Ecological Investigations Findings Report – Phase 2, December 2021

Coorong Infrastructure Investigations Project

Department for Environment and Water
December, 2021

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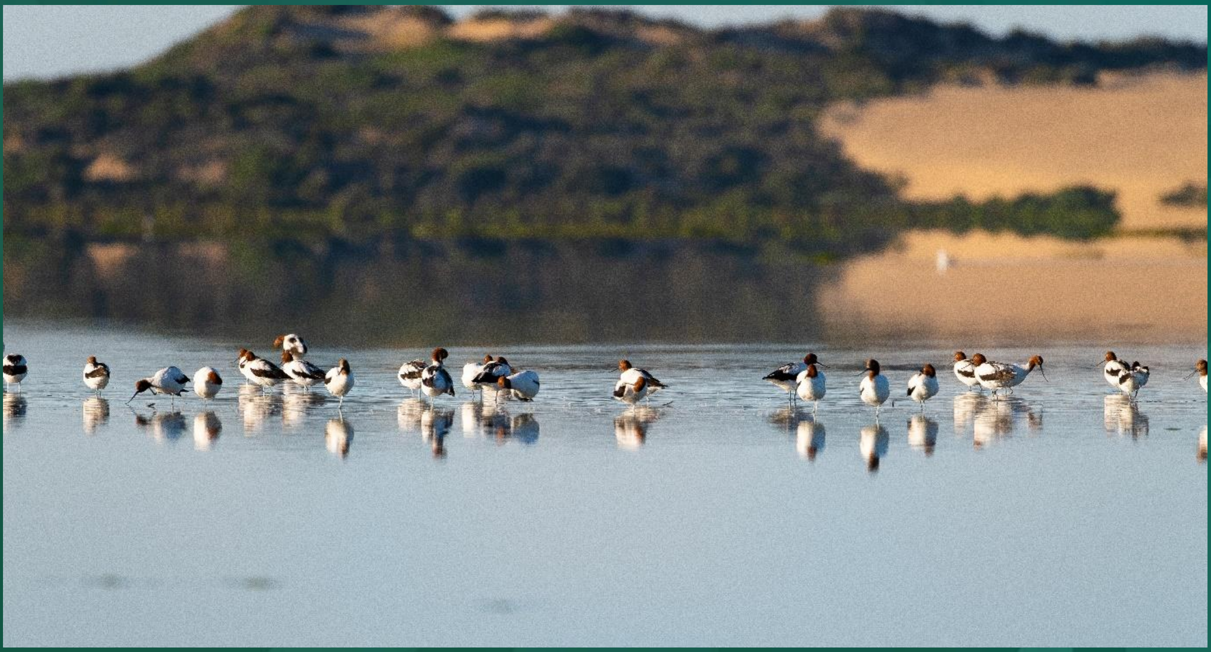

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Forward

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Landscape Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
CHIEF EXECUTIVE
DEPARTMENT FOR ENVIRONMENT AND WATER

Acknowledgements

The project team would like to acknowledge the Traditional Custodians of the lands and waters, current land managers, and all Aboriginal and Torres Strait Islander South Australians. As a Department we acknowledge that Aboriginal Nations are the first managers and decision makers of Country and that Country has sustained their culture and economy for thousands of generations. The care, skill and knowledge of Aboriginal Nations has shaped the character of Country across the continent and is seen as an integrated and interdependent cultural landscape

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.

The work undertaken in the Phase 2 ecological investigations report was part of the Coorong Infrastructure Investigations project. The report was authored by Cristina Vicente, Gareth Oerman and Hugh Wilson.

We thank Dr Daniel Rogers, Mr Gareth Oerman, Dr Luke Mosley, Prof Michelle Waycott, and Dr Matt Gibbs for their support undertaking the Ecological Risk Assessment process and for their input and technical review of this report.

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

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List of abbreviations

CIIP	Coorong Infrastructure Investigations Project
CNL	Coorong North Lagoon
CSL	Coorong South Lagoon
ERAF	Ecological risk assessment framework
HCHB	*Healthy Coorong, Healthy Basin*
KBR	Kellogg Brown & Root
LAC	Lake Albert Connector
mAHD	Elevation in metres with respect to the Australian Height Datum
TN	Total nitrogen
TP	Total phosphorous

Executive Summary

The Coorong Infrastructure Investigations Project is part of the South Australian Government's *Healthy Coorong, Healthy Basin* Program. As part of the *Healthy Coorong, Healthy Basin* Program, the Coorong Infrastructure Investigations Project (CIIP) has been established to investigate the feasibility of long-term infrastructure options for improving the ecological health of the Coorong.

Feasibility investigations under the Coorong Infrastructure Investigations Project (CIIP) were undertaken in two phases:

- Phase 1 assessed and compared the benefits and risks of four shortlisted infrastructure and management options (and combinations thereof) to the Coorong ecosystem, with a focus on the Coorong South Lagoon (CSL).
- Phase 2 optimised options progressed to concept design based on findings from Phase 1, analysed long-term performance, calculated expected utility and identified environmental risks (red flags) associated with the infrastructure and management options.

Modelling of Coorong conditions (hydrodynamic and biogeochemical) under different combinations of infrastructure options, management scenarios, and climate and flow conditions informed each Phase of ecological investigation.

Objectives for Phase 2 were to:

1. optimise the infrastructure and management options that were progressed to concept design based on the outcomes from Phase 1;
2. evaluate the long term performance (30 years) of shortlisted infrastructure and management options in achieving desired salinities, water levels and nutrient concentrations in the Coorong;
3. identify potential risks and uncertainties to the Coorong ecosystem under the operation of an infrastructure and management option; and
4. inform a multi-criteria analysis (MCA) established by Kellogg, Brown and Root (KBR) to assist in the prioritisation of infrastructure and management options to progress to business case development.

An Ecological Risk Assessment Framework (ERAF) was used to analyse, interpret and compare the model outputs of end-points (salinity, water level and nutrients) against a set of ecologically meaningful consequence criteria. Consequence criteria describe how the Coorong ecosystem is expected to respond to varying levels of risk (insignificant, minor, moderate, significant and very significant) associated with each end-point; where an insignificant risk aligns with the objectives for the site and a very significant risk is reflective of the worst conceivable outcome. For each end-point, the likelihood of experiencing each risk consequence level over a prescribed time period (up to 30 years) formed the basis by which proposed infrastructure options were compared against a no-build (hereafter referred to as base case) scenario.

To ensure the results of the ERAF were fit-for-purpose for the inclusion in to the MCA, the likelihood distributions for each risk consequence level for a given end-point were interpolated by a weighting factor into a scoring system that ranged between 1 and 10. A utility score of 10 was reflective of achieving the desired condition for the Coorong, while lower scores inferred greater deviation from the desired condition.

Results Summary

A summary of the results of the ERAF process are shown for each infrastructure option (and combinations thereof) below. A red flag was used in the summary table to identify infrastructure options that had a utility score that was lower than the base case for a given end-point, which could not be managed through operational controls.

Infrastructure option	**End-points**						**Utility value for MCA**
	CSL Salinity	**CSL Nutrients**	**CSL Water level**	**CNL Salinity**	**CNL Nutrients**	**Red Flags**	
Base case	3.45	1	6.8	6	2.7		3.69
Circulation - Simultaneous pumped connection	9.25	4	6.8	8.55	3		6.20
Passive connection	9.35	3.6	6.8	8.25	3		6.12
Bi-directional connection (in or out)	9.25	3.2	6.4	8.25	3		5.89
Pump out connection + Dredging	9.25	3.6	5.2	9	3		5.83
Intermittent pump out connection	9.25	1.7	6.8	8.55	3		5.56
Lake Albert Connector (LAC)	5.05	1	6.8	7.65	1.8 / 2.7		4.20
LAC connector + Dredging	5	1	6.6	7.85	1.7		4.1

Key findings

Key findings from the Phase 2 ecological investigations are summarised below:

- All infrastructure and management options had utility values that exceeded the base case, meaning that all modelled options reduced risk to the Coorong ecosystem.
- The infrastructure and management options with the highest utility scores were *Circulation – simultaneous pumped connection*, *Passive connection*, *Bi-directional connection in or out*, *Pumped connection out of the CSL with dredging* and *Intermittent Pumped connection out of the CSL*.
- The maximum utility value for an infrastructure and management option was 6.20, meaning residual risk to the Coorong ecosystem is still considerable under all options.
- Salinity end-point values for all infrastructure and management options were greater than the base case, meaning all options reduced risk associated with salinity.

- Benefits to CSL salinity were significantly lower for the options associated with the Lake Albert Connector than for the options associated with either a passive or pumped connection with the Southern Ocean. Salinity end-point values were greater than 9 for all options with a connection to the Southern Ocean, meaning that desired salinity conditions (10) were almost permanently met.
- Water level end-point values for all infrastructure and management options did not exceed the base case.
- Three options; *Lake Albert Connector with Dredging*, *Bi-directional connection in or out* and *Pumped connection out of the CSL with dredging* were associated with greater risk (lower end-point value) than the base case. The increased risk posed by inadequate water levels through operation of these two infrastructure options could be managed and mitigated through operational controls.
- Nutrient end-point values for both the base case and under all infrastructure and management options were low due to (1) the hyper-eutrophic state of the CSL where nutrients concentration and total nutrient loads significantly exceed desirable conditions, (2) the positive feedback loop between algae and sediment which maintains the hyper-eutrophic state, and (3) limitations in the current nutrient modelling capability.
- Options associated with the Lake Albert Connector pose a greater risk (compared to the base case) in nutrient conditions to the Coorong ecosystem under the operation of these infrastructure options.
- Options with connection to the Southern Ocean provided some benefit in nutrient conditions (compared to the base case), but end-point values remained low. Nutrients under the operation of these infrastructure options would continue to pose significant risk to the Coorong ecosystem.

1 Background

1.1 Project Background

The Coorong, Lower Lakes and Murray Mouth is a wetland of local, national and international importance and one of the most significant waterbird habitats in the Murray-Darling Basin (Brookes et al. 2018). The site is listed as a Ramsar Wetland of International Importance, and therefore the Australian Government, and South Australian Government as the site manager, has international obligations to maintain the ecological character of the site (Brookes et al. 2018).

Reductions in inflows have led to the long-term decline in the ecological condition of the Coorong, which were exacerbated by the Millennium Drought (2001–10). Increased inflows to the Coorong following the Millennium Drought were expected to enable the recovery of the Coorong, and while some ecological values have recovered, to date, there has been limited recovery of ecological values in the Coorong South Lagoon (CSL) (Brookes et al. 2018).

The CSL's current condition was summarised by DEW (2021a) and Brookes et al. (2021):

- It is degraded and at risk of no longer supporting the elements that make it a wetland of local, national and international importance.
- Prolonged hyper-saline and hyper-eutrophic conditions have significantly affected the waterbirds, fish, plants and invertebrates of the CSL.
- Hyper-eutrophic and hyper-saline conditions, along with inadequate water levels have reduced the quality and availability of habitat and food sources for elements of the Southern Coorong foodweb.
- The CSL is experiencing excessive growth of filamentous algae over summer, which interferes with the reproduction of Ruppia. Filamentous algae also aggregate and form large mats that blanket the mudflat and prohibit migratory shorebirds from probing the sediment in search for food.
- The growth of filamentous algae (and other phytoplankton) are stimulated by the release of nutrients (nitrogen and phosphorus) from anoxic and nutrient-rich sediments.

1.1.1 Desired state

The Department for the Environment and Water (DEW) in partnership with key Coorong scientists have described the desired state of the Southern Coorong (DEW 2021a). The Southern Coorong has the same spatial range as the CSL, and therefore will be referred to as the CSL hereafter. The desired state for the CSL is underpinned by:

- some, but limited, historical information of the Coorong when it was a diverse and resilient ecosystem that supported healthy populations of plants, invertebrates, fish and waterbirds,
- existing hydrological and environmental gradients occurring in the Coorong (e.g. presence of fish, macroinvertebrates and aquatic plants within known salinity ranges); and
- scientific understanding of the biotic and abiotic processes governing complex hypersaline estuarine systems.

1.1.2 *Healthy Coorong, Healthy Basin* program

The South Australian and Australian governments established the *Healthy Coorong, Healthy Basin* (HCHB) program, a $77.7 million 5-year program that aims to support the long-term health of the Coorong by providing evidence-based management options to manage both immediate threats and future conditions anticipated under a changing climate. It is recognised that maintaining the long-term ecological health and resilience of the Coorong may not be achievable through improved knowledge and water resource optimisation alone, and therefore, a number of potential management options have been identified over the years to potentially improve water delivery to, and enhance the ecological health of, the Coorong. Further information about the program is available at https://www.environment.sa.gov.au/topics/coorong/action-plan.

1.1.3 Coorong Infrastructure Investigations Project

As part of the HCHB program, the Coorong Infrastructure Investigations Project (CIIP) has been established to investigate the feasibility of long-term infrastructure and management options to improve the Coorong's ecological health. These feasibility investigations include socio-economic, cultural, engineering, economic and ecological considerations.

A short list of potential infrastructure and management options were developed through an options analysis and community consultation in 2020 and used as the basis for further feasibility investigations, including CIIP ecological investigations.

1.2 CIIP Ecological Investigations

CIIP ecological investigations aim to predict the performance of the infrastructure and management options in terms of their ecological benefit and risk profiles, and ultimately to provide input to the multi-criteria analysis (MCA) decision process (see Section 1.4).

Ecological investigations were undertaken in two phases (Figure 1.1).

- Phase 1 assessed and compared the benefits and risks of four shortlisted infrastructure and management options (and combinations thereof) to the Coorong ecosystem, with a focus on the CSL.
- Phase 2 optimised options progressed to concept design based on findings from Phase 1, analysed long-term performance, calculated expected utility and identified risks (red flags) associated with the infrastructure and management options.

Both Phases of ecological investigations were informed by modelling of Coorong conditions (hydrodynamic and biogeochemical) under different combinations of infrastructure options, management scenarios, and climate and flow conditions.

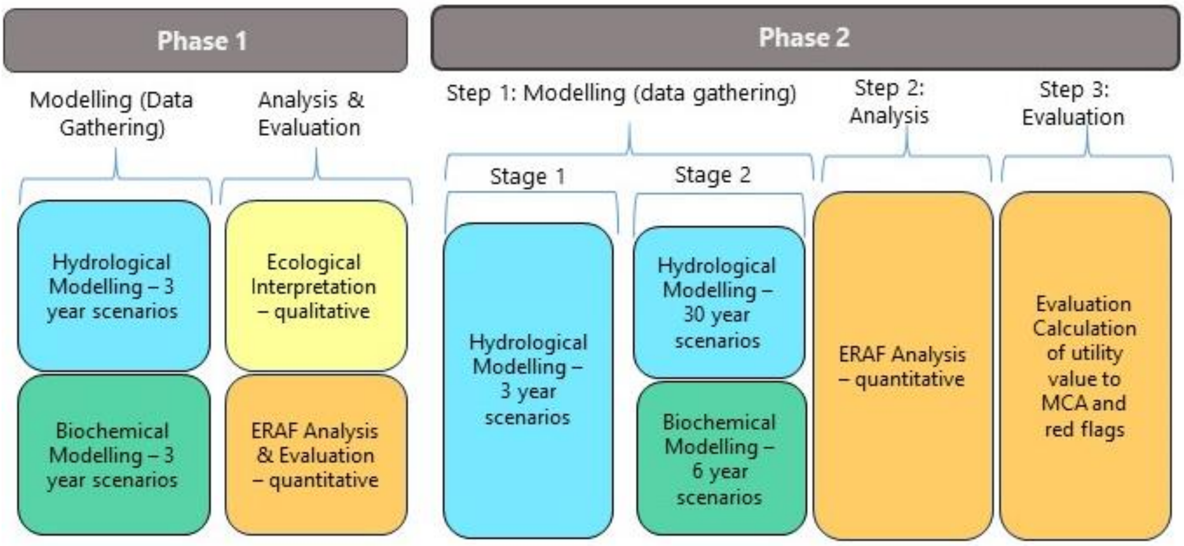


Figure 1.1 Summary of Phase 1 and Phase 2 ecological investigation and assessment activities.

1.2.1 Environmental Risk Assessment Framework (ERAF)

Like the Phase 1 ecological investigations (DEW 2021d), the Phase 2 investigations applied an Environmental Risk Assessment Framework (ERAF) (Butcher and Cottingham, 2021) to evaluate various scenario analysis outputs (Phase 2, Step 2 in Figure 1.1). The ERAF evaluates the changes in level of ecological risk in the Coorong (salinity, water level and nutrients) under a CIIP option with respect to the base case. The ecological risk assessment considers both risk and benefit, with risk measured as a departure from the management objectives for the Coorong as detailed in the *Ramsar Management Plan* and/or the desired state for the Southern Coorong in the *State of the Coorong* report. Benefit was measured and defined as a reduction in residual risk under a CIIP option (DEW 2021b and DEW 2021c).

This risk-based approach was adopted to allow decision makers to have due regard for uncertainty derived from model validity, future climatic and inflow conditions, and the expected performance of infrastructure and management options.

The ERAF defines risk and benefit as follows:

- **Benefit** – an increase in the likelihood of minimal or zero deviation from desired ecological objectives and a decrease in the likelihood of a significant deviation from desired ecological objectives.
- **Risk** – a decrease in the likelihood of minimal or zero deviation from desired ecological objectives and an increase in the likelihood of a significant deviation from desired ecological objectives.

Benefit and risk for each proposed infrastructure and management option was determined by comparing the risk profile with the base case scenario. This considers both likelihood and consequence in keeping with the risk-based approach to evaluation.

1.3 CIIP infrastructure and management options

An initial list of eleven infrastructure and management options were considered through options analysis and community consultation in 2020. The outcome of that option analysis and community consultation was the shortlisting of five infrastructure and management options which were the focus of Phase 1 ecological investigations and other feasibility investigations.

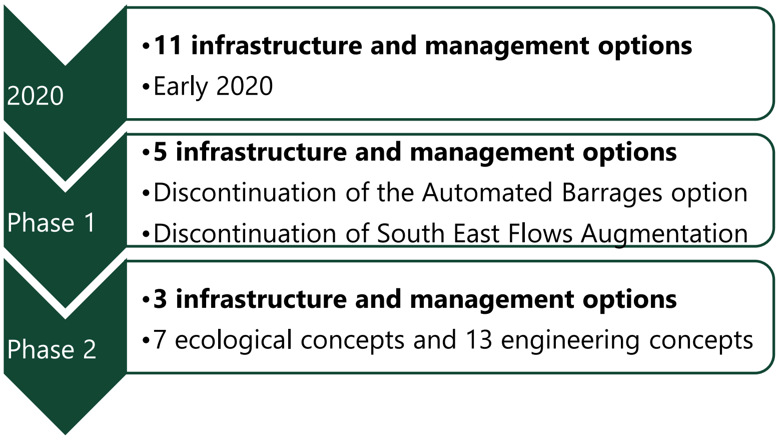


Figure 1.2 CIIP infrastructure and management options timeline.

Following recommendations from Phase 1 and other feasibility investigations, three infrastructure and management options were progressed to Phase 2 ecological investigations (Figure 1.2).

During Phase 2 investigations, variations and combinations of the three infrastructure and management options were identified and optimised. These formed the basis of seven so-called ecological concepts, which are a set of scenarios to be analysed through parameterisation of the hydrodynamic models. The ecological concepts describe sources of water input, volumes of water exchange and any operations to remove impediments to water movement via dredging.

In addition, a set of engineering solutions, known as concept designs, were defined for actualisation of the ecological concepts (i.e. the above mentioned infrastructure and management options). Figure 1.3 illustrates the relationship between the three infrastructure and management options, seven ecological concepts and 13 engineering concepts, which are the focus of the Phase 2 ecological investigations.

CIIP options	Ecological concept	Engineering concepts
Lake Albert Connector	Lake Albert Connector	Via open channel
		Via pipes
Dredging	Dredging and Lake Albert Connector	Via open channel
		Via pipes
	Dredging and pumping out	Nearshore discharge
		Beach discharge
Ocean Connector	Pump out with water level triggers	Nearshore discharge
		Beach discharge
	Pump in or out (not simultaneous)	Two pumping stations
		Wet well and breakwater
	Circulation (in and out)	Nearshore discharge
		Beach discharge
	Passive connector	Passive connector

Figure 1.3. CIIP infrastructure and management options, ecological concepts and engineering concepts.

1.4 Multi-criteria analysis processes to inform infrastructure option decisions

Multi-criteria analysis (MCA) is a decision-making tool to enable decisions to be made that have multiple criteria. Kellogg Brown & Root (KBR) established a MCA process to assist with decisions regarding the infrastructure and management options for the Coorong, as part of the Coorong Infrastructure Investigations project.

The MCA is a multi-attribute utility theory applied to various infrastructure and management options. It aims to estimate the utility, or value, of infrastructure and management options being compared according to a set of evaluation criteria. This is intended to assist in identifying option(s) that best perform when all evaluation criteria are considered. The MCA scores each of the proposed options from 1 to 10 for each of the six evaluation criteria (Table 1.1 and Figure 1.4).

The overall utility for an option is calculated as the weighted sum of the scores against these criteria, with criteria weighted according to their relative importance to decision makers. Evaluation criteria 4 (Environmental & Ecological) has the highest rating since it indicates the desired benefit sought from the proposed infrastructure and management options.

Moreover, community and stakeholders on the HCHB project agreed earlier in the project that the essential outcome of the CIIP is finding the option/s *"that best contribute to improving the ecology of the South Lagoon as determined by scientific evidence, given water availability and constraints."*

Table 1.1 MCA evaluation criteria

	Evaluation criteria	Weighting
1	Financial	10%
2	Constructability & Approvals	10%
3	Operations & Maintenance	10%
4	**Environmental & Ecological**	**40%**
5	Social & Economic	10%
6	First Nations	20%

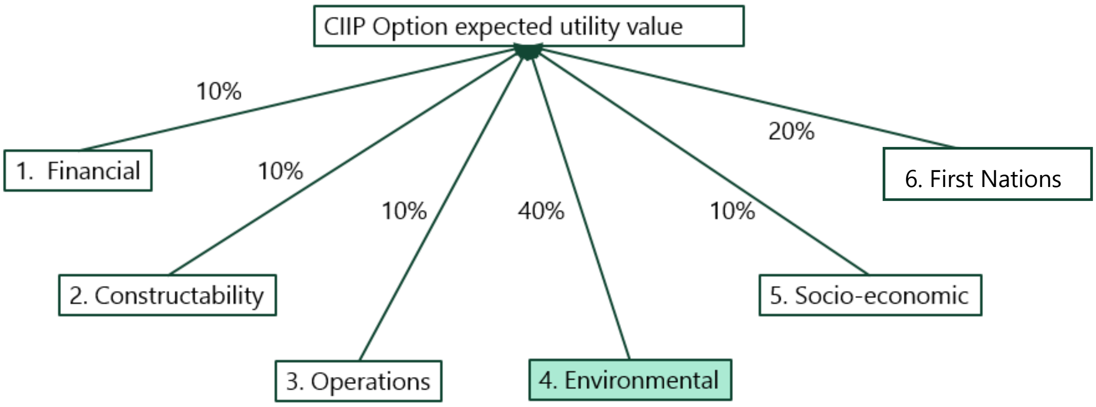


Figure 1.4 MCA evaluation criteria.

Sub-criteria, also known as performance criteria, were defined for each of the six evaluation criteria. Two performance criteria (4.1 and 4.2) were defined for evaluation criteria 4 (Environmental and Ecological), which relate to ecological risk and benefit in the CSL and CNL respectively (Table 1.2).

The Phase 2 ecological investigations applied a qualitative analysis of the model outputs to score both performance criteria.

Table 1.2 Performance criteria for the environmental and ecological evaluation criteria.

ID	Performance criteria	Measure	Scoring	Weighting
4.1	Opportunity for the proposed infrastructure and management option to improve the ecological character and reduce risk of environmental consequences and/or loss of key ecological values of the CSL.	Quantitative	1-10	75%
4.2	Opportunity for the proposed infrastructure and management option to improve the ecological character and reduce risk of environmental consequences and/or loss of key ecological values of the CNL	Quantitative	1-10	25%

The focus of this report is to present the analysis and evaluation of modelling outputs to compare infrastructure and management options on the basis of ecological benefit and risk in order to provide scoring for the Environmental and Ecological MCA performance criteria. The evaluation of remaining MCA criteria such as cost, constructability and other considerations is outside the scope of the present report.

1.5 Phase 2 ecological investigations

The Phase 2 ecological investigations involved refining and further evaluating the three infrastructure and management options shortlisted from Phase 1 over the following three steps:

1. Undertake model runs that simulate ecological parameters (nutrients, salinity and water levels) in the Coorong under different flow conditions and climate scenarios. This step was divided in two stages as per Figure 1.1 and Figure 1.5.

2. Analyse model outputs using the ERAF methodology.

3. Evaluate ERAF results to input into the MCA process; including identification of red flags.

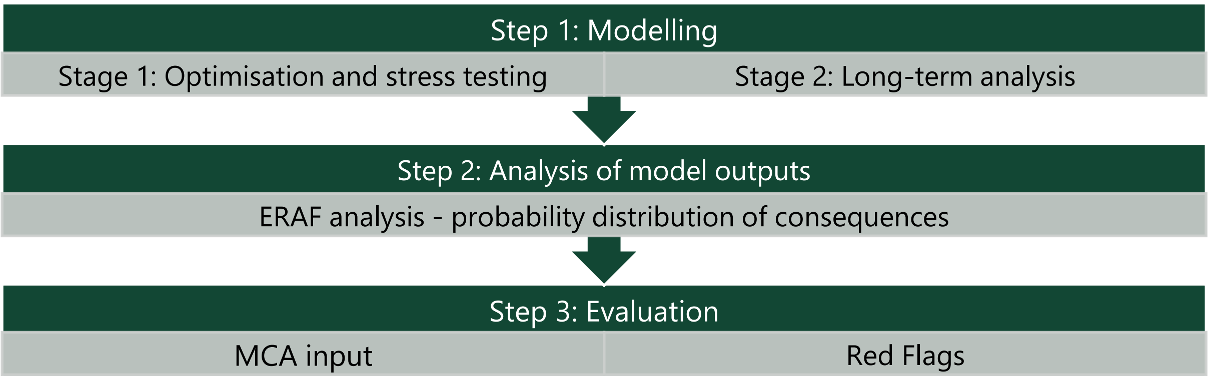


Figure 1.5 Phase 2 ecological investigations scope and steps.

The modelling step is summarised in section 2 of this report, but is covered in more detail in the following reports:

- DEW (2021e): Department for Environment and Water (2021). Hydrodynamic modelling to inform Coorong Infrastructure Investigations Project, DEW Technical report 2021, Government of South Australia, Department for Environment and Water, Adelaide.

- BMT (2021) Coorong Infrastructure Investigations Project: Hydrodynamic, Biogeochemical and Habitat Modelling Study, Report prepared by BMT Commercial Australia for the SA Department for Environment and Water, Adelaide.

2 Step 1: Modelling

As with Phase 1, the Phase 2 ecological investigations were supported by the Coorong Dynamics Model and the TUFLOW-FV Model. During Step 1 (Figure 1.5) of the ecological investigations there were two stages, of model runs;

1) identification of optimum CIIP pumping regimes, followed by

2) long-term analysis to inform the ERAF evaluation.

2.1 Modelling Stage 1: Optimisation and stress testing

The aim of this step was to optimise pumping regimes for the three infrastructure and management options to meet desired salinities and water levels (DEW, 2021b and 2021c). The optimisation process was informed by three-year hydrodynamic simulations using the TUFLOW-FV Model. Refined infrastructure and management options were then further stress tested under a range of scenarios simulating expected climate and inflow conditions. The method and results for this optimisation process are described in a separate report (DEW, 2021e).

This optimisation process identified a total of seven combinations of infrastructure and pumping (Table 2.1). These combinations, known as ecological concepts, were subject to additional modelling and analysis.

Table 2.1 CIIP ecological concepts considered in Phase 2 ecological investigations.

Ecological concepts	Description
Lake Albert Connector (LAC)	Passive connection between Lake Albert and CNL.
LAC connector + Dredging	Passive connection between Lake Albert and CNL and a dredge profile at Parnka Point sufficient to allow connectivity between the CNL and CSL.
Pump out connection with water level triggers	One-directional pumped connection to Southern Ocean out of the CSL when water level is above 0.3 m AHD only.
Pump out connection + Dredging	One-directional pumped connection with Southern Ocean out of the CSL and a dredge profile at Parnka Point sufficient to allow connectivity between the CNL and CSL.
Bi-directional connection in or out (one way at a time)	Bi-directional pumped connection between the Southern Ocean and CSL. Pumping can only occur in one direction at any one time.
Circulation - Simultaneous pumped connection	Bi-directional pumped connection into and out of CSL with infrastructure positioned at two separate locations allowing circulation of flows within CSL. Pumping can occur concurrently through each pumping station.
Passive connection	Bi-directional passive piped connection between the Southern Ocean and the CSL with flow driven by differing water levels.

2.2 Modelling Stage 2: Long-term analysis

Instead of the short term runs (three year) used in Phase 1 and Stage 1 of Phase 2, longer term model runs were conducted using the Coorong Dynamics Model and the TUFLOW-FV Model (six and 30 years, respectively) for each of the seven ecological concepts (Table 2.1) and the base case. These longer term model runs sought to compare the performance of ecological concepts over a range of flow conditions and climate changes scenarios.

The output of these analyses were time series of water quality, water level and nutrient parameters for each of the options.

The TUFLOW-FV Model runs considered three climate scenarios DEW (2021e) as a hindcast (i.e. 1990 - 2019) to understand what the various changes in assumptions would have looked like over the past.

This report used two of those scenarios, including:

1. Current: representing current conditions, derived from the Source Murray Model Current Conditions model which assumes current environmental water recovery and delivery patterns are implemented across the full period (i.e. current level Basin Plan implementation).
2. Climate change: representing current conditions, adjustments to atmospheric drivers, represent projected conditions at 2050 under a high emissions climate change scenario. The adopted projections are as per DEW's 'Guide to Climate Projections for Risk Assessment and Planning in South Australia' (Green and Pannell, 2020). Relevant changes are:
    a. Increased tide level of 0.24 m
    b. Wind reduced by 0.8%
    c. Temperature increase of 1.5 degrees
    d. Reduction in rainfall of 6.6%.
    e. Historic barrage flows, instead of current flows, were adopted, assuming than the median projected decline in runoff is similar to the volume of water returned to the environment under the Basin Plan.

The Coorong Dynamics Model runs were based on a six year subset of the current climate conditions used for the TUFLOW-FV Model.

The list of scenarios, including ecological options, flow rates, climate scenarios, models and model timeframes are presented in Table 2.2. Note that each model run has a unique reference ("Modelling reference") that is used as an identifier through the remainder of this report.

Table 2.2 Scenarios run through TUFLOW-FV Model and Coorong Dynamics Model for each ecological option.

Ecological concept	Flow Rates	Modelling reference	TUFLOW-FV Model (1990-2019)		Coorong Dynamics Model (2013-2019)	
			Climate Change	Current	Dry	Wet
Lake Albert Connector (LAC)	1000 ML/d	SC_01: LAC	√	√	√	√
		SC_01: LAC_improved			√	√
LAC connector + Dredging	1000 ML/d	SC_01_2: LAC+ Dredge	√	√	√	√
Pump out connection with water level triggers	1000 ML/d	SC_03: Pump out	√	√	√	√
Pump out connection + Dredging	250 ML/d	SC_03_2: Pump out + dredge	√	√	√	√
Bi-directional connection in or out (one way at a time)	350 ML/d	SC_04: Pump in or out	√	√	√	√
Circulation - Simultaneous pumped connection	350 ML/d	SC_05: Pump in and out	√	√	√	√
		SC_05c: Pump in and out at Parnka	√	√	√	√

Ecological concept	Flow Rates	Modelling reference	TUFLOW-FV Model (1990-2019)		Coorong Dynamics Model (2013-2019)	
			Climate Change	Current	Dry	Wet
Passive connection		SC_06: Passive connection	√	√	√	√

2.3 Modelling accuracy and validation

A full summary of the Coorong Dynamics Model including its schematisation, outputs and validation are available in Collier et al. (2017), Hipsey et al. (2020) and BMT (2021).

The modelling accuracy and validation of the TUFLOW-FV Model (hydrodynamic) is described in DEW (2021d), DEW (2020a) and DEW (2021e).

For Phase 1 ecological investigations, the Coorong Dynamic Model used a sediment flux rate of ammonium, nitrate, phosphate, and oxygen demand based on literature review of similar coastal sites. Since Phase 1 was completed, the HCHB Trials & Investigations research projects have published data which provide an improved understanding of sediment nutrient release fluxes and oxygen demand (Mosley et al, 2021). Compared to the recent data, the Phase 1 scenarios modelled by the Coorong Dynamic Model relatively overestimated the sediment nitrate flux, and under-estimated the sediment oxygen demand, and ammonium and phosphate sediment fluxes.

Motivated by these recent findings, a sensitivity analysis was undertaken around the sediment flux parameters with the key aims to:

1. update and re-calibrate the Coorong Dynamic Model to model sediment nutrient flux and oxygen demand parameters; and
2. compare the results to the Phase 1 parameter sets to investigate the changes in the prediction of key water quality variables.

The performance of the Coorong Dynamic Model using the alternative sediment flux parameter sets was validated against water quality measurements and showed consistent improvement in the prediction of phytoplankton biomass and most of the nutrient species. The new parameter set was therefore adopted for the Phase 2 biogeochemical and habitat modelling scenario assessments.

While the water column nutrient levels and phytoplankton biomass varied with the alternative parameter sets, the relative performance of CIIP options remained similar to Phase 1, and therefore conclusions drawn from the Phase 1 biogeochemical modelling are considered to still be valid.

The Coorong Dynamics Model was limited in its ability to simulate nutrient concentrations under ecological concepts due as:

- the positive feedbacks from both aquatic plants and macroinvertebrates on sediment nutrient cycling not accounted for model runs;
- model runs not able to determine the longer-term (>6 years) impacts of the proposed options on nutrient removal. For some nutrient parameters the short-term (6 years) model runs suggest that while the proposed options reduce nutrient concentration, the level of removal is not sufficient to shift the system to a desirable state; and
- model runs uncertainties with respect to interactions between nutrients in the sediment and water column

3 Step 2: ERAF analysis

The ERAF is quantitative evaluation of changes in level of ecological risk in the Coorong (with respect to the key hydrological and biogeochemical parameters regarding salinity, water level and nutrients) under a CIIP option with respect to the base case.

The inputs to this analysis are the time series of model predictions produced by modelling and scenario analyses (Section 2) for each of the ERAF end-points, ecological concepts and climate scenarios. The output of the ERAF analysis is a probability distribution of likelihood for each of the five consequence levels of the ERAF end-points. According to this approach, high performing infrastructure and management options are characterised by high likelihoods of nil or minor deviation from ecological objectives and low likelihood of major or significant deviations. Conversely, lower performing infrastructure and management options have high likelihoods of moderate or significant deviation from objectives and low likelihood of insignificant or minor deviation.

For the purposes of this assessment, it is assumed that the TUFLOW-FV Model and Coorong Dynamics Model scenario analyses simulate the ecological effectiveness of infrastructure and management options under the range of inflows and climatic conditions representative of the identified sources of risk (DEW 2021d). The modelling stage produced 30 years of simulation data for three end-points (CSL salinity, CNL salinity, CSL water level) covering the years 1990-2019. There were 6 years of simulation data for the two remaining end-points (CSL nutrients, CNL nutrients).

The Phase 2 ecological investigations adapted the Phase 1 ERAF process to address the longer simulation periods (i.e. 30 years versus 3 years). This section describes the adapted criteria and method.

3.1 Consequence criteria

The ERAF (Butcher and Cottingham, 2021) defines consequence as deviation from ecological objectives and establishes criteria for five levels of consequence (DEW 2021d). The lowest level of consequence (insignificant) describes the goal condition, which is achievement of ecological objectives in the Coorong. The highest level of consequence (very significant) is the worse conceivable ecological outcome over the assessment timeframe.

Phase 1 of the ecological investigations identified five risk assessment end-point criteria (DEW 2021d), which are indicators of ecological condition. These end point criteria were selected based on links with key ecological outcomes for the site (Figure 3.1).

The ERAF criteria were implemented for each of five agreed ecological "end-points" (DEW 2021d) to create five sets of consequence criteria (Table 3.1).

The five risk assessment end-point criteria are representative of the two MCA performance criteria that describe risk and benefit in the CSL and CNL (Table 3.1and Figure 3.1).

Consequence criteria for Coorong South Lagoon water level end-point were updated for Phase 2 investigations, with criteria considering potential impacts to the extent (Ha) of island habitat for breeding and the accessibility of that habitat to foxes. Two water level outcomes explicitly considered waterbird breeding:

- -0.5 m AHD from January to March. This metric was set based on two lines of evidence:
    1. Fairy Terns were recorded to have successfully bred in the Coorong South Lagoon in the 2015/16 breeding season when water levels reached -0.42 m AHD.

2. Water levels below -0.5 m AHD no longer support islands with a Moderate to High (>150 m^3 of water) level of protection from foxes.

- -0.8 m AHD from January to March. Water levels below -0.8 m AHD no longer support a Moderate (>30 m^3 of water) level of protection from foxes, and it is considered that the vast majority, if not all, island habitat within the Coorong South Lagoon is at risk of becoming accessible to foxes.

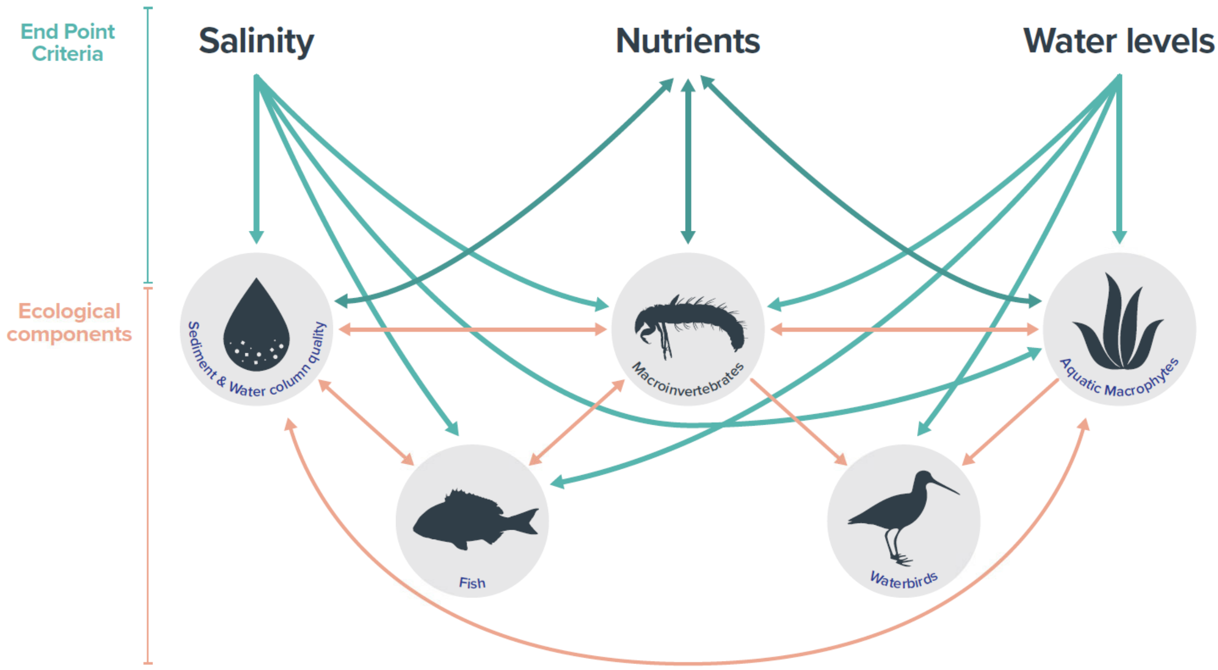


Figure 3.1 Causal links between the ERAF end-points and ecological components of the Coorong.

Table 3.1 ERAF end-points, consequence levels and outcomes.

End-points	Consequence level	Outcome
CSL water levels	Insignificant	Water levels are on 100% of days: • >+0.3 m AHD from June and August, • >+0.2 m AHD from September to December, and • > -0.5 m AHD from January to March.
	Minor	Water levels are on 100% of days: • >+0.3 m AHD from June and August >80% of days, • >+0.2 m AHD from September to December for >80% of days, and • > -0.5 m AHD from January to March.
	Moderate	Water levels are: • >+0.3 m AHD from June to August >70% of days, • >+0.2 m AHD from September to December for >70% of days, and • >-0.5 m AHD from January to March.

End-points	Consequence level	Outcome
	Significant	Water levels are: <+0.3 m AHD for all days between June and August **or** <+0.2 m AHD for all days between September and December **or** are between -0.5 and -0.8 m AHD for ≥1 day from January to March.
	Very significant	Water levels are: <0 m AHD for > 8 consecutive months **or** fall below -0.8 m AHD between January and March for ≥1 day.
CSL salinity	Insignificant	Average daily salinity in the CSL < 60 ppt year-round
	Minor	Maximum average daily salinities in the CSL are 60-100 ppt
	Moderate	Average monthly salinity exceeds 100 ppt for 3 to 6 consecutive months
	Significant	Average monthly salinity exceeds 100 ppt for 6 to 18 consecutive months
	Very Significant	Average monthly salinity exceeds 100 ppt for ≥ 18 consecutive months
CNL salinity	Insignificant	Average monthly salinity < 45 ppt
	Minor	Average monthly salinity > 45 ppt for < 2 months
	Moderate	Average monthly salinity > 45 ppt for 2-6 months
	Significant	Average monthly salinity > 70 ppt for 6-18 consecutive months
	Very significant	Average monthly salinity > 70 ppt for ≥18 consecutive months
CSL nutrients	Insignificant	<1 mg/L Total Nitrogen (TN) and <0.1 mg/L Total Phosphorus (TP) as per Australian Water Quality Guidelines (2018)
	Minor	Average monthly TN >1 mg/L and/or TP > 0.1 mg/L for <2 months
	Moderate	Average monthly TN >2 mg/L and/or TP > 0.2 mg/L for 2-6 consecutive months
	Significant	Average monthly TN > 3 mg/L and/or TP > 0.3 mg/L for 6-18 consecutive months
	Very significant	Average monthly TN > 3 mg/L and/or TP > 0.3 mg/ for ≥18 consecutive months
CNL nutrients	Insignificant	<1 mg/L Total Nitrogen (TN) and <0.1 mg/L Total Phosphorus (TP) as per Australian Water Quality Guidelines (2018)
	Minor	Average monthly TN >1 mg/L and/or TP > 0.1 mg/L for <2 months
	Moderate	Average monthly TN >1 mg/L and/or TP > 0.1 mg/L for 2-6 consecutive months
	Significant	Average monthly TN > 2 mg/L and TP > 0.2 mg/L for 6-18 consecutive months
	Very significant	Average monthly TN > 2 mg/L and TP > 0.2 mg/L for ≥18 consecutive months

3.2 ERAF analysis

The modelling stage 2 (Section 2.2) produced time series of salinity, water levels and nutrients for each of the ecological concepts and the base case. These time series were rendered in daily and or monthly time steps. The ERAF analysis compared the model outputs with the ERAF end-points (Table 3.1) to estimate a probability distribution across the five consequence levels of the ERAF end-points over a future 30-year period given any of the ecological concepts.

For Phase 1, similar assessments were made by a risk analysis team, who visually assessed time series plots to classify likelihood of consequence levels for different CIIP option scenarios. For Phase 2 it was determined that such an approach was impractical given the longer simulation periods and the broader range of conditions. Instead a more robust quantitative analysis approach was developed based on summary statistics of consequence conditions over the time series and criteria for assigning likelihood based on these statistics.

The modified Phase 2 ERAF analysis therefore comprised a two-step process to analyse this data:

1. Excel Workbook Queries to produce summary statistics of the years and months where model output exceeded thresholds for each of the five consequence levels
2. Assign likelihood and consequence.

The output of the ERAF analysis is a likelihood distribution of consequence levels for each ecological option, climate scenario and end-point.

3.2.1 ERAF summary statistics against consequence levels

The outputs of the models were combined into a single Excel worksheet and indexed according to time, ecological option, inflow scenario and end-point.

Excel was used to analyse this data to identify the years that a particular type of consequence was observed, and to count the number of months over which the consequence condition persisted. This analysis employed combination of Excel Workbook Queries and spreadsheet functions such as IF statements and filters. For cases where there were multiple criteria for a given end-point and consequence level, summary statistics were generated for each of the thresholds.

The analysis disregarded the first two years of all modelling scenario analyses to avoid the investigations being biased by the starting conditions. This is consistent with the principle that the investigations are comparing the long-term performance of the ecological concepts.

The output of the analysis was entered into an Excel worksheet indexed according to end-point, inflow scenario, consequence level, ecological concepts and consequence level sub-criterion. Data filtering applied to these indices allowed for convenient retrieval of summary statistics to support evaluation of output.

3.2.2 Assigning likelihood and consequence

The aim of this analysis was to estimate the likelihood, based on the evidence (summary statistics), that each consequence level is the worst observed over the timeframe of the risk assessment. The analysis is made for each consequence level starting from the most severe level (very significant) and progressing to the least severe consequence (insignificant or goal condition), with the analysis considering the entire model run minus the first two years for each case.

A framework for assigning likelihood was established as follows:

- Likelihood = 0 IF the threshold is not met (high certainty)
- Likelihood = 1 IF the threshold is met ≥20% simulation years/months (high certainty)
- 0 < Likelihood < 1 IF the threshold is met <20% simulation years/months (uncertain)

Criteria were established to assign likelihood for those cases meeting the third (uncertain) condition based on the number of years or months for which the consequence was triggered. Separate criteria were developed for nutrients relative to salinity and water level to account for the shorter simulation period for this end-point (six years vs 30 years).

3.2.3 Likelihood criteria – salinity and water level.

Model outputs are over a 30 year period for current condition and climate change forecast (two sets of 30 years). An assumption was made that if the threshold was reached for 20% or more of the years in the modelled time series, then the likelihood of this outcome occurring over a future 30 year period is one (100%). When a threshold is reached for less than the 20% of the model run years, then the chance of this consequence level is less than one, according to the following scale:

Time series threshold	Outcome likelihood
> 6 years	1
5 years	0.9
4 years	0.7
3 years	0.5
2 years	0.3
1 year	0.1

Criteria for "water level" consequence levels consider thresholds in three seasons over a year, which gives three sub-criteria (Table 3.1). In this case an "OR" relationship is applied for the sub-criteria – i.e. if any one of the seasonal thresholds are exceeded, the corresponding consequence level is triggered.

3.2.4 Likelihood criteria – nutrients

Model outputs are over a six-year period. For the purposes of ERAF assessment, monthly thresholds exceedances were tallied. An assumption was made that if the threshold was reached in over 20% of months then the likelihood of the consequence level is one (100%). If a threshold was exceeded for less than 20% of months then the likelihood of the consequence level is less than one according to the following scale:

Time series threshold	Outcome likelihood
> 15 months	1
13 months	0.8
11 months	0.7
9 months	0.6
7 months	0.5
5 months	0.4
3 Months	0.3
1 month	0.2

The nutrients consequence criteria has two sub-criteria according to season (Table 3.1). As with the water level sub-criteria, an "OR" relationship is applied meaning that the likelihood of this endpoint consequence level is determined by the highest consequence level of the sub-criteria.

4 Step 3: Evaluation

This step evaluated the likelihood distributions for the level of risk posed to the ecosystem posed by water levels, salinity and nutrients from the ERAF analysis into scores against the MCA performance criteria (i.e. ecological risk and benefit in the CSL and CNL)

Likelihood distributions were converted into scores by:

i) Assigning weighting values to the different end point criteria informing the two MCA performance criteria based on ecological functions of each ERAF end-point for that performance criteria.

ii) Assigning utility values for the five consequence levels for each ERAF end point, where the worst outcome (very significant deviation) is one and the desired state (insignificant deviation) is 10.

iii) Calculating the expected utility value score (1-10) for each ERAF end-point, ecological options and climate (inflow) scenario by multiplying the likelihood of each of the five consequence levels with its likelihood and summing the results.

iv) Calculating scores for each of the MCA environmental performance criteria as the weighted sum of the expected utility values for the related ERAF end-points in the CSL and CNL.

As a principle, ecological benefit is indicated where an option has higher expected utility value than the base case for a given end-point. Conversely, ecological risk is indicated where an option has lower expected utility value than the base case.

4.1 End-points and performance criteria

Two performance criteria were defined for criterion 4 (Environmental and Ecological), which relate to ecological risk and benefit in the CSL and CNL respectively (Table 1.2Table 1.2).

The five ERAF end-points are representative of the two MCA performance criteria representing risk and benefit in the CSL and CNL (Figure 4.1). The CSL performance criteria is informed by three end point criteria: CSL salinity, CSL nutrients and CSL water level while the CNL performance criteria is informed by two end-points: CNL salinity and CNL nutrients (Table 4.1).

The project team, with the help of technical experts, workshopped the relative weighing of each end point criteria for the two performance criteria based on the impact those parameters would have on the end-point.

Nutrients were weighted (40%) higher than water level (30%) and salinity (30%) for the CSL performance criteria. This reflects a primary operational target for CIIP infrastructure to manage the systems to initially restore the nutrient dynamics (levels and variance) of the CSL. The current state of the CSL as an algae dominated hyper-eutrophic ecosystem has become more pronounced since the Millennium Drought and impedes the recovery of other ecological functions.

As long-term nutrient loads that reside in the system are reduced, a strategy that enables salinity and water level regime management will become a higher priority. Longer-term maintenance to deliver whole of site sustainable operations then becomes feasible on the basis that nutrient dynamics have been successfully rehabilitated in the short-medium term.

Table 4.1 Links between the ERAF and MCA process.

Performance Criteria	ERAF assessment	ERAF end-points	Weight
Opportunity for the proposed infrastructure and management option to improve the ecological character, and reduce risk of environmental consequences and/or loss of key ecological values of the CSL.	Determine probability distributions of consequence for three end-points by comparison of modelling output to consequence criteria. Determine utility value of the infrastructure and management options as the weighted sum for probability distributions for each-end point. Sum utility values for three end-point and scale to 1-10 scores, where 10 corresponds to the desired state.	CSL nutrients	40%
		CSL water level	30%
		CSL salinity	30%
Opportunity for the proposed infrastructure and management option to improve the ecological character, and reduce risk of environmental consequences and/or loss of key ecological values of the CNL	Same method as used for CSL (as above). Inputs to the calculation of utility value are two agreed ERAF end-points for CNL.	CNL nutrients	50%
		CNL salinity	50%

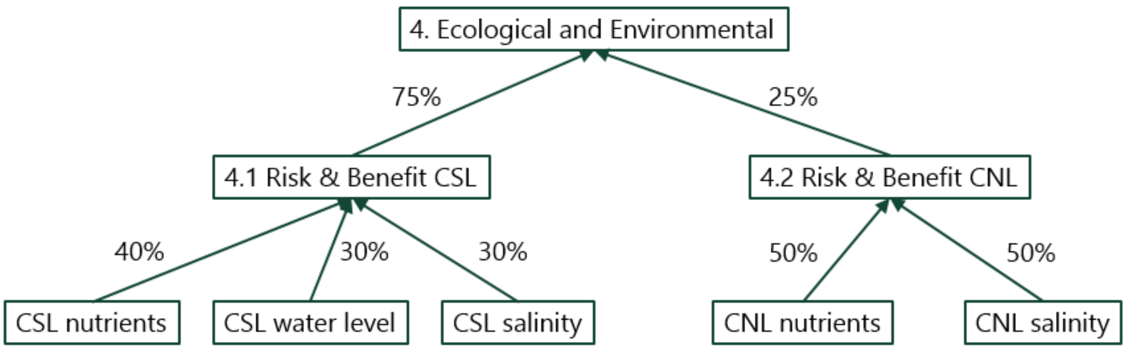


Figure 4.1 MCA criteria and performance criteria, and ERAF end-points.

4.2 Expected utility value

Calculation of expected utility required the assignment of utility values to the different consequence levels for each of the end-points. The utility values for each consequence level aim to reflect the extent to which ecological outcomes are consistent with objectives in accordance with the ERAF consequence criteria (i.e. the "utility" of an option relative to the end-point in question).

The project team workshopped the utility values for each end-point with technical experts, and also addressed the type of relationship between the different consequence levels in terms of their utility (e.g. more difference between a minor and moderate consequence than between a significant and very significant consequence)

Technical experts determined that the relationship between consequence level and utility value varied according to the ERAF end-points. A relatively high value (e.g. seven or eight) was established for moderate consequence level for CSL and CNL salinity and CSL water level (Figure 4.1, Table 4.5 and Table 4.3 respectively), whereas a low value (e.g. three) was set for moderate consequence level for CSL and CNL nutrients (Table 4.4 and Table 4.6).

Table 4.2 CSL salinity utility value for ERAF consequence levels.

Consequence level	Outcome	Utility Value
Insignificant	Average daily salinity in the CSL < 60 ppt year-round	10
Minor	Maximum average daily salinities in the CSL are 60-100 ppt	9
Moderate	Average daily salinity in the CSL are > 60 ppt in winter and annual maximum salinity is >100 ppt	7
Significant	Average monthly salinity exceeds 100 ppt for 6 to 18 consecutive months	2
Very Significant	Average monthly salinity exceeds 100 ppt for ≥ 18 consecutive months	1

Table 4.3 CSL water levels utility value for ERAF consequence levels.

Consequence level	Outcome	Utility Value
Insignificant	Water levels are on 100% of days: • >+0.3 m AHD from June and August, • >+0.2 m AHD from September to December, and • > -0.5 m AHD from January to March.	10
Minor	Water levels are on 100% of days: • >+0.3 m AHD from June and August >80% of days, • >+0.2 m AHD from September to December for >80% of days, and • > -0.5 m AHD from January to March.	8
Moderate	Water levels are: • >+0.3 m AHD from June to August >70% of days, • >+0.2 m AHD from September to December for >70% of days, and • >-0.5 m AHD from January to March.	7
Significant	Water levels are: <+0.3 m AHD for all days between June and August **or** <+0.2 m AHD for all days between September and December **or** are between -0.5 and -0.8 m AHD for ≥1 day from January to March.	3
Very significant	Water levels are: <0 m AHD for > 8 consecutive months **or** fall below -0.8 m AHD between January and March for ≥1 day.	1

Table 4.4 CSL nutrients utility value for ERAF consequence levels.

Consequence level	Outcome	Utility Value
Insignificant	<1 mg/L Total Nitrogen (TN) and <0.1 mg/L Total Phosphorus (TP) as per Australian Water Quality Guidelines (2018)	10
Minor	Average monthly TN >1 mg/L and/or TP > 0.1 mg/L for <2 months	8
Moderate	Average monthly TN >2 mg/L and/or TP > 0.2 mg/L for 2-6 consecutive months	3
Significant	Average monthly TN > 3 mg/L and/or TP > 0.3 mg/L for 6-18 consecutive months	2
Very significant	Average monthly TN > 3 mg/L and/or TP > 0.3 mg/ for ≥18 consecutive months	1

Table 4.5 CNL salinity utility values for ERAF consequence levels.

Consequence level	Outcome	Utility Value
Insignificant	Average monthly salinity < 45 ppt	10
Minor	Average monthly salinity > 45 ppt for < 2 months	9
Moderate	Average monthly salinity > 45 ppt for 2-6 months	8
Significant	Average monthly salinity > 70 ppt for 6-18 consecutive months	4
Very significant	Average monthly salinity > 70 ppt for ≥18 consecutive months	1

Table 4.6 CNL nutrients utility value for ERAF consequence levels.

Consequence level	Outcome	Utility Value
Insignificant	<1 mg/L Total Nitrogen (TN) and <0.1 mg/L Total Phosphorus (TP) as per Australian Water Quality Guidelines (2018)	10
Minor	Average monthly TN >1 mg/L and/or TP > 0.1 mg/L for <2 months	8
Moderate	Average monthly TN >1 mg/L and/or TP > 0.1 mg/L for 2-6 consecutive months	3
Significant	Average monthly TN > 2 mg/L and TP > 0.2 mg/L for 6-18 consecutive months	2
Very significant	Average monthly TN > 2 mg/L and TP > 0.2 mg/L for ≥18 consecutive months	1

4.3 Red flags

Some infrastructure and management options under consideration may reach an impasse at any stage in the project regardless of the MCA scoring and final ranking of the infrastructure and management options. Such an impasse may result from challenges relating to technical, constructability, operability, ecological risks, cultural sensitivities and/or other factors that render an option as being unable to progress further to implementation of the proposed infrastructure.

Identification of these impasses (i.e. red flags) involves assessment of risks associated with specific end-point variables. This ensures that the MCA process does not recommend infrastructure and management options that cause unacceptably high risks despite scoring well according to other end-points.

This risk assessment process will follow a similar method to the risk evaluation step undertaken by ERAF Phase 1 ecological investigations, but will focus on those options and end-points where the utility value was found to be lower than that of the base case scenario.

Utility value results for all end-points are colour coded based on the level of improvement or deterioration in relation to the base case scenario. In this case, red versus green does not represent a healthy versus unhealthy conditions, but deterioration versus improvement of CIIP scenarios compared with the base case scenario.

5 MCA results

Following the methodology described in Sections 3 and 4 and based on the modelling outputs described in Section 2, a utility value between one and 10 was calculated for the two performance criteria (CSL and CNL) and each ERAF end-points for all the ecological concepts and the base case. These utilities values are summarised in Figure 5.1

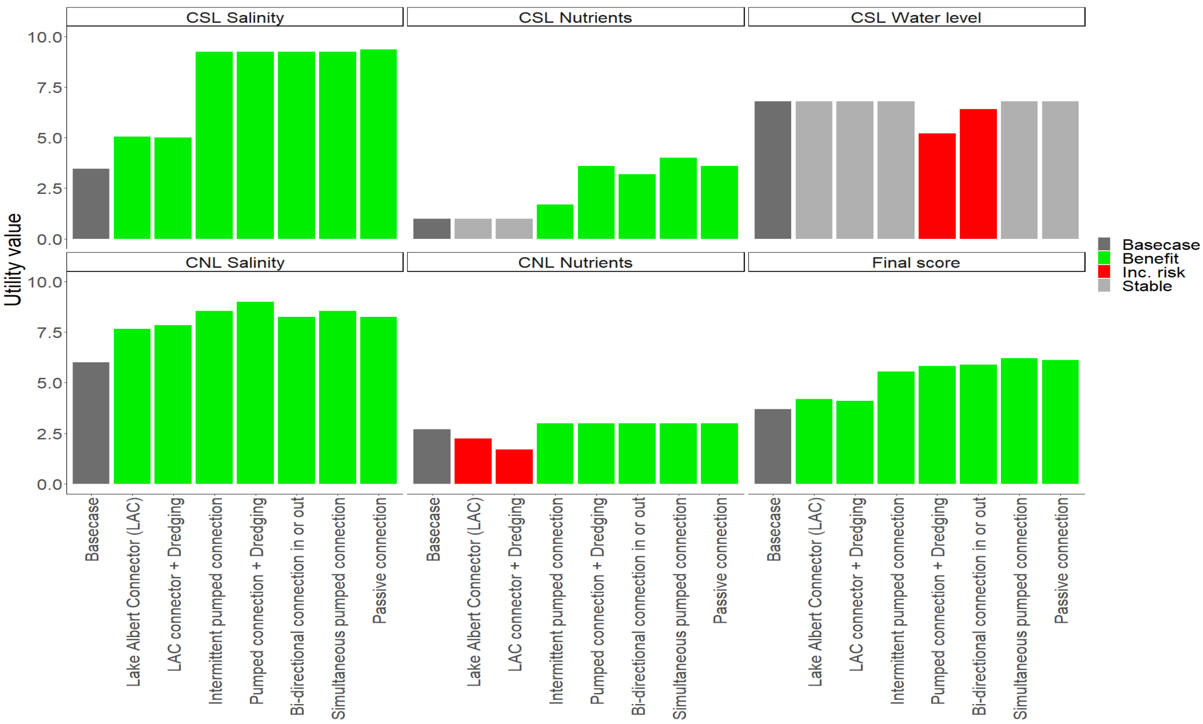


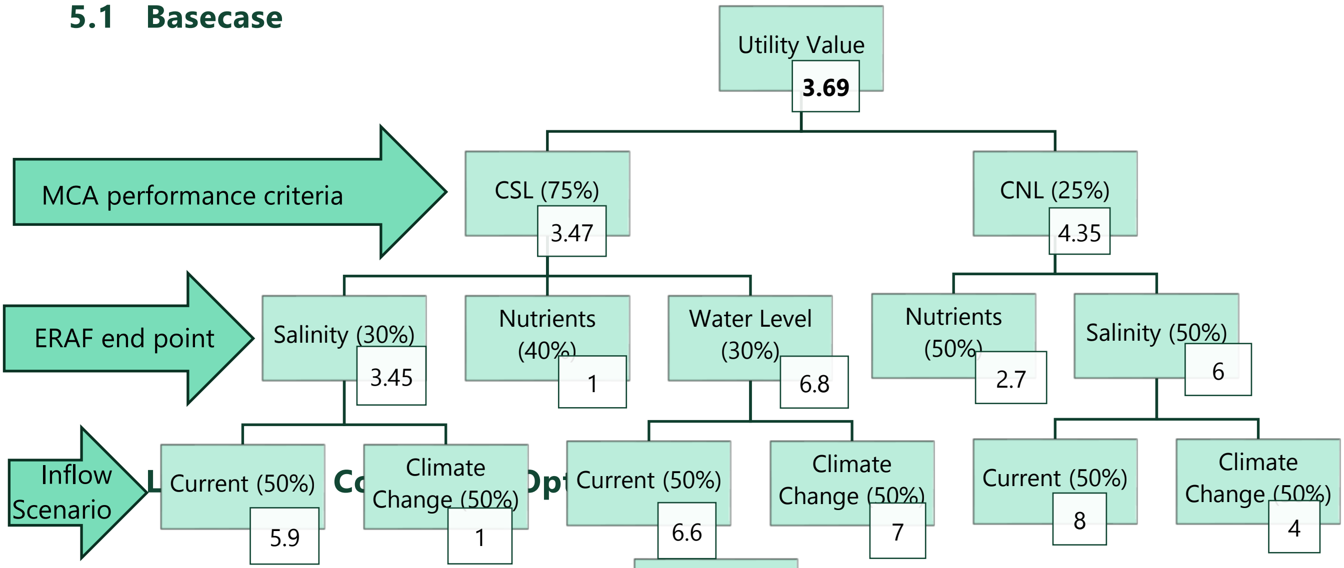
Figure 5.1 Utility values for each end-point and each performance criteria (CSL and CNL)

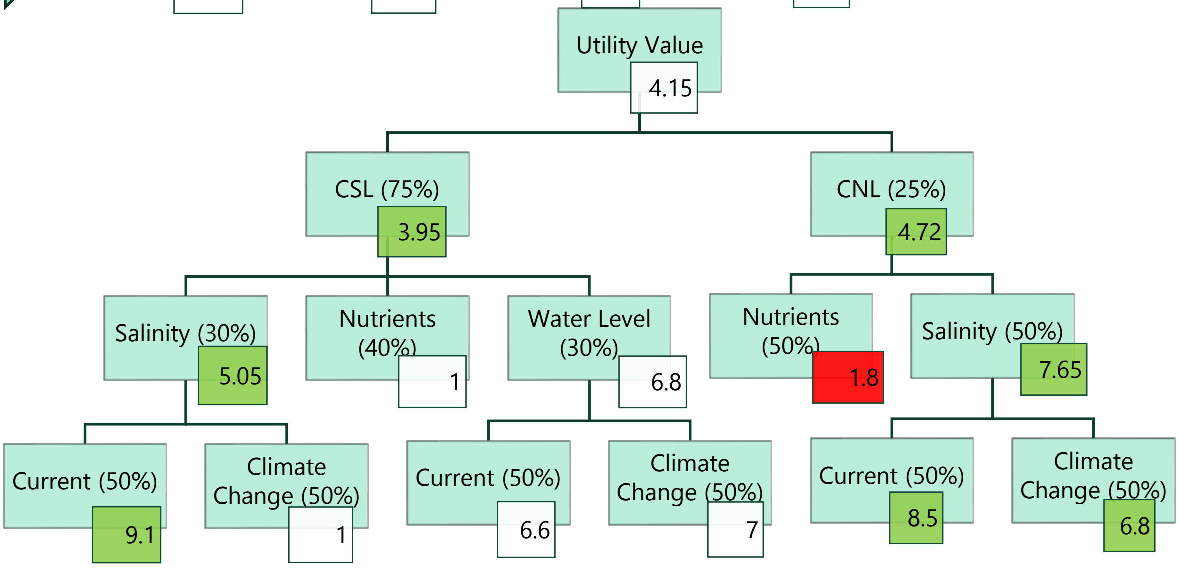
For water level and salinity end-points, utility values were calculated separately for both inflow scenarios (current and climate change) and total utility value for that end-point was considered as an average of both inflow scenarios utility values.

The figures below (i.e. in 5.1-5.8) provide a detailed summary of utility values for the base case and the seven ecological concepts. The Lake Albert connector was modelled twice using water quality parameters from Lake Albert and Lake Alexandrina. The *Lake Albert Connector improved water quality* scenario assumes that after a period of flushing, water quality (i.e. nutrient concentration) in Lake Albert would improve and would be similar to that in Lake Alexandrina. The values for salinity and water level remain unchanged between the *Lake Albert Connector* scenario and the *Lake Albert Connector improved water quality* scenario.

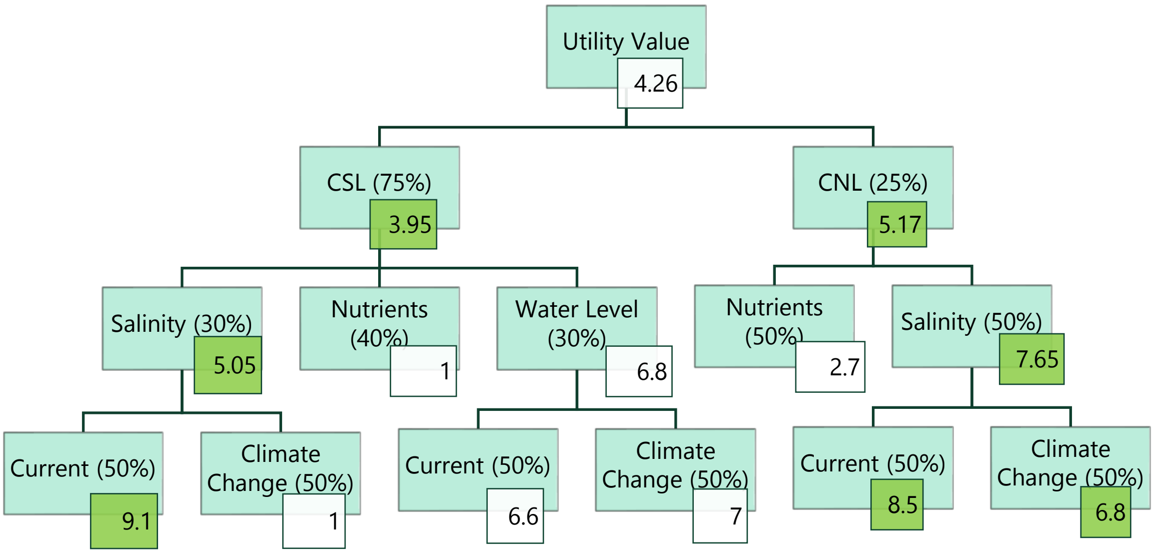
The *Circulation pump in and out* concept was modelled twice to test the difference between circulation direction and pumping locations.

5.1 Basecase



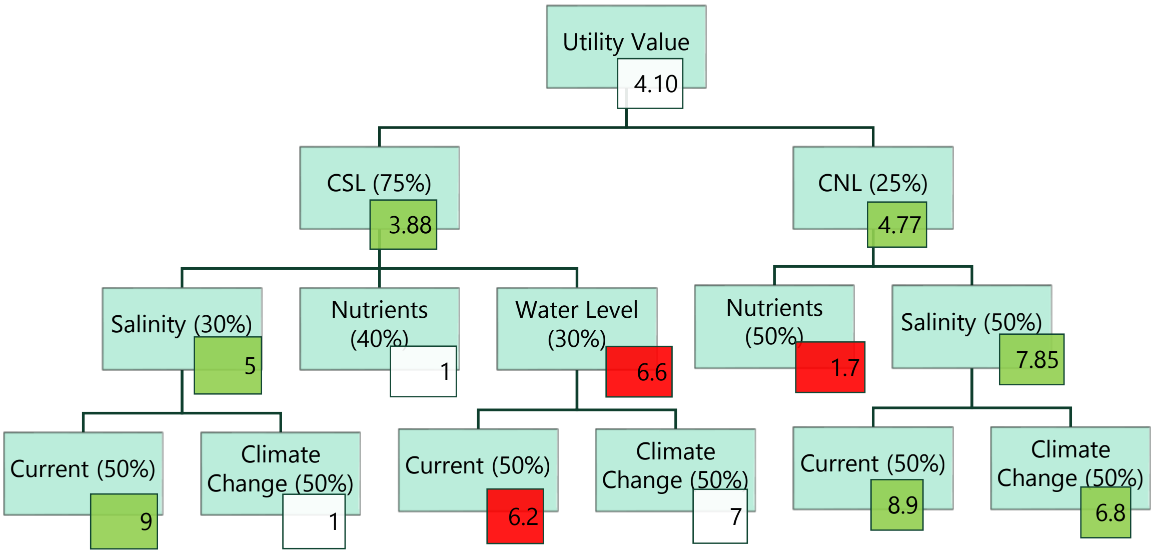


Lake Albert Connector scenario

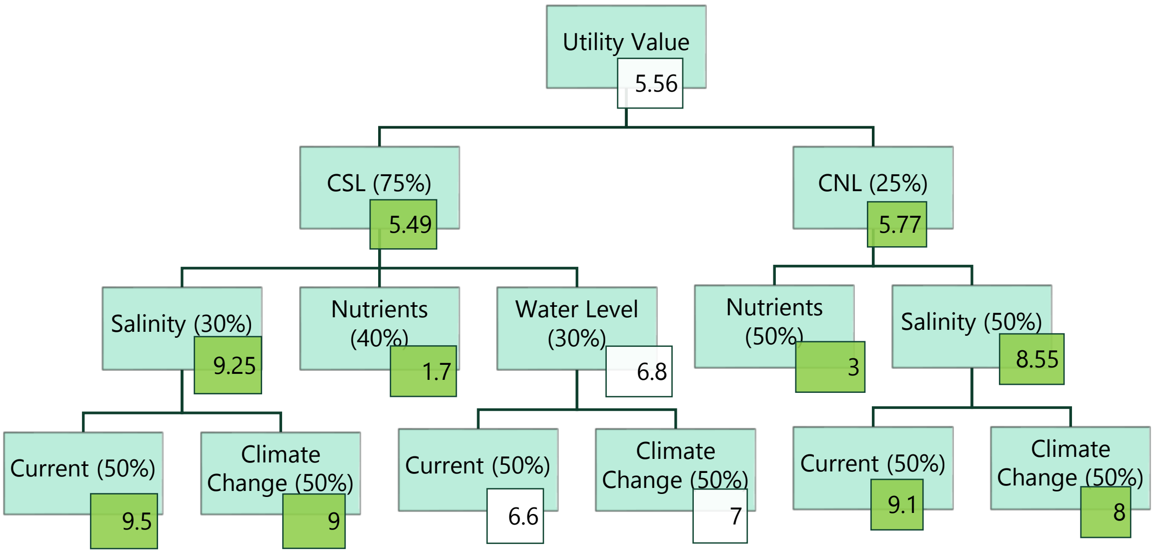


Lake Albert Connector improved water quality scenario

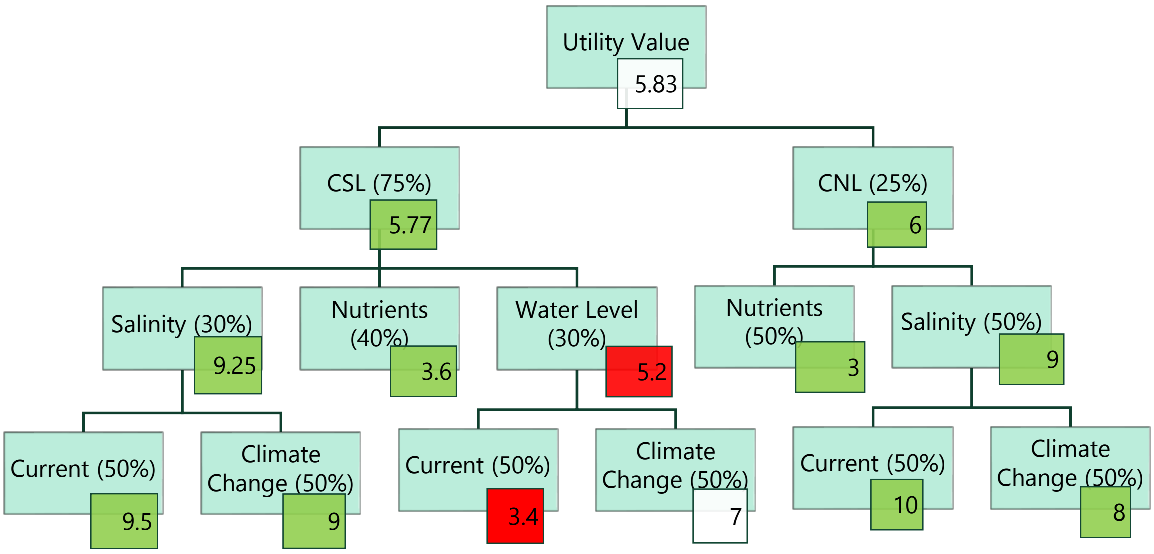
5.3 Lake Albert Connector and dredging (Option 01_2)



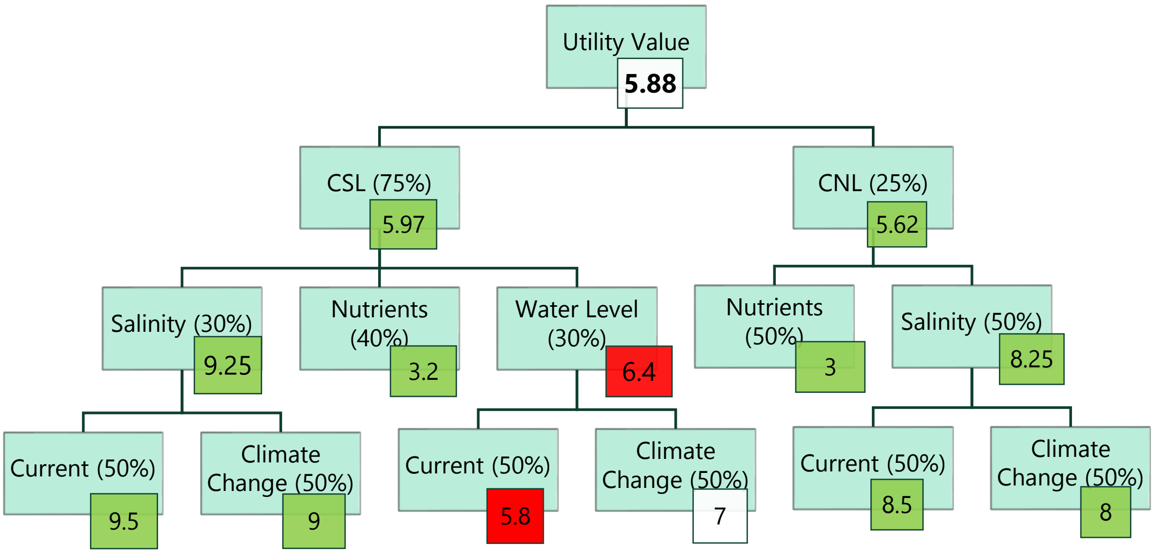
5.4 Pump out with water levels triggers (Option 03)



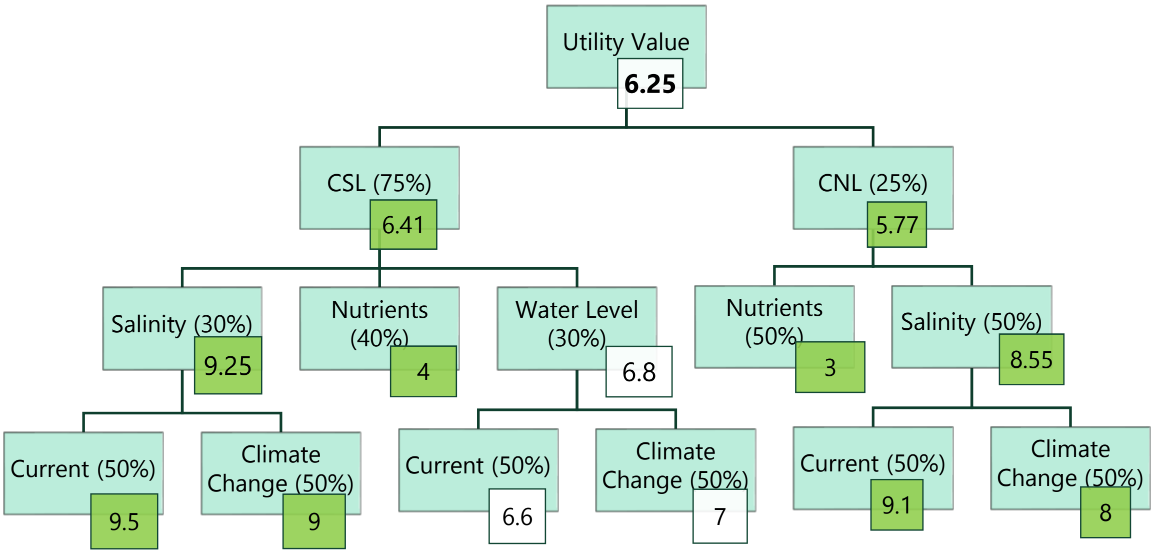
5.5 Pump out with dredging (Option 03_2)



5.6 Pump in or out not simultaneous (Option 04)

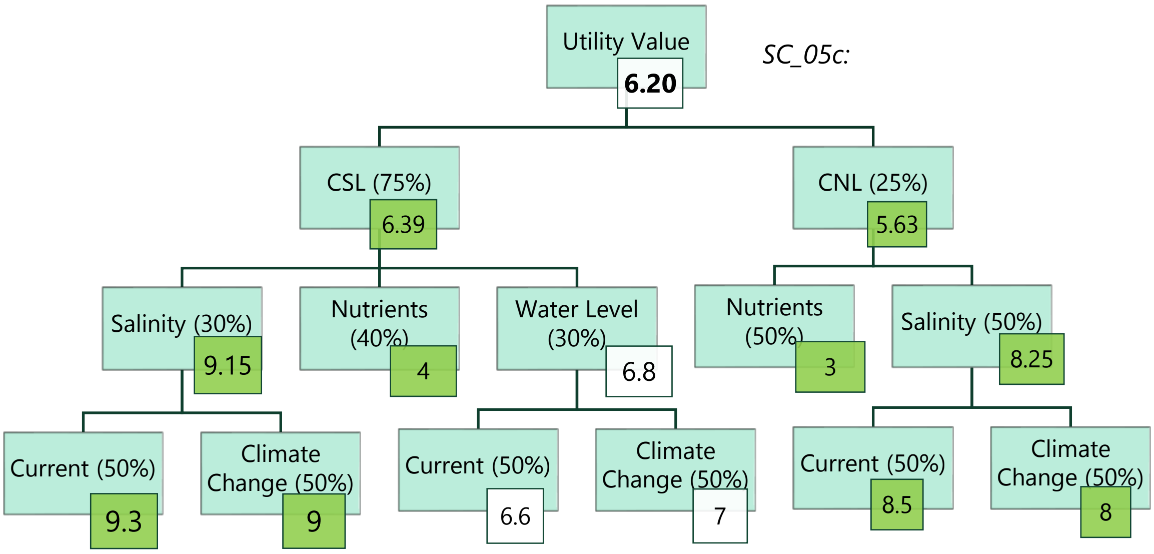


5.7 Circulation pump in and out (Option 05)



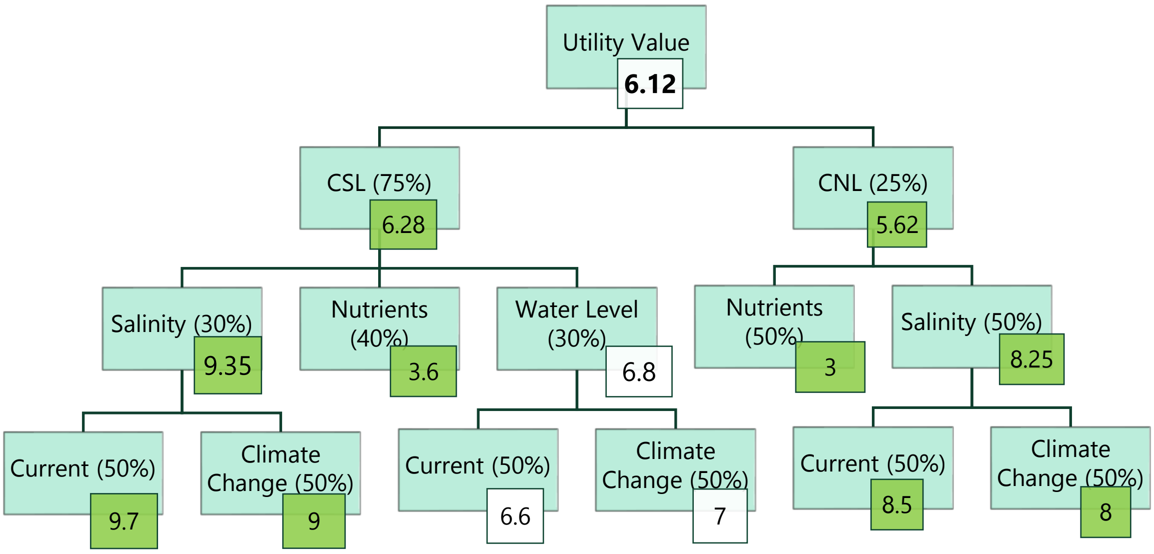
Circulation Scenario A: pump in at Round Island and out at Policeman Point

SC_05c:



Circulation Scenario B: pump in at Policeman Pt when water levels are <+0.3 m AHD and pump out at Parnka

5.8 Passive connection (Option 06)



5.9 Red Flags

Ecological Concepts	Inflow	End Point Criteria	Utility value impact	Description	Ecological Impact
Lake Albert Connector (LAC)	Current	CNL nutrients	-0.9	Under the base case, CNL nutrients did not trigger the threshold for very significant consequence. Likelihood for significant consequences is 0.3, caused by observance of average monthly TN > 2 for 6 or more consecutive months over the simulation period. Under this option, the likelihood of a very significant consequence was 0.2 caused by TN > 2 for 18 or more consecutive months. Furthermore, TN is higher than base case over the entire time series.	An ecological assessment of this red flag determined that the risk caused by the impact of this option on CNL nutrients is high because the potential for high TN levels causing significant ecological harm cannot be managed through operational controls. Furthermore, this option was judged to be higher risk than LAC + Dredge due to lower connectivity between the CSL and CNL leading to potentially worse conditions in the system.
LAC connector + Dredging	Current	CSL water levels	-0.4	Under the base case, the likelihood of a significant consequence for CSL water levels was 0.1, caused by a single observance of water level thresholds during the June to August and September to December periods. Under the SC_01_2 option, the likelihood of a significant consequence was 0.2. This was caused by a one and two observances of water level thresholds in the January to March, and September to December thresholds, respectively.	An ecological assessment of this red flag determined that the risk caused by the impact of this option on CSL water levels is low due to the relatively minor magnitude of the potential ecological impacts relative to base case. However, it was determined that risk posed by this option is higher than the option 04 (albeit still low), because drops in water level are not manageable through operational controls.
LAC connector + Dredging	Current	CNL nutrients	-1	Under the base case, CNL nutrients did not trigger the threshold for very significant consequence. Likelihood for significant consequences is 0.3, caused by observance of average monthly TN > 2 for 6 or more consecutive months over the simulation period. Under this option, the likelihood of a very significant	An ecological assessment of this red flag determined that the risk caused by the impact of this infrastructure and management options on CNL nutrients is high because the potential for high TN levels causing significant ecological harm

Ecological Concepts	Inflow	End Point Criteria	Utility value impact	Description	Ecological Impact
				consequence was 0.3 caused by TN > 2 for 18 or more consecutive months. Furthermore, TN is higher than base case over the entire time series.	cannot be managed through operational controls.
Pump out connection + Dredging	Current	CSL water levels	-3.2	Under the base case, the likelihood of a significant consequence for CSL water levels was 0.1. This was caused by a single observance of water level thresholds during the June to August and September to December periods. Under the SC_03_2 option, the likelihood of a significant consequence was 0.9. This was caused by five observances of water level below -0.5m AHD for one or more days from January to March, and a single observance of water level thresholds in the June to August and September to December periods. Drops in water level from January to March could affect breeding islands and benthic macroinvertebrates.	An ecological assessment of this red flag determined that the risk caused by the impact of SC_03_2 on CSL water levels is low because drops in water level causing significant ecological harm are likely to be manageable through operational controls.
Bi-directional connection in or out (one way at a time)	Current	CSL water levels	-0.8	Under the base case, the likelihood of a significant consequence for CSL water levels was 0.1, caused by a single observance of water level thresholds during the June to August and September to December periods. Under the SC_04 option, the likelihood of a significant consequence was 0.3. This was caused by a one, one and two observances of water level thresholds in the January to March, June to August and September to December thresholds, respectively.	An ecological assessment of this red flag determined that the risk caused by the impact of SC_04 on CSL water levels is low because drops in water level causing significant ecological harm are likely to be manageable through operational controls.

6 Findings

6.1 Key Findings

Ecological Concepts	Key Findings
Lake Albert Connector (LAC)	The LAC option significantly reduced the risk associated with salinity in the CNL and CSL under the current climate scenario, with salinities in both lagoons approaching desired conditions. However, under the climate change scenario, the LAC did not alleviate risk to the ecosystem posed by salinity. The risk posed by inadequate water levels in the CSL under this option were equal to that of the base case. This option poses a greater risk to nutrient conditions in the CNL compared with the base case scenario. However, this risk is not found in the LAC improved scenario; where water quality of Lake Alexandrina was used to represent future water quality of Lake Albert after being flushed by the connector
LAC connector + Dredging	The salinity outcomes under the LAC and dredging option were comparable to that of the LAC option. Therefore, dredging at Parnka Point provided no additional benefit. The LAC and dredging option increased the risk associated with inadequate water levels in the CSL under current inflow conditions, however, this impact was not observed under the climate change scenario. Simulations of LAC and dredging were not conducted using water quality measures from Lake Alexandrina. However, the risk associated with nutrient conditions under this option is expected to be similar to that of the LAC option simulated with Lake Alexandrina water quality measures.
Pump out connection with water level triggers	This option significantly reduced the risk associated with salinity in the CNL and CSL under both the current climate and climate change scenarios, with salinities in both lagoons approaching desired conditions. However, with respect to the base case, this option only marginally reduced the risk posed by nutrients in the CNL and CSL and did not reduce the risk of inadequate water levels in the CSL.
Pump out connection + Dredging	This option significantly reduced the risk associated with salinity in the CNL and CSL under both the current climate and climate change scenarios, with salinities in both lagoons approaching desired conditions. The influence of pumping out and dredging also was one of the best options for reducing risk posed by nutrients to the CNL and CSL, despite the significant residual risk. The risk posed by inadequate water levels in the CSL increased under this option, however, operational controls may help to mitigate this adverse impact.

Ecological Concepts	Key Findings
Bi-directional connection in or out (one way at a time)	This option significantly reduced the risk associated with salinity in the CNL and CSL under both the current climate and climate change scenarios, with salinities in both lagoons approaching desired conditions. Bi-directional connection in or out was also one of the best options for reducing risk posed by nutrients to the CNL and CSL, despite the significant residual risk. The risk posed by inadequate water levels in the CSL increased under this option, however, operational controls are likely to avoid or mitigate this adverse impact.
Circulation - Simultaneous pumped connection	The circulation option was for the most effective at reducing the risk posed by nutrients across the CNL and CSL. However, nutrients still pose significant residual risk to the Coorong ecosystem even under this best performing option. This option also significantly reduced the risk associated with salinity in the CNL and CSL under both the current climate and climate change scenarios, with salinities in both lagoons approaching desired conditions. The risk posed by inadequate water levels in the CSL under this option was equal to that of the base case.
Passive connection	The passive connection option was the most effective at reducing the risk posed by salinity in the CSL, and also significantly reduced risk in the CNL. This option was effective under both current climate and climate change scenarios. Bi-directional connection in or out was also one of the best options for reducing risk posed by nutrients to the CNL and CSL, despite the significant residual risk. The risk posed by inadequate water levels in the CSL under this option was equal to that under the base case.

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