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Utilizing the Coorong, Lower Lakes and Murray Mouth Water Quality and Microalgae monitoring data to evaluate indicators for the Ecological Character Description

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A. Executive Summary

Introduction

The South Australian Department of Environment, Water and Natural Resources (DEWNR) is updating the Ecological Character Description (ECD) of the 1985 designated, Coorong and Lakes Alexandrina and Albert Ramsar wetland, to comply with the requirements of the Federal Department of the Environment, Water, Heritage and the Arts. The updated ECD is required to describe and substantiate any changes that have occurred in critical Components, Processes or Services (CPS), and to assess if these are beyond the bounds of typical seasonal or inter-annual variation and if they exceed the environmental limits of acceptable change (LAC). Based on this information the updated ECD (completed in 2016) will determine if the ecological character of the wetland has changed since its Ramsar designation.

The set of CPS considered critical for maintaining the ecological character of the site were identified previous to commencing this study as comprising: hydrology; fish populations; aquatic vegetation; waterbirds; *Ruppia* spp.; and salinity. Other CPS previously acknowledged as important but not currently considered in the ECD include water quality (nutrients, turbidity, dissolved oxygen, pH, temperature, dissolved metals) and microalgae. The objectives of this project were to collate and analyse time series of hydrological and water quality monitoring data from the Ramsar wetland to determine whether the proposed management criteria for these characteristics are appropriate, and to assess the benefits of including these in the updated ECD.

Methods

Monitoring data from regions of the Coorong, Lower Lakes and Murray Mouth (CLLMM) Ramsar site included for analyses were: the Coorong North Lagoon; Coorong South Lagoon; Lake Alexandrina; Lake Albert; and the Murray Mouth estuary.

Hydrological data included flows over Lock 1 to approximate the inflows to the Lower Lakes, and modelled flows over the barrages between Lake Alexandrina and the Coorong and Murray Mouth. Also included in the analyses were measured water levels in Lake Alexandrina and Lake Albert, and modelled water levels for the Coorong South, Coorong North and Murray Mouth regions.

The physico-chemical water quality parameters collated for analyses from the DEWNR CLLMM Recovery Project monitoring program were: conductivity, turbidity, total phosphorus (TP), total nitrogen (TN), dissolved oxygen (DO), pH, chlorophyll-a and temperature. In the Coorong-Murray Mouth region, salinity data was derived from models as measured data was sparse.

The data analyses that provided descriptive characteristics which are potentially suitable as management targets were:

- *Time series*: these showed concentration changes in water quality parameters indicating the frequency, regularity and continuity of parameter values.
- *Non-exceedance plots*: these showed the probability of occurrence of parameter values across the measured range.
- *Spell duration plots*: these indicated the likelihood of occurrence for particular regimes of parameter values.
- Parameter trends over time were assessed using the non-parametric Mann-Kendall test to determine whether data in the time series from the pre-drought period were likely to provide a reasonable estimate of conditions that prevailed at the time of the Ramsar designation.

Management objectives for comparison with the monitoring data (Table 2) were based on:

- draft LAC developed by DEWNR
- water quality targets proposed in the Murray Darling Basin Plan (MDBP 2012)

- the Australian and New Zealand Environment and Conservation Council (ANZECC), National Water Quality guidelines (2000)

The 2000 to 2010 Millennium Drought in the Murray-Darling Basin included a large anthropogenic driver due to over-development of water resources in the basin. It significantly influenced water quality and microalgae, with large exceedances of the historical data limits and catastrophic impacts on aquatic ecosystems. At five years post-drought, water quality and micro-algae communities had not recovered to pre-drought conditions. The data were analysed with and without the drought period included, but with the full implementation of the Basin Plan such an extreme hydrological drought is not expected in the foreseeable future. To avoid introducing a bias in setting management targets, the Millenium Drought period was excluded from the final statistical analyses and parameter descriptors were based on pre-drought data to better represent the conditions more closely aligned to the time of the Ramsar designation. Time series and non-exceedance probability plots for all of the collated water quality sampling data, and for annual medians of the sampling data (comparing drought and non-drought periods within each region), were provided as a preliminary report that is also included here as Appendix A.

The analyses served to derive the following characteristic descriptors subsequently used to compare proposed Management triggers and LAC:

- the long term median value which indicated where a parameter was situated in its potential range
- percentiles of exceedance and non-exceedance indicating the proportions of time that particular parameter values occurred (1st, 5th, 95th and 99th percentiles)
- the duration and frequency of occurrence of continuous periods of the higher and lower percentiles of parameter values, especially in the case of extreme values and those used as management indicators.

Exceedance and spell duration plots imply that the probability distributions of parameter values are captured by the data sets and are consistent over time, whereas this is not always the case. They are summaries of the best available data and are relevant to the collection period aligning with the intention of this report. They may not be definitive of previous or more extended time periods.

Each of the five regions of the CLLMM was considered through compilation of five corresponding sets of figures illustrating the water quality and microalgae characteristics and comparing them with the associated management indicators (see Figure listing). The data analyses are summarised in Table 4 and can be compared with the management indicators described in Table 2 while the degree of alignment between the two is depicted in Table 3.

Major Findings

Water quality

Across all of the CLLMM sites the water quality management targets for TN, TP, turbidity and chlorophyll-a were regularly exceeded and seemed inappropriate for the CLLMM region. Targets were largely based on the ANZECC (2000) guidelines for South East Australia (Appendix 1). Values from the ANZECC (2000) South Central Australia guidelines (Appendix 1) were in some cases more appropriate but development of specific CLLMM targets were often warranted.

Temperature

Temperature exceedance plots indicated similar ranges across all sites of 10^0 to 25°C. The Basin Plan guideline for temperature is for monthly medians to lie between the 20^{th} and 80^{th} percentiles of the natural monthly water temperature. A potential problem with that proposed guideline is that most monthly mean temperatures could increase by a degree or more and still remain within the 20^{th} and 80^{th} percentile of the monthly temperature range. A prolonged shift of this magnitude could alter the character of the system. To avoid this, the guidelines should contain some indication of a long term monthly median.

Inflows

The draft LAC for Murray River inflows to Lake Alexandrina are expressed as annual averages but are not well defined and they do not reflect the within-year flow patterns that are often required to sustain the ecology of a wetland. Daily flows were analysed and they provided better resolution of flow patterns and characteristic descriptors.

The LAC for barrage flows to the Coorong is not well defined. The draft LAC is that the maximum number of days since “some” barrage flow should be ≤339. Analysis of the pre-drought data indicated that a complete year of zero flows occurred with an ARI of about 5 years, so the LAC of every year is significantly larger than expected. In addition, spell duration analyses indicated that there was generally a single step up from zero flows to the median value, with only a small percentage of time at which flows in between occurred. Based on this the suggested “some flow” in the proposed LAC requires improved definition.

Water levels

Draft LAC for lake water levels generally focused on the lower levels with less concern about higher water levels. This was considered inappropriate as it is important that water level variation occurs over a range and with a pattern that supports the ecosystems. Wetting of the upper edges of lakes and wetlands, even for short periods, can be important for supporting a range of CPS including fresh biofilms, riparian vegetation and water birds.

The influence of the drought on water levels in the Coorong region was evident in the exceedance plots of the total data set. In the North Lagoon the high water levels that occurred for approximately 7% of the time during the pre-drought period did not occur at all during the drought resulting in maximum water levels being >0.1m lower. Similarly, in the Southern Lagoon, there was a reduction in maximum water levels from ca. 1.2m to 0.85m AHD during the drought. Although these high water levels occur only for short periods of time they are critical to the edge ecosystems. A 0.35m reduction in maximum level as observed in the Southern Coorong Lagoon is expected to have resulted in substantial loss of shallow shoreline including important mudflat habitat for wading birds. Even in the Murray Mouth area which is buffered by sea levels, maximum water depths were not attained during the drought. These findings highlight the importance of barrage flows in sustaining water levels in the Coorong and Murray Mouth.

Conductivity/Salinity

The LAC for conductivity/salinity are based on median annual values and was considered problematic for application across the sites because annual medians can be achieved in different ways, some of which are not likely to support the ecosystems. In most cases the proposed LAC were not representative of the sites and in general seemed high, introducing the unacceptable risk that a site will undergo change before the LAC is reached.

The draft LAC for the North Lagoon is that the average monthly salinity does not exceed 75 ppt for more than an 18 month period within any 3 year rolling period. The definition is insufficient to determine if it is the rolling monthly average, or a sequence of 18 months average salinity, or a selection of 18 months in a three year period with salinities in excess of the LAC, so clarification is required. The spell duration curve indicated that salinities of this level and higher occurred for only 2 days with an ARI of 5 years, and a maximum duration of 30 days with an ARI of 20 years. This conflicts with the proposed LAC which allows an 18 month period of undefined salinities greater than 75 ppt.

Microalgae

Microalgae respond quickly and continuously to changing water quality conditions potentially providing accessible, immediate and continuous feedback to inform management actions. Multivariate analyses were used to describe the changes in water quality and microalgae in the Lakes before and after the drought. The data indicated that prior to the drought, in the period from 1982/83 until 1997/98 the microalgae community composition was relatively constrained, occupying a consistent environmental space. The consistency in the microalgae composition during this period suggests that the analyses carried out on water quality attributes prior to the drought could provide reasonable estimates of water quality conditions prevalent at the time of the designation of the Ramsar site, supporting their application in deriving management guidelines.

Management Implications

Defining the LAC for any aquatic ecosystem has proven to be a difficult task. In the context of Ramsar wetlands the LAC have been defined as:

> the variation in a particular component or process of the ecological character of the wetland that is considered acceptable, without indicating a change in ecological character that may lead to a reduction or loss of the criteria for which the site was Ramsar listed.

It has been suggested that LAC can be set around the observed maximum and minimum ranges of a parameter. However, in many cases this is unlikely to be sufficient as a prolonged shift in the median value of a water quality parameter, despite measurements remaining within the normal range of variability, could cause a change in ecological character. An obvious example is salinity. Consideration must also be given to seasonal patterns; the frequency, duration and magnitudes of normal and extreme events; cyclical events; and ecosystem or species resilience. In many cases the variability of conditions is likely to be just as important as the extreme limits in altering or sustaining the character of a wetland. Owing to the lack of compatibility between observed patterns and the LAC concept, there is a need to revisit the LAC concept to develop more prescriptive descriptors.

Comparisons of management objectives with the monitoring data were based on: draft LAC developed by DEWNR; water quality targets proposed in the Murray Darling Basin Plan (MDBP 2012); and the Australian and New Zealand Environment and Conservation Council (ANZECC), National Water Quality guidelines (2000) (Table 2). These comparisons suggested that a number of management indicators were not suitably aligned with the environmental characteristics of the CLLMM site and needed to be re-assessed in the context of the conditions described by the monitoring data. Table 3 indicates the percentage of time that draft LAC, Basin Plan targets or ANZECC guidelines were not met when compared with the monitoring data and highlights significant misalignments. However, it is important to note that a mismatch between a management indicator and the measured values can mean either that water quality is poor and/or that the management guideline value is inappropriate. It also needs to be recognised that the water resources and water quality of the CLLMM area had already undergone significant changes prior to the designation as a Ramsar site, and there is no guarantee that water quality data from the time of designation describes what is required to sustain the long term ecological character of the site.

Characteristic descriptors were drawn from these analyses including the 1st, 5th, median; 95th and 99th percentiles; and for higher and lower percentiles, the continuous duration in days of occurrence and associated annual average return intervals of these periods (see Table 4). These characteristic descriptors were not proposed as specific management guidelines but to provide a framework for discussions that could lead to the development of consistent and endorsed guidelines. The median could be considered a long term target value for a site and the percentile values could be considered as management trigger values. The selection of a particular percentile for a trigger value depends in part on the management capability to reverse a trend that reaches the trigger value. The slower the response capability the more conservative the trigger values need to be. Having a range of trigger values enables a corresponding range of response types and intensities to be prepared for situations where conditions continue to deteriorate. The linking of the derived median and percentile water quality values to ecological responses is also required in order to derive LAC, but this was beyond the scope of our assessment.

> **The comparison of the CLLMM hydrological, water quality and microalgae monitoring data with proposed management indicator values suggested that at all sites and for virtually every parameter there is a need to re-visit the proposed and current management values to ensure that they are relevant to the site and suitable for directing management actions. The data provided in this report should assist with this assessment.**

Recommendations

1. To further the development of appropriate management guidelines it is recommended that a small, select advisory group of researchers and managers with expertise and knowledge of the CPS and ecology at the CLLMM Ramsar site be consulted to help set the management objectives. The data collation and analysis provided in this report should be of major assistance to this task.
2. It would be of benefit if microalgae, water level and water quality parameters were included in the character description of the site as they respond more quickly and continuously to changing conditions than do populations of the larger organisms that are currently used as indicators, potentially providing earlier warnings of changes in ecological character. In conjunction with the current critical CPS, these could provide more accessible, immediate, and continuous management targets to inform management actions and help maintain the ecological character of the CLLMM Wetland.
3. The default Murray Darling Basin Plan targets for Ramsar sites are mostly not appropriate for the CLLMM region and should be revised.
4. Long term monitoring has been essential to determine whether changes within the water quality and microalgae drive a change in the ecological character of the CLLMM Ramsar site. Continued monitoring at key sites is critical to ongoing development and evaluation of management strategies aimed at preserving the ecological character of the site. Without such data it is unclear how relevant management decisions can be objectively evaluated to support their implementation. A long term monitoring plan should be developed and funded for the CLLMM region.
5. The characteristic descriptors provide a reliable basis for managing the ecological character of Ramsar site, but the management application of these requires further development. It will need linking of patterns in major drivers such as hydrology with the fluctuations in the character descriptors so that management actions achieve the required patterns (limits, distribution, recurrence interval etc).

B. Background

Introduction

The South Australian Department of Environment, Water and Natural Resources (DEWNR) is presently updating the Ecological Character Description (ECD) of the Coorong, Lower Lakes and Murray Mouth (CLLMM) Ramsar wetland, which was designated in 1985 (Phillips and Muller 2006). The ECD is being updated so that it complies with the requirements of the Federal Department of the Environment, Water, Heritage and the Arts, as set out in the "National Framework and Guidance for describing the ecological character of Australian Ramsar Wetlands" (DEWHA 2008). It is intended that, with the update, new knowledge gained about the site since the ECD was first published will be included in the updated description. Another requirement is that the updated ECD describe and verify any changes that have occurred in critical ecosystem Components, Processes and Services (CPS), and if there have been changes, there is a requirement to assess if they are beyond the bounds of seasonal or inter-annual variation and whether they exceed the environmental limits of acceptable change (LAC). A particular objective of the updated ECD is to determine if the ecological character of the wetland has changed since its Ramsar designation in 1985. Amongst the threats that have been identified for the Coorong and Lakes Alexandrina and Albert Wetland are water resource developments that reduce water availability, pollution, and flow barriers (Butcher and Brooks 2013). These impact the site through their disruptive influences on the CPS.

The LAC for Ramsar wetlands are defined in terms of those CPS identified as being "Critical" to the ecological character of the site (DEWHA 2008). If a critical CPS breaches its LAC then there is expected to be a change in ecological character that could lead to a reduction in, or loss of the values for which the site was Ramsar listed. Based on the critical CPS, the ECD is required to provide justification as to whether the site still meets the Ramsar criteria for which it was originally listed. Previously the particular components and processes considered critical for maintaining ecological character were identified as hydrology, fish populations, lake bed vegetation, waterbirds, *Ruppia* spp., and salinity (Butcher and Brooks 2013). Other CPS identified as important in supporting the ecological character of the site and in underpinning the critical CPS included water quality (nutrients, turbidity, dissolved oxygen, pH, temperature, dissolved metals) and microalgae. The characteristic ranges of these supporting components and processes have not been extensively investigated although they are widely used in monitoring programs to assess water quality conditions and could be useful in developing broader and more continuous assessments for managing the site to maintain its ecological character.

Water quality and microalgae monitoring data, collected largely by DEWNR through the CLLMM Recovery Project, has been collated and analysed through a series of recent projects to assess changes in conditions over time (Aldridge et al. 2010, Shiel 2010, Mosley et al. 2012, Oliver et al. 2013, Oliver et al. 2014). The results of these studies suggested that the water quality and microalgae data could be sufficient to contribute to the ECD, whereas previously only water quality with respect to salinity was considered. It would be of benefit if microalgae and extra water quality parameters could be included in the suite of indicators supporing management of the site as they respond more quickly and continuously to changing conditions than do the populations of the larger organisms that are currently used as indicators, potentially providing earlier warnings of ecosystem change. In conjunction with the critical CPS, these could provide more accessible, immediate, and continuous management targets to inform management actions and help maintain the ecological character of the Coorong and Lakes Alexandrina and Albert Wetland.

Management trigger values are generally used to indicate when management action is required to reverse a trend that is moving towards a LAC. In this sense a LAC is at the extreme range of the management triggers and represents unacceptable risk of a resulting change in ecosystem character. However, LAC should not be interpreted only as simple percentile limits to parameter ranges, as shifts in long term medians can alter the ecological characteristics of systems yet fall within the parameter ranges. Also important when considering ecological shifts are the periods of time that a parameter may occur within different parts of its range, including when it is at, or near, a trigger value or range limit. Relevant time periods include both the total fraction of time and the length of continuous durations of time. Short, infrequent excursions above a trigger value may be acceptable if inconsequential for ecological shift, but if they increase in frequency and/or duration then system changes are more probable.

This report continues the data collation commenced in a preliminary report (Oliver and Mosley 2014 attached as Appendix A). It aims to generate time series for monitoring sites within the Coorong, Lower Lakes and Murray Mouth (hereafter CLLMM) with long term water quality data and compare the measured data with proposed management triggers and targets. The preliminary report contained some initial comparisons of monitoring data with the draft LAC that had been developed by DEWNR with reference to the water quality targets proposed in the Murray Darling Basin Plan (MDBP 2012), and the Australian and New Zealand Environment and Conservation Council (ANZECC), National Water Quality guidelines (2000). The work indicated that a number of the proposed LAC and water quality management targets were not adequately aligned with the environmental characteristics of the CLLMM site and needed to be re-assessed. The report also showed that the Millennium Drought of 2000-2010 significantly influenced the time series and concluded that analyses should be undertaken of data series excluding the drought period. The present report further collates the monitoring data and attempts to identify time periods that could be used to characterise the water quality and microalgae of the regions and describe the conditions that are most likely to have existed at the time of the designation of the wetland as a Ramsar site. The purpose of this is to support development of the current management targets or to suggest improved targets, and to assess the current condition of the site in regards to water quality and microalgae.

Limits of Acceptable Change, Management Targets and Characteristic Descriptors

Defining the LAC for any ecosystem has proven to be a difficult task. In the context of Ramsar wetlands the LAC have been defined as the variation that is considered acceptable in a particular component or process of the ecological character of the wetland, without indicating change in ecological character that may lead to a reduction or loss of the criteria for which the site was Ramsar listed (DOE modified from definition adopted by Phillips 2006b). In the simplest approach it has been suggested that LAC can be set around the maximum and minimum ranges of a parameter (DSEWPC 2012). Water quality targets are similar in that they are “numerical levels or descriptive statements that must be met within a specified timeframe to protect and maintain environmental values” (Environment Australia 2002). However, in many cases it is not sufficient to solely define wetland LAC as the extremes of a parameter range, as a prolonged shift in the median water quality of a wetland could cause a change in ecological character. Consideration must also be given to seasonal patterns; the frequency, duration and magnitudes of extreme events and events within normal bounds; cyclical events; and ecosystem or species resilience. In many cases the variability of conditions will be just as important as the extreme limits in altering or sustaining the character of a wetland.

In this report we have attempted to define a set of parameters that capture the complexities of the wetland ecosystem while providing descriptive characteristics suitable as management targets and management triggers, at least for those parameters where the monitoring data is currently considered reliable. Three essential but unremarkable sets of indicators have been compiled that we refer to as Characteristic Descriptors. The first of these is the “long term” median value of a parameter; this provides an indication of where a region is poised with respect to its potential parameter range. This might be considered a target value. Exceedance curves were generated to identify the parameter extremes and the total proportion of time spent at particular levels of the parameter range. The extreme values may be seen as management triggers, while the variation shown in these plots indicates that conditions cannot simply be maintained at a constant value, for example just below a critical LAC, in order to meet management requirements. Spell duration curves indicate the typical lengths of time that parameter levels were sustained, particularly the duration of extreme high and extreme low values, again invoking the requirement for variability. This series of steps is followed for each parameter in each of the CLLMM regions where the data allows.

C.Methods

General approach

Sites and samples

The CLLMM region was divided into five distinctive regions for analyses: Lake Alexandrina, Lake Albert, Coorong North Lagoon, Coorong South Lagoon and the Murray Mouth. Previous analyses suggested that, due to the variable hydrological connections between them, these regions were at times sufficiently separated as to have different water quality characteristics (Oliver et al 2013; Oliver et al 2014). In each of these regions the sampling sites with the longest data sets were utilised to provide the templates for describing water quality and microalgae conditions through time (Table 1). Data from the long term sites were collated with data from other, more irregularly sampled sites within the corresponding region, when these extended the period or the frequency of the data available for analyses. In some cases the collated data sets were collected in different ways, (e.g. weekly field samplings and data from deployed recording instruments) and in these cases, where parallel measurements were made on the same day, the values were averaged. In some cases modelled data was used, especially in the Coorong and Murray Mouth regions where monitoring data are scarce.

The data sets, especially those from the field samplings, were often collected at irregular intervals interspersed with extended periods when data was not collected at all. The lack of a regular data sequence made it difficult to reliably describe and analyse time series of parameters and so on occasions the data sets were averaged over different periods (e.g. weekly, monthly, seasonally, annually) to try and improve their regularity, although averaging reduced the temporal resolution of the analyses. In other cases the data were too sparse or too irregular for analyses and simple data displays were used for visual assessment.

Hydrological data

Hydrological data was obtained from DEWNR. This included flows over Lock 1 to approximate the inflow to the Lower Lakes from the River Murray, and calculated flows over the barrages between Lake Alexandrina and the Coorong-Murray Mouth estuary. Also included were measured water levels estimated as the average of 1–5 stations in Lake Alexandrina and the average of 1–3 stations in Lake Albert, site inclusion depending on water depth and extent. In the case of the Coorong South, Coorong North and Murray Mouth regions where measured data was limited, additional modelled outputs were obtained that estimated barrage outflows, salinity and water levels (Jöhnk and Webster 2014).

Water quality data

The CLLMM water quality and microalgae data were extracted from the Environment Protection Authority's (EPA) dataset. This data was collected at various sites and frequencies as previously described (Mosley et al. 2012, Oliver et al. 2013, Oliver et al. 2014; Oliver and Mosley 2014). The physico-chemical water quality parameters included in this report are conductivity, turbidity, total phosphorus (TP), total nitrogen (TN), dissolved oxygen (DO), pH, chlorophyll *a*, and temperature.

Table 1 Long term monitoring sites used in this assessment

Area	Site
Lake Alexandrina	Milang
	Goolwa
	Poltalloch
Lake Albert	Meningie
Coorong - North Lagoon	Monument Road
	Tauwitcherie
	Long Point
	Bonneys
Coorong - South Lagoon	Parnka Point
	Nth Jack Point
	South Salt Creek

Data analysis and visualisation

Water quality analyses

Water quality data from the selected sampling sites is presented in a range of forms depending on the extent of the data (Figure 1). In all cases data are shown as a time series to enable a visual assessment of the suitability for further analyses (Figure 1a). In most cases, and even when the data was not entirely suitable, time series were analysed as "non-exceedance" probability plots (Figure 1b). In addition, where data was sufficient, spell duration analyses were undertaken to indicate the length and probability of occurrence of different durations of typical water quality values (Figure 1c).

The time series show the concentration changes of a water quality parameter indicating the frequency, regularity and continuity of the data set (Figure 1a). Non-exceedance plots show the probability of a particular measure of a parameter not being exceeded, be it based on daily, monthly, annual or other averaging periods. For example, in Figure 1b, the probability of any individual sampling value not being exceeded is shown for daily conductivity measurements at the Meningie sampling site in Lake Albert. A probability of 0.9 means that 90% of the time the water quality parameter has a value below the corresponding daily value. Conversely this means that for 10% of the time the water quality value was exceeded. Annual median values are also shown in Figure 1c and the interpretation is the same except that the probability is of annual medians being below the corresponding annual median value with a 0.9 probability. The spell duration plots indicate for selected values of a water quality parameter, the probability that a particular value will occur for a continuous duration of time. For example Figure 1c shows the spell duration plot for conductivity at Meningie in Lake Albert for data collected prior to the drought. The 99% conductivity non-exceedance level of 1987 µS/cm (i.e. 99% of samples collected prior to the drought were less than this value) is displayed on the spell duration graph and indicates that higher values only occurred for 4 days on average once in every 5 years, while the maximum of a 30 day continuous occurrence happened on average once in every 20 years.

Care is required interpreting both the non-exceedance plots and spell duration plots, as it is often assumed that the probability distribution of the parameter values is always captured by the data set and is consistent over time, which is not always correct. For example, the probability distribution of the data is strongly influenced by the period of time considered. A short set of data is unlikely to represent the total range of variation in the parameter and consequently the probability plots will not be representative. The probability distributions are also influenced by extreme values associated with rare or unusual events, and these values can significantly skew the analyses, especially in time series that are relatively short compared to the duration of an extreme event. The Millennium Drought which ran from 2000 to 2010 across the Murray-Darling Basin catchment is a case-in-point in the data analysed and it significantly influenced the probability plots (Appendix A). In addition, exceedance and spell analyses are influenced by any lack of stationarity in the data, which are circumstances when a parameter is undergoing a continuous change that is trending in one direction, which might occur as a result of the influence of large external forces such as catchment water resource development or climate variation. Consequently the data series is not stable as time proceeds and exceedance probability distributions change when they are recalculated.

Despite these drawbacks, the non-exceedance and spell duration plots provide useful methods for summarising the data from time series, providing visual representation of the data and comparing data to proposed management triggers and LAC. However, they serve as summaries of the best available data and are not necessarily definitive. The extent to which the interpretations can be relied upon is dependent on: the extent of the data; its variability; and other supporting analyses. The longest data sets cover a forty year period from 1975 to 2015, but even with such a long period the 10 year Millennium drought had a major influence on the distribution of probabilities for many parameters. Within the CLLMM the drought impact was most clearly apparent in the water quality data between 2007 and 2010 and in the preliminary report

(Oliver and Mosley 2014; Appendix A) this was considered as the drought period and was highlighted in red both in time series and non-exceedance plots to enable a visual assessment of the water quality impact of this period (e.g. Figure 1). However the more careful definition of the drought period in this report extended that range to include the period 2002 to 2010, so that the results are not directly comparable between the two reports, although often the differences are small. Further expansion of this rationale is provided in the next section.

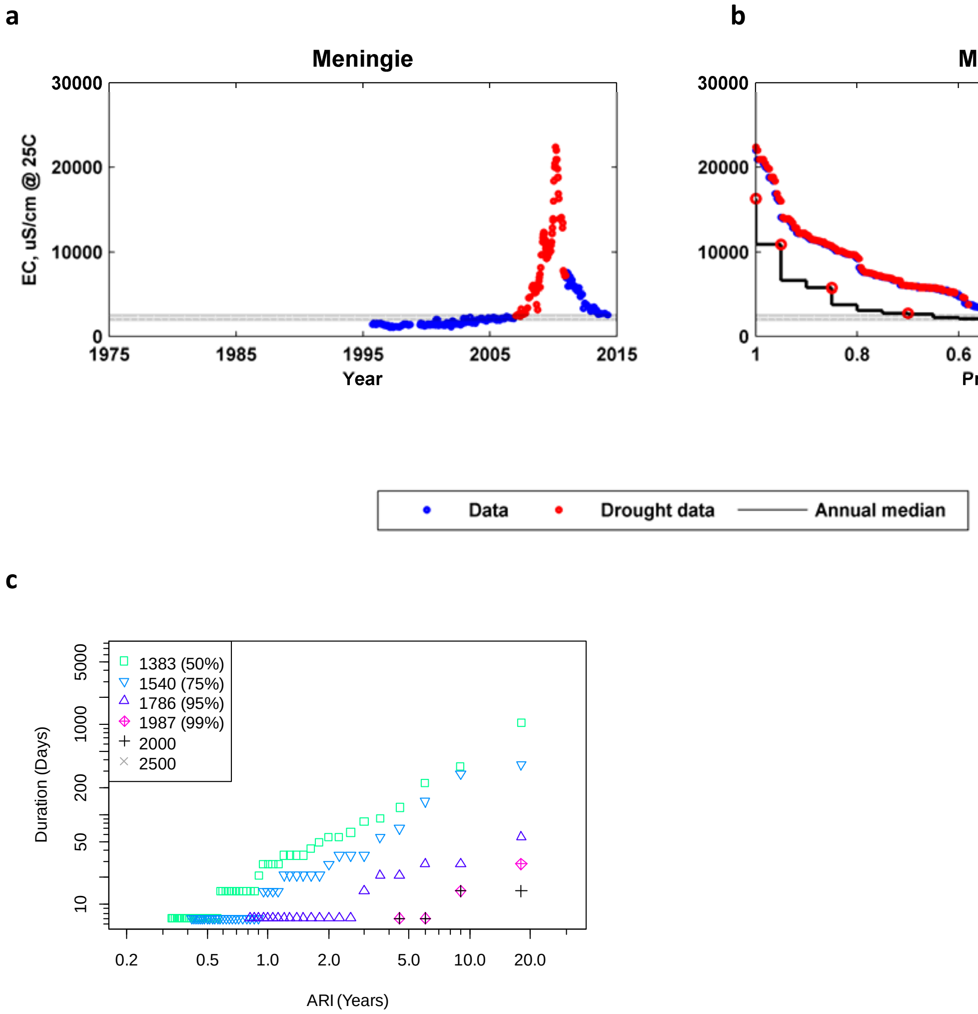


Figure 1 Examples of (a) time series plot (b) non-exceedance probability plot and (c) spell duration plot for conductivity at Meningie in Lake Albert. In the non-exceedance plot the blue and red points are the measured individual data with the red points indicating the drought data, while the black line is the annual median data with open red circles indicating the drought years. The dashed horizontal lines are the relevant LAC, Management Targets or Guidelines. The spell duration plot is for the pre-drought period only, with the coloured symbols indicating the conductivity levels in the key (µS/cm), and the average return interval (ARI) in years for different continuous duration periods in days.

Exclusion of the Millennium Drought period from analyses

There were a number of reasons for not including the drought period in the derivation of management targets. Changes in water quality have occurred since the Ramsar site declaration, but the intention was to set management values that reflected water quality conditions, and ecological responses to water quality, that were as relevant as possible to the time of the declaration, this being considered the best representation of the Ecological Character of the site. The Millennium Drought resulted in catastrophic impacts on water quality and ecology in the CLLMM and were a challenge to its ecological character. The drought had a large anthropogenic driver due to over-development of water resources in the basin and the future water recovery associated with the Basin Plan is designed to ensure that the extreme conditions experienced in the CLLMM during the drought do not occur again (i.e. water levels will not fall below 0 m AHD under the Basin Plan). Consequently, including the drought period in setting LAC and management targets, would bias these values due to the unusually extreme conditions and not be useful for future management, especially under improved Basin Plan flows. These conclusions were supported by the observations that post-drought the water quality and micro-algae communities have not recovered in all areas (e.g. in Lake Albert) and if included would introduce a bias in setting management targets and triggers. For these reasons the descriptors of parameter ranges are based on pre-drought data, although parallel analyses that included the drought data are presented for comparison.

To more objectively identify the period when the Millenium Drought influenced regional water quality, changes in conductivity of Lake Alexandrina were used as an indicator. Lake Alexandrina is directly influenced by changes in flow from the Murray River and conductivity is a measure of salinity, a stable, non-reactive indicator of hydrological change. The Milang conductivity measurements provided a long, uninterrupted series, especially when combined with telemetered gauge data, and produced a detailed data set from 1974, 11 years prior to the Ramsar site designation, up to the present (Figure 2). The time series was analysed for significant changes in salinity using the Lanzante method (Lanzante 1996). This method assesses the “signal-to-noise” ratio of the time series and selects change points when a signal shift is significant compared to the local signal variability. After extensive testing the selection of change periods proved sensitive to small shifts in the data patterns and could be significantly altered by including or excluding only a few data points e.g. with or without an interpolated data point to fill in a single gap in sampling. However, the method consistently identify the large shift in conditions associated with the drought and so it was used to objectively indicate the start and end of the period when drought impacted on conductivity in Lake Alexandrina. Based on this analysis, and rounding to annual periods, the start of the drought period was set as 1/1/2002 while the start of the post-drought period was set as 1/1/2011.

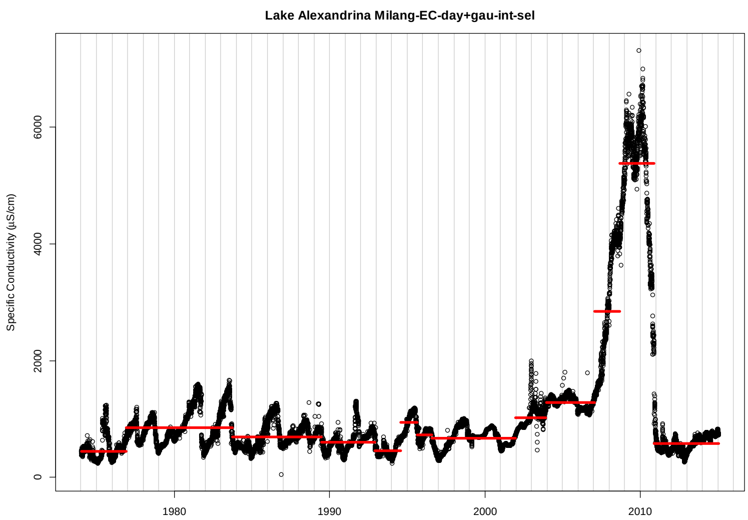


Figure 2 Time series of specific electrical conductivity at Milang showing the periods of change determined by the Lanzante analysis.

Assessing Management targets and LAC

Draft LAC for hydrological characteristics and salinity in the CLLMM were provided by DEWNR (Higham, 2012). Default management values for freshwater-dependent ecosystems declared as Ramsar wetlands are prescribed for particular regional zones in Schedule 11 of the Murray-Darling Basin Plan 2012[1] (Appendix 1). In many cases those values have been selected from the ANZECC national water quality guidelines (ANZECC 2000), but using the generic South Eastern Australia (New South Wales, Victoria) freshwater targets, even for the lower Murray, and it is unlikely that these targets will be applicable to the CLLMM region. However, the Basin Plan provides that targets can be “objectively determined” and revised for a specific region (Appendix 1). More reliable values for the CLLMM might be expected from the ANZECC (2000) guidelines for South Australian estuaries and these have been included in the comparisons to assess their relevance (Appendix 2).

The preliminary report (Oliver and Mosley 2014, see Appendix A) provided a simple measure of the alignment of the Management Triggers and LAC with the available monitoring data from the CLLMM. This used a scoring system based on the percentage of time that the time series measurements fell outside the limits set by the trigger values and LAC using the categories: <10%, 10-25%, 25-75% and >75% of the time. The outcome of this analysis is reproduced in Table 3 and shows that a significant number of target values do not accord well with the monitoring data from the CLLMM region (Oliver and Mosley 2014). The various management targets summarised in Table 2, are displayed on the time series, non-exceedance plots and spell duration analyses derived in this report, to enable a visual assessment of their suitability for the CLLMM regions.

Selecting periods of monitoring data for developing management targets

A key objective of this report was to identify and quantify changes in selected water quality parameters and microalgae across the CLLMM sites over the period from prior to 1985 when the region was declared a Ramsar wetland. A few of the parameters had reliable measurements extending back before 1985 but most did not. To address this short-coming the data from periods following Ramsar designation were assessed for trends in order to assess whether the earlier data in the time series was likely to provide a reasonable estimate of conditions that prevailed at the time of the Ramsar designation. Only Lake Alexandrina and Lake Albert had sufficiently long periods of water quality measurements for this analysis and included the measured Lock 1 flows and recorded lake levels as indicators of changes in hydrology. In contrast, the Coorong regions had limited measurements and modelled values for barrage outflows, water levels and salinity were analysed for trends.

Trends in parameters over time were assessed using the non-parametric Mann-Kendall test (Mann 1945). This test assesses whether water quality concentrations tend to increase or decrease with time (monotonic change). As variables other than time often have considerable influence on water quality fluctuations, obscuring changes over time (Helsel and Hirsch 1992), efforts are made to remove the variation caused by exogenous variables, reducing the background variability or "noise" so that any trend "signal" can be detected. In the Lake Alexandrina and Lake Albert analyses the "exogenous" variable used was water level as this was significantly correlated with water quality in the Lakes (Mosley et al. 2012). The removal of the underlying influence of water level was achieved by first fitting a Locally Weighted Scatter plot Smoothing (LOESS) curve to a plot of the water quality parameter versus water level and then using the residual (R) of the fit in the Mann-Kendall test to identify trends over time (R vs T). The slope and significance (p value) of any trends in unadjusted and LOESS adjusted data were calculated separately for the entire time period, and individually for the pre-drought period (pre 1/1/2002) and the pre- plus post-drought periods combined (pre- 1/1/2002 and post- 1/1/2011). Trends with P-values <0.01 were considered significant. This approach helped to determine whether significant changes in water quality conditions had occurred following the establishment of the Ramsar site. Even with data sets of less than satisfactory duration the

[1] Available at (see legislative instrument): http://www.comlaw.gov.au/Details/F2012L02240/Download

analysis was still undertaken as it provided a useful overview of the changing conditions and helped support judgements regarding how appropriate the non-exceedance plots for pre- drought periods were for setting limits to the water quality conditions.

Table 2 Draft LAC and existing management targets and their sources. Draft LAC were provided by DEWNR (November 2014) while the Basin Plan targets are from Schedule 11 of the Plan (Appendix 1). The ANZECC (2000) values are from tables within the guideline document for the regions South Central Australia (Table 3.3.8; Table 3.3 9) and South East Australia (Table 3.3.2; Table 3.3.3) and these are reproduced in Appendix 2, and the table of trigger values for toxicants (Table 3.4.1) reproduced in Appendix 3.

Zone	Hydrology	Salinity/ Conductivity (µS/cm @ 25°C)	Turbidity (NTU)	TP (µg/L)	TN (µg/L)	DO (% Saturation)[1]	pH	Chl. *a* (µg/L)	Temp. (°C)	Dissolved metals
Lake Alexandrina	**Flow:** **Low flow:** <1000GL/year for 3 out of 6 years. **High flow:** >6000GL/year with Average Annual Return Interval (ARI) 1 in 5 or more; AND/OR >10,000GL/year with ARI 1 in 10 or more. (Draft LAC) **Water level:** Maintained at or above 0.6 m AHD for 8 or more months/year for 3 consecutive years, with <0.5m variation in average monthly levels. (Draft LAC) >0.4 m AHD 95% of the time, >0 m AHD 100% of the time (Basin Plan)	Annual salinity levels should not be >1500 for 2 or more consecutive years out of any 6 year rolling period (Draft LAC) Salinity maintained <1000 EC for 95% of years and less than 1500 all of the time (Basin Plan)	Annual Median 20 (Basin Plan/ANZECC – South East Australia) Upper limit 100 (ANZECC South Australia)	Annual Median 10 (Basin Plan/ANZECC – South East Australia) Trigger value 25 (ANZECC – South Australia)	Annual Median 350 (Basin Plan/ANZECC – South East Australia) Trigger value 1000 (ANZECC – South Australia)	Annual median within range 90–110% (Basin Plan and ANZECC for lower limit)	Annual Median 6.5–8.0 (Basin Plan/ANZECC – South East Australia) Lower and upper limits 6.5–9.0 (ANZECC South Australia)	Trigger value 5 (ANZECC guideline SE Australia lakes) No target provided in ANZECC South Australian guideline or Basin Plan for lakes.	Monthly median between the 20th and 80th percentiles of natural monthly water temperature (Basin Plan)	Metal concentrations enable protection of 99% of species (ANZECC/Basin Plan)

Zone	Hydrology	Salinity/ Conductivity (µS/cm @ 25°C)	Turbidity (NTU)	TP (µg/L)	TN (µg/L)	DO (% Saturation)[1]	pH	Chl. *a* (µg/L)	Temp. (°C)	Dissolved metals
Lake Albert	**Water level** >0.4 m AHD 95% of the time, >0 m AHD 100% of the time (Basin Plan)	*Salinity maintained <2000-2500 (provided by Ann Marie Jolley (DEWNR), from Heneker report)*	Annual Median 20 (Basin Plan/ANZECC – South East Australia) Upper limit 100 (ANZECC South Australia)	Annual Median 10 (Basin Plan/ANZECC – South East Australia) Trigger value 25 (ANZECC – South Australia)	Annual Median 350 (Basin Plan/ANZECC – South East Australia) Trigger value 1000 (ANZECC – South Australia)	Annual median within range 90–110% (Basin Plan and ANZECC for lower limit)	6.5–8.0 Annual Median (Basin Plan/ANZECC – South East Australia) Lower and upper limits 6.5–9.0 (ANZECC South Australia)	Trigger value 5 (ANZECC guideline SE Australia lakes)	Monthly median between the 20th and 80th percentiles of natural monthly water temperature (Basin Plan)	Metals and other toxicant concentrations enable protection of 99% of species (ANZECC/Basin Plan)
Coorong – North Lagoon (NL) & Murray Mouth (MM)	**Flow:** Max number of days since water flow ≤339 days. (Draft LAC). **Water depth:** Average water depth ≥1.99m. (Draft LAC). (Note, depth not defined as AHD)	NL: average monthly conductivity (salinity) not to exceed 93,000 EC (75ppt)[2] for more than 18 month period within any 3 year rolling period (Draft LAC). Maximum daily average salinity <50ppt (Basin Plan) *Estuary and MM: Average monthly conductivity (salinity) not to exceed 55,000 EC (40ppt) for more than any 18 month period within any 3 year*	Upper limit 10 (ANZECC upper limit for estuaries)	Trigger value 100 (ANZECC-South Australia, Estuary)	Trigger value 1000 (ANZECC-South Australia, Estuary)	90–110% (ANZECC for lower limit)	Lower and upper limits 6.5–9.0 (ANZECC South Australia)	Trigger value 5 (ANZECC guideline for South Central estuaries)	Monthly median between the 20th and 80th percentiles of natural monthly water temperature (Basin Plan)	Metals and other toxicant concentrations enable protection of 99% of species (ANZECC)

Zone	Hydrology	Salinity/ Conductivity (µS/cm @ 25°C)	Turbidity (NTU)	TP (µg/L)	TN (µg/L)	DO (% Saturation)[1]	pH	Chl. *a* (µg/L)	Temp. (°C)	Dissolved metals
		rolling period. – (Draft LAC).								
Coorong – South Lagoon (SL)	**Flow:** Max number of days since water flow ≤339 days. (Draft LAC). **Water level** South Lagoon ≥0.37m AHD; Daily tidal range ≥0.05 m; Max (Draft LAC).	Average monthly conductivity (salinity) in SL should not exceed 118,000 EC (100ppt)[2] for more than 18 month period within any 3 year rolling period. (Draft LAC). Maximum average daily salinity <100ppt (Basin Plan)	Upper limit 10 (ANZECC upper limit for estuaries)	Trigger value 100 (ANZECC-South Australia, Estuary)	Trigger value 1000 (ANZECC-South Australia, Estuary)	90–110% (ANZECC)	Lower and upper limits 6.5–9.0 (ANZECC South Australia)	Trigger value 5 (ANZECC guideline for South Central estuaries)	Monthly median between the 20th and 80th percentiles of natural monthly water temperature (Basin Plan)	Metals and other toxicant concentrations enable protection of 99% of species (ANZECC)

1. Where dissolved oxygen saturation (DO_s in mg O_2/L) at a particular temperature (°C) = 14.652 - (0.41022T) + ($0.007991T^2$) - ($7.7774E^{-5}$ T^3) ; from Cox (2003).

2. Where Salinity (mg/L) = 0.5865 * Conductivity + 3 x 10^{-6} * conductivity^2 - 7 x 10^{-12} * conductivity^3 (where conductivity is in µS/cm at 25°C) from Webster (2009), or Conductivity (µS/cm at 25°C) = 1.5911 * Salinity – 6 x 10^{-6} * salinity^2 + 2 x 10^{-11} * salinity^3 (where salinity is in mg/L)

D. Results and Discussion

Introduction

Preliminary report (Appendix A)

Water quality time series and non-exceedance probability plots were presented in the preliminary report - both for the sampling data, and for annual medians of the sampling data, at sites within each region of the CLLMM (Oliver and Mosley 2014). The figures in that report described the Lake Alexandrina sites of Milang, Goolwa and Poltalloch and the Lake Albert site of Meningie (Appendix A: Figures 2 to 11); the Coorong North Lagoon sites of Monument Road, Tauwitcherie, Long Point and Bonneys (Appendix A: Figures 12–20); and the Coorong South Lagoon sites of Parnka Point, Nth Jack Point and South Salt Creek (Appendix A: Figures 21–28). The proposed and current management targets collated for the CLLMM region (Table 2) were included in the figures for comparison with the monitoring data. The report is included as an appendix as the figures provide a useful overview of data across the CLLMM regions and including the influence of the Millennium Drought. The results from the preliminary report regarding the appropriateness of the proposed LAC and current Management Targets as assessed from comparisons with the monitoring data are reproduced in Table 3.

Trend analyses: LOESS curve fits of water quality to water level

The individual trend curves for water quality parameters, with and without LOESS adjustment for water level, are included in the relevant sections of the report for comparison with other analyses. The adjustment for the variation in water level is based on LOESS fits of the water quality parameters to water level changes. In both Lake Alexandrina (Figure 3), and to a slightly lesser extent Lake Albert (Figure 4), the LOESS curves closely followed the changes in most water quality parameters (EC, TN, TP, chlorophyll a) when water levels fell significantly from their usual ranges. The large water depth reductions due to the drought greatly influenced water quality, and LOESS adjustments during this period were expected to have a significant influence on assessing trends.

Collation of Characteristic Descriptors for parameters

In the following sections, each of the five regions of the CLLMM is considered in turn and findings regarding the characteristics of the water quality parameters are illustrated with sets of figures. Drawn from these data are a number of Characteristic Descriptors which comprise all or some of the following: a long term median; the 1st, 5th, 95th and 99th percentiles; continuous duration periods in days, and the average return intervals for higher and lower percentiles. We are not necessarily proposing that these selected values are particular management targets/triggers or LAC. Decisions regarding those targets will require wider discussions, but the values do provide descriptions of the parameters and their variability that are useful for assessing the proposed and current LAC and management targets/triggers. The resulting descriptors determined from the analyses for each site and parameter are summarised in Table 4.

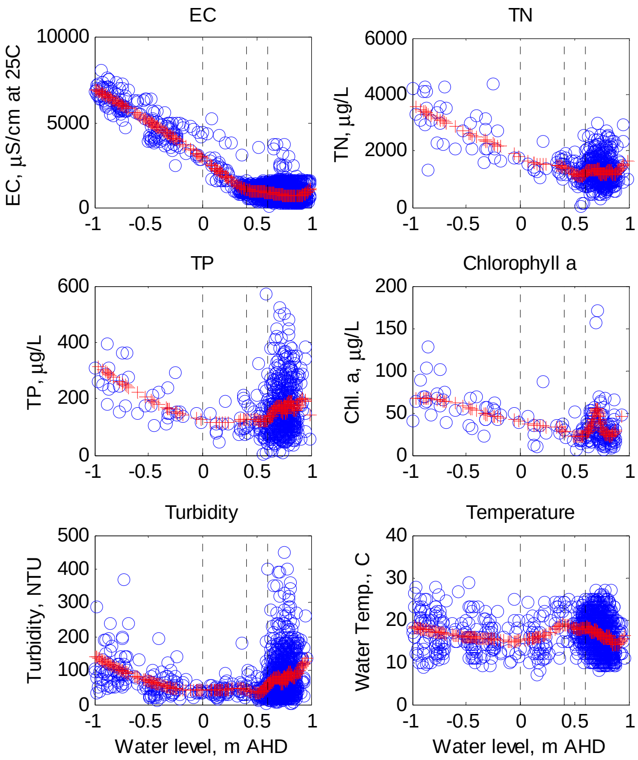


Figure 3 Water quality at Milang at different water levels in Lake Alexandrina. The red line is the LOESS fit of the data and is used to adjust the trend tests.

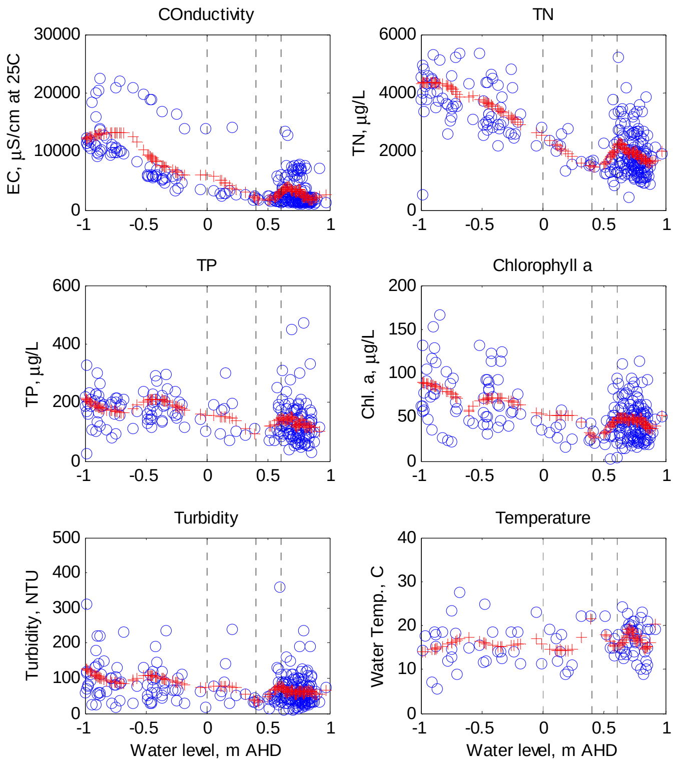


Figure 4 Water quality at Meningie at different water levels in Lake Alexandrina. The red line is the LOESS fit of the data and is used to adjust the trend tests.

Table 3 Assessment of historical water quality against existing targets and draft LAC as described in Table 2. Colours indicate the percentage of time the draft LAC/guidelines are not met: Red >75% of time, **Blue** >25-75% of time, Orange 10-25% of time and Green <10% of time. Temperature data were not analysed.

Zone	Hydrology	Salinity/ Conductivity	Turbidity	TP	TN	DO	pH	Chl. a	Temp.	Dissolved Metals
Lake Alexandrina	Inflow (See Table 2) Water Level AHD (See Table 2)	Not >1500 EC for 2 or more years out of 6 (LAC) <1000 EC 95% of years and <1500 EC all of the time (Basin Plan)	20 NTU 100 NTU	10 µg/L 25 µg/L	350 µg/L 1000 µg/L	90-110%	pH 6.5- 8 pH 6.5-9	5 µg/L	*NA*	Low when pH>6.5
Lake Albert (Frequently limited data and assumed to match Lake Alexandrina at Milang)	Water Level AHD (See Table 2)	<2000-2500 EC	20 NTU 100 NTU	10 µg/L 25 µg/L	350 µg/L 1000 µg/L	90-110%	pH 6.5- 8 pH 6.5-9	5 µg/L	*NA*	Low when pH>6.5
Coorong – North Lagoon (NL) & Murray Mouth (MM)	Zero flows in ≤339 days Depth ≥1.99m (depth undefined)	Not >55000 EC for 18mths in any 3 years (LAC) Not >93000 EC for 18mths in any 3 years (LAC)	10 NTU	100 µg/L	1000 µg/L	90-110%	6.5-9	5 µg/L	*NA*	Low when pH>6.5
Coorong – South Lagoon (SL)	Zero flows in ≤339 days ≥0.37m AHD	Not >118,000 EC for 18mths in any 3 years (LAC)	10 NTU	100 µg/L	1000 µg/L	90-110%	6.5-9	5 µg/L	*NA*	Low when pH>6.5

Table 4 Characteristic descriptors of water quality parameters in the CLLMM including references to figures displaying the relevant data; values of the Median and 1st, 5th, 95th and 99th percentiles; duration in days of periods with ARIs of 1, 5 and 10 years for the 1st and 99th percentiles where for the 1st percentile durations are for periods below the value and for the 99th percentile the durations are for periods above the value. Blanks indicate a lack of suitable data.

Zone	Flow (ML/d)	Water Level (mAHD)	Conductivity (µS/cm)	Turbidity (NTU)	TP (µg/L)	TN (µg/L)	DO (mg/L)	pH	Chl. *a* (µg/L)	Temp. (°C)	Dissolved metals
Lake Alexandrina											
Figure	5	6	7	8	9	10	12	Appendix A Figure 8	11	13	
Median	8062	0.77	660	60.5	144.2	1150	9.2		22.6		
1st %	397	0.55	284	17.4	32.9	513	6.2		13.3		
Less than exceedance:											
1 Year ARI Duration (days)	1	1	1	NA	NA	NA	NA				
5 Year ARI Duration (days)	8	5	5	NA	NA	NA	NA				
10 Year ARI Duration (days)	10	8	10	30	30	30	30				
5th %	1301	0.61	350	20.9	56.0	720	7.6		14.2		
95th %	72400	0.87	1200	207.8	322.4	2000	10.9		41.2		
99th %	119432	0.90	1486	290.7	419.9	2526	11.8		46.0		
Greater than exceedance:											
1 Year ARI Duration (days)	NA	1	1	NA	NA	NA	NA				
5 Year ARI Duration (days)	NA	5	8	NA	NA	NA	NA				
10 Year ARI Duration (days)	10	8	10	30	30	30	30				

Zone	Flow (ML/d)	Water Level (mAHD)	Conductivity (µS/cm)	Turbidity (NTU)	TP (µg/L)	TN (µg/L)	DO (mg/L)	pH	Chl. *a* (µg/L)	Temp. (°C)	Dissolved metals
Lake Albert											
Figure	**As above**	14	15	16	17	18	20	Appendix A Figure 8	19	21	
Median		0.75	1383	48.4	91.3	1458	9.5		36.8		
1st %		0.49	1075	8.3	42.8	865	7.0		17.8		
Less than exceedance:											
1 Year ARI Duration (days)		1	NA	NA							
5 Year ARI Duration (days)		5	7	NA							
10 Year ARI Duration (days)		8	14	NA							
5th %		0.56	1150	13.0	58.9	1049	7.2		20.2		
95th %		0.89	1786	158.0	288.0	2580	11.9		70.6		
99th %		0.97	1987	250.3	431.5	3364	13.3		101.7		
Greater than exceedance:											
1 Year ARI Duration (days)		1	NA	NA							
5 Year ARI Duration (days)		6	7	NA							
10 Year ARI Duration (days)		8	14	NA							

Zone	Flow (ML/d)	Water Level (mAHD)	Salinity (ppt)	Turbidity (NTU)	TP (µg/L)	TN (µg/L)	DO (mg/L)	pH	Chl. *a* (µg/L)	Temp. (°C)	Dissolved metals
Coorong/ Murray Mouth											
Barrage Flows											
Figure	22										
Median	4213										
1st %	0										
Less than exceedance:											
1 Year ARI Duration (days)	NA										
5 Year ARI Duration (days)	NA										
10 Year ARI Duration (days)	1										
5th %	0										
95th %	66713										
99th %	106415										
Greater than exceedance:											
1 Year ARI Duration (days)	NA										
5 Year ARI Duration (days)	7										
10 Year ARI Duration (days)	14										

Zone	Flow (ML/d)	Water Level (mAHD)	Salinity (ppt)	Turbidity (NTU)	TP (µg/L)	TN (µg/L)	DO (mg/L)	pH	Chl. *a* (µg/L)	Temp. (°C)	Dissolved metals
Coorong North											
Figure	**As above**	23	25	31	32	33	Appendix A Figure 21	Appendix A Figure 19	34	35	
Median		0.29	37.5	9.6	158.6	2295			28.8		
1st %		-0.12	7.9	3.6	58.8	803			9.9		
Less than exceedance:											
1 Year ARI Duration (days)		1	NA								
5 Year ARI Duration (days)		4	7								
10 Year ARI Duration (days)		5	14								
5th %		-0.03	13.0	4.3	72.0	1064			13.3		
95th %		0.80	62.8	31.9	314.0	4604			56.5		
99th %		0.97	72.7	37.4	362.1	5975			71.0		
Greater than exceedance:											
1 Year ARI Duration (days)		1	NA								
5 Year ARI Duration (days)		7	NA								
10 Year ARI Duration (days)		14	1								

Zone	Flow (ML/d)	Water Level (mAHD)	Salinity (ppt)	Turbidity (NTU)	TP (µg/L)	TN (µg/L)	DO (mg/L)	pH	Chl. *a* (µg/L)	Temp. (°C)	Dissolved metals
Coorong South											
Figure	**As above**	26	27	36	37	38		Appendix A Figure 26	39	40	
Median		0.28	74.8	16.3	288	5399			56.7		
1st %		-0.35	28.1	6.2	132	2282			9.2		
Less than exceedance:											
1 Year ARI Duration (days)		NA	NA								
5 Year ARI Duration (days)		NA	NA								
10 Year ARI Duration (days)		5	NA								
5th %		-0.24	36.3	7.8	151	3095			12.4		
95th %		0.82	110.9	28.5	510	8837			86.0		
99th %		0.99	128.1	37.1	718	10561			108.2		
Greater than exceedance:											
1 Year ARI Duration (days)		NA	NA								
5 Year ARI Duration (days)		7	NA								
10 Year ARI Duration (days)		10	1								

Zone	Flow (ML/d)	Water Level (mAHD)	Salinity (ppt)	Turbidity (NTU)	TP (µg/L)	TN (µg/L)	DO (mg/L)	pH	Chl. *a* (µg/L)	Temp. (°C)	Dissolved metals
Murray Mouth							Appendix A Figure 21	Appendix A Figure 19			
Figure	**As above**	28	29	41	42	43			44	45	
Median		0.26	23.6	8.3	83	866			13.5		
1st %		-0.09	0.0	0.5	32	210			1.7		
Less than exceedance:											
1 Year ARI Duration (days)		1	NA								
5 Year ARI Duration (days)		4	NA								
10 Year ARI Duration (days)		6	NA								
5th %		-0.01	0.0	1.0	34	330			2.7		
95th %		0.68	41.5	134.0	288	2315			73.4		
99th %		0.87	46.0	169.0	503	3129			91.1		
Greater than exceedance:											
1 Year ARI Duration (days)		1	1								
5 Year ARI Duration (days)		5	4								
10 Year ARI Duration (days)		10	14								

Lake Alexandrina:

Lake Alexandrina Inflows

The draft LAC proposed for the inflows to the Lower Lakes are expressed as average annual flows and their average return intervals (Table 2). As inflows were estimated from the hydrograph at Lock 1, there are some uncertainties about the reliability of these values and also about their actual relationship to the flows that reach Lake Alexandrina. As a result there are different estimates available of the flows into the Lake. Using the Lock 1 gauged flows including the drought period (Appendix A:Figure 2), the annual non-exceedance plot showed that annual flows were below the lower target for only 25% of the time compared with the proposed LAC of approximately 50% of the time, indicating that historically flows were not as low for so often. Flow exceeded the two upper targets for about 30% and 15% of the time so exceeding the proposed ARI of 20% and 10% respectively, suggesting larger flows occurred more often than the minimum set by the LAC. The proposed LAC appear to describe a lower set of flow levels than the historical values, even though the historical series included periods of intense water resource development that have led to changes in the ecology of the CLLMM as evidenced by reductions in bird, fish and plant populations. This requires improved resolution and so further consideration and definition of the proposed LAC are needed.

Annual flow requirements do not reflect the within-year flow patterns that are required to sustain the ecology of a site. This is problematic from an ecological character perspective, as the annual flow target could be delivered in many different ways, some of which would not sustain the flow dependent ecosystems. To provide a better resolution of the patterns, the daily flows at Lock 1 were analysed over the time series (Figure 5a). Comparison of exceedance plots of daily flows by seasons for the complete data set, and for the period prior to the Millennium Drought, indicated a significant difference, especially in autumn flows. Based on the exceedance analyses for all (i.e. not seasonally separated) pre-drought flow data, the long term median was 8062 ML/day (2944 GL/year) and the duration and ARI for this flow was included in the spell duration plots (Figure 5d and 5e). The spell duration plots also show the durations and ARI for the 75th, 95th, and 99th percentiles of flow (Figure 5d) and the 1st, 5th, and 25th percentiles of flow (Figure 5e). The extreme percentiles may be suitable values to consider for management triggers and perhaps as LAC and they are summarised in Table 4. Especially relevant to setting targets is identifying the typical durations and return occurrences of extremes. Also shown on the spell duration curves are durations of periods when any flows occurred at all, that is flows above the minimum flow level (Figure 5d), and durations of zero flows, that is below the minimum flow level (Figure 5e). No flow periods were of durations <20 days. The seasonal differences that are evident in Figure 5c for the pre-drought period, with highest flows in spring and summer, have not been analysed in detail.

Lake Alexandrina water levels

Proposed hydrological targets for Lake Alexandrina are also set through water level conditions and often include a return interval component, but the current descriptions are difficult to interpret and require further clarification (Table 2). The proposed LAC indicates that water level should be maintained at or above 0.6m AHD for 8 or more months per year (ca. 66% of time) for 3 consecutive years, but does not indicate what should occur outside the eight months or the 3 years. Further bounds are required to clearly define this LAC.

An extended time series of water levels was available for Lake Alexandrina and clearly showed the significant effect of the drought (Figure 6a). Exceedance plots of this data confirmed the large effect of the drought (Figures 6b and 6c) and the following analyses utilised the pre-drought period as a better indicator of earlier conditions. The long term median water level was 0.77m with a 95th percentile of 0.87m and values higher than this occurred 5% of the time typically for durations of about 5-20 days with ARIs of 1 to 10 years (Figure 6d). The 5th percentile was 0.61m and similar to the proposed LAC value. Levels less than this typically occurred for 5 to 10 days durations with ARIs of 1 to 7 years. However occasionally, about every 10 to 20 years, levels less than 0.61m lasted for up to about 100 days, which is similar to the LAC value, except the LAC indicates this could occur annually. Rarely did levels fall below 0.55m, the 1st percentile, and only then for a maximum of 5 days (Figure 6e).

The proposed LAC recommends a limit of <0.5m variation in average monthly levels. Monthly levels were not investigated but the seasonal difference in the distribution of water levels was very small, with a maximum range in level of about 0.5m, supporting the proposed variation term in the LAC (Figure 6c).

The Basin Plan provides a simpler guide to water level, and is applied to both Lake Alexandrina and Lake Albert, but it may allow the level to drop below the draft LAC. The guide is that water level should be >0.4m AHD for 95% of the time, and above 0.0m AHD all of the time (Table 2). In Lake Alexandrina water level was not observed to drop below 0.4m at any time in the pre-drought data, whereas in the basin plan this could occur for 5% of the time. Water level did not drop below zero AHD prior to the drought which is in accordance with the Basin Plan target for water level to always be above this value.

Lake Alexandrina Conductivity/salinity

The proposed LAC is based on annual conductivity levels not exceeding 1500 EC for 2 or more consecutive years out of any 6 year rolling period (Table 2). As mentioned previously in relation to flows, using annual levels as indicators has problems because annual medians (assuming this is what was meant in the LAC) can be achieved in different ways, at least some of which might not support the ecosystems. The Basin Plan provides the simpler guide that average daily conductivity should be less than 1000 EC for 95% of years and less than 1500 EC all of the time.

An extended time series of conductivities was available for Lake Alexandrina, although sampling ceased between 1999 and 2003, a rather critical time with respect to the onset of the drought (Figure 7a). The exceedance plots for all the conductivity data (Figure 7c) and for the pre-drought data (Figure 7d) confirmed the major influence of the drought. The trend plots indicated that even when the analysis was restricted to the pre-drought period there was a significant increase in conductivity at an average rate of 8 µS/cm per year (Figure 7b). The pre-drought data series covered approximately 25 years over which time, due to the trend, the average conductivity was predicted to have increased by 200 units. The median conductivity of the pre-drought data was 660 µS/cm so an increase in 200 units over the monitoring period was significant. However, rather than try to identify a reduced period of earlier data to set an initial value, all of the pre-drought data was included. Consequently the average characteristic conductivity derived from the pre-drought analyses might be about 100 µS/cm larger than expected at the beginning of the time series.

The 95th percentile was 1200 µS/cm and values higher than this had typical durations of 5-10 days with ARI's of 2 to 10 years (Figure 7e). The 99th percentile was 1486 µS/cm close to the LAC value of 1500 µS/cm with values greater than this having maximum durations of 5-10 days and ARI's of 3-20 years.

The lower range of salinities are often considered less important as all are classified as freshwaters and expected to have similar ecological effects on the receiving systems. However, as their occurrences could be important to particular organisms, or in maintaining median conditions, so the data is presented in Figure 7f.

Lake Alexandrina Turbidity

The Basin Plan sets the annual median turbidity target at 20 NTU, which is the default ANZECC guideline for South East Australia (Appendix 2). The turbidity time series for Lake Alexandrina shows that these low levels are infrequently attained, even outside the drought period (Figure 8a). An alternative target is 100 NTU, the upper limit of the ANZECC Guidelines for South Australia, which falls within the time series (Figure 8a). The trend analyses of turbidity in Lake Alexandrina suggested that turbidity had declined over time (Figure 8b). Even when using only the data for the pre-drought period, the turbidity was predicted to have declined over time at a rate of 5NTU per year. Over the 17 years of the pre-drought time series this would represent a decline of 85 NTU. It is suspected that the decline in turbidity is associated with the increase in conductivity and increased lake residence time due to reduced flows (Oliver et al 2010; Mosley et al. 2012). The non-exceedance plots for the total time series and for the pre-drought data are not greatly different. Using the pre-drought period as the best estimate of prior conditions the median turbidity was 60.5NTU, although this may be approximately 40 NTU less than expected due to the declining trend. This would suggest a median near 100 NTU that matches the proposed target. The other characteristic descriptors may similarly have been less at the start of the monitoring sequence. Seasonal differences are evident in the non-exceedance plots, with turbidity often substantially higher in spring and summer than in winter and autumn (Figure 8d). This seasonality has not been further analysed with the following findings based on the full pre-drought data series.

The 95th percentile turbidity was 207.8 with higher values lasting for between 100 and 200 days with ARI's of 10 to 20 years (Figure 8e). The 99th percentile turbidity was 290.7 NTU and higher values occurred for 30-60 days duration with ARI's of 10-20 years (Figure 8e). On the lower side the 1st and 5th percentiles were 17.4NTU and 20.9NTU respectively and occurrences below these values only occurred for 1 or 2 months with ARI's of 10-20 years.

The non-exceedance plot for pre-drought conditions indicated that the suggested target of 10 NTU was achieved less than 10% of the time, and even this may be overestimated. The target is clearly unsuitable for this system, whereas the upper limit ANZECC guideline for South Central Australia at 100 NTU appears to be more appropriate.

Lake Alexandrina Total Phosphorus (TP)

The total phosphorus guideline in the Basin Plan is for an annual median of 10 µg/L, which is the default ANZECC guideline for South East Australia (Appendix 2). This is less than half the commensurate ANZECC guideline value for South Central Australia, which is 25 µg/L. The time series of TP data showed that neither of these values appeared appropriate to the conditions observed in the Lakes as they were well below most of the measurements (Figure 9a). The trend analysis of the time series indicated that there was a slight but significant decline in TP of 1.5 µg/L per year. Over the approximately 25 years of pre-drought data this would lead to a reduction in concentration of 37.5 µg/L. This was unexpected as increasing human disturbance in catchments usually leads to increases in TP loads unless careful management is put in place, and there are no large scale management improvements to reduce TP loads in the catchments supplying the CLLMM. Instead, the decline in TP over time is suspected to be associated with the parallel decline in turbidity, as much of the TP is associated with suspended particles. Consequently the decline in

TP is also associated with the increasing conductivity and lake residence time. These interconnections suggest how the change in one parameter, such as conductivity, can potentially influence a raft of water quality attributes.

Differences between the exceedance curves for the total data set and for the pre-drought period were small, suggesting no major changes in TP ranges even during the drought period (Figures 9c and 9e). Analyses were carried out on the pre-drought data giving a median TP of 144.2 µg/L. As with other parameters, the declining trend over time was significant compared to the median and indicated that values earlier in the sequence may be of the order of 19 µg/L lower than the average estimates.

The 95th percentile was a TP concentration of 322.4 µg/L and the 99th percentile 419.9 µg/L. The highest concentrations occurred only for 1-3 months with ARI's of 10-20 years. The 1st percentile was 32.9 µg/L and values less than this similarly occurred only for a month with ARI's of 10-20 years. These data suggested that the proposed targets are unrealistic, unless there is a desire to reduce the nutrient levels in the lakes below those observed for the thirty years prior to the drought, perhaps based on targets from general lake management models. For example, TP is often related to the microalgae concentration that occurs in lakes and efforts to reduce the plankton biomass where it is problematic often include reductions in nutrient loads, especially of phosphorus.

Lake Alexandrina Total Nitrogen (TN)

The TN target set in the Basin Plan is an annual median of 350 µg/L, which is the ANZECC guideline value for South East Australia (Appendices 1 and 2). The time series of TN data indicated that this guideline was well below most of the measurements (Figure 10a). The ANZECC upper limit guideline for South Central Australia is 1000 µg/L which appeared to be more reasonable, at least occurring within the observed data range. The trend analysis of the TN data suggested that there was no significant change over time in concentrations ($p>0.01$) (Figure 10b). The exceedance plots of the complete TN time series (Figure 10c) and the pre-drought data (Figure 10d) did not differ greatly except for some higher values in the total data set that were due to the drought, as evident from the time series (Figure 10a). The median TN of the pre-drought data was 1150 µg/L, similar to the ANZECC upper limit guideline for South Central Australia, suggesting higher concentrations in the Lake than expected. Whether this indicates that the TN concentration in the lakes is too high, or that the guideline is too low, requires further consideration, but the available data suggests that the guideline is too low. The 95th percentile TN concentration was 2000 µg/L typically occurring for up to 1-2 months with ARI's of 3-15 years. The 99th percentile TN concentration was 2526 µg/L occurring occasionally for 1-2 months duration. The 1st percentile TN concentration of 513 µg/L indicates that the Basin Plan targets are too low.

Lake Alexandrina Chlorophyll-*a*

The ANZECC guidelines do not contain trigger values for chlorophyll-*a* that are relevant to the Lower Lakes (there is no value for South Central Australia). They are either for freshwater lakes and reservoirs in South East Australia or for open estuaries, in both cases suggesting 5 µg/L as guideline values (Appendix 2). The chlorophyll-a data for Lake Alexandrina is sparse and disjointed and there are few pre-drought data points, but overall the time series suggests that the concentrations in the lake are always higher than the proposed target values (Figure 11a). Despite the sparseness of the chlorophyll-*a* data the standard analyses were applied to provide a visual assessment of the information. There was insufficient pre-drought data for a reliable trend analysis and so in addition to an analysis of the total data set, the pre- and post- periods were also combined to see if there were significant changes following the drought. The time series suggested that the drought had a significant effect on the chlorophyll-a concentration with higher values more evident (Figure 11a). Analyses of the LOESS adjusted combined pre- and post-periods indicated there were no significant changes in chlorophyll-a concentration outside of the drought period once corrected for water level (Figure 11b). Based on this, the pre-drought data was used to describe the characteristics of the chlorophyll-a concentration, but the data was limited and the analysis unreliable. Major differences were apparent between the exceedance curve for all data (Figure 11c) and for pre drought data (Figure 11d). The limited pre-drought data indicated a median chlorophyll-a concentration of 22.6 µg/L whereas the exceedance curve for all data indicated a median of 35 µg/L. The pre-drought data indicates a 99th percentile concentration of 46 µg/L.

Lake Alexandrina Dissolved Oxygen

The Basin Plan values for dissolved oxygen are based on percent saturation values and are equivalent to the lower ANZECC trigger value for South Central Australia and South East Australia, and an upper value equivalent to the ANZECC trigger value for South East Australia. The target is to have annual median percent saturation between 90 and 110%. As discussed previously, the problem with annual medians is that they can hide within them conditions that are unsuitable for the ecosystem. An extreme example is 11 months of 110% saturation and a single month of 0% saturation provides an annual mean of 100% saturation so meeting the target, yet a month of zero oxygen would be catastrophic to most systems. Also, percent saturation is not always an ideal measure as the same percentage does not mean the same oxygen concentration as the oxygen solubility is also affected by other conditions including temperature and salinity. As temperature and salinity increase, the same saturation level represents a decreased concentration of oxygen. Percent saturation is often a useful way to quickly compare conditions, but as organisms respond to oxygen concentrations targets should also be set on dissolved oxygen concentrations. In the water quality database, most measurements included the oxygen concentration while only a small proportion also reported percent saturation. In the preliminary report these data were compared with the guidelines (Appendix A: Figure 11). The comparison indicated that at the freshwater Milang sampling site oxygen concentrations fell below the 90% lower limit approximately 30% of the time and above the upper limit 10% of the time with a median value of 100% saturation. Importantly, because of the lethal effect of very low oxygen levels on aquatic organisms, the exceedance plot indicated that 95% of the time the oxygen saturation was above 50% which would not generally be considered problematic. However, the 5% of the time below 50% saturation could be potentially problematic as it represents 5% of 15 years, so extended durations of low oxygen concentrations could have occurred.

The oxygen concentration time series for Lake Alexandrina was analysed to provide characteristic descriptors (Figure 12a). The trend analysis was not undertaken as the concentration range for most of the data was relatively narrow. The exceedance curves for all of the data (Figure 12b) and for the pre-drought data (Figure 12c) showed little difference, but with a small number of higher oxygen concentrations when all data was included as a result of the drought period. The pre-drought data had a median oxygen concentration of 9.26 mg/L and a 95th percentile of 10.91 mg/L (Figure 12e). Most concern with oxygen is if concentrations fall too low and so the 1st and 5th percentiles are of importance (Figure 12f). These were respectively 6.15 and 7.57 mg/L which are not expected to cause problems especially as these levels lasted for only 1 or 2 months (Figure 12f).

Lake Alexandrina Temperature

The Basin Plan temperature guidelines are that the monthly medians should be between the 20th and 80th percentile of the natural monthly water temperature. The time series of temperature in Lake Alexandrina indicated a relatively consistent pattern that was not significantly influenced by the drought (Figure 13a) as was also concluded by Mosley et al. (2012). The trend analyses of the temperature data indicated that there was no significant change over time in the Lake and the exceedance plot for all data showed a range largely between 10°C and 25°C (Figure 13b). Temperature limits are set on a monthly basis because of the strong, cyclical seasonal changes that are evident in the data, the importance of temperature to a wide range of biotic and abiotic functions, and the irrelevance of setting longer term targets such as annual medians. Box plots showed the characteristics of the monthly temperatures for all of the data (Figure 13c) and for the pre-drought data (Figure 13d) were not greatly different. A possible problem with the proposed guide is that most monthly mean temperatures could increase by a degree or more and still remain within the 20th and 80th percentile of the monthly temperature range. A prolonged shift of this magnitude could influence the character of the system and the guidelines should also contain some indication of a long term median. This would provide a stronger basis for identifying change, so that the effects could be considered to inform wetland management.

Lake Alexandrina pH

The guideline values for pH in the Basin Plan are the ANZECC values for South East Australia, which is that the annual median should be between 6.5 and 8. This outcome was not observed at any of the lake sites, where the annual exceedance plot indicated that approximately 90% of the time the median exceeded pH 8 (Appendix A: Figure 8). The high pH values observed in the lakes are probably related to the large biomass of microalgae that often develops seasonally. The South Central Australia guideline with its increased upper value of pH 9 appears to be better aligned with the typical levels observed in the lakes, and is exceeded only a small percentage of the time. Values of less than the lower limit (pH 6.5) were recorded only under exceptional circumstances during rewetting of exposed acid sulfate soils on the lake margins during the Millenium Drought (Mosley et al. 2014).

Lake Albert

Lake Albert Water level

The Basin Plan targets for Lake Albert are the same as for Lake Alexandrina, that water level should be >0.4m AHD 95% of the time and >0.0m AHD 100% of the time. The time series showed the major influence of the drought period on water levels (Figure 14A) as did a comparison of the exceedance plots for all of the data (Figure 14b) and for the pre-drought data (Figure 14c). Analyses were restricted to the pre-drought period to provide an estimate of earlier typical water levels that influenced the ecosystems. The median water level for the pre-drought period was 0.75m AHD with the 95th percentile at 0.89m AHD (Figure 14e). There is less concern about higher water levels but this is somewhat misplaced as it is important that water level variation occurs over a range and with a pattern that supports the ecosystem. On average the higher water level was observed for periods of 8-20 days with ARI's of 1-5 years. The 99th percentile water level was 0.97m AHD which occurred for periods of 1-10 days with ARI's of 1-10 years. Wetting the upper edges of lakes, even for short periods, can produce significant ecological responses, for example in supporting the growth of fresh biofilm and riparian vegetation. Lower water levels are generally considered of greater concern because they reflect the reduced water availability. The 5th percentile water level was 0.56m AHD while the 1st percentile level was 0.49m AHD. These water levels were higher than the proposed targets with the 5th percentile 0.16m higher than the target value. Whether or not this is critical depends on the characteristics of the lake morphology, the ecosystems at the water's edge, and how the 0.4m target value would be applied, especially as the measured levels only fell below 0.49m AHD for 1% of the time and for durations of only 1-5 days (Figure 14f). The suggested target requires further investigation, including discussions concerning lake edge conditions.

Lake Albert Conductivity

A proposed guideline value for conductivity in Lake Albert is that it should be maintained <2000-2500 µS/cm. The time series of measurements indicated that prior to the drought conductivities were often substantially below these values and were consistently exceeded only after several years of drought (Figure 15a). Trend analysis of the pre-drought data with LOESS adjustment indicated that salinity was not changing significantly over time, suggesting the pre-drought data might provide a reliable estimate of prior conditions (Figure 15b). Exceedance plots of all data and of pre-drought data confirmed the large effect of the drought period and the relatively small variation in conductivity prior to the drought (Figures 15c and 15d). The median conductivity for the pre-drought period was 1383 µS/cm, substantially less than the guideline values, with the 95th and 99th percentile conductivities of 1786 and 1987 respectively closer to the proposed lower guideline value (Figure 15e). However, the 99th percentile values only occurred for periods of 7-30 days with ARI's of 5-20 years, suggesting the guideline is too high. Even the 95th percentile only lasted for periods of a few days to 2 months, although occurring more frequently (Figure 15e). The 5th percentile conductivity level was 1150 µS/cm and similarly only occurred for periods of a few days to 2 months with ARI's of 1-20 years (Figure 15f). The guideline does not capture the typical median conductivities in Lake Albert, or the typical range of values and their variation over time. The targets for this require further definition.

Lake Albert Turbidity

The turbidity target set in the Basin Plan is that the annual median be 20 NTU which is the default ANZECC guideline for South East Australia (Appendix 2). The turbidity time series for Lake Albert showed that these levels were infrequently attained, even outside the drought period (Figure 16a). An alternative target of 100 NTU, the upper limit of the ANZECC Guidelines for South Central Australia, fell within the time series (Figure 16a). The trend analyses of turbidity in Lake Albert suggested that turbidity had not changed significantly over time (Figure 16b). The non-exceedance plots for the total time series and for the pre-drought data were not greatly different (Figures 16c and 16d), but the pre-drought period was analysed to generate the best estimate of prior conditions, even though this greatly reduced the data set. As a result the characteristic descriptors are less reliable and should be considered indicative only. The pre-drought median turbidity was 48.4 NTU, substantially less than the 60.5 NTU median in Lake Alexandrina, which may be nearer 100 NTU if the decreasing turbidity trends in the lake are taken into consideration. The pre-drought 95th percentile turbidity in Lake Albert was 158 NTU with the 5% occurrences greater than this lasting for between 30 and 90 days but infrequently in the available data set (Figure 16e). On the lower side the 5th percentile was 13 NTU but again with few occurrences in the limited data set. More reliable estimates are made of values that occur more frequently and in considering target values it may be better to use the 25th and 75th percentiles in this case.

The non-exceedance plot for pre-drought conditions indicated that the suggested target of 20 NTU was achieved less than approximately 10% of the time and is unsuitable for this system. The upper limit ANZECC guideline for South Central Australia is 100 NTU which appeared to be high for this Lake.

Lake Albert Total Phosphorus

The total phosphorus target in the Basin Plan is that the annual median be 10 µg/L, which is the default ANZECC guideline for South East Australia (Appendix 2). This is less than half the commensurate ANZECC guideline value for South Central Australia of 25 µg/L. The time series of TP data for Lake Albert was limited, but suggested that neither of these values appeared to be appropriate as both were below most of the measurements (Figure 17a). The LOESS adjusted trend analyses of the time series are unreliable because of the limited data set and the large gaps in monitoring, but suggested that there was no significant change in TP over time, except when the drought data was included in the analysis (Figure 17b). Differences between the exceedance curves for the total data set and for the pre-drought period were apparent, with higher values in the total data set due to drought and post-drought conditions (Figures 17c and 17d). The exceedance curve for the pre-drought data was too sparse to be reliable but was the only source of data on pre-drought conditions. Best estimates from the exceedance curve indicated a median TP of 91 µg/L, a 95th percentile of 288 µg/L, and a 5th percentile of 58.9 µg/L. The pre-drought data was too sparse for spell duration analyses. These results indicate that the annual median values proposed in the Basin Plan are unsuitable for Lake Albert.

Lake Albert Total Nitrogen

The TN target set in the Basin Plan is an annual median of 350 µg/L which is the ANZECC guideline values for South East Australia (Appendix 1 and 2). The time series of TN data indicated that this was well below most of the measurements (Figure 18a). The ANZECC upper limit guideline for South Central Australia is 1000 µg/L which appeared more relevant to the Lake although most measurements were also above this level. The trend analyses of the LOESS adjusted TN data suggested that there has been an increase in TN over time in the Lake, but the pre-drought data is too sparse to provide a reliable estimate even though the slope is significant (Figure 18b). The trend analyses of the pre- plus post-drought data suggested a small rate of increase that is not significant at the p=0.01 level, and on balance it was concluded that there was not a significant change in TN during the pre-drought measurements. The Lake Alexandrina measured TN data (Figure 10) supported this conclusion. Comparison of the exceedance plots showed generally increased concentrations when all data were used (Figure 18c) compared to the limited pre-drought data (Figure 18d). The exceedance curve for the pre-drought data was too sparse to be reliable but was the only source of information on earlier conditions. Best estimates from the data indicated a median of 1458 µg/L with a 95th percentile of 2580 µg/L and a 5th percentile of 1049 µg/L. This indicated that the ANZECC upper limit guideline for South Central Australia of 1000 µg/L might be too low a target for this lake.

Lake Albert Chlorophyll-*a*

The ANZECC guidelines do not contain trigger values for chlorophyll-*a* that are relevant to the Lower Lakes (there is no value for South Central Australia). They are either for freshwater lakes and reservoirs in South East Australia, or for open estuaries, in both cases recommending 5 µg/L as guideline values (Appendix 2). The chlorophyll-a data for Lake Albert was sparse and there were few pre-drought data points, but overall the time series indicated that the concentrations in the Lake were always higher than the proposed target values (Figure 19a). Despite the sparseness of the chlorophyll-*a* data the standard analyses were applied to provide a visual assessment of the information. The time series suggested that during the drought significantly higher chlorophyll-a concentrations were experienced (Figure 19a). Analyses of the LOESS adjusted pre-drought and combined pre- and post-periods indicated that there was no significant change in chlorophyll-a concentration outside of the drought period (Figure 11b). Major differences were apparent between the exceedance curve for all data (Figure 19c) and for pre drought data (Figure 19d). Based on this, the pre-drought data were used to describe the characteristics of the chlorophyll-a concentrations even though the data were limited and the analyses unreliable. The pre-drought data indicated a median chlorophyll-a concentration of 36.8 µg/L whereas the exceedance curve for all data indicated a median of 50 µg/L. The pre-drought data indicated a 99th percentile concentration of 101.7 µg/L and a 5th percentile of 20.2 µg/L. The suggested guidelines do not appear to be suitable for this lake.

Lake Albert Dissolved Oxygen

The Basin Plan values for dissolved oxygen are based on percent saturation and are equivalent to the lower ANZECC trigger value for South Central Australia and South East Australia, and an upper value equivalent to the ANZECC trigger value for South East Australia. The target is to have the annual median percent saturation between 90 and 110%. Although percent saturation is often a useful way to quickly compare conditions, organisms respond to oxygen concentrations and targets should also be set around these values. The oxygen concentration time series for Lake Albert was very limited, and comprised data largely from the drought period (Figure 20a). These measurements generally fell within a similar range to those observed in Lake Alexandrina indicating that the Lake was generally well oxygenated. The exceedance plot for all of the data (Figure 20b) was also similar to that observed for Lake Alexandrina with a median oxygen concentration around 10 mg/L. The characteristic descriptors from Lake Alexandrina appear to be suitable for Lake Albert when the Lakes are connected.

Lake Albert Temperature

The Basin Plan temperature guidelines are that the monthly medians should be between the 20th and 80th percentile of the natural monthly water temperature. The applicable time series of temperature in Lake Albert was restricted to the drought and post-drought periods (Figure 21a).

The trend analyses of the LOESS adjusted temperature data indicated that there was no significant change over time in the Lake. As seen in Lake Alexandrina there was a relatively consistent pattern in temperature within a range of 10°C to 25°C that was not significantly influenced by the drought (Figure 21c). Temperature limits are set on a monthly basis because of the strong, cyclical seasonal changes that occur; the importance of temperature to a wide range of biotic and abiotic functions; and the irrelevance of setting longer term targets such as annual medians. Box plots were not reliable for the small amount of pre-drought data available and so all data were used to show the characteristics of the monthly temperatures (Figure 21d). As observed for Lake Alexandrina, a potential problem with the proposed guideline is that most monthly mean temperatures could increase by a degree or more and still remain within the 20th and 80th percentile of the monthly temperature range, yet a prolonged shift of this magnitude could influence the ecological character of the system. To avoid this, the guidelines should contain an indication of a long term median to provide a stronger basis for identifying change, and so that the effects could be considered to inform wetland management.

Lake Albert pH

As with some of the previous parameters the guideline values for pH in the Basin Plan are the ANZECC values for South East Australia. The Basin Plan guideline is that the annual median should be between pH 6.5 and 8 but this is not typical of the lake where instead, approximately 90% of the time, the median exceeds pH 8 (Appendix A: Figure 8). The South Central Australia guideline with its increased upper value of pH 9 appears to be better aligned with the typical levels observed in the lakes, and was exceeded only a small percentage of the time in Lake Albert.

Lower Lake metals and acidity

The relationship between dissolved metal concentrations and pH in the Lower Lakes is shown in Appendix Figure 29. This data was collected during the extreme drought period only. Dissolved metal exceedances above the ANZECC (2000) guidelines to protect aquatic ecosystems are only likely if pH is less than 6.5 and as discussed above for each of the Lakes, this is the lower guideline limit for pH and so metals are not discussed here.

The acid sulfate soil draft LAC that has been proposed to help manage acid sulfate soils, that the "lake margin sediment alkalinity is less than 1.5 mg/L of calcium carbonate" needs revision as the water quality data used to derive this number was measured in the water column and cannot be transferred to sediment quality. Generally, sediment alkalinity is not measured in mg/L but in $CaCO_3$ per kg of sediment. The net acidity data from the sediment (=acid generating capacity-acid neutralising capacity) is more routinely used to derive an acid sulfate soil hazard assessment. However, the potential acid neutralising capacity associated with the sediment $CaCO_3$ does not readily relate to ecological risk as $CaCO_3$ comprises much of the shell material of molluscs and other organisms and it seems inappropriate to consider these as buffers to acidification. Hence it is considered appropriate to simply have a pH (<6.5) and water level target (0m AHD in the Basin Plan) to prevent acid sulfate soil impacts on ecological character. If a specific sediment quality LAC is desired then pH (e.g. pH<5) would be preferable as this corresponds to the point at which sediments release metals such as Al.

The Coorong areas: modelled water level and salinity

In general there was far less data available for the Coorong sites than for the Lakes. This made reliable analyses more difficult and required a greater use of modelled data in order to describe the range of variation in parameters. In the following sections, the barrage flows that influence all of these regions are analysed and then the matching modelled data on water level and salinity are analysed for each of the sites in turn. After that each of the water quality parameters that were collected using grab samples are compared across the sites but there was relatively little data available, particularly for the pre-drought period.

Coorong North, Coorong South and Murray Mouth: Barrage Flows

The major source of freshwater flow to the estuarine system is through the barrages from Lake Alexandrina. At times there is also flow into the Southern Coorong from the Morella Basin which is part of the Upper South East Drainage System. The relative contribution from the Morella Basin is typically small, although it directly influences the South Lagoon. DEWNR plans to alter the catchment characteristics and discharge patterns of Morella Basin through its South East Flow Management Action (a component of the CLLMM Recovery Project). That activity could alter the reliability of these analyses in representing water quality for the Southern Lagoon.

In the preliminary report (Appendix A: Figure 12) modelled and measured data on barrage flows to the Coorong, and inflows to the Coorong Southern Lagoon from Morella Basin, were summed to give total inflows. The time series plot and exceedance plot of the annual median data provided a first approximation to assess the draft LAC that the maximum number of days since some flow should be ≤339 days at all sites. The non-exceedance plot of annual medians, including the drought period, indicated that annual periods of no-flow occurred around 10% of the time (Appendix A: Figure 12). The time series indicated that zero annual flows did occasionally occur for one year and that it was only during the drought that longer periods were observed. Based on this data the draft LAC seemed to define some of the flow requirements, at least in terms of no-flow periods, but it did not provide information on the frequency of occurrences of flow periods occurring at ≤339 day intervals, or what flows might sustain the ecological character of the site. In essence “some flow” may not be sufficient to maintain character. Hence further discussion and revision of the Coorong flow LAC/targets is recommended.

Measured barrage flows were available on a daily basis but were closely represented by modelled flows that “standardised” the data across the different measurement techniques used over time (Jöhnk and Webster 2014). The modelled flow data were used in the analyses because: they were consistent across time, they underpinned the modelled series of salinity and water levels at the sites, and because there was little measured data.

The time series of modelled flows showed the impact of the Millennium Drought (Figure 22a). Trend analyses are difficult for this type of intermittent zero flow data, but suggested little change over the period (Figure 22b). The influence of the drought on flow patterns can be seen from comparison of the exceedance plots for all data (Figure 22c) and for pre-drought data (Figure 22d), with differences clearly evident during winter and autumn. The pre-drought data were considered to best represent conditions that might have existed at the time of the Ramsar designation. The -drought data had a median daily flow of 4213 ML/day with a 95^{th} percentile of 66,713 ML/day (Figure 22e) and a 5^{th} percentile of zero flow. The periods of zero flow and their duration are an important attribute as they strongly influence the water quality and hydrology of the receiving systems. Around 25% of the time during the pre-drought period there were zero flows, with durations of 1 to 300 days and ARI's of 1 to 20 years (Figure 22f). A maximum zero flow period lasting 2 years occurred once in the data set. The pre-drought data indicated that a year of zero flows occurs with an ARI of about 5 years. The simple LAC that has been proposed captures this data pattern, but it needs to go further and clearly identify the frequency of occurrence of no-flow durations. Also the spell duration plot for flows below the median indicated that there was generally a step up from zero flows to the median value, with only a small percentage of time in between. Perhaps this is an operational quirk, but pre-drought flows below the median value were rare. Based on this the suggested "some flow" in the proposed LAC should perhaps be the median value or higher.

Coorong North Modelled Water level

The proposed LAC for the North Lagoon is an average water depth of ≥1.99m. Unfortunately the modelled water level data, and also the measurements from the monitoring database, were in metres AHD. No simple conversion could be found between water depth and AHD and consequently the data analyses could not be readily compared to the proposed LAC. In fact DEWNR no longer has a LAC associated with water depth in the North Lagoon although this is likely to be an important attribute.

The water level fluctuations in the North Lagoon did not show any long term trends and even the drought measurements fell within the ranges of pre-drought levels (Figures 23a and 23b). This is probably the result of the ocean influence through the Murray Mouth that provides a minimum depth and a range of fluctuations even without flow over the barrages. The similarities of the flow patterns were evident in the exceedance plots for the total data set (Figure 23c) and for the pre-drought data (Figure 23d) which showed only small differences. However, exceedance plots presented in the first report of the total data set showing the drought period indicated a major change (Figure 30). The maximum water levels that occurred for approximately 7% of the time in the pre-drought period were not sustained during the drought, during which maximum levels were >0.1m lower. This lowering could potentially have major influences on the functioning of lake edge and shallow water ecosystems.

Further analyses used the pre-drought data in an effort to ensure descriptors that were representative of earlier periods relevant to the Ramsar designation. The pre-drought exceedance plot indicated a median value of 0.29m AHD with a 95th percentile of 0.8m and a 5th percentile -0.03m AHD. These characteristics could not be converted to water depths and compared with the LAC, a shortcoming that needs to be addressed. It was not apparent where the water depth LAC was derived from but it will probably be preferable to have the LAC defined in terms of AHD to enable easier comparison to the measured values. The highest and lowest levels had maximum durations of 1-3 weeks (Figures 23e and 23f) implying that a drop in water level from the highest values could result in desiccation for as much as 3 weeks in the littoral and shallow regions.

Given extended periods of water level measurements were available for the North Lagoon, these are presented in Figure 24 for comparison with Figure 23 to demonstrate that the modelled data provided a reliable representation of the actual data.

Coorong North modelled salinity

As limited measurements of conductivity data were available for the Coorong North Lagoon, modelled data were used in the analyses. The time series of modelled salinity showed the significant influence of the drought (Figure 25a). The trend analyses indicated a pre-drought increase in salinity of 0.22 ppt per year which over the 37 years of data represented a shift of almost 6 ppt (Figure 25b). The drought influence was also evident in the difference between the non-exceedance plots for all data (Figure 25c) and the pre-drought period (Figure 25d). The median salinity of the pre-drought modelled data was 37.5 ppt, quite similar to seawater, with a 95th percentile of 62.8 ppt and a 5th percentile of 13 ppt. These values may be somewhat higher than would have occurred in the absence of the gradual salinity increase, perhaps by about 3 ppt. The draft LAC for the North Lagoon is that average monthly salinity does not exceed 75 ppt for more than an 18 month period within any 3 year rolling period. The spell duration curve for salinities higher than the median (Figure 25e) contained the 75 ppt response and indicated that salinities of this level and higher had occurred for only 2 days with an ARI of 5 years, and a maximum duration of 30 days with an ARI of 20 years. This does not seem to match well with the proposed LAC as an 18 month period of salinities greater than 75 ppt did not occur at all in the data from the pre-drought period. The proposed LAC seems high for this region and this is problematic as a high salinity in the Northern Lagoon will drive higher salinities in the Southern Lagoon and consequently the proposed LAC requires further consideration.

Coorong South Modelled Water level

The draft LAC for the South Lagoon is that water levels should be ≥0.37m AHD with a daily tidal range of ≥0.05m. The modelled time series of water level fluctuations in the South Lagoon did not show any long term trends and even the drought period measurements fell within the ranges of pre-drought levels (Figure 26a and 26b). The trend analyses indicated that there was a slow decline in level when all the data was used, but no significant change when the pre-drought, or the pre- plus post-drought data (ie. without the drought period), were analysed, indicating the influence of the drought. Exceedance plots using all of the data and highlighting the drought period showed a reduction in maximum water levels from ca. 1.2m to 0.85m (Figure 30). Although these high water levels only occurred for short periods of time they are capable of causing critical alteration to the edge ecosystems as a 0.35m reduction in maximum level could result in substantial loss of shallow riparian areas including important mudflat habitat for wading birds. The exceedance plots for the total data set (Figure 26c) and for the pre-drought data (Figure 23d) showed only small differences in distributions, but further analyses were based on the pre-drought data in an effort to ensure descriptors were representative of earlier periods relevant to the time of the Ramsar designation. The pre-drought exceedance plot had a median value of 0.28m AHD with a 95th percentile of 0.82m and a 5th percentile -0.24 AHD. This lower percentile is substantially less than the -0.03m for the North Lagoon. The spell duration analyses indicated that the proposed LAC depth of 0.37m AHD had a similar distribution of durations to the median value (Figures 26e and 26f) and that both higher and lower water levels would be expected. This does not seem to be in accord with the suggested LAC that water levels should be ≥0.37m AHD.

Actual water level measurements were available through part of this period (not shown) and gave similar results to the model, as demonstrated for the North Lagoon (Figure 23 and Figure 24). However, as the measured data covered a shorter period of time, the modelled data were used.

Coorong South modelled salinity

As limited measured conductivity data was available for the Coorong South Lagoon, modelled data was used in the analyses. The time series of modelled salinity showed the significant influence of the drought (Figure 25a). The trend analysis of the pre-drought data indicated that salinity was increasing at 0.47ppt per year (Figure 25b). Over the 37 year data period this would result in an increase of 17 ppt, a considerable change that might be expected with occurrence of a decreasing exchange of water into the Southern Lagoon. The drought influence was evident in the difference between the exceedance plots for all data (Figure 25c) and the pre-drought period (Figure 25d) and analyses were based on the pre-drought data. The median salinity was 74.8 ppt, about twice the concentration of seawater, with a 95th percentile of 110.9 ppt and a 5th percentile of 36.3 ppt.

The draft LAC for the South Lagoon is that average monthly salinity should not exceed 118,000 EC (100ppt) for more than an 18 month period within any 3 year rolling period. The spell duration curve for salinities higher than the median (Figure 27f) indicated that salinities of 100ppt and higher occurred for 200 sequential days with an ARI of 5 years. This does not seem to match the proposed LAC although further analyses are required to determine if an 18 month total period, but not of sequential duration, occurred in any 3 year period. An initial assessment is that the proposed LAC seems high for the region.

Murray Mouth Modelled Water level

The proposed LAC for the Murray Mouth is an average water depth of ≥1.99m but the water level data estimated from the model, and also the measurements from the database, were in metres AHD. No simple conversion between water depth and AHD could be found so the analyses could not readily be compared to the LAC.

The water level fluctuations in the Murray Mouth did not show any long term trends and even the drought period measurements fell within the ranges of pre-drought levels (Figure 23a). This is likely to be the result of the ocean influence through the Murray Mouth that provides a minimum depth and a range of fluctuations even without flows over the barrages. However the exceedance plot of all data with the drought period highlighted showed that even in this area maximum water depths were not attained during the drought (Figure 30). This highlights the importance of barrage flows in sustaining water levels in the Coorong and Murray Mouth. The exceedance plots for the total data set (Figure 23c) and for the pre-drought data (Figure 23d) showed only small differences so further analyses used the pre-drought data. The pre-drought exceedance plot indicated a median value of 0.26m AHD with a 95th percentile of 0.68m and a 5th percentile -0.01 AHD. Diurnal tidal ratios were not calculated in this analysis but could also be useful to consider in terms of setting water level LAC for the Murray Mouth.

Murray Mouth modelled salinity

The time series of modelled salinity showed the significant influence of the drought (Figure 29a). Trend analyses of the pre-drought data suggested no significant change over time, which is likely to be the result of the ocean influence through the Murray Mouth (Figure 29b). The drought influence is evident in the difference between the exceedance plots for all data (Figure 29c) and the pre-drought period (Figure 29d) and pre-drought data was used for the analyses. The median salinity was 23.6 ppt, below that of seawater and due to the freshening by the barrage flows, with a 95th percentile of 41.5 ppt and a 5th percentile of 0.0 ppt, although this lower value is a limit of detection issue as salinity does not decrease to zero. The draft LAC for the Murray Mouth is that average monthly salinity does not exceed 55,000 EC (40ppt) for more than any 18 month period within any 3 year rolling period. The meaning of this is not entirely clear, as to whether it is the rolling monthly average, or a sequence of 18 months, or a selection of the highest 18 months in a three year period with salinities in excess of the LAC. Further clarification is required. The spell duration plot for salinities higher than the median (Figure 29e) showed the 40 ppt response and indicated that salinities of this level and higher occurred for only 20 sequential days with an ARI of 5 years, and a maximum duration of 30 sequential days with an ARI of 20 years. This does not seem to match well with the proposed LAC as an 18 month period of salinities greater than 40 ppt did not occur in the data from the pre-drought period. Alternatively, if the LAC means that for less than half the time in any rolling 3 year period (any 18 months) the salinity is less than 40ppt, this does not match with a median of 23.6 ppt, except if the salinity was very low for the other half of the time. Also the LAC does not set any upper limit for when salinity is >40ppt. The proposed LAC seems high for this region when compared with the modelled data.

Coorong estuary, North lagoon and South lagoon Water Quality

The same target values have been set in the North Lagoon, South Lagoon and Murray Mouth for the selected water quality parameters (Table 2). Consequently each water parameter is dealt with in turn, for all regions, in the following sections.

Turbidity

In each of the Coorong areas monitoring data was only available from 2000 to2013, with few data points outside the drought period (Figure 31a; Figure; 36a; Figure 41a). Due to the limited data the exceedance plot for each total data set was analysed (Figure 31b; Figure 36b; Figure 41b), although with only 4 years of data these plots are unlikely to be good indicators of the long term character of the sites. However, as this is the only data available the basic character descriptors were extracted from these exceedance curves. At the Coorong North site there was a median turbidity of 9.6 NTU with a 95th percentile of 31.9 NTU and a 5th percentile of 4.25 NTU. At the Coorong South site the median turbidity was 16.3 with a 95th percentile of 28.5 and a 5th percentile of 7.8 NTU. At the Murray Mouth site the median turbidity was 8.3 with a 95th percentile of 134 and a 5th percentile of 1.0 NTU. The high turbidity in the Murray Mouth was related to high barrage flows and presumably reflected the delivery of more turbid freshwaters. The lower values at other sites likely reflect aggregation of colloids in the high salinities and particle settling. The ANZECC Guidelines set a maximum turbidity value for estuaries of 10 NTU which was exceeded 20-60% of the time in the North Lagoon and 70-80% of the time in the South Lagoon. Whether the data is representative of the long term turbidity of each site or represents a shift in turbidity since the designation of the Ramsar site cannot be determined. Perhaps the ANZECC guideline sets a desirable target, but it may be unrealistic for these areas and further monitoring is required to assess this.

Total Phosphorus

Similar to turbidity, the data for TP from sampling sites was available only for the period 1997 to 2013, with a slightly longer pre-drought period than turbidity (Figures 32a; 37a; 42a), but still too short for reliable analysis. The characteristics of each data set were determined from the exceedance plots of all data (Figures 32b; 37b; 42b). In the Coorong North, the median TP was 158.6 with a 95th percentile of 314 and a 5th percentile of 72. In the Coorong South the median was 288 with a 95th percentile of 510 and a 5th percentile of 151. In the Murray Mouth the median was 83 with a 95th percentile of 287.6 and a 5th percentile of 34. The ANZECC guideline values for South Central Australian estuaries were used to place the measured data into context (Appendix 2). Total phosphorus exceeded the 100 µg/L guideline between 40% and 90% of the time in the North Lagoon (Appendix A: Figure 18) and 90%-95% of the time in the South Lagoon (Appendix A: Figure 25), indicating that either the guideline is too low or the Coorong region is enriched. Considerations will need to include an assessment of whether the various areas are considered excessively nutrient enriched and how to make this judgement.

Total Nitrogen

Total nitrogen sampling matched that of TP and so only covers the period 1997 to 2013 (Figures 33a; 38a; 43a). The characteristics of each data set were determined from the exceedance plots of all data (Figures 33b; 38b; 43b). In the Coorong North, the median TN was 2295 with a 95th percentile of 4604 and a 5th percentile of 1064. In the Coorong South the median was 5399 with a

95th percentile of 8837 and a 5th percentile of 3095. In the Murray Mouth the median was 866 with a 95th percentile of 2315 and a 5th percentile of 330. The ANZECC guideline value for South Central Australian estuaries is 1000 µg/L. In the Coorong North Lagoon the total nitrogen values exceeded the guideline between 50% and 100% of the time, depending on the site (Appendix A: Figure 17) while in the South Lagoon the guideline was exceeded 100% of the time (Appendix A: Figure 24). As with TP, further assessment is required before target values could be established.

Chlorophyll-*a*

Chlorophyll-a measurements were only available from 2000 to 2013 (Figures 34a; 39a; 44a). In the Coorong North the median value was 28.8 µg/L with a 95th percentile of 56.5 and a 5th percentile of 13.3. In the Coorong South the median was 56.7 µg/L with a 95th percentile of 86 and a 5th percentile of 12.4. In the Murray Mouth the median was 13.5 µg/L with a 95th percentile of 73.4 and a 5th percentile of 2.7. The ANZECC guideline value for estuaries is 5 µg/L chlorophyll-*a*. In the Coorong North Lagoon and estuary the chlorophyll-*a* concentration exceeded the guideline value between 80% and 100% of the time depending on location (Appendix A: Figure 20). Similarly in the South Lagoon the chlorophyll-*a* concentration was above the guideline value for 90% to 100% of the time, with very high values, greater than 40 µg/L (hyper-eutrophic), occurring over 50% of the time (Appendix A: Figure 27). Further analyses should provide improved trigger values relative to the observed measurements, but consideration will also need to be given to what are desired levels within the system.

Dissolved oxygen

There were few oxygen measurements available to us from any of the locations and analysis was not possible.

Temperature

Temperature data included sampling data and also gauged data from telemetered stations but the time period was relatively short, 1998-2014 in the North and South Lagoon, and from 2002-2014 in the Murray Mouth (Figures 35a; 40a, 45a). The exceedance plots indicated similar temperature ranges across all sites and similar to those observed in the Lakes (Figures 35b; 40b, 45b) with a range of 10^0 to 25^oC. Monthly data was summarised in box plots and the monthly medians for each full data set (Figures 35c; 40c, 45c) and for the pre-drought data when it was available (Figures 35d; 40d), showed similar ranges across sites. The Basin Plan temperature guideline is that the monthly medians should be between the 20th and 80th percentile of the natural monthly water temperature and these limits are shown on the box plots. A potential problem with the proposed guideline is that most monthly mean temperatures could increase by a degree or more and still remain within the 20th and 80th percentile of the monthly temperature range. A prolonged shift of this magnitude could influence the character of the system. To avoid this, the guidelines should contain some indication of a long term median to provide a stronger basis for identifying change, even if the change cannot be managed.

pH

The South Central Australia ANZECC guideline values of pH 6.5-9 are shown on the plots of pH for the North Lagoon and Murray Mouth estuary (Appendix A: Figure 19) and the South Lagoon (Appendix A: Figure 26). In both the North Lagoon and the South Lagoon the pH was always within the guideline values and generally showed a narrow range of variation, suggesting that these were suitable targets.

Comparisons with microalgae community changes

Microalgae respond quickly and continuously to changing water quality conditions potentially providing accessible, immediate and continuous warnings to inform management actions. Previous reports (Oliver et al 2013; Oliver et al 2014) used multivariate analyses to describe the changes in water quality and microalgae in the Lakes before and after the drought. The other sites were largely precluded from this comparison because of insufficient data. It was found that in both Lake Alexandrina and Lake Albert, the microalgae community composition changed significantly in response to the drought. In Lake Alexandrina the microalgae community shifted from dominance by green algae to cyanobacteria (Figure 46). Multivariate analyses of the microalgae community indicated that it had changed between 1997/98 and 2005/06 and had then remained in the new condition (Figure 48). This shift was aligned with changes in the water quality that occurred between 1997/98 and 2005/06, but unlike the microalgae community composition the water quality returned to the prior conditions in 2010/11 and has remained similar since (Figure 47).

The microalgae data from Lake Albert was more restricted than from Lake Alexandrina (Figure 49), but in 2005/06 when the monitoring commenced the community composition was similar to that in Lake Alexandrina and remained so up to 2006/07 when it became dissimilar to that in the adjacent lake. The time series of community composition in Lake Albert indicated that it had not returned to pre-drought conditions (Figure 51). Water quality in Lake Albert was also similar to that in Lake Alexandrina in 2005/06 but then varied from it in the following years and remained significantly different at the end of the monitoring sequence (Figure 50). These analyses were constrained by a lack of monitoring of the critical years during the shift into the drought period. However the data does suggest that prior to the drought, in the period from 1982/83 until 1997/98, the microalgae community composition filled a consistent environmental space. This consistency in the microalgae composition would suggest that many of the analyses carried out on water quality attributes prior to the drought could provide reasonable estimates of conditions prevalent at the time of the designation of the Ramsar site. This argument could also hold for the flow analyses, but will not be as relevant to parameters such as water level. Changes in water depth do influence microalgae but not in the same way that they influence littoral zone environments and water shallows used by wading birds and attached aquatic plants. These organisms will need to be monitored directly to assess their responses to such changes.

Summary and conclusions

A range of hydrological and water quality LAC, targets and trigger values have been proposed for managing the CLLMM Ramsar site (Table 2). Initial comparisons of monitoring data with the draft LAC developed by DEWNR, the water quality targets proposed in the Murray Darling Basin Plan (MDBP 2012), and the Australian and New Zealand Environment and Conservation Council (ANZECC), National Water Quality guidelines (2000), suggested that most were not suitably aligned with the environmental characteristics of the CLLMM site and needed to be re-assessed in the context of the conditions described by the monitoring data (Table 3). In some cases the proposed management target did not fall within the observed parameter ranges, while in other cases the proposed management targets were not fully described and require enhanced descriptions to better define their intent and to reliably guide management actions. Table 3 summarises the current targets and indicates the percentage of time the draft LAC, Basin Plan targets or ANZECC guidelines were or were not met by the data. It is important to note that a mismatch between these target values and the measured values can mean:

- Water quality is poor, and/or
- The draft LAC/Basin Plan/ANZECC guideline value is inappropriate

Deciding between these two options is not straightforward even when data is available. Analyses of the monitoring data focused on the pre-drought period to maximise the likelihood that parameter values derived from the data were as closely aligned as possible with what might have been typical conditions at the time of the Ramsar site designation. In an effort to further improve the reliability of the interpretations, data trends were analysed to identify whether there had been consistent changes in water quality during the pre-drought period. In some cases, trends were observed and the characteristic descriptors developed from those data sets suggest LAC require adjustment in order to better reflect earlier conditions. However, despite all of these efforts, it needs to be recognised that the water resources and water quality of the CLLMM area had already undergone significant changes prior to the designation as a Ramsar site, and there is no guarantee that water quality data from the time of designation describes all that is required to sustain the long term ecological character of the site. That being said, the monitoring data provides a starting point for identifying the characteristic requirements, and adaptive management suggests that these defined conditions are the first targets to be achieved along with continued monitoring to assess the response of the site.

In some instances there is a desire to identify the limits of acceptable change and to manage to these limits. The LAC are defined as the variation that is considered acceptable in a particular component or process of the ecological character of the wetland, without indicating change in ecological character that may lead to a reduction or loss of the criteria for which the site was Ramsar listed. The setting of LAC is notoriously difficult because of the innate variability of environmental conditions, and because an acceptable variation in a particular component or process is often the outcome of a subjective decision and the links with ecological character are not usually well known. Frequently, the recognition of an unacceptable change is only made after the event. In the simplest approach it has been suggested that LAC can be set around the maximum and minimum ranges of a parameter. However, in many cases it is not sufficient to solely define wetland LAC as the extremes of a parameter range, as a prolonged shift in the median water quality but within the extremes of measured variability, could cause a change in ecological character. Consideration must also be given to seasonal patterns; the frequency, duration and magnitudes of normal and extreme events; cyclical events; and ecosystem or species resilience. In many cases the variability of conditions will be just as important as the extreme limits in altering or sustaining the character of a wetland. Against this background, target values and trigger values can be more readily defined where suitable monitoring data is available. If LAC are to be better integrated to management, then they need better definition to make clear their meaning.

The monitoring data sets were analysed to provide improved information for setting guideline values for the CLLMM. Time series, exceedance plots and spell duration plots were used to identify characteristic descriptors of the water quality and hydrological parameters. These included the long term median, and the 1^{st}, 5^{th}, 95^{th} and 99^{th} percentiles, and the probability that a particular value of a parameter occurred for a continuous duration of time. These values are summarised in Table 4 and can be compared with guidelines described in Table 2 and the extent of alignment presented in Table 3. Although not presented as specific management guidelines the median could be considered a long term target value for a site, while the percentile values could be considered as management trigger values. The selection of particular percentiles as trigger values depends on the management capability to reverse a trend as it reaches the trigger value. The slower the response capability the earlier the trigger values needs to be set. Having a range of trigger values enables first responses followed by increasing responses if conditions continue to deteriorate. Importantly, these data visualisations reinforce the fact that variability occurs in water quality conditions, and a similar variability is required in order to sustain the ecological character of a site.

Across all of the sites the water quality targets for TN, TP, turbidity and chlorophyll-a were based on the ANZECC (2000) guidelines for South East Australia (Appendix 1). As these are regularly exceeded they seemed inappropriate for the CLLMM region. Values from the ANZECC (2000) South Central Australia guidelines (Appendix 1) were in some cases more appropriate but often there was still a need to identify more specific CLLMM targets, although this will depend on whether the differences are considered to be due to poor water quality or inappropriate guideline values. In some cases the guideline values may be chosen in order to try and improve water quality. However, if the pre-drought monitoring data is considered representative of the requirements of the CLLMM region then site specific values will need to be selected for a number of the hydrological and water quality parameters and could be based on the analyses provided here.

Flows, water levels and conductivity/salinity were the other important attributes analysed. The draft LAC for Lake Alexandrina inflows from the Murray River were expressed as annual averages that do not reflect the within-year flow patterns that are often required to sustain the ecology of a site and daily flows were analysed to provide better resolution of flow patterns. The barrage flows similarly had a LAC that was not well defined. The draft LAC is that the maximum number of days since some barrage flow should be ≤339. This does not provide information on what the flows should be when they occur, or what flows are required to sustain the ecological character of the site. Analysis of the pre-drought data indicated that a year of zero flows occurred with an ARI of about 5 years, so the LAC of every year seems significantly larger than expected. Spell duration analyses also indicated that there was generally a step up from zero flows to the median value, with only a small percentage of time at flows in between. Perhaps this is an operational quirk, but extended periods of flow below the median value were rare. Based on this the suggested "some flow" in the proposed LAC requires further clarification and should perhaps be the median value or higher.

Similarly LAC for conductivity/salinity were based on annual levels which has problems because annual medians can be achieved in different ways, at least some of which might not support the ecosystems. In most cases the LAC were not considered to be well representative of the sites and in most cases seemed high. The problem with this is that if a LAC is set too high, this increases the risk that a site will undergo a change in ecological character before the LAC is reached. Monitoring data provided supporting information that could be used to improve the identification of these management triggers and targets. The draft LAC for the North Lagoon is that average monthly salinity does not exceed 75 ppt for more than an 18 month period within any 3 year rolling period. The meaning of this is not entirely clear as to whether it is the rolling monthly average, or a sequence of 18 months average salinity, or a selection of the highest 18 months in a three year period with salinities in excess of the LAC, so further clarification is required. The spell duration curve indicated that salinities of this level and higher occurred for only 2 days with an ARI of 5 years, and a maximum duration of 30 days with an ARI of 20 years. This does not seem to match well with the proposed LAC which allows an 18 month period of undefined salinities greater than 75 ppt. The proposed LAC seems high for this region and this is problematic as a high salinity in the Northern Lagoon will drive higher salinities in the Southern Lagoon. This is an example of the salinity targets that need to be reconsidered in the light of the data analyses provided here.

Draft LAC for water levels in the lakes were often focused on the lower levels with less concern about higher water levels. This is somewhat misplaced as it is important that water level variation occurs over a range and with a pattern that supports the ecosystems. Wetting the upper edges of lakes, even for short periods, can be important for example the growth of fresh biofilm and riparian vegetation. The influence of the drought on water levels in the Coorong region was evident in the exceedance plots of the total data set with the drought period highlighted. In the North Lagoon the maximum range of water levels that occurred during the pre-drought period approximately 7% of the time did not occur at all during the drought resulting in maximum water levels being >0.1m lower. This could have major influences on lake edge and shallow water ecosystems. Similarly, in the Southern Lagoon there was a reduction in maximum water levels from ca. 1.2m to 0.85m during the drought. Although these high water levels only occur for short periods of time they are critical to the edge ecosystems and a 0.35m reduction in maximum level could result in substantial loss of shallow riparian areas including important mudflat habitat for wading birds. Even in the Murray Mouth area maximum water depths were not attained during the drought. These findings highlight the importance of barrage flows in sustaining water levels in the Coorong and Murray Mouth. These analyses of the monitoring data should help provide clearer definition of proposed management targets.

Temperature exceedance plots indicated similar values across all sites with a range of 10^0 to 25^oC. Monthly data was summarised in box plots and showed similar monthly ranges across sites. The Basin Plan guideline for temperature is that the monthly medians should be between the 20^{th} and 80^{th} percentile of the natural monthly water temperature. A potential problem with the proposed guideline is that most monthly mean temperatures could increase by a degree or more and still remain within the 20^{th} and 80^{th} percentile of the monthly temperature range. A prolonged shift of this magnitude could influence the character of the system. To avoid this, the guidelines should contain some indication of a long term monthly median as a target.

The monitoring data demonstrated that the generally applied guidelines for pH that have been taken from the ANZECC values for South East Australia and state that the annual median should be between pH 6.5 and 8, are not suitable for the CLLMM. The South Central Australia ANZECC guideline with an increased upper value of pH 9 appears to be better aligned with the typical levels observed. Metals were not analysed directly but dissolved metal exceedances to be above the ANZECC (2000) guidelines that protect aquatic ecosystems are only considered likely if pH is less than 6.5 and this was only observed in specific areas during the drought.

Microalgae respond quickly and continuously to changing water quality conditions potentially providing accessible, immediate and continuous warnings to inform management actions. Multivariate analyses were used to describe the changes in water quality and microalgae in the Lakes before and after the drought. The data indicated that prior to the drought, in the period from 1982/83 until 1997/98, the microalgae community composition occupied a consistent environmental space. This consistency in the microalgae composition suggests that the analyses carried out on water quality attributes prior to the drought could be expected to provide reasonable estimates of water quality conditions prevalent at the time of the designation of the Ramsar site, supporting their application in management guidelines.

Overall the comparison of the CLLMM hydrological, water quality and microalgae monitoring data with proposed management indicator values suggested that at all sites and for virtually every parameter there is a need to re-visit the proposed and current management values to ensure that they are relevant to the site and suitable for directing management actions. The data provided in this report should assist with this assessment.

Long term monitoring has been essential to determine whether changes within the water quality and microalgae drive a change in the ecological character of the CLLMM Ramsar site. Continued monitoring at key sites is critical to ongoing development and evaluation of management strategies aimed at preserving the ecological character of the site. Without such data it is unclear how relevant management decisions can be objectively evaluated to support their implementation. A long term monitoring plan should be developed and funded for the CLLMM region.

The characteristic descriptors provide a reliable basis for managing the ecological character of Ramsar site, but the management application of these requires further development. It will need linking of patterns in major drivers such as hydrology with the fluctuations in the character descriptors so that management actions achieve the required patterns (limits, distribution, recurrence interval etc).

Lake Alexandrina Hydrology: Inflows

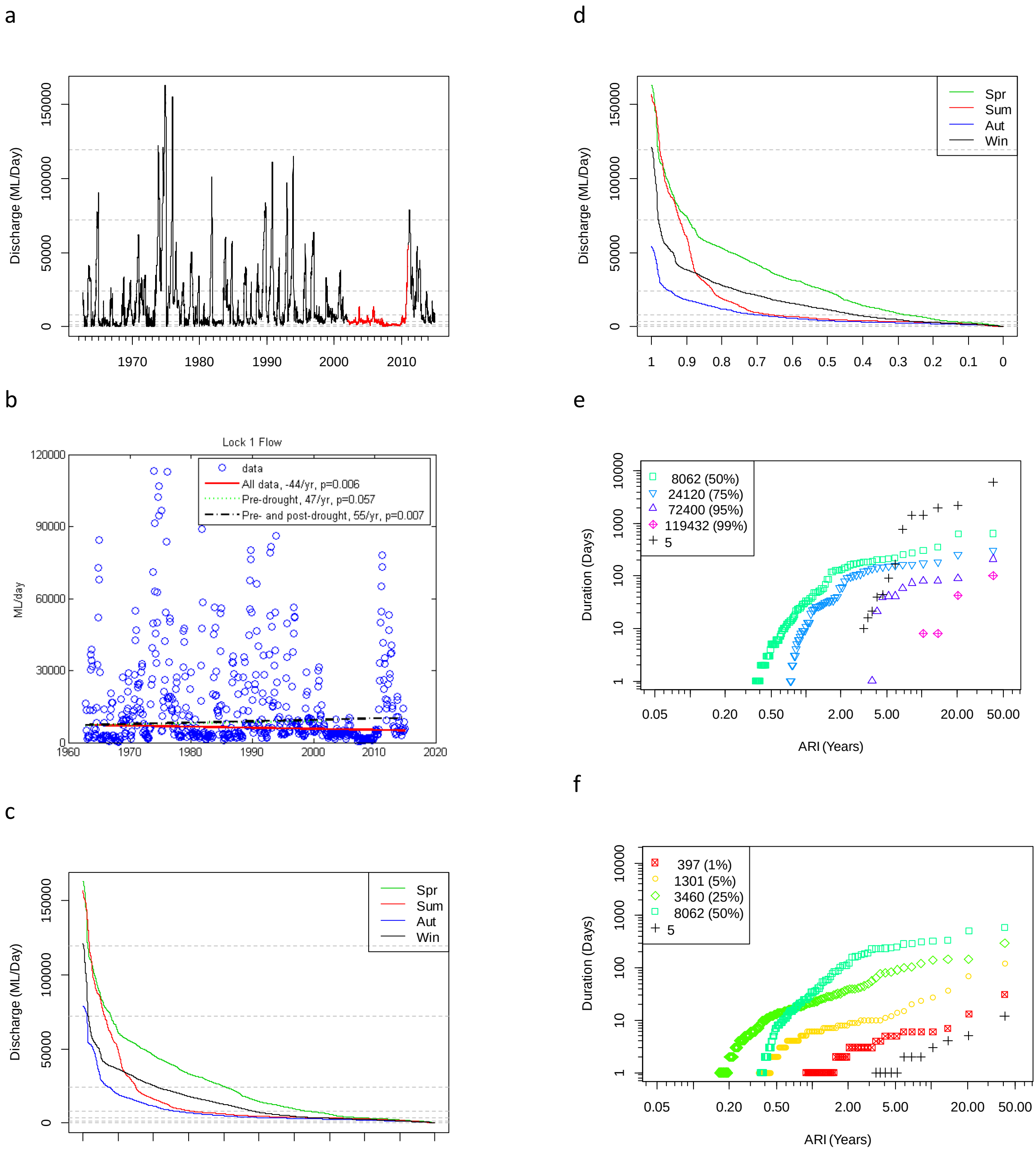
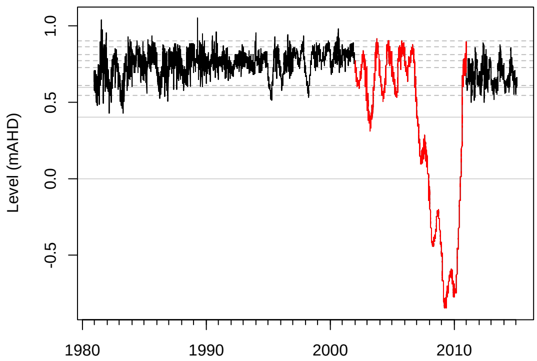


Figure 5 Lake Alexandrina Hydrology: Inflows (a) Time series of discharge at Lock 1 (b) Trend plots for discharge (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The minimum flow level is indicated on the spell duration plots representing periods of some flow (e) and periods of zero flow (f).

Lake Alexandrina Hydrology: Water level

a



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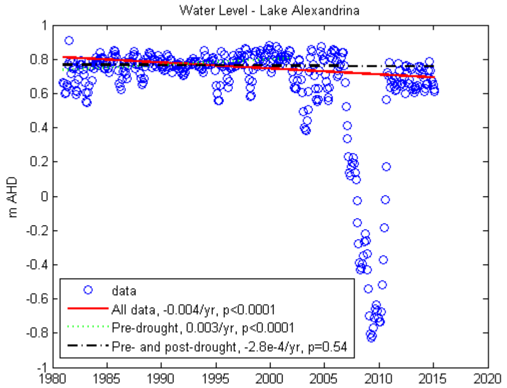

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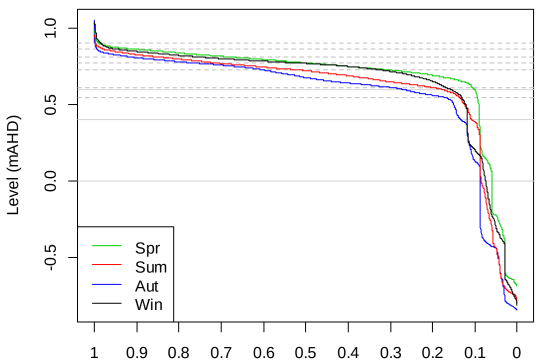

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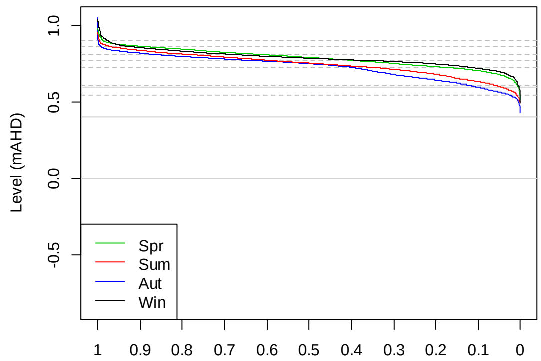
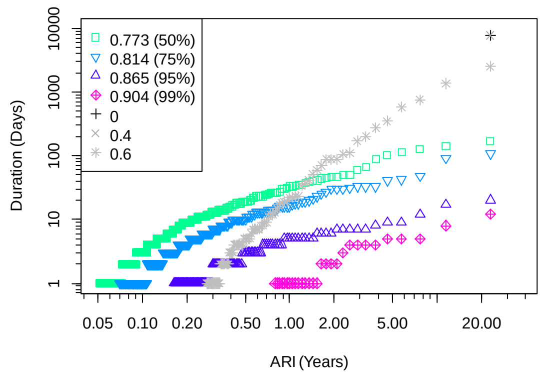


d



e

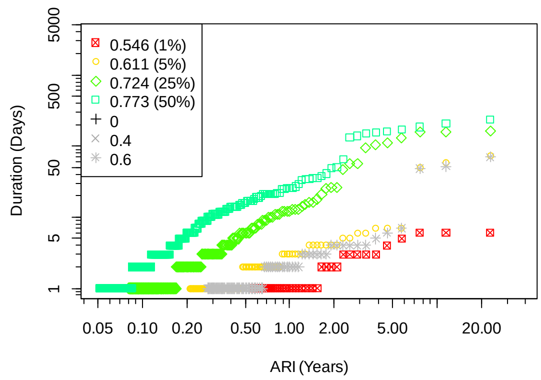


Figure 6 Lake Alexandrina Hydrology: Water level (a) Time series of water level (b) Trend plots for water level (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC or management targets, see Table 2.

Lake Alexandrina Conductivity

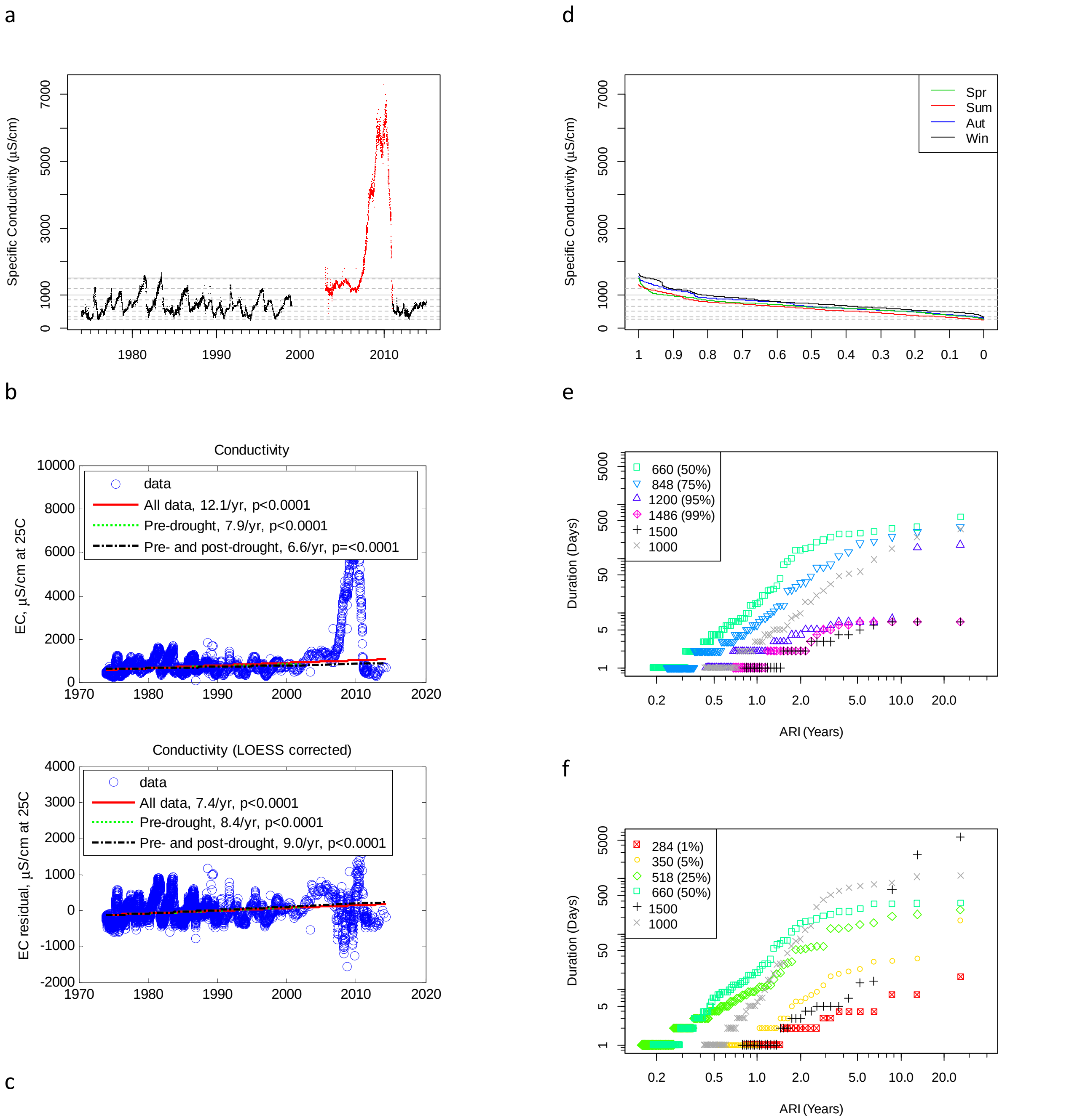


Figure 7 Lake Alexandrina Conductivity (a) Time series (b) Trend plots for conductivity with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Lake Alexandrina Turbidity

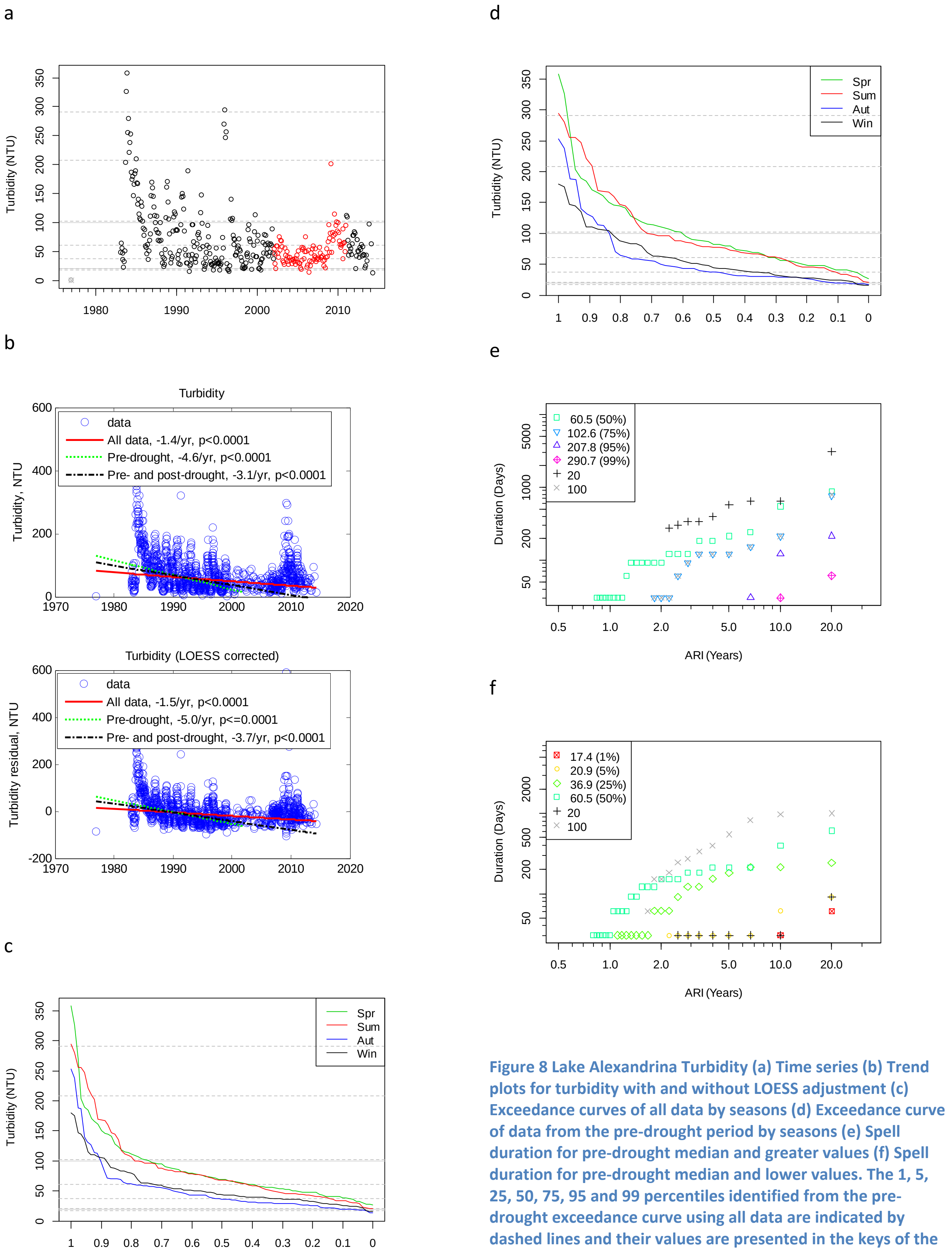
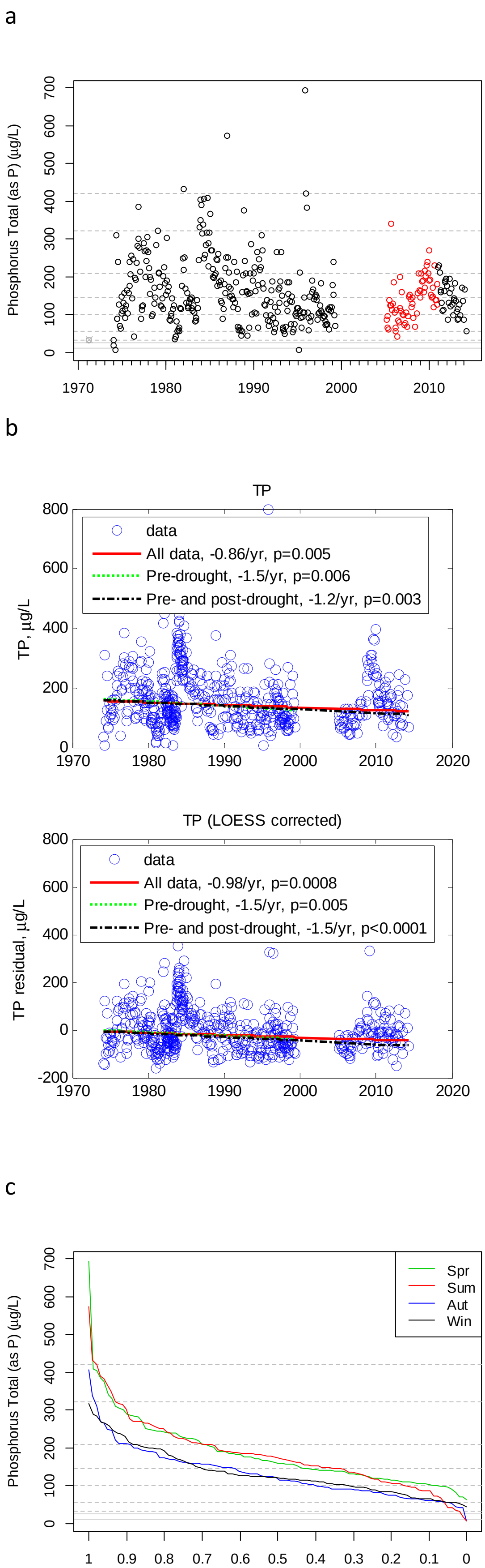


Figure 8 Lake Alexandrina Turbidity (a) Time series (b) Trend plots for turbidity with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Lake Alexandrina: Total Phosphorus



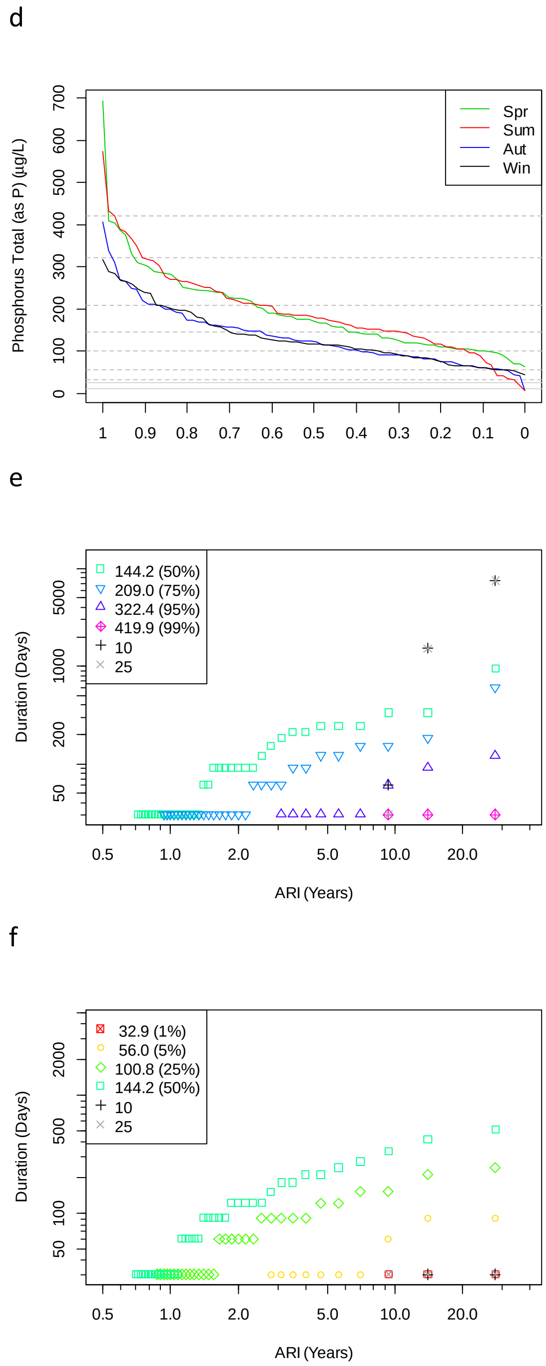


Figure 9 Lake Alexandrina Total Phosphorus (a) Time series (b) Trend plots for total phosphorus with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Lake Alexandrina: Total Nitrogen

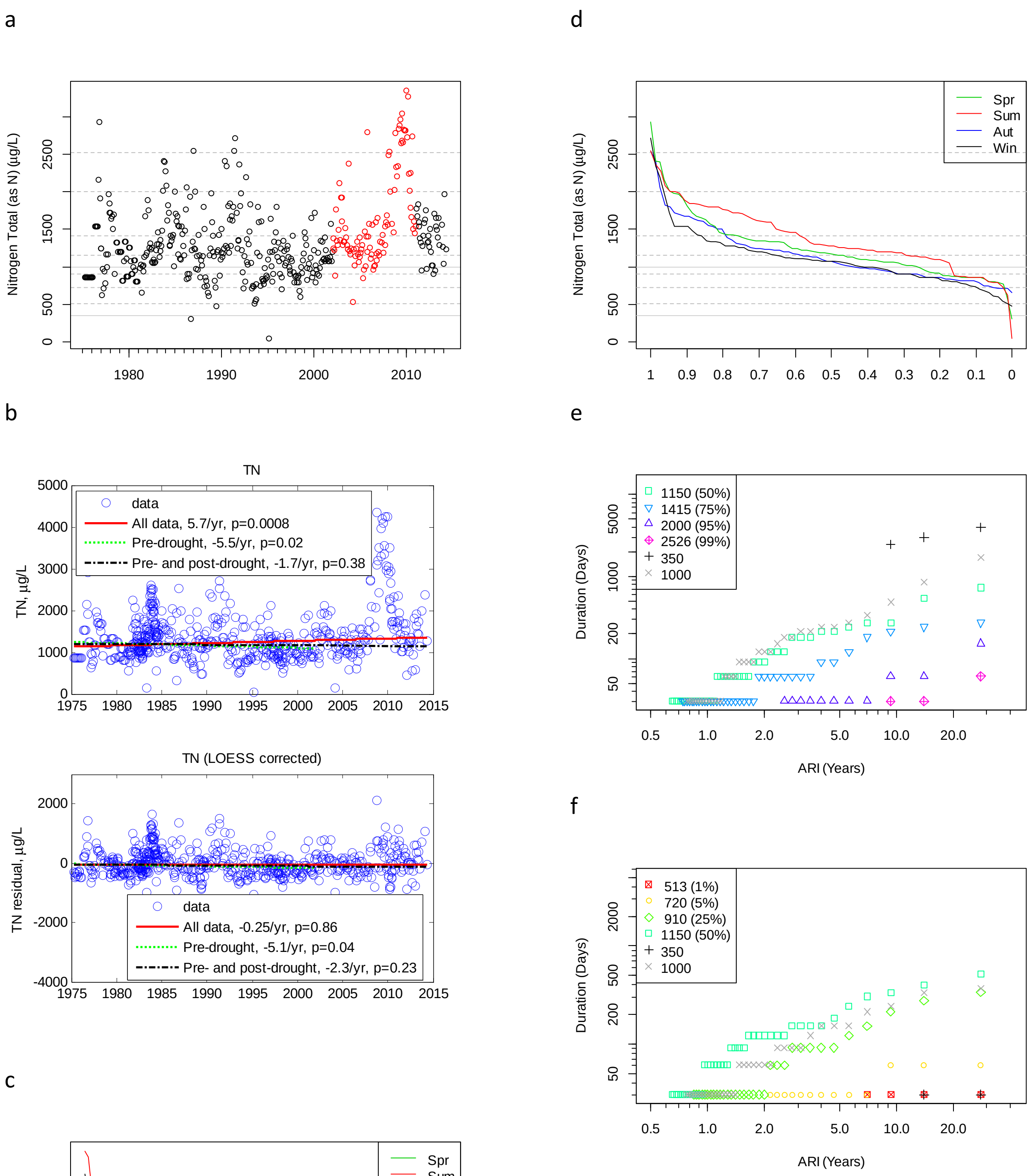
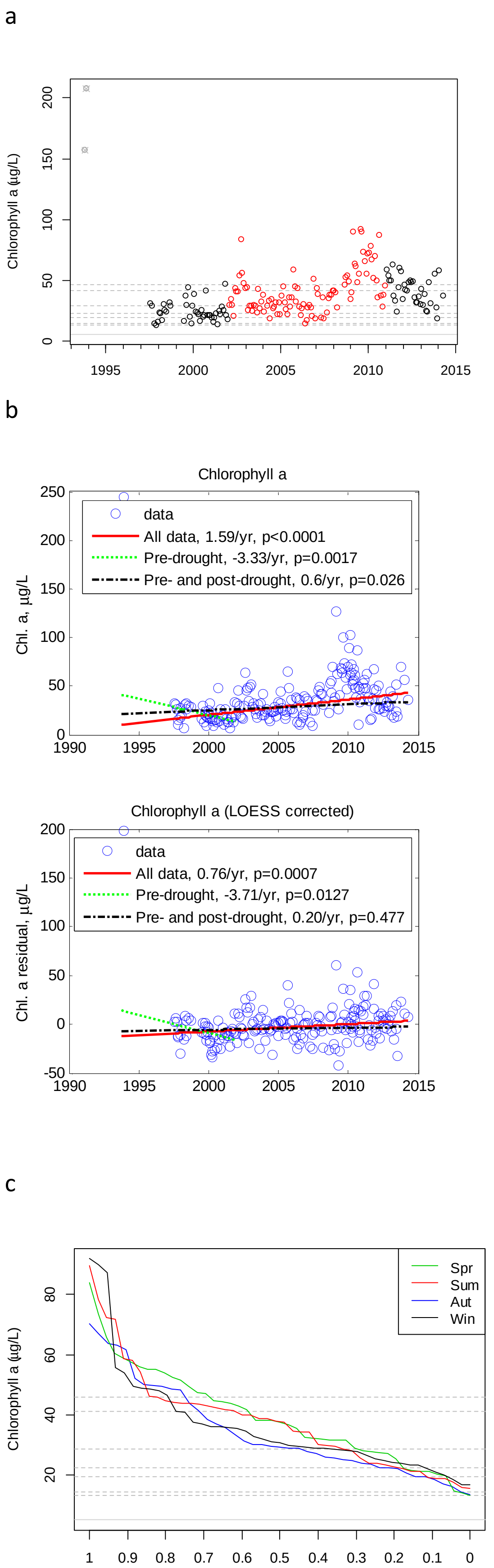


Figure 10 Lake Alexandrina Total Nitrogen (a) Time series (b) Trend plots for total nitrogen with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Lake Alexandrina: Chlorophyll-a



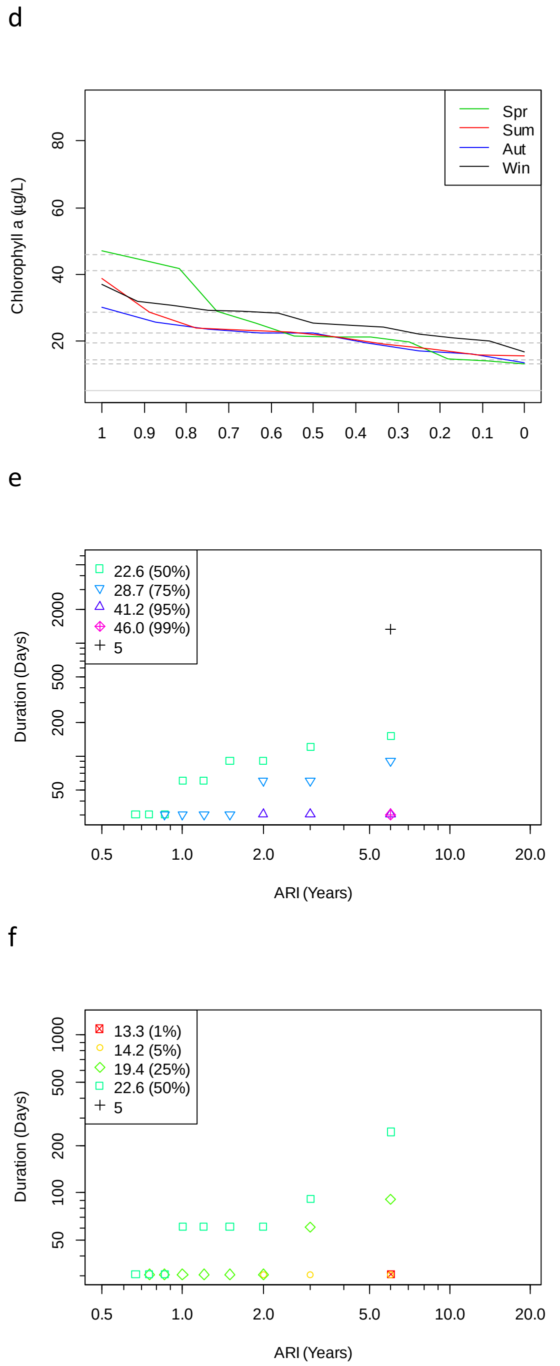


Figure 11 Lake Alexandrina Chlorophyll-a (a) Time series (b) Trend plots for chlorophyll-a with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Lake Alexandrina: Dissolved Oxygen

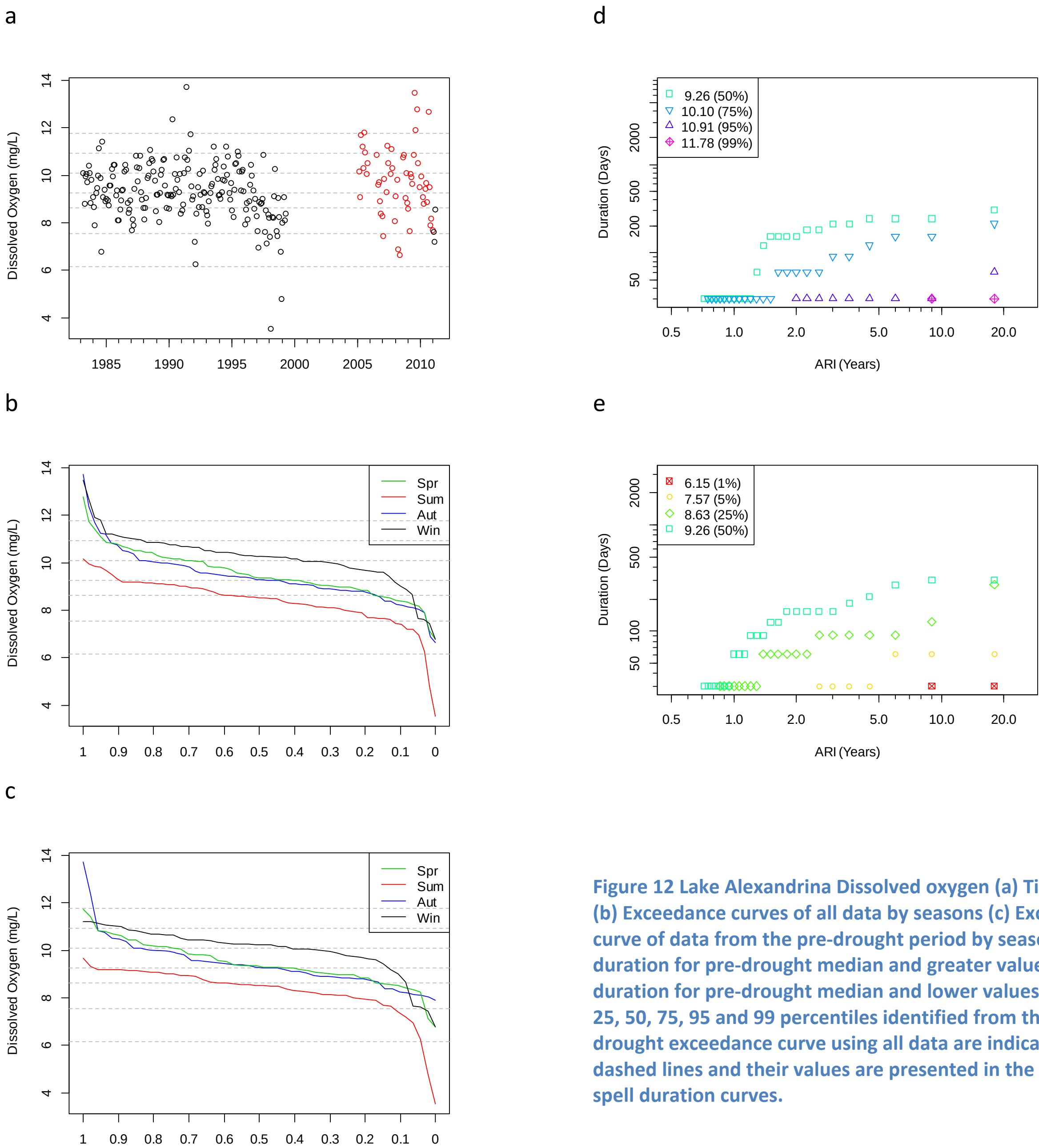
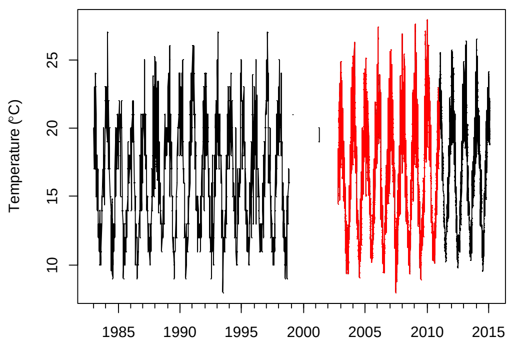


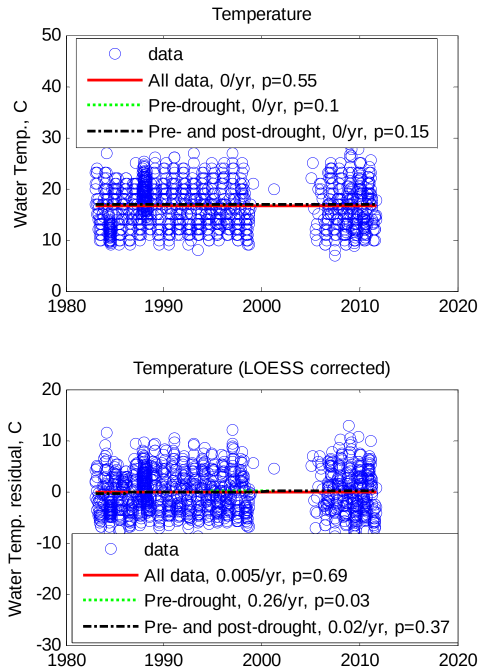
Figure 12 Lake Alexandrina Dissolved oxygen (a) Time series (b) Exceedance curves of all data by seasons (c) Exceedance curve of data from the pre-drought period by seasons (d) Spell duration for pre-drought median and greater values (e) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves.

Lake Alexandrina: Temperature

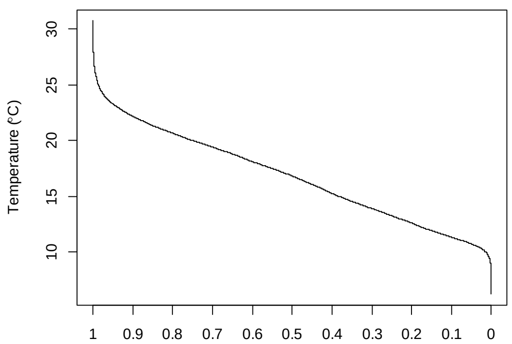
a



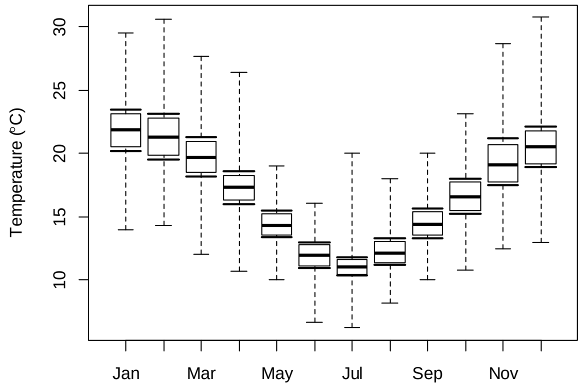
b



c



d



e

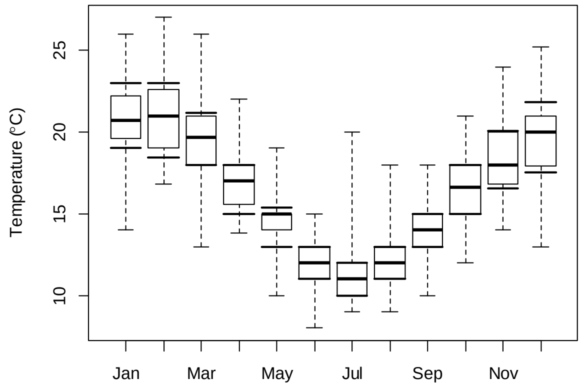


Figure 13 Lake Alexandrina Temperature (a) Time series (b) Trend plots for temperature with and without LOESS adjustment (c) Exceedance curve for all data (d) Monthly box plot for all values (d) Monthly box plot for pre-drought values. Box plots show the 20, 25, 50, 75, and 80 percentiles identified from the pre-drought monthly data. The proposed management targets are the monthly 20 and 80 percentile limits.

Lake Albert Hydrology: Water Level

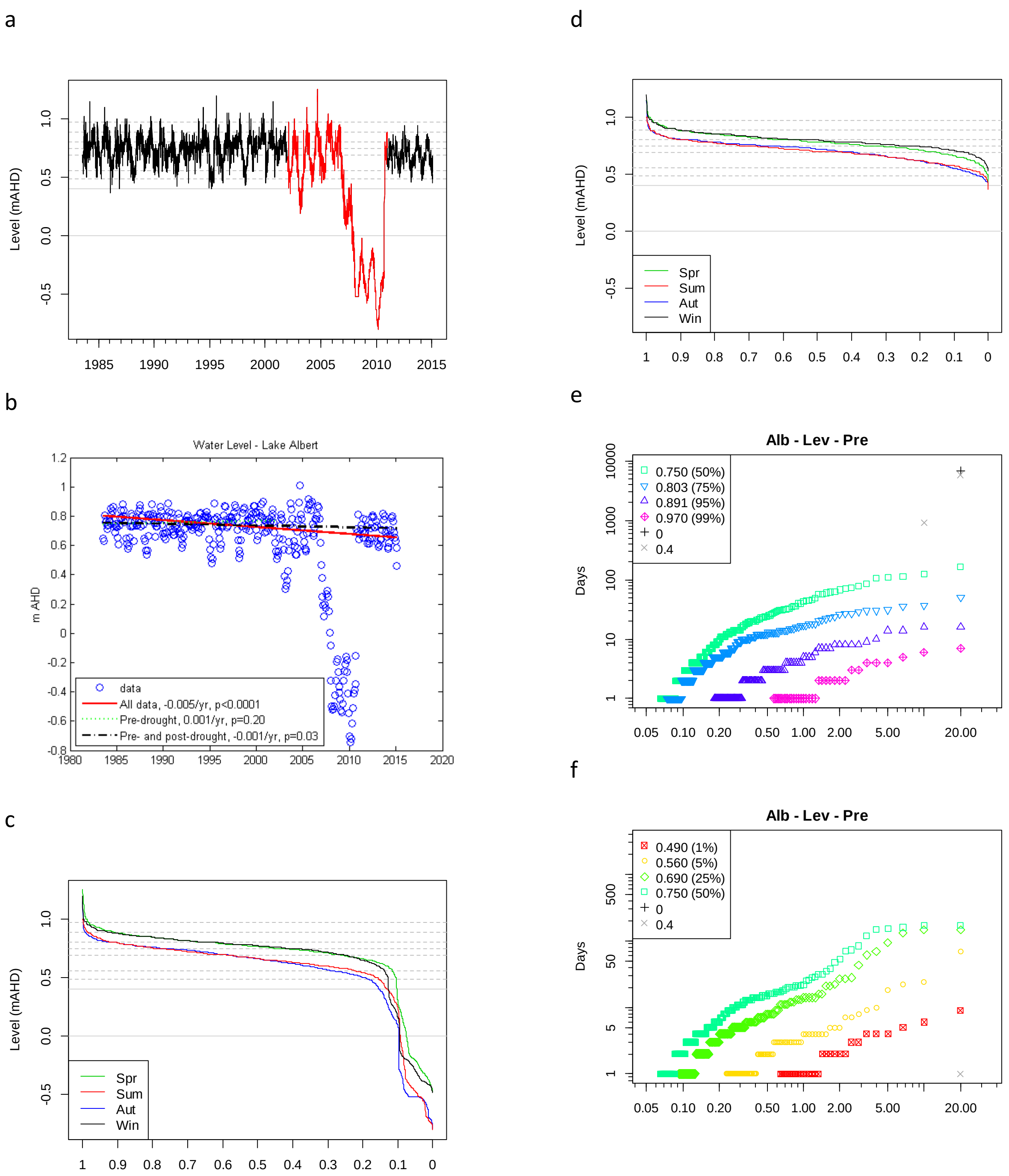
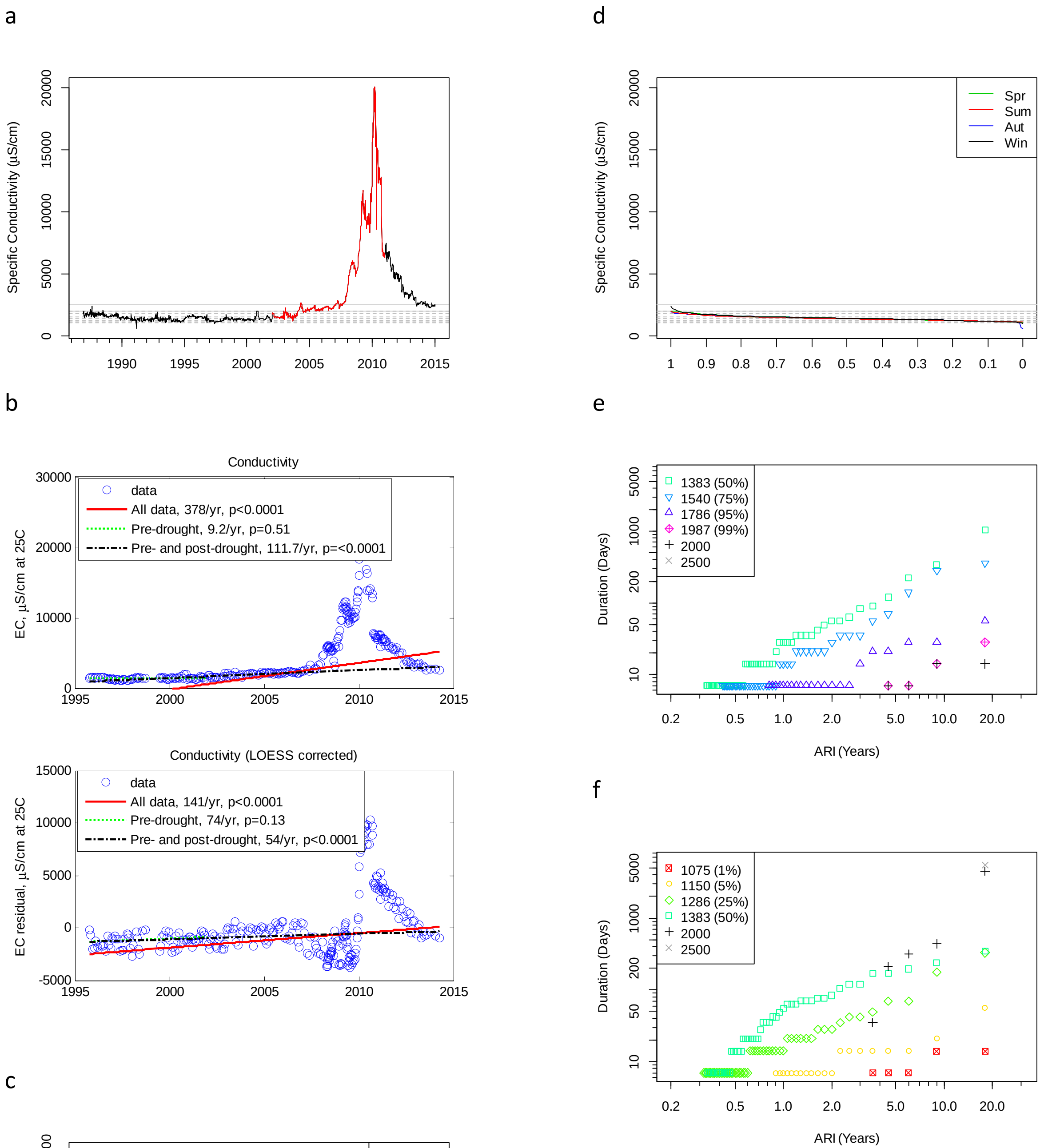


Figure 14 Lake Albert Water Level (a) Time series (b) Trend plots for water level (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Lake Albert: Conductivity



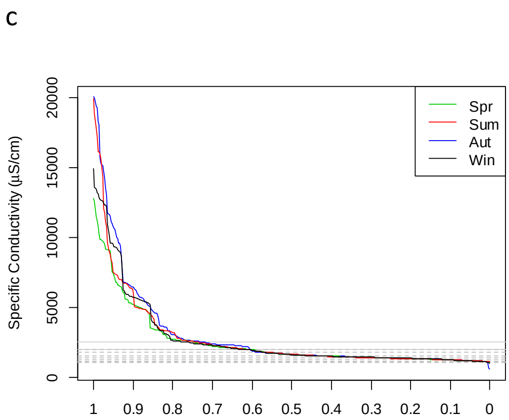
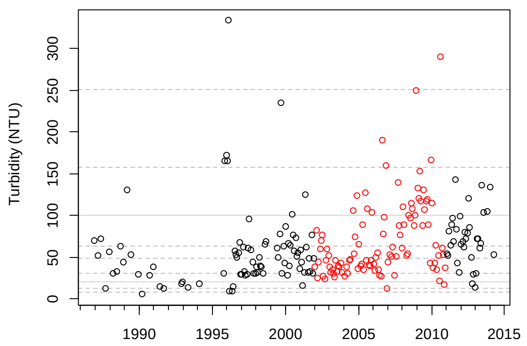


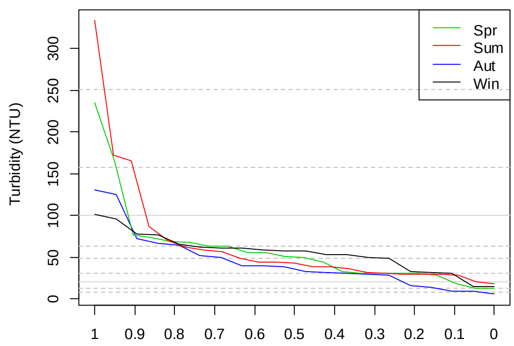
Figure 15 Lake Albert Conductivity (a) Time series (b) Trend plots for conductivity with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Lake Albert: Turbidity

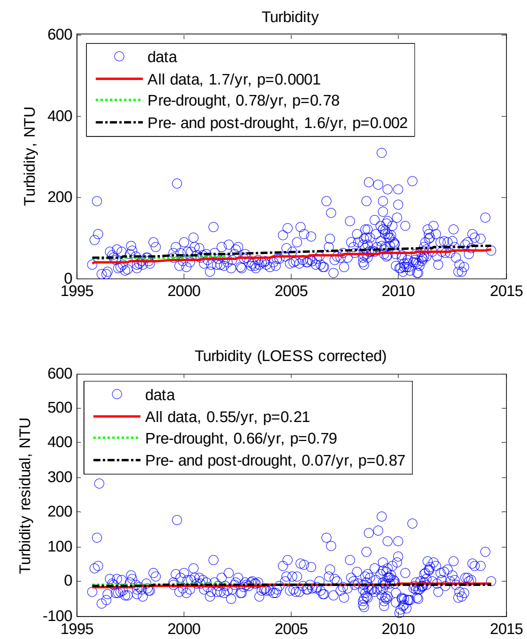
a



d



b



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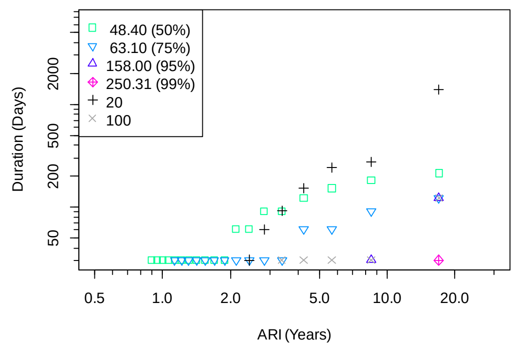
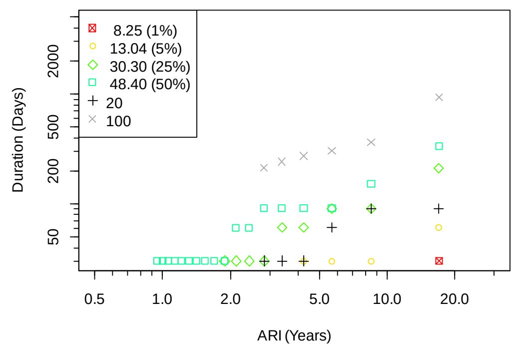


f



c

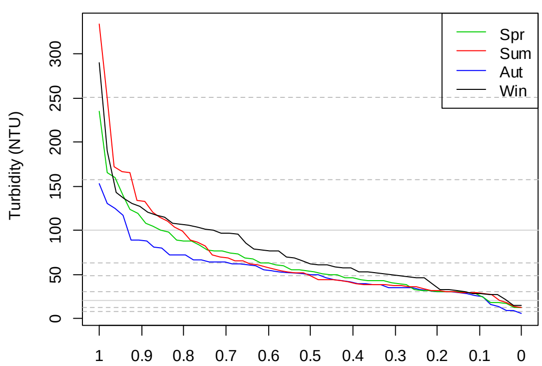
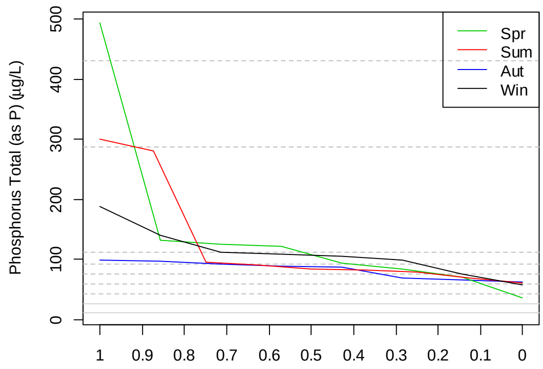


Figure 16 Lake Albert Turbidity (a) Time series (b) Trend plots for turbidity with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Lake Albert: Total Phosphorus

a

d



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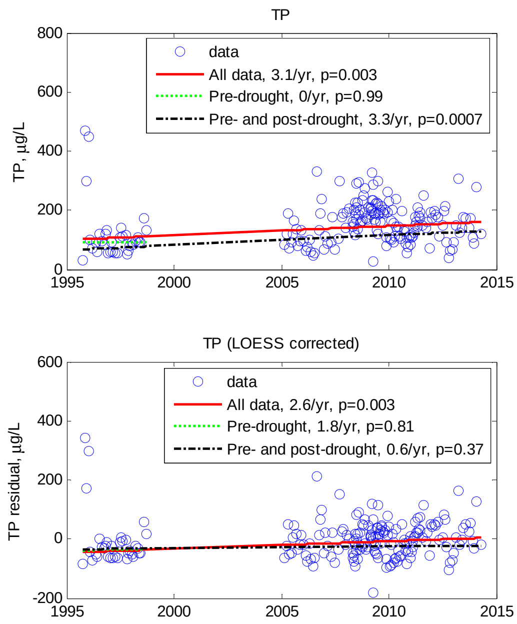
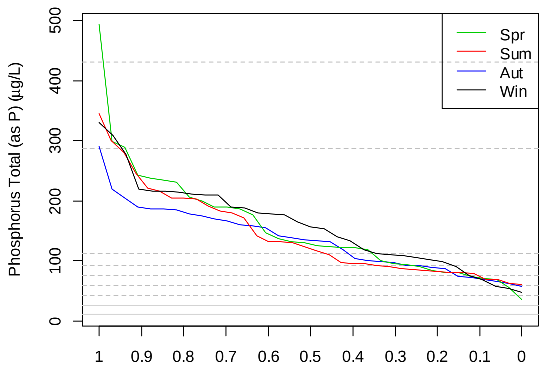


Figure 17 Lake Albert Total Phosphorus (a) Time series (b) Trend plots for total phosphorus with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are reported in the text. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

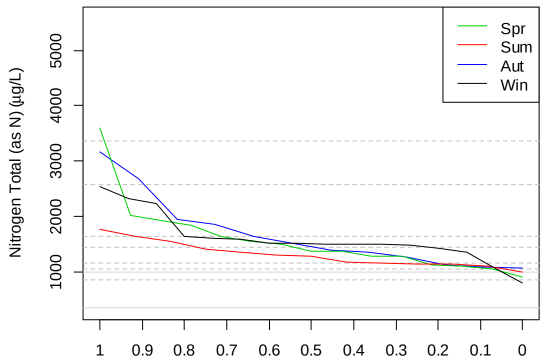
c



Lake Albert: Total Nitrogen

a

d



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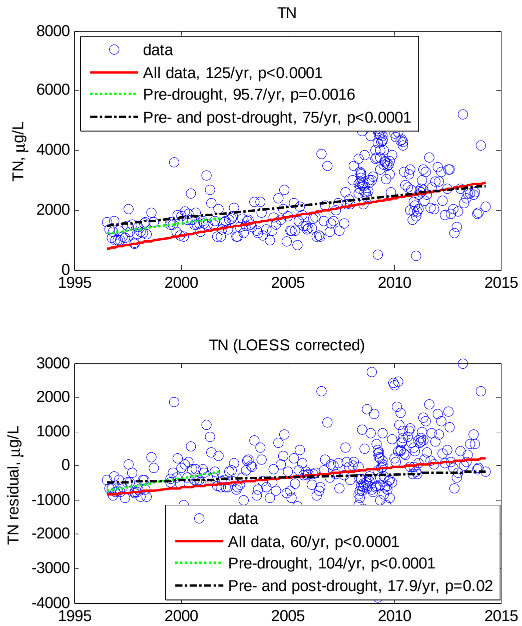


c

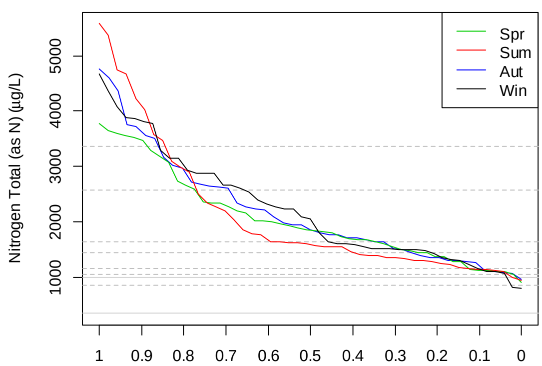
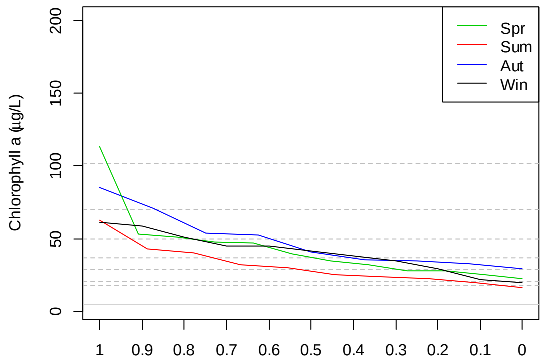


Figure 18 Lake Albert Total Nitrogen (a) Time series (b) Trend plots for total nitrogen with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are reported in the text. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Lake Albert: Chlorophyll-a

a

d



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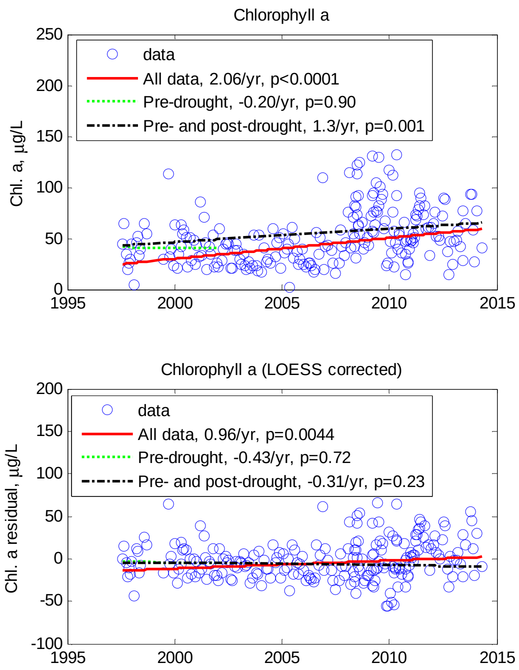
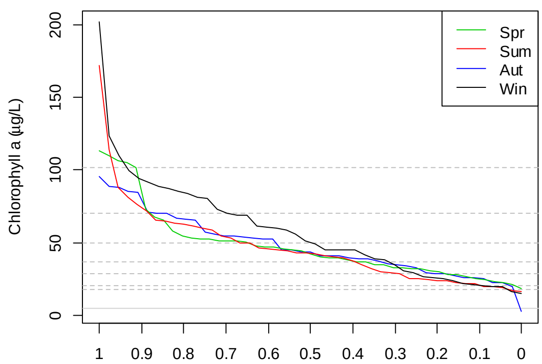


Figure 19 Lake Albert Chlorophyll-a (a) Time series (b) Trend plots for chlorophyll-a with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the text. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

c



Lake Albert Dissolved Oxygen

a

b

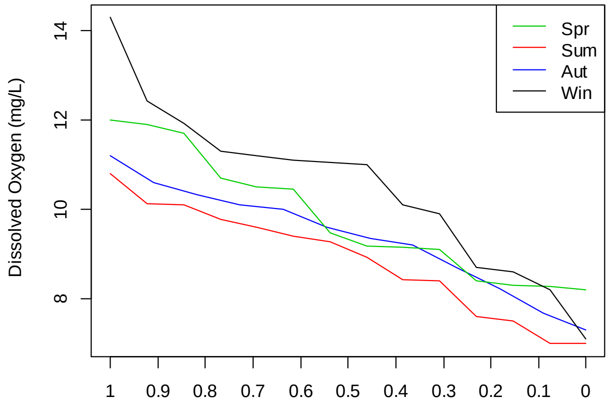
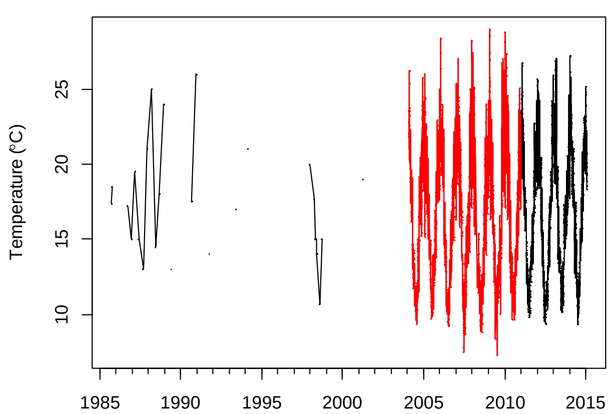


Figure 20 Lake Albert Dissolved Oxygen (a) Time series (b) Exceedance curves of all data by seasons

Lake Albert: Temperature

a



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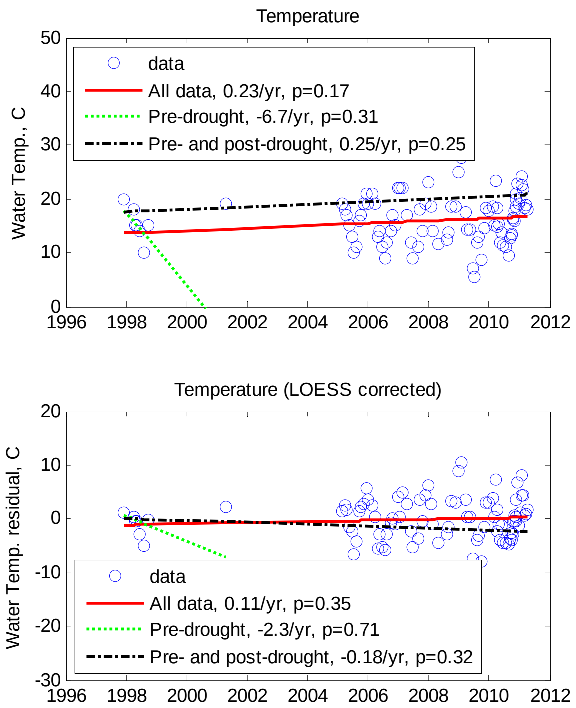

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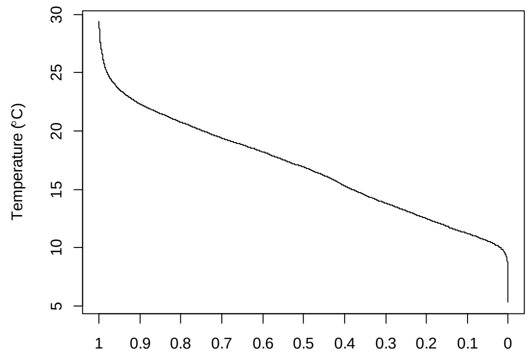


d

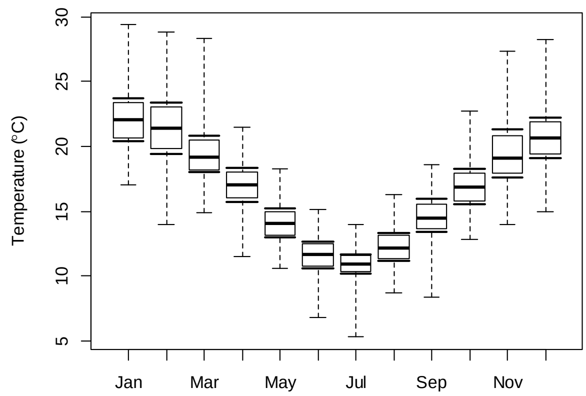


Figure 21 Lake Albert Temperature (a) Time series (b) Trend plots for temperature with and without LOESS adjustment (c) Exceedance plot for all data (d) Monthly box plot for all values. Box plots show the 20, 25, 50, 75, and 80 percentiles identified from the monthly data. The proposed management targets are the monthly 20 and 80 percentile limits.

Coorong North, Coorong South and Murray Mouth:
Modelled Barrage Flows

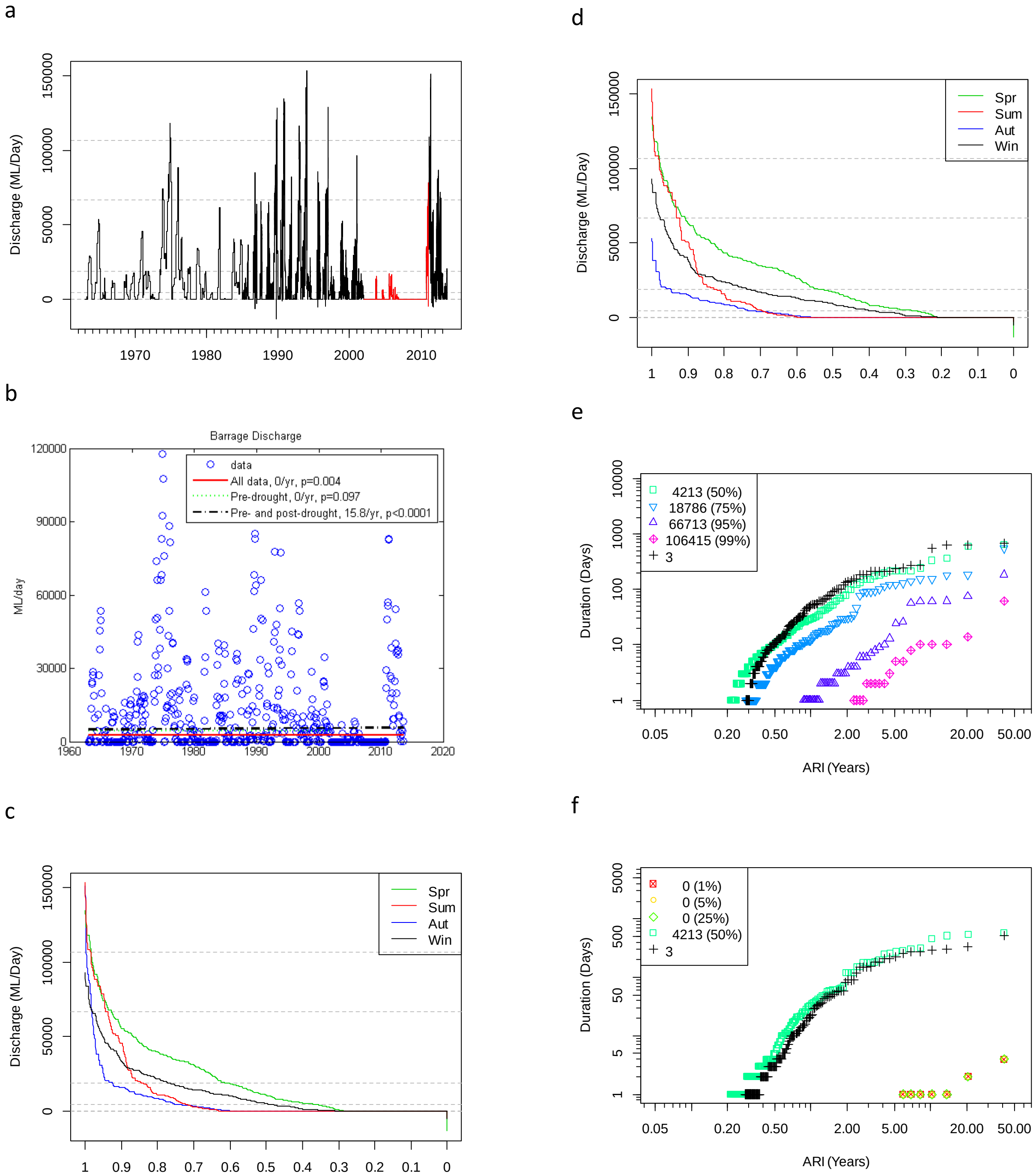


Figure 22 Coorong and Murray Mouth Barrage Flow (a) Time series (b) Trend plots for barrage flow (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The minimum flow level is indicated on the spell duration plots representing periods of some flow (e) and periods of zero flow (f). No management targets set.

Coorong North Hydrology: Modelled Water Level

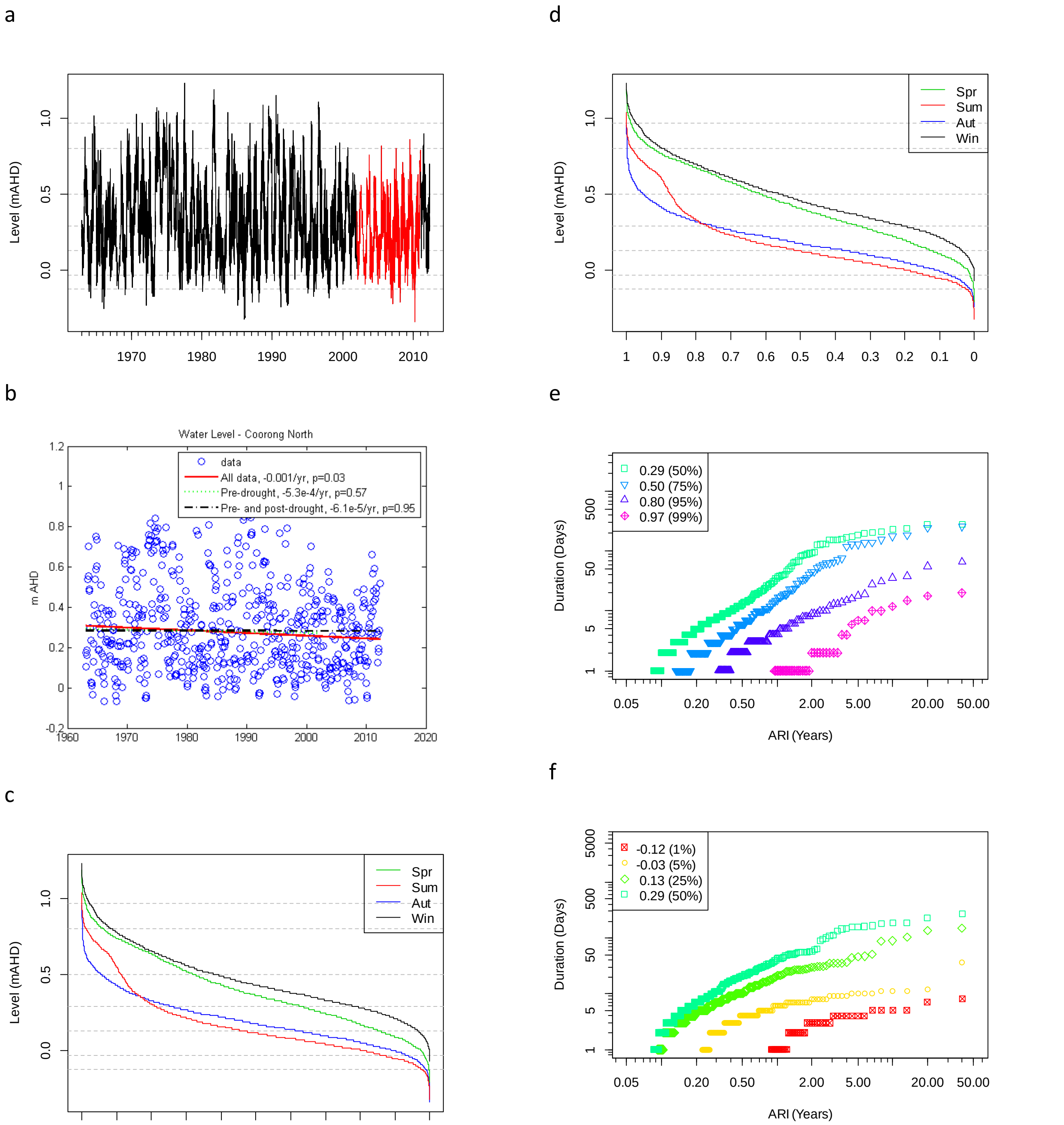
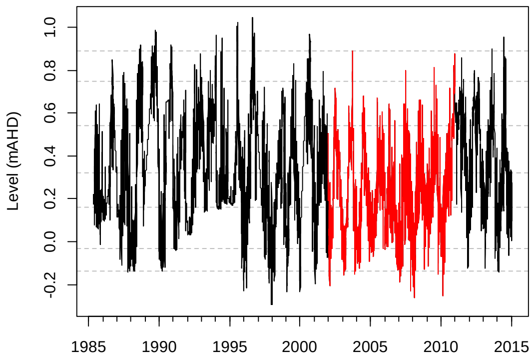


Figure 23 Coorong North Modelled Water Level (a) Time series (b) Trend plots for modelled water level with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves.

Coorong North Hydrology: Measured Water Level

a



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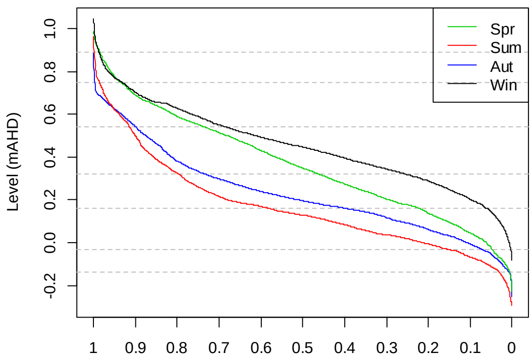

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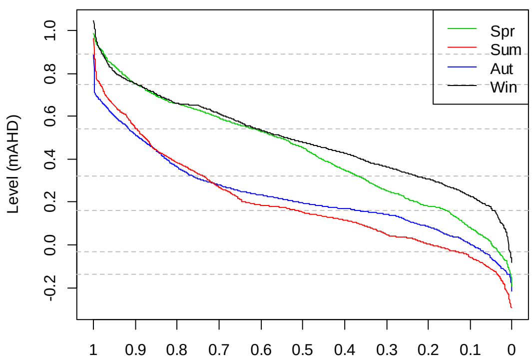

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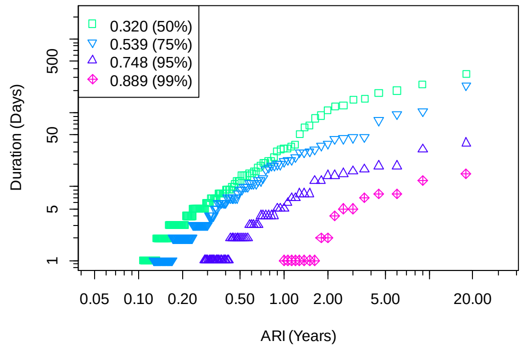

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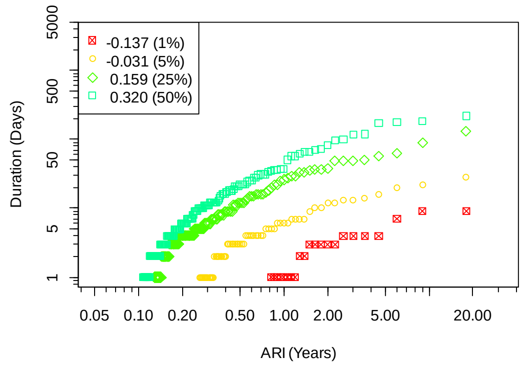
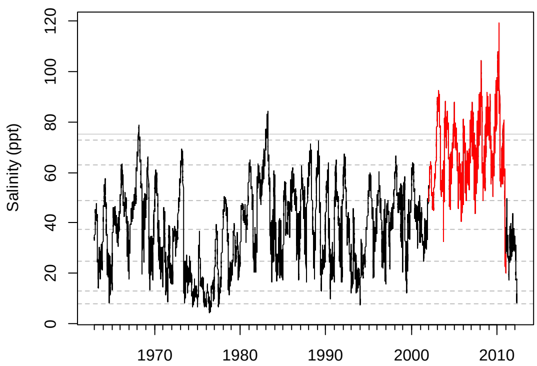


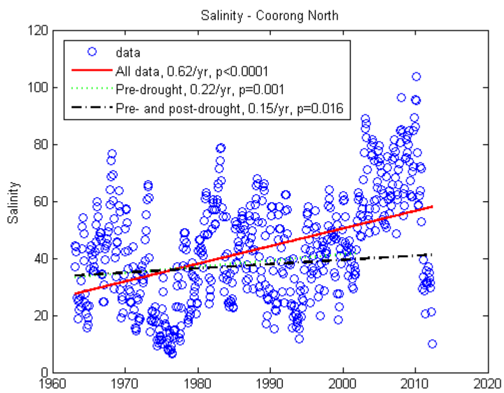
Figure 24 Coorong North Measured Water Level (a) Time series (b) Exceedance curves of all data by seasons (c) Exceedance curve of data from the pre-drought period by seasons (d) Spell duration for pre-drought median and greater values (e) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves.

Coorong North: Modelled Salinity

a



b



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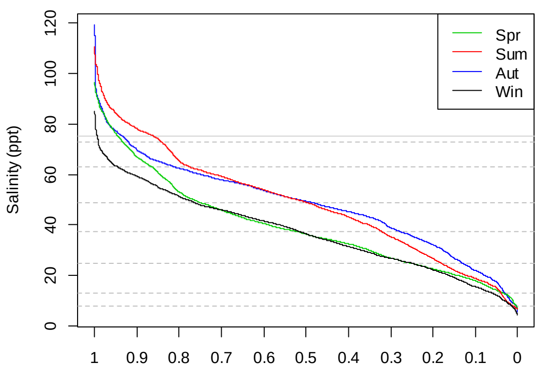

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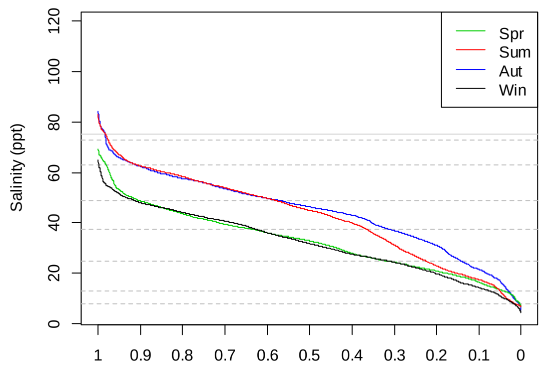
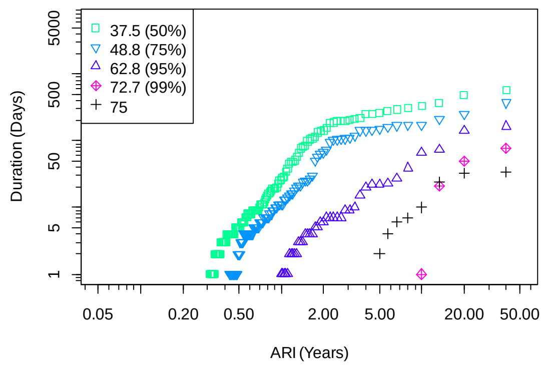


e



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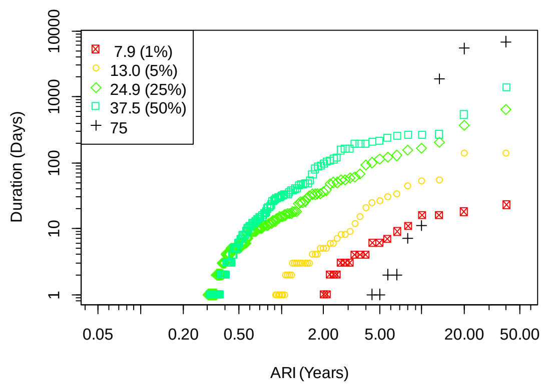


Figure 25 Coorong North Modelled Salinity (a) Time series (b) Trend plots for modelled salinity (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Coorong South: Modelled Water Level

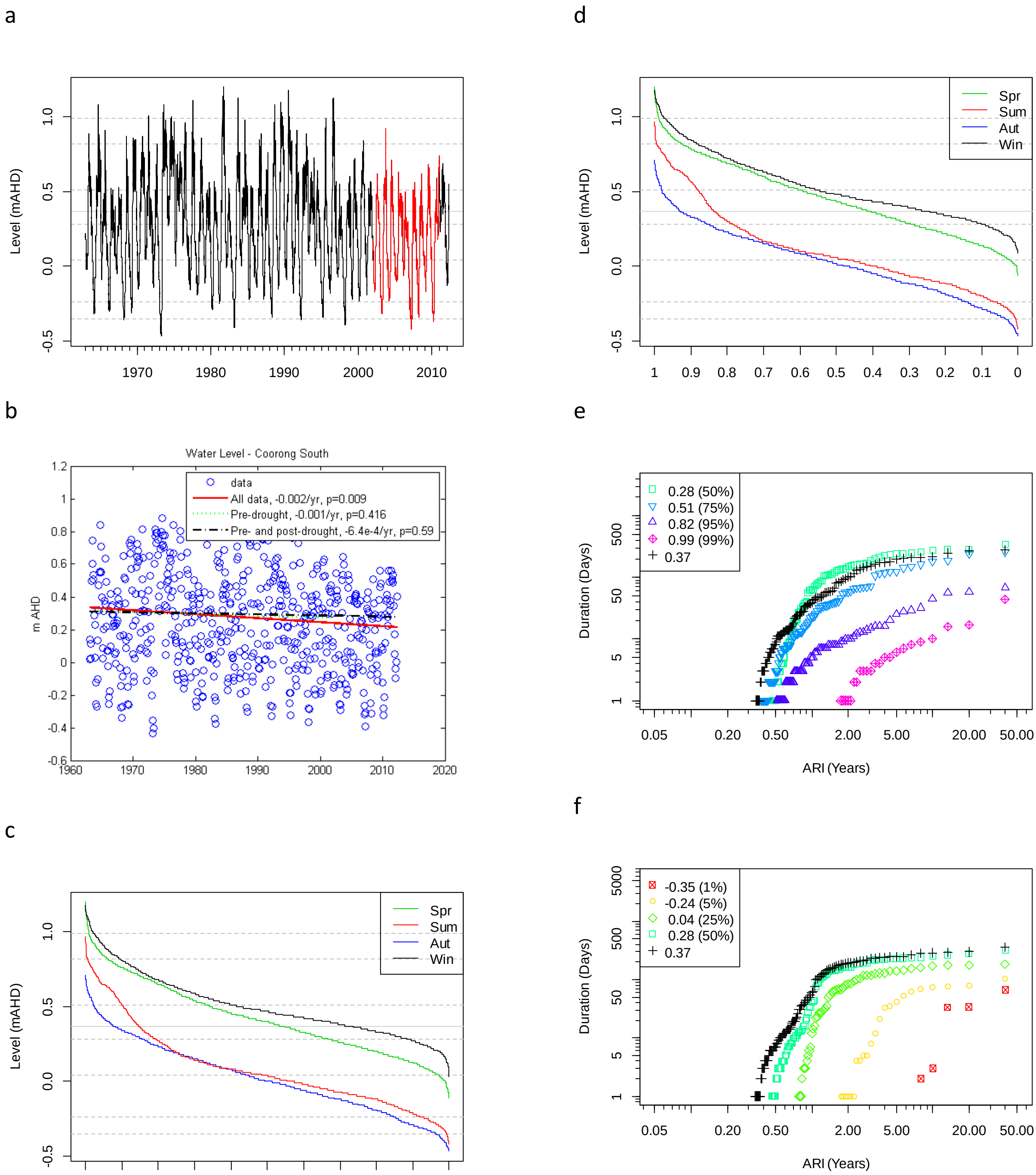
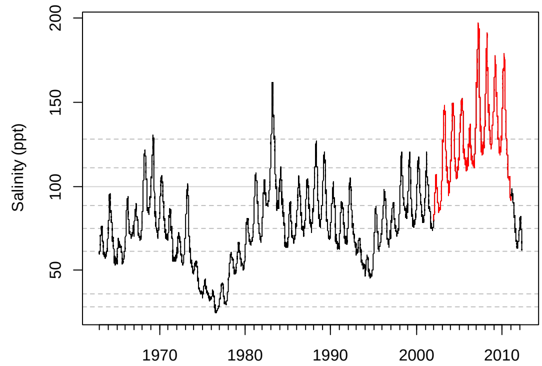


Figure 26 Coorong South Water Level (a) Time series (b) Trend plots for water level (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Coorong South: Modelled Salinity

a



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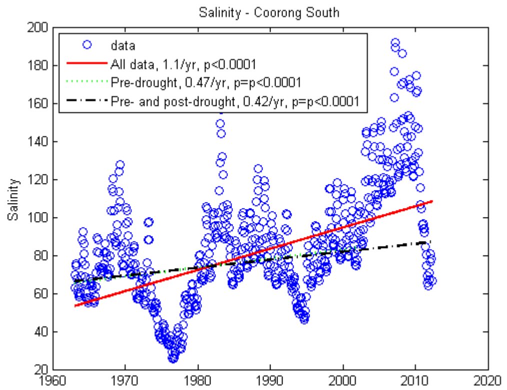

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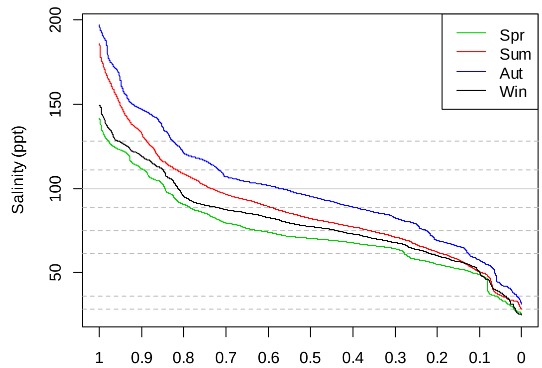

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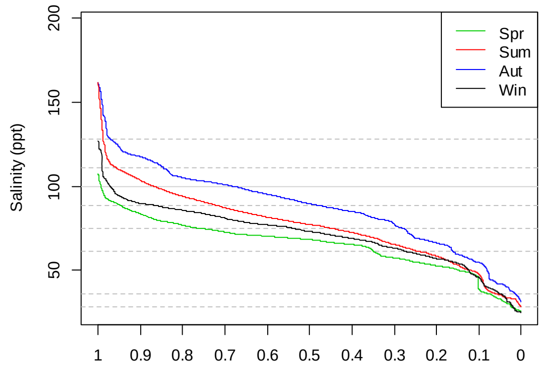
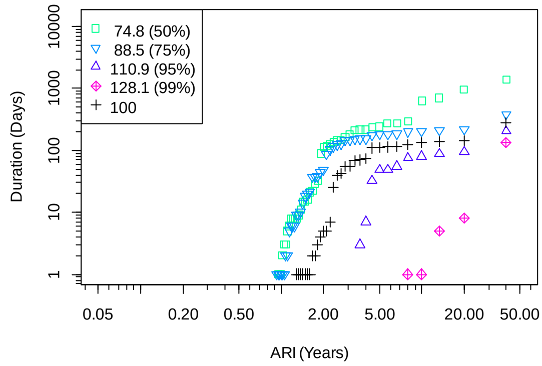


e



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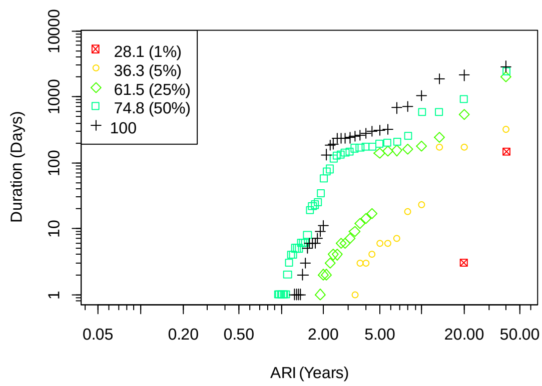


Figure 27 Coorong South Modelled Salinity (a) Time series (b) Trend plots for modelled salinity with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

Murray Mouth Hydrology: Modelled Water Level

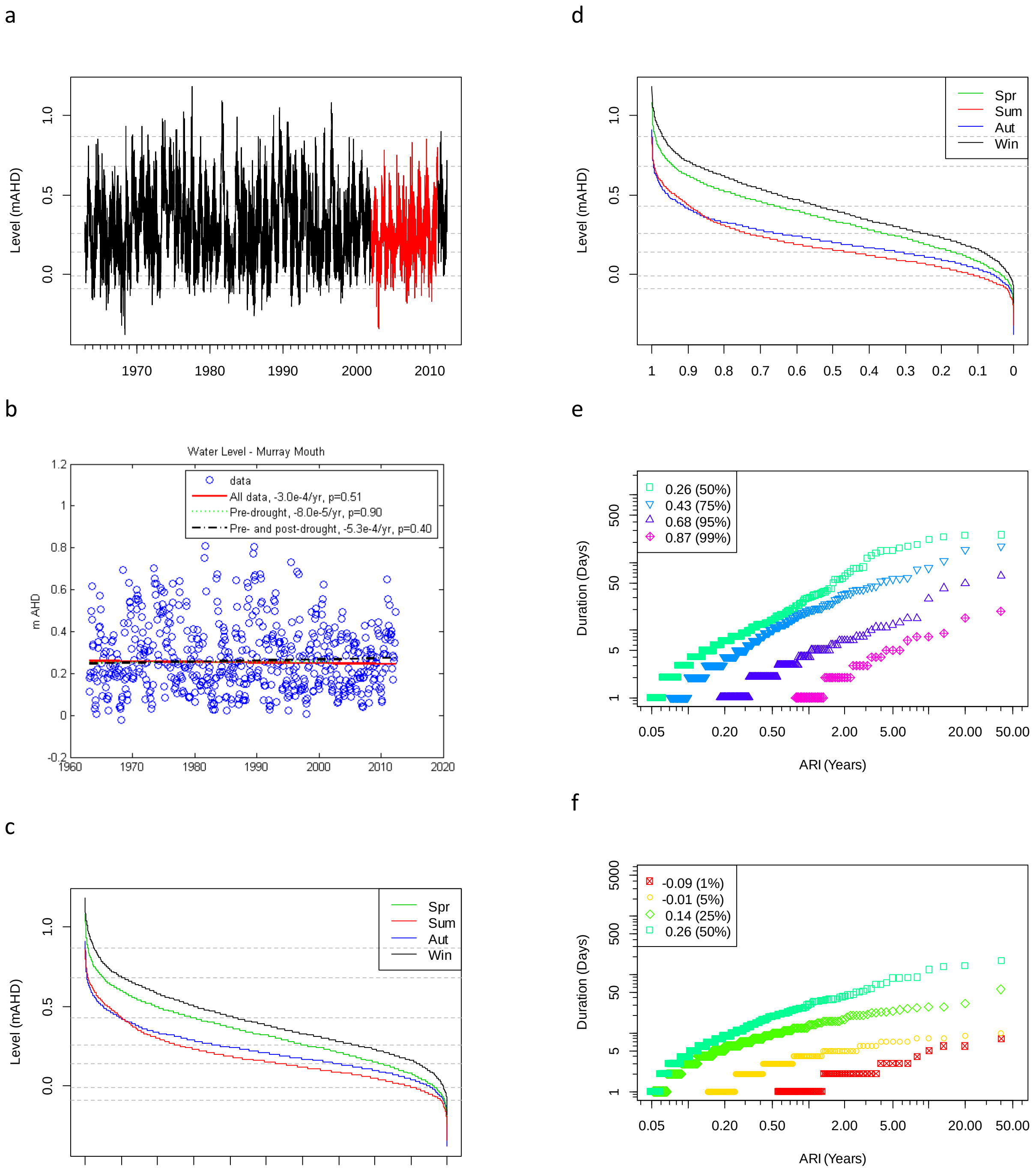


Figure 28 Murray Mouth Modelled Water Level (a) Time series (b) Trend plots for modelled water level with and without LOESS adjustment (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. No management targets set.

Murray Mouth: Modelled Salinity

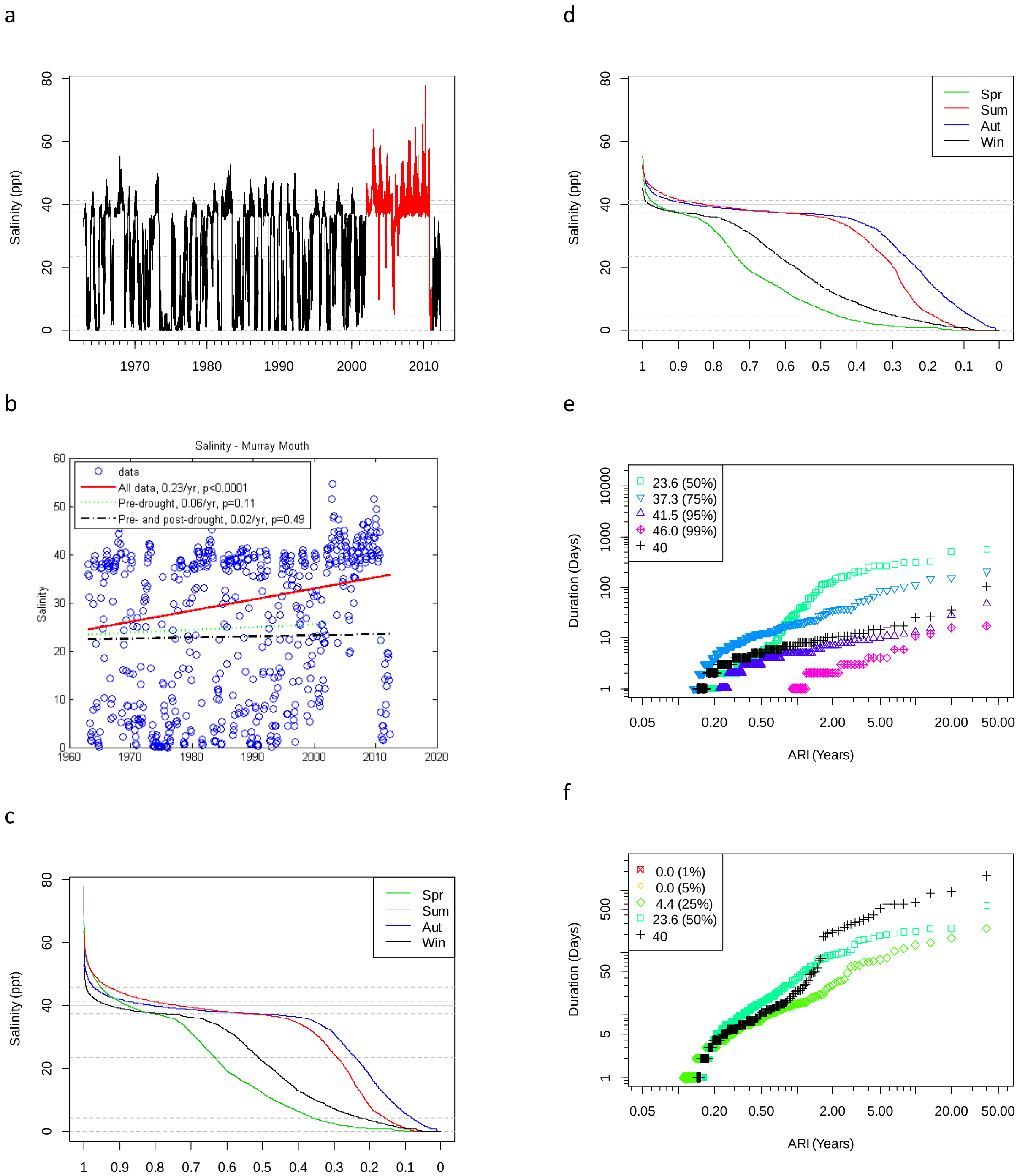


Figure 29 Murray Mouth Modelled Salinity (a) Time series (b) Trend plots for modelled salinity (c) Exceedance curves of all data by seasons (d) Exceedance curve of data from the pre-drought period by seasons (e) Spell duration for pre-drought median and greater values (f) Spell duration for pre-drought median and lower values. The 1, 5, 25, 50, 75, 95 and 99 percentiles identified from the pre-drought exceedance curve using all data are indicated by dashed lines and their values are presented in the keys of the spell duration curves. The grey solid lines indicate current or proposed LAC and management targets (Table 2) with values indicated in the key of the spell duration curves and plotted there by symbols.

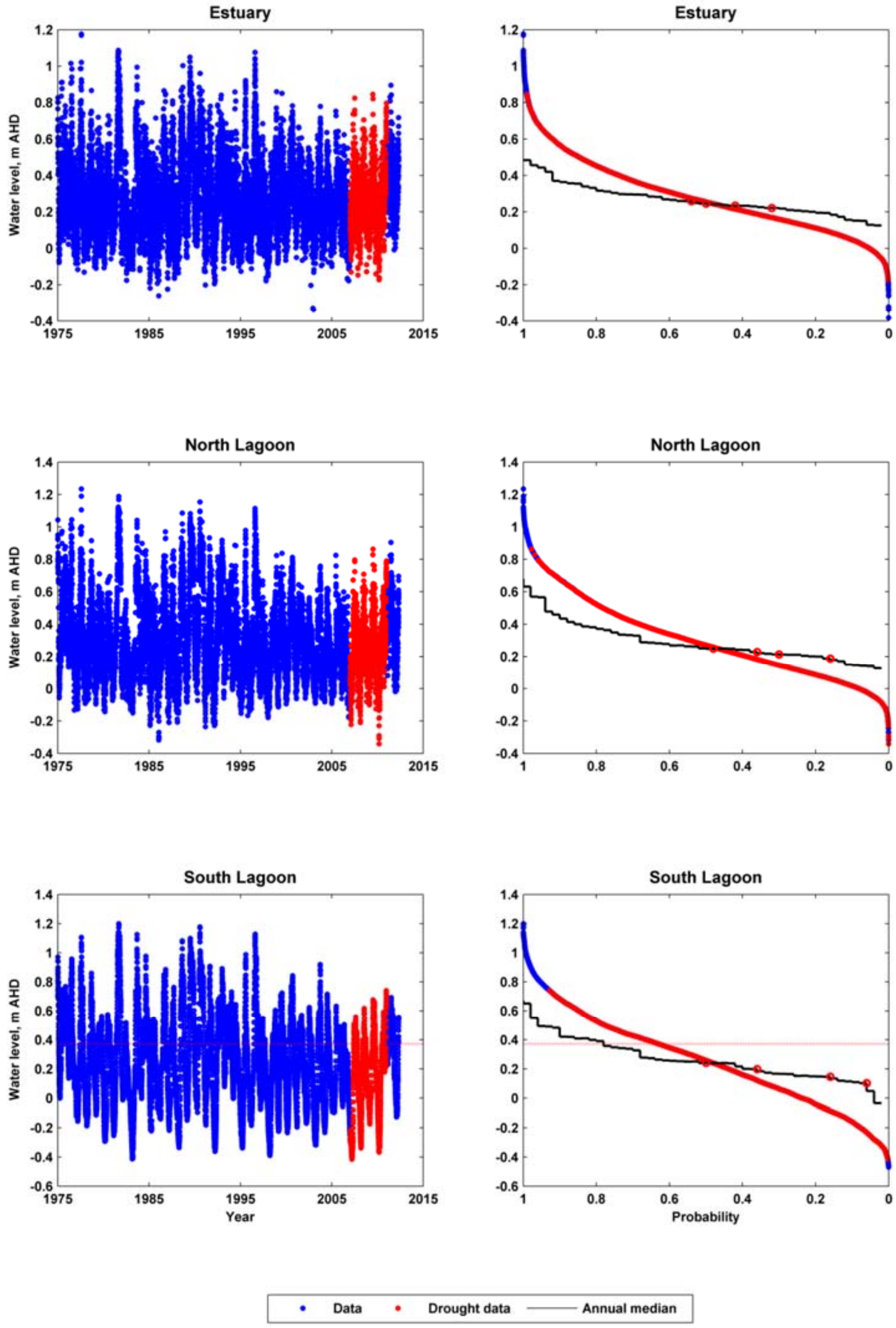
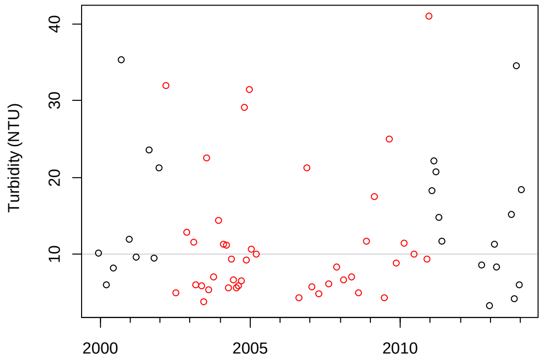


Figure 30 Water level times series and exceedance plots for the Coorong Murray Mouth (estuary), North Lagoon and South Lagoon areas, highlighting the data from the drought period.

Coorong North: Turbidity

a



b

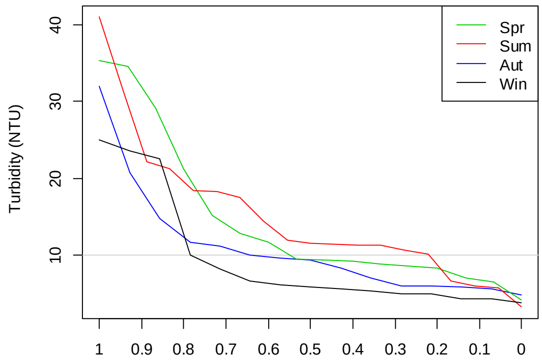
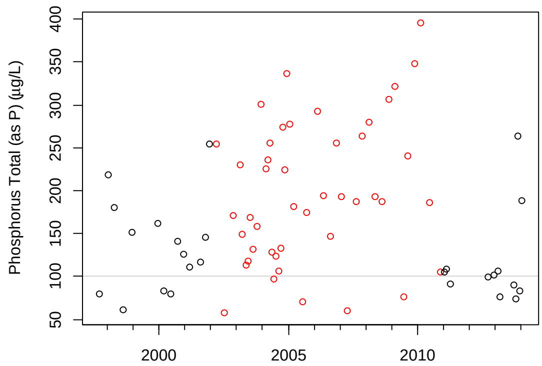


Figure 31 Coorong North Turbidity (a) Time series (b) Exceedance curves of all data by seasons. The grey solid lines indicate current or proposed LAC and management targets (Table 2)

Coorong North: Total Phosphorus

a



b

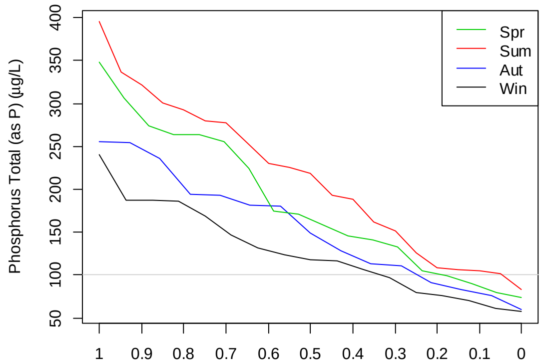
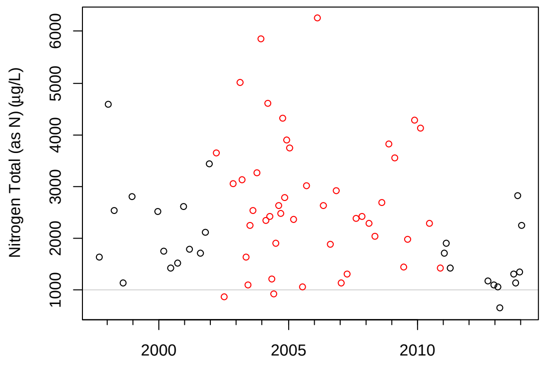


Figure 32 Coorong North Total Phosphorus (a) Time series (b) Exceedance curves of all data by seasons. The grey solid lines indicate current or proposed LAC and management targets (Table 2).

Coorong North: Total Nitrogen

a



b

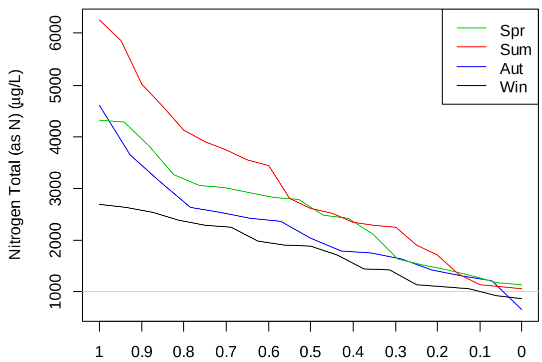
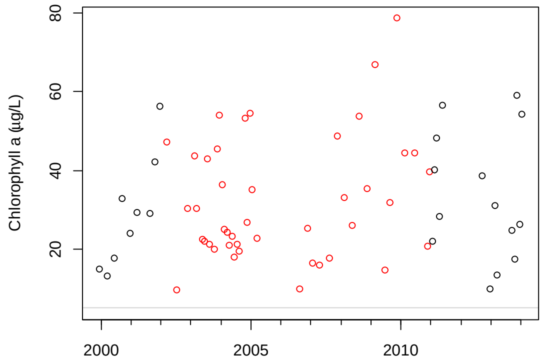


Figure 33 Coorong North Total Nitrogen (a) Time series (b) Exceedance curves of all data by seasons. The grey solid lines indicate current or proposed LAC and management targets (Table 2).

Coorong North: Chlorophyll-a

a



b

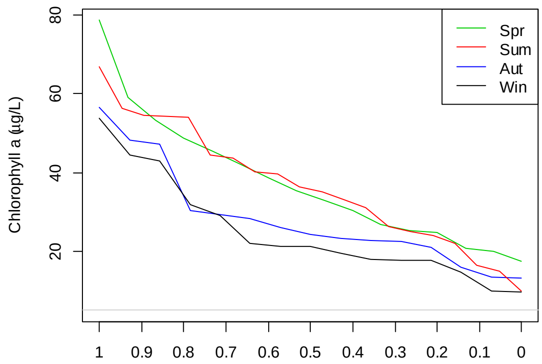
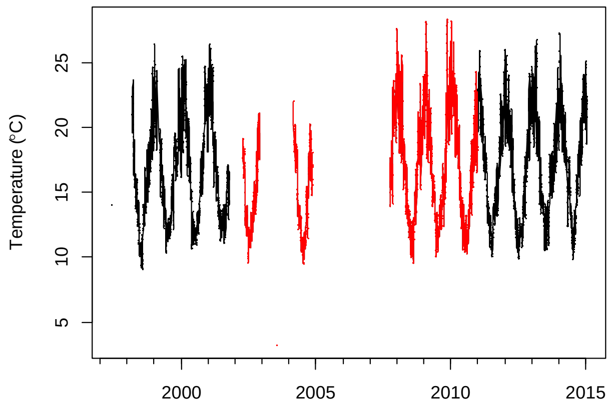


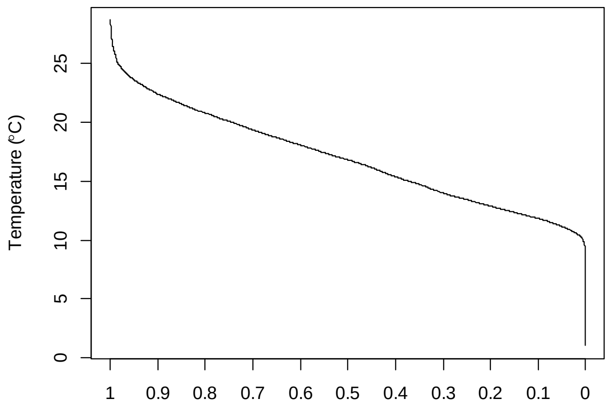
Figure 34 Coorong North Chlorophyll-a (a) Time series (b) Exceedance curves of all data by seasons. The grey solid lines indicate current or proposed LAC and management targets (Table 2).

Coorong North: Temperature

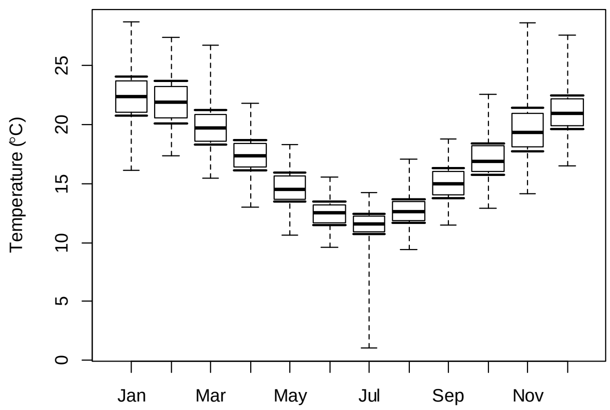
a



b



c



d

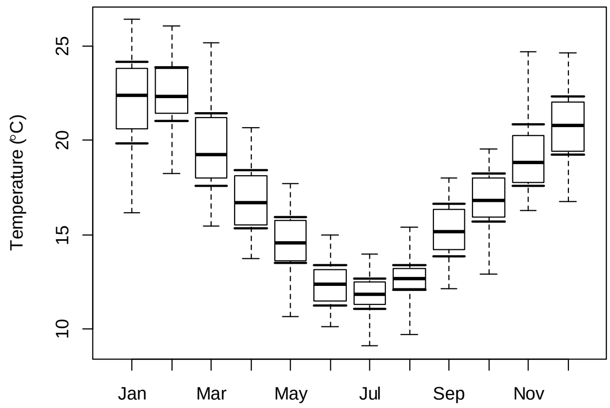
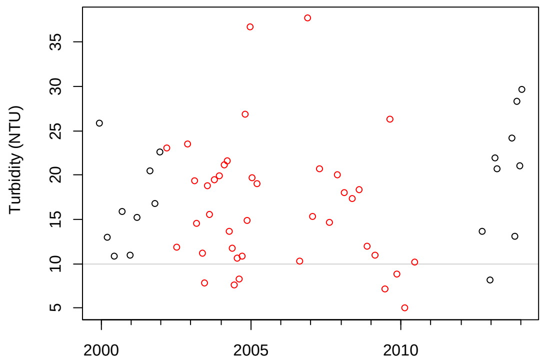


Figure 35 Coorong North Temperature (a) Time series (b) Exceedance plot of all data (c) Monthly box plot for all values (d) Monthly box plot for pre-drought values. Box plots show the 20, 25, 50, 75, and 80 percentiles identified from all or pre-drought monthly data. The proposed management targets are the monthly 20 and 80 percentile limits.

Coorong South: Turbidity

a



b

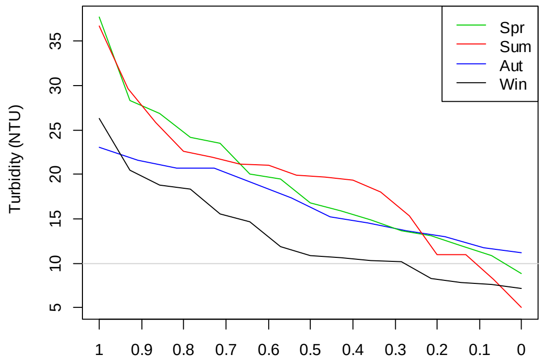
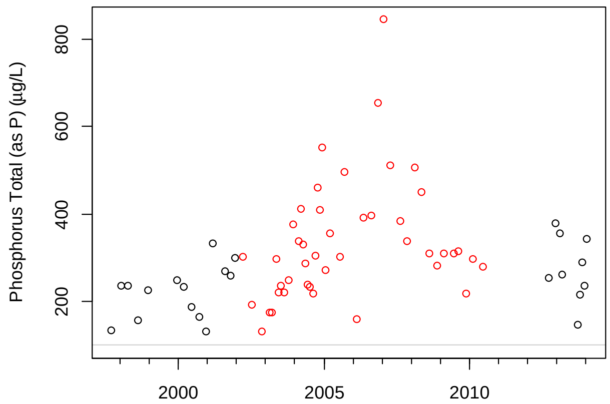


Figure 36 Coorong South Turbidity (a) Time series (b) Exceedance curves of all data by seasons The grey solid lines indicate current or proposed LAC and management targets (Table 2).

Coorong South: Total Phosphorus

a



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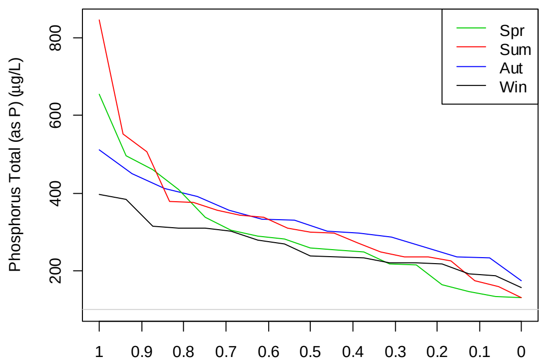
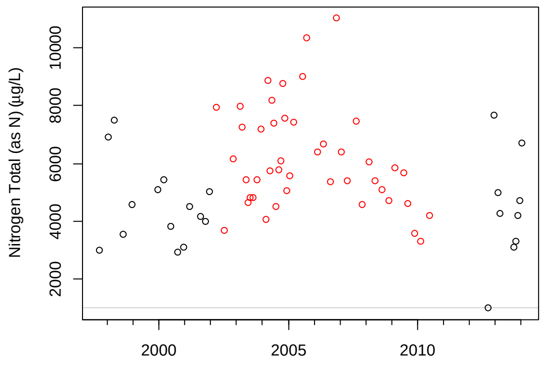


Figure 37 Coorong South Total Phosphorus (a) Time series (b) Exceedance curves of all data by seasons. The grey solid lines indicate current or proposed LAC and management targets (Table 2).

Coorong South: Total Nitrogen

a



b

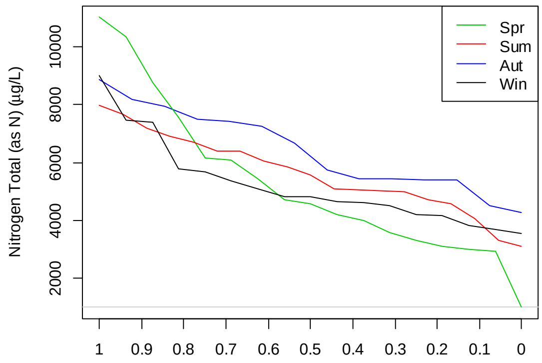
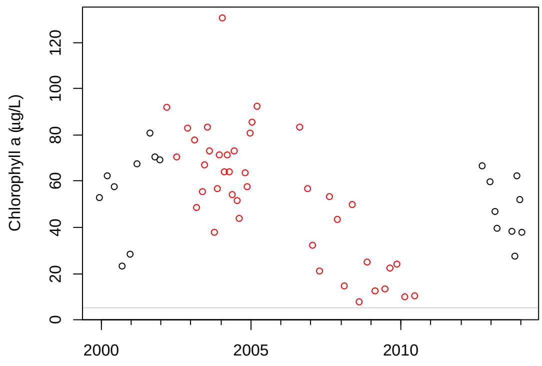


Figure 38 Coorong South Total Nitrogen (a) Time series (b) Exceedance curves of all data by seasons. The grey solid lines indicate current or proposed LAC and management targets (Table 2).

Coorong South: Chlorophyll-a

a



b

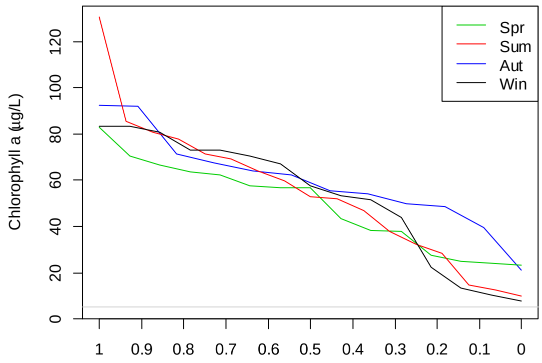
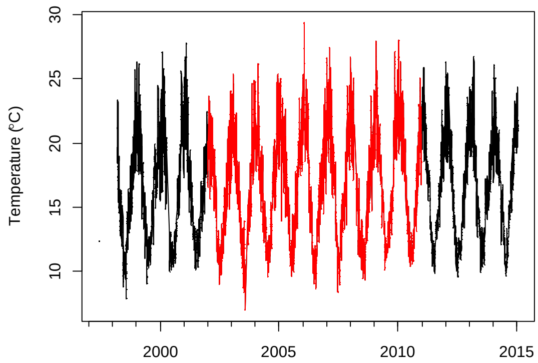


Figure 39 Coorong South Chlorophyll-a (a) Time series (b) Exceedance curves of all data by seasons. The grey solid lines indicate current or proposed LAC and management targets (Table 2).

Coorong South: Temperature

a



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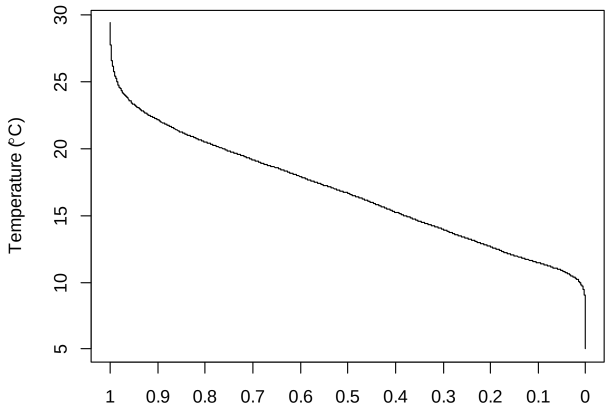

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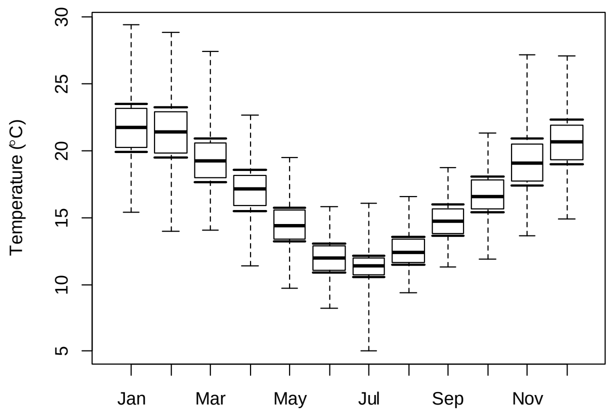

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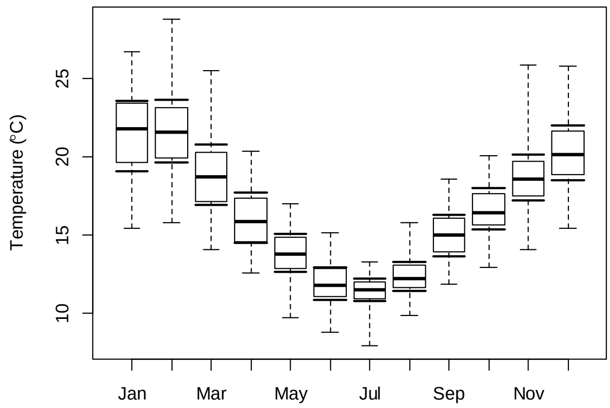
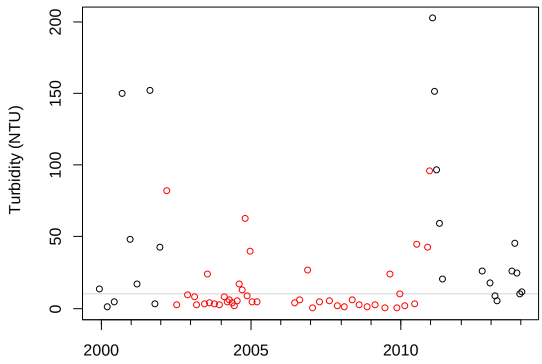


Figure 40 Coorong South Temperature (a) Time series (b) Exceedance plot of all data (c) Monthly box plot for all values (d) Monthly box plot for pre-drought values. Box plots show the 20, 25, 50, 75, and 80 percentiles identified from all or pre-drought monthly data. The proposed management targets are the monthly 20 and 80 percentile limits.

Murray Mouth: Turbidity

a



b

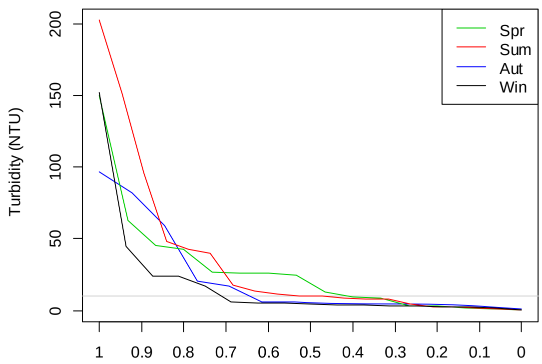
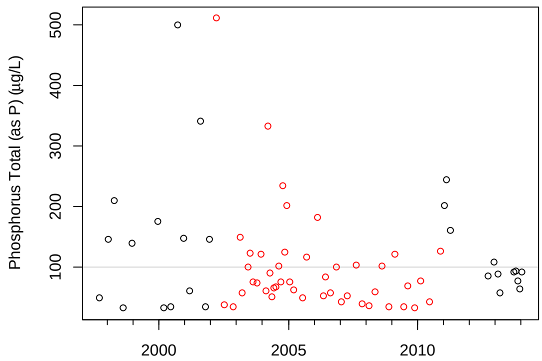


Figure 41 Murray Mouth Turbidity (a) Time series (b) Exceedance curves of all data by seasons. The grey solid lines indicate current or proposed LAC and management targets (Table 2).

Murray Mouth: Total Phosphorus

a



b

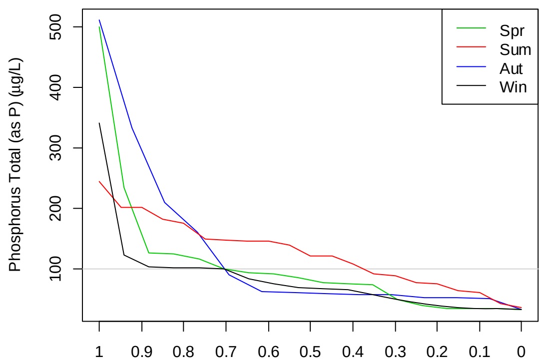


Figure 42 Murray Mouth Total Phosphorus (a) Time series (b) Exceedance curves of all data by seasons. The grey solid lines indicate current or proposed LAC and management targets (Table 2).

Murray Mouth: Total Nitrogen:

a

b

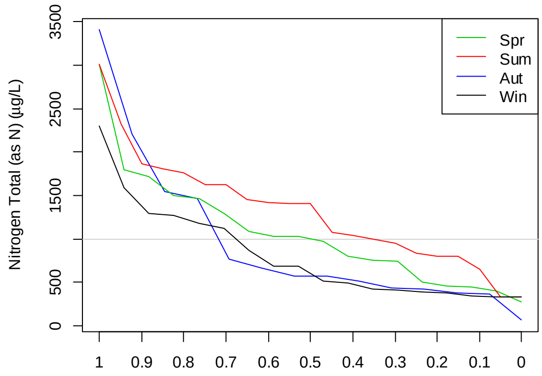
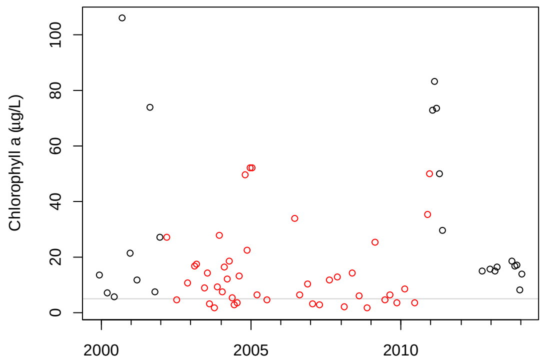


Figure 43 Murray Mouth Total Nitrogen (a) Time series (b) Exceedance curves of all data by seasons. The grey solid lines indicate current or proposed LAC and management targets (Table 2).

Murray Mouth: Chlorophyll-a

a



b

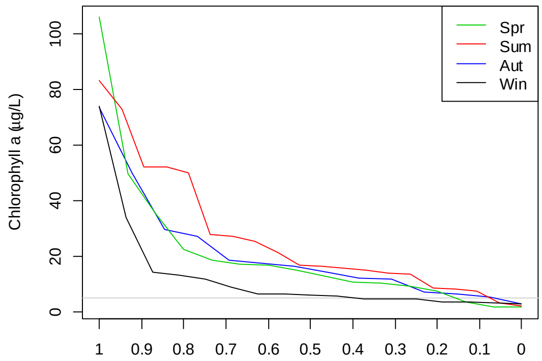
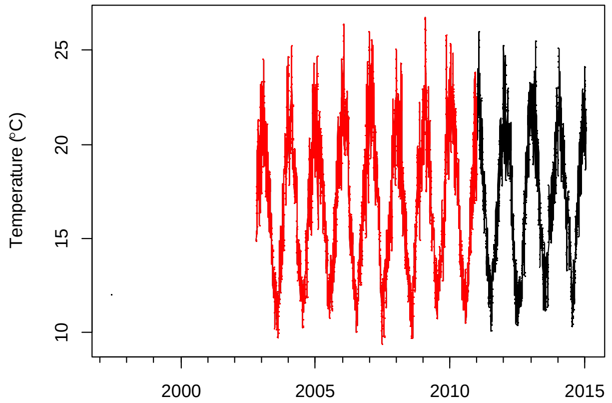


Figure 44 Murray Mouth Chlorophyll-a (a) Time series (b) Exceedance curves of all data by seasons. The grey solid lines indicate current or proposed LAC and management targets (Table 2).

Murray Mouth: Temperature

a



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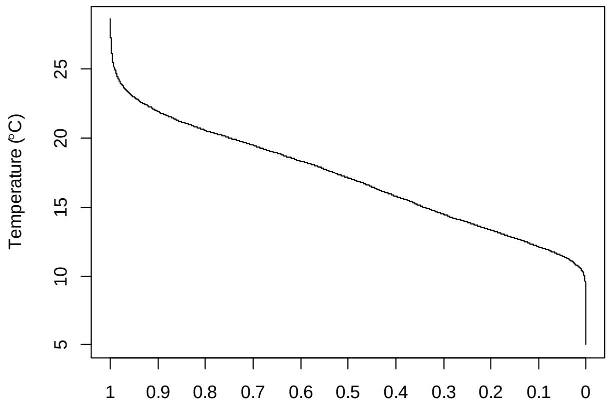

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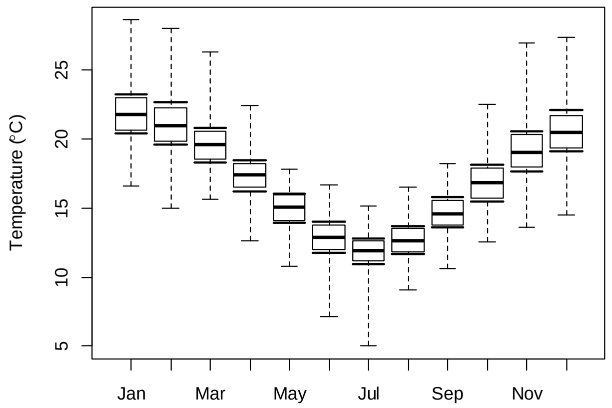

Figure 45 Murray Mouth Temperature (a) Time series (b) Exceedance plot of all data (c) Monthly box plot for all values. Box plots show the 20, 25, 50, 75, and 80 percentiles identified from all or pre-drought monthly data. The proposed management targets are the monthly 20 and 80 percentile limits.

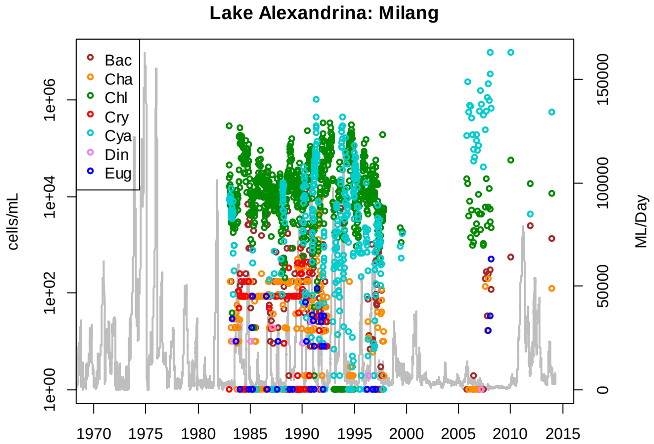

Figure 46 Time series of abundance of major microalgae groups at Milang in Lake Alexandrina: Bacillariophyceae (Bac, diatoms), Charophyta (Cha), Chlorophyta (Chl, green algae), Cryptophyta (Cry), Cyanophyta (Cya, blue green algae), Dinophyceae (Din) and Euglenophyceae (Eug) (Oliver et al 2014).

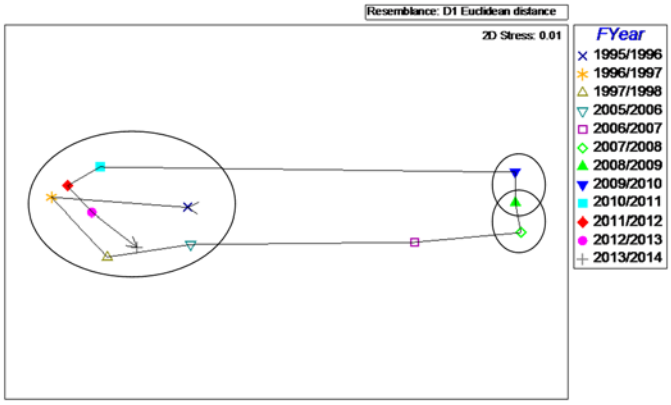

Figure 47 Time sequence of changes in water quality in Lake Alexandrina based on centroids of financial year average seasonal data commencing in 1995/96 prior to the drought. Ellipses enclose years that are not significantly different based on PERMANOVA of seasonal water quality characteristics (Oliver et al 2014).

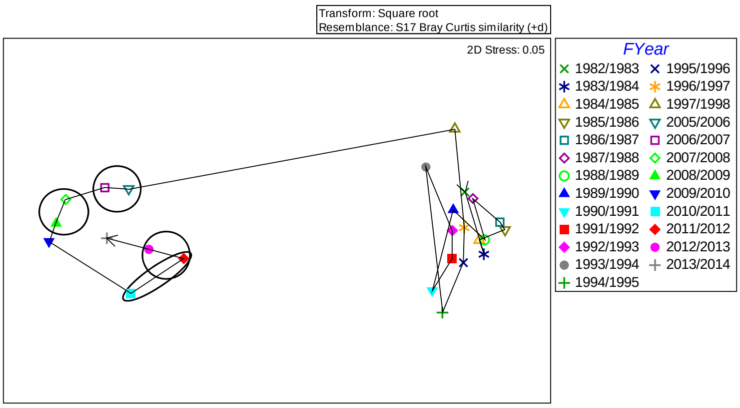

Figure 48 Time sequence of changes in microalgae community composition pre-drought (1982-1998) and from 2005/06 onwards in Lake Alexandrina based on centroids of financial year average seasonal community data. Ellipses enclose years from 2005/06 onwards that are not significantly different based on PERMANOVA of seasonal microalgae community composition (Oliver et al 2014).

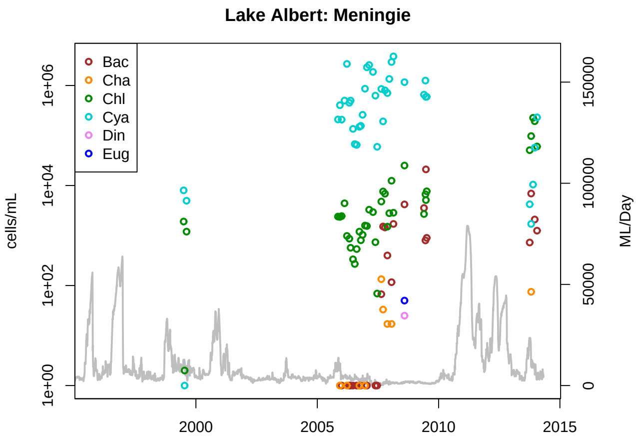

Figure 49 Time series at Meningie in Lake Albert of major microalgae group abundances: Bacillariophyceae (Bac, diatoms), Charophyta (Cha), Chlorophyta (Chl, green algae), Cryptophyta (Cry), Cyanophyta (Cya, blue green algae), Dinophyceae (Din) and Euglenophyceae (Eug) (Oliver et al 2014).

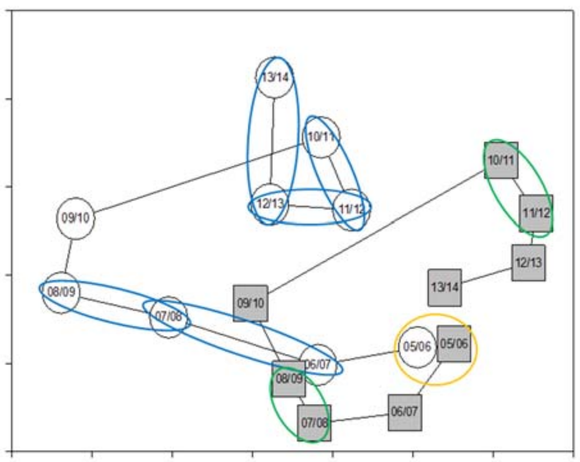

Figure 50 Time sequence of changes in water quality in Lake Alexandrina (filled rectangles) and Lake Albert (circles) based on centroids of financial year average seasonal data commencing 2005/06. Ellipses enclose years that are not significantly different based on PERMANOVA of seasonal water quality characteristics (Oliver et al 2014).

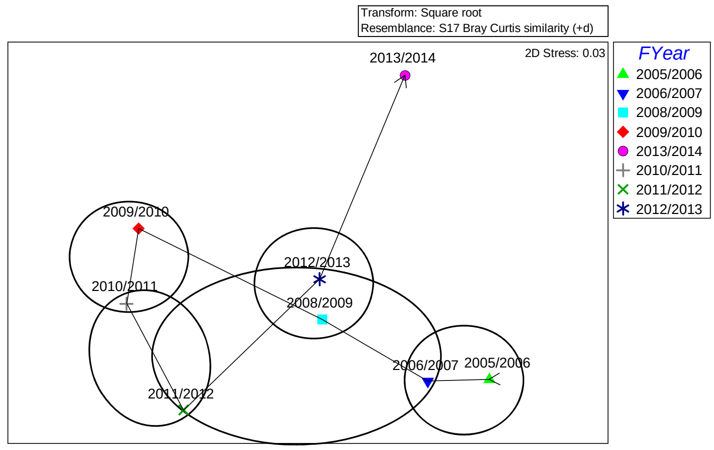

Figure 51 Time sequence of changes in microalgae community composition in Lake Albert based on centroids of financial year average seasonal community data. Ellipses enclose years that are not significantly different based on PERMANOVA of seasonal microalgae community composition (Oliver et al 2014).

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APPENDIX 1 Basin Plan default targets for inclusion in SA WQM Plans

10.32- 2(a) for fresh water-dependent ecosystems—the applicable target values referred to in section 9.16

9.16 Water quality targets for fresh water-dependent ecosystems

(1) The water quality targets for fresh water-dependent ecosystems (including fresh water-dependent ecosystems that are declared Ramsar wetlands) are that a water quality characteristic in a target application zone meets the target value for that characteristic and zone set out in Schedule 11 (SEE BELOW).

(2) The ***target application zone***, of a particular name, means the area within the boundary described by the polygon of that name included in the dataset that:

(a) is titled *Water Quality Zones*; and

(b) has a dataset scale of 1:250,000; and

(c) is held by the Authority at the commencement of the Basin Plan.

(3) The Authority must publish on its website a map that:

(a) identifies each target application zone; and

(b) uses the dataset referred to in subsection (2).

Schedule 11

Target application zones (Target assessment)	Water-dependent ecosystem	Ecosystem Type	Turbidity (NTU) (Annual median)	Total Phosphorus (µg/L) (Annual median)	Total Nitrogen (µg/L) (Annual median)	Dissolved oxygen (mg/L; or saturation (%)) (Annual median within the range)	pH (Annual median within the range)	Salinity	Temperature (Monthly median within the range)	Pesticides, heavy metals and other toxic contaminants (values in table 3.4.1 of the ANZECC Guidelines for) (Must not be exceeded)
IM (Lower Murray)	Declared Ramsar wetlands	Streams and rivers	50	100	1000	85-110%	6.5-9.0		between the 20%ile and 80%ile of natural monthly water temperature	the protection of 99% of species
		Lakes and wetlands	20	10	350	90–110%	6.5–8.0		between the 20%ile and 80%ile of natural monthly water temperature	the protection of 99% of species
	Other water-dependent ecosystems	Streams, rivers, lakes and wetlands	50	100	1000	85-110%	6.5-9.0	End-of-Valley targets in Appendix 1 of Schedule B to the Agreement	between the 20%ile and 80%ile of natural monthly water temperature	the protection of 95% of species

The Basin Plan also gives South Australia an ability to set an objectively determined (alternative) value as defined in the Basin Plan section 10.32(4):

However, if the objectively determined actual value of a water quality characteristic at a site is better than the target value identified in subsection (2), then the target value is that better value.

Note: See the objective in section 9.08.

(4) The WQM Plan may specify an alternative water quality target value if:

(a) it is consistent with the water quality objectives in Part 3 of Chapter 9; and

(b) it is determined in accordance with the procedures set out in the ANZECC Guidelines; and

(c) either:

(i) the alternative target value provides a better level of protection than the value that would apply under subsection (2) or (3), as applicable; or

(ii) the WQM Plan sets out reasons why the alternative target value will be as effective in achieving the objectives in Part 3 of Chapter 9; or

(iii) the WQM Plan sets out reasons why the target value in subsection (2) or (3), as applicable, is inappropriate for the water resource plan area; and

(d) for a water resource that is also covered by a water resource plan area of another Basin State—it is developed in consultation with that State.

9.18 Water quality targets for recreational water

The water quality targets for water used for recreational purposes are that the values for cyanobacteria cell counts or biovolume meet the guideline values set out in Chapter 6 of the Guidelines for Managing Risks in Recreational Water.

Schedule 5—Enhanced environmental outcomes referred to in paragraph 7.09(e)

(1) The outcomes listed below are ones that will be pursued under the Commonwealth's program to increase the volume of water resources available for environmental use by 450 GL per year.

(2) The outcomes that will be pursued are:

(a) further reducing salinity levels in the Coorong and Lower Lakes so that improved water quality contributes to the health of macroinvertebrates, fish and plants that form important parts of the food chain, for example:

- (i) maximum average daily salinity in the Coorong South Lagoon is less than 100 grams per litre; and
- (ii) maximum average daily salinity in the Coorong North Lagoon is less than 50 grams per litre; and
- (iii) average daily salinity in Lake Alexandrina is less than 1000EC for 95% of years and 1500EC all of the time;

(b) keeping water levels in the Lower Lakes above 0.4 metres AHD for 95% of the time and above 0.0 metres AHD at all times to help maintain flows to the Coorong, prevent acidification, prevent acid drainage and prevent riverbank collapse below Lock 1;

(c) ensuring the mouth of the River Murray is open without the need for dredging in at least 95% of years, with flows every year through the Murray Mouth Barrages;

(d) exporting 2 million tonnes per year of salt from the Murray-Darling Basin as a long-term average;

(e) increasing flows through the barrages to the Coorong and supporting more years where critical fish migrations can occur;

Schedule 6—Default method for calculation of supply contribution

S6.07 Limits of changes in score or outcomes

The following limits of change in score or outcome will apply in the method under the historic climate conditions:

(c) for the Coorong, Lower Lakes, Murray Mouth—maintenance or improvement of the following:

- (i) Lake Alexandrina salinity: less than 1500EC for 100% of the time and less than 1000EC for 95% of days;
- (ii) Barrage flows: greater than 2000 GL per year on a three year rolling average basis with a minimum of 650 GL in any year, to be achieved for 95% of years;

(iii) Barrage flows: greater than 600 GL over any two year period, to be achieved for 100% of the time;

(iv) Coorong salinity: South Lagoon average daily salinity less than 100 grams per litre for 96% of days;

(v) Mouth openness: Mouth open to an average annual depth of 1 metres (-1.0 m AHD) or more for at least 90% of years and 0.7 metres (-0.7 m AHD) for 95% of years;

APPENDIX 2 - Tables from ANZECC (2000) guidelines for South Central Australia and also for South Eastern Australia that appear to have been used as default targets in the Basin Plan.

Table 3.3.8 Default trigger values for physical and chemical stressors for south central Australia — low rainfall areas — for slightly disturbed ecosystems. Trigger values are used to assess risk of adverse effects due to nutrients, biodegradable organic matter and pH in various ecosystem types. Data derived from trigger values supplied by South Australia. Chl *a* = chlorophyll *a*, TP = total phosphorus, FRP = filterable reactive phosphate, TN = total nitrogen, NO_x = oxides of nitrogen, NH_4^+ = ammonium, DO = dissolved oxygen.

Ecosystem type	Chl *a* ($\mu g L^{-1}$)	TP ($\mu g P L^{-1}$)	FRP ($\mu g P L^{-1}$)	TN ($\mu g N L^{-1}$)	NO_x ($\mu g N L^{-1}$)	NH_4^+ ($\mu g N L^{-1}$)	DO (% saturation) Lower limit	DO (% saturation) Upper limit	pH Lower limit	pH Upper limit
Upland river	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Lowland river	no data	100	40	1000	100	100	90	no data	6.5	9.0
Freshwater lakes & reservoirs	no data	25	10	1000	100	25	90	no data	6.5	9.0
Wetlands	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Estuaries	5	100	10	1000	100	50	90	no data	6.5	9.0
Marine	1	100	10	1000	50	50	no data	no data	8.0	8.5

Table 3.3.9 Ranges of default trigger values for conductivity (EC, salinity), turbidity and suspended particulate matter (SPM) indicative of slightly disturbed ecosystems in south central Australia — low rainfall areas. Ranges for turbidity and SPM are similar and only turbidity is reported here. Values reflect high site-specific and regional variability. Explanatory notes provide detail on specific variability issues for groupings of ecosystem type.

Ecosystem types	Salinity ($\mu S cm^{-1}$)	Explanatory notes
Lowland rivers	100–5000	Salinity can be highly variable depending on flow.
Lakes, reservoirs & wetlands	300–1000	Wetlands can have substantially higher salinity due to saline groundwater intrusion and evaporation.
	Turbidity (NTU)	
Upland & lowland rivers	1–50	Turbidity and SPM are highly variable and dependent on seasonal rainfall runoff.
Lakes & reservoirs/ wetlands	1–100	Shallow lakes and reservoirs may have higher turbidity naturally due to wind-induced resuspension of sediments. Lakes and reservoirs in catchments with highly dispersible soils will have high turbidity.
Estuarine & marine	0.5–10	Higher values are representative of estuarine waters.

Tables 3.3.2–3.3.3 South-east Australia

The following tables outline default trigger values applicable to Victoria, New South Wales, south-east Queensland, the Australian Capital Territory and Tasmania. Where individual states or territories have developed their own regional guideline trigger values, those values should be used in preference to the default values provided below. (Upland streams are defined as those at >150 m altitude, while alpine streams are those at altitudes >1500 m.)

Table 3.3.2 Default trigger values for physical and chemical stressors for south-east Australia for slightly disturbed ecosystems. Trigger values are used to assess risk of adverse effects due to nutrients, biodegradable organic matter and pH in various ecosystem types. Data derived from trigger values supplied by Australian states and territories. Chl *a* = chlorophyll *a*, TP = total phosphorus, FRP = filterable reactive phosphate, TN = total nitrogen, NO_x = oxides of nitrogen, NH_4^+ = ammonium, DO = dissolved oxygen.

Ecosystem type	Chl *a*	TP	FRP	TN	NO_x	NH_4^+	DO (% saturation)[l]		pH	
	($\mu g\ L^{-1}$)	($\mu g\ P\ L^{-1}$)	($\mu g\ P\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	Lower limit	Upper limit	Lower limit	Upper limit
Upland river	na[a]	20[b]	15[g]	250[c]	15[h]	13[i]	90	110	6.5	7.5[m]
Lowland river[d]	5	50	20	500	40[o]	20	85	110	6.5	8.0
Freshwater lakes & Reservoirs	5[e]	10	5	350	10	10	90	110	6.5	8.0[m]
Wetlands	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Estuaries[p]	4[f]	30	5[j]	300	15	15	80	110	7.0	8.5
Marine[p]	1[n]	25[n]	10	120	5[k]	15[k]	90	110	8.0	8.4

na = not applicable;
a = monitoring of periphyton and not phytoplankton biomass is recommended in upland rivers — values for periphyton biomass (mg Chl *a* m^{-2}) to be developed;
b = values are 30 μgL^{-1} for Qld rivers, 10 μgL^{-1} for Vic. alpine streams and 13 μgL^{-1} for Tas. rivers;
c = values are 100 μgL^{-1} for Vic. alpine streams and 480 μgL^{-1} for Tas. rivers;
d = values are 3 μgL^{-1} for Chl *a*, 25 μgL^{-1} for TP and 350 μgL^{-1} for TN for NSW & Vic. east flowing coastal rivers;
e = values are 3 μgL^{-1} for Tas. lakes;
f = value is 5 μgL^{-1} for Qld estuaries;
g = value is 5 μgL^{-1} for Vic. alpine streams and Tas. rivers;
h = value is 190 μgL^{-1} for Tas. rivers;
i = value is 10 μgL^{-1} for Qld. rivers;
j = value is 15 μgL^{-1} for Qld. estuaries;
k = values of 25 μgL^{-1} for NO_x and 20 μgL^{-1} for NH_4^+ for NSW are elevated due to frequent upwelling events;
l = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability (see Section 3.3.3.2);
m = values for NSW upland rivers are 6.5–8.0, for NSW lowland rivers 6.5–8.5, for humic rich Tas. lakes and rivers 4.0-6.5;
n = values are 20 μgL^{-1} for TP for offshore waters and 1.5 μgL^{-1} for Chl *a* for Qld inshore waters;
o = value is 60 μgL^{-1} for Qld rivers;
p = no data available for Tasmanian estuarine and marine waters. A precautionary approach should be adopted when applying default trigger values to these systems.

Table 3.3.3 Ranges of default trigger values for conductivity (EC, salinity), turbidity and suspended particulate matter (SPM) indicative of slightly disturbed ecosystems in south-east Australia. Ranges for turbidity and SPM are similar and only turbidity is reported here. Values reflect high site-specific and regional variability. Explanatory notes provide detail on specific variability issues for ecosystem type.

Ecosystem type	Salinity (μScm^{-1})	Explanatory notes
Upland rivers	30–350	Conductivity in upland streams will vary depending upon catchment geology. Low values are found in Vic. alpine regions (30 μScm^{-1}) and eastern highlands (55 μScm^{-1}), and high values (350 μScm^{-1}) in NSW rivers. Tasmanian rivers are mid-range (90 μScm^{-1}).
Lowland rivers	125–2200	Lowland rivers may have higher conductivity during low flow periods and if the system receives saline groundwater inputs. Low values are found in eastern highlands of Vic. (125 μScm^{-1}) and higher values in western lowlands and northern plains of Vic (2200 μScm^{-1}). NSW coastal rivers are typically in the range 200–300 μScm^{-1}.
Lakes & reservoirs	20–30	Conductivity in lakes and reservoirs is generally low, but will vary depending upon catchment geology. Values provided are typical of Tasmanian lakes and reservoirs.
	Turbidity (NTU)	
Upland rivers	2–25	Most good condition upland streams have low turbidity. High values may be observed during high flow events.
Lowland rivers	6–50	Turbidity in lowland rivers can be extremely variable. Values at the low end of the range would be found in rivers flowing through well vegetated catchments and at low flows. Values at the high end of the range would be found in rivers draining slightly disturbed catchments and in many rivers at high flows.
Lakes & reservoirs	1–20	Most deep lakes and reservoirs have low turbidity. However, shallow lakes and reservoirs may have higher natural turbidity due to wind-induced resuspension of sediments. Lakes and reservoirs in catchments with highly dispersible soils will have high turbidity.
Estuarine & marine	0.5–10	Low turbidity values are normally found in offshore waters. Higher values may be found in estuaries or inshore coastal waters due to wind-induced resuspension or to the input of turbid water from the catchment. Turbidity is not a very useful indicator in estuarine and marine waters. A move towards the measurement of light attenuation in preference to turbidity is recommended.

APPENDIX 3 - Table from ANZECC (2000) with trigger values for toxicants. Only selected metal toxicants were considered in this report based on data available.

Table 3.4.1 Trigger values for toxicants at alternative levels of protection. Values in grey shading are the trigger values applying to typical *slightly–moderately disturbed systems*; see table 3.4.2 and Section 3.4.2.4 for guidance on applying these levels to different ecosystem conditions.

Chemical	Trigger values for freshwater (μgL^{-1})				Trigger values for marine water (μgL^{-1})			
	Level of protection (% species)				Level of protection (% species)			
	99%	95%	90%	80%	99%	95%	90%	80%
METALS & METALLOIDS								
Aluminium pH >6.5	27	55	80	150	ID	ID	ID	ID
Aluminium pH <6.5	ID	ID	ID	ID	ID	ID	ID	ID
Antimony	ID	ID	ID	ID	ID	ID	ID	ID
Arsenic (As III)	1	24	94 [C]	360 [C]	ID	ID	ID	ID
Arsenic (AsV)	0.8	13	42	140 [C]	ID	ID	ID	ID
Beryllium	ID	ID	ID	ID	ID	ID	ID	ID
Bismuth	ID	ID	ID	ID	ID	ID	ID	ID
Boron	90	370 [C]	680 [C]	1300 [C]	ID	ID	ID	ID
Cadmium H	0.06	0.2	0.4	0.8 [C]	0.7 [B]	5.5 [B,C]	14 [B,C]	36 [B,A]
Chromium (Cr III) H	ID	ID	ID	ID	7.7	27.4	48.6	90.6
Chromium (CrVI)	0.01	1.0 [C]	6 [A]	40 [A]	0.14	4.4	20 [C]	85 [C]
Cobalt	ID	ID	ID	ID	0.005	1	14	150 [C]
Copper H	1.0	1.4	1.8 [C]	2.5 [C]	0.3	1.3	3 [C]	8 [A]
Gallium	ID	ID	ID	ID	ID	ID	ID	ID
Iron	ID	ID	ID	ID	ID	ID	ID	ID
Lanthanum	ID	ID	ID	ID	ID	ID	ID	ID
Lead H	1.0	3.4	5.6	9.4 [C]	2.2	4.4	6.6 [C]	12 [C]
Manganese	1200	1900 [C]	2500 [C]	3600 [C]	ID	ID	ID	ID
Mercury (inorganic) B	0.06	0.6	1.9 [C]	5.4 [A]	0.1	0.4 [C]	0.7 [C]	1.4 [C]
Mercury (methyl)	ID	ID	ID	ID	ID	ID	ID	ID
Molybdenum	ID	ID	ID	ID	ID	ID	ID	ID
Nickel H	8	11	13	17 [C]	7	70 [C]	200 [A]	560 [A]
Selenium (Total) B	5	11	18	34	ID	ID	ID	ID
Selenium (SeIV) B	ID	ID	ID	ID	ID	ID	ID	ID
Silver	0.02	0.05	0.1	0.2 [C]	0.8	1.4	1.8	2.6 [C]
Thallium	ID	ID	ID	ID	ID	ID	ID	ID
Tin (inorganic, SnIV)	ID	ID	ID	ID	ID	ID	ID	ID
Tributyltin (as µg/L Sn)	ID	ID	ID	ID	0.0004	0.006 [C]	0.02 [C]	0.05 [C]
Uranium	ID	ID	ID	ID	ID	ID	ID	ID
Vanadium	ID	ID	ID	ID	50	100	160	280
Zinc H	2.4	8.0 [C]	15 [C]	31 [C]	7	15 [C]	23 [C]	43 [C]

Appendix A - Preliminary Report by Oliver and Mosley (2014)

The attached report:

Oliver R. and Mosley L. (2014) *An Assessment of the Coorong, Lower Lakes and Murray Mouth Water Quality and Microalgae – A preliminary evaluation of water quality trigger values associated with the Ecological Character Description.* CSIRO Land and Water Flagship, Australia

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