South East Flows Restoration Project

Water quality risk assessment for the Coorong

DEWNR Technical report 2016/01

Government of South Australia
Department of Environment, Water and Natural Resources

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Foreword

The Department of Environment, Water and Natural Resources (DEWNR) 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.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management 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.

Sandy Pitcher
CHIEF EXECUTIVE
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Introduction

The South East Flows Restoration Project (SEFRP) aims to enable the diversion of additional water from the South East drainage system to the Coorong South Lagoon (CSL) to help maintain salinity within the ecologically defined management target range of 60 to 100 g/L. It will also provide additional flows to wetlands *en route*.

While the SEFRP is intended to reduce risks to the ecological character of the Coorong caused by excessive salinity, the project itself may cause unintended water quality risks.

The SEFRP Steering Committee initiated this risk assessment to:

- Identify potential water quality risks to the Coorong caused by the project
- Determine the level and tolerability of these risks
- Identify and evaluate the effectiveness of any treatment (management) options to reduce risks to tolerable levels.

The findings from this risk assessment will inform the design and operation of the SEFRP and contribute to the approval process for undertaking the project, as required by the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

Risk assessment

This risk assessment draws upon the concepts and processes of DEWNR's risk management framework for water planning and management (DEWNR 2012), based on the AS/NZS ISO 31000:2009 risk management standard. Under the standard, *risk* is defined as the effect of uncertainty on objectives, and *risk management* describes coordinated activities intended to direct and control an organisation with regard to risk.

According to the standard, the risk management process comprises three key steps:

1. Establishing the context
2. Assessing the risks, including:
    a. Risk identification
    b. Risk analysis
    c. Risk evaluation
3. Identifying risk treatments.

This report outlines the methodology used for the SEFRP Water Quality Risk Assessment and the results at each risk management step.

South East Flows Restoration Project

The Coorong is a large, internationally recognised estuary at the mouth of the River Murray. It is an important component of the Ramsar-listed Coorong and Lakes Alexandrina and Albert Wetland of International Importance.

Flows from the Murray–Darling Basin (MDB) over the barrages are a key driver of salinity in the Coorong, hence its ecological character (Phillips and Muller 2006). The only other source of fresh water (apart from local rainfall) is from the South East drainage system, but this is a relatively small volume (compared to River Murray flows) of seasonal flows discharged from the Morella Basin via Salt Creek into the Coorong South Lagoon. The recent 'Millennium Drought' of 1997 to 2010 had a profound impact on the Coorong ecosystem Years without significant flows over the barrages, supplemented only by the relatively minor flows from the South East, resulted in extreme hypersaline conditions in the Coorong South Lagoon. Subsequently the Coorong South Lagoon ecosystem changed profoundly. Aquatic vegetation (particularly the key species *Ruppia tuberosa*) was lost and important small-bodied fish species (e.g. the small-mouthed hardyhead, *Atherinosoma microstoma*) withdrew to the North Lagoon and Murray Mouth.

Since 2010, significant flows over the barrages, combined with increased flows from the South East, have reduced salinity in the Coorong South Lagoon and helped to maintain it generally within the ecological target range (60 – 100 g/L). However, the ecosystem has been slow to respond, demonstrating the long-term nature of impacts associated with periods of low River Murray flows and extreme salinity.

The SEFRP aims to:

1) Divert additional relatively fresh water from the South East drainage system to the Coorong to assist in managing salinity in the Coorong South Lagoon during periods of low River Murray flows, thus building resilience and promoting a healthy ecosystem; and

2) Provide additional environmental benefits by increasing the frequency and extent of inundation of the Tilley Swamp (design permitting) and Taratap wetlands in the Upper South East.

To achieve its aims, the SEFRP will modify and link elements of the existing Upper South East drainage system, using a combination of widened existing drains (totalling approximately 81 kilometres) and newly constructed drains (totalling approximately 12 kilometres). In a year of median run-off in the drainage system catchment, the new infrastructure will make available 26.5 GL of additional water to the Coorong South Lagoon. This additional water currently flows directly to sea via an artificial channel, the lower Blackford Drain.

In consultation with the local community and landholders, DEWNR has been investigating two design scenarios for the SEFRP:

- SEFRP Scenario 1 (S1): the 'fully channelised' option, whereby flows to the Coorong are confined to the existing Tilley Swamp drain *en route* to the Coorong, and
- SEFRP Scenario 2 (S2): the 'watercourse' option, whereby flows to the Coorong can be fully channelised to the Coorong if required, but the adjacent Tilley Swamp Watercourse can be used to convey and/or store water when appropriate.

Both of these options bring their own unique elements, benefits and limitations. This risk assessment is part of a larger process of determining the best option that will maximise the benefits while minimising and mitigating any risks.

Establishing the context

Experts in water quality, Coorong ecology and risk assessment, both internal and external to DEWNR, were invited to participate in the risk assessment. The external organisations involved were:

- The University of Adelaide
- Environmental Protection Authority
- Flinders University

- CSIRO
- SARDI Aquatic Sciences.

At the initial context setting workshop, participants agreed to the following general guidelines. The risk assessment should:

- Address sources of risk introduced by the SEFRP
- Consider unintended benefits caused by SEFRP as well as risks
- Consider both SEFRP design options
- Consider the current situation (Scenario 0) as a baseline against which to evaluate risks presented by the SEFRP (Scenarios 1 or 2)
- Be based on existing information and use existing tools and models
- Focus (as risk assessment end points) on ecological features of the Coorong that define its ecological character and are sensitive to the potential water quality risks of the SEFRP
- Identify risk treatment options to reduce the level of risk.

It was agreed that the risk assessment would consider the first 10 years of SEFRP operation.

The assessment focuses on the southernmost 56 linear km of the Coorong, covering the entire South Lagoon and approximately 5 km of the southernmost North Lagoon.

'End points' are the features or values that a risk assessment seeks to protect. In the Coorong South Lagoon these are:

- Tuberous sea-tassel *Ruppia tuberosa* – the only aquatic plant species present
- Small-mouthed hardyhead *Atherinosoma microstoma* – one of the more abundant fish species
- Aquatic larvae of the insect *Tanytarsus barbitarsis*, a chironomid or midge which occurs on seasonally and permanently inundated mudflats and is an important link in the food web.

Use of these three end points is consistent with contemporary scientific understanding and management of the Coorong.

Risk identification

Participants identified a number of potential sources of risk, events (changed water quality in the Coorong) and consequences (ecological changes in the Coorong) that could occur as a result of SEFRP. From these, 33 complete risk statements (Appendix A) were developed. These were grouped into seven categories:

1. Risks related to over freshening
2. Risks related to increased turbidity
3. Risks related to increased loading of total nutrients (nitrogen and/or phosphorus)
4. Risks related to increased loading of bioavailable nutrients (nitrogen and/or phosphorus)
5. Risks related to increased loading of total organic carbon (TOC) (comprising dissolved organic carbon (DOC) and particulate organic carbon (POC))
6. Risks related to changed water temperature

7. Risks during construction.

The risk analysis enabled these risk categories to be examined in combination (cumulative risk) and separately.

Risk analysis

A modelling approach to the risk analysis was adopted, using a Bayesian Belief Network (BBN) as the modelling platform. A BBN is a method to represent relationships between circumstances or variables ('nodes'), especially when these involve uncertainty, unpredictability or imprecision.

In this case, the BBN structure was comprised of 15 nodes. It was designed to comprehensively cover the risk statements, although some identified risk statements and potential cause-effect relationships were deemed of such low risk that they were omitted *a priori*, for sake of simplicity. These were:

- Risks related to construction, which it is assumed will be avoided by mandated water quality protection measures for construction in a watercourse.
- Risks related to changed water temperature, which participants concluded were low, as temperature profiles of inflows and receiving waters are unlikely to change under the SEFRP.
- Risks related to low dissolved oxygen on mudflats during shallow inundation/exposure, which participants concluded were unlikely to change under the SEFRP.

Having defined the overall BBN structure, the next task was to define an appropriate set of discrete categories for each node (a task referred to as 'discretisation'). Parameterisation for a BBN model is the task of assigning probabilities to describe belief regarding the state of each node. Appendix B contains a detailed description of each node in the BBN, including its discretisation and parameterisation, and the evidence supporting both.

A sensitivity analysis of the BBN was undertaken, showing that:

- the model adequately represents the knowledge that salinity, filamentous algae cover and chlorophyll *a* concentration (indicating phytoplankton abundance) are key influencers of *Ruppia*, small-mouthed hardyhead and chironomids in the CSL; and
- even accounting for uncertainty, risks relating to increased loading of TOC in the Coorong ("first flush" effect) are low.

Raw outputs of the BBN were evaluated using a first pass (low resolution) approach and second pass (high resolution) approach. These two approaches are mentioned below.

Conclusions

The conclusions of the risk assessment are valid provided that the following design, operational and monitoring features are incorporated into the SEFRP:

- The ability to divert Blackford Drain water to sea to avoid over freshening of the CSL
- The ability to slow or stop Salt Creek inflows to the Coorong by closing Morella Basin outlet regulator and storing water for later release or complete draw down (via evaporation and seepage) to create storage for the following winter. This applies to both SEFRP Scenarios 1 and 2, noting that S2 has a greater storage capacity than S1. The purpose is to avoid risks related to over freshening and bioavailable nutrients.

- Under SEFRP Scenario 2, to incorporate operational flexibility into the design such that flows through the Tilley Swamp Watercourse can either be held and allowed to draw down completely or allowed to pass through to Morella Basin the and Coorong. The purpose is to avoid risks related to over freshening, bioavailable nutrients and the first flush (total organic carbon).
- Existing real-time salinity monitoring in the CSL be should be maintained as it is necessary to avoid over freshening of the CSL.
- Real time water level gauges (i.e. storage volume) in Morella Basin (both S1 and S2), and Tilley Swamp Watercourse (S2 only) should be maintained and installed respectively. The purpose is to enable real time decision making regarding the diversion of Blackford Drain flows, which is necessary to avoid over freshening of the CSL.
- CSL salinity forecasting based on barrage flows forecasting should be incorporated into SEFRP operations. The purpose is to avoid over freshening.

The conclusions of the risk assessment are:

- Taken cumulatively, given both the first (low resolution) and second pass (high resolution) evaluations, there is a low risk that the SEFRP will lead to significant adverse impacts to the ecological character of the Coorong due to water quality changes. This conclusion applies to both SEFRP Scenarios 1 and 2.
- When considered individually, given the first pass (low resolution) evaluation, no risk category appears likely to cause a significant adverse impact to the ecological character of the Coorong due to water quality changes. This conclusion applies to both SEFRP Scenario 1 and 2.
- The second pass (high resolution) evaluation indicated a moderate risk to the vigour of *Ruppia* stands due to increased loading of bioavailable nutrients under SEFRP Scenario 2 (only), but this risk would readily be avoided by routine adherence to the existing salinity target minima for the CSL.

1 Introduction and context

1.1 Introduction

1.1.1 Risk assessment purpose

The SEFRP provides options to increase and flexibly manage freshwater inflows to the Coorong South Lagoon during periods when climatic and hydrological conditions in the Murray Darling Basin would place the ecosystem at significant risk of degradation.

While the SEFRP is intended to reduce risks to the ecological character of the Coorong caused by excessive salinity, stakeholders and experts have raised the possibility that the project itself may cause additional risks due to other water quality impacts. Therefore a risk assessment was undertaken with the purpose of:

- identifying potential risks to Coorong water quality caused by the project;
- determining the level and tolerability of these risks;
- identifying and evaluating the effectiveness of risk treatment (management) options.

The risk assessment findings documented in this report will inform:

1. decisions regarding the design and operation of the SEFRP
2. approvals for undertaking the project required by the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

1.1.2 Risk assessment approach

This risk assessment draws upon the concepts and processes of DEWNR's risk management framework for water planning and management (DEWNR 2012), based on the AS/NZS ISO 31000:2009 risk management standard. Under the standard, risk is defined as the effect of uncertainty on objectives, and risk management describes coordinated activities intended to direct and control an organisation with regard to risk.

According to the standard, the risk management process comprises:

1) Establishing context - determining the scope of the risks to be examined
2) Risk assessment, involving:
    a. Risk identification
    b. Risk analysis - determining the level of risk
    c. Risk evaluation – determining the tolerability of the risk
3) Risk treatment – identifying strategies to reduce the level of risk.

This report outlines the presents the methodology used for the SEFRP water quality risk assessment and the results for each of the above risk management steps.

1.2 Background

1.2.1 The Coorong

The Coorong is a large estuary situated at the mouth of the River Murray (Figure 1). Recognised internationally for the spectacular abundance and diversity of its waterbirds, the Coorong forms an important component of the Ramsar-listed Coorong, Lakes Alexandrina and Albert Wetland of International Importance. From the Murray Mouth, the Coorong stretches for approximately 140 km in a south-easterly direction, separated from the Southern Ocean by the Younghusband Peninsula, a Holocene barrier dune, and terminates in the Upper South East region of South Australia.

The Upper South East of South Australia is a biologically rich, yet highly modified landscape (Foulkes and Heard 2003). Broadscale land clearance and the construction of an extensive drainage network has altered the wetland dominated landscape in favour of agricultural production. The South East drainage network, which collects and diverts slow-moving surface- and groundwater across natural dunal barriers to the Southern Ocean and Coorong South Lagoon, has reduced flooding, lowered saline watertables and resulted in significant agricultural productivity gains. However, this development has come at the cost of substantial local wetland habitat and has likely reduced surface and groundwater inflows to the Coorong (SEDB 1980).

Flows from the Murray–Darling Basin (MDB) over the barrages are an important component of the Coorong's hydrological regime, raising or lowering water levels. These flows are a key driver of salinity in the Coorong, hence its ecological character (Phillips and Muller 2006). The only other source of freshwater flow into the Coorong (other than local rainfall) is from the South East drainage network, a relatively small volume (compared to River Murray flows) of seasonal flows discharged from the Morella Basin via Salt Creek into the Coorong South Lagoon. The recent MDB drought of 1997 to 2010 had a profound impact on the Coorong ecosystem (Paton 2010). Years without significant flows over the barrages, supplemented only by the relatively minor flows from the South East, resulted in extreme hypersaline conditions in the Coorong South Lagoon. Subsequently the Coorong South Lagoon ecosystem changed profoundly. Aquatic vegetation (the key aquatic plant, the tuberous sea-tassel *Ruppia tuberosa*) was lost and small bodied fish species (particularly the small-mouthed hardyhead *Atherinosoma microstoma*) withdrew to the North Lagoon and Murray Mouth (Paton 2010).

Since 2010, significant flows over the barrages, combined with increased flows from the South East, have reduced salinity in the Coorong South Lagoon and helped maintain it generally within the ecological target range (60 – 100 g/L). However, the ecosystem has been slow to respond, demonstrating the long term nature of impacts associated with periods of low River Murray flows and extreme salinity.

1.2.2 The Coorong Lower Lakes and Murray Mouth (CLLMM) Recovery Project

The South East Flows Restoration Project (SEFRP) is one of 20 management actions being implemented by the Coorong Lower Lakes and Murray Mouth (CLLMM) Recovery Project, funded by the Commonwealth's Sustainable Rural Water Use and Infrastructure Program, and delivered through South Australia's Murray Futures Program. The CLLMM Recovery Project supports the CLLMM Long Term Plan, which aims to secure a future for the region as a healthy, productive and resilient Wetland of International Importance.

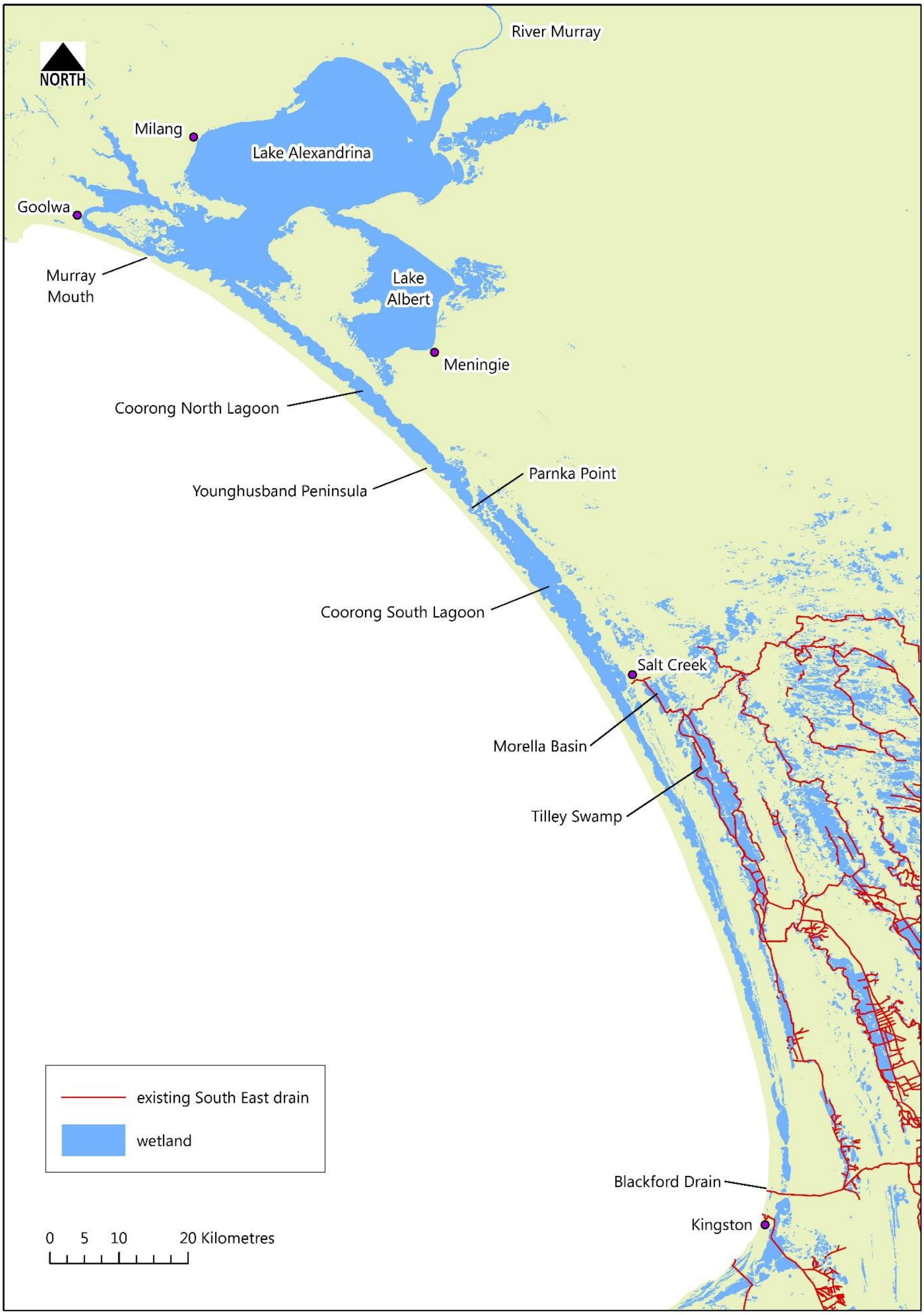

Figure 1. The Lower Lakes, Coorong and SEFRP project area

1.2.3 The South East Flows Restoration Project

The South East Flows Restoration Project (SEFRP) aims to:

1. Divert additional relatively fresh water from the South East drainage system to the Coorong to assist in managing salinity in the Coorong South Lagoon during periods of low River Murray flows, thus building resilience and supporting a healthy ecosystem
2. Provide additional environmental benefits by increasing the frequency and extent of inundation of the Tilley Swamp (design permitting) and Taratap wetlands in the Upper South East.

To achieve its aims, the SEFRP will modify and link elements of the existing Upper South East drainage system, using a combination of widened existing drains (totalling approximately 81 kilometres) and newly constructed drains (totalling approximately 12 km). The new infrastructure will make available, in a year of median run-off in the drainage system catchment, 26.5 GL of additional water to the Coorong South Lagoon. This additional water currently flows directly to sea via an artificial channel, the lower Blackford Drain. It flows from a catchment with very similar landuse to the existing Salt Creek catchment, primarily broad acre agriculture (sheep and cattle grazing) with some conserved native vegetation.

1.2.4 SEFRP design scenarios

In consultation with the local community and landholders, DEWNR has been investigating two scenarios for the SEFRP (Figure 2):

- SEFRP Scenario 1 (S1): the ‘fully channelised’ option, whereby flows to the Coorong are confined to the existing Tilley Swamp drain *en route* to the Coorong.
- SEFRP Scenario 2 (S2): the ‘watercourse’ option, whereby flows to the Coorong can be fully channelised to the Coorong if required, but the adjacent Tilley Swamp Watercourse can be used to convey and/or store water when appropriate.

Ecological, hydraulic and hydrological investigations of these two SEFRP scenarios have confirmed the feasibility of both options, without compromising the ability to deliver water to the Coorong.

Elements consistent to both scenarios are:

- Capacity to provide an additional 26.5 GL to the Coorong in a median year in the Salt Creek catchment
- Same catchment area
- Two way flow regulator at Blackford Drain, with ability to direct flow to sea via the existing lower Blackford Drain or to divert water towards the Coorong
- Construction works to create a new linking channel between the Blackford Drain and the existing Taratap Drain
- Upgrading of the existing Taratap and Tilley Swamp Drains to the required capacity.

Scenario 1 unique elements:

- Upgrading of existing Tilley Swamp Drain to capacity required to enable all flow to be fully channelised to Morella Basin and the Coorong
- No option of watering Tilley Swamp Watercourse
- Morella Basin remains the only storage basin *en route* to the Coorong, with a capacity of approximately 8 GL.

Scenario 2 unique elements:

- Upgrading of existing Tilley Swamp Drain to capacity required to enable all but very high (>600 ML/day) flow to be fully channelised to Morella Basin and the Coorong
- Optional diversion into Tilley Swamp Watercourse incorporated into design
- Storage *en route* expanded to include both Morella Basin and Tilley Swamp Watercourse, with a total capacity of approximately 42 GL.

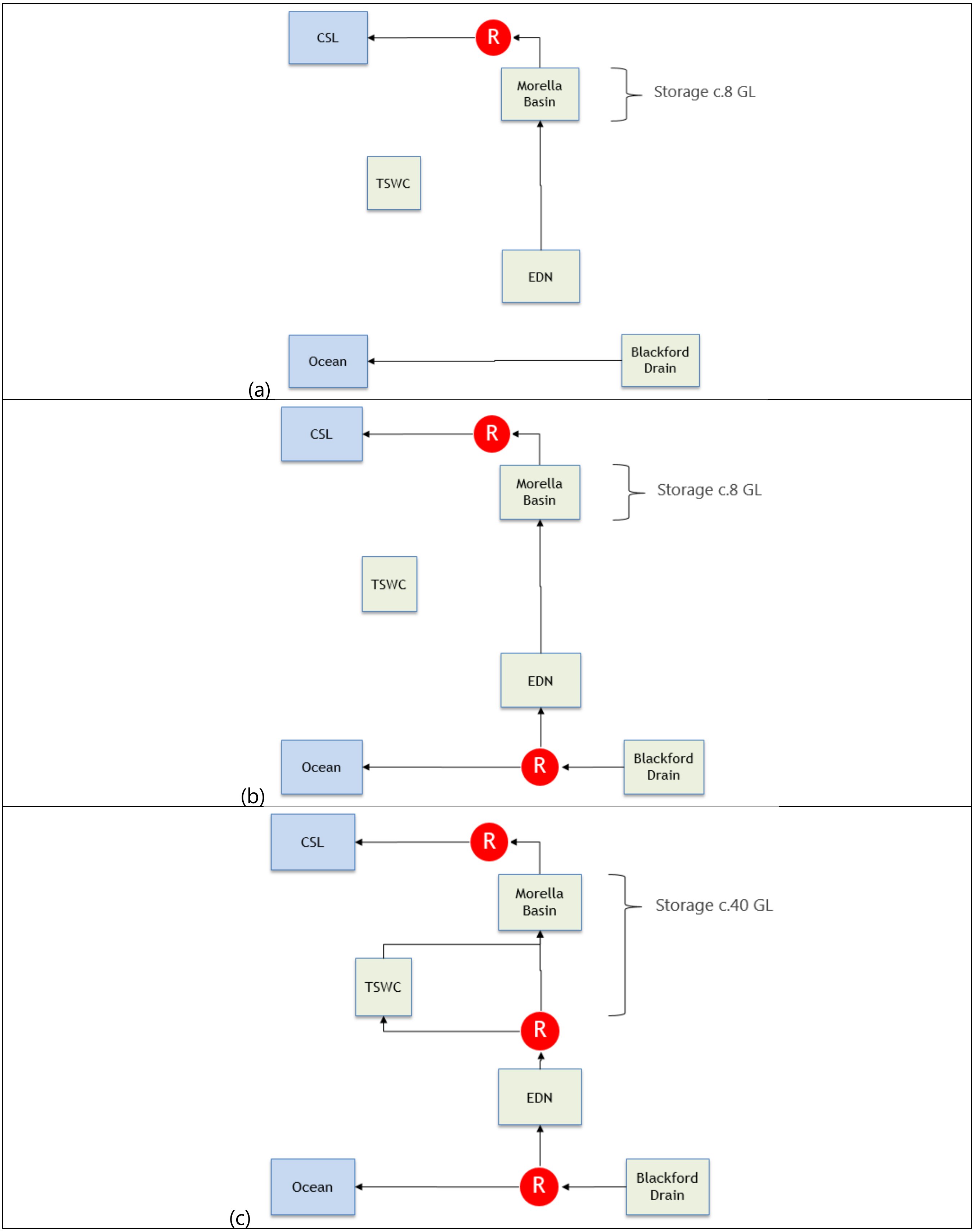

Figure 2. Schematic representation of (a) existing arrangements (Scenario 0), (b) Scenario 1 and (c) Scenario 2. CSL = Coorong South Lagoon, R = regulator, TSWC = Tilley Swamp Watercourse, EDN = existing drainage network.

2 Establishing the context

2.1 Expert participation

Experts in water quality, Coorong ecology and risk assessment, both internal and external to DEWNR, were a central part of the methodology. The experts were invited to participate in the risk assessment through:

- Attendance at workshops
- Supply of data
- Interpretation of data
- Preparation of supporting reports
- Review of the Bayesian Belief Network (BBN) model developed to analyse the risks and review of this report.

External organisations involved in the risk assessment included:

- The University of Adelaide
- Environmental Protection Authority
- Flinders University
- CSIRO
- SARDI Aquatic Sciences.

Five facilitated workshops were held and are summarised in Table 1. Additionally, a considerable amount of discussion and input occurred out of session.

Table 1. Summary of workshops held for the SEFRP WQRA

Workshop	Outcomes
Workshop 1 - 2 July 2015: **"Context Setting"**	Agreed scope, purpose and outcomes of risk assessment Understanding of the SEFRP and potential water quality impacts Agreed SEFRP design scenarios to be evaluated by the risk assessment Agreed risk assessment process
Workshop 2 - 29 July 2015: **"Risk Identification"**	Agreed risk assessment end point (consequence) indicators Risk statements (see Appendix A – Complete risk statements)
Workshop 3 – 16 September 2015: **"Risk Analysis"**	Agreed BBN model structure Feedback in BBN variables and values
Workshop 4 – 23 September 2015 **"Risk Treatment"**	Proposed risk treatments

Workshop	Outcomes
Workshop 5 – 11 November 2015: **“Review”**	Comments on draft report received

2.2 Risk assessment scope

2.2.1 Scope

At the initial context setting workshop participants agreed to the following general guidelines. The risk assessment should:

- Address sources of risk introduced by the SEFRP
- Consider unintended benefits caused by SEFRP as well as risks
- Consider both SEFRP design options
- Consider the current situation (Scenario 0) as a baseline against which to evaluate risks presented by the SEFRP (Scenarios 1 or 2)
- Be based on existing information and use existing tools and models
- Focus (as risk assessment end points) on ecological features of the Coorong that define its ecological character and are sensitive to the potential water quality risks of the SEFRP
- Identify risk treatment options to reduce the level of risk.

It was noted that one of the benefits of the risk assessment is that it will serve to build an understanding of existing data and information relating to water quality, potentially informing future monitoring and management.

2.2.2 Exclusion (out of scope)

It is recognised that water level is a key determinant of ecosystem health in the Coorong, but it is also understood from modelling (Jöhnk and Webster 2014) and monitoring (Mosely 2015) that Salt Creek flows have negligible influence on Coorong water levels. Therefore the risk assessment has not focussed on the issue of Coorong water levels.

It was agreed that while risks to social and economic values of the Coorong may be identified, they would not be quantified as part of this risk assessment. Rather, the risk assessment is focused on ecological values.

2.2.3 SEFRP design assumptions

For this risk assessment the following assumptions have been made regarding the SEFRP design scenarios:

- If the Coorong South Lagoon is sufficiently fresh when flows from the South East are available, under Scenario 2 water can be used to enhance local wetland values, rather than be diverted to sea via the lower Blackford Drain, as required under Scenario 1. In this way Scenario 2 would restore flows to approximately 4500 ha of wetland in the Tilley Swamp Watercourse.

- Because losses are greater for water diverted through the Tilley Swamp Watercourse *en route* to the Coorong compared to flows via the Tilley Swamp Drain, it has been assumed that when South East flows are required for salinity management in the Coorong they will be fully channelised. However, for flow diverted through Tilley Swamp Watercourse, it is likely that water quality into the Coorong would be improved (noting risks associated with the "first flush" – see Section 3.2). Thus, if sufficient water were available, some or all of the flows destined for the Coorong could be directed through the watercourse. The water quality risks and benefits have been examined by this risk assessment.
- Due to the greater *en route* storage of Scenario 2, the risk of "over freshening" the Coorong South Lagoon, i.e. of driving salinity below the 60 g/L target minimum with South East water is likely to be reduced. Note that even without the addition of Blackford Drain water, the existing drainage network on occasion provides water in excess of the Coorong's immediate requirement and pushes salinity in the South Lagoon below 60 g/L. The Tilley Swamp Watercourse provides an alternative to the immediate release of this water into the Coorong.
- Water stored in the Tilley Swamp Watercourse to prevent over freshening of the Coorong in winter/spring can be held for later release into the Coorong South Lagoon when salinity has increased above 60 g/L. Although stored water would be subject to losses, and therefore the volume available for the Coorong would reduce through time, this water would be unavailable for the Coorong under Scenario 1 as it would have been diverted to sea in winter/spring.

At the time this Water Quality Risk Assessment was commissioned, the design of the SEFRP was not finalised. Therefore the water quality risks of both Scenario 1 and Scenario 2 have been assessed.

2.2.4 Temporal and spatial scale

To assess risk quantitatively, it is important to define the temporal and spatial scales relevant for an expression of likelihood and consequence. Participants agreed that the risk assessment would consider a timeframe of the first 10 years of SEFRP operation.

Salt Creek discharges directly into the Coorong South Lagoon and modelling indicates that the salinity benefits of the SEFRP apply primarily to the South Lagoon (Lester *et al.* 2012). The potential water quality risks of the SEFRP are therefore likely to be most apparent in the South Lagoon. The assessment focused on the southernmost 56 linear km of the Coorong, which corresponds with the desirable extent of occurrence of *Ruppia tuberosa* (see Section 2.3). This area covers the entire South Lagoon and approximately 5 km of the southernmost North Lagoon.

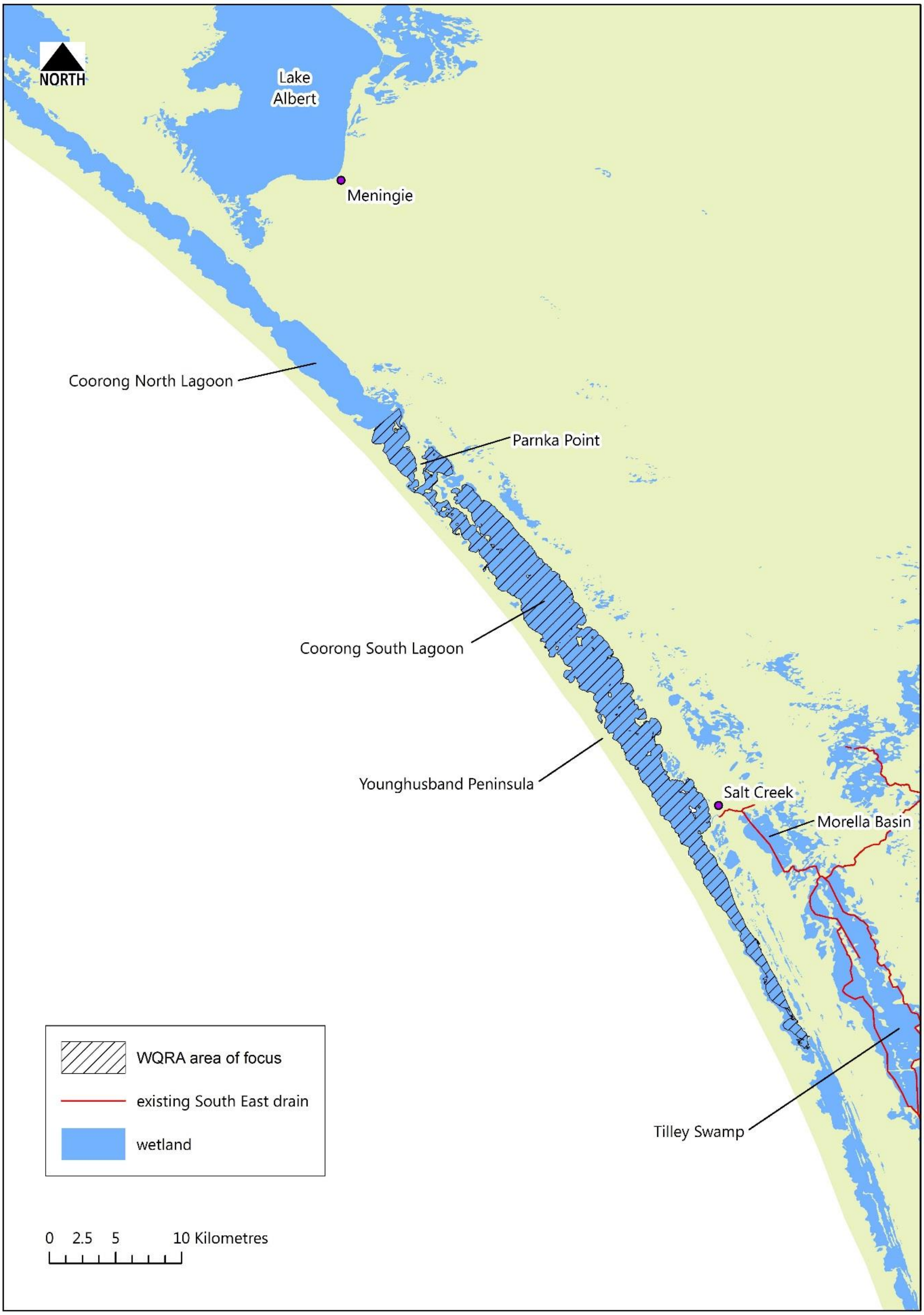

Figure 3. Map of the Coorong showing the area of focus for the risk assessment

2.3 Risk assessment end points

"End points" are the features or values that a risk assessment is concerned with protecting. Indicators of the Coorong's ecological character were selected as the end points for this risk assessment. Participants noted that these should have the following characteristics:

- Be sensitive to the water quality risks identified at relevant spatial and temporal scales, thus providing a true indication of the response of the Coorong ecosystem to water quality changes.
- Describe the full range of possible water quality effects upon the ecological values of the Coorong, from insignificant through to the worst case.
- Provide a direct indication of the status of the Coorong's ecological character.
- Be classifiable into discrete categories (although they may be continuous variables in reality) that describe different levels of ecological 'health'. Three to five categories are common for risk assessments.
- Be measureable, with contemporary data available.

While a single measure of ecological value (a single end point) would have simplified the risk assessment, participants agreed that several important ecological values of the Coorong may be affected in different, unrelated ways by certain water quality risks. It was therefore necessary to design the risk assessment with multiple end points.

The end points selected for the Coorong South Lagoon were the distribution and abundance of:

- *Ruppia tuberosa* – the only aquatic plant present
- Small-mouthed hardyhead *Atherinosoma microstoma* – one of the more abundant fish species
- The aquatic larvae of the insect *Tanytarsus barbitarsis* (a chironomid or midge) – which occurs on seasonally and permanently inundated mudflats and forms an important link in the food web, including as a food source to small-mouthed hardyhead.

Use of these three end points is consistent with contemporary scientific understanding and management of the Coorong. For example Brookes *et al*. (2009b) used *Ruppia*, fish and benthic invertebrates as "key species" to define the ecological response of the Coorong to different management. The Ecological Character Description (ECD) for the Coorong and Lower Lakes (Phillips and Muller 2006) also emphasizes the centrality of these biota to the overall status of the Coorong ecosystem, particularly the South Lagoon, where they are part of the food web that supports the waterbird community. It should be noted that historically (prior to river regulation in the Murray–Darling Basin and drainage in the South East) the Coorong, particularly the South Lagoon, supported a more diverse aquatic plant, fish and invertebrate community than that described as the target community by the ECD (Phillips and Muller 2006). The ECD is based upon the status of the ecosystem in 1985, the time the site was listed as a Wetland of International Importance, when the Coorong ecosystem was somewhat degraded. As explained in the ECD, the status of the ecosystem in 1985 represents the accepted benchmark against which to compare future change.

Waterbird populations in the Coorong (and Lower Lakes) are highly significant for the status of the site as internationally important and unique, but they were deemed less useful as an end point for this risk assessment. Waterbird populations may be affected by external factors not related to water quality conditions in the Coorong, (e.g. habitat availability elsewhere). In contrast, *Ruppia*, fish and midge larvae are obligate aquatic species and are directly affected by water quality. Moreover, they cover the full suite of food resources for the different guilds of waterbird that utilize the Coorong (Paton 2010). Participants concluded that optimal conditions for *Ruppia*, fish and benthic macroinvertebrates in the Coorong would provide optimal habitat for waterbirds. This conclusion is supported by a number of studies (Rogers and Paton 2009, Deegan *et al.* 2010, Paton 2010).

2.3.1 End point 1 - *Ruppia tuberosa*

Paton *et al*. (2015b) defined targets for the status of *Ruppia tuberosa* in the Coorong relevant to the maintenance of the Coorong's ecological character. Targets were defined for the following measures, based on an annual winter monitoring program in the Coorong (see Paton *et al.* 2015a):

- Extent of occurrence – *Ruppia* should occupy at least the southernmost 56 linear km of the Coorong (i.e. from 42 Mile Crossing to the Needles)
- Area of occupation – within the area of occurrence, shoots should be present at ≥80% of sites and seed at ≥50% of sites
- Vigour – cover of *Ruppia* should be ≥30% at ≥50% of sites, and ≤5% at <20% of sites
- Resilience – seed density where *Ruppia* is present should be >2,000/m^2.

For the purposes of the risk assessment a single measure of vigour was adopted as the target state for *Ruppia* (Table 2). The target state integrates both the cover of *Ruppia* at individual sites and the distribution of the species in the Coorong. It is likely to be correlated with the other measures, with the possible exception of resilience (seed density), particularly in recent years (Paton *et al.* 2015a). Three categories were defined for the risk assessment (Table 2), representing different levels of deviation from the target state defined by Paton *et al*. (2015b).

Table 2. End point for *Ruppia tuberosa* adopted for the SEFRP WQRA

	Deviation from target state		
Measure	Insignificant	Moderate	High
Vigour: Cover ≥30%	≥51% of sites	50 – 11% of sites	≤10% of sites

2.3.2 End point 2 – small-mouthed hardyhead

A number of fish species occur in the Coorong, including the Southern Lagoon (Phillips and Muller 2006, Paton 2010), and a diverse fish community is ecologically important. However, clear ecological management targets have been defined only for small-mouthed hardyhead (SMHH), *Atherinosoma microstoma*, which is a full-time resident species in the Southern Lagoon, unlike several other fish species. Targets were defined by Ye *et al*. (2014), based catch per unit effort (CPUE) for long-term, annual SMHH monitoring at eight sites in the Coorong (four in the North Lagoon, four in the South Lagoon) for the Murray–Darling Basin Authority's *The Living Murray Icon Site Condition Monitoring* program. One unit of effort is defined as one standard seine net and one small seine net, noting both gear types are used as complementary sampling method to cover all size classes of SMHH. Targets were defined for the following measures of SMHH:

- Relative abundance - mean adult* CPUE across all sites in spring/early summer 158±40 (mean ± 25%)
- Recruitment - mean juvenile** CPUE across all sites in late summer 1052±263. Proportion of juveniles >60% at ≥6 out of 8 sites
- Distribution – both adults and juveniles present at ≥7 out of 8 sites.

*≥40 mm total length
**<40 mm total length

For the purposes of the risk assessment a single measure of SMHH relative abundance in the Coorong South Lagoon was adapted from Ye *et al*. (2014) as the target state for fish (Table 3). Three categories were defined for the risk assessment (Table 3), representing different levels of deviation from the target state defined by Ye *et al*. (2014). The categories integrate both the abundance of SMHH at individual sites and the geographic range of the species in the Coorong South Lagoon.

Table 3. End point for small-mouthed hardyhead (SMHH) adopted for the SEFRP WQRA

Measure	Deviation from target state		
	Insignificant	Moderate	High
SMHH relative abundance: Mean adult CPUE in the Coorong Southern Lagoon in spring/early summer ≥118	≥51% of sites	50 – 11% of sites	≤10% of sites

1.1.1 End point 3 – Chironomid larvae

Benthic macroinvertebrates are an important food source for waterbirds and fish in the Coorong South Lagoon (Phillips and Muller 2006, Paton 2010). Macroinvertebrates occur on the seasonally and permanently inundated mudflats of the Coorong. Species diversity tends to decline from north to south along the Coorong as salinity increases (Geddes and Butler 1984). The 60 – 100 g/L target salinity range for the Coorong South Lagoon supports a relatively low diversity of benthic macroinvertebrates, yet certain salt-tolerant species can occur in high abundance (Paton 2010). One such species is the chironomid (midge) *Tanytarsus barbitarsis* that, in its aquatic larval phase, can be the dominant macroinvertebrate on CSL mudflats in terms of abundance. Due to the low diversity in the South Lagoon, it is assumed that waterbirds, and migratory shorebirds in particular, are attracted to the high invertebrate abundance or biomass for feeding (see Colwell and Landrum 1993, Bolduc and Afton 2004, Rogers and Paton 2008, Brookes *et al*. 2009a). However, a target biomass or abundance in South Lagoon mudflats to support waterbird feeding has not been determined (Dan Rogers, pers. comm.).

Despite the lack of an existing target, participants agreed that abundance of chironomids (individuals per m^2) provides an indicator of the capacity for macroinvertebrate populations to support waterbirds and fish. Analysis of unpublished chironomid abundance data over the period from 2004 to 2013 showed that years having salinity well in excess of the target maximum in the Coorong (2007, 2008 and 2009) corresponded with low abundances (Figure 3). Based on these data, the target state for chironomid abundance was set at ≥200 individuals per m^2. The end point for chironomid abundance is presented in Table 4.

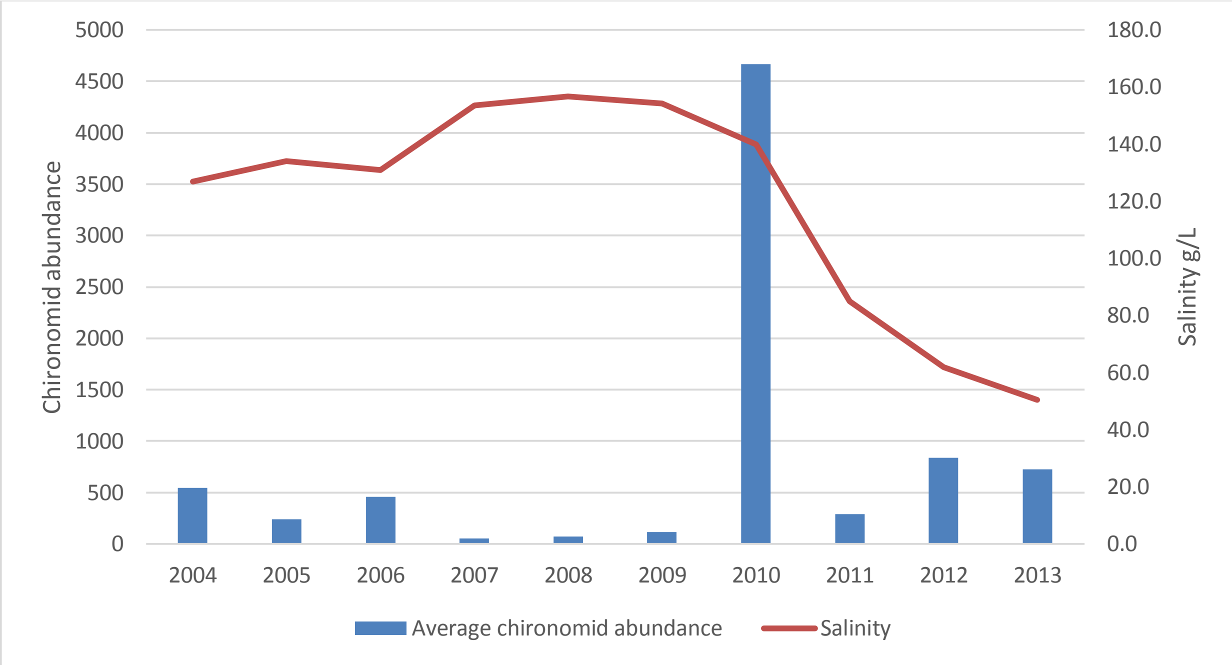

Figure 4. Average chironomid abundance and salinity (Coorong North and South Lagoon) (Dittman, unpub.), 2004–13.

Table 4. End point for chironomid abundance adopted for the SEFRP WQRA

Measure	Deviation from target state		
	Insignificant	Moderate	High
Chironomid abundance: Individuals/m^2 ≥200	≥51% of sites	50 – 11% of sites	≤10% of sites

2.4 Risk criteria

2.4.1 Introduction

Risk criteria are the terms of reference for determining whether a risk is significant or not. The present assessment is concerned with the extent to which any unintended water quality changes caused by the project could negatively impact the ecological character of the Coorong, as represented by the agreed end points. The risk level therefore is the likely difference in the end points between the existing arrangements (Scenario 0) and the project (Scenario 1 or 2).

The risk evaluation was undertaken in two passes. The first pass was a comparison between current arrangements (S0) and the SEFRP (S1 or S2) based on *a priori* defined risk levels. It can be considered a low resolution evaluation of risk.

The second pass was a more sensitive evaluation which considered the difference between the status of the end points under S0 and the project (S1 or S2) without reference to an *a priori* classification of risk level. The second pass can be considered a high resolution evaluation of risk.

2.4.2 First pass evaluation criteria

The first pass (low resolution) risk evaluation compares the likelihood and consequences of a risk, as determined through the analysis, with a risk matrix (Table 5). The risk matrix returns three levels of risk, namely low, medium and high. Low risk represents the desirable state for the Coorong.

These consequence criteria are based on the level of deviation from the desired state for the risk assessment end points (Section 2.3). The likelihood levels (Table 6) are adapted from (DEWNR 2012).

Table 5. Risk criteria - risk level = likelihood * consequence

Consequence \ Likelihood	Rare	Unlikely	Possible	Likely	Almost certain
Severe	Low	Moderate	Moderate	High	High
Moderate	Low	Low	Low	Moderate	High
Insignificant	Low	Low	Low	Low	Low

Table 6. Likelihood levels

	Likelihood level				
	1	2	3	4	5
Qualitative description	Rare Only occurs in exceptional circumstances	Unlikely Unusual but not exceptional	Possible Less than even probability of occurring, but not unusual	Likely Greater than even probability of occurring, but not certain	Almost certain Expected to occur in all circumstances
Frequency over 10 year timeframe	< 10%	11-25%	26-50%	51-90%	>90%

2.4.3 Second pass evaluation criteria

It was identified that the first pass evaluation could be insensitive to large changes in the likelihood of some outcomes due to the large and uneven sizes of the likelihood levels (Table 6). The second pass, high resolution evaluation addresses this insensitivity by investigating the differences in expected value (EV) of the end point indicators caused by the project.

Calculation of expected value

The expected value for each scenario and end point indicator was determined by calculating the weighted mean of the posterior probability distribution, which is the sum of the product of the value and its probability of occurring in each case. Thus, as the output of the analysis X has a discrete distribution with probability density function f(x), the expected value of X is:

$$E(X) = \sum_{x \in S} x f(x)$$

Consistent with the definition of the end point indicators, the unit for expected value is the percentage of sites where the target condition occurs for *Ruppia tuberosa*, chironomids and small-mouthed hardyhead respectively.

In this case, calculation of expected value must account for end point values which are themselves a sub-range of values which we assume are equi-probable (i.e. 0-10, 11-50, and 51-100). It is therefore necessary to first determine the expected value for each of these sub-ranges, in this case the midpoint (Table 7).

Table 7. Conversion of end point ranges to values (*P* = probability)

Consequence severity level	Range	Value	*P*
Insignificant	51 – 100	75	0.75
Moderate	10 – 50	30	0.30
Severe	0 – 10	5	0.05

The second pass risk evaluation calculates the change in EV between existing arrangements (S0) and the project (S1 and S2) for each risk statement category. For the purposes of the present assessment, limits of acceptable change for EV were defined as follows:

- Low risk: 0-5% change in EV
- Moderate risk: 5-10% change in EV
- High risk: >10% change in EV.

3 Risk Identification

3.1 Introduction

Risk identification is the process of identifying, recognising and describing risks (Joint Technical Committee OB-007 Risk Management 2009). It yields a set of risk statements, setting the scope for the risk analysis and evaluation.

Risk statements are structured to describe a chain of circumstances leading to events and consequences. The following template for risk statements is based on the concepts of the AS/NZS ISO 31000:2009 standard:

There is the potential for **<source of risk>** to cause **<an event>** in turn leading to **<consequence>**

where:

- Sources of risk are elements which alone or combination have intrinsic potential to give rise to risk
- An event is an occurrence or change in a particular set of circumstances
- A consequence is an outcome of an event affecting objectives.

3.2 General findings

Workshop participants raised a number of general points relevant to risk identification (and analysis) for the SERFRP WQRA, many of which are supported by data.

Coorong and inflow water quality:

- The primary issue of concern is the potential for increased loading of nutrients (nitrogen, phosphorus and carbon) into the Coorong, and the potential response of the Coorong ecosystem, particularly the potential for displacement of *Ruppia tuberosa* by filamentous green algae.
- The Coorong South Lagoon is a eutrophic (nutrient-rich) environment, with typically very high concentrations of total nitrogen (c. 5 mg/L) and total phosphorus (c. 0.25 mg/L) measured in the water column during the last 20 years (Mosely 2015). In general, total nitrogen of ≥0.3 mg/L and total phosphorus of 0.03 mg/L are considered high in estuaries (ANZECC 2000). Thus the potential for algal growth is already high; the risk is that the potential would be realised under the SEFRP due to changed water quality conditions that lead to greater bioavailability of nutrients. Although the Coorong is currently eutrophic, as a principle it was agreed that it is preferable to maintain or reduce total nutrient levels rather than increase them given the nature of the risks (see Section 3.3 and Appendix A – Complete risk statements).
- Low concentrations of bioavailable nitrogen (NO_x) and high concentrations of chlorophyll *a* have been observed in the water column of the Coorong South Lagoon over the last 20 years (Mosely 2015). This suggests that available nutrients tend to be rapidly taken up by phytoplankton.
- The Blackford Drain water quality data (1976 – 2009) shows a similar concentration of total nitrogen and total phosphorus to the existing Salt Creek water quality data (Taylor 2014). Therefore a marked departure from current Salt Creek inflows concentrations is not anticipated. The possible exception to this is occasionally elevated bioavailable nitrogen (NO_x) under high flow conditions in the Blackford Drain. It is uncertain how NO_x concentration would change over the c.90 km between the Blackford Drain and the Coorong. Therefore the assumption that Blackford NO_x concentration remains unchanged *en route* should be made.

- Water quality monitoring data show that current Salt Creek inflows generally have a much lower concentration of total nitrogen (TN) and total phosphorus (TP) than the Coorong South Lagoon (Mosely 2015), and thus a diluting effect upon these water quality parameters. Water quality data for the Blackford Drain shows similar TN and TP concentrations to those of Salt Creek (see Appendix A – Complete risk statements, TNutrients_conc).
- Modelling by DEWNR using CSIRO's 1-dimensional hydrodynamic model (Jöhnk and Webster 2014) indicates that increased Salt Creek flows increase the south to north flux of water at Parnka Point (i.e. they push water from the South Lagoon into the North Lagoon) (Fuller 2015). Thus, Salt Creek flows are likely to displace nutrient rich water from the South Lagoon. Water quality monitoring in the Coorong supports this hypothesis (Mosely 2015). Note that other drivers, such as grazing of phytoplankton by zooplankton and adsorption of nutrients on sediments, may also have caused some of the observed reductions in total nutrient concentrations in the South Lagoon during Salt Creek inflow events.
- The release of bioavailable nutrients from Coorong sediments into the water column could occur, leading to increased abundance of phytoplankton and/or filamentous algae, with implications for ecological character. This could occur conditions that lead to thermal and/or salinity stratification of the water column, in turn leading to hypoxia of sediments and the lower water column. Increased loading of organic carbon (particulate and dissolved) may exacerbate this risk because microbial decomposition of organic carbon consumes oxygen, increasing the risk of anoxia. It is also possible that increased loading of nitrogen and phosphorus could occur and increase the sediment loading of these nutrients. The current nutrient status of CSL sediments is not well understood. However, available dissolved oxygen data for the CSL water column do not indicate episodes of anoxia (Mosely 2015) (see Appendix B – Detailed description of BBN nodes, Sites_pelagic_DO_less90).
- The relationships between salinity, bioavailable nutrient concentration, phytoplankton, filamentous algae and *Ruppia* in the Coorong are not well understood. However, long term Coorong water quality data indicates that lower salinities are correlated with lower total nitrogen, total phosphorus and chlorophyll *a* concentrations (Oliver *et al.* 2013, Mosely 2015).
- Sediment loads into the Coorong from Salt Creek appear to be low currently (Mosely 2015), as do sediment loads in the Blackford Drain, although data are limited. Sediment loads into the Coorong under the SEFRP are anticipated to remain low.

SEFRP design:

- In the longer term there is likely to be a reduced loading of nutrients into the Coorong under S2 due to greater wetland through-flow and storage *en route* and enhanced removal of particulate and dissolved materials (particularly nitrogen, phosphorus and carbon) compared to S1.
- Over time, if aquatic plant abundance in the watercourse increases, as anticipated under S2, the watercourse is anticipated to become a nitrogen sink due to uptake by aquatic plants from the water column during inundation and denitrification during the dry phase. Slower flow rates (and thus greater retention time) of flows through the watercourse are likely to contribute to this effect. Given the salinities and water regime likely in the watercourse under S2, the aquatic vegetation anticipated to re-establish is seasonal brackish to saline aquatic bed in the lower lying areas, with fringing *Gahnia filum* tussock sedgeland and *Melaleuca halmaturorum* tall shrubland (see Ecological Associates 2009).
- S2 provides greater control on the inflow rate and annual inflow volume into the Coorong through increased terminal storage (c. 40 GL) compared to S1 (and S0) (both c. 8 GL).
- S2 may present a temporarily elevated risk of increased loading of particulate and dissolved organic carbon to the Coorong. This may result as a consequence of the entrainment of plant material, both alive and dead, via the first few through-flow events in the Tilley Swamp Watercourse (the first flush event). The watercourse has received virtually no flushing flows since the construction of the existing Tilley Swamp Drain in 2000 and has subsequently become increasingly "terrestrialised", i.e. open wetland vegetation has

been replaced by shrubland. Following the reinstatement of regular flows under S2, a transition period is anticipated, during which aquatic vegetation is anticipated to increase. This transition period could take one to three inundation events. After the transition period, the risks associated with the first flush event are anticipated to be negligible, provided regular watercourse inundation continues. For the assessment of the risks associated with the first flush event, the conservative assumption should be made that, under S2, all flows to the Coorong have passed through the watercourse.

- In general, flow of water through the watercourse will lead to higher losses through evaporation and seepage (AWE 2015), noting that both S1 and S2 feature the facility to bypass the Tilley Swamp Watercourse and fully channelise flows to the Coorong. Therefore, the assumption that all flows entering the Coorong have been fully channelised, under both S1 and S2, should be made (except where this assumption is not conservative, i.e. in the assessment of risks related to increased loading of total organic carbon into the CSL).
- Flows of water though the watercourse are much slower than through the channel, approximately 50 days versus 4 days respectively in an average year (KBR 2015).

Mixing zone:

- The 'mixing zone', or plume, is an important feature to consider. The mixing zone can be defined as the area of relatively fresh water (salinity below the 'background' within the CSL) at the Salt Creek outlet caused by inflows from the South East drainage system. The spatial and temporal extent of the mixing zone is influenced by the duration and flow rate, and total annual volume, of Salt Creek inflows. In 2014, in response to a total inflow of 18.8 GL, the mixing zone at its zenith occupied <3 linear km of the Coorong South Lagoon (Mosely 2015). Risks may manifest at the mixing zone scale, while others at the whole of South Lagoon or whole of Coorong scale. To support the assessment, the size of the mixing zone was modelled under S0, S1 and S2 (Fuller 2015). Modelling predicted that the project (S1 and S2) is likely to increase the size of the mixing zone in a small proportion of years.

3.3 Risk statements

Taking a comprehensive approach (i.e. without regard to likelihood or consequence at this stage of the process) participants identified the following sources, events and consequences:

Sources of risk:

- Increased catchment size leading to higher volumes of fresh water flow into the Coorong
- SEFRP to cause increased loading of total organic carbon (TOC) organic particulate matter (comprising dissolved organic carbon (DOC) and particulate organic carbon (POC), including phytoplankton)
- SEFRP to cause increased loading of inorganic sediments
- SEFRP to change constituents of inflow water during construction
- SEFRP to cause increased loading of total nutrients (TN and/or TP)
- SEFRP to cause increased loading of bioavailable nutrients (N and/or P)
- SEFRP to cause changed temperature of inflow water
- SEFRP to increase water release in late spring/summer (implications for water temperature and salinity; particularly S2).

Events (changed water quality in Coorong):

- Increased total N and/or P concentration in the entire Coorong and/or mixing zone
- Increased bioavailable N and/or P concentration in the entire Coorong and/or mixing zone
- Low dissolved oxygen (DO) in sediments and water column in the entire Coorong and/or mixing zone
- Increased sulphides (due to anoxia) in the sediments in the entire Coorong and/or mixing zone
- Increased organic particulate matter deposition in the mixing zone
- Increased inorganic sediment deposition in the mixing zone
- Changed temperature of water in the mixing zone
- Over freshening of water in the entire Coorong South Lagoon (average monthly whole-of-lagoon salinity)
- Increased spatial and temporal extent of mixing zone
- Change of seasonal variation of salinity in the entire Coorong
- Increased DOC concentration in the entire Coorong and/or mixing zone
- Increased DOC concentration in entire Coorong
- Increased salinity gradient in mixing zone causing osmotic shock and death of organisms (particularly phytoplankton)

Consequences (ecological changes in the Coorong affecting ecological character):

- Increased abundance and distribution of filamentous algae leading to (via reduced light availability, interference with flowering) reduced extent and/or coverage of *Ruppia* in turn causing impacts to fish and waterbirds
- Increased microbial growth in sediments and/or water column in mixing zone causing low DO in turn causing fish kills and impacts on invertebrates (benthic and pelagic) in turn causing impacts to waterbirds
- Increased abundance and distribution of filamentous algae leading to low DO on exposed sediments in turn causing impacts to invertebrates in turn causing impacts to waterbirds
- Increased phytoplankton growth in mixing zone causing reduced light availability causing reduced extent and/or coverage of *Ruppia* causing impacts to fish and waterbirds
- Increased turbidity (non-living suspended particulate matter, organic and/or inorganic) in mixing zone causing reduced light availability causing reduced extent and/or coverage of *Ruppia* causing impacts to fish and waterbirds
- Increased sulphides in sediment in mixing zone impacting both invertebrates and extent and/or coverage of *Ruppia* in turn causing impacts to fish and waterbirds
- Changed community composition of algae and invertebrates leading to food web impacts in turn causing impacts to fish and waterbirds
- Reduced stability of substrate leading to reduced cover and/or extent of *Ruppia* and/or altered community of invertebrates in turn causing impacts to fish and waterbirds.

The sources, events and consequences have been combined into 33 complete risk statements (Appendix A). The risk statements have been grouped into seven risk statement categories according to the nature of the risks as follows:

- Risks related to over freshening
- Risks related to increased turbidity
- Risks related to increased loading of total nutrients (nitrogen and/or phosphorus)
- Risks related to increased loading of bioavailable nutrients (nitrogen and/or phosphorus)
- Risks related to increased loading of total organic carbon (TOC) (comprising dissolved organic carbon (DOC) and particulate organic carbon (POC))
- Risks related to changed water temperature
- Risks during construction.

4 Risk analysis

4.1 Method: Bayesian Belief Network (BBN)

Risk analysis is the task of determining the level of risk level posed by the risk statements. The output of risk analysis is an estimation of the likelihood and consequence of each risk statement, both in isolation and in combination.

A modelling approach to the risk analysis was adopted, with Bayesian Belief Networks (BBNs) selected as the modelling tool because:

- In situations where a considerable amount of relevant data and expert knowledge related to the issue exist, but the specific questions raised by the issue have not been formally addressed by scientific study, BBNs provide an appropriate tool to address uncertainty and are often employed as such.
- The large number of risks and scenarios to be analysed meant that eliciting expert judgments was likely to be a time consuming and resource intensive process. By contrast, development of a probabilistic model focusses expert opinion on fewer key cause-effect relationships shared by many Risk statements.
- Many risk statements describe long and complex pathways of cause and effect. The use of a model such as a BBN allows those pathways to be articulated and specified in probabilistic terms. This supports consistency in understanding between risk assessment participants.
- A model can report specific risks in isolation, but importantly it can report cumulative risk given all identified risk statements. This is an important function in the present case.
- BBN models are open to review and emendation as necessary.

BBNs have utility for the risk management task since they explicitly represent uncertainty, provide an easy to understand graphical representation of risk pathways, allow combination of quantitative data and qualitative judgment, and, through use of Bayes' theorem, provide valid and falsifiable inferences regarding the likelihood and consequence of events (Pollino and Henderson 2010).

The development of a BBN for risk analysis generally involves the following tasks (Pollino *et al*. 2006):

1. Structural development and evaluation, which involves choosing nodes and configuring the arcs between the nodes.
2. Parameter estimation, which involves specifying conditional probability tables (CPTs) for each node.
3. Validation, whereby the model is subject to quantitative and/or qualitative evaluation to determine whether it is appropriately realistic and meets requirements.

BBNs can be implemented using commercially available software. Norsys Netica (http://www.norsys.com) was used for this assessment.

4.2 BBN structure

Development of the BBN structure involved the following steps:

- Configuring the input and output variables (nodes) of the BBN to be consistent with risk statements.

- Identifying the broad categories of risk pathway that cover the chains of circumstance described by the risk statements (as per Cain 2001).
- Ensuring all risk pathways were adequately represented.

For this assessment, the input or starting node represents the SEFRP design scenarios (Section 1.2), while the output or dependent variables are the risk assessment end points (Section 2.3). The intermediate nodes describe pathways of cause and effect between the inputs and outputs. Two thirds of the risks identified described events and consequences in the mixing zone. It was recognised that in some cases consequences may be limited to the extent of the mixing zone, whereas in other cases mixing zone events may have relevance for the ecological character of the Coorong as a whole. For the purposes of developing the BBN model, the potential impact of mixing zone processes were addressed as outlined in Table 8.

Table 8. BBN structure – broad types of risk pathway potentially affecting Coorong ecological character

	Description of pathway
1	SEFR scenario -> water quality event in Coorong -> consequences in Coorong
2	SEFR scenario -> water quality event in mixing zone -> water quality event in Coorong -> consequences in Coorong
3	SEFR scenario -> water quality event in mixing zone -> consequences in the mixing zone

The BBN structure is comprised of 15 nodes (Figure 5). The colour of the nodes represents five categories of variables (Table 9). The BBN structure was designed to comprehensively cover the risk statements. However, a number of identified risk statements and potential cause-effect relationships were *a priori* deemed of such low risk that, for sake of simplicity, they were omitted from the BBN. These were:

- Risks related to construction, which it is assumed will be avoided by mandated water quality protection measures for construction in a watercourse.
- Risks related to changed water temperature, which participants concluded were low given temperature profiles of inflows and receiving waters are unlikely to change under the SEFRP. Analysis of the 2012 to 2015 DO data for the CSL shows hypoxic water is rarely observed (Mosely 2015), suggesting the CSL is well mixed, likely due to its shallow and exposed nature.
- Risks related to low dissolved oxygen on mudflats during shallow inundation/exposure, which participants concluded were unlikely to change under the SEFRP.

Additionally, a number of inherent design and operational features of the SEFRP that will perform roles in risk control have been assumed in the BBN structure and its discretisation and parameterisation (see Section 4.3). These are:

- The ability to divert all flows in the Blackford Drain to sea will be retained.
- The ability to partially or completely close the Morella Basin outlet regulator and store water prior to release will be retained. Under S1 the storage capacity will be unchanged from current arrangements (c.8 GL), while under S2 the storage capacity will increase to c. 40 GL.
- Blackford Drain water will not be used to deliberately over freshen the CSL (i.e. push salinity below the 60 g/L target minimum).
- SEFRP infrastructure will enable the diversion of some or all (i.e. 0 – 100%) of flows through Tilley Swamp Watercourse.

- Under S2, water diverted into Tilley Swamp Watercourse could be stored and not released into the Coorong. Modelling indicates this water will have evaporated completely by the following winter (AWE 2006).
- The upgraded Morella Basin outlet regulator will feature over-shot gates, which is the regulator design that best ensures particulate matter is retained upstream.

Table 9. BBN water quality model, categories of nodes

Node colour	Category
Yellow	SEFRP design scenario/current state of Coorong
Dark green	Conditions or events confined to the mixing zone
Blue	Water quality events affecting the Coorong
Orange	Intermediate biological or water quality impacts affecting the Coorong
Light green	End points

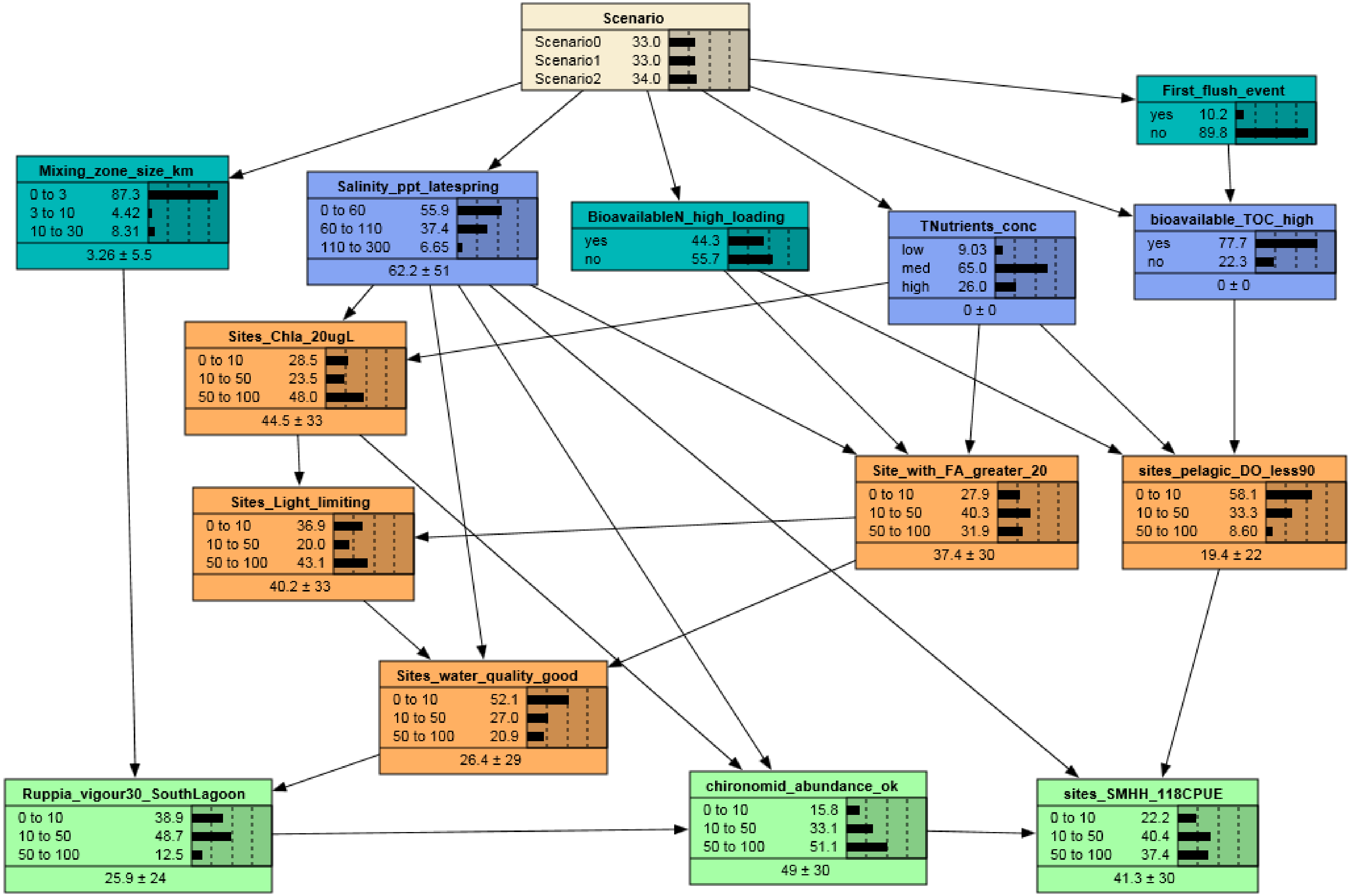

Figure 5. BBN model for the SEFRP WQRA

4.3 BBN discretisation and parameterisation

Having defined the overall BBN structure, the next task was to define an appropriate set of discrete categories for each node (a task referred to as 'discretisation'). The approach recommended by Pollino *et al*. (2006) was applied. Where possible, existing classifications, management thresholds or guidelines were used. Where these were not available, guidance was sought from relevant experts. Care was taken to limit the number of categories in each case to ensure that the parameterisation task (see below) remained manageable.

The nodes denoting intermediate biological or water quality impacts affecting the Coorong (orange) and nodes denoting the end points (light green) are quantified as a percentage of sites having a specified condition over the 10 year timeframe of the assessment. The actual geographic area represented by the "sites" for each node is the southernmost 56 linear km of the Coorong, i.e. corresponding to the ideal extent of occurrence for *Ruppia* (Paton *et al.* 2015b). This incorporates the entire South Lagoon and the southernmost 5 linear km of the North Lagoon as far north as The Needles. A "site" can be defined as a location where a feature defined by the node could be expected to occur. For example, *Ruppia* sites are locations where water regime, wave action and sediment type are suitable for that species (Paton *et al.* 2015b).

Parameterisation for a BBN model is the task of assigning probabilities to describe belief regarding the state of each node. In BBN parlance, the output of this process is a set of conditional probability tables (CPTs), with one CPT per node. CPTs can be informed by existing data, models or expert judgement. Consistent with the approach outlined by Pollino *et al*. (2006), determination of CPTs involved addressing the generic question, 'What is the probability that Node A takes state *X* given information *Y*?' Consideration was also given to the level of certainty regarding these estimates which is then accounted for through the distribution of probabilities in the relevant CPT.

Appendix B contains a detailed description of each node in the BBN, including its discretisation and parameterisation, and the evidence supporting both.

4.4 Model validation

Validation is the process whereby the model is subjected to quantitative and/or qualitative evaluation to determine whether it is appropriately realistic and meets requirements.

The risk assessment team framed the following key questions to be addressed by model validation:

1. To what extent does the BBN represent a comprehensive coverage of the identified risks?
2. To what extent does discretisation address transitions or thresholds relevant to ecological value in the Coorong?
3. To what extent do the CPTs represent the best available knowledge regarding dependencies between the modelled variables?
    a. Is the order of influence of each variable correct?
    b. Have we got the relationships right?
4. To what extent does the sensitivity analysis of the model to findings at each node match expectations?
5. To what extent does the modelled expected value for the end point variables match the expectations from experts?

Questions 1 and 2 were addressed through development of the BBN structure and variable discretisation (Section 4.3). The validation occurred through targeted engagement with experts and the workshop process (Workshop 3).

Question 3 has been partially addressed through the model parameterisation process and through targeted engagement with experts.

Question 4 was addressed through application of the sensitivity analysis function of the BBN software (Section 4.4.1).

Question 5 was addressed through review of the risk analysis outputs (Section 5.2)

4.4.1 Sensitivity analysis

A sensitivity analysis (Hart and Pollino 2009) was undertaken to:

- verify that knowledge of risk causal pathways has been correctly represented in the BBN model;
- identify those nodes where uncertainty has the most important influence on the outputs of the risk analysis; and
- conversely, to identify those nodes that do not strongly influence the end points.

In the event of a finding of high risk, the sensitivity analysis identifies the priorities for further research to better understand risk pathways to thereby reduce uncertainty.

Norsys Netica (version 5) provides a sensitivity analysis function which reports the “mutual information” between the selected variable and all other variables of the model. Mutual information is formally defined as the expected reduction in entropy of the query node due to findings in other nodes. Mutual information of 0 means independence from the query node.

Sensitivity analysis was performed for the three end point variables (Figure 6, Figure 7 and Figure 8). These results can be interpreted as presenting relative sensitivity of the end points to the other nodes of the model in each case. Note that the nodes are described in Appendix B – Detailed description of BBN nodes.

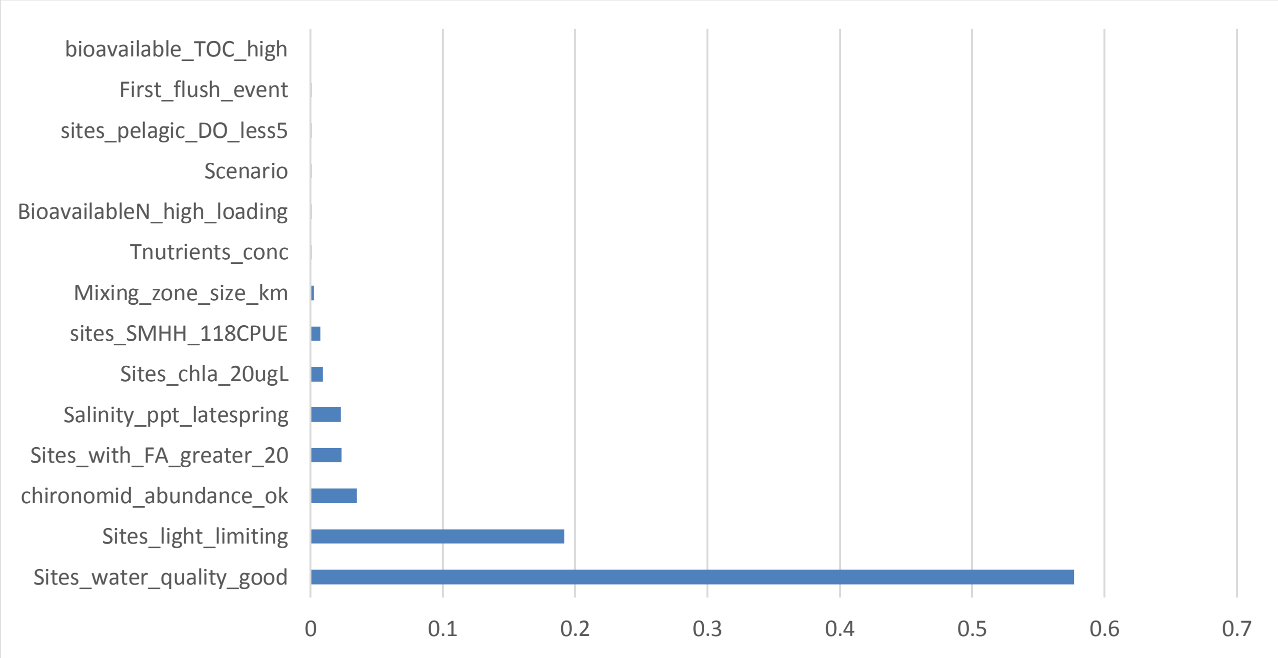

Figure 6. Sensitivity to findings. Endpoint node = *Ruppia* vigour.

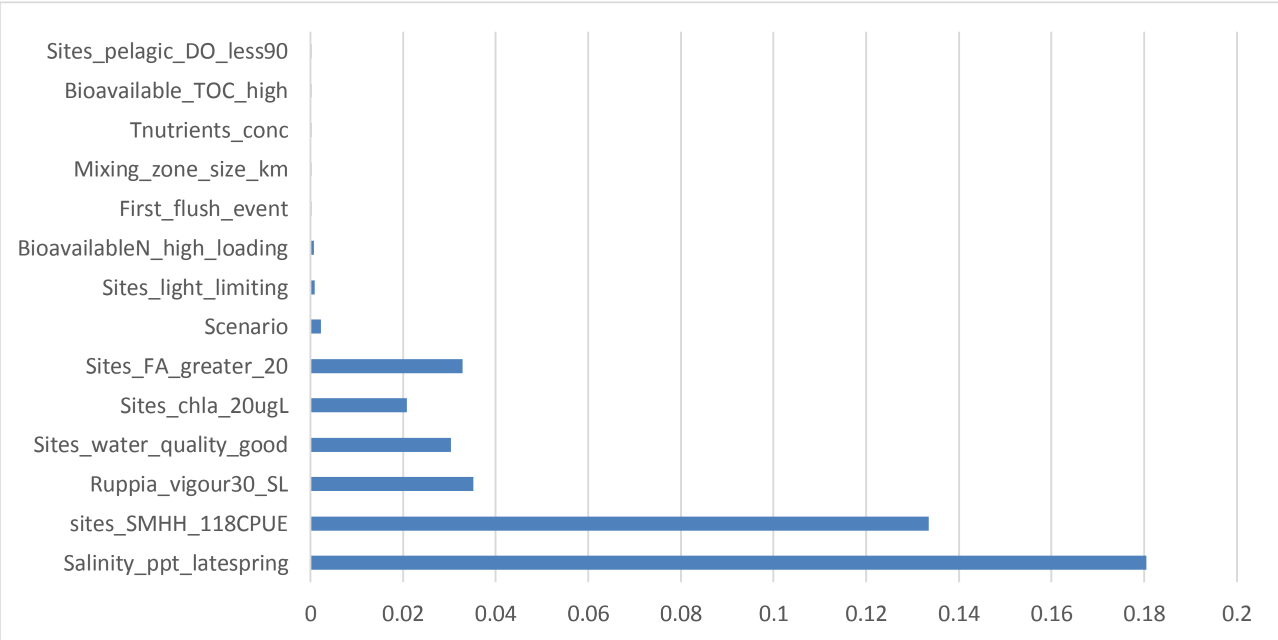

Figure 7. Sensitivity to findings. Endpoint node = chironomid abundance.

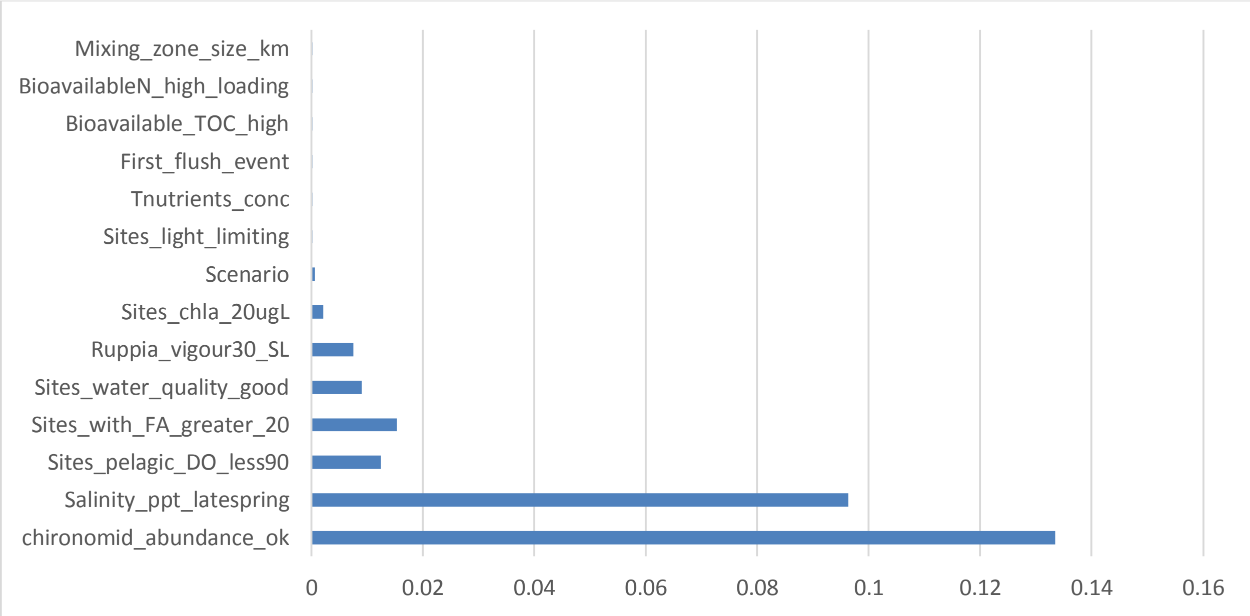

Figure 8. Sensitivity to findings. Endpoint node = small-mouthed hardyhead abundance.

The end point variables tended to be most sensitive to findings at directly connected nodes and less sensitive to nodes that are indirectly connected. In general, most sensitivity for each output was dominated by relatively few nodes.

Nodes shown to be the most important included salinity_ppt_latespring and sites_water_quality_good. When considered across all three outputs, these nodes accounted for approximately 50% of the sensitivity reported by the sensitivity analysis. Due to mutual interdependencies, findings at the three end point nodes were also found to be relatively important.

Nodes having moderate levels of sensitivity (i.e. between 5 and 10% of the overall sensitivity observed) included Sites_light_limiting and Sites_FA_greater_20.

The least important nodes were found to be 'bioavailable_TOC_high', 'first_flush_event' and 'Tnutrients_conc'. These nodes each accounted for less than 0.05% of the total sensitivity observed across all three outputs.

In summary, the sensitivity analysis indicated that:

- the model adequately represents the knowledge that salinity, filamentous algal cover and chlorophyll a concentration (phytoplankton abundance) are key influencers of *Ruppia*, small-mouthed hardyhead and chironomids in the CSL; and
- even accounting for uncertainty, risks relating to increased loading of TOC in the Coorong ("first flush" effect) are low.

5 Risk assessment results

5.1 Introduction

This section presents the results of the risk analysis and evaluation process. The results include the outputs of the BBN model considering the risk pathways identified in two ways:

- Cumulative risk, whereby the risks have been considered in combination to determine an overall profile of risk caused by the SEFRP
- Risk for each category of risk statement (see Appendix A – Complete risk statements).

In each case, the level of risk has been evaluated according to both the first and second pass approaches (Section 2.4).

5.2 BBN outputs

5.2.1 Posterior probability distributions

Having undergone structural development (Section 4.2), parameterisation (Section 4.3) and validation (Section 4.4), the BBN model calculates posterior probability distributions for the three end point nodes given the findings entered at the evidence (input) nodes. A posterior probability distribution, in the context of this risk assessment, describes the probable status of each endpoint, taking into account risk. For example:

	for end point A		
	Probable proportion of CSL sites in target state		
	low	medium	high
Taking into account Risk B	X%	Y%	Z%

where X+Y+Z=100%

The posterior probability distributions represent the output of the risk analysis.

5.2.2 Attributing risk level to risk statement categories

The BBN output was recorded for each SEFRP design scenario. Cumulative risk is the posterior probabilities calculated when all risk categories are considered in combination. To calculate cumulative risk, the only manual adjustment made to the BBN is to set the relevant SEFRP scenario.

The BBN was also able to calculate risk attributable to individual risk statement categories. This required the influence of other risk statement categories to be 'blocked' within the BBN. The blocking of risk statement categories involved setting relevant nodes in the BBN to pre-determined values that minimises their influence. Table 10 shows the how evidence nodes were blocked to determine risk attributable to each risk statement category.

The following notes apply in relation to the analysis of risk for individual risk statement categories:

- Blocked variables were set to the most likely values as indicated by their initial (no-evidence) posterior probability distributions.
- Blocked variables tended to be represented in the top portion of the model, which addresses water quality and mixing zone events.
- In some cases, a blocked variable isolated other event nodes from influencing posterior probabilities causing them to be blocked as well.

Table 10. BBN settings to calculate risk for risk statement categories

Risk statement category	Blocked variables	Value
Cumulative (all) risk	None	
Over freshening	BioavailableN_high_loading	No
	Tnutrients_conc	Medium
	Bioavailable_TOC_high	Yes
Turbidity	First_flush_event	No
	BioavailableN_high_loading	No
	Salinity_ppt_latespring	0-60
Total nutrients	First_flush_event	No
	BioavailableN_high_loading	No
	Bioavailable_TOC_high	Yes
	Salinity_ppt_latespring	0-60
Bioavailable nutrients	First_flush_event	No
	Bioavailable_DOC_high	Yes
	Salinity_ppt_latespring	60-110
	Tnutrients_conc	Medium
First flush event	Salinity_ppt_latespring	0-60
	BioavailableN_high_loading	No
	Mixing_zone_processes	No additional nutrients

5.2.3 Raw results

The BBN calculates 'belief', presented as probabilities, regarding the percentage of sites (suitable habitat under ideal conditions) in the Coorong (southernmost 56 linear km) supporting the target state of each end point over the first 10 years of SEFRP operation. These posterior probabilities are presented for cumulative risk and for each risk statement category for the existing arrangements (S0) and the two SEFRP Scenarios (S1 and S2) (Table 11).

Caution should be applied when comparing absolute risk levels between risk statement categories, because the findings entered at blocked variables in each case may represent an unrealistic combination of conditions.

Table 11. Risk analysis results. Posterior probabilities for end points given design scenario and risk statement category

Risk statement category	***Ruppia tuberosa****			**chironomids***			**Small-mouthed hardyhead***		
SEFRP design scenario	<10	10-50	>50	<10	10-50	>50	<10	10-50	>50
Cumulative									
Existing arrangements (S0)	38.7	48.3	13.1	18.5	32.8	48.7	23.9	39.9	36.3
Channelized (S1)	38.8	49	12.2	14.7	34.1	51.2	21.5	40.9	37.6
Watercourse (S2)	39.1	48.7	12.2	14.2	32.4	53.3	21.3	40.5	38.2
Over freshening									
Existing arrangements (S0)	37.9	48.7	13.3	18.7	32.8	48.4	24.0	39.9	36.1
Channelized (S1)	37.1	49.1	13.8	14.7	33.8	51.4	20.8	41.0	38.2
Watercourse (S2)	37.3	48.7	14.0	14.2	32.2	53.6	20.5	40.6	38.9
Turbidity									
Existing arrangements (S0)	34.8	51.9	13.4	12.1	40.6	47.3	18.3	43.5	38.3
Channelized (S1)	35.0	51.6	13.3	12.3	40.7	47.0	18.3	43.5	38.2
Watercourse (S2)	34.8	51.8	13.3	12.3	40.7	46.9	18.3	43.5	38.2
Total nutrients									
Existing arrangements (S0)	34.8	51.9	13.4	12.1	40.6	47.3	18.5	43.4	38.0
Channelized (S1)	35.0	51.6	13.3	12.3	40.7	47.0	18.5	43.5	38.0
Watercourse (S2)	34.8	51.8	13.3	12.3	40.7	46.9	18.5	43.5	38.0
Bioavailable nutrients									
Existing arrangements (S0)	33.7	52.4	13.9	12.5	40.6	46.9	18.4	43.5	38.1
Channelized (S1)	35.8	52.0	12.3	12.7	41.0	46.3	19.3	43.4	37.3
Watercourse (S2)	35.9	52.1	12.0	12.7	41.0	46.3	19.4	43.4	37.2
First flush event									
Existing arrangements (S0)	33.7	52.4	13.9	12.5	40.6	46.9	18.2	43.5	38.3
Channelized (S1)	34.4	51.9	13.6	12.5	40.7	46.7	18.3	43.5	38.2
Watercourse (S2)	34.4	52.1	13.5	12.5	40.7	46.7	18.3	43.5	38.1

* Probability (%) that the percentage of sites meeting the target state falls within range

In accordance with the principles of the AS/NZS ISO 31000:2009 risk management guidelines, these results represent the raw output of the risk analysis, as they describe the likelihood and consequence of events. The raw results require interpretation to evaluate the significance of the risk level given the context of this assessment (see Section 5.3). However, the raw results have the following notable features:

- Under existing arrangements (S0), the probability that a high proportion of CSL sites (>50%) have *Ruppia* in its target state is quite low (<14%). For chironomids and small-mouthed hardyhead the probabilities are higher but still less than 50%. In other words, the BBN is indicating that existing arrangements (S0) pose a 'background' level of risk to the ecological character of the Coorong and that optimal ecological conditions, particularly in relation to *Ruppia*, are not typical.
- Also notable is that there is very little difference between the design scenarios for cumulative risk or any individual risk statement category. This suggests the SEFRP (S1 or S2) leads to little to no change to the indicators of ecological character in the Coorong compared to existing arrangements (S0).

5.3 Risk evaluation

5.3.1 First pass evaluation

Risks were evaluated by comparing the posterior probabilities of the BBN end points (Table 11) with a risk matrix (Table 5) to produce risk ratings for the existing arrangements (S0) and each SEFRP scenario (S1 and S2). For each risk statement category, the highest level of risk was reported.

To be a significant risk, according to the first pass evaluation criteria, a risk must change to a higher risk rating as a result of the project. The outputs of the risk evaluation for S1 and S2 were compared to S0 to determine the extent to which the project causes a significant change in the overall risk level for the Coorong (Table 12).

Table 12. First pass (low resolution) evaluation

Scenario/pathway	*Ruppia tuberosa*	chironomids	SMHH	Change in risk level under SEFRP
Cumulative				
Existing arrangements (S0)	Moderate	Moderate	Moderate	
Channelized (S1)	Moderate	Moderate	Moderate	None
Watercourse (S2)	Moderate	Moderate	Moderate	None
Over freshening				
Existing arrangements (S0)	Moderate	Moderate	Moderate	
Channelized (S1)	Moderate	Moderate	Moderate	None
Watercourse (S2)	Moderate	Moderate	Moderate	None
Turbidity				
Existing arrangements (S0)	Moderate	Moderate	Moderate	
Channelized (S1)	Moderate	Moderate	Moderate	None
Watercourse (S2)	Moderate	Moderate	Moderate	None
More total nutrients				

Scenario/pathway	*Ruppia tuberosa*	chironomids	SMHH	Change in risk level under SEFRP
Existing arrangements (S0)	Moderate	Moderate	Moderate	
Channelized (S1)	Moderate	Moderate	Moderate	None
Watercourse (S2)	Moderate	Moderate	Moderate	None
More bioavailable N				
Existing arrangements (S0)	Moderate	Moderate	Moderate	
Channelized (S1)	Moderate	Moderate	Moderate	None
Watercourse (S2)	Moderate	Moderate	Moderate	None
First flush event				
Existing arrangements (S0)	Moderate	Moderate	Moderate	
Channelized (S1)	Moderate	Moderate	Moderate	None
Watercourse (S2)	Moderate	Moderate	Moderate	None

The first pass, low resolution evaluation has found:

- There is a moderate level of 'background' risk to all three end points under existing arrangements (S0), and
- The SEFRP (either S1 or S2) does not increase the risk level to the end points.

5.3.2 Second pass evaluation

To determine the significance of risk under the second pass evaluation, the difference in expected value between each SEFRP scenario and existing arrangements was calculated, with higher risk being correlated with a loss of expected value caused by the project. This difference was compared with the second pass evaluation criteria (Section 2.4.3) to determine whether the loss or benefit caused by the SEFRP scenario is significant. The outputs of the second pass risk evaluation for Scenarios 0, 1 and 2 were compared to determine the extent to which the project causes a significant change in the overall inherent risk level for the Coorong (Table 13).

The second pass, high resolution evaluation found:

- For cumulative risk:
  - SEFRP Scenario 2 leads to a moderate increase in the prevalence of the target state for chironomids.
- For risks related to over freshening:
  - SEFRP Scenarios 2 leads to a moderate increase in the prevalence of the target state for chironomids.
  - SEFRP Scenario 2 leads to a moderate increase in the prevalence of the target state for small-mouthed hardyhead.
- No significant risks related to turbidity.
- No significant risks related to total nutrients.

- For risks related to bioavailable nutrients:
    - SEFRP Scenario 2 leads to a deleterious moderate decrease in the prevalence of the target state for *Ruppia*. Treatment of this risk is discussed in Section 6.2.

No significant risks related to the first flush event (total organic carbon).

Table 13. Second pass evaluation. Difference (% sites in target state) in expected value for each end point*.

End point	*Ruppia tuberosa*		chironomids		small-mouthed hardyhead	
Scenario	**Channelised (S1)**	**Watercourse (S2)**	**Channelised (S1)**	**Watercourse (S2)**	**Channelised (S1)**	**Watercourse (S2)**
Cumulative risk	1.8%	2.0%	-4.4%	-6.6%	-2.9%	-3.7%
Over freshening	-1.7%	-1.9%	-5.0%	-7.4%	-4.3%	-5.3%
Turbidity	0.6%	0.4%	0.4%	0.4%	0.2%	0.2%
Total nutrients	0.6%	0.4%	0.4%	0.4%	-0.1%	-0.1%
Bioavailable nutrients	4.4%	5.0%	0.7%	0.7%	1.4%	1.5%
First flush event	1.2%	1.2%	0.0%	0.0%	0.2%	0.3%

*

Moderate benefit   Moderate risk

5.4 Summary

The first pass, low resolution evaluation of the BBN outputs indicates:

- No significant risk to the ecological character of the Coorong caused by the SEFRP (either S1 or S2) for cumulative risk (i.e. all risk statement categories combined)
- No significant risk to the ecological character of the Coorong caused by the SEFRP (either S1 or S2) for any of the individual risk statement categories.

The second pass, high resolution evaluation of the BBN outputs indicates:

- For cumulative risk
    - No significant risk to the ecological character of the Coorong caused by the SEFRP.
    - Moderate benefit to chironomid abundance under SEFRP Scenario 2.

- For individual risk statement categories
    - Moderate risk of increased bioavailable nutrients leading to reduced *Ruppia tuberosa* vigour under SEFRP Scenario 2 (risk treatment discussed in Section 6.2).
    - Moderate benefit arising from over freshening (i.e. more favourable salinity) leading to increased chironomid abundance under both SEFRP scenarios and small-mouthed hardyhead abundance under Scenario 2.

6 Risk treatment

6.1 General recommendations

Risk treatment refers to the management response to risk. Avoiding risk or minimising the level of risk involves steps to address the source of risk or modify the consequences. As a general rule, preventative measures which address the source of risk are more cost-effective than modifying consequences.

The risk analysis found that all risks examined were low/insignificant (with one exception, see Section 6.2) and therefore tolerable. Therefore risk treatment is not required. However, it should be noted that a number of risk treatments were regarded as inherent in the proposed design, operation and monitoring of the SEFRP and therefore were assumed to be in place for the risk analysis. It is important from a Coorong water quality perspective that these assumptions are borne out in the completed project. The primary objective of these treatments is to avoid over freshening of the CSL. The avoidance of over freshening with water from the South East drainage system will also serve to minimise the risks arising from elevated bioavailable nutrients (see Section 6.2). The management of risks related to the first flush (total organic carbon) also has design and operational implications. The design features and monitoring required for water quality management in the Coorong under the SEFRP are:

- The ability to divert Blackford Drain water to sea to prevent over freshening of the CSL;
- The ability to slow or stop Salt Creek inflows to the Coorong by closing Morella Basin outlet regulator and storing water for later release or complete draw down (via evaporation and seepage) to create storage for the following winter;
- Under SEFRP Scenario 2, to incorporate operational flexibility into the design such that flows through the Tilley Swamp Watercourse can either be held and allowed to draw down completely or allowed to pass through to Morella Basin the and Coorong;
- Existing real time salinity monitoring in the CSL be should be maintained;
- Real time water level gauges (i.e. storage volume) in Morella Basin, and under S2 in Tilley Swamp Watercourse, should be maintained and installed respectively;
- CSL salinity forecasting based on barrage flows forecasting should be incorporated into SEFRP operations.

For a detailed summary of risk treatment, informed by participants at Workshop 4, see Appendix C – Risk treatment.

6.2 Recommended risk treatment for bioavailable nutrients

The only variable determined by the analysis (second pass, high resolution) to have a higher risk level (moderate) under the SEFRP (S2) compared to existing arrangements, namely the risk to *Ruppia* vigour posed by increased bioavailable nutrient loading, did not have an assumed treatment in place in the analysis. However treatment of this risk is inherent in the proposed SEFRP design and operations, and the effective treatment of this risk is believed to be readily achievable.

Risks related to increased bioavailable nutrient loading arise as a consequence of the diversion of Blackford Drain flows, which can contain elevated bioavailable nitrogen (see Appendix B – Detailed description of BBN nodes, BioavailableN_high_loading), towards the Coorong. The causal pathways by which increased bioavailable nutrient loading may lead to reduced *Ruppia* vigour involve increased filamentous algal abundance. The treatment for risks involving filamentous algae is adherence to the target salinity minimum (60 g/L) for the CSL, i.e. the avoidance of over freshening. Indeed, the rationale for the target salinity minimum is to maintain conditions that promote growth of *Ruppia* over filamentous algae. The belief inherent in the target minimum is that high salinity provides a physiological restriction on filamentous algal growth that minimises its impact upon *Ruppia* vigour (Paton *et al.* 2015b). Under the SEFRP, avoidance of over freshening with Blackford Drain water is readily achieved by diverting Blackford Drain water to sea and/or into wetlands *en route*. Under the SEFRP, Blackford Drain water would not be used to deliberately over freshen the CSL as it is so readily diverted elsewhere. Thus, the risk posed by bioavailable nutrient loading to *Ruppia* vigour would be avoided as a matter of course, given the target salinity range for the CSL that will guide SEFRP operations. Given this, and other factors such as the eutrophic condition of the CSL, the overall diluting effect for total nutrients anticipated under the SEFRP and the conservativeness of the assumptions regarding the transfer of bioavailable nutrients from the Blackford Drain to the CSL in the BBN, the residual (treated) risk is considered to be low, provided the risk treatments outlined in Section 6.1 are implemented.

7 Discussion and conclusions

The water quality risk assessment has considered a broad range of potential risks to the ecological character of the Coorong posed by the SEFRP, as identified by participants in the process. Risks to the selected indicators of ecological character, *Ruppia tuberosa*, chironomids and small-mouthed hardyhead, were categorised as:

- Risks related to over freshening
- Risks related to increased turbidity
- Risks related to increased loading of total nutrients (nitrogen and/or phosphorus)
- Risks related to increased loading of bioavailable nutrients (nitrogen and/or phosphorus)
- Risks related to increased loading of total organic carbon (TOC) (comprising dissolved organic carbon (DOC) and particulate organic carbon (POC))
- Risks related to changed water temperature
- Risks during construction.

The risk assessment has drawn upon a considerable body of data, including high temporal and spatial resolution water quality (WQ) data for the Coorong South Lagoon collected during Salt Creek inflows under current arrangements (Mosely 2015), lower resolution Coorong WQ data extending over 20 years (Mosely 2015) and WQ data for the Blackford Drain extending over 30 years (Taylor 2014). Leading experts in water quality science and Coorong ecology have participated in the assessment. The conclusions of the risk assessment are:

- Taken cumulatively, given both the first (low resolution) and second pass (high resolution) evaluations, there is a low risk that the SEFRP will lead to significant impacts to the ecological character of the Coorong due to water quality changes. This conclusion applies to both SEFRP Scenarios 1 and 2.
- When considered individually, given the first pass (low resolution) evaluation, no risk category appears likely to cause a significant impact to the ecological character of the Coorong due to water quality changes. This conclusion applies to both SEFRP Scenarios 1 and 2.
- While the second pass (high resolution) evaluation indicated a moderate risk for *Ruppia* vigour due to increased loading of bioavailable nutrients under SEFRP Scenario 2 (only), this risk would in fact be readily avoided as a matter of course by adherence to the existing salinity target minima for the CSL.

These conclusions are valid provided that the following design, operational and monitoring features are incorporated into the SEFRP:

- The ability to divert Blackford Drain water to sea to avoid over freshening of the CSL.
- The ability to slow or stop Salt Creek inflows to the Coorong by closing Morella Basin outlet regulator and storing water for later release or complete draw down (via evaporation and seepage) to create storage for the following winter. This applies to both SEFRP Scenarios 1 and 2, noting that S2 has a greater storage capacity than S1. The purpose is to avoid risks related to over freshening and bioavailable nutrients.
- Under SEFRP Scenario 2, to incorporate operational flexibility into the design such that flows through the Tilley Swamp Watercourse can either be held and allowed to draw down completely or allowed to pass through to Morella Basin the and Coorong. The purpose is to avoid risks related to over freshening, bioavailable nutrients and the first flush (total organic carbon).
- Existing real time salinity monitoring should be maintained as it is necessary to avoid over freshening of the CSL.

- Real time water level gauges (i.e. storage volume) in Morella Basin (both S1 and S2), and Tilley Swamp Watercourse (S2 only), should be maintained and installed respectively. The purpose is to enable real time decision making regarding the diversion of Blackford Drain flows, which is necessary to avoid over freshening of the CSL.
- CSL salinity forecasting based on barrage flows forecasting should be incorporated into SEFRP operations. The purpose is to avoid over freshening.

Because the water quality risks to the Coorong arising from the SEFRP have been assessed as low, the immediate need for further research to reduce uncertainty is relatively low. However, two findings of the assessment should be considered in prioritising any future studies that aim to better inform SEFRP operations. Firstly, the sensitivity analysis has identified the water quality parameters that have the greatest influence upon the indicators of ecological character in the Coorong. Secondly, the process of parameterizing the BBN identified the water quality parameters for which current understanding, and thus confidence, is the lowest. Taking these findings into account, the priorities for future study to best inform the operation of the SEFRP are:

- Improved understanding of the response of filamentous algae to bioavailable nutrients and salinity;
- Improved understanding of the response of *Ruppia tuberosa* to filamentous algal cover;
- Post SEFRP construction monitoring of bioavailable nutrients in the Blackford Drain, SEFRP channel, Morella Basin and Salt Creek to better understand the fate of bioavailable nutrients *en route* to the Coorong;
- Improved understanding of the response of phytoplankton to bioavailable nutrients;
- Improved understanding of the response of *Ruppia tuberosa* to phytoplankton abundance;
- Characterisation of Coorong sediments with regard to storage and release of nutrients and any spatial variability in relation to this characterisation, particularly any spatial relationship to the mouth of Salt Creek;
- Characterisation of Coorong sediments with regard to capacity to generate low dissolved oxygen concentrations in the water column, and any spatial variability in relation to this characterisation, particularly any spatial relationship to the mouth of Salt Creek.

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Appendix A – Complete risk statements

Risks related to over freshening

Statement 1. ***There is the potential for*** increased catchment size leading to higher volumes of fresh water flow into the Coorong ***to cause*** over freshening of water in the entire Coorong (average monthly whole-of-lagoon salinity) ***in turn leading to*** increased abundance and distribution of filamentous algae leading to reduced extent and/or coverage of *Ruppia* (via reduced light availability, interference with flowering) in turn causing impacts to fish and waterbirds.

Statement 2. ***There is the potential for*** increased catchment size leading to higher volumes of fresh water flow into the Coorong ***to cause*** over freshening of water in the entire Coorong (average monthly whole-of-lagoon salinity) ***in turn leading to*** increased abundance and distribution of filamentous algae leading to low DO on exposed sediments in turn causing impacts to invertebrates in turn causing impacts to waterbirds.

Statement 3. ***There is the potential for*** increased catchment size leading to higher volumes of fresh water flow into the Coorong ***to cause*** over freshening of water in the entire Coorong (average monthly whole-of-lagoon salinity) ***in turn leading to*** changed community composition of algae and invertebrates leading to food web impacts in turn causing impacts to fish and waterbirds.

Statement 4. ***There is the potential for*** the SEFRP to increase water release in late spring/summer ***to cause*** increased salinity gradient in mixing zone causing osmotic shock and death of organisms (particularly phytoplankton) ***in turn causing*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased abundance and distribution of filamentous algae leading to reduced extent and/or coverage of *Ruppia* (via reduced light availability, interference with flowering) in turn causing impacts to fish and waterbirds.

Statement 5. ***There is the potential for*** the SEFRP to increase water release in late spring/summer ***to cause*** increased salinity gradient in mixing zone causing osmotic shock and death of organisms (particularly phytoplankton) ***in turn causing*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased abundance and distribution of filamentous algae leading to low DO on exposed sediments in turn causing impacts to invertebrates in turn causing impacts to waterbirds.

Statement 6. ***There is the potential for*** the SEFRP to increase water release in late spring/summer ***to cause*** increased salinity gradient in mixing zone causing osmotic shock and death of organisms (particularly phytoplankton) ***in turn causing*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased phytoplankton growth in mixing zone causing reduced light availability causing reduced extent and/or coverage of *Ruppia* causing impacts to fish and waterbirds.

Risks related to increased particulate organic carbon (POC) deposition in the mixing zone

Statement 7. ***There is the potential for*** SEFRP to cause increased loading of POC (including phytoplankton) ***to cause*** increased POC deposition in the mixing zone ***in turn leading to*** increased microbial growth in sediments and/or water column in mixing zone causing low DO in turn causing fish kills and impacts on invertebrates (benthic and pelagic) in turn causing impacts to waterbirds.

Statement 8. ***There is the potential for*** SEFRP to cause increased loading of POC (including phytoplankton) ***to cause*** increased POC deposition in the mixing zone ***in turn causing*** increased microbial growth in sediments and/or water column in mixing zone ***in turn causing*** low DO in mixing zone ***in turn causing*** release of bioavailable N and/or P from sediments ***in turn causing*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased abundance and distribution of filamentous algae leading to reduced extent and/or coverage of *Ruppia* (via reduced light availability, interference with flowering) in turn causing impacts to fish and waterbirds.

Statement 9. ***There is the potential for*** SEFRP to cause increased loading of POC (including phytoplankton) ***to cause*** increased POC deposition in the mixing zone ***in turn causing*** increased microbial growth in sediments and/or water column in mixing zone ***in turn causing*** low DO in mixing zone ***in turn causing*** release of bioavailable N and/or P from sediments ***in turn causing*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased abundance and distribution of filamentous algae leading to low DO on exposed sediments in turn causing impacts to invertebrates in turn causing impacts to waterbirds

Statement 10. ***There is the potential for*** SEFRP to cause increased loading of POC (including phytoplankton) ***to cause*** increased POC deposition in the mixing zone ***in turn causing*** increased microbial growth in sediments and/or water column in mixing zone ***in turn causing*** low DO in mixing zone ***in turn causing*** release of bioavailable N and/or P from sediments ***in turn causing*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased phytoplankton growth in mixing zone causing reduced light availability causing reduced extent and/or coverage of *Ruppia* causing impacts to fish and waterbirds.

Statement 11. ***There is the potential for*** SEFRP to cause increased loading of POC (including phytoplankton) ***to cause*** increased POC deposition in the mixing zone ***in turn leading to*** increased microbial growth in sediments and/or water column in mixing zone ***in turn causing*** low DO in mixing zone ***in turn causing*** increased sulphides in sediment in mixing zone impacting both invertebrates and extent and/or coverage of *Ruppia* in turn causing impacts to fish and waterbirds.

Statement 12. ***There is the potential for*** SEFRP to cause increased loading of POC including phytoplankton ***to cause*** increased POC deposition in the mixing zone ***in turn leading to*** reduced stability of substrate leading to reduced cover and/or extent of *Ruppia* and/or altered community of invertebrates in turn causing impacts to fish and waterbirds.

Risks related to increased turbidity

Statement 13. ***There is the potential for*** the SEFRP to cause increased loading of organic particulate matter (including phytoplankton) ***in turn leading to*** increased turbidity (non-living suspended particulate matter, organic and/or inorganic) in mixing zone causing reduced light availability causing reduced extent and/or coverage of *Ruppia* causing impacts to fish and waterbirds.

Statement 14. ***There is the potential for*** the SEFRP to cause increased loading of inorganic sediments ***in turn leading to*** increased turbidity (non-living suspended particulate matter, organic and/or inorganic) in mixing zone causing reduced light availability causing reduced extent and/or coverage of *Ruppia* causing impacts to fish and waterbirds.

Risks related to increased loading of total nutrients (nitrogen and/or phosphorus)

Statement 15. ***There is the potential for*** the SEFRP to cause increased loading of TN and/or TP ***to cause*** increased total N and/or P concentration in the entire Coorong ***in turn leading to*** increased abundance and distribution of filamentous algae leading to reduced extent and/or coverage of *Ruppia* (via reduced light availability, interference with flowering) in turn causing impacts to fish and waterbirds.

Statement 16. ***There is the potential for*** the SEFRP to cause increased loading of TN and/or TP ***to cause*** increased total N and/or P concentration in the entire Coorong ***in turn leading to*** increased abundance and distribution of filamentous algae leading to low DO on exposed sediments in turn causing impacts to invertebrates in turn causing impacts to waterbirds.

Statement 17. ***There is the potential for*** the SEFRP to cause increased loading of TN and/or TP ***to cause*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased abundance and distribution of filamentous algae leading to reduced extent and/or coverage of *Ruppia* (via reduced light availability, interference with flowering) in turn causing impacts to fish and waterbirds.

Statement 18. ***There is the potential for*** the SEFRP to cause increased loading of TN and/or TP ***to cause*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased abundance and distribution of filamentous algae leading to low DO on exposed sediments in turn causing impacts to invertebrates in turn causing impacts to waterbirds.

Statement 19. ***There is the potential for*** the SEFRP to cause increased loading of TN and/or TP ***to cause*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased phytoplankton growth in mixing zone causing reduced light availability causing reduced extent and/or coverage of *Ruppia* causing impacts to fish and waterbirds.

Risks related to increased loading of bioavailable nutrients (nitrogen and/or phosphorus)

Statement 20. ***There is the potential for*** the SEFRP to cause increased loading of bioavailable N and/or P ***to cause*** increased total N and/or P concentration in the entire Coorong ***in turn leading to*** increased abundance and distribution of filamentous algae leading to reduced extent and/or coverage of *Ruppia* (via reduced light availability, interference with flowering) in turn causing impacts to fish and waterbirds.

Statement 21. ***There is the potential for*** the SEFRP to cause increased loading of bioavailable N and/or P ***to cause*** increased total N and/or P concentration in the entire Coorong ***in turn leading to*** increased abundance and distribution of filamentous algae leading to low DO on exposed sediments in turn causing impacts to invertebrates in turn causing impacts to waterbirds.

Statement 22. ***There is the potential for*** the SEFRP to cause increased loading of bioavailable N and/or P ***to cause*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased abundance and distribution of filamentous algae leading to reduced extent and/or coverage of *Ruppia* (via reduced light availability, interference with flowering) in turn causing impacts to fish and waterbirds.

Statement 23. ***There is the potential for*** the SEFRP to cause increased loading of bioavailable N and/or P ***to cause*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased abundance and distribution of filamentous algae leading to low DO on exposed sediments in turn causing impacts to invertebrates in turn causing impacts to waterbirds.

Statement 24. ***There is the potential for*** the SEFRP to cause increased loading of bioavailable N and/or P ***to cause*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased phytoplankton growth in mixing zone causing reduced light availability causing reduced extent and/or coverage of *Ruppia* causing impacts to fish and waterbirds.

Risks related to increased loading of dissolved organic carbon (DOC)

Statement 25. ***There is the potential for*** the SEFRP to cause increased loading of DOC ***to cause*** increased DOC concentration in the mixing zone ***in turn leading to*** increased microbial growth in sediments and/or water column in mixing zone causing low DO in turn causing fish kills and impacts on invertebrates (benthic and pelagic) in turn causing impacts to waterbirds

Statement 26. ***There is the potential for*** the SEFRP to cause increased loading of DOC ***to cause*** increased DOC concentration in the mixing zone ***in turn causing*** increased microbial growth in sediments and/or water column in mixing zone ***in turn causing*** low DO in mixing zone ***in turn causing*** release of bioavailable N and/or P from sediments ***in turn causing*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased abundance and distribution of filamentous algae leading to reduced extent and/or coverage of *Ruppia* (via reduced light availability, interference with flowering) in turn causing impacts to fish and waterbirds.

Statement 27. ***There is the potential for*** the SEFRP to cause increased loading of DOC ***to cause*** increased DOC concentration in the mixing zone ***in turn causing*** increased microbial growth in sediments and/or water column in mixing zone ***in turn causing*** low DO in mixing zone ***in turn causing*** release of bioavailable N and/or P from sediments ***in turn causing*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased abundance and distribution of filamentous algae leading to low DO on exposed sediments in turn causing impacts to invertebrates in turn causing impacts to waterbirds.

Statement 28.***There is the potential for*** the SEFRP to cause increased loading of DOC ***to cause*** increased DOC concentration in the mixing zone ***in turn causing*** increased microbial growth in sediments and/or water column in mixing zone ***in turn causing*** low DO in mixing zone ***in turn causing*** release of bioavailable N and/or P from sediments ***in turn causing*** increased bioavailable N and/or P concentration in the mixing zone ***in turn leading to*** increased phytoplankton growth in mixing zone causing reduced light availability causing reduced extent and/or coverage of *Ruppia* causing impacts to fish and waterbirds.

Statement 29.***There is the potential for*** the SEFRP to cause increased loading of DOC ***to cause*** increased DOC concentration in the mixing zone ***in turn causing*** increased microbial growth in sediments and/or water column in mixing zone ***in turn causing*** low DO in mixing zone ***in turn causing*** release of bioavailable N and/or P from sediments ***in turn causing*** increased sulphides in sediment in mixing zone impacting both invertebrates and extent and/or coverage of *Ruppia* in turn causing impacts to fish and waterbirds.

Statement 30.***There is the potential for*** the SEFRP to cause increased loading of DOC ***to cause*** increased DOC concentration in the entire Coorong ***in turn leading to*** all of the above DOC related risks to occur at the entire Coorong scale

Risks related to changed water temperature

Statement 31.***There is the potential for*** the SEFRP to cause reduced temperature of inflow water ***to cause*** changed temperature of water in the mixing zone ***in turn leading to*** changes to the rates of biological processes implicit in all other Risk statements.

Statement 32.***There is the potential for*** SEFRP to increase water release in late spring/summer ***to cause*** changed temperature of water in the mixing zone ***in turn leading to*** changes to the rates of biological processes implicit in all other Risk statements.

Risks during construction

Statement 33.***There is the potential for*** the SEFRP to change constituents of inflow water during construction ***to cause*** any of the identified events (short term) ***in turn leading to*** any of the identified consequences (short term).

Appendix B – Detailed description of BBN nodes

Scenario

Rationale: Represents the SEFRP scenario being examined, including existing arrangements.

Discretisation: Three classes representing the three SEFRP scenarios under examination:

- Scenario 0 – existing arrangements (no project)
- Scenario 1 – SEFRP fully channelised design
- Scenario 2 – SEFRP watercourse design

Daily inflows to the Coorong were modelled for each Scenario (Fuller 2015) based on detailed catchment modelling undertaken for the SEFRP (AWE 2015). The modelled daily inflows under each Scenario were represented by the following rules:

- Scenario 0 – daily inflows from the existing Salt Creek catchment
- Scenario 1 - daily inflows from the existing Salt Creek catchment plus the Blackford Drain, reduced to existing Salt Creek catchment only when average Coorong South Lagoon salinity falls below 60 g/L
- Scenario 2 - daily inflows from the existing Salt Creek catchment plus the Blackford Drain, reduced to zero flow when average Coorong South Lagoon salinity falls below 60 g/L

The rule for Scenario 1 reflects the ability to direct the Blackford Drain flows to sea, instead of towards the Coorong, once the CSL is sufficiently fresh. The rule for Scenario 2 reflects the ability to completely close the Morella Basin regulator and store all flows in the combined Morella Basin and Tilley Swamp Watercourse once the CSL is sufficiently fresh.

Input variables and interactions: None

Parameterisation: The SEFRP scenario being examined was set to 100%, the other two scenarios to 0%.

Mixing_zone_size_km

Rationale: The size of the mixing zone is likely to have an important affect upon water quality in the Coorong because:

- Water quality (e.g. salinity) in the mixing zone may at times be outside of the target range
- Certain processes with potentially undesirable impacts upon water quality may occur in the mixing zone, e.g.:
    - Uptake of bioavailable nutrients and consequent increase on abundance/cover of phytoplankton and/or filamentous algae
    - Deposition of particulate matter onto Coorong sediments
    - High turbidity during inflow events
    - Release from sediments of accumulated nutrients in bioavailable form during conditions when thermal and/or salinity stratification may occur
- As described in Section 4.2, water quality events in the mixing zone may have impacts at the mixing zone scale or at the greater Coorong scale

The mixing zone was defined as the area within which salinity is ≤90% of the maximum salinity in the South Lagoon, contiguous with the Salt Creek outlet and caused by Salt Creek flows (not River Murray flows) (Fuller 2015).

Discretisation: Given it's long, narrow shape, locations or zones of the Coorong can be described as linear km based in its long SE-NW axis. Three classes of mixing zone size were thus defined:

- 0 – 3 km (small)
- 3 – 10 km (medium)
- 10 – 30 km (large)

The classes represent the maximum size attained by the mixing zone in a given year. The zone classes took into account:

- The overall focus of the WQRA, i.e. the southernmost 56 linear km of the Coorong,
- Plume sizes observed by past (ongoing) Coorong water quality monitoring (Mosely 2015); and
- Plume size as predicted by the 1-dimensional Coorong hydrodynamic model (Jöhnk and Webster 2014) under the three SEFRP scenarios, with the plume defined as the area of the Coorong, contiguous with the Salt Creek outlet, where salinity is below 90% of the South Lagoon maximum (Fuller 2015).

Using salinity as the indicator of plume size is a conservative approach, i.e. it is more likely to over-estimate the size of the plume than under-estimate it. This is because dissolved salt is passive and influenced primarily by hydrodynamic processes (mixing). It is not influenced by biological process (e.g. uptake by organisms) and it does not drop out of the water column and accumulate in sediments.

Input variables and interactions:

- SEFRP Design Scenario – the scenario influences the daily inflow rate and total annual inflow, both of which influence the size of the mixing zone. Modelling indicated generally modest differences in mixing zone size under the different scenarios.

Parameterisation: Mixing zone size was represented in the BBN by the following conditional probability table (CPT):

SEFRP Design Scenario	0 to 3 km	3 to 10 km	10 to 30 km

S0	94	0	6
S1	87	0	13
S2	81	13	6

Explanatory note: under Scenario 1 (fully channelised) the maximum annual mixing zone size is predicted to be in the 10 – 30 km size class in 13% of years during the first 10 years of SEFRP operation.

The CPT shows the dependency of mixing zone size upon SEFRP scenarios. The probabilities in the CPT represent predictions supported by modelled data. The CPT was populated directly from the modelled mixing zone size under S0, 1 and 2, as indicated in the table below sourced from Fuller (2015). Note that Fuller modelled the 30 year period 1971 – 2000, which is consistent with all other hydrological modelling informing the SEFRP. This 30 year period has been assumed to provide an indication of the mixing zone sizes anticipated during the first 10 years of SEFRP operation.

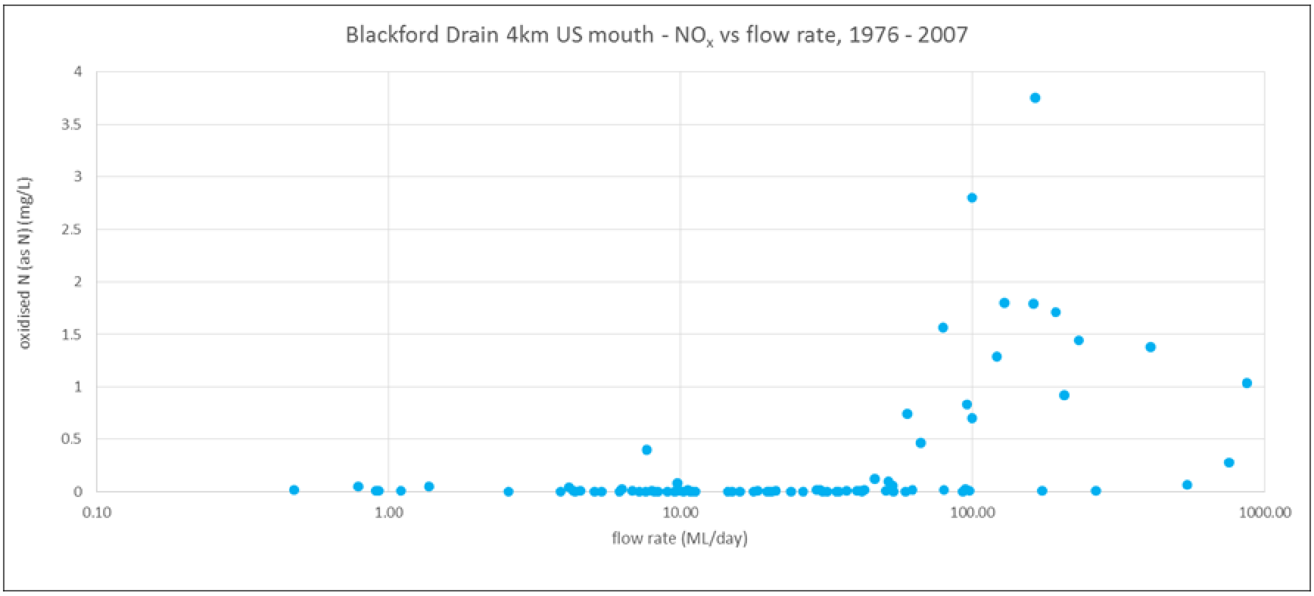
	Maximum mixing zone size (km)		
Year	Base Case EDN (Scenario 0)	SEFRP Fully Channelised (Scenario 1)	SEFRP Watercourse (Scenario 2)
1971	1	1	0
1972	11	11	9
1973	0	0	0
1974	0	0	0
1975	0	0	0
1976	0	0	0
1977	28	28	0
1978	0	0	0
1979	0	0	0
1980	0	0	0
1981	0	1	1
1982	0	0	0
1983	0	13	13
1984	0	0	0
1985	0	0	0
1986	0	0	5
1987	0	0	6
1988	0	1	1
1989	0	0	0
1990	0	0	0
1991	0	0	0
1992	0	0	0
1993	0	0	0
1994	0	0	0
1995	0	0	0
1996	0	0	0
1997	0	0	0
1998	0	0	0
1999	0	0	0

	Maximum mixing zone size (km)		
Year	Base Case EDN (Scenario 0)	SEFRP Fully Channelised (Scenario 1)	SEFRP Watercourse (Scenario 2)
2000	0	14	13

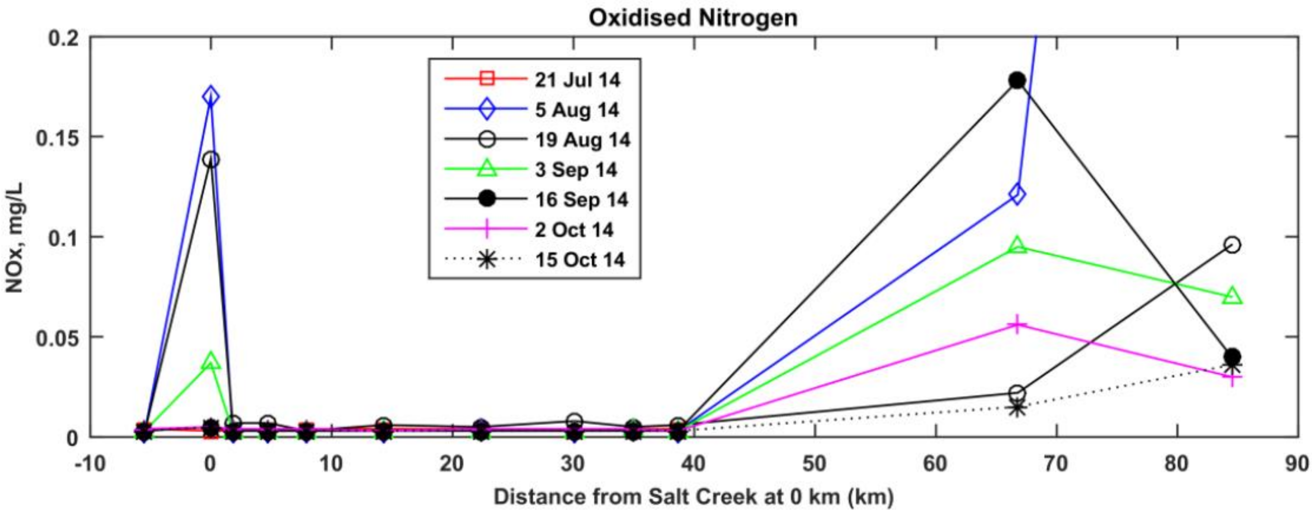
BioavailableN_high_loading

Rationale: Blackford Drain water quality data indicates occasionally elevated concentrations of bioavailable nitrogen (NO_x) under high flows (see below). Increased loading of bioavailable nitrogen into the Coorong was identified as a potential risk to ecological values. The pathways by which this risk potentially manifests are described by Risk statements 20 to 24 (Appendix A). Note that although the Risk statements refer to "nitrogen and/or phosphorus", this node is focussed on nitrogen only. The available data for bioavailable phosphorus for the Blackford Drain and current Salt Creek flows (Taylor 2014) indicates median concentrations similar to the ANZECC guidelines for estuaries (0.005 mg/L) (ANZECC 2000), with spikes above this background concentration very rare. This is to be expected for flows in the South East drainage system given the unconfined limestone aquifer that characterises the region; phosphorus has a tendency to bind with limestone (Clive Jenkins, EPA, pers. comm.). Recent water quality monitoring in the Coorong supports the belief that bioavailable phosphorus entering at Salt Creek is low and has negligible influence on Coorong water quality (Mosely 2015).

Discretisation: A high bioavailable nitrogen loading to the Coorong has been defined by two classes; yes and no. The yes situation was defined as the periods when Salt Creek flows to the Coorong are >200 ML/day under Scenarios 1 or 2. This is based on water quality data for the Blackford Drain (below), which indicates that elevated bioavailable N occurs at flows above approximately 100 ML/day, noting that Blackford daily flows would typically comprise approximately 50% of Salt Creek daily flows under the SEFRP (AWE 2015).



Salt Creek flows from the existing catchment, even under high flows, appear to have much lower concentrations of bioavailable nitrogen that the elevated concentrations recorded in the Blackford Drain under high flows. The figure below from Mosely (2015) shows bioavailable nitrogen concentration along the length of the Coorong through time during the 2014 Salt Creek inflows. At 0 km from Salt Creek NO_x concentration is indicative of that in Salt Creek inflows. The maximum concentration recorded in 2014 is 0.175 mg/L on 5 August, with Salt Creek flowing at 365 ML/day. This high flow concentration is an order of magnitude lower that the elevated concentrations recorded in the Blackford Drain under high flows. Given the similarity in land use in the existing Salt Creek and Blackford catchments, and the similar flow volumes, this difference in bioavailable N concentration may be explained by the storage period (of variable duration) in Morella Basin prior to release of Salt Creek water. Passage of water through Morella Basin will remain a feature of all Salt Creek flows under the SEFRP, including fully channelised operations.



As outlined in Section 3.2, given the uncertainty regarding the fate of elevated bioavailable nitrogen from the Blackford Drain, the assumption that the bioavailable nitrogen concentration of Blackford Drain water remains unchanged during its 90 km journey from the Blackford Drain to the Coorong has been made. This is a conservative assumption, i.e. it is more likely to over-estimate than under-estimate the frequency that bioavailable N loading is predicted to be high. In practice, considering current Salt Creek water quality (Mosely 2015), some uptake, and thus reduction in concentration, of bioavailable N is likely to occur *en route* to the Coorong, even under fully channelised flows.

Input variables and interactions:

- SEFRP Design Scenario – the scenario influences the volume of flow that enters the Coorong at flow rates >200 ML/day

Parameterisation: High loading of NO_x was represented in the BBN by the following CPT:

Scenario	yes	no
S0	0	100
S1	62	38
S2	70	30

Explanatory note: under Scenario 2 the percentage of the total volume of water entering the Coorong in the first 10 years of SEFRP operation anticipated to have an elevated bioavailable N concentration is 70%.

The values in the CPT are the proportion of total inflows to the Coorong that are delivered at flow rates >200 ML/day for the "yes" case, and <200 ML/day for the "no" case, as modelled by Fuller (2015) and AWE (2015), except for S0, which does not include Blackford flows and therefore is always the "no" case.

First_flush_event

Rationale: As discussed in Section 3.2, Scenario 2 has the potential to increase the total organic carbon (TOC) load entering the Coorong during the first one to three through-flow events through the Tilley Swamp Watercourse. TOC consists of particulate organic carbon (POC) and dissolved organic carbon (DOC) The pathways by which this risk potentially manifests are described by Risk statements 7 to 12 and 25 to 30 (Appendix A).

Discretisation: The first flush event has been defined by two classes; yes and no. The yes situation applies when flows to the Coorong have passed through the Tilley Swamp Watercourse, and this only occurs in years when water availability from the South East drainage system is greater than the Coorong's requirement in winter/spring. The first flush event applies only to Scenario 2.

Input variables and interactions:

- SEFRP Design Scenario

Parameterisation: First flush event was represented in the BBN by the following CPT:

Scenario	yes	no
S0	0	100
S1	0	100
S2	30	70

Explanatory note: under Scenario 2 the anticipated percentage of the total volume of water entering the Coorong in the first 10 years of SEFRP operation that has flowed through the Tilley Swamp Watercourse is 30%.

The probabilities in the CPT represent expert opinion, based on modelling (AWE 2015, Fuller 2015), regarding the proportion of total flows to the Coorong likely to have passed through the Tilley Swamp Watercourse during the first 10 years of SEFRP operation.

Salinity_ppt_latespring

Rationale: Salinity in the Coorong South Lagoon in late spring (November) is thought to strongly influence the condition of *Ruppia tuberosa* (Brookes *et al.* 2009b, Paton 2010, Paton *et al.* 2015b), with excessively low or high salinities potentially disadvantaging the species, leading to implications for ecological character. Expert opinion is that at salinities below 60 g/L in late spring, filamentous algae is advantaged over *Ruppia* and therefore *Ruppia* vigour can be expected to decline.

Discretisation: Three classes of salinity in late spring were defined based on the accepted management target range for *Ruppia* in the Coorong South Lagoon:

- 0 – 60 g/L – likely to be excessively low and advantage filamentous algae over *Ruppia*;
- 60 – 110 g/L – the optimal range for *Ruppia*; and
- 110 – 300 g/L – excessively high for *Ruppia* and other biota.

Input variables and interactions:

- SEFRP Design Scenario – influences annual volume of water delivered to the Coorong, which directly influences late spring salinity.

Parameterisation: Salinity in late spring was represented in the BBN by the following CPT:

Scenario	0 to 60	60 to 110	110 to 300
S0	59	31	10
S1	59	35	5
S2	49	46	5

Explanatory note: under Scenario 1 (fully channelised) Coorong South Lagoon salinity is anticipated to be in the 60 – 110 g/L range in November in 35% of years for the first 10 years of SEFRP operation.

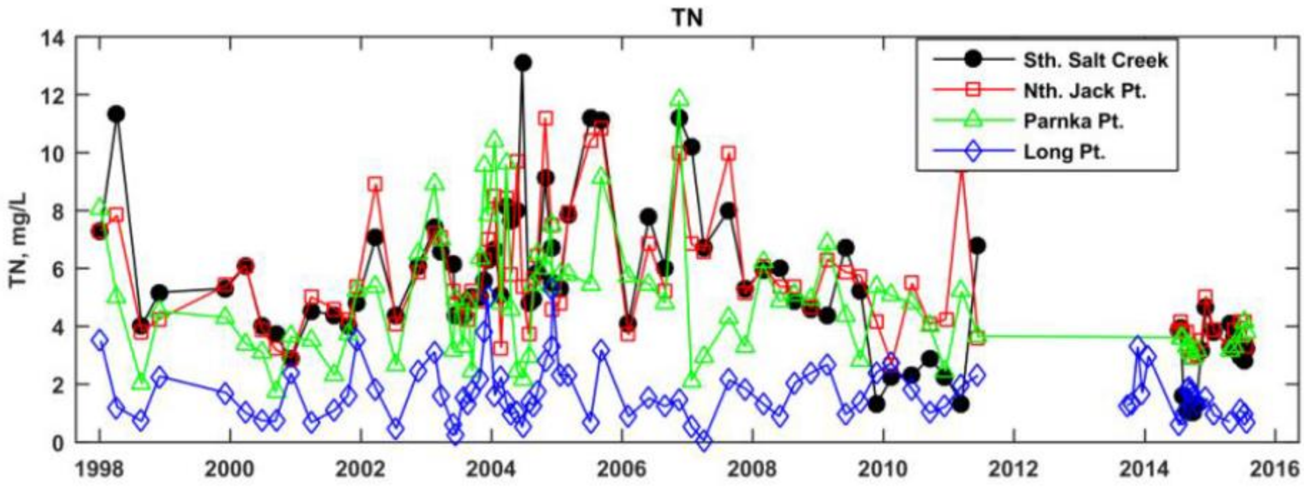
The probabilities in the CPT reflect the predicted Coorong South Lagoon salinities as modelled by Fuller (2015), refined to take into account the operational flexibility that will be possible but is not reflected in Fuller's simple operational rules.

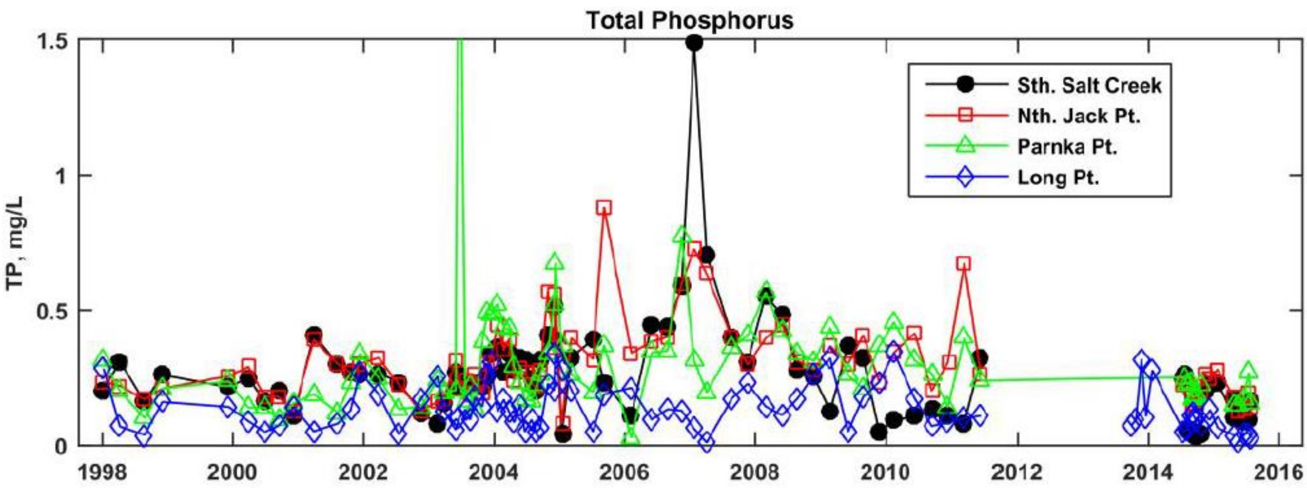
TNutrients_conc

Rationale: The total nutrient concentration in the water column of the Coorong has implications for ecological character via a number of risk pathways explained by Risk statements 15 to 19 (Appendix A). The SEFRP scenarios have the potential to influence this water quality parameter.

Discretisation: Three classes of total nutrient concentration in the water column of the Coorong South Lagoon were defined, based on the long term (1998 – present) data (Mosely 2015) (see figures below – note Long Point is in the North Lagoon outside the area of focus of the risk assessment):

- Low = total nitrogen 0 - 3 mg/L and total phosphorus 0 – 0.2 mg/L;
- Med = total nitrogen 3 - 6 mg/L and total phosphorus 0.2 – 0.5 mg/L; and
- High = total nitrogen > 6 mg/L and total phosphorus > 0.5 mg/L.





Average total nitrogen (TN) concentration in Salt Creek flows under current management and in the Blackford Drain are very similar, both approximately 1.5 mg/L (Taylor 2014, Mosely 2015), and therefore Salt Creek inflows under the SEFRP can be anticipated to have an average TN concentration of approximately 1.5 mg/L. This concentration is markedly lower than the typical Coorong South Lagoon TN concentration of >4 mg/L (see figure above). Thus current Salt Creek inflows have a diluting effect upon CSL TN, which has been measured (Mosely 2015), and is anticipated to continue under the SEFRP. The Coorong hydrodynamic model (Jöhnk and Webster 2014) shows increased export of water from CSL to CNL in response to increased Salt Creek inflows. Exported water is likely to contain TN at a higher concentration than it is entering at Salt Creek, thus increased Salt Creek inflows may lead to a net export of TN from the CSL. This possibility was raised by (Taylor 2014) and is supported by the Coorong water quality monitoring data (Mosely 2015). However alternative explanations for reduced CSL TN concentration during Salt Creek inflows, such as sedimentation and zooplankton grazing, cannot be ruled out (Mosely 2015).

For total phosphorus (TP) a very similar story applies. Blackford Drain and Salt Creek under current management both have a very similar average TP concentration of approximately 0.05 mg/L and therefore this average concentration can be anticipated to continue under the SEFRP. The CSL has a typical TP concentration >1.5 mg/L (see figure above) and Salt Creek inflows have a measured diluting effect (Mosely 2015) that can be expected to continue under the SEFRP and may be explained by the same processes affecting TN.

Input variables and interactions:

- SEFRP Design Scenario – influences the volume of Salt Creek inflows

Parameterisation: Total nutrient concentration was represented in the BBN by the following CPT:

Scenario	low	med	high
S0	5	65	30
S1	10	65	25
S2	12	65	23

Explanatory note: under Scenario 2 the CSL is anticipated to have a high total nutrient concentration for 23% of the time during the first 10 years of SEFRP operation.

The CPT reflects the slight lowering of total nutrient concentrations in the CSL, via increased dilution and possible export, anticipated under the SEFRP, with Scenario 2 anticipated to have a slightly greater effect than Scenario 1 due to the slightly greater total inflow volumes anticipated under the former.

Bioavailable_TOC_high

Rationale: This node describes the risk of a net increase in the bioavailable total organic carbon (TOC) loading of the CSL as a consequence of increased Salt Creek inflows. It also describes the influence of the first flush event (Scenario 2 only) upon the likelihood of increasing TOC in the CSL. The risk pathways by which increased bioavailable TOC may affect the ecological character of the Coorong are described by Risk statements 7 to 12 and 25 to 30 (Appendix A).

Discretisation: This node was defined by two classes; yes – meaning TOC in the CSL is high, and no – meaning TOC in the CSL is not high.

Input variables and interactions:

- First flush event – if "yes" then S2 is more likely to result in high TOC in the CSL than if "no". If "no" then S1 and S2 have the same likelihood of leading to high TOC, because Salt Creek inflows are fully channelized under both Scenarios.
- SEFRP Design Scenario – influences the volume of Salt Creek inflows and therefore the TOC load entering the CSL.

Parameterisation: Bioavailable TOC was represented in the BBN by the following CPT:

first flush event	scenario	yes	no
yes	S0	70	30
yes	S1	80	20
yes	S2	90	10
no	S0	70	30
no	S1	80	20
no	S2	80	20

Explanatory note: under S2, when the first flush event is not occurring, the CSL is anticipated to have a high TOC concentration 80% of the time during the first 10 years of SEFRP operations.

Evidence to support this node is limited and it is therefore largely reliant upon expert opinion. The CPT reflects the belief that TOC concentration in the CSL is naturally high (i.e. under S0), for which there is some supporting evidence (Ford 2007). The CPT also reflects the assumption that increased Salt Creek inflows will increase TOC concentration in the CSL. Organic nitrogen concentration is a surrogate for TOC. Recent data indicate that current Salt Creek inflows have an organic nitrogen concentration that is 25 – 75% of the CSL concentration (Mosely 2015). Rather than increase CSL TOC, Salt Creek inflows may reduce it via the same hydrodynamic processes postulated for total nutrients (see above). However, given the paucity of data and low confidence, the conservative assumption that the SEFRP will increase TOC loading has been used.

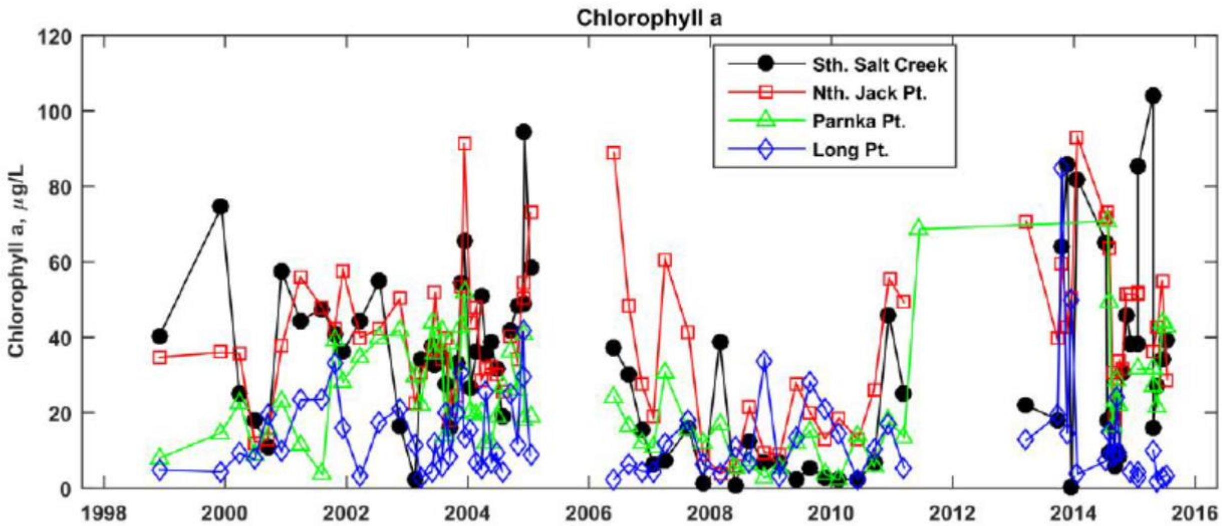
Sites_Chla_20ug/L

Rationale: Chlorophyll a concentration in the water column of the Coorong South Lagoon is a surrogate measure of phytoplankton abundance. The higher the phytoplankton abundance the lower the light penetration through the water column and therefore the lower light incident upon submerged beds of *Ruppia tuberosa* and the lower the growth rate of *Ruppia*.

Discretisation: Three classes have been defined for this node:

- 0 – 10 % of sites in the CSL with a chlorophyll a concentration in the water column of >20 ug/L;
- 10 – 50 % of sites in the CSL with a chlorophyll a concentration in the water column of >20 ug/L; and
- 50 – 100 % of sites in the CSL with a chlorophyll a concentration in the water column of >20 ug/L.

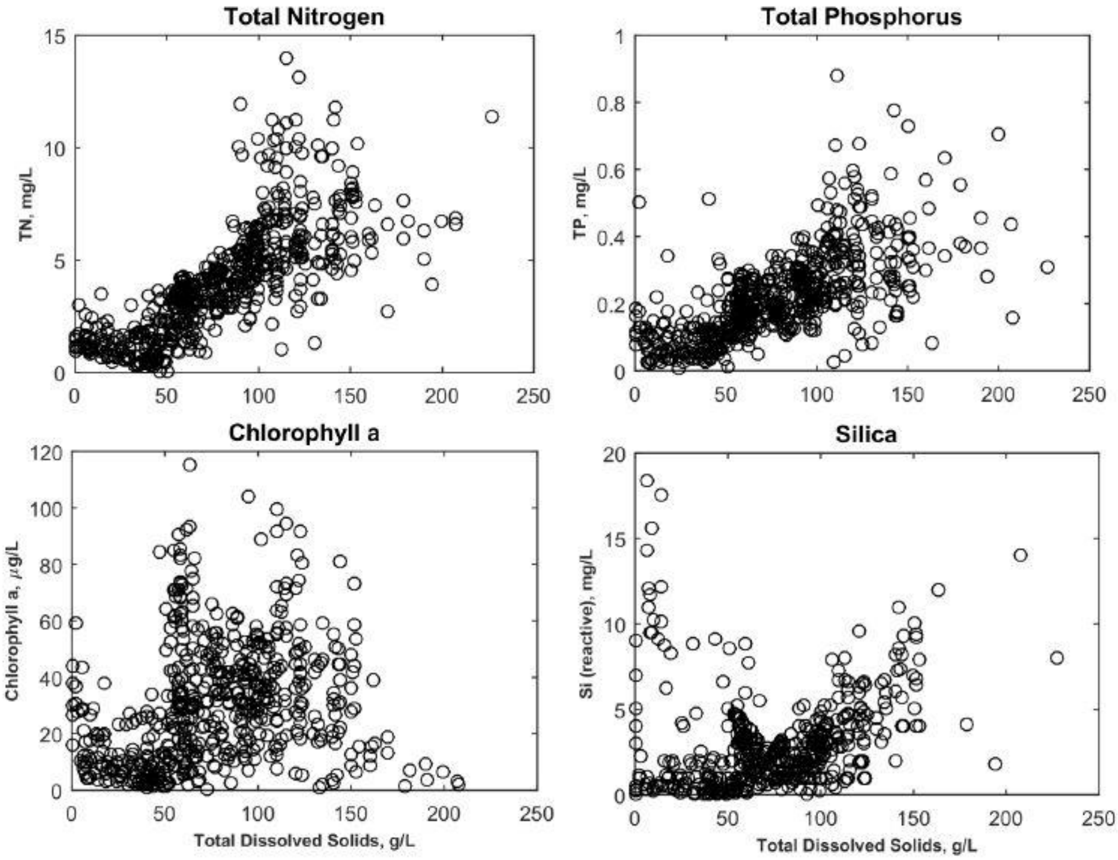
The 20 µg/L threshold reflects expert opinion regarding the concentration at which implications for *Ruppia* vigour are likely to occur. Given the long term chlorophyll a concentration data for the CSL (Mosely 2015 - see below), it is a relatively low, and therefore conservative, threshold.



Input variables and interactions:

- Salinity_ppt_latespring – long term data for the CSL indicates low salinity (0 – 60 g/L) is correlated with low chlorophyll a concentration, moderate salinity (60 – 110 g/L) with high chlorophyll a and high salinity (>110 g/L) with variable chlorophyll a (see figure below from Mosely 2015)

- Tnutrients_conc – long term data for the CSL indicates low salinity (0 – 60 g/L) is correlated with low TN and TP, with TN and TP increasing linearly with increasing salinity above 60 g/L (see figure below from Mosely 2015)



Parameterisation: Chlorophyll a concentration was represented in the BBN by the following CPT:

Salinity_ppt _latespring	Tnutrients_ conc	0 to 10	10 to 50	50 to 100
0 to 60	low	70	20	10
0 to 60	med	50	30	20
0 to 60	high	30	40	30
60 to 110	low	10	10	80
60 to 110	med	5	10	85
60 to 110	high	0	10	90
110 to 300	low	20	30	50
110 to 300	med	15	30	55
110 to 300	high	10	30	60

Explanatory note: if CSL salinity in late spring is in the 0 – 60 g/L range and the total nutrient concentration is high, there is a 30% probability that 50 – 100% of sites in the CSL will have a chlorphyll a concentration >20 µg/L.

Site_with_FA_greater_20

Rationale: The cover/abundance of filamentous algae (FA) in the Coorong South Lagoon has direct implications for *Ruppia tuberosa* (Paton *et al.* 2015b), and indirect implications for other components of ecological character, as reflected by a number of Risk statements. Filamentous algae can reduce light penetration into the water column and the thereby reduce the growth rate of *Ruppia*. Filamentous algae can also directly interfere with *Ruppia* flowering, thereby reducing seed production. This node in the BBN reflects the belief that the cover of filamentous algae is likely to be higher under conditions of higher bioavailable and total nutrient concentrations, but that its growth is mediated by salinity, with salinity above 60 g/L advantaging *Ruppia* over algae. This reflects current understanding and management objectives.

Discretisation: Three classes have been defined for this node:

- 0 – 10 % of sites in the CSL with a filamentous algae cover of >20 %;
- 10 – 50 % of sites in the CSL with a filamentous algae cover of >20 %; and
- 50 – 100 % of sites in the CSL with a filamentous algae cover of >20 %.

The 20% figure refers to the projected cover of filamentous algae at an individual site. The 20% threshold reflects expert opinion regarding the cover at which implications for *Ruppia* vigour are likely to occur due to a combination of shading and interference with flowering.

Input variables and interactions:

- Bioavailable nitrogen high loading – it has been assumed, based on expert opinion, that a high bioavailable N loading leads to increased probability of filamentous algae cover >20%
- Salinity late spring – it has been assumed, based on expert opinion (e.g. Paton *et al.* 2015b), that increasing salinity in late spring leads to reduced probability of filamentous algae cover >20%
- Total nutrient concentration – it has been assumed that increased total nutrient concentration leads to greater probability of filamentous algae cover >20%

Parameterisation: Sites with filamentous algae >20% cover was represented in the BBN by the following CPT:

BioavailableN_ high_loading	Salinity_ppt_ latespring	Tnutrients_ conc	0 to 10	10 to 50	50 to 100
yes	0 to 60	low	10	50	40
yes	0 to 60	med	5	45	50
yes	0 to 60	high	0	40	60
yes	60 to 110	low	20	70	10
yes	60 to 110	med	30	50	20
yes	60 to 110	high	40	30	30
yes	110 to 300	low	100	0	0
yes	110 to 300	med	100	0	0
yes	110 to 300	high	100	0	0
no	0 to 60	low	20	50	30
no	0 to 60	med	15	45	40
no	0 to 60	high	10	40	50
no	60 to 110	low	40	60	0
no	60 to 110	med	50	40	10
no	60 to 110	high	60	20	20
no	110 to 300	low	100	0	0
no	110 to 300	med	100	0	0
no	110 to 300	high	100	0	0

Explanatory note: if there has been no loading of the Coorong with elevated bioavailable nitrogen, late spring salinity is in the 110 – 300 g/L range and total nutrient concentration is high there is 100% probability that 0 – 10% of sites in the CSL will have a chlorophyll a concentration greater than 20 ug/L.

Sites_light_limiting

Rationale: This node reflects the belief that the growth of *Ruppia* is influenced by the amount of light that penetrates the water column of the Coorong, with implications for *Ruppia* condition and ecological character more generally. The position of the node in the BBN structure reflects the belief that the abundance of phytoplankton combined with the cover of filamentous algae will influence the penetration of light through the water column.

Discretisation: Three classes have been defined for this node:

- 0 – 10 % of sites in the CSL with light limiting to the growth of *Ruppia*;
- 10 – 50 % of sites in the CSL with light limiting to the growth of *Ruppia*; and
- 50 – 100 % of sites in the CSL with light limiting to the growth of *Ruppia*.

Input variables and interactions:

- Sites chlorophyll a >20 ug/L – an increasing proportion of sites with chlorophyll a >20 ug/L leads to an increasing probability of light limitation
- Sites filamentous algae >20% - an increasing proportion of sites with filamentous algae >20% projected cover leads to an increasing probability of light limitation

Parameterisation: Sites light limiting was represented in the BBN by the following CPT:

sites_chla _20ugl	**sites_FA_greater_ 20**	**0 to 10**	**10 to 50**	**50 to 100**
0 to 10	0 to 10	60	20	20
0 to 10	10 to 50	55	20	25
0 to 10	50 to 100	50	20	30
10 to 50	0 to 10	45	20	35
10 to 50	10 to 50	40	20	40
10 to 50	50 to 100	35	20	45
50 to 100	0 to 10	30	20	50
50 to 100	10 to 50	25	20	55
50 to 100	50 to 100	20	20	60

Explanatory note: if 10 – 50 % of sites in the CSL have a chlorophyll a concentration >20 ug/L and 0 – 10 % of sites in the CSL have a filamentous algae cover of >20 %, then there is a 35% probability that 50 – 100 % of sites in the CSL will be light limited for *Ruppia* growth.

The probabilities in the CPT have been assigned to reflect the lack of data and thus low confidence in the relationship between the input variables and light limitation, i.e. a relatively ‘flat’ probability range.

Sites_pelagic_DO_less90

Rationale: Low dissolved oxygen (DO) in the water column can be lethal to aquatic organisms including fish and macroinvertebrates. Low DO can be caused by the microbial decomposition of organic carbon, in both dissolved and particulate forms. Risk pathways involving low DO were described by Risk statements 7 to 12 and 25 to 30.

Discretisation: Low pelagic DO was defined as less than 90% saturation, in line with the Australian water quality guidelines (ANZECC 2000). Two classes were defined: yes – having pelagic DO <90% saturation, and no – having pelagic DO ≥90% saturation.

Input variables and interactions:

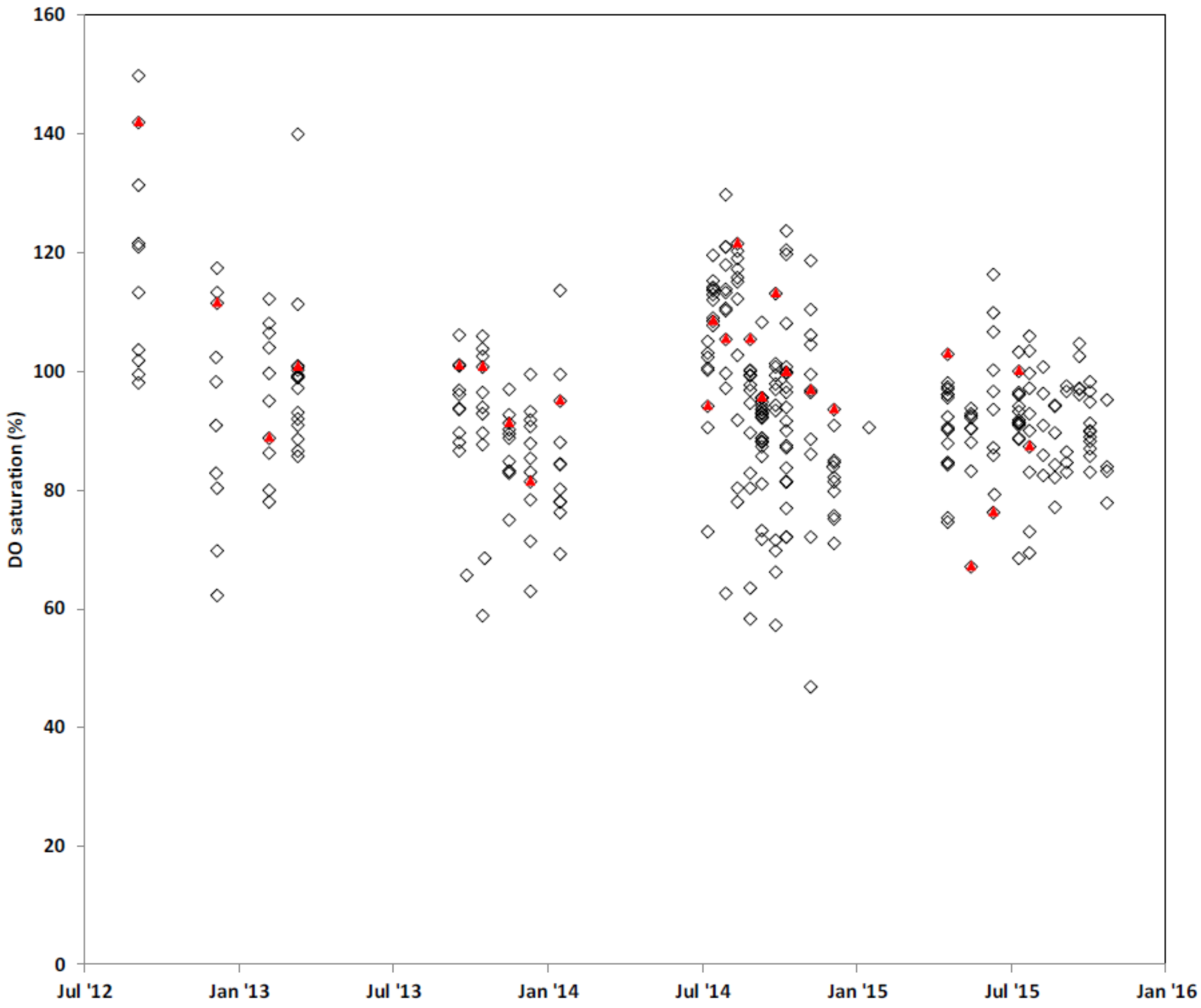
- Bioavailable nitrogen high loading – a high bioavailable N loading has been assumed to increase the probability of low pelagic DO
- Bioavailable DOC high - a high bioavailable DOC loading has been assumed to increase the probability of low pelagic DO
- Total nutrient concentration - a high total nutrient concentration has been assumed to increase the probability of low pelagic DO

Parameterisation: Site with pelagic DO <90% saturation was represented in the BBN by the following CPT:

BioavailableN_high_loading	bioavailable_TOC_high	Tnutrients_conc	0 to 10	10 to 50	50 to 100
yes	yes	low	60	30	10
yes	yes	med	55	30	15
yes	yes	high	50	30	20
yes	no	low	65	35	0
yes	no	med	60	35	5
yes	no	high	55	35	10
no	yes	low	65	35	0
no	yes	med	60	35	5
no	yes	high	55	35	10
no	no	low	70	30	0
no	no	med	65	35	0
no	no	high	60	40	0

Explanatory note: if there has been no high loading of bioavailable N, no high loading of bioavailable TOC, and total nutrient concentration is high, there is a 60% probability that 0 – 10% of sites in the CSL have low pelagic DO.

The CPT reflects the belief, supported by data (Mosely 2015) that widespread (50 – 100% of sites) low pelagic DO has a relatively low probability of occurring in the CSL. The available DO data for the Coorong indicates that pelagic DO below 90% saturation is not unusual under current management, with approximately 30% of samples in this category (see figure below from Mosely 2015). Notably, DO data for the CSL at the mouth of Salt Creek, indicated by the red data points in the figure below, do not suggest low DO is more likely at this location than elsewhere. This suggests that Salt Creek inflows under current management have not created localised conditions in the CSL more likely to result in low pelagic DO than conditions generally.



DO saturation (%)
160
140
120
100
80
60
40
20
0
Jul '12
Jan '13
Jul '13
Jan '14
Jul '14
Jan '15
Jul '15
Jan '16

Sites_water_quality_good

Rationale: This node was created to reduce the number of input variables to the *Ruppia* end point. It combines the three water quality factors understood to have the strongest direct effect upon *Ruppia* vigour into a single node that summarises the suitability of water quality conditions in the Coorong for *Ruppia*.

Discretisation: The BBN treats water quality as either good for *Ruppia* or not good. The beliefs regarding what is good and not good are reflected by the input variables and how their status affects the probability of water quality being good.

Input variables and interactions:

- Salinity late spring – the proportion of sites with good water quality declines at salinities above 110 g/L. Salinities below this threshold are all considered good for *Ruppia*, but note the influence of salinity upon the other input variables.
- Sites light limiting –as the proportion of sites with light limitation increases, the proportion of sites with good water quality declines, reflecting the belief that light limitation leads to poor status of *Ruppia*.
- Sites FA>20 - as the proportion of sites with filamentous algae >20 cover increases, the proportion of sites with good water quality declines, reflecting the belief that filamentous algae interferes with *Ruppia* reproduction, leading to poor status of *Ruppia*.

Parameterisation: Sites with good water quality for *Ruppia* was represented in the BBN by the following CPT:

Salinity_ppt_latespring	sites_light_limiting	sites_FA_greater_20	0 to 10	10 to 50	50 to 100
0 to 60	0 to 10	0 to 10	5	10	85
0 to 60	0 to 10	10 to 50	5	60	35
0 to 60	0 to 10	50 to 100	25	50	25
0 to 60	10 to 50	0 to 10	5	35	60
0 to 60	10 to 50	10 to 50	10	70	20
0 to 60	10 to 50	50 to 100	70	20	10
0 to 60	50 to 100	0 to 10	90	7	3
0 to 60	50 to 100	10 to 50	90	7	3
0 to 60	50 to 100	50 to 100	90	7	3
60 to 110	0 to 10	0 to 10	5	10	85
60 to 110	0 to 10	10 to 50	5	60	35
60 to 110	0 to 10	50 to 100	25	50	25
60 to 110	10 to 50	0 to 10	5	35	60
60 to 110	10 to 50	10 to 50	10	70	20
60 to 110	10 to 50	50 to 100	70	20	10
60 to 110	50 to 100	0 to 10	90	7	3
60 to 110	50 to 100	10 to 50	90	7	3
60 to 110	50 to 100	50 to 100	90	7	3
110 to 300	0 to 10	0 to 10	95	3	2
110 to 300	0 to 10	10 to 50	95	3	2
110 to 300	0 to 10	50 to 100	95	3	2
110 to 300	10 to 50	0 to 10	95	3	2
110 to 300	10 to 50	10 to 50	95	3	2

Salinity_ppt_latespring	sites_light_limiting	sites_FA_greater_20	0 to 10	10 to 50	50 to 100
110 to 300	10 to 50	50 to 100	95	3	2
110 to 300	50 to 100	0 to 10	95	3	2
110 to 300	50 to 100	10 to 50	95	3	2
110 to 300	50 to 100	50 to 100	95	3	2

Explanatory note: if salinity is in the 110 – 300 g/L range, 50-100% of CSL sites have light limitation and 50-100% of CSL sites have filamentous algae cover >20%, there is a 95% probability that 0 – 10% of sites in the CSL good water quality for *Ruppia*.

Ruppia_vigour30_SouthLagoon

Rationale: Risk assessment end point (see Section 2.3).

Discretisation: As described in Section 2.3.

Input variables and interactions:

- Sites water quality good – the greater the proportion of sites with good water quality for Ruppia, the greater the anticipated proportion of sites with *Ruppia* cover >30%.
- Mixing zone size – the greater the size of the mixing zone, the smaller the anticipated proportion of sites with *Ruppia* cover >30%, however the effect is relatively small.

Parameterisation: *Ruppia* vigour was represented in the BBN by the following CPT:

Sites_water_quality_good	Mixing_zone_size_km	0 to 10	10 to 50	50 to 100
0 to 10	0 to 3	70	30	0
0 to 10	3 to 10	75	25	0
0 to 10	10 to 30	80	20	0
10 to 50	0 to 3	5	90	5
10 to 50	3 to 10	10	90	0
10 to 50	10 to 30	15	85	0
50 to 100	0 to 3	0	45	55
50 to 100	3 to 10	5	45	50
50 to 100	10 to 30	10	45	45

Explanatory note: if 50-100% of CSL sites have good water quality for *Ruppia* and the size of the mixing zone is 10-30 km, there is a 10% probability that *Ruppia* cover will be >30% at 0-10% of CSL sites.

Chironomid_abundance_ok

Rationale: Risk assessment end point (see Section 2.3).

Discretisation: As described in Section 2.3.

Input variables and interactions:

- Salinity late spring – the influence of salinity reflects the belief that the optimal salinity for chironomids is 60-110 g/L, with 0-60 g/L only marginally suboptimal but 110-300 g/L very suboptimal.
- Sites chlorophyll a >20µg/L – the influence of chlorophyll a concentration reflects the belief that chlorophyll a concentration is a surrogate measure of food availability for chironomids, thus the greater proportion of sites with chlorophyll a concentration >20µg/L the greater the anticipated proportion of sites with chironomid abundance ≥200/m^2.
- *Ruppia* vigour 30 South Lagoon – the influence of *Ruppia* vigour reflects the belief that *Ruppia* provides a food source for chiromonids, thus the greater the proportion of sites with Ruppia >30% cover, the greater the anticipated proportion of sites with chironomid abundance ≥200/m^2.

Parameterisation: Chironomid abundance ok was represented in the BBN by the following CPT:

Salinity_ppt_ latespring	Sites_chla_ 20ugL	Ruppia_vigour30_ SouthLagoon	0 to 10	10 to 50	50 to 100
0 to 60	0 to 10	0 to 10	25	50	25
0 to 60	0 to 10	10 to 50	15	40	45
0 to 60	0 to 10	50 to 100	5	30	65
0 to 60	10 to 50	0 to 10	15	50	35
0 to 60	10 to 50	10 to 50	10	40	50
0 to 60	10 to 50	50 to 100	5	30	65
0 to 60	50 to 100	0 to 10	5	40	55
0 to 60	50 to 100	10 to 50	5	35	60
0 to 60	50 to 100	50 to 100	5	30	65
60 to 110	0 to 10	0 to 10	30	30	40
60 to 110	0 to 10	10 to 50	15	25	60
60 to 110	0 to 10	50 to 100	5	15	80
60 to 110	10 to 50	0 to 10	15	35	50
60 to 110	10 to 50	10 to 50	10	25	65
60 to 110	10 to 50	50 to 100	5	15	80
60 to 110	50 to 100	0 to 10	10	30	60
60 to 110	50 to 100	10 to 50	5	25	70
60 to 110	50 to 100	50 to 100	5	15	80
110 to 300	0 to 10	0 to 10	90	10	0
110 to 300	0 to 10	10 to 50	90	10	0
110 to 300	0 to 10	50 to 100	90	10	0
110 to 300	10 to 50	0 to 10	90	10	0
110 to 300	10 to 50	10 to 50	90	10	0
110 to 300	10 to 50	50 to 100	90	10	0
110 to 300	50 to 100	0 to 10	90	10	0

Salinity_ppt_ latespring	Sites_chla_ 20ugL	Ruppia_vigour30_ SouthLagoon	0 to 10	10 to 50	50 to 100
110 to 300	50 to 100	10 to 50	90	10	0
110 to 300	50 to 100	50 to 100	90	10	0

Explanatory note: if salinity in late spring is 110–300 g/L, 50–100% of CSL sites have a chlorophyll a concentration >20µg/L and 50-100% of CSL sites have Ruppia cover >30%, there is a 90% probability that 0–10% of CSL sites will have chironomid abundance ≥200/m^2.

Sites_SMHH_118CPUE

Rationale: Risk assessment end point (see Section 2.3).

Discretisation: As described in Section 2.3.

Input variables and interactions:

- Salinity late spring – the influence of salinity reflects the belief that salinities <110 g/L are tolerable for small-mouthed hardyhead
- Chironomid abundance ok – the influence of chironomid abundance reflects the belief that chironomids are a food source for small-mouthed hardyhead or a surrogate measure of food availability
- Sites pelagic DO<90 – the influence of pelagic DO reflects the belief that small-mouthed hardyhead abundance is inversely proportional to pelagic DO

Parameterisation: Sites with small-mouthed hardyhead abundance >118 CPUE was represented in the BBN by the following CPT:

Salinity_ppt_latespring	chironomid_abundance_ok	Sites_pelagic_DO_less90	0 to 10	10 to 50	50 to 100
0 to 60	0 to 10	0 to 10	35	50	15
0 to 60	0 to 10	10 to 50	40	50	10
0 to 60	0 to 10	50 to 100	45	50	5
0 to 60	10 to 50	0 to 10	15	55	30
0 to 60	10 to 50	10 to 50	25	50	25
0 to 60	10 to 50	50 to 100	35	45	20
0 to 60	50 to 100	0 to 10	10	30	60
0 to 60	50 to 100	10 to 50	15	40	45
0 to 60	50 to 100	50 to 100	25	35	40
60 to 110	0 to 10	0 to 10	35	50	15
60 to 110	0 to 10	10 to 50	40	50	10
60 to 110	0 to 10	50 to 100	45	50	5
60 to 110	10 to 50	0 to 10	15	55	30
60 to 110	10 to 50	10 to 50	25	50	25
60 to 110	10 to 50	50 to 100	35	45	20
60 to 110	50 to 100	0 to 10	10	30	60
60 to 110	50 to 100	10 to 50	15	40	45
60 to 110	50 to 100	50 to 100	25	35	40
110 to 300	0 to 10	0 to 10	80	20	0
110 to 300	0 to 10	10 to 50	80	20	0
110 to 300	0 to 10	50 to 100	80	20	0
110 to 300	10 to 50	0 to 10	90	10	0
110 to 300	10 to 50	10 to 50	90	10	0
110 to 300	10 to 50	50 to 100	90	10	0
110 to 300	50 to 100	0 to 10	95	5	0
110 to 300	50 to 100	10 to 50	95	5	0
110 to 300	50 to 100	50 to 100	95	5	0

Explanatory note: if salinity in late spring is 0–60 g/L, 0–10% of CSL sites have ok chironomid abundance and 0-10% of CSL sites have pelagic DO <90, there is a 15% probability that 50–100% of CSL sites will have small-mouthed hardyhead abundance >118 CPUE

Appendix C – Risk treatment

Summary of risk treatment workshop findings

Risk Statement Category	Relevant Risk Statements	Inherent Risk level	Risk Treatment		Treatment accounted for by risk analysis?	Data Requirements	Data collected via existing or proposed monitoring?	Residual Risk level
			Design	**Operations**				
Over freshening the Coorong	1, 2, 3, 4, 5, 6	n/a	Morella Regulator to accommodate variable degrees of closure	An Operations Manual that includes: Partially or completely close Morella regulator to reduce winter/spring inflows	yes			1st pass: low 2nd pass: not significant
As above						Existing real-time telemetered salinity stations in Coorong	existing	
As above						Existing real-time telemetered salinity in Morella Basin	existing	
As above						Existing real-time telemetered water level in Morella Basin	existing	
As above						Regular manual salinity monitoring in the Coorong during releases (as per current EPA program)	currenty occurring under SEFRP. May need to continue post SEFRP	

Risk Statement Category	Relevant Risk Statements	Inherent Risk level	Risk Treatment		Treatment accounted for by risk analysis?	Data Requirements	Data collected via existing or proposed monitoring?	Residual Risk level
			Design	Operations				
As above				An Operations Manual that includes: Basin scale approach (with MDBA, CEWO) for managing the two sources of water to Coorong.	No (analysis based on simple assumption that SE flows switched off when CSL reaches target minimum salinity)	Barrage flow/Coorong salinity forecasting and reporting.	existing (refinement as a tool for SEFRP decision making to occur under SEFRP Operations Manual development)	
As above				An Operations Manual that includes: links with greater SE drainage operations.	yes			
As above			Blackford Weir design to enable partial or complete diversion to sea.	An Operations Manual that includes: Partially or completely divert Blackford flows to sea.	yes			
Increased loading of POC (due to "first flush" or bushfire in *en route* wetlands)	7, 8, 9, 10, 11, 12	n/a	Control over proportion of flow diverted through TSWC (range 0-100%) - relates to SEFRP S2 Scenario only		yes			1st pass: low 2nd pass: not significant

Risk Statement Category	Relevant Risk Statements	Inherent Risk level	Risk Treatment		Treatment accounted for by risk analysis?	Data Requirements	Data collected via existing or proposed monitoring?	Residual Risk level
			Design	**Operations**				
As above		n/a	Morella Regulator to accommodate variable degrees of closure	Reduce rate of release from Morella.	yes			1st pass: low 2nd pass: not significant
As above		n/a	Overshot gates at Morella outlet regulator		yes			1st pass: low 2nd pass: not significant
As above		n/a		Temporary (1-3 year) reduction to volume of water entering Coorong that has passed through TSWC.	yes			1st pass: low 2nd pass: not significant
As above						Improved understanding of baseline POC from catchment and in CSL	Low priority given Sensitivity Analysis, however could occur under SEFRP	
Increased turbidity	13, 14	n/a	Overshot gates at Morella outlet regulator		yes			1st pass: low 2nd pass: not significant

Risk Statement Category	Relevant Risk Statements	Inherent Risk level	Risk Treatment		Treatment accounted for by risk analysis?	Data Requirements	Data collected via existing or proposed monitoring?	Residual Risk level
			Design	Operations				
As above		n/a	Morella Regulator to accommodate variable degrees of closure	Reduce rate of release from Morella.	yes			1st pass: low 2nd pass: not significant
Increased loading of total nutrients	15, 16, 17, 18, 19	1st pass: low 2nd pass: not significant	Morella Regulator to accommodate variable degrees of closure	Increase residence time in Morella	no - but note low raw risk	None – low raw risk		low
As above						Improved understanding of TN and TP in Salt Creek, Morella, Tilley Swamp watercourse and CSL.	currenty occurring under SEFRP. May need to continue post SEFRP	
Increased loading of bioavailable nutrients	20, 21, 22, 23, 24	1st pass: low 2nd pass: moderate	See "over freshening" design implications	Only release from Morella when CSL salinity >60g/L	no - but see Section 6.2	See "over freshening" monitoring implications	See "over freshening"	Low – see Section 6.2
As above		n/a		Increase residence time in Morella and/or TSWC	no - but see Section 6.2			Low – see Section 6.2
As above						Improved understanding of bioavailable N and P in Salt Creek, Morella, Tilley Swamp watercourse and CSL.	currenty occurring under SEFRP. May need to continue post SEFRP	

Risk Statement Category	Relevant Risk Statements	Inherent Risk level	Risk Treatment		Treatment accounted for by risk analysis?	Data Requirements	Data collected via existing or proposed monitoring?	Residual Risk level
			Design	Operations				
Increased loading of DOC	25, 26, 27, 28, 29, 30	n/a	Control over proportion of flow diverted through TSWC (range 0-100%) - relates to SEFRP S2 Scenario only		yes			1st pass: low 2nd pass: not significant
As above						Improved understanding of baseline DOC from catchment and in CSL	Low priority given Sensitivity Analysis, however could occur under SEFRP	
Risks during construction		Very low		Mandated WQ protection measures for construction in a watercourse		WQ monitoring (relevant parameters, locations) during construction	Proposed under SEFRP	Very low
Risks related to changed water temperature		Very low						Very low

Units of measurement

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microliter	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

Abbreviations

Abbreviations used in this report

BBN	Bayesian Belief Network
CPT	Conditional Probability Table
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CNL	Coorong North Lagoon
CPUE	Catch Per Unit Effort
CSL	Coorong South Lagoon
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
POC	Particulate Organic Carbon
SARDI	South Australian Research and Development Institute
SEFRP	South East Flows Restoration Project
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
WQ	Water Quality
WQRA	Water Quality Risk Assessment

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