Preliminary climate change vulnerability assessment for the Coorong, Lower Lakes and Murray Mouth

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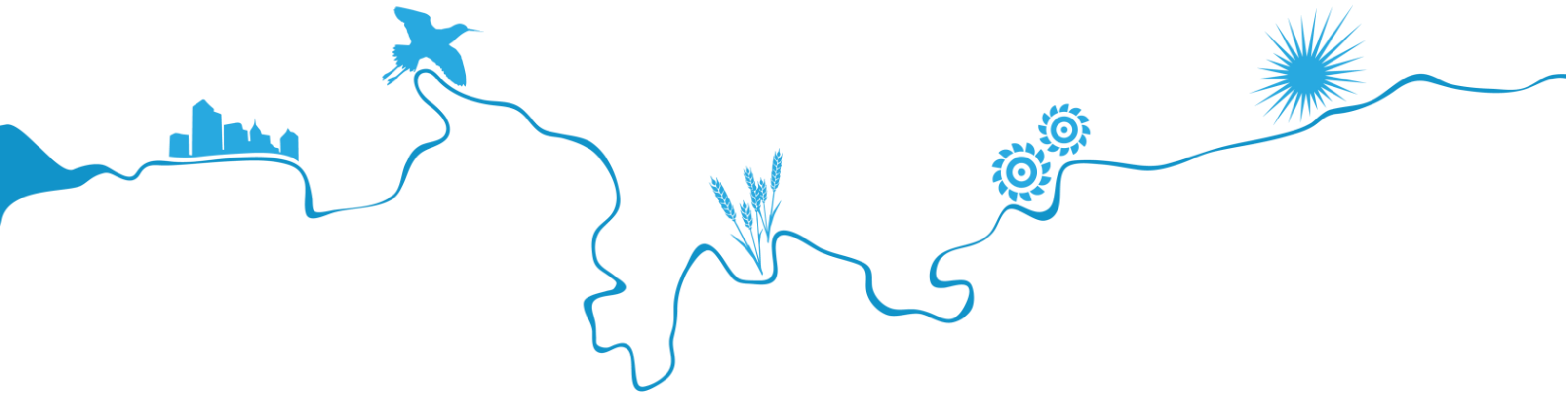

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Respect and reconciliation

Aboriginal people are the First Peoples and Nations of South Australia. The Coorong, connected waters and surrounding lands have sustained unique First Nations' cultures since time immemorial.

The Goyder Institute for Water Research acknowledges the range of First Nations' rights, interests and obligations for the Coorong and connected waterways and the cultural connections that exist between the Ngarrindjeri Nation and First Nations of the South East peoples across the region and seeks to support their equitable engagement.

Aboriginal peoples' spiritual, social, cultural and economic practices come from their lands and waters, and they continue to maintain their cultural heritage, economies, languages and laws which are of ongoing importance.

Executive summary

Climate change will be a driver of large change in the Coorong, Lower Lakes and Murray Mouth (CLLMM) in the coming decades and beyond (Rees et al. 2022). Thinking about, discussing, and planning for such change is difficult for many reasons: the change is large, and likely to be transformational for ecosystems and people; there is much uncertainty about what the impacts will be on CLLMM ecosystems and people's relationships with them; and there are diverse and deeply held values at stake. Finding ways to think about, discuss and plan together will be vital if the system is to be managed successfully through these changes.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has developed a set of climate adaptation planning practices that are designed to address this need. The Healthy Coorong, Healthy Basin (HCHB) Program Trials and Investigations (T&I) Climate Adaptation Component has created an opportunity to test these practices in the CLLMM region. One component of climate adaptation planning practices is a method for assessing the vulnerability of Ramsar wetlands to climate change, and this report documents the results of using this method through the HCHB Program.

We developed two potential future scenarios to provide common, evidence-based assumptions for exploring implications of future change in the CLLMM region. Scenario 1 represents the most extreme point of a drying trajectory caused by reductions in freshwater inflow and increased evaporation, before sea level rise dominates and CLLMM water levels rise to the point where existing barrages would no longer be effective barriers (Scenario 2). We worked closely with the South Australian Department for Environment and Water (DEW) to characterise features that are the focus of CLLMM ecosystem management and are valued by diverse stakeholders. These features (and their attributes) were based on a detailed understanding among DEW staff of the CLLMM ecosystem and the components, processes, and services (CPS) of the site, as described in the site's Ecological Character Description (ECD).

The project team collaborated with DEW staff to deliberate over each feature, while being mindful of assumptions and uncertainties, and established a shared understanding of which attributes are likely to change and which are likely to persist in the face of climate change. We then assessed whether the importance or value of each feature was associated with the changing or persisting attributes. This 'values-mapping' assessment was conducted from two perspectives: a Ramsar management perspective (i.e. does the change correspond to a change in ecological character according to the current defined Limits of Acceptable Change (LAC) in the ECD?); and a more general societal perspective (i.e. to what extent does the change affect non-critical CPS in the ECD and societal biodiversity values associated with the feature?). We also deliberated over whether and how the site might continue to meet its Ramsar nomination criteria under the two scenarios.

The features, changing and persisting attributes, and the values-mapping were all summarised in 'change-persistence tables' that allowed us to compare findings across features and scenarios and identify system patterns. Together with DEW, we used a structured series of analysis questions to make a preliminary assessment of what increases or decreases the vulnerability of the CLLMM to climate change, informed by responses to past extremes. The results were summarised into a 'vulnerability narrative' for the CLLMM. The intent of the narrative was to describe multiple factors affecting how the system might respond and be valued in the face of transformational change.

The results of this vulnerability assessment should be regarded as *preliminary*, because they were developed in consultation with a subset of DEW staff and did not involve First Nations groups and other stakeholders. The outputs do not represent official departmental positions. The engagement with DEW staff served to draw on their extensive experience and detailed knowledge of the CLLMM system, including how the system has previously responded to extremes, and its management. It was also an opportunity to introduce new concepts and tools to DEW to enable them to think about transformational change in a structured way, liberated from the currently dominant, stationary narrative of preservation and restoration. Participation by DEW staff identified several insights about the CLLMM that were brought to the fore in this analysis. There was heightened recognition of the need to think and plan now, even though many of the changes will not be experienced for decades and considering them is potentially disruptive to current planning and negotiations. Some people expressed heightened appreciation for the freshwater components in the system and a wariness of assumptions that the historically fresh Lower Lakes could be a healthy estuarine system under Scenario 2. Lessons learnt in the Millennium Drought were valuable, especially around the consequences of protracted salt and nutrient accumulation, where there is the danger of transitions to unhealthy states that become ecologically locked-in, are difficult to recover from, and may require significant management interventions to reverse. Even though the sheer scale of unknowns was daunting for participants, clear ways forward were identified. These included the need to prepare for future change in shorelines and the habitat requirements of organisms as their distributions change, and future considerations for management of the system.

Given that the primary purpose of the work was to test this approach to vulnerability assessment in the CLLMM, we also sought feedback on the process from DEW staff and summarised a set of methodological insights, including identified benefits of the process and sensitivities of findings to scenario assumptions.

This preliminary vulnerability assessment provided a foundation for developing adaptation pathways with DEW in subsequent activities of this HCHB T&I Climate Adaptation Component. Conducting an assessment like this with participants from First Nations groups and the general community would give a more complete understanding of the vulnerability of the CLLMM to potentially transformational climate change.

Acknowledgments

This project is part of the South Australian Government's Healthy Coorong, Healthy Basin Program, which is jointly funded by the Australian and South Australian governments.

We thank the participants of the expert workshops that were held to test, validate, and add detail to the change-persistence tables and vulnerability assessment questions. Their experience and intimate knowledge of the CLLMM and how it has responded to past changes was invaluable for this activity. We are grateful for very useful comments on the draft from DEW staff and two independent reviewers.

We thank Monica Stasiak and Stephen Madigan for their vital work facilitating collaboration between the CSIRO team and DEW.

We thank Alec Rolston and Amy Ide for their patience and careful attention to detail in managing the report review processes.

1 Introduction

The Coorong, Lower Lakes, and Murray Mouth (CLLMM) system (Figure 1) is culturally, environmentally, and economically important at local, national and international scales but has experienced a long-term decline in its ecological condition due to reductions in freshwater inflows. While there has been recovery of some elements of CLLMM ecosystems associated with increased inflows since the Millennium Drought ended in 2010, the Coorong South Lagoon has been recovering at a slower rate than expected. That ecosystem experienced a switch from being dominated by aquatic plants to algae, associated with eutrophication (nutrient enrichment), with subsequent impacts on invertebrates, fish and waterbirds. These changes in the ecosystem and the lack of recovery is likely caused by a number of complex, interacting factors, which are not well understood (DEW, 2021).

The Phase One Trials and Investigations (T&I) project of the Healthy Coorong, Healthy Basin (HCHB) Program consists of a series of integrated components that collectively provide knowledge to inform the future management of the Coorong. *Component 6 - Climate Adaptation* examines how the Coorong, Lower Lakes and Murray Mouth region might be affected by continuing climate change, how this could affect the various values people hold for the CLLMM and the options for preserving values in the face of change. It is structured into four phases that implement a sequence of steps over a two-year period which are designed to build the understanding and capacity of decision makers and other stakeholders. These phases and steps include:

Context:

- Synthesise the long history of environmental and social changes in the Coorong and Lower Lakes, as a context for analysing current and future change.
- Review anticipated long-term environmental and ecological impacts of climate change in the Coorong and Lower Lakes, with a focus on the breadth of change processes as well as the possible magnitude of change, to provide a robust understanding of future changes.
- Clarify the range of current management and research activities, and how they are expected to lead to behavioural and physical changes that contribute to the current objectives for the Coorong (using 'Theory of Change' methodologies).
- Explore the sensitivity of current activities (above) and ecological objectives to climate change.

Vulnerability

- Develop a set of trajectories of environmental and ecological change for the Coorong to provide a common platform for anticipating the implications of future change.
- Understand the diversity of values for the Coorong and Lower Lakes resulting from the multiple relationships people have with the Coorong and Lower Lakes and clarify the biophysical elements of those value relationships (the 'things' that are valued).
- Explore how these biophysical elements and values might be affected by different trajectories of change, recognising that depending on the specific trajectory many features and values might persist despite significant change.

Adaptation pathways:

- Construct visions of a 'healthy Coorong and Lower Lakes', or other versions of 'success', in the face of significant ecological change.
- Scope alternative sets of the key decisions, changes in management or new interventions (collectively making 'adaptation pathways') that would be needed to achieve the visions of a 'healthy Coorong' under different change trajectories.
- Assess the requirements for those decisions to be made in an informed manner.
- Identify near-term actions and interventions that will strategically overcome the decision-making barriers and increase the range of options available to manage the Coorong into the future.

Translation:

- Draw on insights gained during the project analyses to identify issues and opportunities to build capacity to assess, deliberate on and plan actions for adapting to future transformational impacts of climate change, both within DEW and with First Nations, the general community and other stakeholders.

This report describes the process and results of a preliminary vulnerability assessment conducted by Commonwealth Scientific and Industrial Research Organisation (CSIRO) with a subset of staff from the South Australian Department for Environment and Water (DEW). This assessment used the methodology for assessing the vulnerability of Ramsar sites to climate change, developed by CSIRO and the Australian Government (Dunlop and Grigg, 2019). The analysis was undertaken by CSIRO with staff from DEW that had a range of expertise and responsibilities relevant to the management of the CLLMM. It should be regarded as a preliminary analysis because the methodology was being trialled with DEW only, and it has yet to involve other stakeholders (e.g. First Nations groups, the community, or other stakeholders). Using this approach enabled DEW to experience the process and concepts in order to inform future engagements with stakeholders.

It is very likely that climate change will continue to have a wide range of impacts on Ramsar-listed wetlands (Partridge and Finlayson, 2022), particularly the CLLMM, and there is a significant possibility that these impacts will alter the ecological character of these wetlands. Rather than ask how likely it is that a site will be affected by climate change, this assessment methodology seeks to help people understand the consequences of future significant climate change should they occur.

The assessment focussed on the hydrological and ecological features of the site and the societal context and relationships. It considers how the site might change, and the consequences of this change for the multiple ways in which people value the site. These values reflect Australia's commitment, as a party to the Ramsar Convention, to maintain the ecological character of the site, and the strong societal and cultural connections to the natural environment of the CLLMM. The assessment built upon literature, and previous activities and outputs of this HCHB T&I Climate Adaptation Component, and an involved review and deliberation by DEW staff with various expertise, interests, and responsibilities in the CLLMM.

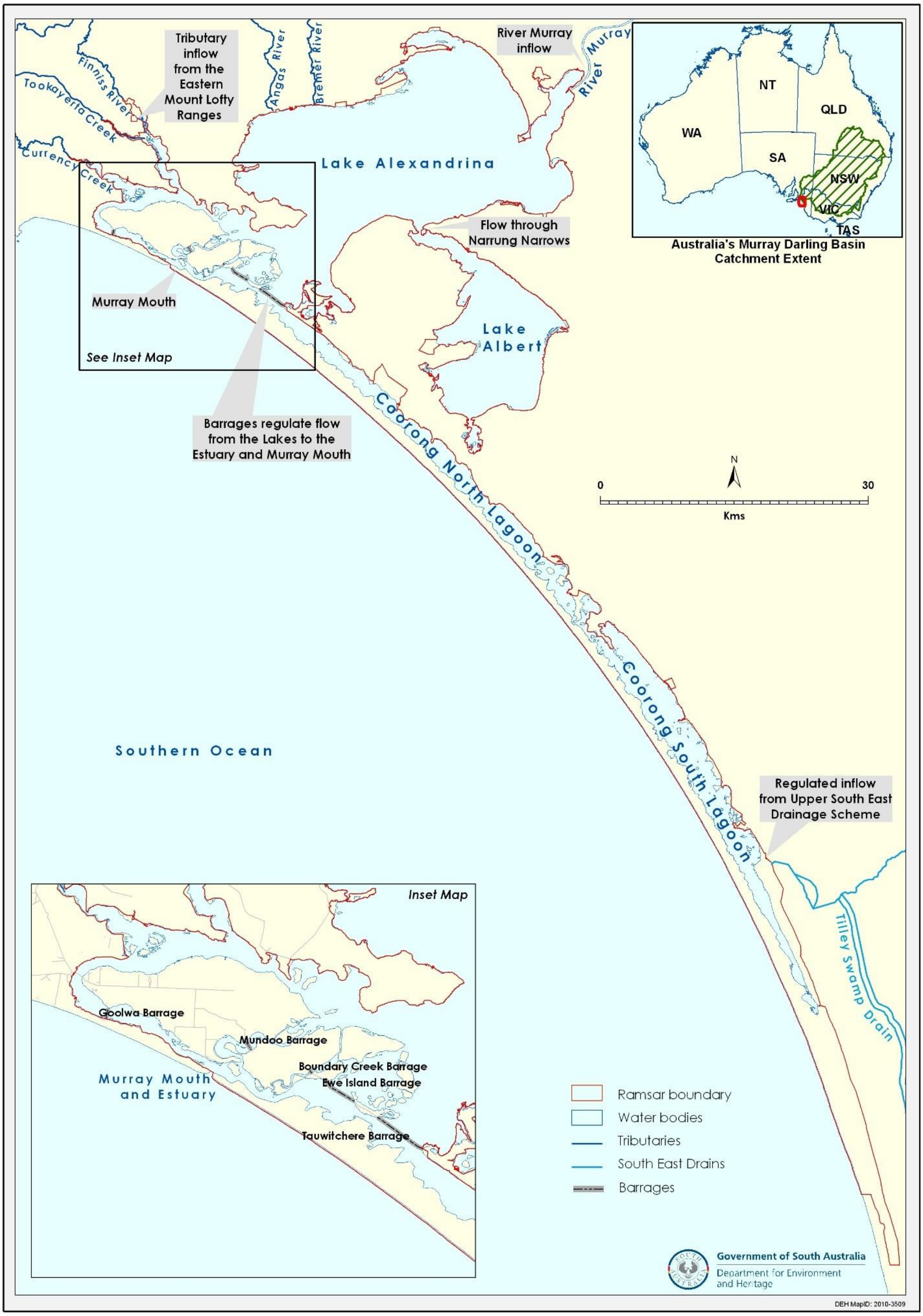


Figure 1. Map of the Coorong, Lower Lakes and Murray Mouth. The Ramsar boundary is marked in red.

2 Methods

We conducted the assessment using the methodology for analysing the vulnerability to climate change of Ramsar wetland sites developed for the Australian Government (Dunlop and Grigg, 2019). The methodology involved three stages that were undertaken by the CSIRO team, in addition to participation of DEW staff in two workshops. DEW staff spanned a range of expertise and areas of responsibility, including Ramsar site management, strategic planning, water management, First Nations engagement, climate change, coastal planning, parks management, ecological monitoring, community engagement and integrated adaptive management.

2.1 Stage 1: Context

Stage 1 involved preparing context material following eight steps outlined in the Ramsar vulnerability assessment methodology:

Step 1. Physical description of the site.

Step 2. Institutional context of the site.

Step 3. History of use and change.

Step 4. Current stakeholders and their relationships to the site (values at stake).

Step 5. Ramsar values.

Step 6. Current threats and changes.

Step 7. Responses to past extremes.

Step 8. Current management activities and priorities.

This context material was prepared by the CSIRO team and circulated to DEW workshop participants before the first workshop (see Section 3.1 and Appendix A).

2.2 Stage 2: Scoping future impacts

Stage 2 involved scoping future impacts of climate change on the Coorong. This drew on the review conducted in Activity 6.2 ('A synthesis of the anticipated ecological impacts of climate change in the Coorong') and scenario development in Activity 6.5 ('Trajectories of ecological change in the Coorong and Lower Lakes, in response to climate change') (Rees et al. 2022) to summarise the primary drivers of change and a sequence of two scenarios. Scenario 1 is a hot, dry scenario with decreasing freshwater inputs. It is followed by a Scenario 2, where sea level rise becomes more of an influence on water level than freshwater inputs. The scenarios are described in Section 3.2.

The scenarios were used to develop 'change-persistence tables'. Each row of a change-persistence table represents a feature of the CLLMM. Features are things in nature that people value, and attributes of features are qualities or characteristics that people value (e.g. 'recreational fishers value the abundance of fish'). The change-persistence table is a format for describing a change scenario explicitly in terms of the attributes of a feature that might be expected to change and those attributes that can be expected to persist despite the change. It is specifically used to help assess the extent to which the values that people hold for a site might persist or be lost in the face of ecological change. This contrasts with a standard threat or vulnerability assessment that focusses on the attributes most likely to change with the implicit assumption that any change equates to loss.

The features included in this change-persistence analysis are based on the components, processes, and services (CPS) described in the 2015 Ecological Character Description (ECD) (DEW, in prep). These were used as maintaining the ecological character, represented by the CPS, is a primary objective for Ramsar sites. All critical CPS have been included, as well as some non-critical CPS. Some CPS have been separated into multiple rows in the table to highlight different change phenomena; other CPS have been aggregated. We note that there are likely to be additional features and values of significance to Ngarrindjeri and the First Nations of the South East, and these have not been included in this preliminary assessment, as First Nations, and other community members, were not participants in this analysis.

A draft change-persistence table was developed by the CSIRO project team, based on the scenarios developed with DEW (Rees et al. 2022), with some evolution in the detail and input from DEW staff. A one-day workshop was held with 27 DEW staff on 9 February 2022 to review and validate the draft change-persistence table. This will be referred to as workshop 1.

Parts of the workshop were run using an online whiteboard platform, Miro[1], which allowed participants to interact directly with the content, adding their own comments and suggested revisions. Some participants experienced technical difficulties using Miro, and so they viewed the content via screen-sharing, and we listened to their input and added it to the whiteboard on their behalf.

Workshop participants also deliberated over the extent to which various values are most associated with the changing or persisting attributes for each feature in the original change-persistence table. *Value* refers to the reason a thing is deemed as important (e.g. 'the value of the site is in its diversity and uniqueness'). *Value* relates to why or how much a thing is held to be important to by a person or society more broadly. Things may be important for different reasons to different people. For example, a Ramsar site is identified as being important for meeting a set of criteria, and an Ecological Character Description (ECD) identifies key features that are linked to the recognised value of the site, within the Ramsar framework. However, many sites, including the CLLMM, are important to society for many reasons other than those listed in Ramsar documents, such as cultural, aesthetic, or recreational connections. These reasons may relate to features in an ECD or additional features. 'Value' can also be used to refer to a thing that is valued. We avoid this usage in this Climate Adaptation Component.

The focus in the workshop was on participants' perspectives on Ramsar values, as well as on the societal values associated with biodiversity. The different expressions of values can be expressed as questions:

1. Does the change correspond to a change in ecological character, as described by the Ramsar ECD?
    - The Limits to Acceptable Change (LAC) from the 2015 ECD (DEW in prep.) were used as a reference to rate impact on this value. While they were not developed for this purpose, they are the clearest existing statement of what changes might correspond to changing character.
      Note: A 'change in ecological character' for an Australian Ramsar wetland has a specific meaning under the Ramsar Convention and can only be determined through a detailed assessment process, which is followed by notification to the Ramsar Secretariat by the Ramsar Administrative Authority within the Australian Government.
    - Change or persistence in character was indicated respectively with red or green scroll icons (,).
2. To what extent does the change affect societal biodiversity values associated with the feature?
    - This was rated by participants as individual members of society, not as representative of any stakeholder groups or DEW (while also recognising that DEW staff bring particular interests, qualifications and inclinations, and so this is not a substitute for broader stakeholder engagement).
    - The association of this value to changing or persisting attributes was indicated respectively by red or green heart icons (,).
3. Will the site still be an 'Internationally Important Wetland'?
    - This was referenced to the Ramsar listing criteria and assessed for the site as a whole, not against each feature in the table. It was explained to participants that Ramsar listing criteria

[1] www.miro.com

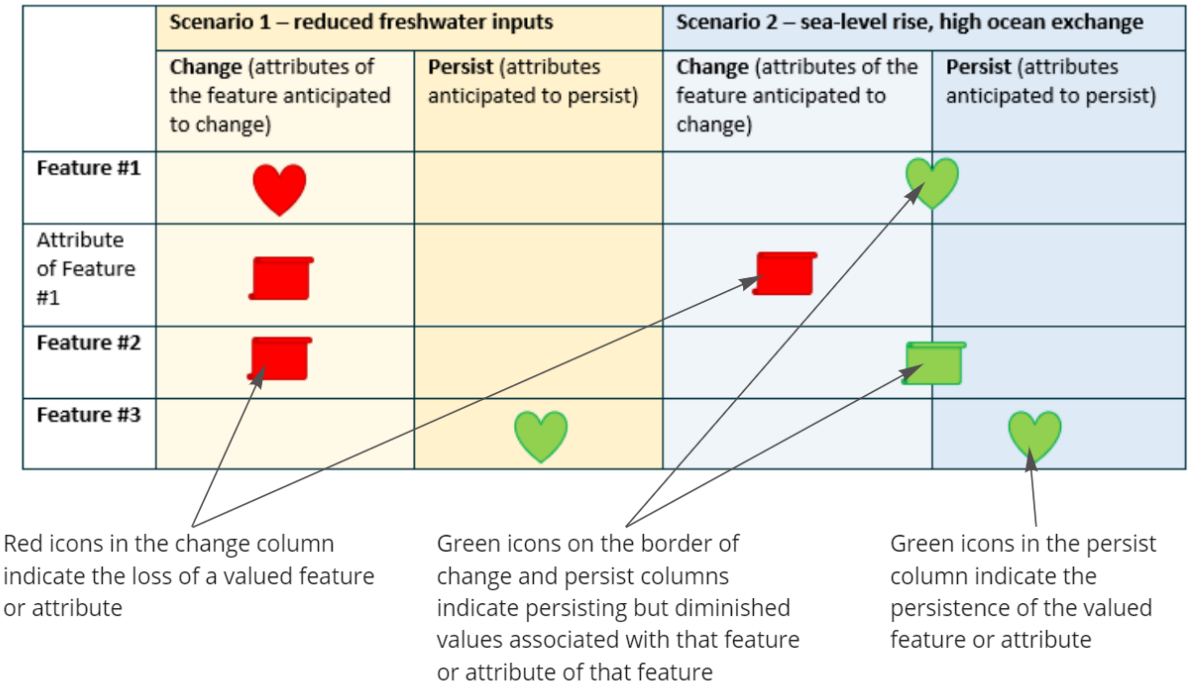
are different to the Ramsar Ecological Character Description (ECD), and that wetlands could undergo significant change in ecological character while still meeting listing criteria.
- Ceasing and continuing to meet the Ramsar criteria was indicated respectively with red and green checklist icons ( , ).

The consequence of the changes to each feature in each scenario for the Ramsar and societal biodiversity values were rated using a three-level scale:

1. Value lost or significantly diminished: changes lead to the feature (or attributes of the feature) no longer being valued. It may not be possible to protect the feature for that value (or it may not be worth it)
2. Value persists but is diminished: Change has affected the feature or its attributes, but the feature or some of its attributes are still valued and worth protecting for that value even if it is diminished
3. Value persists: there may be some change but the feature is valued just as much as now, or more so.

In all cases, the assessment of whether a feature changes or persists is *relative to the current state aspired to by management, as articulated in the ECD*. Table 1 demonstrates how the values ratings are represented on the change-persistence table using the heart and scroll icons. A similar activity was conducted for the Ramsar listing criteria for the CLLMM, where the rows of the table were Ramsar listing criteria, and the icon was the checklist icon.

Table 1. Illustration of values-mapping. The heart icons represent societal biodiversity values, and the scroll icons represent Ramsar values as expressed in the Limits of Acceptable Change. An icon was only included if participants expressed a clear view about the fate of the relevant value associated with the feature under the scenario.



The output of Stage 2 was a set of revised change-persistence tables with the icons showing the values-mapping. A summary of the mapping is presented in Section 3.3 and the remaining change-persistence tables are in Appendix B. Additional columns were added to the table to record assumptions and other considerations. Throughout the process participants were asked to assume the 'best case' in environmental management of the site (while facing scenarios that are considered 'worst case').

2.3 Stage 3: Interpretation

Stage 3 brought 13 DEW participants together in workshop 2 on 2 March 2022 to deliberate on the findings from workshop 1 and respond to a set of analysis questions. The analysis questions are listed in Section 3.4 along with an overview of the findings, and the full responses are provided in Appendix C. The final output of this stage is a preliminary narrative summary of the vulnerability of the CLLMM, which is presented in Section 3.5 of this report. The change-persistence tables and narrative are key results from this work, however they are preliminary in nature having involved only a subset of DEW staff, and they do not represent official DEW positions.

The narrative follows the template provided in the Ramsar methodology (Dunlop and Grigg, 2019). The blank template is as follows, with bold words indicating the sentence structure, and light grey words to be replaced with Coorong-specific details:

> **The** [name] **Ramsar site is vulnerable to** [main changes / change in character] **in the face of significant climate change, but is likely to retain** [main persisting features / (most) Ramsar criteria and other conservation values].
>
> **The major climatic changes of concern for this site are** [reduced rainfall, increased temperature, sea level rise, …], **which would lead to** [hydrological change] and [ecological change] **at the site**. **In particular, climate change is likely to affect** [components] by [how]. **This in turn would affect** [processes] and [services]. **In addition** [other valued features] could [change].
>
> **Despite these changes** [some components] **can be expected to persist. Similarly** [process and services] **are likely to persist, and the site can be expected to retain** [other conservation values].
>
> **The site may cease to meet criteria** [###], **but would continue to meet criteria** [zzz].
>
> **Threatening process at the site are expected to** [interact / increase / new ones]. **Overall, the site will be most threatened by** [current anthropogenic threats amplified by climate change / emerging anthropogenic threats / direct climate change impacts in the catchment or on site / a combination of climate change and threats].
>
> **In order to retain values as it changes**, [changes in management and policy] **may be needed. The key processes driving change are** [hydrological / ecological process / institutional] **which** [may need additional monitoring / research / has already begun being monitored] **to understand their future dynamics**.

2.4 Attributing contribution to project analyses and findings

During the course of this project, and during the review of the reports, questions were occasionally asked about the source of the findings: ‘Are they the research team’s opinions?’, ‘Are they the opinions of DEW staff?’ and ‘Are they deduced from published literature?’. The project team recognised and drew upon information from a range of sources, including published literature, specialist experience and perspectives expressed by the subset of DEW staff in workshops, and CSIRO team observations, inferences, and perspectives based on their specialist knowledge and experience in other adaptation projects. Below we outline why this blend of sources is inevitable for work investigating long-term issues in social, institutional, and ecological systems.

This work set out to explore:

- how significant ecological changes, that could arise from long-term climate change, might affect the values that society holds for the CLLMM
- the types of decisions that might confront DEW and others in the face of transformational change in the CLLMM, and pathways to making those decisions effectively.

Any actual judgments about the CLLMM as it changes or transformational decisions about its management will be made in the future based on extensive observations, experiences, analyses, consultations, and policy reforms, which will be conducted incrementally by DEW and partners over a period of decades. The intent of the Climate Adaptation Component was to start scoping the nature of that enabling work. Understanding how the values of the CLLMM might be affected by possible future transformational change, and scoping the implications of this, are key outputs of this analysis.

To scope those changes and their implications we, and the people we consulted, had to have an understanding of how change might affect different valued features of the CLLMM. We constructed two scenarios of environmental and ecological change, explored how each of long list of different features might respond under those scenarios, then rated how these might be judged according to several different ways of framing 'value' in the context of the CLLMM. These scenarios, anticipated changes to features and assessments of value were a blend of publicly available scientific information, publicly available policy documents, additional technical information from DEW, expert knowledge from DEW and HCHB researchers, and the CSIRO team's knowledge and experience with transformational climate adaptation. The scenarios and assessment also included various assumptions or settings that were chosen when there were key uncertainties. Some of these uncertainties and assumptions were significant and were discussed at length in expert workshops, and the rationales for the chosen setting were documented (e.g. concerning future levels of hydrological connectivity; rates of transport of salt, nutrients, and sediment; regimes of variation in flows and salinity; responses of different groups of species to that variation).

These, and many other uncertainties, may not be fully known until during or after transformational changes have started occurring. However, by carefully imagining these changes, it is possible to anticipate the broad types of issues and decision challenge that will confront DEW and others, and the types of societal conditions (knowledge, values, and rules) that DEW may need to make these decisions effectively. Then, considering DEW's current scope of work, it is possible to imagine activities that could be done to help create the enabling conditions.

Over the course of the Climate Adaptation Component, the research team drew on published literature, unpublished analyses and policy documents, and on many discussions and workshops with DEW and HCHB researchers. With this we drafted scenarios, scoped how different features (components, processes, and services) might be affected, assessed how these changes might affect different perceptions of value. Some drafts were rejected, while others were validated and enriched in workshops, further exchanges with DEW and consultations with additional technical experts. These products were then further analysed, synthesised, and documented by the research team drawing on all this information and their knowledge of transformational adaptation. Diligently tracking and reporting which parts of which findings were based on any one source of information would create a complex output that would be difficult to make sense of. It would also divert people away from the main purpose and messages of this work. The purpose is not to predict the future with this level of detail, but to create an experience of what a plausible future would be like to navigate, so that the broad types of challenges and opportunities can be identified, deliberated over, and planned for.

While the details in the scenarios are quite uncertain, we contend that the core elements of the scenarios are robust enough to enable consideration of 'greatest plausible changes'. Similarly, we believe the nature of the assessment of values, based on the scenarios, are sound. It is important to note that this study focussed on DEW, as a *preliminary* analysis, and additional important values and insights about change would be identified through engagement with other groups.

The process to develop the project outputs was carefully designed, detailed, extensive, and highly consultative. However, we suggest that ultimately the legitimacy, credibility, and relevance of these project outputs rests primarily on:

- the logic of the narratives that link the drivers of change, scenarios, values, and assessments, rather than the specific details of the assumptions required to operationalise our approach
- the extent to which these narratives are compelling to people interested in the CLLMM, even if they are challenged by them

- the intended use of the outputs.

Insights from the research are ‘offered’, to be considered by users rather than taken as facts or prescriptions. The analyses are labelled preliminary, in part due to the limited consultation, but also recognising that analyses like these can never be definitive, and they should be updated periodically as more information about the future becomes available, preferences evolve and opportunities for action change.

We note this approach is different from quantitative biophysical analyses, based on experiments, field analysis and modelling, that are more familiar to many people interested in the CLLMM. However, we suggest that any attempt to seek to understand the nature of coupled social-institutional-environmental challenges facing future decision-making will need to draw on and integrate a range of knowledge types similar to those that we used. Indeed, this is part of the ambiguous reality we, as society, need to become comfortable with if we seek to proactively plan to navigate future transformational changes in the CLLMM or elsewhere.

3 Results

3.1 Stage 1: context

Prior to workshop 1, a set of material describing the CLLMM context was sent to workshop participants. It drew on the outputs of previous T&I Component 6 activities and addressed the context questions listed in Section 2.1. We expected that participants would already be familiar with this material, and it was provided as a check to ensure we were all working from a shared, initial understanding of the CLLMM context. The context material is provided in Appendix A and the following is a summary of key points.

Throughout history the unique mosaic of diverse wetland types comprising the CLLMM have been ever-changing. The complex dynamics of freshwater and marine influences have shaped changes over thousands of years, including droughts, floods, and sea level variation. First Nations groups have the longest human connections with the CLLMM and their connections endure to this day. More recently the CLLMM has been changed by human activities including river regulation and extractions, construction of barrages and drainage systems, land use, fisheries, tourism, and natural resource management. It is a history of diverse and changing social values coupled with physical and ecological change, each profoundly influencing the other in complex, interdependent ways.

There has also been a history of changing practices for caring for the many and diverse ways in which the CLLMM is valued by people, starting with First Nations' laws and practices. Colonial institutions brought a focus on property rights that endures to this day. Over the years since colonisation, institutions have also evolved to recognise Native Title and other First Nations' rights, and to include more and more complex processes for protecting the CLLMM in the service of more diverse values, and especially biodiversity conservation. There is a rich and detailed understanding of the complex ecological nature of the CLLMM, and it is regarded as a wetland of international significance, meeting eight criteria listed in the Ramsar Convention.

The CLLMM faces threats from reduction and regulation of freshwater inflows. The negative ecological consequences of upstream water extraction have been evident from the early twentieth century, and these impacts have only grown over time. Barrages and low flow periods have reduced the ecological connectivity between the Lower Lakes and the estuary, and the Coorong is susceptible to hypersalinity and eutrophication as a result. The Lower Lakes are also vulnerable to acid sulfate soils (ASS). These threats were most apparent (and most damaging) during the extremes of the Millennium Drought, with widespread impacts on water quality (eutrophication, hypersalinity, acidification and heavy metal release) and reductions in fish and bird abundance and distributions. The Coorong South Lagoon has yet to fully recover from the Millennium Drought.

Current management activities focus on multiple objectives using diverse management levers. These include barrage operations, environmental flows, monitoring, research, First Nations partnerships, stakeholder engagement, and exploration of future long-term management options.

This history of constant change is the context in which decisions will be made about managing future change.

3.2 Stage 2: scenarios

Scenarios were developed to allow workshop participants to explore potential responses and changes due to climate change in the CLLMM. Details on the underpinning evidence and assumptions were provided in Rees et al. (2022). The following scenario details were provided to workshop participants before workshop 1.

The three major **drivers** of change to the CLLMM, likely to result from climate change, are:

- Decreasing freshwater inflows from the River Murray, the South East and Eastern Mount Lofty Ranges tributaries

- Increasing sea level
- Warming of land and water.

While each of these climate change drivers are projected to have future impacts that are potentially very significant, the action of these drivers started decades ago and occurs simultaneously with other influencing factors (e.g. upstream water extraction and management of flow regimes).

While the concentration of carbon dioxide in the ocean is also likely to increase acidification of the sea water, it is not anticipated this will exceed critical thresholds for fish and invertebrates, particularly in comparison to the other major drivers. However, less is known about the impact of acidification on carbonate dependent lifeforms, for example corals and tubeworms and this driver may warrant consideration in the future.

These drivers are likely to lead to a trajectory of change in the system, which is conceptually represented in Figure 2. For more details, including how the trajectory has been informed by and relates to published climate change scenarios and projections, see Rees et al. (2022).

We identify three phases along the trajectory:

- **First phase: Decreasing freshwater inflows**, reduced exchanges through the Murray Mouth, reduced ratio of inflows to evaporative losses, and lower water levels in parts of the system and increased accumulation of salt and nutrients. The system has experienced many decades of drying conditions, largely as a result of water extractions from the Murray-Darling system but also attributable to climate change. Ongoing climate change will lead to continuation of this drying trend into the future.
- **Second phase: Transition period**, with the influences of decreased freshwater flows and rising sea level varying over relatively short timeframes.
- **Third phase: Increasing sea level** leading to water levels in the Lower Lakes and Coorong being dominated by sea level rather than River Murray and barrage flows. Overall increase in water levels throughout the system and increasing flooding of barrier islands and eventual over-topping of the barrages, and increased hydrological connectivity throughout the system. The level of exchange of water through the Murray Mouth, and transport of salt and nutrients out of the Coorong will depend on sedimentation rates in the mouth and estuary. Similarly rates of exchange with the Lower Lakes will depend on future changes to the barrages and their operations. In this scenario, *it is assumed* that dredging will be used to keep the Murray Mouth open if needed, there is increased exchange of water and material along the Coorong, and that barrages will be operated to enable regular flows of water in and out of the Lower Lakes from the estuary.

For this analysis we describe the possible states of the system at two key points on the trajectory of change resulting from the combined action of the drivers described above (Figure 2).

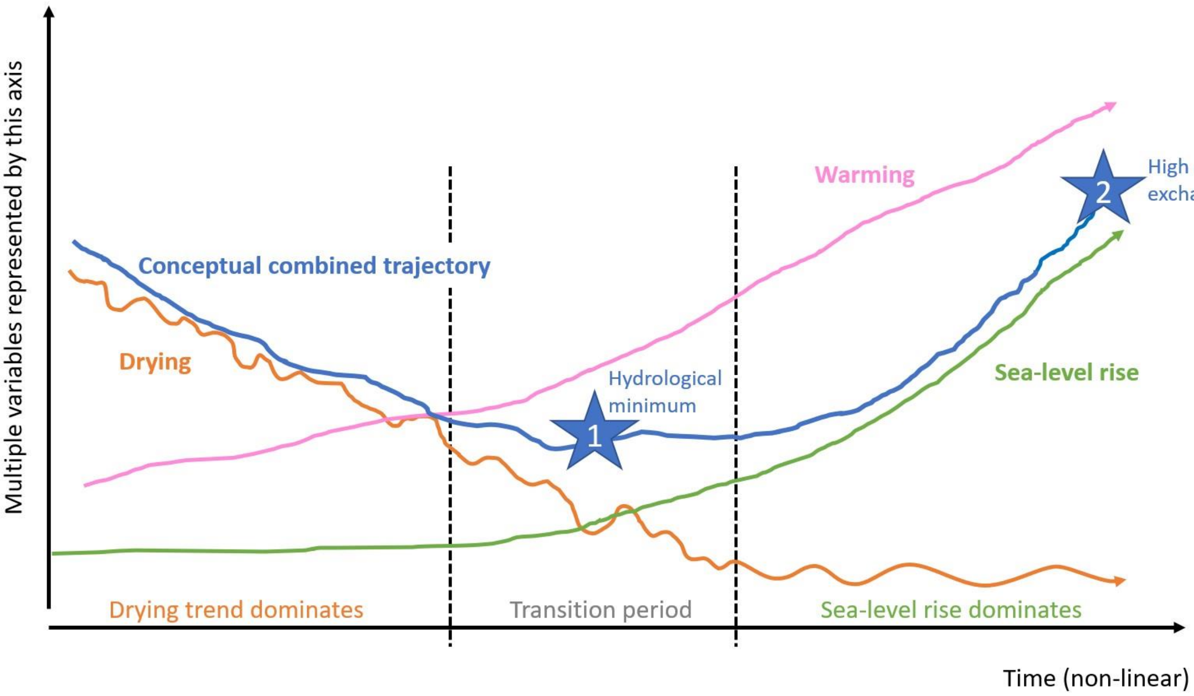


Figure 2. Plausible trajectory of change resulting from a combination of drivers operating over different time scales. The orange line represents drying (decreasing freshwater inflows and increasing evaporation), the green line represents sea level rise, and the pink line represents warming. These combine into a conceptually plausible trajectory of change, represented by the blue line. For each of the Coorong and the Lower Lakes, we describe one scenario at the point of minimum inflows (1), and a point when sea level rise has become significant (2).

Key scenario characteristics highlighted for workshop participants included:

- Two main drivers: decreased River Murray and tributary flows, rising sea level.
- Drivers play out on different time frames, drying *then* sea level; they are two *sequential*, not alternative, scenarios.
- The timings are a function of both the rate of global and regional climate change and local and Murray-Darling Basin (MDB) management decisions: Scenario 1 (transition / water level minimum) may be approximately 2070, Scenario 2 (sea level rise dominates Coorong and Lower Lakes water levels) may be approximately 2100, however the uncertainties are large and the timing of the lowest point of the U-shape may differ by decades.
- Scenario 2 includes active facilitation of flows between the Lakes and estuary (e.g. barrage operations or removal), maintaining/increasing flow through the Murray Mouth and into the Coorong (e.g. dredging) and management to actively reduce long-term salt and nutrient accumulation in the South Lagoon if necessary (e.g. infrastructure).

In discussions with workshop participants, the following scenario assumptions were noted:

- The increases in allocation of water for the environment set in the Basin Plan are assumed to be fully implemented in both scenarios.
- Both scenarios assume the Murray Mouth will be kept open by dredging if needed, possibly with increased dredging capacity required as river flows decline and if there is increased net transport of sand in through the mouth with higher sea level. This assumption reflects long-standing policy, and it was agreed that it is an appropriate assumption for the purposes of this preliminary vulnerability assessment.
- Scenario 2 assumes the barrages are either operated or removed to enable significant flows of sea water into and out of the Lower Lakes. This assumption was to reflect an inevitability of sea water

ingress. A variant on this scenario was considered, in which the influence of sea level rise on the Lower Lakes is resisted indefinitely, but there were doubts that this could be a viable strategy and there was a preference to explore the influence of sea level rise as an inevitability.

- It is assumed that new infrastructure can successfully remove significant nutrients and salt from the southern Coorong and that this is effective in the near-term and for recovery after droughts. In Scenario 1, it is assumed infrastructure is not able to fully mitigate the sustained rates of accumulation of salt and nutrients. In Scenario 2, it is assumed that increased exchange of water between the North and South Lagoon due to sea level rise in combination with infrastructure (if necessary) can achieve net export of salt and nutrient.

In discussions with workshop participants, the following key uncertainties associated with the scenarios were highlighted:

- There could be some change in seasonality of flows into the Lower Lakes as a result of increased rainfall in the (unregulated) northern Basin and decrease in the southern Basin. This may provide flows to lengthen the period that the South Coorong is better connected to the North Coorong.
- There is seasonal variation in sea level. It is unclear how, in Scenario 2, this will combine with seasonal variability in inflows and evaporation to affect water levels in the Lower Lakes and the Coorong.
- Sedimentation in the mouth that exceeds the rate of dredging and reduced river flows could lead to reduction in exchange between the Southern Ocean and the Murray Estuary, which would create an outcome that is very different from Scenario 2. It would likely be a mixture of elements of Scenario 1 and Scenario 2.
- The priorities for using available environmental water in the CLLMM could change, especially in Scenario 2. For example, in Lake Alexandrina environmental water could be targeted toward maintaining a salinity gradient or regime of temporal variation in salinity, rather than maintaining water levels.
- Future changes to water sharing arrangements could feasibly lead to allocations of environmental water for the CLLMM being increased or decreased, which could significantly alter the outcomes described in both scenarios. Significant increases in water for the environment could lead to maintenance of conditions in Scenario 1 and maintenance of freshwater character of the Lower Lakes in Scenario 2. Decreases in environmental water allocation could lead to greater declines in wetland condition in Scenario 1 and complete loss of freshwater components in Scenario 2.

These uncertainties and assumptions were the subject of several discussions with DEW and other experts, and by making them explicit it is easier to revisit their implications in subsequent Adaptation Pathways analyses for the CLLMM (Activities 6.7 'Adaptation Pathways, Part 1 – visions and feasible outcomes', and 6.8 'Preliminary adaptation pathways for the Coorong, Lower Lakes and Murray Mouth' of the HCHB T&I Climate Adaptation Component, and analyses conducted in the future by DEW or others).

The scenario details were described more fully in different versions of a change-persistence table. The simplest of these is Table 2,which provides a synthesis of the valued ecological (row 1), and social and cultural (row 2) features of the CLLMM. The other change-persistence tables are provided in Section 3.3 and Appendix B . These tables are intended to delineate clearly what changes and what persists under each scenario so that it is easier to identify valued attributes that could persist in the face of climate change and could be a focus of management activities. The text in Table 2 represents a high-level summary of change-persistence tables that contain many more rows that disaggregate features in more detail. The more detailed change-persist tables are presented in the next section and Appendix B. Descriptions of changing or persisting attributes are described relative to the aspired current state (as characterised in the ECD), except for some descriptions in Scenario 2 where it makes more sense to compare relative to Scenario 1.

Table 2. Summary change-persistence table. This table summarises the two scenarios in terms of attributes of the CLLMM that can be anticipated to change or to persist. Descriptions are provided for ecological features and social and cultural elements of the CLLMM.

	Scenario 1 – reduced freshwater inputs		**Scenario 2 – sea level rise, high ocean exchange**	
	Change (attributes anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes anticipated to change)	**Persist** (attributes anticipated to persist)
Coorong, Lower Lakes and Murray Mouth as a dynamic ecological system	There is an increase in the frequency of low flow years when salt and nutrients accumulate in the Lower Lakes and the Coorong, sediment builds up in the Murray Estuary and acid sulfate soils (ASS) are exposed. During low flow years plant and invertebrate communities generally decline, reducing food and habitat for fish and birds. However, in these low flow years the CLLMM system is increasingly important as refuge for Australian waterbirds and international migrants, as other wetlands reduce in size and dry out. There is a decrease in the frequency of medium and high flow years. These years are important for replenishing the Coorong, Lower Lakes and Murray Mouth. They export accumulated salt, nutrient and sediment. They allow regeneration of freshwater ecosystems and populations of invertebrates, fish and amphibians, and those species that depend on effective connectivity between the Lakes and the Estuary. The change in distribution of low flow and high flow years is resulting in a	Freshwater flows in to the CLLMM system vary significantly between years with regeneration in periods of high flow and critical drought refuge provided in periods of low flow. Across these varying years there is a very high abundance and diversity of freshwater and saltwater fish, plants and waterbirds using and depending on the CLLMM system.	With sea level dominating the water levels in the Lakes and Coorong, there has been a significant change to temporal variability of the water levels and salinity in the CLLMM. This results in a dramatic change in the ecological dynamics of regeneration and drought refuge of the system, to a more constant, productive and reliable system, compared to Scenario 1. However, the system has significantly less freshwater wetland habitat and smaller and more variable populations of freshwater species. In Lake Alexandrina, water levels are more constant, but salinity varies, building up during low flow periods with a gradient from estuarine to brackish extending into the River Murray. Periodically, salinity significantly drops with flushing from episodes of high river flows (at least annually except drought). These flushing episodes also lead to temporary elevated lake levels, which could also create temporary freshwater habitats. In the South Lagoon of the Coorong, there has been gradual export of salt and nutrients and increased diluting flows. While salinity of the system is predominantly marine or higher,	There is a very high abundance and diversity of fish, plants and waterbirds using and depending on a large variety of habitat types the CLLMM system. The site supports resident and seasonal migratory waterbirds, and during drought the site is a nationally significant refuge. Freshwater wetland habitats and species continue to be present in the system but in fewer locations, covering significantly smaller areas and with reduced species diversity and abundance. Freshwater species are periodically replenished by high flows. South Lagoon of the Coorong is hypersaline, but has returned to a state with low nutrient availability, slow nutrient dynamics, and reduced peak salinity, enabling a dominance of benthic macrophytes, including abundant *Rupia tuberosa*, and low abundance of filamentous algae.

	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
	Change (attributes anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes anticipated to change)	**Persist** (attributes anticipated to persist)
	decline in the ability of the CLLMM system to be an effective drought refuge at the same time as it is becoming more important as one.		periods of excessive salinity and nutrient availability are infrequent. There has been and continues to be significant change in the location of habitats, including the creation of new reedbeds, saltmarsh and mudflats as coastal land is inundated. However, this is gradual and continual – on a decadal scale as the sea level rises, rather than being dominated by flood and drought cycles. As a result, wetland habitats are more stable, allowing for more diverse assemblages to form, and an increase in the abundance of specialist species in habitat niches. The site is dominated by marine and salt-tolerant species. Freshwater wetlands are restricted spatially, with freshwater species abundance increasing periodically in Lakes Alexandrina and Albert with periods of sustained high flows. There is permanently very good connectivity between the Lakes and the Estuary supporting diadromous and other migratory species. No new exposure of ASS.	

	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
	Change (attributes anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes anticipated to change)	**Persist** (attributes anticipated to persist)
Coorong, Lower Lakes and Murray Mouth as source of social and cultural values	Reduced ocean connectivity, changes in the distribution and abundance of iconic and culturally significant species, and altered ecological nature change the way people experience the system. A loss of resources leads to a reduced potential for providing educational insights about the system. The aesthetic value of the region declines with an increase in areas of exposed shorelines and wetlands, poor ecosystem health, and unpleasant odours. Recreational opportunities reduce with declining water level and quality, preferred fishing sites and abundance of species changes.	Most iconic and culturally significant species will persist in the system, if not at their traditional locations. Memories, stories and culturally significant species will persist, as well as the wonder and awe of environment-based spiritual experiences. The system remains valuable for scientific and educational purposes, with fresh opportunities for citizen science. Diverse natural land and waterscapes, and associated weather events, seasonal patterns, and other natural phenomena. Opportunities for nature-based recreation, and nature-based and cultural tourism (e.g. fishing, camping, water sports, bird watching, photography).	Increased ocean connectivity, changes in the distribution and abundance of iconic and culturally significant species and altered ecological nature change the way people experience the system, and create the potential for new recreational, cultural and spiritual experiences. Ocean connectivity, location of culturally significant species and ecological nature will change, and this changed environment will create the potential for new spiritual experiences. Changing ecological conditions provide potential new educational insights about the system. Changing aesthetic as water levels are less variable and marine influence on the system grows. Improved water quality and stable water levels lead to more reliable recreation and tourism opportunities. With rising water level, some camping locations change. Preferred fishing sites change and the there is a change in the dominant species in Lake Alexandrina. Increased ocean connectivity offers new recreational opportunities.	Most iconic and culturally significant species will persist in the system, if not at their traditional locations. Memories, stories and culturally significant species will persist, as well as the wonder and awe of environment-based spiritual experiences. The system remains valuable for scientific and educational purposes, with fresh opportunities for citizen science. Diverse natural land and waterscapes, and associated weather events, seasonal patterns, and other natural phenomena. Opportunities for nature-based recreation, and nature-based and cultural tourism (e.g. fishing, camping, water sports, bird watching, photography).

3.3 Stage 2: change-persistence table

Draft change-persistence tables were prepared and then circulated to participants before workshop 1. Three tables were provided: a high-level synthesis (Table 2), a full list of features with detailed descriptions in the change and persist columns (Table 7, Appendix B), and a full list of features with shorter descriptions in the change and persist columns (Table 5, Appendix B). The workshop used Table 5. Participants were first given an opportunity to revise the descriptions of each feature, then Ramsar and societal values were mapped to changing or persisting attributes of each feature using the scroll and heart icons. New rows were added where needed (e.g. participants expressed concern about potential changes to Lake Albert in Scenario 2, and a row was added to capture this concern). Table 5 (Appendix B) is the final version of the table used during workshops, after revisions were made and values mapped. A high-level summary of Table 5, showing only the value-mapping icons without extra description is provided in Table 3.

The assessment of whether a feature changes or persists is generally relative to the current state aspired to by management, as articulated in the Ramsar Management Plan (DEH, 2000). Scenario 2 occurs after Scenario 1, and so where relevant some of the text descriptions of change in Scenario 2 are relative to Scenario 1, and this is always stated explicitly. For some features, values were mapped as red icons in the change column for Scenario 1 (indicating values would be lost), and yet were mapped as green icons in the persist column for Scenario 2 (indicating values would be retained). This assumed that in Scenario 2 there is scope for recovery from Scenario 1.

An additional change-persistence table (Table 6, Appendix B) was created with each row as a Ramsar listing criterion for the CLLMM, and workshop participants were asked whether attributes of each criterion would change or persist under each scenario. Ramsar listing criteria serve a different purpose and have a different focus to the CPS of the ECD. It is possible for wetlands to undergo a large change in ecological character while still meeting Ramsar listing criteria. Workshop participants agreed that all listing criteria would continue to be met under both scenarios, but for many criteria they would be met in a different way to when the CLLMM was first listed.

Table 3. Summary of the mapping of different values to the changing or persisting attributes of selected features for each scenario. This table presents a summary of how each feature of the CLLMM is valued under the two scenarios. Icons were not allocated for features/scenarios where there was no opinion expressed from participants. Valued features are based on the CPS from the 2015 ECD. Rows marked by the -> symbol are subsets of a previous row.

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**	
		Change	**Persist**	**Change**	**Persist**
1	**Hydrology – Lower Lakes**				
2	**Hydrology – Coorong, Murray Mouth**				
3	**Salinity**				
->	Lake Alexandrina				
->	Coorong				
4	**Water and sediment quality ('non-critical' in 2015 ECD)**				
5	**Wetland flora and fauna – general (all taxa)**				

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change	Persist	Change	Persist
->	Lakes				
->	Coorong				
6	**Threatened ecological communities and species - general (all taxa)**				
8	**Diversity of plant species and communities in different habitats**				
->	Lower Lakes				
->	Freshwater habitat				
->	Coorong				
9	**Specific plant species**				
->	Structural spp.				
->	Freshwater (Lakes)				
->	Salt-tolerant (Coorong)				
10	**Threatened ecological plant communities (Swamps of the Fleurieu Peninsula)**				
11	**Threatened ecological plant communities (coast saltmarshes)**				
13	**Diversity and abundance of fish communities in different habitats**				
14	**Specific fish species**				
->	Pest species				
->	Freshwater				
->	Estuarine and Marine				
->	Movement and recruitment				
15	**Threatened fish species**				
->	Murray hardyhead				

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change	Persist	Change	Persist
->	Southern pygmy perch				
16	**Waterbirds**				
->	Lower Lakes -diversity				
->	Waders				
->	colonial nesting (freshwater)				
->	Coorong – diversity				
18	**Threatened birds** **Domestic spp.** - Australasian bittern, Australian fairy tern, Hooded plover, Mount Lofty Ranges southern emu-wren.				
->	**Migratory species**				
19	**Other wetland fauna – Reptiles, frogs and mammals - General**				
20	**Threatened species – OTHER** • Southern bell frog				
21	**Wetland habitat**				
22	**Invertebrates** • Macrobenthic invertebrates • Zooplankton	Yabbies Freshwater mussels Tube worms		Yabbies Freshwater mussels	
23	**Coorong food web**				
->	*Lake Albert [although Lake Albert is not part of the Coorong, when discussing impacts on the Coorong food web participants warned that in Scenario 2 Lake Albert could be more like the South Lagoon is now in its risk of accumulating salt and nutrients]*				
->	*Ruppia tuberosa* – primary producer				
->	Benthic macroinvertebrates – primary consumers,				
->	Small-mouthed hardyhead – secondary consumer				
24	**Geomorphic setting (non-critical)**				

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change	**Persist**	**Change**	**Persist**
25	**Healthy Ngarrindjeri Ruwe/Ruwar ('non-critical' in 2015 ECD)**				
	First Nations of the South East				
26	**Spiritual and inspirational ('non-critical' in 2015 ECD)**				
27	**Science and education ('non-critical' in 2015 ECD)** Unique lake / estuarine system				
28	**Aesthetic amenity ('non-critical' in 2015 ECD)**				
29	**Recreation and tourism ('non-critical' in 2015 ECD)**				

Row 27 of the change-persistence table (science and education) has red icons in the change columns and green icons in the persist column. This reflected a mix of views of participants. Given more time this would be handled by disaggregating attributes further so that there is only one icon per row, per scenario.

3.4 Stage 3: analysis questions

Stage 3 was about interpreting the change-persistence table and values-mapping conducted in Stage 2. It involved having a conversation about the results with DEW staff in the second workshop, collectively making sense of unexpected patterns and their implications, and drawing out insights about the vulnerability of the site. This conversation was guided by a series of analysis questions based on Dunlop and Grigg (2019), draft answers were provided then reviewed and updated by workshop participants, and the agreed responses are summarised in Appendix C. This process prompted some discussion on implications for planning and management, but these were noted for further discussion in the more comprehensive adaptation analysis to be conducted in Activities 6.7 'Adaptation Pathways, Part 1 – visions and feasible outcomes' and 6.8 'Preliminary adaptation pathways for the Coorong, Lower Lakes and Murray Mouth' of the HCHB T&I Climate Adaptation Component.

Participants were given different categories of values and asked which ones might be retained or lost under the different scenarios. The results are summarised in Table 4. Values expected to be maintained are marked with a tick and those expected to change are marked with a cross. Conditions associated with the judgments are included as bullet points, and further explanations of features that are counter to the general trend are provided in Section C.2.2.

Table 4. Overall rating of the retention or loss of the three expressions of values for Coorong and the Lower Lakes under the two scenarios.

Expression of value	Scenario 1 - Reduced freshwater inputs	Scenario 2 - High ocean exchange
Ramsar criteria for which originally listed	✓ Continue to meet criteria - but in different ways	✓ Continue to meet criteria - but in different ways
CPS of the **ecological character**	× Significant risk to many CPS	✓ Coorong, assuming: - recovery after scenario 1 - salt/nutrient extremes are contained × Lower Lakes: significant risk to some CPS
Societal biodiversity values	× Significant risk to many values	✓ Many values present - assuming recovery after scenario 1

		× Values dependent on freshwater in the Lower Lakes at risk

The findings were summarised for the two scenarios that were analysed as follows:

- Scenario 1: The site would experience significant changes in ecological character and loss of many social biodiversity values, but it would retain some important characteristics and values. It would retain its status as an internationally important wetland.
- Scenario 2: The site would experience some changes in ecological character (e.g. a decline in freshwater communities and migratory species), but with careful management the site could retain many key aspects of its character and its social biodiversity values. It would retain its status as an internationally important wetland.

Synthesising the observed patterns and responses to the analysis questions, the project team drafted a narrative that summarises the multiple dimensions of the vulnerability of the site. This vulnerability narrative for the CLLMM was reviewed by DEW staff then revised and is reported in Section 3.5. The structure of the vulnerability narrative was based on the template in Section 2.3 (Dunlop and Grigg, 2019).

3.5 Stage 3: vulnerability narrative

The primary output of the Stage 3 analysis is a narrative summary of the vulnerability of the CLLMM to transformational change resulting from climate change. The narrative focusses on vulnerability under Scenario 2, recognising that the system first passes through Scenario 1. An initial version of the narrative was presented to participants after the two workshops, and participants subsequently provided feedback on that draft narrative. The narrative has also been revised for clarification during the review process.

As noted previously, this work should be regarded as a *preliminary* vulnerability assessment, as its intent was to help DEW explore the nature of the vulnerability of the CLLMM and its implications and trial the methodology, recognising that this methodology could subsequently be adapted and used with other CLLMM stakeholders. For this reason, the vulnerability narrative presented here should also be regarded as a *preliminary* description of the vulnerability of features identified as important in the ECD to transformational climate change. Such a narrative could be tailored for different communication purposes, including reporting or education.

Box 1 Preliminary vulnerability narrative for the Coorong, Lower Lakes and Murray Mouth (CLLMM).

The Coorong, Lakes Alexandrina and Albert Ramsar site is vulnerable to reductions in freshwater inflows and greater input of seawater. Under the greatest plausible change scenarios that were considered in this analysis, the site would be likely to experience a change in the 'ecological character' documented in the ECD[2]. Significant changes in site management or river flows could lead to different outcomes. Despite this, the site is likely to retain many of the valued features identified in its ecological character, such as a diversity of wetland types, and high abundances and diversity of birds, fish, vegetation and other species. It would be likely to continue to meet all the Ramsar criteria it was listed under. Key internationally and nationally significant conservation and cultural values would be likely to continuing to persist.

The major climate-driven changes of concern for this site are reduced rainfall across the Murray-Darling Basin leading to reduced freshwater inflows to the site, increased temperature and rising sea level which, depending on Basin and site management, may lead to altered hydrodynamic, salinity and nutrient regimes, and changes in composition, distributions and dynamics of most ecological components and processes of

[2] A 'change in ecological character' for an Australian Ramsar wetland has a specific meaning under the Ramsar Convention and can only be determined through a detailed assessment process, which is followed by notification to the Ramsar Secretariat by the Ramsar Administrative Authority within the Australian Government.

the site. If these changes are significant enough, it would be likely to result in a change in ecological character.

Reduced River Murray inflows, before sea level rise becomes a significant influence, will lead to reduced connectivity, reducing material and ecological exchange between the Lower Lakes, the Murray Estuary and the North and South Lagoons of the Coorong. In particular, this will restrict fish migrations between salt and freshwater habitats, and lead to extreme hypersalinity and high nutrient availability in the Coorong South Lagoon. This in turn would reduce the abundance and diversity of freshwater plants, fish, and waterbirds communities.

Once sea level rise dominates the system, it is likely to experience increased hydrological and ecological connectivity, increased and more stable water levels across the system, increased spatial and temporal variation in salinity in the Lower Lakes, and reduced extremes and temporal variability in salinity and nutrient availability in the Coorong. There will also be changes in the distributions of shoreline habitats as some are flooded and others created by inundation. This is likely to lead to a recovery in abundance and diversity of flora and fauna, although possibly not to current baseline levels. Distributions of species will change, in particular estuarine and marine-estuarine opportunist species will expand into the Lower Lakes, and there will be significant reductions in the spatial extent and abundance and increasing temporal variability of freshwater-dependent habitats and species, and probably loss of some freshwater wetland types.

Despite these changes, the site will continue to be a very large, diverse and dynamic system of permanent wetlands, with the capacity to support a high abundance and diversity of plants, invertebrates, fish and birds. In particular, the site is likely to continue to be an important feeding ground for international migratory waterbirds and drought refuge for domestic waterbirds. Once sea level rise dominates, the site will also continue to provide breeding and nursery habitat for many fish species, including diadromous species, with fresh- and saltwater phases to their life cycle, due to ongoing, important connection with the River Murray. People who live in and visit the region will enjoy a wide range of benefits from the Lower Lakes, Murray Estuary and Murray Mouth, and Coorong, with more stable water levels, tidal near the estuary, and few poor water quality extremes.

Threatening process at the site are expected to continue or increase, with the potential for new threats to emerge. Overall, the site will be most threatened by anthropogenic reductions in freshwater river flows, given that the salinity regime and water quality across the system is highly affected by freshwater inflows.

Emerging priorities for supporting the retention of values of the Ramsar site under climate change may include:

- Environmental flows targeted to support freshwater habitats, system connectivity and export of nutrients and salt from the Lower Lakes
- Improving connectivity and water exchange along the Coorong to support the flushing of salt and nutrients from the South Lagoon
- Different objectives for the operation of the barrages, including facilitation of seawater exchange with the Lower Lakes
- Enhanced management of the sedimentation in the Murray Mouth and Murray Estuary
- Management of estuarine and marine species and communities that may encroach into the Lower Lakes (e.g. tubeworms, sharks, fur seals)
- Managing site boundaries and shoreline areas to accommodate shifting shoreline habitats, including saltmarsh species, mudflats, and beach nesting sites
- Effective planning, with stakeholders, for long-term transitions in ecological conditions, objectives, and management
- Establishment and maintenance of narratives about the CLLMM, highlighting values that are retained while acknowledging and honouring those that are diminished.

Sustained drying, before sea level rise dominates water levels, could have a significant impact on many values in the CLLMM. In addition, the condition of the Lower Lakes and Coorong at that time will have long lasting effects on the ecological trajectory of the system as sea level rises, increasing water levels and exchange. This suggests a need to:

- manage the system to maintain the inherent capacity for the ecosystems of the Lower Lakes and Coorong to transition to different configurations and for the ecological health of the system to improve when water levels increase

- strategically managing the timing of the transition to a more marine and estuarine system, including how to deal with diminution and loss of highly valued freshwater-dependent components and change in ecological character.

The key processes driving change are hydrological (declining river inflows and increasing ocean exchange) both of which will be affected by natural processes (rainfall and sea level rise) and management (water management, barrage operations and dredging). Both drivers are already well understood and managed, but there are emerging uncertainties about their future dynamics and impacts:

- multiple parts of the CLLMM system will be in novel regimes of physical dynamics and ecological responses
- there will be different objectives and management of both freshwater and seawater inputs / exchange in the system
- there is likely to be further evolution of local, state, Murray-Darling Basin, national and international institutional arrangements
- societal/cultural values in relation to water levels and quality and reconfiguring populations and ecosystems
- evolving attitudes locally, nationally, and internationally about climate change driven changes in ecological character of wetlands.

Lessons learnt from the Millennium Drought have provided valuable insights into how site management, stakeholders, First Nations groups, and communities can navigate large change, creating a solid foundation for ongoing learning and adaptation.

4 Discussion

The vulnerability assessment activities were intended to stimulate different thinking about the CLLMM system and transformational change. At the end of each workshop, DEW staff and the CSIRO project team shared insights from the processes about the CLLMM, Ramsar processes, transformational change in general and the vulnerability assessment process. The insights below were synthesised from transcripts of the workshops, CSIRO team notes and the Miro boards (see Section 2.2) used by participants in this part of the workshops. Quotations below are directly from the workshop transcripts or the Miro board. Many of these issues were explored more fully in the adaptation pathway analysis conducted subsequently in this HCHB T&I Climate Adaptation Component.

4.1 Insights about the Coorong, Lower Lakes and Murray Mouth

At the end of workshop 1 participants were asked to reflect on any new insights about the future of the CLLMM. Participants raised the following:

1. **Preparing for transition needs time.** Even though many of the anticipated changes are decades away, they entail a complete change in management of the whole region if barrages no longer work properly and ocean exchange becomes significant. It could take 20 or more years to work up to addressing some of the management changes required and get the resources together to act, and changes in policy and community values can also take decades. This suggests it warrants exploring possible future management options sooner so transition pathways can be scoped and enabling conditions identified to inform near-term adaptation (sequencing of responses over time was addressed explicitly in the subsequent adaptation pathway analysis).
2. **Learn from interventions.** There are many uncertainties in how the Coorong will respond to different conditions. Long-term management options (e.g. infrastructure) provide an opportunity to learn more about the ecological and social responses to management interventions as part of a deliberate adaptive management strategy. For example, installation of blocking banks around the Goolwa Channel during the Millennium Drought generated lessons in how the system can respond, how an early intervention can support transition, and how community engagement during times of change/crisis is critical. 'If the system is in a healthier state to begin with then it is more likely to transition to a functional future state.'
3. **'Freshwater dream'.** For some participants, the exploration of these scenarios heightened their appreciation of the freshwater parts of the system, and they were wary of perceived benefits of a healthy estuarine system in Lake Alexandrina in Scenario 2, as opposed to a degraded freshwater system in Scenario 1. This was expressed as: 'hold onto that freshwater dream for as long as possible'.
4. **Prevent locked-in degradation.** The South Lagoon has not recovered fully from the Millennium Drought because accumulated salt and nutrients could not leave the system. At least occasional flushing of the system, with additional management levers (e.g. infrastructure) and/or very high River Murray flows, will likely be required to prevent such locked-in accumulation of salt and nutrients in the drying periods in Scenario 1.
5. **Preparing for future shore locations.** Revegetation efforts take time, especially for infill and overstory creation. Managing the vegetation for future shorelines requires actions decades in advance of shoreline change. DEW is experienced in thinking about revegetation in this way: 'We did a heap of revegetation that is up to 5km from the current lake edge, so it's not performing the same function now that it will under future lake level – we've started to create vegetation for the future lake edge.' Infrastructure near the shore is typically long lasting, so it could take decades of preparation to effectively reduce the impacts on infrastructure of changes in water level in the Lower Lakes, Murray Estuary and Coorong, including initial declines in water level or later increases. While new inundation has the potential to create new shoreline habitats, which may compensate for loss elsewhere, the effectiveness of this new habitat is unclear (especially those that are currently tidal

saltmarsh, mud flats) and it may require management (sandy nesting beach habitat that is currently on islands), including ensuring land is available to be inundated. Mudflat habitats in the Coorong are at low elevations, but at higher elevations there is rocky terrain, so identification and protection of future mudflat locations would be needed.

6. **Many unknowns.** 'We are a long way from understanding the implications of these two scenarios and whether you can shift between managing for the two different outcomes. There's a whole lot of modelling that would help me understand the nature of the changes that might follow, but we are a long way from understanding what they will be.' Participants also mentioned drivers that we hadn't considered very much, such as invasive species and changes in seasonality. Other unknowns include future dynamics that can't be predicted with modelling, either because the inputs are unclear (e.g. changing weather patterns, actual river flow regimes, rate of sea level rise, stakeholder connection to changing and persisting features), or the dynamics will likely be novel (e.g. sand movement, new habitat creation, persistence of freshwater components, increased frequency of extreme events).
7. **Time lags.** A variety of different types of time lags were raised in discussion. Recovery times (e.g. post drought) are slow for many reasons, such as slow flushing of accumulated salt and nutrients, time for species to recolonise and populations to grow, time for vegetation to grow and mature. These concerns were reinforced by one reviewer, who suggested from experience that recovery from disturbance in wetland systems can take ten times as long as the duration of the disturbance, which could imply that it may take a very long time for a stable healthy regime of ecosystems to establish in Scenario 2, and a need to consider interventions to prepare for and accelerate that process. It also takes time to plan new shorelines, new habitats for where birds may have to move to, especially if there are land tenure / land use barriers to making such changes.
8. **When to plan**. It was also recognised by participants that planning would best be done when the system was relatively stable rather than when it is in a state of crisis (like during the Millennium Drought), and that delays in planning for change will make it more likely that decisions will be made during crisis situations that can be expected to occur more frequently if not constantly.

4.2 Institutional insights

'Institutional barriers to adaptation are our greatest risk.' – Workshop participant.

Vulnerability to climate change arises not just from the physical processes and ecological sensitivities within the CLLMM, but also from decisions people make in response to climate change that affect the CLLMM. Therefore, the institutions that shape decision-making are part of the vulnerability context of the CLLMM. This includes institutions shaping decisions directly about the CLLMM but also broader decisions at Basin, national and international scales. Workshop participants made a range of observations about the way issues are considered and decisions are made affecting the CLLMM and how they might be affected by the prospect of significant change. These were offered as personal reflections and participants were conscious that their views were not representative of the entirety of DEW – as one participant put it: 'this group is not the whole Department'. Based on these reflections the CSIRO project team made a series of observations about these institutions.

Ramsar listing

Workshop participants noted that this process has reaffirmed the critical importance of Ramsar listing for the CLLMM as it illustrated that the site, with good management and sufficient water, could continue to meet the Ramsar criteria for a Wetland on International Importance, even if it did face significant change in character. Further, this process highlights that even with this change in character, many of the components, processes, and services contributing to its character (as described in the ECD) could potentially persist and contribute to the site continuing to be worthy of conservation.

Participants also highlighted that the Ramsar listing, and the location of the Coorong at the end of the MDB system, give the site status and resources that might not otherwise be available under current environmental protection legislation.

Interpretation of change in ecological character

Under the Ramsar Convention, there is a process for identifying and notifying the Ramsar Secretariat regarding changes in ecological character to Ramsar sites. However, the process is far from clear cut, especially as wetlands are dynamic over time and there are often limitations in data. This was illustrated with notification about potential change in character of the CLLMM during the Millennium Drought. The criteria for change in character are not well defined. One participant noted, 'Part of the issue is that nobody knows what change in ecological character is.' This is made even more complicated under climate change where changes may be driven by climate (rather than local threats), or in the case of the CLLMM climate change *in combination with* other human activities (i.e. water extraction from the MDB).

Further, it is not clear how changes in character as a result of climate change should be assessed and reported for the Ramsar Convention to still be effective as a conservation instrument. Ideally, descriptions of ecological character need to accommodate some change but not allow 'inappropriate' change. However, there is currently very little guidance or experiences, nationally or internationally, about assessing or determining appropriateness. The rolling Ramsar management planning process does provide some capacity to accommodate gradual change in character, but it does not provide guidance about the extent to which such change could be considered appropriate or reportable, or how to anticipate change so these decisions are made against a realistic baseline. One reviewer suggested that these important matters warrant consideration by the Australian Ramsar Administrative Authority as they will begin to affect all Australian Ramsar sites and need to be addressed at the Convention scale.

Nationally, if the definition of ecological character and procedures for assessing and reporting change are not reformed to accommodate anticipated change, then, as the character of Ramsar sites does change, there is a risk that changes in character are interpreted or used as evidence that the conservation and societal value of sites has been diminished or lost. This could then trigger a reduction in their protection and an increase in threats from other pressures such as water diversion and land development in or near sites.

Upstream arrangements can't be escaped

A core piece of the management puzzle for the CLLMM region has always been upstream water management and upstream deliberation and decision-making about water – this is very unlikely to change. Consequently, outcomes for the CLLMM will depend on how CLLMM issues are represented in those processes, and CLLMM outcomes will inevitably depend on trade-offs that are being made elsewhere and at a different scale. In particular, the fate of the CLLMM and the South Lagoon rests very much in the Basin Plan, the extent to which committed additional flows are delivered, and future revisions to the Basin Plan in response to changing rainfall and competing demands for water. While there are significant actions that can be undertaken locally, the amount of water allocated and delivered to the CLLMM will always be a critical determinant of outcomes in the CLLMM.

Narratives of change

Given the dependence on MDB-scale decisions, there is a risk if the overarching narrative for the long-term objectives of the CLLMM is different from the current short-term narrative. By considering significant change, the analysis in this report considers outcomes that deviate from the current narrative, which focuses on recovery and maintenance. For example, it is clear the current MDB institutions and level of deliberation among stakeholders are not yet seeking to (nor required to) integrate future transformational change narratives and near-term recovery/persistence narratives. Technically, the narratives are not *incompatible* as our scenarios are several-to-many decades away, whereas the implementation of the Basin Plan has a shorter-term horizon. However, the research team observed that differences or tensions between the narratives can cause ambiguity and reduce willingness to actively consider the implications of the longer-term change. Other issues include discomfort with considering the prospect of significant change, lack of familiarity with the types of uncertainties involved, and lack of processes for developing agreed visions for the CLLMM in the face of change, uncertainties and the diversity of values held for the CLLMM and the MDB. The Adaptation Pathways analysis conducted subsequently in this HCHB T&I Climate Adaptation Component sought to provide insights and tools to help bridge this gap. The assessment of vulnerability in this analysis and summarised in the vulnerability narrative does rely on a significant amount of adaptation in management of the system. If this adaptation were to be inhibited or delayed as a result of institutional barriers then the outcomes anticipated could be significantly less favourable.

A values-focus to management objectives

DEW staff recognised that a wide range of people have a stake in the CLLMM and that they hold the site and region as being of value to them. As the site experiences physical change, engaging with the diversity of values held for the CLLMM, rather than just providing information about change, will help DEW ensure that future objectives focus on preserving valued aspects of the CLLMM as physical change occurs. Decisions made on the basis of these objectives will then be more likely to maintain the connections people have to the CLLMM.

4.3 Methodological insights

This analysis was conducted with DEW to provide insights about the vulnerability of the CLLMM, but also to generate insights about *the process* of considering transformational changes in the system. These include things that DEW staff learnt that can be used internally and when planning engagement with stakeholders. They also include information about the application of various adaptation concepts and tools in a particularly complex physical and institutional context. Some of the key insights that were apparent or shared with the project team are discussed below.

4.3.1 Benefits of the process

The process provided an opportunity and structured format to deliberate over and make collective sense of issues that people were aware of to an extent but had not previously made explicit.

- 'Aside from the system itself, the process we are going through has that benefit. We are having the discussion, and it allows us to be proactive about what is likely/may happen, what options are for doing something about it (and when). Assume there's a pathways element to that. Map things out. Raise barrages, or transition to estuary. Work back along timeline and what you need to do in the timeline. I really like that people are asking questions and raising concerns about timing. This process is working and we are asking those questions, documenting and can do something about it.'
- 'I've been a big supporter of this process because it addresses deficiencies in previous conversations on dealing with drought. Taking it from a crisis to being more planned. It harnesses people who have an opinion about how the site should be managed because it brings them in.'
- 'Careful working through two scaled scenarios has allowed greater assessment of interactions that change processes will include - so we are better placed for making assumptions in thinking about vulnerability and applying them...'

The process fostered hope and agency. Even though participants were working with scenarios of large change and losses in a highly valued system, they could see many things they valued could persist and by focussing on them there were viable opportunities to manage the CLLMM. The process is designed to enable this, to avoid leaving participants with a sense of despair.

- 'People were more optimistic than I thought they would be about what will persist and what won't.'
- 'We have more consistency within the Department than I thought – more potential to move together, I don't think we're quite as far apart.'
- 'Lots of opportunities moving forward.'

4.3.2 Sensitivity to scenario assumptions

Following the values-mapping activity in workshop 1, participants were asked to reflect on whether a different scenario would change the values-mapping significantly. Four critical assumptions were identified and their implications for the analysis were discussed:

1. **Ocean exchange rates.** Scenario 2 assumes the Murray Mouth remains open and there is high exchange with the ocean and along the length of the Coorong. The values-mapping exercise revealed a much higher level of persistence of attributes that are valued (green hearts in the 'persist' column) for Scenario 2 compared with Scenario 1, and much of this difference was attributed to the higher level of exchange with the ocean specified in Scenario 2. Without such high exchange, the combination of higher sea level and reduced freshwater flows could see further accumulation and concentration of salt and nutrients and a continuation of conditions in Scenario 1. The high-exchange setting was chosen on the basis that a) maintaining the openness of the mouth and good exchange would continue to be a priority and would become more important with reduced river flows, and b) it could be achieved with significantly increased dredging activity, if necessary. However, it is not guaranteed. Some participants expressed concern that these assumptions meant that there were 'too many green hearts in Scenario 2'.
2. **Freshwater inflows.** The details of Scenario 1 (and the associated values-mapping) are shaped by assumptions about volumes of freshwater, including environmental water, entering the system from the River Murray. Scenario 1 reflects conditions seen in the Millennium Drought, motivated by modelled river flows corresponding to a median-level reduction in Basin rainfall and full implementation of the current Basin Plan; but volumes of freshwater inflows may be higher or lower than this. Furthermore, the variability between years in high and low flows will also affect the ecological response (e.g. an increased frequency of extreme low flow events would mean there is less time for ecological recovery between these events); and decreased frequency of high and medium flow years would also slow recovery. While people hoped that the levels of environmental water specified in the Basin Plan would persist, some identified that they could be subject to future change. The condition of Lake Alexandrina in Scenario 2 is also dependent on the volume and regime of freshwater flows to maintain a salinity gradient, flushing and regular periods of freshwater habitat.
3. **Relative timing and magnitude of drying and sea level rise.** There are assumptions in Scenario 2 (and the associated values-mapping) that the system recovers some features that were degraded or lost in Scenario 1. The severity of change in Scenario 1 and the potential for recovery in Scenario 2 are dependent on the relative timing and magnitude of drying and sea level rise. If features are irreversibly lost in Scenario 1 then they may not be recoverable in Scenario 2. Furthermore, there is a risk that large shifts will select for generalists and invasive species, rather than a more ecologically diverse response. Even if recovery to a healthy system is possible, it may take many decades for that to occur.
4. **Physical Infrastructure.** Assumptions about physical infrastructure influence the results in several ways:
    a. The scenarios assume that dredging of the Murray Mouth continues through both scenarios, and the scenario details and values-mapping would be very different if dredging (or equivalent means of enabling ocean exchange) is not maintained.
    b. There are assumptions that the barrages remain in place throughout Scenario 1, and the influence of the barrages reduces over time in Scenario 2 as they are over-topped more frequently and barrier islands become inundated. If barrages are heightened or new barrages are built, then this will change the scenarios (and the values-mapping) significantly. It is possible that the Lower Lakes would remain in a Scenario 1 state, with continual decline in condition, while the Coorong would be in Scenario 2 state, but possibly with even less influence of occasional high River Murray flows. Critically, connectivity between the Lower Lakes and the estuary would be significantly reduced or lost, nullifying a significant portion of the 'persistence' identified in Scenario 2.

c. Infrastructure being considered in the HCHB Coorong Infrastructure Investigations Project (CIIP) is designed to improve the recovery of the South Lagoon from the effects of the Millennium Drought. Such infrastructure could substantially change the health of the system at the start of Scenario 1 and could also provide more management levers to manage the health of the system during Scenario 1. This improved health would increase the likelihood and rate of the 'recovery' identified in Scenario 2 in the South Lagoon.

d. More generally, infrastructure options in conjunction with either scenario have the potential to reconfigure the whole system and provide more management levers.

e. This analysis has not considered the consequences of increased salinity and water levels in Lake Alexandrina for the lower River Murray, and any needs for additional infrastructure.

Given the sensitivity of results to these assumptions, these issues were identified as key uncertainties for the subsequent Adaptation Pathways analyses undertaken as part of this HCHB T&I Climate Adaptation Component, considering when and how managers might detect deviation from the anticipated trajectory of change, and actions that might need to be taken in response. In this way, the importance of these uncertainties and the need to further investigate them remains open for exploration. As one participant said, 'we are a long way from understanding the implications of these two scenarios'.

We also note that this analysis is identified as a *preliminary* vulnerability analysis on the basis that consultation was limited to a subset of DEW staff and a number of researchers involved in the HCHB T&I project, and it focussed on features identified as important in the ECD. Other personal and cultural perspectives about change, which features are valued, and how those features and the connections people have to them might be affected by change would be expected to provide different insights on the vulnerability of the CLLMM.

4.3.3 CSIRO team observations

The CSIRO project team made a series of observations about the application of the vulnerability assessment methodology in this complex setting.

The construction of the scenarios as sequential states as opposed to alternative states is novel in scenario planning (as far as we know). While the impact on values can be assessed separately for each scenario, there are dependencies between them; outcomes in Scenario 2 will depend on the condition of the system in Scenario 1, and management decisions in Scenario 1 should consider the implications of different choices on outcomes in Scenario 2.

In the values-mapping activity, nominally, placing red icons in the change column indicates that the value associated with those features is lost by the specified changes to those features and there is little to no value associated with the persisting attributes of the features. In workshop 1, participants nominated red icons in the change column for a high proportion of features, despite the discussion suggesting that there would likely be some value associated with the persisting attributes of these features. This was discussed in workshop 2. Participants clarified that for most of these features, the persisting attributes would likely be valued such that *it would be reasonable to actively manage to preserve those attributes* that had the potential to persist despite the loss of the value associated with the changing attributes. However, because of the significance of the decline in values associated with the changing attributes, they were not happy nominating green icons for these features. The values-mapping system used was not initially designed to accommodate this situation. This points to the need for the mapping process to more deliberately separate the concepts of values that are lost from value associated with what might persist. There was also a diversity of opinion, with some people expressing a very strong desire to hold on to the current values as long as possible, potentially for example, preferring a degraded (nominally) freshwater Lower Lakes to a healthy deliberately estuarine Lower Lakes. However, it should be noted that neither this Vulnerability Assessment nor the subsequent Adaptation Pathways analysis is prescribing which outcome will or should be preferred, rather they seek to understand the consequences, barriers and enablers associated with different feasible future outcomes *should they be preferred in the future*, and scope near-term actions that might *help maintain or create options* for future decision makers.

The above issue highlighted the inherent tension in transformational adaptation planning, between maintaining current values and accommodating change through revised objectives focussing on different values, and that this tension has personal and institutional manifestations and dimensions relating to the (evolving) values, rules and knowledge that are applicable to planning and decision-making (Gorddard et al 2016).

Discussion about the physical and institutional factors in the CLLMM system that increase or decrease vulnerability was illuminating. It suggested managers are doing some things in response to factors that increase vulnerability (often recognised as 'threats'), but they tended to focus less on factors in the system that decreased vulnerability. Focussing on these factors does represent an adaptation opportunity for the CLLMM. There was also a very rich discussion about institutional factors, reflecting that adaptation is as much about changing people and institutions as it is about physical interventions.

The process of developing the scenarios and the narratives around them, with DEW, highlighted the importance of narratives, the need for them to be developed collectively, and their power to affect the societal values, rules and knowledge that shape the options available to decision makers (Gorddard et al 2016).

Despite the high levels of uncertainty, the number of critical assumptions, and an innate desire to work with certainty, the process of co-developing the content and deliberately allowing time to address the implications of the uncertainties, most participants demonstrated a high capacity to work with complexity, uncertainty, and ambiguity inherent in the scenarios. This capacity was a vital strength of the collaborative analysis and nurturing it should be a key design criterion for applying the methodology with other participants.

5 Conclusions

This activity of the HCHB T&I Climate Adaptation Component, assessed the vulnerability of the CLLMM to climate change, using two scenarios corresponding to significant hydrological and ecological change in the system. The analyses sought to identify features of the CLLMM that might persist under each scenario, recognising that many attributes of features will change, and to characterise the extent to which the site might continue to be valued as a result of the persisting attributes of features. This is in contrast to traditional risk assessments that focus on what is most likely to be lost. The assessment was conducted to provide information about the vulnerability of the CLLMM, and also to further the capacity of DEW representatives to make sense of and deliberate about future transformational changes, and help them prepare for engaging with their stakeholders about these issues (an explicit objective of subsequent activities in this project). The deliberations we undertook in the project were restricted to a subset of DEW representatives and did not include perspectives from First Nations groups or the broader community. As such the outputs should be considered a preliminary assessment. Similar analyses, informed by this one, could be undertaken in the future with First Nations groups and the community.

The assessment identified that with a sustained reduction in rainfall and River Murray inflows (Scenario 1), there is likely to be a more frequent and sustained return to conditions experienced during the Millennium Drought, with low water levels, poor connectivity, salt and nutrient accumulation, hyper salinity and elevated nutrient availability in the South Lagoon, and disruption to food webs and the lifecycle of many species. These changes would correspond to changes in character for most valued features (CPS), and would likely lead to the loss of many societal values associated with CLLMM. Despite these changes, it was assessed that a range of values associated with the site would persist and the site would still likely meet the Ramsar criteria for a Wetland of International Importance.

In contrast, with sustained increases in sea level and action to ensure effective exchange of seawater between the Southern Ocean, the Murray Estuary, the Lower Lakes and the Coorong (Scenario 2), there is a more complicated vulnerability story, with differences between the Lower Lakes and the Coorong and between ecological health and ecological character. The system as a whole would likely experience a general improvement in ecological health (compared to Scenario 1, but not necessarily when compared with current conditions), but this would include significant spatial rearrangements in habitats and species. There would likely be an improvement in the ecological health in the South Lagoon with a reduction in peak salinity and nutrient levels, and a restoration of ecological character of the Coorong. However, in the Lower Lakes there would be a significant decline in the abundance and extent of freshwater habitats and species. The scenario anticipated these critical components would be able to persist in low abundance during dryer times when salinity would increase, then expand during high flow events when salt was flushed from the system, and populations of estuarine and marine species and communities would establish in the Lower Lakes. These changes would likely correspond to a change in the ecological character of the Lower Lakes. The assessment suggests that despite the significant hydrological and ecological changes, most of the societal values associated with the CLLMM would be retained, notwithstanding that the way in which they are experienced might be altered (in different locations or abundances). There would be significant loss of societal values that were associated with the declining freshwater communities and species.

There are many factors that would determine how a trajectory that was dominated initially by decreasing rainfall and then by sea level rise might play out. These include a number of institutional and managed factors affecting inflows and interventions to slow or enable ocean exchange. One of the most critical factors in determining the outcome in Scenario 2 would be the extent to which the inherent regeneration capacity of the CLLMM system is diminished during the phase of declining condition in Scenario 1, and the effectiveness of management to maintain or build this capacity during Scenario 1 and the transition to Scenario 2.

Participants found it useful to make use of the two scenarios, paying deliberate attention to attributes that might persist, as well as those that are likely to change, and the mapping of different expression of values to those attributes. It enabled them to take a long-term perspective of the CLLMM, recognise that the system has the potential to retain significant values despite significant ecological change and uncertainty about it, and that there are clear opportunities for management to increase the persistence of many values.

Participants recognised that the core concepts of the analysis would be useful for engaging with stakeholders about transformational change, building understanding, deliberating over longer-term actions, and building narratives about a healthy but changing CLLMM that focus on the values that persist and help people appropriately acknowledge and respect those that are diminished or lost. To be most effective, modifications to the process would be needed for each stakeholder group; for example, participants could identify and focus on features that they identify as of value to themselves, in addition to being made aware of the CPS derived from the 2015 ECD. This would also help inform state and MDB institutional processes that make decisions affecting the CLLMM, its values and the people whose wellbeing depend on it, and it would help inform international efforts to address climate change and include other values in the Ramsar processes.

In a subsequent analysis and series of engagements, an adaptation pathway approach was used to scope future 'climate-ready' objectives for the CLLMM, and long- and near-term actions that might be needed to achieve those outcomes and navigate significant uncertainty associated with anticipating and planning for change (Dunlop et al. 2022).

List of shortened forms and glossary

ASS	Acid Sulfate Soils. This is the common name given to soils and sediments containing iron sulfides, the most common being pyrite. When exposed to air due to drainage or disturbance, these soils produce sulfuric acid, often releasing toxic quantities of iron, aluminium and heavy metals. Source: Government of South Australia (2014).
attribute	An *attribute* of a *feature is* a quality or a characteristic that relates to the reason why a feature is valued. A species might be a feature and its cultural significance the attribute that makes it valued. Some attributes can also be features: waterbirds are an attribute of the Coorong, but they are features with attributes (their abundance, global distribution etc).
Change-persistence table	As some ecological features change, almost always some attributes of that feature persist, and often the attributes that persist are also of value to people.
CIIP	Coorong Infrastructure Investigations Project.
CLLMM	Coorong, Lower Lakes and Murray Mouth.
CPS	Components, processes and services specified in the Ecological Character Description. These are further classified into ‘critical’ and ‘non-critical’ CPS.
ECD	Ecological Character Description. A formal description of critical ecosystem components, processes, and services (see next entry) at a defined point in time, often the time of listing of a site.
ecological character	In the context of the Ramsar Convention, ecological character refers to the formal Ecological Character Description (ECD). Under the Convention 'ecological character' and 'change in ecological character' are defined as follows (see Resolution IX.1, Annex A, November 2005 & Ramsar Handbook No. 1, Wise use of Wetlands 3rd edition, 2007). ‘Ecological character is the combination of the ecosystem components, processes and benefits*/services that characterise the wetland at a given point in time.’ and ‘… change in ecological character is the human-induced adverse alteration of any ecosystem component, process, and/or ecosystem benefit*/service.’ * Within this context, ecosystem benefits are defined in accordance with the Millennium Ecosystem Assessment's definition of ecosystem services as ‘the benefits that people receive from ecosystems’.
evapoconcentration	Concentration of the constituents in a water body (e.g. salt and nutrients) by evaporation.
features	*Features* are things that are in nature. The rows of the change-persistence tables are features. Features have *attributes* such as abundance, location, community. Some features can be attributes of other features.
HCHB	Healthy Coorong, Healthy Basin.
LAC	Limits of acceptable change. the variation that is considered acceptable for a measure or parameter of a particular component or process of the ecological character of the wetland. Source: Phillips (2006).

macrophytes	Plants growing in or near water.
MDB	Murray-Darling Basin.
Millennium Drought	An Australian drought which impacted the Murray-Darling Basin over the period 1996-2010, and substantially impacted the Coorong over the period 2001-2010.
Ramsar	City in Iran, on the shores of the Caspian Sea, where the *Convention on Wetlands of International Importance especially as Waterfowl Habitat* was signed on 2 February 1971; the Convention's short title, 'Ramsar Convention on Wetlands'.
Ramsar Criteria	Criteria for identifying Wetlands of International Importance, used by Contracting Parties (see Ramsar Convention) and advisory bodies to identify wetlands as qualifying for the Ramsar List on the basis of representativeness or uniqueness or of biodiversity values.
Ramsar Convention	Convention on Wetlands of International Importance especially as Waterfowl Habitat. Ramsar (Iran), 2 February 1971. UN Treaty Series No. 14583. As amended by the Paris Protocol, 3 December 1982 and Regina Amendments, 28 May 1987. The abbreviated names 'Convention on Wetlands (Ramsar, Iran, 1971)' or 'Ramsar Convention' are more commonly used. Nearly 90% of UN member states (>170) have become Contracting Parties to the Convention. See https://www.ramsar.org/about-the-convention-on-wetlands-0 for more details.
Ramsar List	The List of Wetlands of International Importance.
Ramsar Sites	Wetlands designated by the Contracting Parties for inclusion in the List of Wetlands of International Importance because they meet one or more of the Ramsar Criteria.
T&I	The Trials and Investigations project of the Healthy Coorong, Healthy Basin (HCHB) program. For more details see https://www.environment.sa.gov.au/topics/coorong/healthy-coorong-healthy-basin/scientific-trials-investigations
transformation	Transformation or transformational change involve fundamental change that requires radical, systemic shifts in values and beliefs, patterns of social behaviour, and multilevel governance and management regimes (Olsson et al. 2014).
value	When used as a verb, *value* refers to the act of liking or appreciating or caring about a *feature* or an *attribute* of a feature (e.g. 'recreational fishers value the abundance of fish'). When used as a noun, *value* refers to the reason a thing is deemed as important. 'The value of the site is in its diversity and uniqueness.' Value relates to why or how much a thing is held to be important to by a person or society more broadly. Things may be important for different reasons to different people. For example, a Ramsar site is identified as being important for meeting a set of criteria, and an Ecological Character Description (ECD) identifies key features that are linked to the recognised value of the site, within the Ramsar framework. However, many sites, including the CLLMM, are important to society for many other reasons other than those listed in Ramsar documents, such as cultural, aesthetic or recreational connections. These reasons may relate to features in an ECD or additional features. Value can also be used to refer to a thing that is valued. We avoid this usage in the Climate Adaptation Component.
vulnerability	Risk to the values associated with the persisting attributes (accepting the inevitability of some changes).

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Appendix A Context

The following context material was provided to workshop participants in preparation for workshop #1. It draws on the outputs of previous T&I Component 6 activities, and is organised according to the context questions comprising Steps 1 to 8 of the methodology (Dunlop and Grigg, 2019). It was expected that this material was already familiar to workshop participants, and it was provided as a check to ensure we were all working from a shared, initial understanding of the CLLMM context.

A.1 Physical description

- The Coorong, and Lakes Alexandrina and Albert Wetland consists of a unique mosaic of 23 Ramsar wetland types, including intertidal mud, sand or salt flats, coastal brackish/saline lagoons, permanent freshwater Lakes, permanent freshwater marshes/pools, shrub-dominated wetlands, and water storage areas. The site is unique in its wide representation of wetland types within the bioregion and is the only estuarine system within the Murray-Darling Basin (Phillips and Muller, 2006).
- Geographic extent of this work includes the North and South Lagoon of the Coorong as well as Lake Alexandrina and Lake Albert in South Australia.
- The geographic extent of Ramsar listing is an indicative (as opposed to exact) boundary that includes the Coorong, the Younghusband Peninsula, Lake Albert, Lake Alexandrina and all the islands in Lake Alexandrina and all of Hindmarsh Island. The ephemeral wetlands inundated by the 1956 flood and Sir Richard Peninsula are not included (DEH, 2000).
- The extensive drainage infrastructure in the region includes 2589 km of drains and floodways.

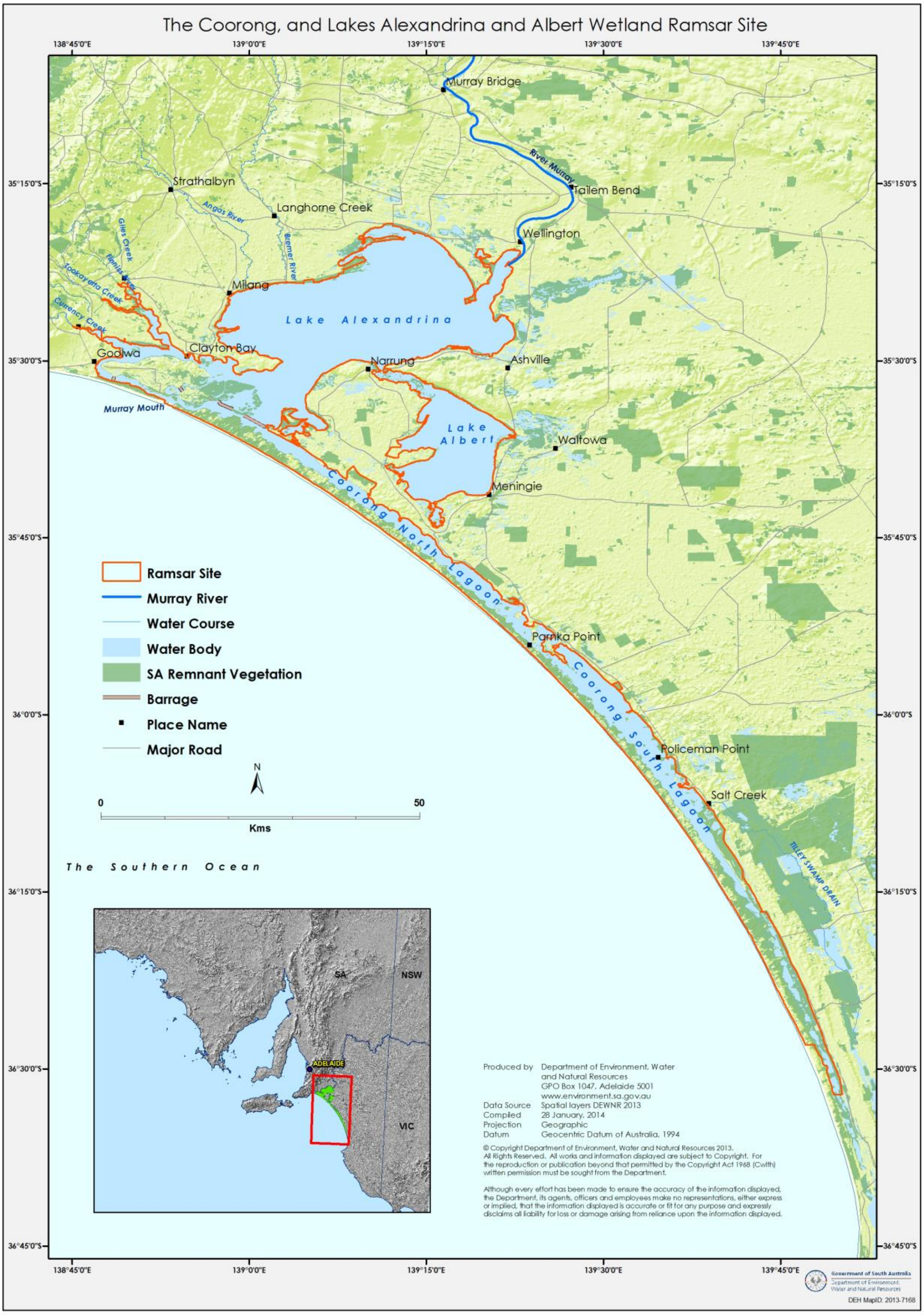


Figure 3. The Coorong and Lower Lakes Wetland Ramsar Area. Source: South Australian Department for Environment and Water, 2014

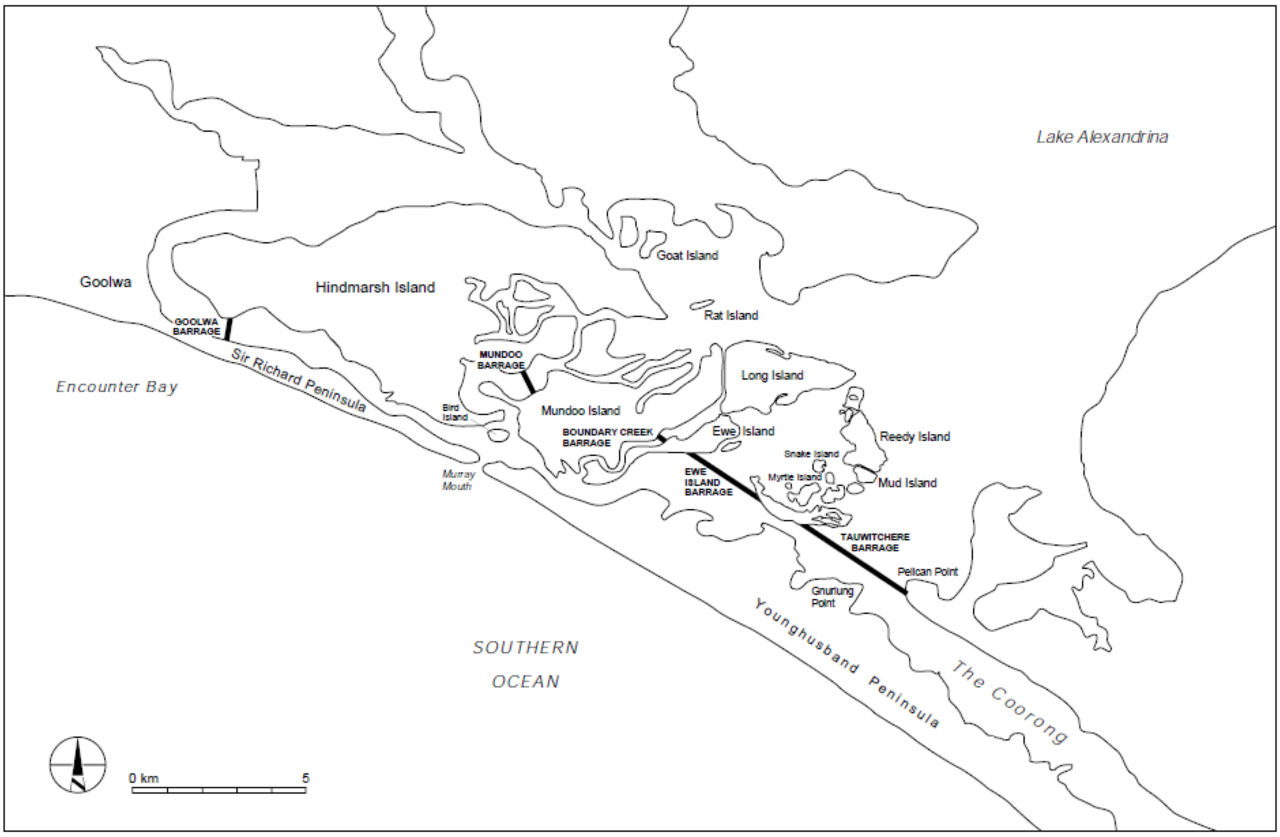


Figure 4. The barrages and the islands adjacent to the Murray Mouth. Source: Ramsar management plan 2000

A.2 Institutional context

- The region was Ramsar-listed in 1985.
- Migratory bird agreements with Japan (JAMBA in 1974), China (CAMBA in 1986), and the Republic of Korea (RoKAMBA in 2007) have been signed.
- The region is managed by South Australian Department for Environment and Water with State Department managed on-ground works.
- The Ngarrindjeri Native Title Claim was lodged in 1998, registered in 2000 with decisions made in 2016 and 2017 with the outcome that Native Title exists in parts of the determination area (National Native Title Tribunal, 2020b).
- The First Nations of the South East also hold a Native Title claim that has been accepted for registration, although still awaiting final determination (National Native Title Tribunal, 2020a).
- Water allocation is managed under the Basin Plan and listed under 'current management' below.

A.3 History of use and change

- Ngarrindjeri never ceded or sold their lands and waters (Ngarrindjeri Nation, 2007).
- The 1836 Letters Patent established the Province of South Australia in colonial law.

- Camping reserves of 5 acres in size were established in the northern Coorong from 1901 for use by professional and recreational fishers.
- There are reports of concern over 'riparian rights' to fresh water by people who had purchased properties on the shores of Lakes Alexandrina and Albert and were experiencing declining water quality and saltier water in the Lakes in the early 1900s (Sim and Muller, 2004).
- The Birds Protection Act of 1908 saw the establishment of the first sanctuary for bird protection (covering islands south of Parnka Point), and further expansion of sanctuary areas occurred in 1914 and 1920.
- Lobbying against the sanctuaries in 1920, defending duck-shooting as an important livelihood for returned soldiers, saw a reduction in sanctuary areas in 1925.
- The Northern area of the peninsula (6660 ha) was declared a sanctuary in the Animals and Birds Protection Act of 1919-1938 (Minister of Agriculture).
- The Coorong Game Reserve was purchased in 1968 and came under the administration of the National Parks and Wildlife service in 1972.
- The Coorong National Park was established in 1967 (under the *National Parks Act 1966*).
- The Coorong Game Reserve was formally abolished in 1993 and added to the Coorong National Park.

A.4 Current stakeholders and their relationships (values at stake)

- Australian and International community recognise the site as an important for its diversity of wetland types, the abundance and diversity of native flora and fauna and its unique geomorphological setting.
- Local residents (including First Nations) – for what the land provides re: livelihoods, food, shelter.
- First Nations – for their enduring and unalienable cultural connections to the site, obligations to protect it and the dependence of their wellbeing on it.
- Land managers/state government – stewardship role.
- South Australians – for contribution to economy via tourism/ Pride in local nature and culture that contributes to South Australian identity.
- Australians.
- Tourism, fishing, camping, etc.

A.5 Ecological Character Description, listing criteria and other listed values

- Some of the components, processes, and services in the Ecological Character Description:
  - Hydrology – inflows, rainfall and evaporation, lake levels, barrage flows, tidal signal.
  - Salinity – Lakes Alexandrina and Albert, Eastern Mount Lofty Ranges tributaries, Murray Estuary and Coorong.
  - Water and sediment quality – nutrients, acid sulfate soils (ASS).

- Vegetation – submergent freshwater vegetation, emergent freshwater vegetation, submergent halophytes, emergent halophytes.
- Fish – diversity species richness and biodisparity, movement and recruitment, threatened species.
- Waterbirds – diversity, abundance, foraging, refuge and roosting habitat, breeding, threatened species.
- Threatened ecological communities and species – swamps of the Fleurieu Peninsula, subtropical and temperate coast saltmarsh, southern bell frog.
- Wetland habitat – diversity, estuary of the Murray-Darling Basin.
- Invertebrates – microbenthic invertebrates, zooplankton.
- Food webs – Coorong Food web.

- Ramsar criteria under which the site was listed.
    - Criterion 1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.
    - Criterion 2: A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.
    - Criterion 3: A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.
    - Criterion 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.
    - Criterion 5: A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.
    - Criterion 6: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.
    - Criterion 7: A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity.
    - Criterion 8: A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend (DEWNR, 2013).

A.6 Current threats and changes

- Reduction and regulation of freshwater inflows from the River Murray. The negative consequences of upstream water extraction have been evident as early as the early twentieth century, but they have increased steadily and are most acute during drought.
- There is reduced ecological connectivity between the Lower Lakes and estuary.

- There is increasing salinity and nutrient concentrations in low flow periods (droughts).
- There is hypersalinity and eutrophication in the southern lagoon leading to a dominance by filamentous algae and loss of keystone *Ruppia tuberosa.*
- Acid sulfate soils are an ongoing threat.

A.7 Responses to recent extremes

- The Millennium Drought was the most notable recent extreme event, providing new insights to possible consequences of climate change.
- The impacts were severe and significantly exacerbated by upstream extraction of water.
- Novel hydro-chemical-ecological dynamics were observed with a very prolonged recovery.
- Reduced water level in the Lower Lakes.
- Exposed acid sulfate soils with a significant risk of acidification and heavy metals.
- Reduced ecological connectivity between the Lower Lakes and the estuary.
- In the southern lagoon, hypersalinity and high nutrient availability, leading to a dominance by filamentous algae and loss of keystone *Ruppia tuberosa.*
- Significant impacts on bird and fish species distributions and abundance.
- The site still has not fully recovered from the Millennium Drought – particularly the Southern Lagoon.

A.8 Current management activities and priorities

- Hypersalinity in the Southern Lagoon is the top priority.
- Water level in the Lower Lakes and Coorong need to be managed.
- Advocacy and information to ensure minimum and timely freshwater inflows flows from the River Murray.
- Multiple future infrastructure options are being considered, especially to manage salinity and nutrient levels in the Southern Lagoon.
- Barrage operations to maintain seasonal water levels and manage salinity:
    - Minimum annual flow from the barrages required to achieve salinity target of <1,000 µS/cm in Lake Alexandrina 95% of the time (650 GL/y minimum in any year incorporating a three-year average of 2,000 GL/y) (MDBA, 2014).
    - Minimum annual flow required to keep the Murray Mouth open (730—1,090 GL/y) (MDBA, 2014).
    - Flows of at least 2,500 GL over two years to prevent the Coorong existing in a degraded ecosystem state (MDBA, 2014).
    - Flows of 6,000 and 10,000 GL per year every three and seven years respectively to achieve a healthy Coorong ecosystem state (MDBA, 2014).

Appendix B Change-persistence tables

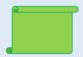
The scenarios and analyses of them are presented in five tables:

- **Table 2** – A high-level / integrated summary of the scenarios. This serves to introduce to the scenarios in holistic way.
- **Table 3** – A summary of the mapping of different values to the changing or persisting attributes of each CPS for each scenario. This table presents a summary of how each component, process and service of the CLLMM is valued under the two scenarios.
- **Table 5** – A summary for each component, process and service of the attributes that are anticipated to change and those that may persist, with a mapping of different values to the changing or persisting attributes.
- **Table 6** – A mapping of the Ramsar criteria used to list the CLLMM on to changing or persisting attributes.
- **Table 7**– Details for each component, process and service of the attributes that are anticipated to change and those that may persist. It is intended that this table is used as a reference, if readers want additional detail of the intent of the summary information. Note that this table was provided to participants prior to workshops and has not been revised in light of workshop findings. If any inconsistencies arise, Table 5 should take precedence.

Table 5. Change-persistence table, summary text for selected features of the CLLMM. This table presents a summary of how selected features of the CLLMM are anticipated to change or to persist under the two scenarios.

A draft of this table was used in workshop 1 for reviewing the anticipated changes and mapping values to changing or persisting attributes of the CPS. Icons were not allocated for features/scenarios where there was no opinion expressed from participants. Valued features are based on the CPS from the 2015 ECD. Rows marked by the -> symbol are subsets of a previous row.
For additional detail of changing or persisting attributes, refer to Table 7.

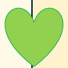
Scrolls = Ecological character as represented by the Limits to Acceptable Change. **Hearts** = social value of biodiversity.
Red = value loses or experiences significant decline in value. **Green** = value retains significant value.

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
1	**Hydrology – Lower Lakes** Inflows, Rainfall and evaporation, Lake levels, Barrage flows, Tidal signal	Reduced runoff in the Murray-Darling Basin (MDB) has increased the frequency, duration and severity of low flows periods, with water levels sometimes as low as during the Millennium Drought and poor connection between the Lakes. Barrage flows often fail to meet current targets.  	The Lakes are large, permanent waterbodies experiencing high interannual variability in water levels. The River Murray is the dominant source of water.	Lake water level is higher than in Scenario 1, set by sea level and less variable between and within years. The barrier islands are frequently inundated. Lakes Albert and Alexandrina are better connected. Lake Alexandrina is periodically flushed by high river flow events. 	The Lakes are large, permanent waterbodies experiencing high interannual variability in freshwater inputs from the River Murray. 	• Current LAC indicator is a measure of water level only (not picking up freshwater inflows), so it can be met due to sea level rise even if freshwater flows reduce. • The reduced volume of freshwater flows in Scenario 1 and reduced variation in Scenario 2 leads to reduced flexibility in management levers.	• There is an assumption in Scenario 2 that the Lakes will be flushed. Decent flow events will turnover Lake Alexandrina but not Lake Albert.

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
2	**Hydrology – Coorong, Murray Mouth** Inflows, Rainfall and evaporation, Lake levels, Barrage flows, Tidal signal	There are significantly reduced freshwater flows into the Coorong. The North and South Lagoons are poorly connected for up to several months each year, leading to higher peaks in summer salinities in the South Lagoon.	The Coorong is an extensive, permanent wetland system with high seasonal and interannual variability in water level determined by flows from the Lower Lakes and variation in sea level.	Water levels throughout the CLLMM are set predominantly by sea level. They are higher, more tidally influenced in the estuary and North Lagoon, and less influenced by seasonal or interannual variability in freshwater inputs. North and South Lagoons are permanently connected, with greater rates of mixing between the Lagoons, and greater exchange with the ocean than Scenario 1.	The Coorong is an extensive permanent wetland system. The North Lagoon periodically receives freshwater from the Lower Lakes and the South Lagoon receives some fresh inputs from the south east. There is seasonal variation in water level due flows from the Lower Lakes and variation in sea level.	• The mouth is more vulnerable to closure in Scenario 1 (barrages in place and declining flows). • The position and bathymetry of the mouth impacts how ocean water translates through and propagates. This is a big unknown. • There is a potentially larger tidal prism in Scenario 2, but will still have a lot of sand coming into system, and not much flow coming out from river. There will be enough sand in the system that cross-sectional area of the mouth won't be changed by sea level rise – sand will keep it adjusting so it is dependent on flow volumes and speeds.	• Scenario 2 assumes that the Murray Mouth will be kept open.

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
3	**Salinity** Lakes Alexandrina and Albert, EMLR tributaries, Murray Estuary and Coorong	Salinity increases throughout the CLLMM, with thresholds exceeded more frequently. Lake Albert is frequently several times the salinity of Lake Alexandrina, and the South Lagoon salinity several times saltier than seawater, with estuarine conditions observed infrequently in the Coorong. The estuary becomes more marine.	Salinity across the system varies spatially and over time under the influence of freshwater flows from the River Murray. There is a strong north-south salinity gradient in the Coorong.	There is increased salinity in the Lower Lakes. Lake Alexandrina salinity is variable depending on river flows. There is typically a gradient from marine near the mouth to brackish, with Lake Albert more saline. The Murray Estuary becomes a predominantly marine habitat, and estuarine conditions move upstream (to the other side of the barrage). In the South Lagoon, the extremes of hypersalinity seen in Scenario 1 are no longer experienced. Freshwater habitats are lost from the system.	Lake Alexandrina experiences periods of fresh to brackish salinities in years of high rainfall in the MDB. There is a north-south salinity gradient in the Coorong. South Lagoon salinities are mostly within current management targets due to greater ocean exchange (flushing).	• Ramsar site boundary may need to be expanded. • There is uncertainty about the salinity regime, however DEW has modelled this. • There will be fewer salinity extremes experienced, and that narrower salinity range will reduce habitat diversity reflected in the salinity gradient.	
->	Lake Alexandrina						
->	Coorong						

4	**Water and sediment quality ('non-critical' in 2015 ECD)** Nutrients, acid sulfate soils (ASS)	Increased turbidity and concentrations of nutrients and organic matter in the Coorong and Lower Lakes, amplified by associated sediment organic matter accumulation, oxygen depletion and loss of benthic invertebrates. Increased exposure of acid sulfate soils and acidification of the Lower Lakes. Potential for accumulation of salt and nutrients in the Lower Lakes due to inadequate flushing.	Episodes of freshwater flows lead to rapid water quality improvements in Lake Alexandrina and some (slower) recovery in Lake Albert. Strong nutrient and salinity gradients persist in the Coorong, and the Coorong is accumulating salt, nutrients, and organic matter.	Turbidity levels and concentrations of nutrients and organic matter are lower than Scenario 1, and sediment quality is more suitable for benthic invertebrates and vegetation. Increased risk of heavy metal contaminant release from sediments. Lakes will be influenced by seawater, ratchetting up salinity in between flushing events, which will be infrequent and small.	Nutrient and salinity gradients from north to south in the Coorong.	• Water quality is likely to be highly sensitive to residence time in the Lakes. Big events may reset water quality, but medium and small events may cause problems (mobilising metals and nutrients already present, increasing suspension, and not bringing enough alkalinity). This was avoided in the Millennium Drought because there were big flushing events – metals went offshore. Partial refilling is a concern. • Sea level rise and low inflows will result in higher salt inputs and may increase release of heavy metals. • Higher evaporation off the Lakes will require more flushing. • Monosulfidic black ooze (MBO) risk (Scenario 1). • Scenario 2: Islands under water – theoretically more water movement. • May have more wind seiche movement. • Mass dying-off of vegetation when inundated can impact	• Turbidity assumptions warrant checking because submergent aquatic plants and low flows may increase stability and clarity.

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
						water quality (especially if happens quickly and depending on the time of year).	
5	**Wetland flora and fauna – general (all taxa)**	There are significant changes in the abundance of some species and the distribution of many species throughout the CLLMM system, with a general decline in salt-sensitive species. Species with shorter lifespans or resting stages will be less able to persist between flow events.	There is a high abundance and diversity of flora and fauna species in the CLLMM, with their distribution largely determined by salinity, water level and water quality that varies significantly spatially and between and within years.	There are significant changes in the abundance of some species and the distribution of many species throughout the CLLMM system, with a general decline in freshwater species and increase in estuarine and marine species.	There is a high abundance and diversity of flora and fauna species in the CLLMM, with their distribution largely determined by salinity, water level and water quality that varies significantly spatially and between and within years.	• Distributions will depend on the location and variability of the saltwater/freshwater interface, and knowledge of its dynamics may be helpful for management.	
->	Lower Lakes						
->	Coorong						
6	**Threatened ecological communities and species - general (all taxa)**	There are declines in habitat of current threatened species, and increases in the number of threatened species that rely on the CLLMM. Capacity to support declines, but importance increases. 	The system supports a range of threatened communities and species, especially during drought.	There are declines in threatened freshwater species and communities, and increases in the number of regionally and nationally threatened species that rely on the CLLMM. 	The system supports a range of threatened communities and species, especially during drought.		

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
8[3]	**Diversity of plant species and communities in different habitats**	Change in the abundance, distribution and diversity of many plant species, and communities in response to increasing salinity and decreasing water levels. General decline in salt-sensitive communities as salt-tolerant communities become better established. Reduced complexity and productivity.	A high diversity across the system of viable plant species and communities persist throughout the CLLMM, with distributions determined by varying patterns of salinity driven by freshwater inflows.	Many species and communities return to a more stable distribution and abundance due to more stable water levels and reduction in salinity extremes. Freshwater communities are highly restricted spatially and temporally. Salt-tolerant species predominate throughout the system, including Lake Alexandrina. Shoreline vegetation moves upslope with rising sea level.	A high diversity of viable vegetation communities persist throughout the CLLMM, with distributions determined by patterns of salinity variable freshwater inflows.	• Vegetation LAC indicators are measures of water level rather than vegetation condition, so these LACs could be met with sea level rise, failing to reflect the loss of freshwater vegetation.	
->	Lower Lakes	Initially good lower habitat, then terrestrialisation and weeds, large reduction.	Rushes OK, not increasing.	Some of the aquatic species need variability in water level.		• Scenario 2: Likely colonisation of agricultural land that currently lacks appropriate seedbanks, sediment • Weed management likely to be an issue.	
->	Freshwater habitat			Loss of freshwater habitats.			

[3] Note that the original row 7 and row 12 (vegetation and fish) have been expanded into more detail in the rows below them. Consequently, row numbering skips from 6 to 8 and then again from 11 to 13.

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
->	Coorong			Increased diversity as peak salinity decreases (can be positive or negative). Perennial seagrass creates a different system.			• Assumes management of nutrients.
9	**Specific plant species**	The distribution and abundance of individual species changes extensively. Freshwater species are less abundant, while halophytes are more abundant. *R. tuberosa* presence in the South Lagoon depends partially on reseeding efforts after droughts.	Most current plant species persist, including *R. tuberosa.*	Significant reduction in the abundance, and contractions in the distribution of salt-sensitive plant species, especially in Lake Alexandrina.	Most salt-sensitive species and all salt-tolerant species persist, including healthy populations of *R. tuberosa (where salinity high enough).*		
	Structural species Melaleuca Lignum			Inundation. Stable water level is bad for them, no regeneration.			
->	Freshwater (Lakes)						
->	Salt-tolerant (Coorong)						

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
10	**Threatened ecological plant communities (specific)** Swamps of the Fleurieu Peninsula Metallic sun orchid, Sandhill greenhood orchid, Silver daisy bush	Significant reduction in the abundance and distribution of species characteristic of the Swamps of the Fleurieu Peninsula.	Most species characteristic of these swamps persist locally, in reduced abundance.	The Swamps of the Fleurieu Peninsula are no longer present in their current form.	Species characteristic of these swamps persist either locally or elsewhere. Orchids persist.		
11	**Threatened ecological plant communities (specific)** Subtropical and temperate coastal saltmarsh	Minimal change to the distribution of subtropical and temperate coast saltmarshes.	This community persists at multiple locations Murray Estuary and Coorong.	There are changes in the distribution of subtropical and temperate coast saltmarshes due to inundation of existing habitat and creation of new habitat. Loss in diversity will depend on the rate of change.	Healthy subtropical and temperate coastal saltmarsh communities are found in many locations throughout the CLLMM system.		• Values-mapping is based on *mobile biotic community* persisting, not the currently mapped extent (which will change).

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
13[4]	**Diversity and abundance of fish communities in different habitats**	The distribution and abundance of individual species changes extensively. Freshwater species are less abundant, while salt-tolerant species are more abundant. Reduced connectivity reduces local diversity.	A high diversity of viable fish communities persist, with distribution and abundance of many determined by variable freshwater inflows.	Fish communities fluctuate significantly in abundance and diversity with variation in salinity.	A high diversity and abundance of fish communities persist, with distributions of many determined by variable freshwater inflows. There will be changes in composition and function.		
14	**Specific fish species**	The distribution and abundance of individual species changes extensively. Freshwater species are less abundant, while saltwater species are more abundant.	There is a high diversity of fish in the system with distributions variable depending on river flows. Most current species persist.	The distribution and abundance of individual species changes extensively. Salt-sensitive species are significantly less abundant, and salt-tolerant, estuarine and marine species are more abundant.	There is a very high diversity and abundance of fish in the system with distributions variable depending on river flows. Most current species persist.		
->	Pest species			Increase in sharks, fur seals, tubeworms and stingrays, which may be regarded as pests by some people.			
->	Freshwater					• Accumulation of acid metals from ASS, and accumulation of salt, if flushing is not there.	

[4] Note that the original row 7 and row 12 (vegetation and fish) have been expanded into more detail in the rows below them. Consequently, row numbering skips from 6 to 8 and then again from 11 to 13.

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
->	Estuarine and Marine						
->	Movement and recruitment (congoli, galaxids)					• Breeding LAC affected by loss of habitat, movement LAC OK • Less cues for migration.	
15	**Threatened fish species**	Murray hardyhead are reduced in abundance due to a decline in habitat. Southern pygmy perch becomes extirpated.	The Murray hardyhead persists in the Lower Lakes.	Murray hardyhead abundance and distribution is variable depending on freshwater in flows.	The Murray hardyhead persists in the Lower Lakes.		
->	Murray hardyhead					• They need fringing habitat, submergent vegetation • More likely to exist in northern Lakes, where there is more freshwater.	
->	Southern pygmy perch						
16	**Waterbirds** Diversity, Abundance, Foraging, refuge and roosting habitat, Breeding,	There are declines in abundance and diversity, and changes in distribution of waterbirds in the CLLMM.	There is a very high diversity and abundance of waterbirds using the CLLMM.	There are significant changes in the abundance and diversity of waterbirds in the CLLMM, and where different species are located within the site.	There is a very high diversity and abundance of waterbirds using the CLLMM.	• Depends on habitat, specially mudflats, (their use in Lakes and their creation in Coorong in Scenario 2).	• Questions of how dry the system becomes in Scenario 1, before sea level rise dominates in Scenario s (and what it means for mudflat habitat in particular).

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
->	Lower Lakes -diversity						• Values-mapping assumes requirements for vegetation availability are met.
->	waders						• Assumes availability of suitable mud flat habitats, and that lower salinity extremes are good for invertebrates.
->	colonial nesting (freshwater)						
->	**Coorong - diversity**						
18	**Threatened birds** **Domestic spp** - Australasian bittern, Australian fairy tern, Hooded plover, Mount Lofty Ranges southern emu-wren.	Some threatened species are affected by habitat changes in the CLLMM and elsewhere. The Fairy Tern and Emu-Wren are lost and there is a decline in Bittern populations.	The site provides important habitat for a wide range of threatened bird species.	There are significant changes to the habitat of some threatened species.	The site provides important habitat for a wide range of threatened bird species.		

#	Valued feature (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
->	Migratory species - Curlew sandpiper, eastern curlew, black-tailed godwit, common greenshank, Pacific golden plover, red-necked stint, sanderling, sharp-tailed sandpiper					• Curlew sandpiper is likely to be lost, but this because of issues in the flyway, not a local climate change issue.	
19	**Other wetland fauna – Reptiles, frogs and mammals - General**	There is reduced abundance and altered distribution of wetland-dependent reptiles of biodiversity significance (tortoises and yellow-bellied skink) due to the highly restricted habitat and food. Drier conditions see reduced abundance and altered distribution of frog species. Some frogs and turtles lost including the freshwater tortoise.	Reptiles, frogs and mammals persist.	There is reduced abundance and altered distribution of wetland-dependent reptiles of biodiversity significance (tortoises and yellow-bellied skink) due to the highly restricted habitat and food. Drier conditions and reduction in freshwater habitat see reduced abundance and altered distribution of frog species. Some frogs and turtles lost including the freshwater tortoise, and there are fewer tiger snakes.	Reptiles, frogs and mammals persist.		
20	**Threatened species – OTHER** Southern bell frog	Decline in southern bell frog abundance and distribution.	Southern bell frog persists.	Decline in southern bell frog abundance and distribution.	Southern bell frog persists.		

#	Valued feature (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
21	**Wetland habitat** • Diversity • Estuary of the Murray-Darling Basin	General decline in condition of many wetland habitats. Lose some of the 23 different types. Some new ones (extent of fringing).	There is a range of different wetland types that provide habitat for a diversity of species, species lifecycles and during drought.	Changes in the distribution of wetland habitat and significant decline in the distribution of freshwater wetland habitat. Lose temporary habitats, gain more estuarine permanent habitat. Diversity decline.	There is a wide range of different wetland types that provide habitat for a diversity of species, species lifecycles and during drought.		
22	**Invertebrates** • Macrobenthic invertebrates • Zooplankton	Reduced diversity and abundance of freshwater taxa. Estuarine taxa spread to the Lakes. Benthic invertebrates are lost from the Coorong due to exposed mudflats, high salinities, and high organic loads. Brine shrimp populations increase in the South Lagoon. Significant decline in South Lagoon. Potential for tubeworm reefs and increase in biodiversity and biological processes around reefs. - yabbies, - freshwater mussels, - tube worms (in the Lower Lakes; infrastructure, boating access; tortoises).	There are periodic influxes of freshwater invertebrates with high flow events. Invertebrates are grazers, predators and prey in CLLMM foodwebs. Macroinvertebrates' abundance, diversity and biomass decreases from north to south in the Coorong.	Marine invertebrates dominate throughout the Coorong, and abundance and diversity in the South Lagoon is higher than in Scenario 1. Also increase in biodiversity around reefs. - yabbies, - freshwater mussels, - tube worms (in the Lower Lakes; infrastructure, boating access; tortoises).	There is a high diversity and abundance of invertebrates. There are influxes of freshwater invertebrates with high flow events. Invertebrates are grazers, predators and prey in CLLMM foodwebs. Macroinvertebrates' abundance, diversity and biomass decreases from north to south in the Coorong.	• Because there are no direct LACs, salinity was used here instead. • Invertebrates are mainly important as food resources for other groups.	

#	Valued feature (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
23	**Coorong food web**	Hypersalinity, nutrient enriched conditions, and associated algal domination reduce the quality and availability of food sources and habitat, especially in the South Lagoon foodweb.	Distinct foodwebs exist along the Coorong salinity gradient, based on the presence or absence of keystone species.	Coorong fish and waterbird populations are supported by more diverse and abundant food sources than in Scenario 1, including aquatic plant (Ruppia) communities and invertebrates.	Distinct foodwebs exist along the Coorong salinity gradient, based on the presence or absence of keystone species. There are diverse foodweb functions and ecosystem services, including stabilisation of habitats and carbon fixation.		
->	*Lake Albert [although Lake Albert is not part of the Coorong, when discussing impacts on the Coorong food web participants warned than in Scenario 2 Lake Albert could be more like the South Lagoon is now in its risk of accumulating salt and nutrients]*						
->	• *Ruppia tuberosa* – primary producer						
->	• Benthic macroinvertebrates – primary consumers,					• There is uncertainty about the mudflats.	
->	• Small-mouthed hardyhead – secondary consumer						

#	Valued feature (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
24	**Geomorphic setting (non-critical)**	There is an increase erosion risk due to loss of vegetation in some locations, especially at lake edges.	Key geomorphic features and processes (including the inverse estuary, Lagoons, and Lakes) persist. The Murray Mouth is kept open by dredging. 	There are altered shorelines and channel morphology, inundation of smaller islands and formation of new bigger islands. Increased salinity and water level lead to a more erosion-prone lake margin. 	Key geomorphic features and processes (including the inverse estuary, Lagoons and Lakes) persist. The Murray Mouth is kept open by dredging.	• There are property lease considerations. • There is a risk of slowly filling up Lakes. • A shifting mouth would lead to decisions about where dredging should be conducted.	
25	**Healthy Ngarrindjeri Ruwe/Ruwar ('non-critical' in 2015 ECD)**	*[Not our place to speculate beyond generic spiritual/inspirational suggestions in Row 26]*	*[Not our place to speculate beyond generic spiritual/inspirational suggestions in Row 26]*	*[Not our place to speculate beyond generic spiritual/inspirational suggestions in Row 26]*	*[Not our place to speculate beyond generic spiritual/inspirational suggestions in Row 26]*	•	
->	**First Nations of the South East**	*[Not our place to speculate beyond generic spiritual/inspirational suggestions in Row 26]*	*[Not our place to speculate beyond generic spiritual/inspirational suggestions in Row 26]*	*[Not our place to speculate beyond generic spiritual/inspirational suggestions in Row 26]*	*[Not our place to speculate beyond generic spiritual/inspirational suggestions in Row 26]*	•	
26	**Spiritual and inspirational ('non-critical' in 2015 ECD)**	Ocean connectivity, iconic species, and ecological character change, and this changed environment affects personal connections and experiences (experienced as a loss for those with historical connections to the system). 	Memories, stories, and iconic species persist, as well as the wonder and awe of nature-based experiences. People will be able to find new, meaningful connections with nature.	Ocean connectivity, iconic species and ecological character change, and land is lost to inundation. The changed environment affects existing and create new personal connections and experiences (experienced as a loss for those with historical connections to the system). 	Memories, stories, and iconic species persist, as well as the wonder and awe of nature-based experiences. People will be able to find new, meaningful connections with nature.		

#	Valued feature (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
27	**Science and education ('non-critical' in 2015 ECD)** • Unique lake / estuarine system	A loss of features leads to a reduced potential for providing familiar educational insights about the system.	The system remains valuable for scientific and educational purposes, with fresh opportunities for citizen science in observing and recording change.	A loss of features leads to a reduced potential for providing familiar educational insights about the system. New opportunities to learn about novel wetland dynamics.	The system remains valuable for scientific and educational purposes, with fresh opportunities for citizen science in observing and recording wetlands responses to change.		
28	**Aesthetic amenity ('non-critical' in 2015 ECD)** • Unique waterscapes, • Cultural interpretations	The aesthetic value of the region declines with declining ecosystem health.	Diverse, extensive, natural land and waterscapes, seasonal patterns, and other natural phenomena.	Changing aesthetic experiences as marine influence on the system grows.	Diverse, extensive, healthy natural land and waterscapes, seasonal patterns, and other natural phenomena.	• The aesthetics of the Lakes in Scenario 2 will be shaped by quality and nature of the emergent vegetation. • People's perceptions of aesthetics are very personal and diverse, depending on what they value and engage with – there's a role for management to understand what is valued to inform management.	

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange		Management notes	Assumptions (management, scenario, etc.)
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)		
29	**Recreation and tourism ('non-critical' in 2015 ECD)** • Physical and water activity, and nature experience • Caring for Country • Western, Ngarrindjeri and First Nations of the South East	Some reduction in recreation opportunities, camping sites, fishing locations, and opportunities to learn from Ngarrindjeri and First Nations of the South East teaching. Change in the species of fish available to recreational fishers. Game reserves will change (locations, species, and seasonality).	Opportunities for nature-based recreation and cultural tourism (e.g. boating, fishing, camping, water sports, bird watching, photography, Ngarrindjeri and First Nations of the South East teaching).	Camping sites and fishing locations change (old sites lost, new sites formed) and the species of fish available to recreational fishers changes. Increased ocean connectivity offers new recreational opportunities. Game reserves will change (locations, species, and seasonality).	Opportunities for nature-based recreation and cultural tourism (e.g. boating, fishing, camping, water sports, bird watching, photography, Ngarrindjeri and First Nations of the South East teaching).	• Narratives are an important management consideration. A public narrative of 'decline' (e.g. during the Millennium, Drought) can affect tourist visitation and experience. • New activities may emerge that will require management (e.g. 4WDs on the lake bed!), and there may be different patterns of use (e.g. more boats in the South Lagoon due to higher water levels, and potential safety issues if boats try to move between Coorong and Lakes as connectivity increases). • The CIIP consultation process has found that the community is excited by new physical structures.	• Tourism values can change a lot and very quickly. These ratings are based on the past. Shouldn't assume that tourism is going to be a constant – it moves at a faster speed than environmental change.

Table 6. Change-persistence table for the Ramsar listing criteria. This table presents a summary of whether the Ramsar criteria used to list the CLLMM might still be met by the attributes of the CPS that persist. Icons in the middle represent criteria still met, but in a different way.

#	Listing Criterion	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange		Comments
		Change (attributes of the criterion anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the criterion anticipated to change)	**Persist** (attributes anticipated to persist)	
1	Criterion 1: A wetland should be considered internationally important if it contains a representative, rare or uniqueexample of a natural or near-natural wetland type found within the appropriate biogeographic region.					Some but fewer different wetland types left.
2	Criterion 2: A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.					The species nominated to meet this criterion are likely to be different to current.
	Criterion 3: A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.					The site is very likely to remain critical for supporting populations of species that contribute to the regional biological diversity, even if there is an overall change in regional and site species composition.
	Criterion 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.					The site will continue to provide critical breeding, migration and drought habitat, even if there are changes in the abundance and composition of the species supported.

#	Listing Criterion	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange		Comments
		Change (attributes of the criterion anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the criterion anticipated to change)	**Persist** (attributes anticipated to persist)	
	Criterion 5: A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.					Anticipated to easily continue to regularly support more than
	Criterion 6: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.					Anticipated to readily support greater than 1% of several water bird species. There may be changes in some of the specific species supported and local and global changes in total abundance.
	Criterion 7: A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity.					Declines and possible loss of some freshwater-dependent taxa are likely, but the site is expected to continue to support significant proportions of other taxa, including being critical for diadromous species.
	Criterion 8: A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.					Likely to be declines in some freshwarter-dependent taxa, but overall continued support fish breeding and migration for local and Basin fish.

Table 7. Draft change-persistence table, full detail for each selected feature. This draft table was provided to participants as part of the background material prior to workshops. It has not been revised in light of workshop findings; if there are any inconsistencies between the tables, Table 5 should be regarded as the output of the deliberations of the workshop and the source for subsequent steps in the analysis. This table can be used as a reference in case readers need extra detail to augment the summary text in Table 5, and to help them imagine and contemplate possible ecological responses to the scenarios.

#	**Valued feature** (e.g. component, process, service)	**Scenario 1 – reduced freshwater inputs**		**Scenario 2 – sea level rise, high ocean exchange**	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
1	**Hydrology – Lower Lakes** Inflows, Rainfall and evaporation, Lake levels, Barrage flows, Tidal signal	A decline in the long-term average runoff in the Murray-Darling Basin (MDB) has resulted in more frequent, longer and more severe periods of very low flows (droughts). Flows from the Eastern Mount Lofty Ranges tributaries are low or non-existent. Lake water levels fluctuate and are sometimes as low as during the Millennium Drought. Barrage flows often fail to meet current annual flow targets. Lake Albert is often poorly connected with Lake Alexandrina.	The Lower Lakes are a large permanent waterbody. Even in dry times the River Murray continues to be the dominant source of water in the Lower Lakes. Interannual variability in river flows is very high with sequences of many dry and wet years. During prolonged high rainfall events in the MDB there are large quantities of freshwater flowing into Lake Alexandrina. The lake level continues to be variable.	A decision has been made to allow seawater to enter the Lakes, in a managed way, in response to low lake levels and increased frequency of barrage over-topping / island flooding with sea level rise. Increased connection with the ocean causes significant tidal flows of seawater through the estuary channels into the Lakes. Large parts of the barrier islands are frequently inundated. The tidal influence in Lake Alexandrina is strongest closer to the barrages. The Lake level is higher than current managed levels and is relatively stable, with moderate tidal variation. Lake water levels are maintained by sea level, rather than freshwater inputs. During prolonged high rainfall events in the MDB there is sustained freshwater input and the water level in Lake Alexandrina can rise to flood levels. Lake Albert is connected all the time. [This scenario is described as occurring with sea level rise around 0.8 m, but opening Lake Alexandrina to the ocean could occur with a sea level rise of 0.5m or	The Lower Lakes are a large permanent waterbody. The River Murray continues to be the dominant source of freshwater in the Lower Lakes. The interannual variability in river flows is very high with sequences of many dry and wet years. During prolonged high rainfall events in the MDB there are large quantities of freshwater flowing into Lake Alexandrina.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
				less, with some similar and some different consequences.]	
2	**Hydrology – Coorong, Murray Mouth** Inflows, Rainfall and evaporation, Lake levels, Barrage flows, Tidal signal	Periods of very low flows (droughts) from the MDB are more frequent and of longer duration. There are long periods where current barrage flow targets are not met and there are minimal freshwater inputs to the Coorong from the Lakes. The maximum number of days without flow over the barrages has increased and the return interval for these periods has decreased. During prolonged high rainfall events in the MDB there are large quantities of freshwater flowing into the Murray Estuary and Coorong. There is very little flow and exchange of water along the Coorong. The South Lagoon is poorly connected from the North Lagoon for up to several months each year, leading to higher peak salinities in summer in the South Lagoon.	The Coorong is an extensive permanent wetland system. It is periodically recharged with freshwater from the Lower Lakes (predominantly) and flows from the south east. Water levels vary seasonally and between years. Periodic high rainfall / high flow events provide freshwater inputs to the North Lagoon. The Murray Mouth is open permanently (due to continued dredging).	Water level in the Lower Lakes is set by sea level, with variation due to wind and high river flow events. There is some tidal influence in Lake Alexandrina, near the estuary, and gradual mixing of lake and ocean water. Periodic high-flow flush the marine water from the Lakes. A gradual increase in sea levels has significantly increased water levels in the Murray Estuary and Coorong. There is permanent connection between the South and North Lagoons. The amount of time the South Lagoon fails to meet water level targets is reduced. Higher water levels allow increased tidal flow and variation in level in the northern Coorong due to increased sea level and higher flows in and out of the Lakes. There is greater mixing along the Coorong and between the Lagoons (due to annual sea level fluctuation and wind-driven processes). There is less seasonal variation than currently, and interannual variation in rainfall has less impact on water level. As sea level rises there is significant inundation of mudflats in the estuary, partial inundation of some of the Coorong islands, the shoreline flats around Parnka Point and south of Saltwater Creek, and of some fringing wetlands. Some new islands	The Murray Mouth is open permanently (due to continued dredging). The Coorong is an extensive permanent wetland system. It is periodically recharged with freshwater from the Lower Lakes (predominantly) and flows from the south east. Water levels vary on many different time scales due to annual and seasonal cycles, wind-driven seiches and tidal flows.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
				are formed, and some of the ephemeral wetlands to the south of the Coorong become permanently filled (by rising groundwater).	
3	**Salinity** Lakes Alexandrina and Albert, EMLR tributaries, Murray Estuary and Coorong	Reduced freshwater inputs and increased evapotranspiration lead to increases in salinity throughout the CLLMM and thresholds frequently being exceeded. Salinity of the water flows from the EMLR tributaries also increases during local droughts. The area of estuarine habitat in the Murray Estuary and Coorong reduces, and the area of marine habitat increases and occurs more frequently. Salinity thresholds will occasionally be exceeded at some sites in the Murray Estuary, and salinity thresholds for the South Lagoon are exceeded most of the time. Salinities at the southern end of the Coorong regularly reach greater than four times that of sea water.	Salinity across the system varies spatially and over time under the influence of freshwater flows from the River Murray. Salinities in Lake Alexandrina, Murray Estuary and North Lagoon reduce quickly after periods of high flow. Salinities in Lake Albert and the South Lagoon take longer to decline as they have slower water exchange rates compare with other parts of the system. There is a strong north-south salinity gradient in the Coorong creating a diversity of habitats.	Salinity in Lake Alexandrina has increased due to reduced freshwater inputs, increased evapotranspiration and inputs from the ocean. There is a variable salinity gradient from the estuary to the River. Salinity increases gradually, then periodically drops with flushing from high river flows (at least annually except during drought). Salinity in Lake Alexandrina is well below sea salinity. Lake Albert is more saline than Lake Alexandrina, but does not become hypersaline. Rising sea level enables greater exchange of water along the Coorong and transport of salt and nutrients out of the South Lagoon where they concentrate with evaporation. Once sea level exceeds 0.24m AHD there are fewer extremes in salinity in the South Lagoon and the amount of time salinity thresholds are exceeded is reduced (relative to Scenario 1). Murray Estuary area becomes predominately marine habitat.	Salinity across the system varies spatially and over time under the influence of freshwater flows from the River Murray. Years with high rainfall in the MDB result in significant freshwater flows and significant decreases in salinity in Lake Alexandrina (fresh to brackish). There is a north-south salinity gradient in the Coorong creating a diversity of habitats. South Lagoon salinities are mostly within current management targets due to greater ocean exchange.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
4	**Water and sediment quality** Nutrients, acid sulfate soils (ASS)	Reduced inflows result in reduced flushing and so increased concentrations of nutrients, organic matter, and turbidity in the Lower Lakes. These increases are associated with lack of outflow concentrating material within the Lakes and increased wind-driven resuspension of sediment from the lakebed due to lower water levels. Acid sulfate soils at the margins of the Lower Lakes are exposed and oxidised, and subsequently cause severe, but localised, extreme water quality effects when they become wet. In the Coorong, reduced inflows and increased evaporation result in nutrient and organic matter concentrations increasing During extreme hypersaline conditions, TN and TP concentrations temporarily stabilise or decline, as do chlorophyll *a*.. Extensive areas of acid sulfate soils are exposed in the Lower Lakes as a result of unprecedented low water levels. This has results in soil acidification (pH<4) over large areas. Acidification of surface waters also occurs in some localised areas where acidity is been transported from the soil	When flows return, water quality in Lake Alexandrina recovers relatively quickly (in months), being flushed via the large River Murray inflows inputs and barrage outputs. Lake Albert requires flushing for > 6 years to return to normal levels. Nutrient and organic matter concentrations show a strong increasing gradient from north to south in the Coorong. The South Lagoon is a net sink of salt, nutrients and organic matter. Nutrient dynamics remain a critical determinant of ecological outcomes.	Increased nutrient input only occurs from high intensity river flows. There is lower turbidity due to high salinities. The elevated nutrient levels that occurred during Scenario 1 are stable or decreasing in the Coorong due to increased seawater exchange. Seawater inundation during dry periods in Lake Alexandrina increases contaminant (acid, metal, metalloid and nutrient) release compared to freshwater during the transition period. There is dilution and gradual transport of heavy metals out of Lake Alexandrina due to tidal influence, which is slower further from the estuary.	Nutrient dynamics remain a critical determinant of ecological outcomes. TN, TP and chlorophyll a show an increasing concentration gradient from north to south in the Coorong.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
		profile. The risk of broad-scale acidification of the lake increases each time water levels are lower than or with prolonged time near -1.5m and -0.5m ± 0.25m AHD for Lake Alexandrina and Albert respectively. When lake acidification occurs, recovery of water quality takes months to years.			
5	**Wetland flora and fauna – general (all taxa)**	There are significant changes in the abundance of some species and the distribution of many species throughout the CLLMM system due to increases in salinity and nutrients and decreases in water levels. Some parts of the system experiencing hypersalinity and eutrophication have significantly reduced diversity and abundance. There is a general declining freshwater species and increase in salt-tolerant species. There is decreased biological connectively in the system.	There is a high abundance and diversity of flora and fauna species in the CLLMM, with their distribution largely determined by salinity that varies significantly spatially and between and within years.	There are significant changes in the abundance of some species and the distribution of many species throughout the CLLMM system due to increases in salinity and nutrients and decreases in water levels. There is a general decline in freshwater species and increase in salt-tolerant, estuarine and marine species. Relative to Scenario 1, fewer locations have abundance and diversity restricted by hypersalinity and eutrophication. There is increased biological connectivity in the system.	There is a high abundance and diversity of flora and fauna species in the CLLMM, with their distribution largely determined by salinity that varies significantly spatially and between and within years.
6	**Threatened ecological communities and species -**	Habitat for many threatened communities and species declines. Reduction in freshwater habitats also drive declines in the abundance of other species,	The system provides critical but variable habitat for a range of threatened communities and species, especially during drought,	Habitat for threatened freshwater communities and species declines, and are very localised, becoming more abundant after high flow events. There is an	The system provides reliable critical habitat for a range of threatened communities and species, especially during drought,

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
	general (all taxa)	leading to an increase in the number of threatened species in the CLLMM. Drying of terrestrial and wetland habitats in the surrounding region and continentally, increases the number of species identified as threatened that are resident in or rely on the CLLMM.	when wetlands elsewhere are affected.	increase in the number of threatened freshwater species. Improvements in water quality and habitat in Lake Albert and the South Lagoon, compared to Scenario 1, increase the diversity of habitat available for salt-tolerant threatened species. Continued drying of terrestrial and wetland habitats in the surrounding region and continentally, increases the number of species identified as threatened that are resident in the CLLMM.	when wetlands elsewhere are affected.
8	**Diversity of plant species and communities in different habitats**	The distributions and relative abundance of plant communities are very dynamic in response to variable salinity and water level. Many communities have moved location within the system in response to increasing salinity and decreasing water level, including intertidal through to shallow-water communities moving downslope. There has been a general decline in abundance and health of freshwater communities, and an increase in the extent of salt-tolerant communities. There are periodic increases in freshwater communities following high flow events.	There is a high diversity of viable plant communities present throughout the system. plant communities are variable in space and time as a function of freshwater inflows affecting water levels and salinity.	Plant communities have gradually returned to a more stable distribution and abundance, due to more stable water levels and reduction in salinity extremes, and they tend to be more healthy and diverse than in Scenario 1. Shoreline plant communities have moved upslope to and beyond their original locations with rising water levels. Saltwater communities predominate throughout the system. Freshwater communities are present in the Lower Lakes and Mount Lofty tributaries, in proximity to freshwater sources. Salt-sensitive species that do persist flourish during periodically high river sloe events.	There is a high diversity of healthy and diverse plant communities present throughout the system. Plant communities are variable in space and time as a function of freshwater inflows affecting water levels and salinity.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
9	**Specific plant species**	There has been extensive change in the distribution and abundance of individual species, with a decline in abundance of freshwater species and increase in abundance of salt-tolerant species. The presence of *R. tuberosa* varies spatially within the Coorong and Lake Albert, with significant fluctuations in abundance in the North and South Lagoons. Its presence in the South Lagoon is dependent on reseeding (naturally or assisted) after periods of extended drought.	Most species have persisted, occurring where conditions are favourable in the system. *R. tuberosa* is permanently present in the Coorong.	Significant reduction in the abundance and contraction of the distribution of salt-sensitive species, especially in Lake Alexandrina. Expansion of salt-tolerant species in Lake Alexandrina. Persisting salt-sensitive species flourish during periodic times of high freshwater inflows.	Most salt-sensitive species and all salt-tolerant species persist at some location it the system. Healthy populations of *R. tuberosa* are present in the system.
10	**Threatened ecological plant communities (specific communities)** Swamps of the Fleurieu Peninsula Metallic sun orchid (Thelymitra epipactoides), Sandhill greenhood orchid (Pterostylis arenicola), Silver daisy bush (Olearia pannosa ssp. Pannosa)	As local rainfall decreases the rain-filled wetlands of the Fleurieu Peninsula decline and take on a more terrestrial form for longer periods in their life cycle, filling less frequently. Significant reduction in the abundance and distribution of species characteristic of the Swamps of the Fleurieu Peninsula.	Most species characteristic of these swamps persist locally, in reduced abundance. Species characteristic of these swamps are also typically found in a range of other habitats and locations. Two plants and one bird listed as threatened are very rare, but none are restricted to the SFP.	The Swamps of the Fleurieu Peninsula are no longer present in their current form, becoming colonised by a range of terrestrial species due to reduced freshwater flow.	Many of the species characteristic of these swamps persist in reduced abundance locally. Species characteristic of these swamps are also typically found in a range of other habitats and locations. Two plants and one bird listed as threatened are very rare, but none are restricted to the SFP.
11	**Threatened ecological plant communities**	Minimal change to the distribution of subtropical and temperate coast saltmarshes.	Subtropical and temperate coastal saltmarsh threatened community persists at	Much of the existing subtropical and temperate coastal saltmarsh communities in the Murray Estuary and the Coorong is	Healthy Subtropical and temperate coastal saltmarsh communities are

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
	(specific communities) Subtropical and temperate coastal saltmarsh		multiple locations Murray Estuary and Coorong.	inundated by rising sea level. At the same time new habitat is created where suitable substates occur. These are both up slope of existing marshes and in new locations, including the Lower Lakes.	found in many locations throughout the CLLMM system.
13	**Diversity of fish communities in different habitats**	The distributions and relative abundance of fish communities are very dynamic in response to variable salinity and water level. Many communities have moved location within the system in response to increasing salinity, decreasing water level, and changing aquatic vegetation communities. There has been a general decline in abundance and diversity of freshwater fish communities, and an increase in the extent of salt-tolerant communities. There are periodic increases in freshwater communities following high flow events. There is a general decline in local abundance due to reduced connectivity. There is a decline in abundance and diversity in the Lower Lakes. Fish diversity and abundances in the Murray Estuary are substantially reduced during low freshwater discharge and enhanced	There is a high diversity of viable fish communities present throughout the system. Fish communities are variable in space and time as a function of freshwater inflows affecting water levels, connectivity salinity and habitat.	Fish communities have gradually returned to a more stable distribution and abundance, and tend to be higher abundance and diversity than in Scenario 1. There is a significant reduction in abundance of freshwater communities, they most abundant in areas proximal to freshwater sources and after periods of high flow. Generalist, salt-tolerant and marine communities predominate. Increased connectivity leads to significant increases in local diversity and in abundance of diadromous fish. There is a high abundance and diversity of fish in the Coorong, strongly dominated by marine taxa and others that tolerate high salinity. After periods of high flows there are temporary increases in the abundance and distribution of freshwater species. Less extreme hypersalinity in South Lagoon sees significant increases in fish diversity and abundance.	There is a high diversity of viable fish communities present throughout the system. Fish communities are variable in space and time as a function of freshwater inflows affecting water levels, salinity and habitat.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
		during periods of high discharge. During low discharge marine stragglers are prevalent with less freshwater species. During periods of low or no discharge from the Lakes, fish community composition in the Coorong is low and dominated by those preferring marine salinities, or able to tolerate higher salinities. Diversity is lowest in the South Lagoon as conditions are hypersaline, with the assemblage dominated by highly salt-tolerant species.			
14	**Specific fish species**	There has been extensive change in the distribution and abundance of fish species, with a decline in abundance of freshwater species and increase in abundance of salt-tolerant species. Reduced flows lead to desiccation of fringing littoral and off-channel habitats critical to small-bodied fish species (i.e. Murray hardyhead and southern pygmy perch). As salinity increases there is a corresponding decline in the abundance of threatened small-bodied freshwater fish and congolli and an increasing dominance of generalist freshwater (e.g. Australian smelt)	. Populations of most current species have persisted, occurring where conditions are favourable in the system.	There is extensive change in the distribution and abundance of individual species. There is a significant reduction in the abundance and distribution of salt-sensitive species (Murray cod, golden perch and southern pygmy perch) with some being eliminated (including European carp). Those that persist expand in abundance and distribution in response to periods of high river flows Less extreme hypersalinity in South Lagoon sees significant increases in fish diversity and abundance. Diadromous and other migratory species increase in abundance, but congolli and	There is a very high diversity and abundance of fish in the system with distributions variable depending on river flows, salinity, water levels, and habitat.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
		and estuarine species (e.g. lagoon goby) in the Lakes. The southern pygmy perch is extirpated. During times of higher river flows and lake levels estuarine species become less abundant, while generalist freshwater species, including non-native fishes (e.g. common carp) and catadromous species (e.g. congolli), dominate the assemblage. Lack of connectivity between the Lower Lakes and Murray Estuary the has led to a notable decline in abundance diadromous species (congolli, lamprey and galaxias). Purple spotted gudgeon and Southern pygmy perch populations have declined significantly.		common galaxias are restricted in most years by availability of preferred habitat.	
15	**Threatened fish species** Murray hardyhead (*Craterocephalus fluviatilis*) Southern pygmy perch (*Nannoperca australis*)	Murray hardyhead are reduced in abundance due to a decline in habitat. Southern pygmy perch are lost from the system. Some species depended on connectivity and migration become threatened in the system.	The Murray hardyhead does persists in the Lower Lakes.	Murray hardyhead abundance and distribution is variable depending on freshwater in flows. Some other freshwater species become locally extinct or restricted in abundance.	The Murray hardyhead persists in the Lower Lakes.
16	**Waterbirds** Diversity, Abundance,	There are declines in abundance and diversity, and changes in	There is a very high diversity and abundance of waterbirds using the CLLMM.	There are significant changes in the abundance and diversity of waterbirds in	A diverse and abundant assemblage of water birds use the CLLMM site. The numbers vary

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
	Foraging, refuge and roosting habitat, Breeding,	distribution of waterbirds in the CLLMM. A general decline in international migratory bird species has led to a decrease in their abundance in the system. Waterbird diversity and abundance has generally declined due to changes to habitat. The abundance of some waterbird species has increased due to a decline in wetland habitat elsewhere in the region and continent. There are more frequent periods of increased habitat for wading birds in the Lakes as a result of water levels dropping below 0.5 m AHD during periods of low river flow. As salinities increase in the South Lagoon, the distributions the smallmouth hardyhead, and the salt-tolerant chironomid (*Tanytarsus barbitarsis*), which are important food resources retract northwards, along with those waterbirds that forage on the retracting food resource. The population of fairy terns declines when fish are absent in the southern Coorong.	The numbers of waterbirds continue to vary spatially and within and between years, with abundances at their highest during summer and in periods of inland drought. The distribution of individual species throughout the site is dependent on the distribution of food resources which is dependent of water levels and salinity throughout the site. Piscivorous species able to forage outside the Coorong (greater crested terns, Caspian terns and Australian pelicans) continue to breed even when the South Lagoon has no fish due to increased salinity. Iconic species such as pelicans continue to breed in abundance at the site.	the CLLMM, and where different species are located within the site. International migratory species continue to decline, but the site is increasingly important for them. Bird diversity and abundance has increased compared with Scenario 1, but different taxa have responded to the conditions and subsequent food resources. Current mudflats are likely to be inundated in the Lower Lakes, Murray Estuary and Coorong resulting in a local reduction in shorebirds. Shorebird abundance and diversity increases where additional mudflats are created in the Lower Lakes, South Lagoon and the ephemeral lakes to the south. Possible reduction in the numbers of larger bodied fish could result in a reduction of key piscivorous species such as Australian pelican, White-bellied sea eagle and Caspian tern. There is likely to be an increase in salt-tolerant small-bodied fish for other piscivorous birds as a food source.	spatially and within and between years, with abundances at their highest during summer and in periods of inland drought. The distribution of individual species throughout the site is dependent on the variable distribution of food resources. Iconic species such as pelicans continue to breed in abundance at the site Waterfowl that can survive on estuarine/marine zooplankton (teal, pink-eared duck and shoveler) are present in large numbers.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
		In exceptionally low flow years when reedbeds become disconnected species such as cormorants do not breed. There is an increase in the frequency of banded stilt taking advantage of an abundance of brine shrimps in the South Lagoon, when salinities exceed 150 g L^{-1}.			
17	**Specific waterbird species** [We may choose to highlight detail for some specific species]				
18	**Threatened birds** Australasian bittern (*Botarus poiciloptilus*), Australian fairy tern (*Sternula nereis*), Curlew sandpiper (*Calidris ferruginea*), Eastern curlew (*Numenius madagascariensis*), Hooded plover (*Thinornis rubricollis*), Mount Lofty Ranges southern emu-wren (*Stipiturus	There has been a decline in the abundance of curlew sandpiper due to impacts along its flyway. Decline in habitat for Mount Lofty Ranges southern emu-wren. The site is increasingly important for current and new threatened species as wetland habitat elsewhere is affected by climate change and development.	Critical seasonal habitat for curlew sandpiper, and other migratory species affected by threats to the flyway. The site continues to provide habitat for a range of threatened species.	Most of the current fairy tern nesting sites in the southern Coorong are inundated, with scope for new sites dependent on suitable habitat for nesting being available, and food resources are more abundant in the South Lagoon. Decline in curlew sandpiper abundance continues. Decline in habitat for the Mount Lofty Ranges southern emu-wren continues.	Fairy terns persist, with abundance depending on the availability of new suitable nesting habitat as sand flats are inundated. Other threatened waterbird species continue to use the site. Increasingly important for these species and other wetland species affected by habitat loss due to drying and human activities across the region, MDBA and Australia. Critical seasonal habitat for curlew sandpiper.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
	malachurus intermedius). Migratory species - Black-tailed godwit (*Limosa lapponica*), common greenshank (*Tringa nebularia*), Pacific golden plover (*Pluvialis fulva*), Red-necked stint (*Calidris ruficollis*), sanderling (*Calidris alba*) and sharp-tailed sandpiper (*Calidris acuminata*).				
19	**Other wetland fauna – Reptiles, frogs and mammals**	There is reduced abundance and altered distribution of wetland-dependent reptiles of biodiversity significance (tortoises and yellow-bellied skink). Drier conditions see reduced abundance and altered distribution of frog species.	Reptiles, frogs and mammals persist.	There is reduced abundance and altered distribution of wetland-dependent reptiles of biodiversity significance (tortoises and yellow-bellied skink). Drier conditions and reduction in freshwater habitat see reduced abundance and altered distribution of frog species.	Reptiles, frogs and mammals persist.
20	**Threatened species – OTHER** [Threatened fish and birds are included above.] Southern bell frog	Salt-sensitive taxa such as Southern bell frog are less frequently present.	Very isolated populations of the Southern bell frog.	Salt-sensitive taxa such as Southern bell frog are less frequently present.	Very isolated populations of the Southern bell frog.
21	**Wetland habitat** **Diversity, *Estuary of the Murray-Darling Basin*	During periods of low flow wetland condition in the Lakes and Coorong declines.	There is a range of different wetland types that provide habitat for a diversity of species, species lifecycles and during drought.	There are significant changes in the distribution of wetland habitats across the CLLMM, including substantial decline in the distribution of freshwater wetland	There is a range of different wetland types that provide habitat for a diversity of species, species lifecycles and during drought.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
	[unsure if this is a separate feature (valued in a different way) or adequately covered by other features]	The spatial distribution and relative sizes of different wetland types change. Some existing wetlands become ephemeral and/or terrestrialised.	Habitat condition improves when River Murray inflows occur.	habitat in the Lower Lakes, and increase in brackish and estuarine habitat. Existing mudflats, saltmarsh and other shoreline habitat has been inundated, with new habitat created elsewhere, depending on local topology. Low-lying freshwater soaks are inundated.	Habitat type and condition are dynamic in response to river flows.
22	**Invertebrates** Macrobenthic invertebrates, Zooplankton	There is loss of freshwater taxa from the Lakes as salinity increases. Estuarine taxa such as the tubeworm (*Ficopomatus enigmaticus*) have spread into Lake Alexandrina as salinity increases Important benthic invertebrates are lost from the Coorong as decreasing water levels expose mudflats. Anoxic sediments caused by high organic loads, combined with hypersaline conditions restricts invertebrates that are key to foodwebs, such as the chironomid. Brine shrimp are present in the water column of the South Lagoon.	Invertebrates are grazers, predators and prey in CLLMM foodwebs, and influence habitat and conditions for other species (e.g. benthic macroinvertebrates improve sediment conditions through bioturbation). Macroinvertebrate abundance and distribution in the Coorong reflects the strong North-South gradient of environmental conditions (particularly salinity). Flushes of some freshwater invertebrates after high flow episodes.	Marine fauna dominate and are present throughout the Coorong, and parts of the Lower Lakes. Invertebrates colonise newly created mudflats and submerged rocky shore habitat South Lagoon macroinvertebrate diversity, abundance and biomass is higher than in Scenario 1.	Invertebrates are grazers, predators and prey in CLLMM foodwebs, and influence habitat and conditions for other species (e.g. benthic macroinvertebrates improve sediment conditions through bioturbation). Macroinvertebrate abundance and distribution in the Coorong reflects the strong North-South gradient of environmental conditions (particularly salinity). Flushes of some freshwater invertebrates after high flow episodes.
23	**Coorong food web** Ruppia tuberosa – primary producer, Benthic macroinvertebrates – primary	Salinities greater than 120 ppt in the Coorong South Lagoon and the southern section of the North Lagoon severely alter the structure of the Coorong food web which is characterised by low species	Small-mouthed hardyhead are present during periods of high flow if salinities reduce sufficiently. Recovery of the *Ruppia/Althenia* community and macroinvertebrate	The foodweb structure across the Lakes strongly reflects the estuarine and marine conditions that are present across the Lakes. Mudflats in the Murray Estuary are inundated. The foodweb structure across	Distinct foodwebs exist along the Coorong salinity gradient, based on the presence or absence of keystone species.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
	consumers, Small-mouthed hardyhead – secondary consumer	diversity, high densities of phytoplankton and ostracods, and the Australian brine shrimp. Reduced flow to the Coorong combined with high evaporation rates, results in water levels in the South Lagoon dropping below a threshold for *R.tuberosa* (+0.3 m AHD) for the whole of spring period prevents seed bank and turion production, reducing the resilience and regeneration of the population in subsequent growing season. Eutrophication in the Coorong promotes seasonal growth of filamentous green algae that results in co-dominance of the seagrass *Ruppia/Althenia* and the algal communities. Persistent hypersalinity in the South Lagoon reinforces the eutrophication process by negatively impacting benthic macroinvertebrates and seagrass communities. Extreme hypersalinity and lower water levels in the Murray Estuary and the Coorong expose mudflat sediments, which become uninhabitable for macroinvertebrates. Distribution ranges of macro- invertebrate	populations take longer the longer the period of reduced flows.	the Coorong strongly reflects the marine conditions that are present.	

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
		species become restricted, their abundances decline, and several species are no longer found if drought conditions persist over several years. Amphipods and chironomid larvae respond quickly to freshwater inflows, and their abundances increase to very high numbers. For most other macroinvertebrate species, a time lag in recovery has been noted.			
24	**Geomorphic setting (non-critical)**	Loss of vegetation leads to erosion in some locations. There is increased sand transport through the Murry Mouth into the estuary. At times there will be loss of sediment, or gaining of sediment leading to changing of shoreline communities.	Spatially and temporally dynamic mixing of fresh and marine waters. While some erosion happens as part of dynamic shoreline processes, establishment of vegetation communities suitable for prevailing salinity and substrate support the accretion of sediment.	Increased marine influence, and the mixing of salt and fresh water is dynamic and in Lake Alexandrina most of the time. Significant parts of the barrier islands are inundated. There is altered shorelines and channel morphology. Significant areas of mudflat in the estuary are permanently inundate and new mud flats are created in the South Lagoon and ephemeral wetlands to the south of the Coorong. Coorong islands are partially inundated but new islands are formed. Inundation leads to formation of submerged rocky platforms on the eastern back on the Coorong.	Spatially and temporally dynamic mixing of fresh and marine waters. While some erosion happens as part of dynamic shoreline processes, establishment of vegetation communities suitable for prevailing salinity and substrate support the accretion of sediment.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
25	**Healthy Ngarrindjeri Ruwe/Ruwar ('non-critical' in 2015 ECD)** The lands, the waters, all living things, the ancestors and Ngarrindjeri are all part of the living body – all have responsibility to each other. This is a reciprocal relationship that reproduces wellbeing for the 'body'. Ngarrindjeri have a cultural responsibility to maintain the health of their lands and waters as a part of their own living body. Exercising this responsibility ensures that they benefit from all aspects of a healthy 'Country' Ruwe/Ruwar therefore can be understood as a system of interconnected benefit through flow, connectedness,	[Not our place to speculate beyond generic spiritual/inspirational suggestions in next row]	[Not our place to speculate beyond generic spiritual/inspirational suggestions in next row]	[Not our place to speculate beyond generic spiritual/inspirational suggestions in next row]	[Not our place to speculate beyond generic spiritual/inspirational suggestions in next row]

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
	responsibility and reciprocity. Ruwe/Ruwar requires connectivity and flow to occur between all living things and the lands and waters and the spirit world. Flows come together and produce life as fish breed in the Lakes and Coorong where the freshwater and saltwater mix; birds breed in the places where life is produced; and the complexity and interrelatedness of the processes concerned are recognised in Ngarrindjeri philosophy. the unique interactions Ngarrindjeri experience with Yarluwar-Ruwe				
26	**Spiritual and inspirational ('non-critical' in 2015 ECD)**	Reduced physical connection between the Murray-Darling Basin, Lower Lakes, Murray Mouth and Coorong is experienced as a loss of, or harm to, spiritual connection.	Memories and stories of spiritual connectivity. Culturally significant or iconic species persist, albeit in different locations and abundance.	Increased connectivity with the ocean creates a more spatially and temporally dynamic 'Meeting of the Waters'. Changes in health, abundance and distribution of culturally significant or iconic species (e.g. loss of freshwater species from Lower Lakes).	'Meeting of the waters' connections, and potential for spiritual connectivity, persists. Culturally significant or iconic species persist, albeit in different locations and abundance.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
		Changes in health, abundance and distribution of culturally significant or iconic species. Reduced capacity to sustain productive, biodiverse foodwebs is experienced as degraded health (of the CLLMM), and disrespect for nature and legacy from ancestors and elders. Change in ecological character changes personal connection (e.g. experiences of loss and grief) and sources of inspiration (e.g. curiosity and wonder at novel outcomes).	Potential for wonder, awe and new meaningful connections and spiritual experiences.	Change in ecological character changes personal connection (e.g. experiences of loss and grief) and sources of inspiration (e.g. curiosity and wonder at novel outcomes).	Potential for wonder, awe and new meaningful connections and spiritual experiences.
27	**Science and education ('non-critical' in 2015 ECD)** *Unique lake / estuarine system* *Ngarrindjeri Yarluwar-Ruwe*	Change in features that are available for science and education activities. Loss of features that have been valuable in past science and education activities. Reduced potential for providing insights about diverse estuarine ecosystems. Increased opportunity to learn about change in wetlands.	National and globally unique ecological site. An increasingly valued site for understanding ecological change. Opportunities for citizen science initiatives.	Change in features that are available for science and education activities. Opportunity to study novel wetlands dynamics. Loss of features that have been valuable in past science and education activities.	National and globally unique ecological site. An increasingly valued site for understanding ecological change. Opportunities for citizen science initiatives.
28	**Aesthetic amenity ('non-critical' in 2015 ECD)**	Decrease in aesthetic value of region (e.g. due to drying and disconnected system, more impoverished ecosystems in some	Diverse natural land and waterscapes, and associated weather events, seasonal patterns, and other natural phenomena.	Changing aesthetic experiences as marine influence on the system grows.	Diverse natural land and waterscapes, and associated weather events, seasonal patterns, and other natural phenomena.

#	Valued feature (e.g. component, process, service)	Scenario 1 – reduced freshwater inputs		Scenario 2 – sea level rise, high ocean exchange	
		Change (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)	**Change** (attributes of the feature anticipated to change)	**Persist** (attributes anticipated to persist)
	Unique waterscapes, *Ngarrindjeri Yarluwar-Ruwe* *Cultural interpretations*	locations, and events such as algal blooms and fish kills). Potential for increase in unpleasant odours due to eutrophication. Potential for more built infrastructure (e.g. dredges, pipes) to manage connectivity, salinity and water levels.			
29	**Recreation and tourism (‘non-critical’ in 2015 ECD)** *Physical and water activity, and nature experience* *Caring for Country* *Western and Ngarrindjeri*	Reduction in some recreational opportunities due to decline in condition, decrease in aesthetic value of region. Some decline in ability of Ngarrindjeri to teach others about their values, culture and traditions. Change in location of some camping and fishing sites. Change in fish species mix available to recreational fishers.	Opportunities for nature-based recreation and cultural tourism (e.g. fishing, camping, water sports, bird watching, photography, Ngarrindjeri teaching).	Change in location of camping and fishing sites. Change in fish species mix available to recreational fishers. Changed opportunities for Ngarrindjeri to teach others about their values, culture and traditions. Potential to sail to the ocean from the Lower Lakes via southern estuary as a tourist activity (if barrages removed). Potential for dolphin spotting/swim with the dolphins in the Lakes.	Opportunities for nature-based recreation and cultural tourism (e.g. fishing, camping, water sports, bird watching, photography, Ngarrindjeri teaching).

Appendix C Analysis questions

The following analysis questions are based on Dunlop and Grigg (2019), and they were answered with participants in the second workshop.

C.1 Patterns in the results

C.1.1 Are there features (CPS) that stand out as particularly subject to change in character or values?

- Most features are vulnerable to change in Scenario 1.
- Freshwater-dependent features are particularly vulnerable to change in Scenario 2.

C.1.2 Are there features that stand out as likely to persist, i.e. retain character or values?

- A diversity of wetland types persists in both scenarios (some may be highly restricted and require careful management).
- Diversity and abundance of fish and waterbirds persist in both scenarios.
- Geomorphic setting also persists across both scenarios.
- The CLLMM continues to be a very large, diverse and dynamic system (high value, more options for ecological responses, hard to manage).

C.1.3 Are there features that may change ecologically but retain their Ramsar values or other conservation values?

- All Ramsar criteria continue to be met, although in a different way (i.e. with a change in ecological character), across both scenarios (see Table 6, Appendix B).

C.1.4 What are the dominant drivers of the changes, and are they similar to or different from the threats that are currently managed?

- <u>Reduced rainfall combined with MDB water extraction:</u> initially very similar to current threats (drought combined with water extraction), but the regime of variation (severity, frequency, and duration) will become more severe over time, eventually requiring different responses (which may have near-term entailments).
- <u>Sea level rise:</u> a very different kind of change to current threats. Scenario 2 will require different thinking and action rather than an extrapolation of current practice. The barrages were built to keep seawater out at a time when river flows were able to fill the Lakes. Currently, over-topping of the barrier islands occurs infrequently and is relatively minor. Sea level rise will gradually lead to frequent over-topping and significant sea water ingress into Lake Alexandrina.

C.1.5 What change processes dominate the impacts?

- Scenario 1: Low water level and water quality in the Lower Lakes. Reduced connectivity between Lakes Alexandrina and Albert, and between the Lakes and Coorong. Accumulation of salt and nutrients in the Coorong, declining water level affecting the dynamics and functioning of macrophytes, both leading to altered food webs.

- Scenario 2: Significant reduction in freshwater habitat and species in the Lower Lakes, potential loss of tidally inundated mudflat and saltmarsh in Coorong.
- Both scenarios: Loss of cues for migration and recruitment of fish.

C.1.6 How important are interactions with other threats?

(Note: early adaptation thinking emphasised 'minimising other threats' to give systems a better capacity to handle climate change. This remains important but is now often seen as inadequate and is not always possible. For example, while work participating in the East Asian-Australian Flyway Partnership is intended to influence settings in international migratory bird flyways, DEW cannot directly manage threats acting on flyways).

- Relative water extraction – without water extraction in the Murray-Darling Basin, the drying trend would not be a significant issue. At the moment, legally, water extraction should not increase, and it may decrease with improving compliance. However, future changes in policy / law, e.g. as a result of drying, could lead to an increase in extraction, in which case the impact of the drying trend would be much worse on the CLLMM. The timing of extraction / environmental flows is important.
- Threats to international migratory bird flyways are important and exacerbated by climate change.
- Nutrient inputs from past and current land use and agricultural practices interacting with reduced flushing. Reduced flushing out of the Murray Mouth reduces the export of salt and nutrients from the system, and salt and nutrients carried in River Murray flows are more likely to accumulate in the Lakes and Coorong. Furthermore, eutrophic conditions can worsen more rapidly if ecological functions are lost, e.g. losing aquatic vegetation that fixes (removes) nutrients from sediments and water column leads to greater nutrient accumulation.

C.2 Integrating the results

C.2.1 Select the categories below which, <u>in general</u>, best describe the CLLMM

Participants were given different categories of values and asked which ones might be retained or lost under the different scenarios. The results are summarised in Table 8. Values expected to be maintained are marked with a tick, and those expected to change are marked with a cross. Conditions associated with the judgments are included as bullet points , and further explanations of features that are counter to the general trend are described provided in Section C.2.2.

Table 8. Overall rating of the retention or loss of the three expressions of values for Coorong and the Lower Lakes under the two scenarios.

Expression of value	Scenario 1 - Reduced freshwater inputs	Scenario 2 - High ocean exchange
Ramsar criteria for which originally listed	✓ Continue to meet criteria - but in different ways	✓ Continue to meet criteria - but in different ways
CPS of the **ecological character**	× Significant risk to many CPS	✓ Coorong, assuming: - recovery after scenario 1 - salt/nutrient extremes are contained × Lower Lakes: significant risk to some CPS
Societal biodiversity values	× Significant risk to many values	✓ Many values present - assuming recovery after scenario 1

		× Values dependent on freshwater in the Lower Lakes at risk

C.2.2 Note features that counter the general trend in C.2.1

- Scenario 2, Lower Lakes: the reduction in freshwater components risk losing some of their social biodiversity value.
- Scenario 2, Coorong: Inundation of existing tidal/shoreline habitat and lack of tidal variation in new 'potential' habitat created by inundation of flats risks a loss in feeding habitat for waders (ecological character) and societal conservation value of those species.
- Scenario 2, value associated with the persistence of estuarine species persists, but there may be some loss of value associated with their move from the Murray Estuary and Coorong into the Lower Lakes.

C.2.3 Summary

- Scenario 1: The site would experience significant changes in ecological character and loss of many social biodiversity values, but retain some important characteristics and values. It would retain its status as an internationally important wetland.
- Scenario 2: The site would experience some changes in ecological character (e.g. a decline in freshwater communities and migratory species), but with careful management the site could retain many key aspects of its character and its social biodiversity values. It will retain its status as an internationally important wetland.

C.3 Implications

C.3.1 When might these ecological changes occur? What observation, monitoring or modelling would be needed to detect or confirm that various changes were occurring or inevitable?

- <u>Drying</u> may not lead to a single point at which ecological character changes, but a sequence of change and recovery, driven by drought and wet years, and this could be affected (amplified or dampened) by changing water sharing arrangements and water management and other non-local decisions.
    - Key indicator: increasingly frequent or longer periods of low water level and poor water quality in the Lower Lakes and insufficient high and medium flows periods to rejuvenate the system. Measures include water levels, flow events and annual volumes and timing of inflows.
    - Key indicator: the next extreme drought occurring before the system has time to recover from the last one. Understanding 'capacity for recovery' and ecological thresholds will be a key challenge.
    - Key indicator: Duration and frequency of disconnection between the Lower Lakes and the Murray Estuary, restricting migration of diadromous fish.
    - There may be 'tipping points' in the form or ecological thresholds that are crossed, or limits in capacity to recover.
- <u>Sea level rise, Lower Lakes,</u> key factors will include: the frequency and volume of over-topping of islands and barrages, and the condition of the Lower Lakes (in the absence and presence of sea water incursion). The water quality impacts will also depend on the frequency of river flow events that mobilise and flush accumulated salt and nutrients from the Lakes.
- <u>Sea level rise, Coorong:</u> the amount of exchange of water (and salt and nutrient) between the ocean, estuary and Coorong North and South Lagoons.

- Note: the occurrence of all of these factors will be the result of a combination of climate change impacts, impacts of other drivers of change, and management actions (at various scales).

C.3.2 Are there key factors at the CLLMM that reduce its vulnerability?

Physical

- Great diversity of habitats and hydrodynamics across the site.
- The size of the site.
- Ecosystems are adapted to coping with temporal variability and extremes (e.g. drought).
- The ability of wetland communities and fauna to move around the system and colonise new suitable habitat elsewhere (*Ruppia*, other seagrasses, saltmarsh species, mudflat).
- The opportunity to manage to help create new habitats.
- The rising sea level reduces vulnerability to declining inputs from the River Murray.
- The barrages will continue to mitigate some impacts of the drying phase (Scenario 1) and provide management lever for using limited water. They provide options for when and how a transition to Scenario 2 might occur.
- Submergent macrophytes are a keystone species and there is the potential for their ecological services to be provided by a variety of different species. However, while there may be some diversity in seedbanks there may be need for management (and research) to facilitate new macrophyte establishment.

Social / institutional

- Societal expressions of importance/value/love for the site, locally and nationally (e.g. those associated with the film, 'Storm Boy'). Being an MDB icon site and Ramsar Convention listed wetland (institutional expressions of importance) mean it will attract attention, priority and resources.
- First Nations: caring for country and connection over millennia increases value, well recognised broadly and supported. And provides greater potential to manage healthy country through change.
- Shared experience of the Millennium Drought.
- There's a lot of knowledge about the CLLMM, a system for acquiring it, and a culture of sharing and acting on it.
- Existing environmental flows entitlements. And the overarching system for allocating and delivering water to the environment in amounts and at times that are effective. Could maintain or even increase environmental water allocations despite Basin-scale drying.
- Rolling planning process for Ramsar sites, enables incremental assessment of and accommodation of change and updated understanding and management of change.

C.3.3 What are the factors that do or might increase the vulnerability of the CLLMM?

Physical

- High level of water extraction in MDB, drainage of the agricultural landscapes in the South East.
- Dependence on freshwater inflows.
- Salt and nutrient loads combined with evapoconcentration and low flushing.
- Very high accumulation of salt and nutrient in the South Lagoon. Unknown ability of management to lower them in a sustained way.
- Sediment reducing seawater and material exchange through the Murray Mouth, estuary and along the Coorong.
- ASS.
- Inverse estuary.
- Estuary constrained by infrastructure. The barrage line fixes the location of the salt/fresh boundary. Shoreline infrastructure makes it difficult to respond dynamically to variable water levels.

- Sensitivity of international migratory species to impacts elsewhere in the flyway.
- Sensitivity of benthic fauna that are critical in the nutrient and ecological dynamics of the system. They will be affected in Scenario 1, will they recover? Already low resilience; limited recovery in the South Lagoon after the Millennium Drought.
- Groundwater is shallow and highly saline; if rising seas elevate the saline water it will affect many valued terrestrial components: pasture, infrastructure, creeks, native vegetation, etc.

Social / institutional

- Dependence of environmental water on future MDB-scale decisions about how to deal with reduced inflows across the Basin.
- Contestation about values of the site, especially fresh status of the Lower Lakes.
- No well-established process, at any level, for revising management objectives in the face of transformational ecological change. Not only formal structure (acts and conventions, targets) but also institutional culture. This is not restricted to Ramsar institutions, more broadly we don't have clear and consistent ways to think about adaptation of environmental management and other sectors that interact with it.
- Risk that environmental water allocations might be jeopardised by any consideration of the possibility of opening of the Lower Lakes to sea water, even in the far future.
- Difficulty of planning in a multi-jurisdiction, multi-stakeholder context, leading to delayed action.
- Ecological change, especially leading up to Scenario 1, will unfold through a series of droughts and wet periods, so that trends are unlikely to be clear. As a result, the signals that a significant change in management is warranted will be contested. There is a risk that initially the signal of trend change will be weak so key decisions will only be made during 'crisis' situations, and eventually such situations will be so common that there will be no 'normal' times to make well-considered, long-term decisions. Values vary between crisis and normal times.
- Intolerance of uncertainty is a vulnerability. Many stakeholders have a high level of discomfort with uncertainty about the system they love and depend upon, so it may be difficult for them to engage early in deliberations about managing and living successfully with significant change in the CLLMM, and difficult for DEW and researchers when they 'don't have the answers to all questions'.

C.3.4 What issues may require management to preserve values associated with persisting attributes of the CPS / features, while accommodating those aspects of ecological change that are inevitable?

Note: these are issues that arose in the deliberations about the scenarios and vulnerability of the CLLMM, they are not the result of a dedicated process exploring management needs and actions; this will be done as part of subsequent HCHB T&I Climate Adaptation Component activities.

Scenario 1:

- Acid sulfate soils exposed and rewet during frequent low and higher river flow phases.
- Nutrient and salt accumulation in Lake Albert and Southern Coorong.
- Operation of the fishways during low flow periods.
- Maintain the inherent capacity for the ecosystems of the Lower Lakes and Coorong to transition to different configurations and for the ecological health of the system to improve, when water levels increase.

Scenario 2:

- Facilitate seawater exchange, into the estuary, between the estuary and the Lower Lakes and along the Coorong to maintain water levels, connectivity and ensure export of accumulated salt and nutrient.
- There is an active reduction of salt and nutrient loads in Southern Coorong.
- The creation / colonisation / inundation of new habitats, including salt marshes and mudflats and protected sand beaches for nesting terns is facilitated.

- Freshwater components persist in spatial and temporally restricted populations.
- There are different priorities for use of environmental flows, for example, to support freshwater habitats, system connectivity and export of nutrients and salt from the Lower Lakes.
- There is potential estuarine and marine life that may encroach into the Lower Lakes (e.g. tubeworms, sharks, fur seals).
- The Murray Mouth is shifting.
- Positive narratives about the CLLMM are established and values that are retained are highlighted while acknowledging and honouring those that are diminished.
- The discomfort and grief of diverse stakeholders, including DEW staff, as they understand, anticipate, make sense of, maybe accept and experience significant ecological change affecting the things they connect to and value, is managed.

C.4 Summary narrative about the vulnerability of the site

The responses to these questions were synthesised into a narrative that summarises the insights about the vulnerability of the site from this analysis. The narrative is reported in Section 3.5. This narrative could be tailored for different communication purposes, such as reporting or education.

The Goyder Institute for Water Research is a research alliance between the South Australian Government through the Department for Environment and Water, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.