 |
| More degraded | 0.05 |
| Less degraded | 0.04 |



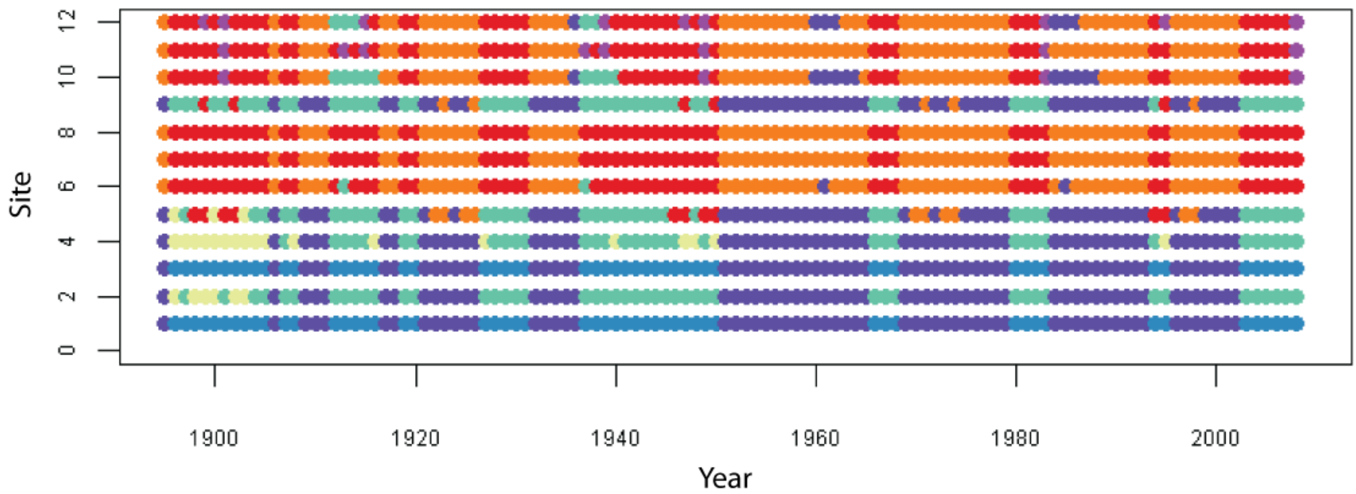
## D.10 Dry Future, -10 cm SLR (Scenario 10)

| | |
|---|---|
| Climate | Dry |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | Minimum<br>10 cm decrease |
| TLM infrastructure | None |
| TLM environmental water | None |

| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | 0.05 |
| **Gini coefficients** | |
| Tidal range | 0.21 |
| MaxDSF | 0.51 |
| Water level | -0.28 |
| Water depth | 0.04 |
| Salinity | 0.18 |



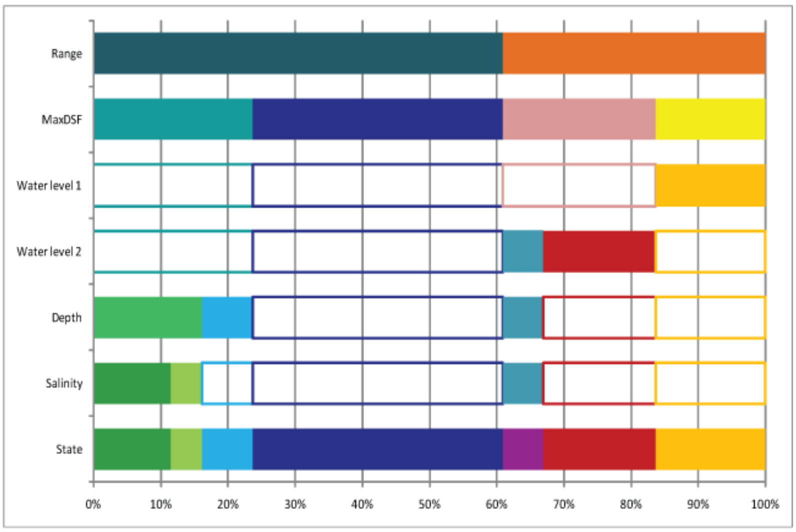

Note: Green lines indicate thresholds




Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **Transitions between states** | |
| Overall | 0.29 |
| Between basins | 0.10 |
| More degraded | 0.10 |
| Less degraded | 0.09 |

| | |
|---|---|
| **State characteristics** | |
| State richness | 7of 8 present |
| % within marine basin | 0.61 |
| % within hypersaline basin | 0.39 |
| % healthy | 0.54 |
| % degraded | 0.46 |



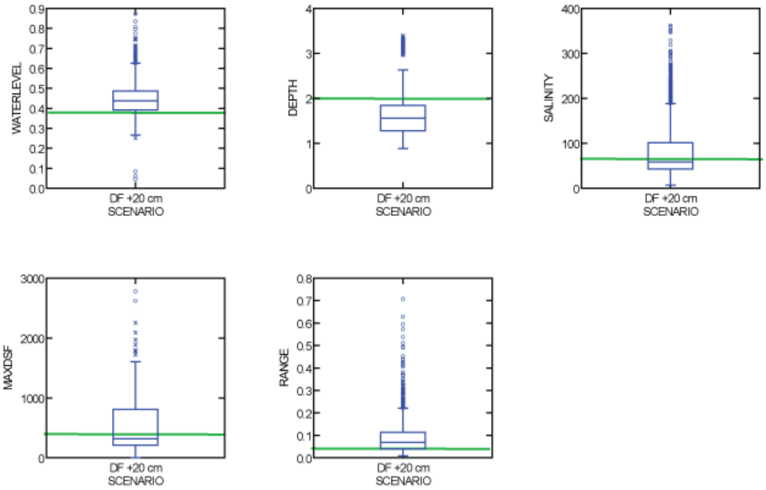
## D.11 Dry Future, +20 cm SLR (Scenario 11)

| | |
|---|---|
| Climate | Dry |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | Median 20 cm rise |
| TLM infrastructure | None |
| TLM environmental water | None |

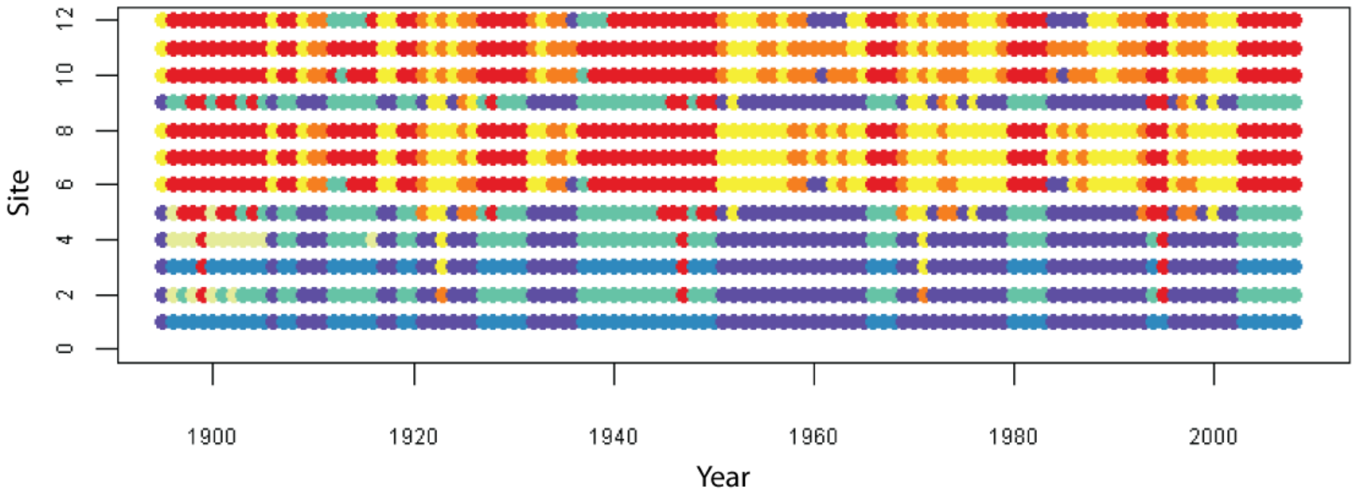
| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | 0.25 |

**Gini coefficients**

| | |
|---|---|
| Tidal range | 0.21 |
| MaxDSF | 0.51 |
| Water level | 0.08 |
| Water depth | 0.02 |
| Salinity | 0.18 |




Note: Green lines indicate thresholds, Water Level B threshold was lower than the plot range



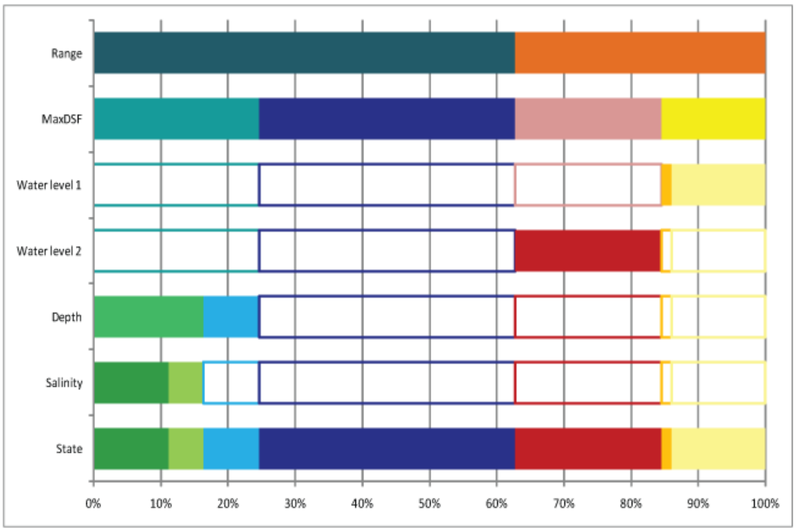

Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

**State characteristics**

| | |
|---|---|
| State richness | 7of 8 present |
| % within marine basin | 0.63 |
| % within hypersaline basin | 0.37 |
| % healthy | 0.54 |
| % degraded | 0.46 |

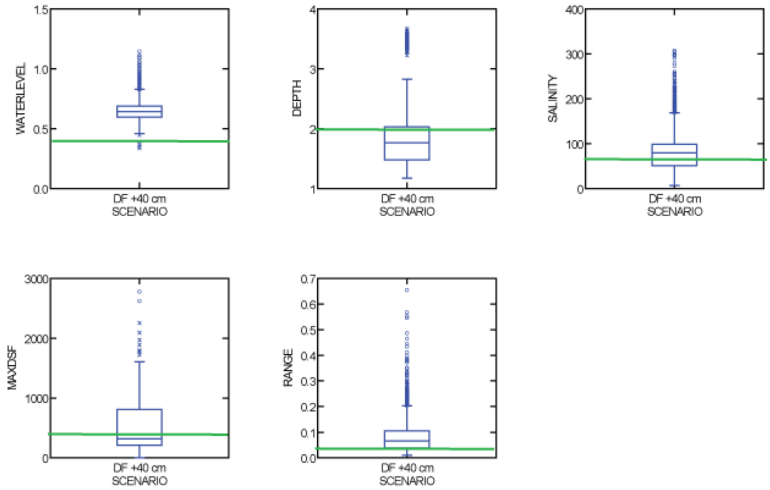
**Transitions between states**

| | |
|---|---|
| Overall | 0.29 |
| Between basins | 0.11 |
| More degraded | 0.10 |
| Less degraded | 0.09 |

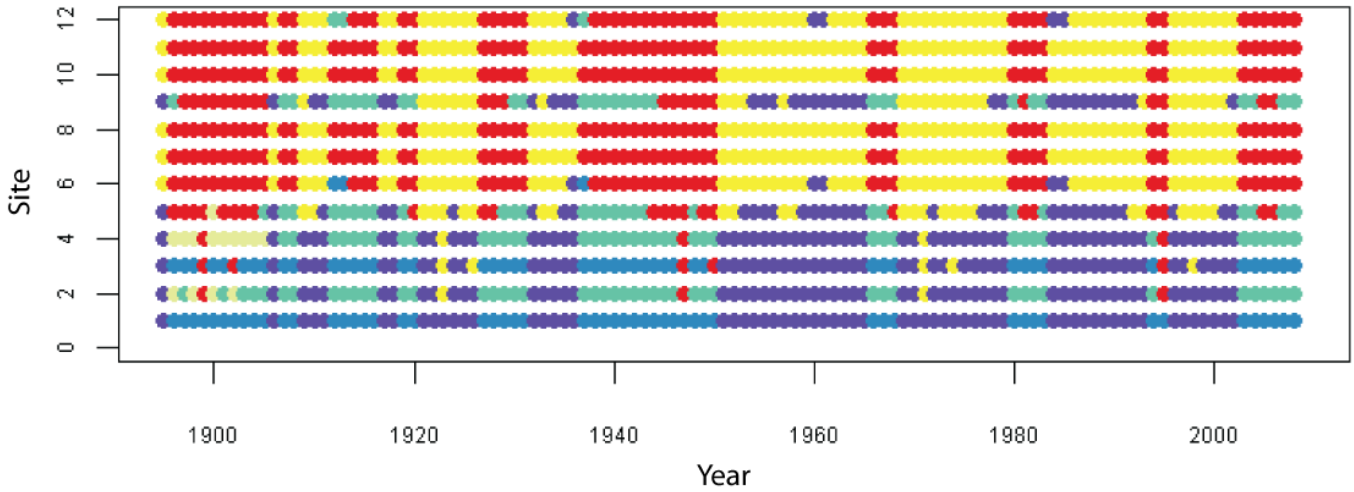


## D.12 Dry Future, +40 cm SLR (Scenario 12)

| | |
|---|---|
| Climate | Dry |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | High<br>40 cm rise |
| TLM infrastructure | None |
| TLM environmental water | None |
| | |
| % salinity data over 100 g $L^{-1}$ | 0.60 |
| | |
| **Gini coefficients** | |
| Tidal range | 0.21 |
| MaxDSF | 0.51 |
| Water level | 0.06 |
| Water depth | 0.02 |
| Salinity | 0.07 |

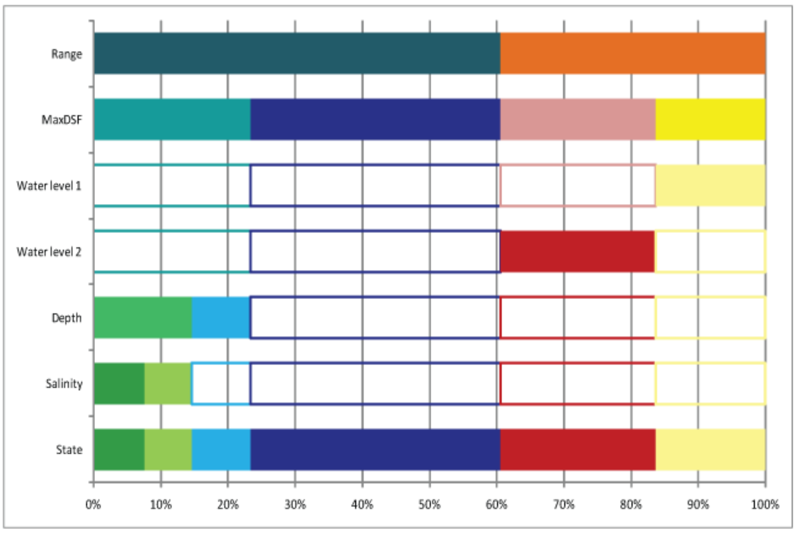



Note: Green lines indicate thresholds, Water Level B threshold was lower than the plot range



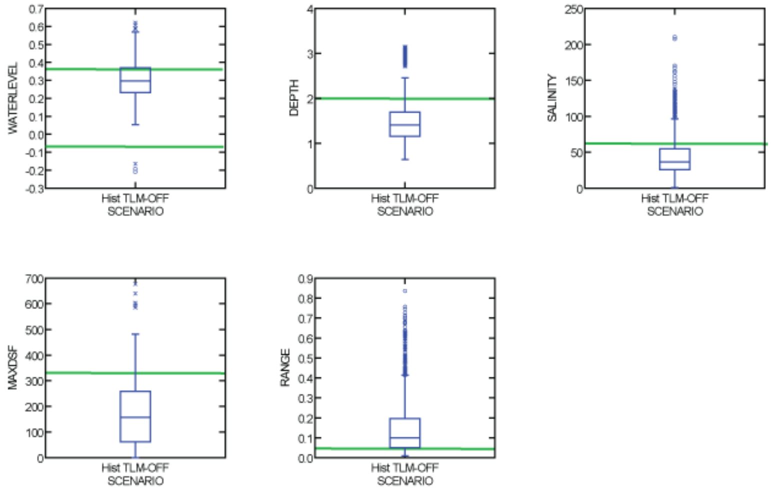

Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 6of 8 present |
| % within marine basin | 0.61 |
| % within hypersaline basin | 0.39 |
| % healthy | 0.54 |
| % degraded | 0.46 |
| | |
| **Transitions between states** | |
| Overall | 0.26 |
| Between basins | 0.11 |
| More degraded | 0.08 |
| Less degraded | 0.07 |



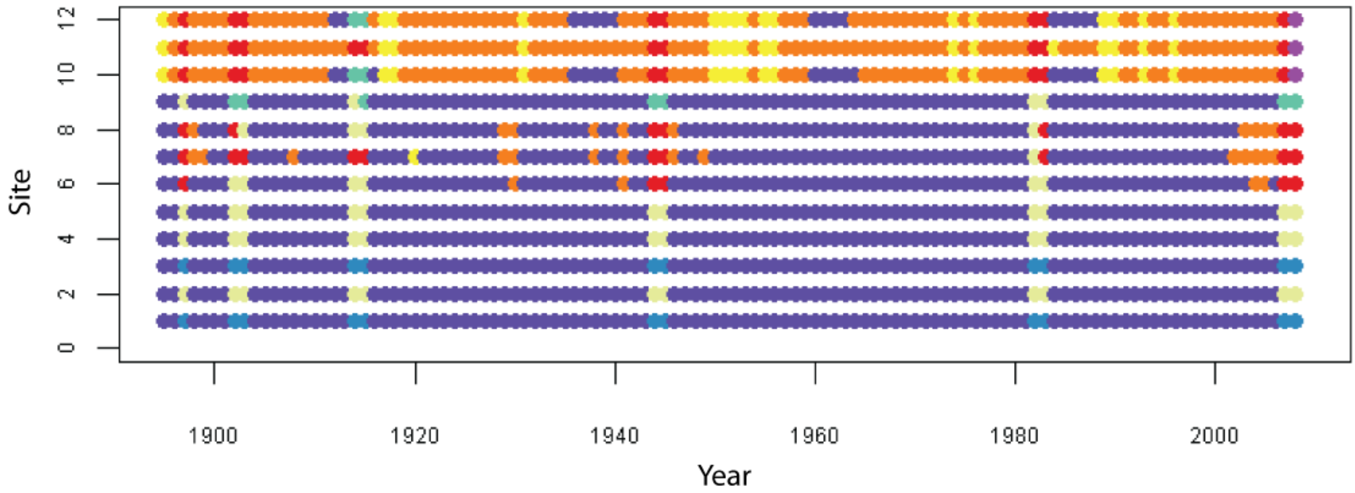
## D.13 Historic TLM off (Scenario 13)

| | |
|---|---|
| Climate | Historic |
| Extraction levels | Current |
| Flow over the barrages | Current |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | Present |
| TLM environmental water | None |




Note: Green lines indicate thresholds

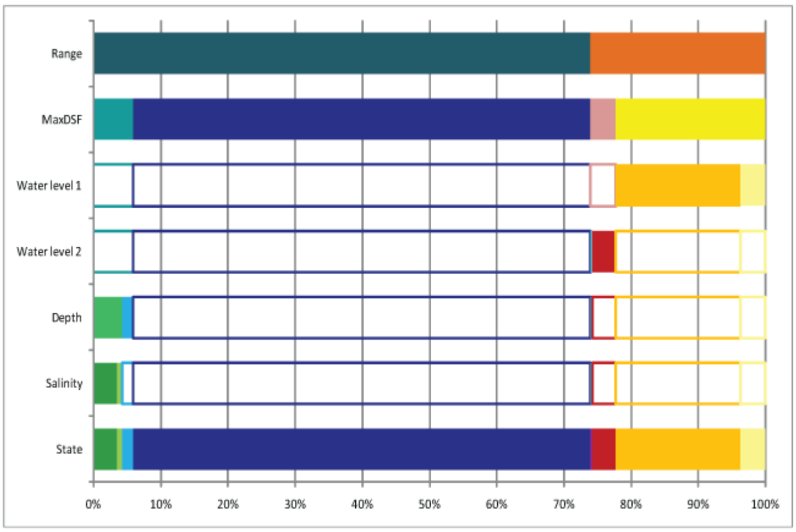
| | |
|---|---|
| % salinity data over 100 g L$^{-1}$ | 0.06 |
| **Gini coefficients** | |
| Tidal range | 0.17 |
| MaxDSF | 0.45 |
| Water level | 0.04 |
| Water depth | 0.09 |
| Salinity | 0.21 |




Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 7 of 8 present |
| % within marine basin | 0.74 |
| % within hypersaline basin | 0.26 |
| % healthy | 0.90 |
| % degraded | 0.10 |

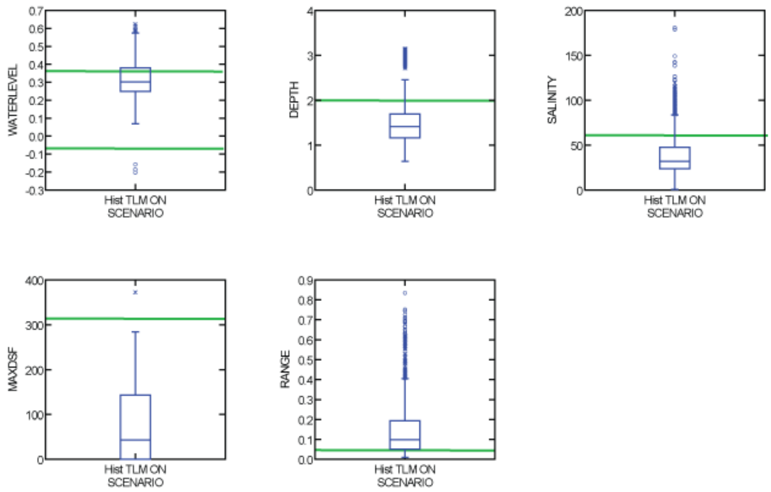
| | |
|---|---|
| **Transitions between states** | |
| Overall | 0.17 |
| Between basins | 0.04 |
| More degraded | 0.09 |
| Less degraded | 0.05 |



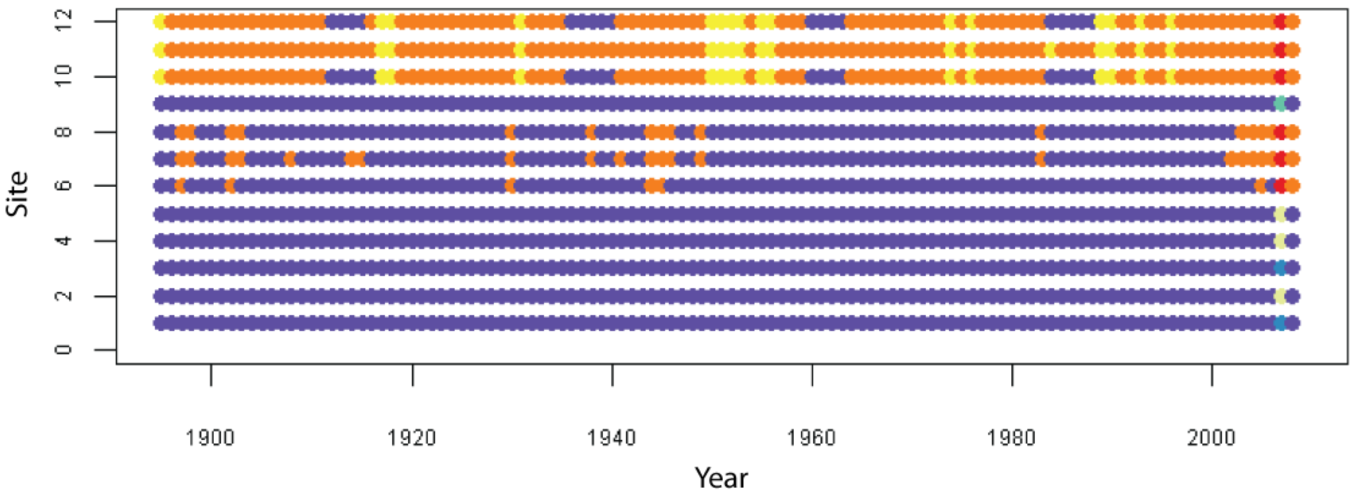
## D.14 Historic TLM on (Scenario 14)

| | |
|---|---|
| Climate | Historic |
| Extraction levels | Current |
| Flow over the barrages | Current |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | Present |
| TLM environmental water | 500 GL |

| | |
|---|---|
| % salinity data over 100 g L$^{-1}$ | 0.03 |
| **Gini coefficients** | |
| Tidal range | 0.10 |
| MaxDSF | 0.60 |
| Water level | 0.16 |
| Water depth | 0.03 |
| Salinity | 0.20 |

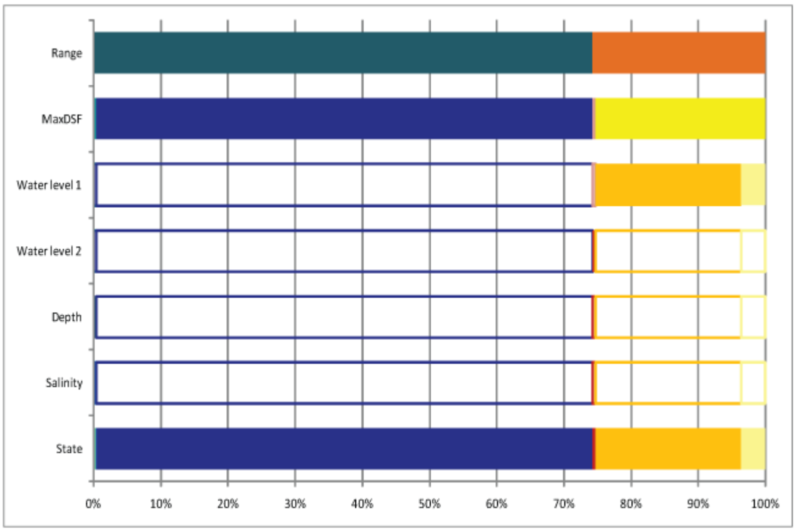



Note: Green lines indicate thresholds



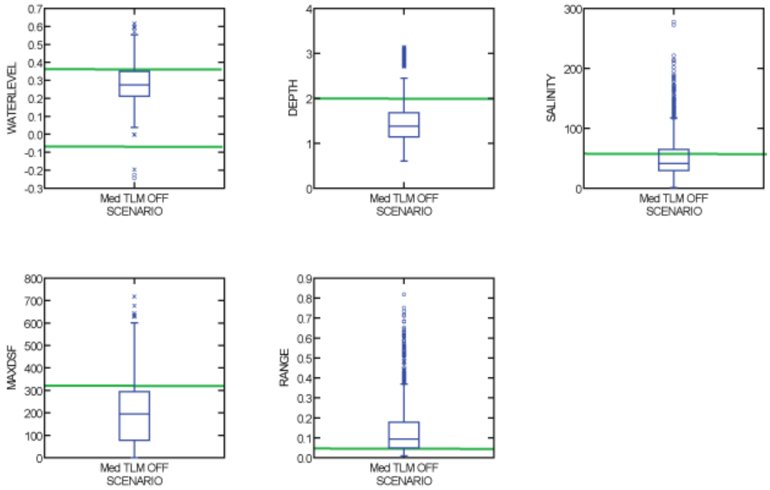

Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 7 of 8 present |
| % within marine basin | 0.74 |
| % within hypersaline basin | 0.26 |
| % healthy | 0.99 |
| % degraded | 0.01 |
| **Transitions between states** | |
| Overall | 0.10 |
| Between basins | 0.02 |
| More degraded | 0.05 |
| Less degraded | 0.05 |



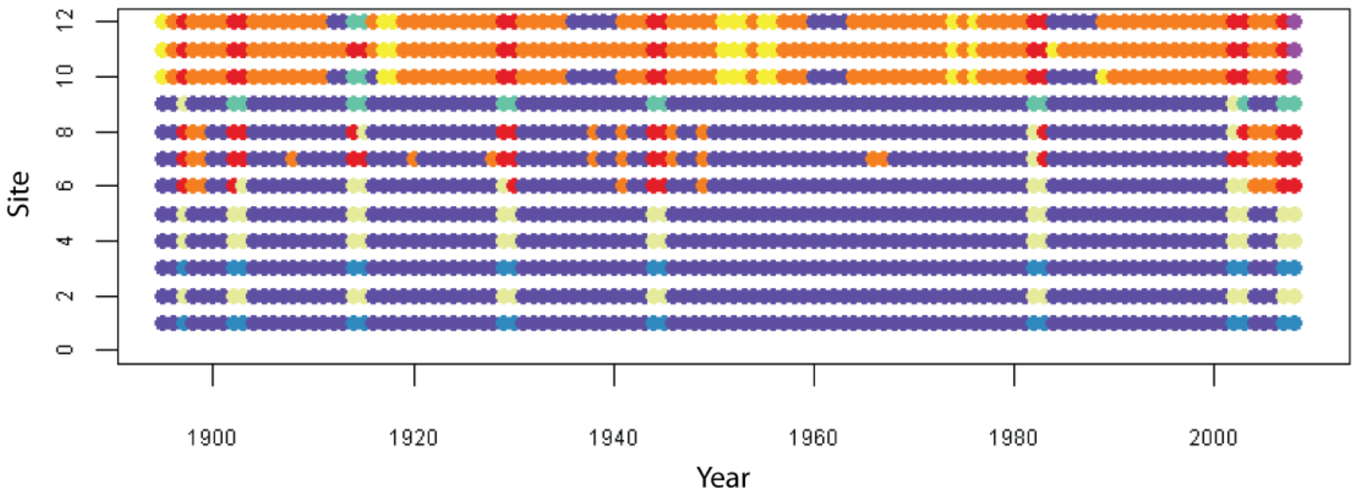
## D.15 Median TLM off (Scenario 15)

| | |
|---|---|
| Climate | Median |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | Present |
| TLM environmental water | None |




Note: Green lines indicate thresholds

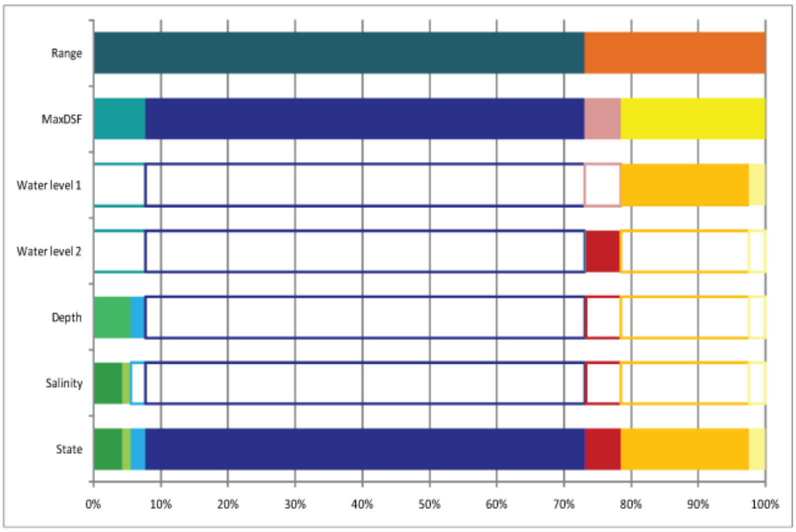
| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | 0.13 |
| **Gini coefficients** | |
| Tidal range | 0.20 |
| MaxDSF | 0.42 |
| Water level | 0.19 |
| Water depth | 0.04 |
| Salinity | 0.20 |




Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 8 of 8 present |
| % within marine basin | 0.73 |
| % within hypersaline basin | 0.27 |
| % healthy | 0.87 |
| % degraded | 0.13 |

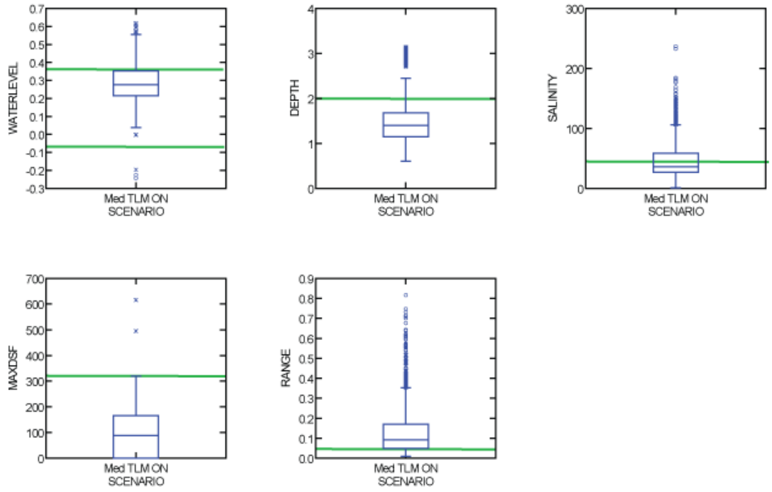
| | |
|---|---|
| **Transitions between states** | |
| Overall | 0.20 |
| Between basins | 0.05 |
| More degraded | 0.08 |
| Less degraded | 0.06 |



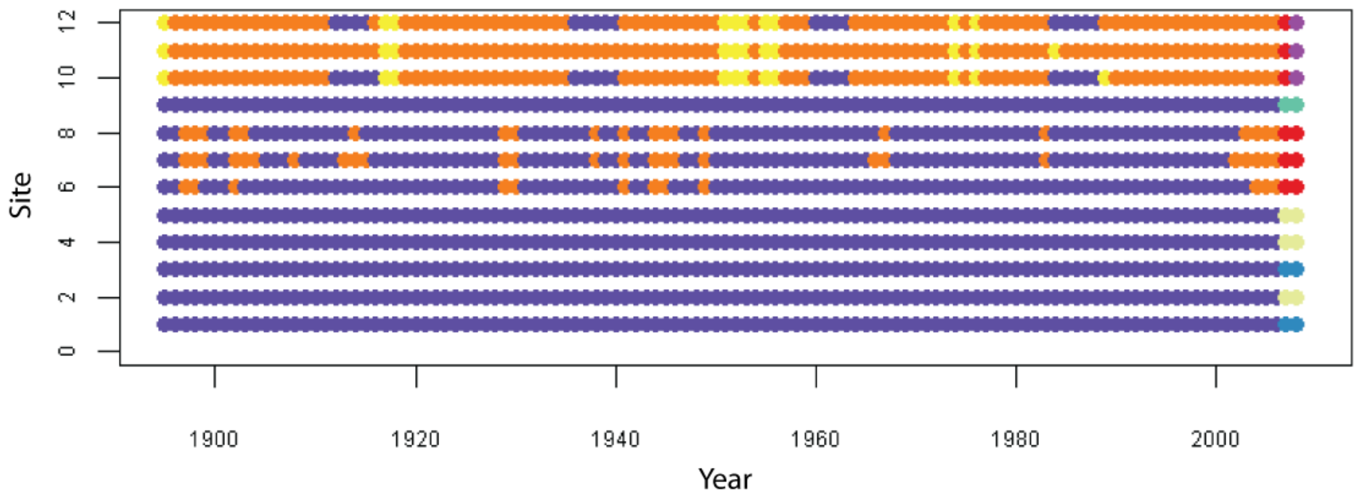
## D.16 Median TLM on (Scenario 16)

| | |
|---|---|
| Climate | Median |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | Present |
| TLM environmental water | 500 GL |

| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | 0.09 |
| **Gini coefficients** | |
| Tidal range | 0..18 |
| MaxDSF | 0.54 |
| Water level | 0.19 |
| Water depth | 0.03 |
| Salinity | 0.19 |

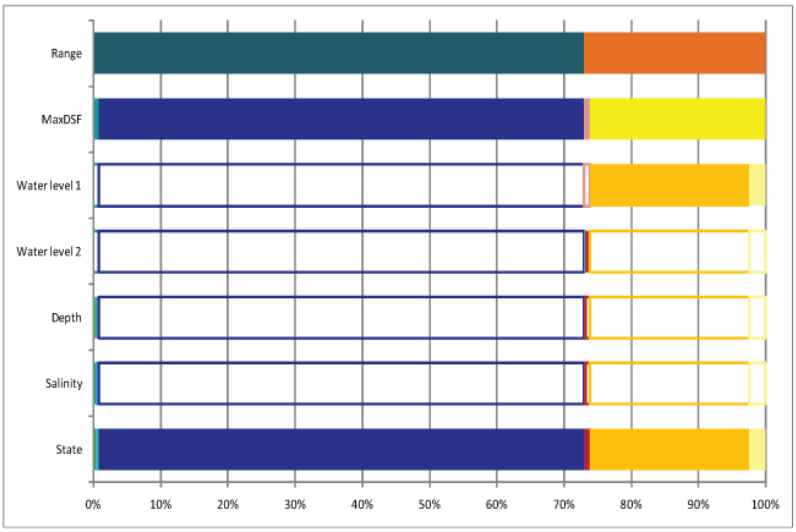



Note: Green lines indicate thresholds



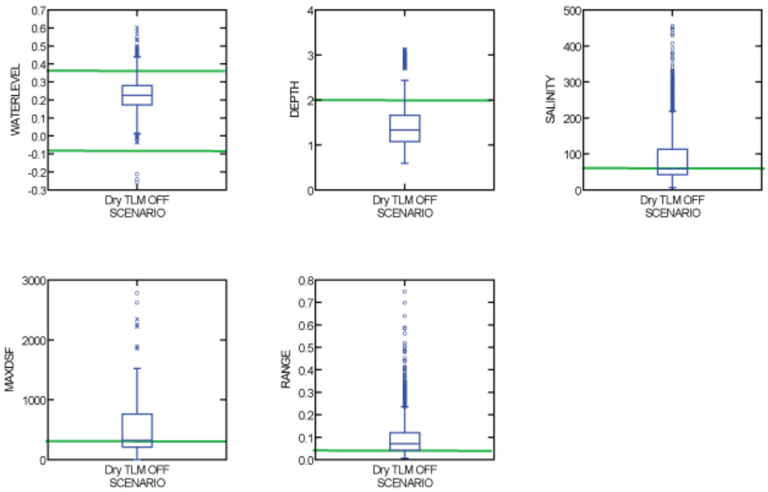

Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 8 of 8 present |
| % within marine basin | 0.73 |
| % within hypersaline basin | 0.27 |
| % healthy | 0.98 |
| % degraded | 0.02 |
| **Transitions between states** | |
| Overall | 0.03 |
| Between basins | 0.01 |
| More degraded | 0.01 |
| Less degraded | 0.01 |



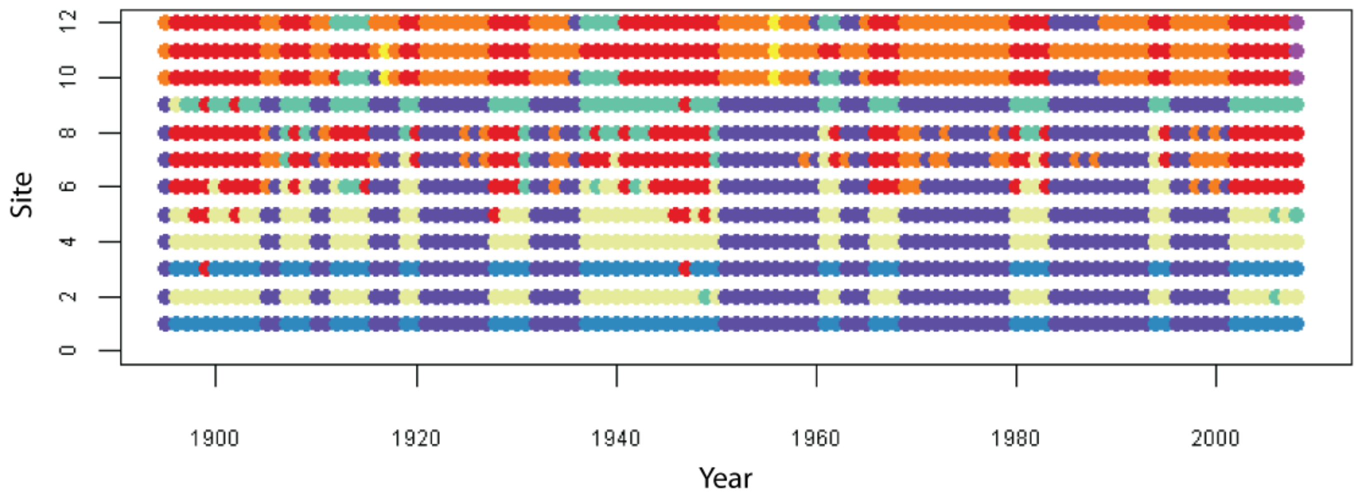
## D.17 Dry TLM off (Scenario 17)

| | |
|---|---|
| Climate | Dry (MDB SY C) |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | Present |
| TLM environmental water | None |



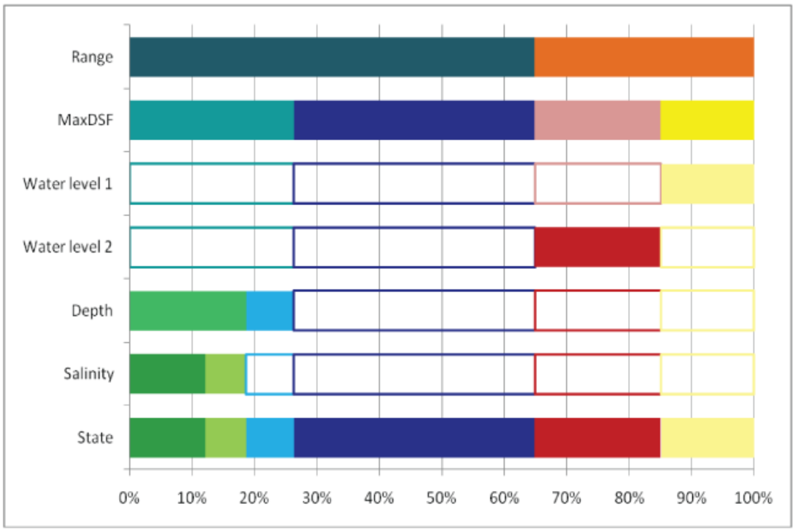

Note: Green lines indicate thresholds

| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | 29.0 |
| **Gini coefficients** | |
| Tidal range | 0.20 |
| MaxDSF | 0.21 |
| Water level | 0.03 |
| Water depth | 0.49 |
| Salinity | 0.17 |




Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **Transitions between states** | |
| Overall | 0.26 |
| Between basins | 0.10 |
| More degraded | 0.09 |
| Less degraded | 0.07 |
| **State characteristics** | |
| State richness | 8 of 8 present |
| % within marine basin | 0.66 |
| % within hypersaline basin | 0.34 |
| % healthy | 0.53 |
| % degraded | 0.47 |

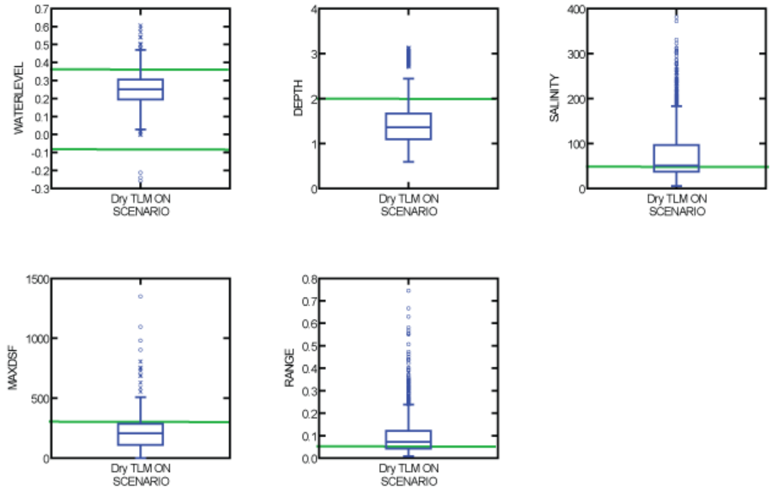


## D.18 Dry TLM on (Scenario 18)

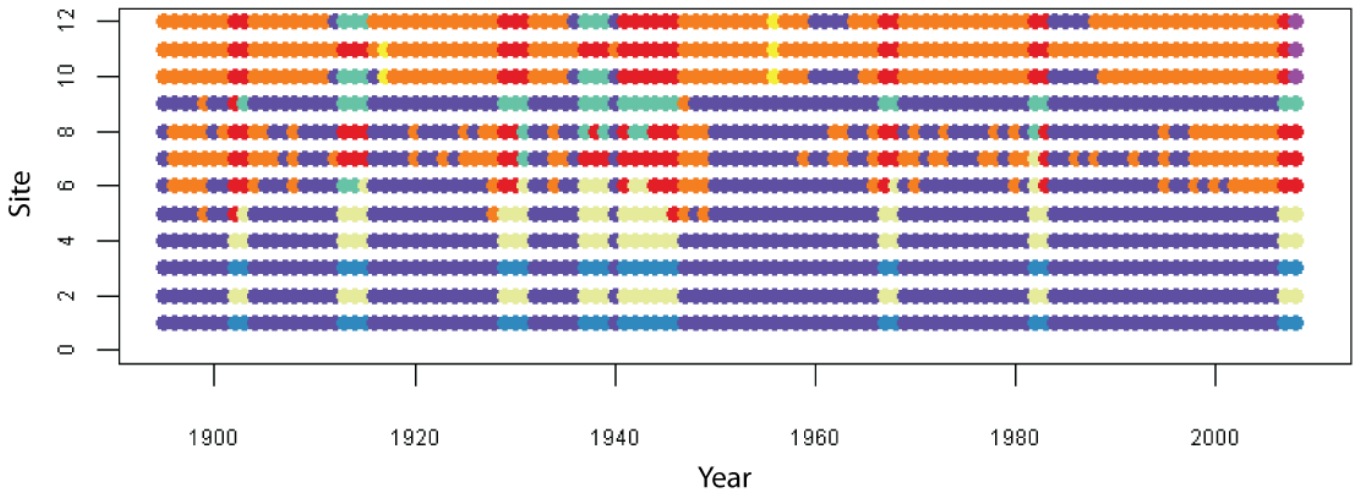
| | |
|---|---|
| Climate | Dry (MDB SY C) |
| Extraction levels | Current |
| Flow over the barrages | Possible |
| USED flows | Average |
| Murray Mouth dredging | None |
| Sea level rise | None |
| TLM infrastructure | Present |
| TLM environmental water | 500 GL |

% salinity data over 100 g L$^{-1}$ 24.0

| **Gini coefficients** | |
|---|---|
| Tidal range | 0.19 |
| MaxDSF | 0.18 |
| Water level | 0.03 |
| Water depth | 0.48 |
| Salinity | 0.16 |



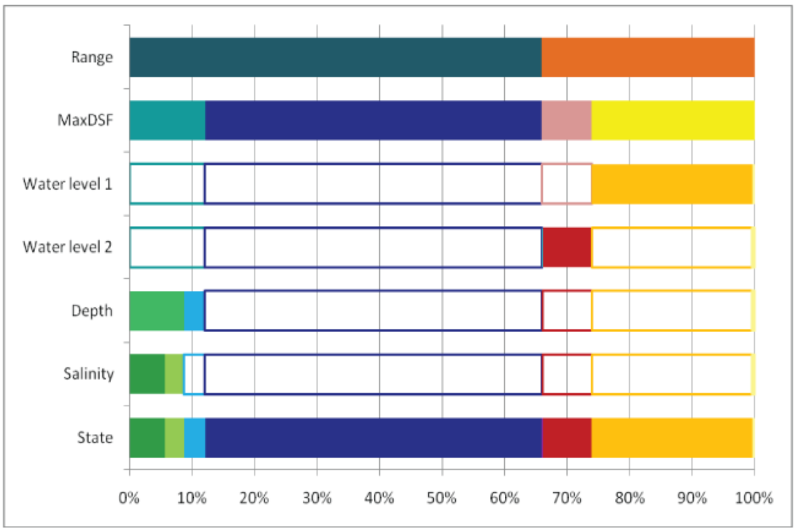

Note: Green lines indicate thresholds




Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| **Transitions between states** | |
|---|---|
| Overall | 0.23 |
| Between basins | 0.10 |
| More degraded | 0.07 |
| Less degraded | 0.06 |

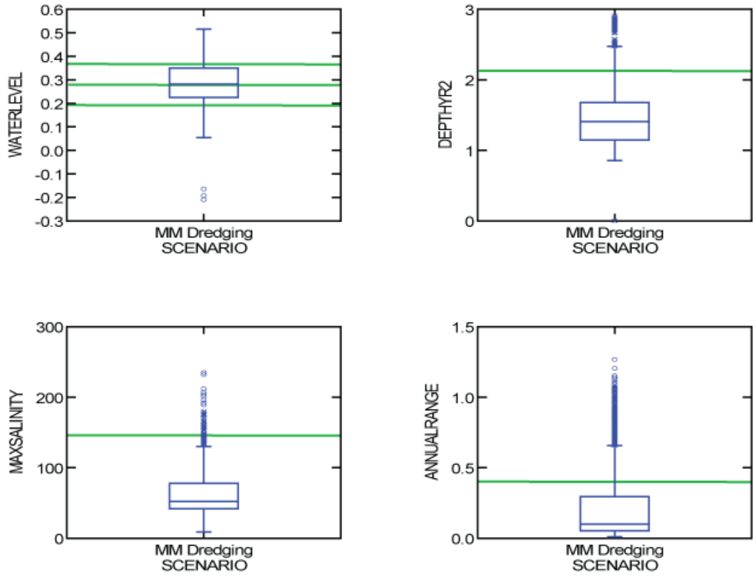
| **State characteristics** | |
|---|---|
| State richness | 8 of 8 present |
| % within marine basin | 0.65 |
| % within hypersaline basin | 0.35 |
| % healthy | 0.54 |
| % degraded | 0.46 |



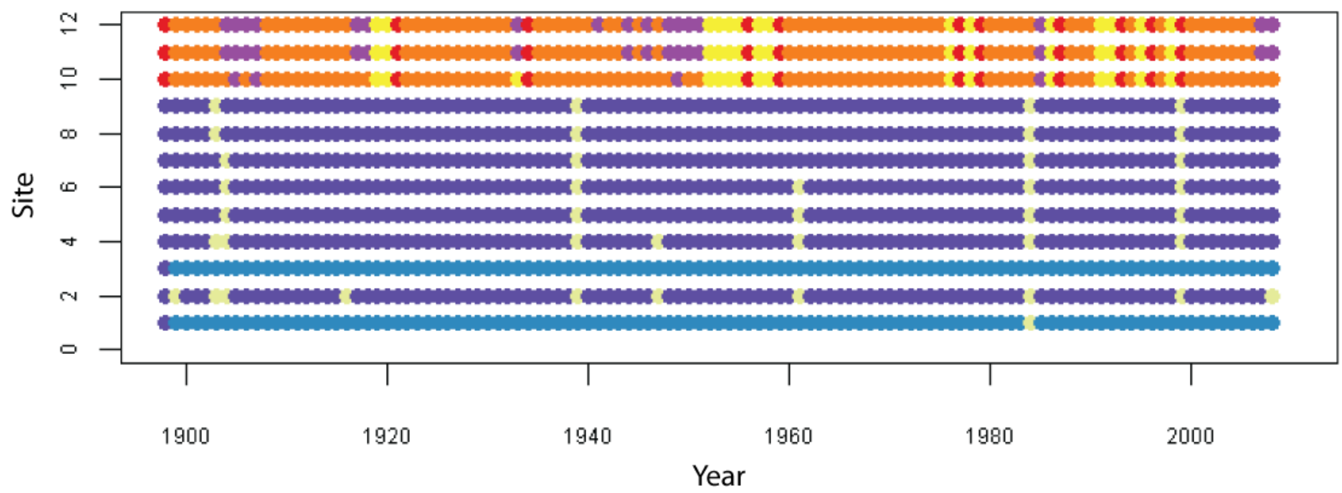
## D.19 MM Dredging (Scenario 19)

| | |
|---|---|
| Climate | Historic (MDB SY A) |
| Extraction levels | Current |
| Flow over the barrages | Current |
| USED flows | Average |
| Murray Mouth dredging | Present |
| Sea level rise | None |
| TLM infrastructure | None |
| TLM environmental water | None |

| | |
|---|---|
| % salinity data over 100 g $L^{-1}$ | 14.0 |
| **Gini coefficients** | |
| Water level | 0.10 |
| Water depth | 0.03 |
| Annual range in water level | 0.12 |
| Maximum salinity | 0.16 |

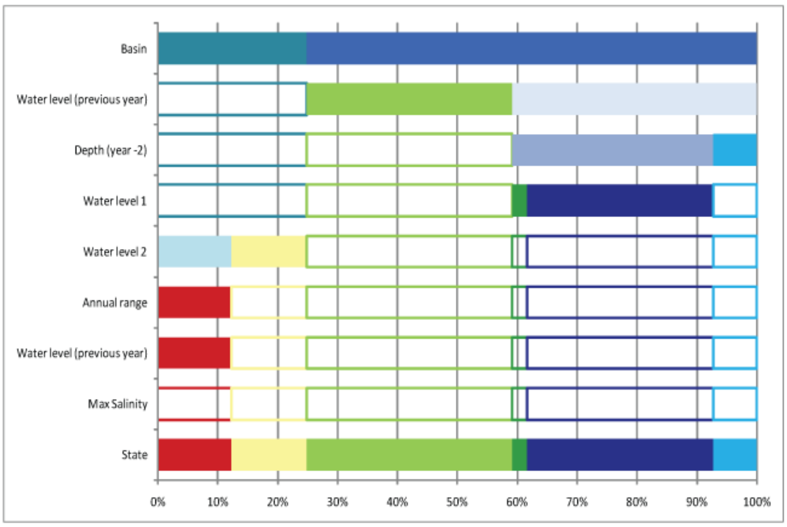



Note: Green lines indicate thresholds




Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| | |
|---|---|
| **State characteristics** | |
| State richness | 7 of 8 present |
| % within marine basin | 0.75 |
| % within hypersaline basin | 0.25 |
| % healthy | 0.74 |
| % degraded | 0.26 |
| **Transitions between states** | |
| Overall | 0.15 |
| Between basins | 0.00 |
| More degraded | 0.07 |
| Less degraded | 0.08 |

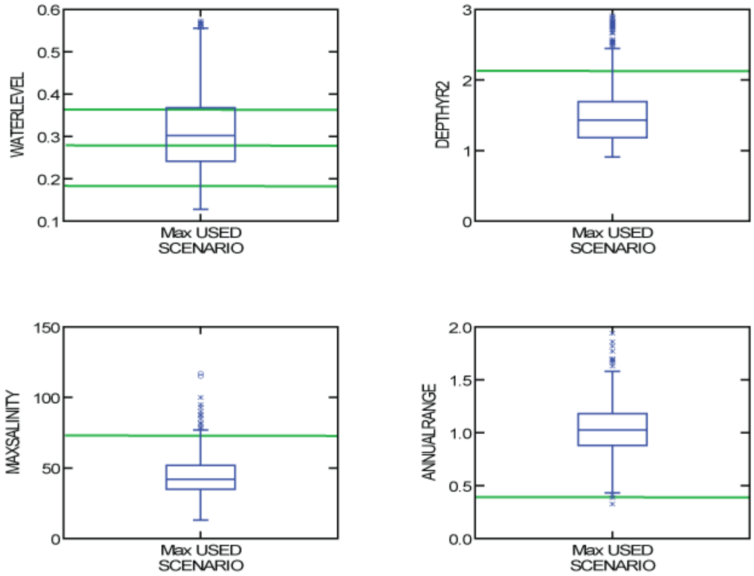


## D.20 Max USED Flows (Scenario 20)

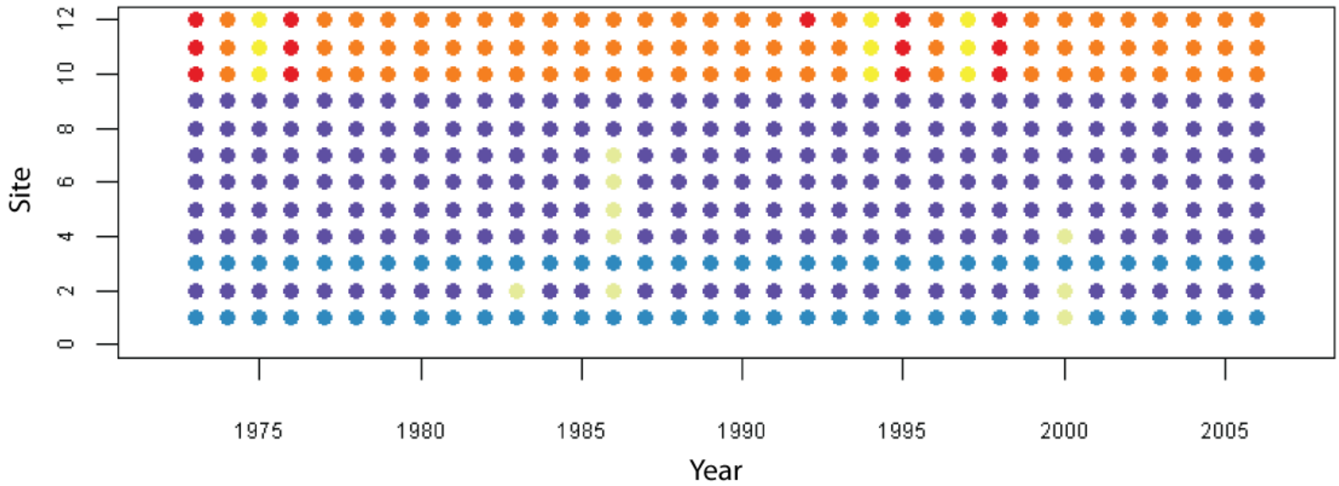
| | |
|---|---|
| Climate | Historic (MDB SY A) |
| Extraction levels | Current |
| Flow over the barrages | Current |
| USED flows | Average |
| Murray Mouth dredging | Present |
| Sea level rise | None |
| TLM infrastructure | None |
| TLM environmental water | None |

| | |
|---|---|
| % salinity data over 100 g L$^{-1}$ | 1.0 |

| **Gini coefficients** | |
|---|---|
| Water level | 0.26 |
| Water depth | 0.03 |
| Annual range in water level | 0.11 |
| Maximum salinity | 0.16 |




Note: Green lines indicate thresholds




Note: For each bar, colours represent the following states: yellow = Estuarine/Marine, red = Marine, blue = Unhealthy Marine, green = Degraded Marine, purple = Healthy Hypersaline, orange =Average Hypersaline, brown = Unhealthy Hypersaline and grey = Degraded Hypersaline.

| **State characteristics** | |
|---|---|
| State richness | 6 of 8 present |
| % within marine basin | 0.75 |
| % within hypersaline basin | 0.25 |
| % healthy | 0.78 |
| % degraded | 0.22 |

| **Transitions between states** | |
|---|---|
| Overall | 0.13 |
| Between basins | 0.00 |
| More degraded | 0.05 |
| Less degraded | 0.08 |