Response of the Coorong Ecosystems to Alternative Murray-Darling Flow Scenarios

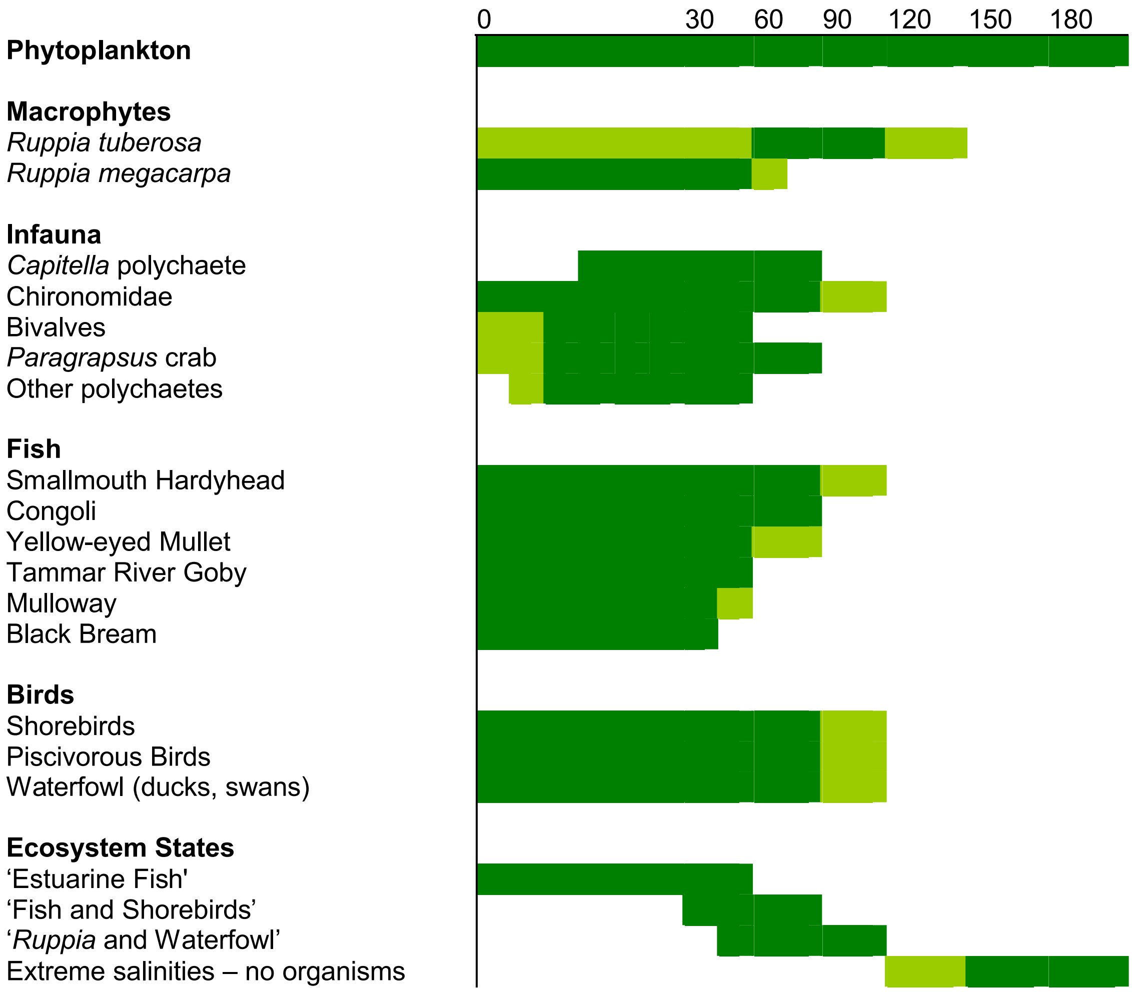
A report prepared for the South Australian Murray Darling Basin Natural Resource Management Board by members of the CLLAMMecology Research Cluster

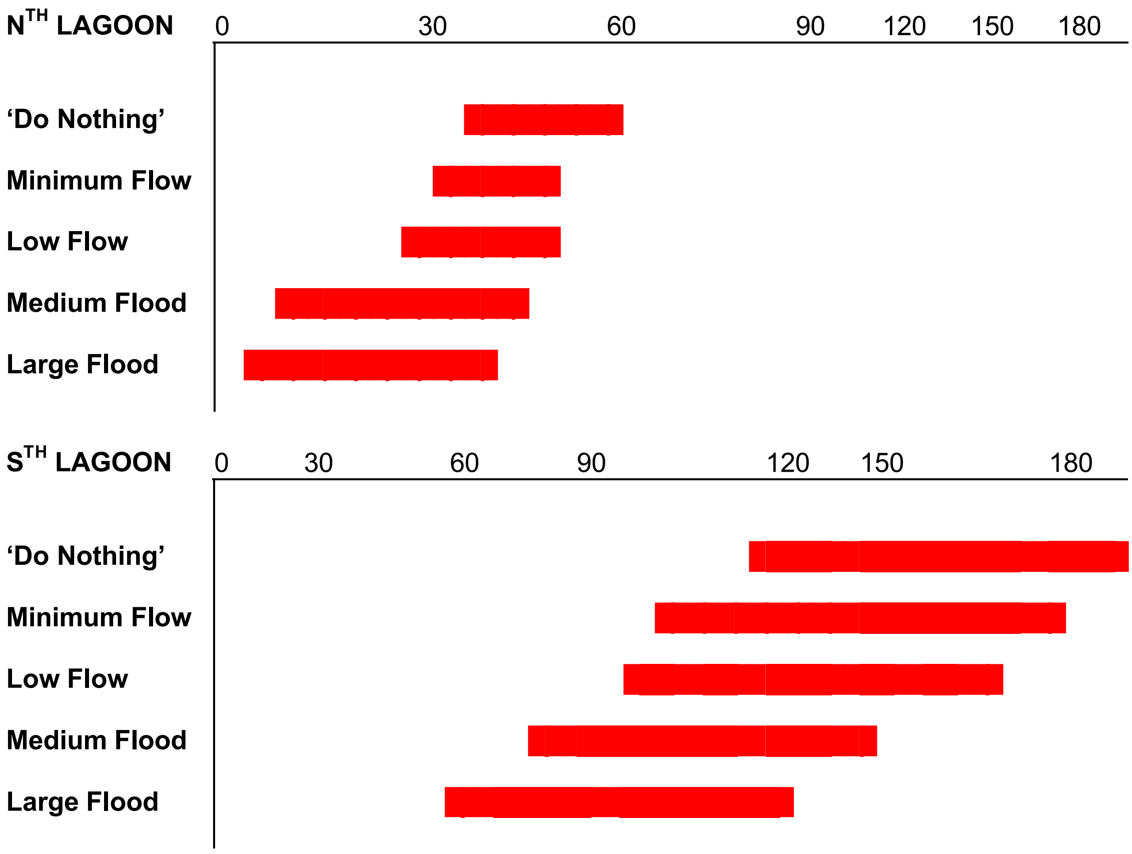
June 2008

Executive Summary

The current ecological conditions present within the Coorong today are not suitable for the continued support and sustainability of its diverse ecological communities. A lack of freshwater inflows is responsible for significantly altering the hydrological and salinity regimes within this ecosystem. This has had significant negative ecological impacts, particularly in the South Lagoon. The Ramsar and Icon Site status of the region means that there is an obligation to address the hydrological and severe ecological declines currently being experienced. The aim of this discussion paper is to investigate a series of flow scenarios that have been proposed under The Living Murray program, and explore the likely response of the Coorong ecosystem to each scenario, based on the key drivers of water level and salinity. Five alternative scenarios were assessed: do nothing, minimum flows (average of 304 GL/yr), low flows (average of 579 GL/yr), moderate floods (average of 1190 GL/yr) and large floods (average of 2935 GL/yr).

The salinity tolerance range of key organisms in the Coorong is summarised below, along with the range of salinities that are likely to be experienced under alternative flow scenarios.





The hydrological and ecological responses to these five scenarios are as follows:

- Under a continuation of current conditions ('Do Nothing'), extremely high salinities, and low water levels will continue to be experienced in the South Lagoon. These conditions are well outside of the physiological tolerances of all of the ecological assets on which the system's value depends, and will result in the catastrophic loss of the Coorong as a functioning ecological wetland
- Compared to the 'Do Nothing' scenario, Minimum Flows provide little benefit in mitigating the current high salinities in the South Lagoon. However, even these small regular flows reduce the extreme summertime salinities currently experienced in both lagoons
- Low Flows provide a small benefit in reducing extreme salinities, although under current conditions this reduction was not enough to bring salinities within the tolerance range of most organisms
- Medium and Large Floods provide a significant reduction in salinity in the South Lagoon in particular, and provide an important estuarine signal in the North Lagoon during flood periods. This estuarine signal is critical in the life history of key organisms, particularly large-bodied fish (Black Bream, Mulloway)
- Minimum water levels in the South Lagoon were only significantly affected under Medium and Large Flood conditions. The maintenance of high water levels under these conditions provided excellent recruitment conditions for the key aquatic plant *Ruppia tuberosa*. Water levels in the North Lagoon were typically more stable, spiking only during flooding conditions
- Under smaller flows (304-579 GL/yr), salinity is at least maintained (ie is not *increasing*), and would provide significant benefit for salinity maintenance if

current South Lagoon salinities were significantly reduced using alternative methods (ie South Lagoon pumping)

It was clear from the results of this study that there would be a positive response from all components of the system from the freshwater inputs from the Murray-Darling Basin. The apparent benefits would be more strongly observed in the South Lagoon, as the provision of flow would essentially provide habitat for colonisation by many organisms that are now constrained within the North Lagoon. It is also clear that significant widespread benefits will not be achieved until substantial flows across the barrages are provided.

Much of the Coorong ecosystem is currently being constricted to a small and ever-shrinking area. Immediate action is required to prevent total collapse of the system. Under ideal conditions, regular large inflows from the MDB would provide the required fluctuations in salinity and water level and result in a productive and diverse ecosystem. Even with large inflows, the Coorong ecosystem would take some time to restore, and so a long-term recovery strategy is required. This long-term strategy, however, requires immediate execution if we are to maintain even small populations of the key organisms for future restoration. Such short-term actions include salt mitigation in the South Lagoon, through the removal of hypersaline water. While we still have an opportunity to restore the Coorong ecosystem, only through this combination of short-term interventions and long-term flow strategies can this restoration work progress.

Preamble

The information presented in this document was compiled by members of the CLLAMMecology Research Cluster, including Kane Aldridge, Brian Deegan, Rebecca Lester, Craig Noell, Dan Rogers, Alec Rolston, Sunil Sharma and Ian Webster. The information used to develop these predictions was based on discussions by the authors during a one-day workshop held at the University of Adelaide on 18 June 2008. This information, in turn, was drawn from sources that include long-term monitoring, *in situ* and *ex situ* experiments and other expert opinion. The predicted responses are thus based on our current understanding of the system. However, the strength of these predictions will become significantly greater in the period leading to December 2008, when the CLLAMMecology Research Cluster is due for completion.

These predictions are also based on the assumption that the biotic responses to hydrological change will replicate responses that were observed historically. However, given the current dire state of the Coorong ecosystem, such an assumption cannot be made with complete certainty, and requires confirmation.

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Background

Flows from the Murray Darling Basin (MDB) to the Coorong over the last seven years have been at an historic low. Since 2003, flows over the barrages have been non-existent, with the exception of small flows to operate fishways until 2005. This has resulted in significant negative impacts to the Coorong ecosystem, with the South Lagoon, in particular, currently in a highly degraded state and continuing to decline.

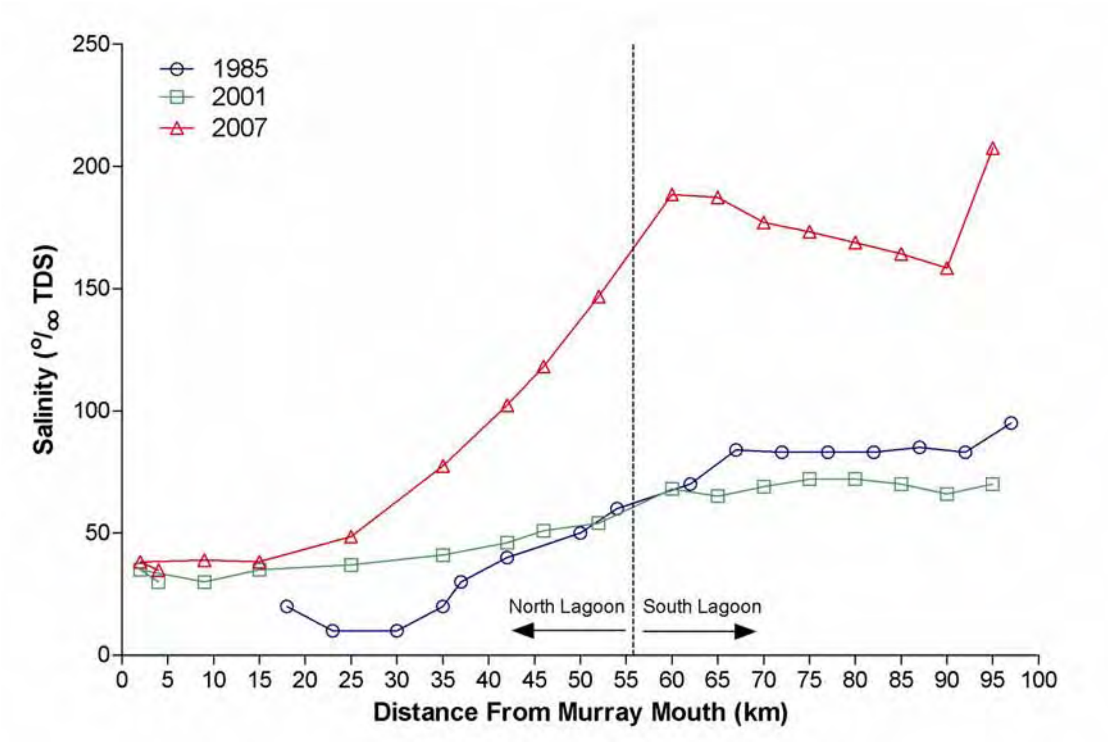
As a result of the lack of inflows from the MDB, current salinities in the Coorong range from marine (~35 ‰ TDS) in the Murray Mouth region, to extremely hypersaline in the South Lagoon (100-160 ‰). This salinity regime has changed dramatically in recent years, particularly since MDB flows ceased in 2003-4 (Figure 1). This has led to both the loss of estuarine (<35 ‰) salinities, and the loss of a salinity gradient in the South Lagoon. In addition to high salinities, water regimes have also been affected. In the Murray estuary, dredging is needed to maintain tidal flux. The South Lagoon regime has also changed, such that summer water levels are at historic lows. In combination, salinity and water level regimes are the main drivers of ecological condition in the Coorong. The distribution and abundance of many organisms in the region are limited by salinity, either directly (through physiological tolerance), or indirectly (by driving the distribution of prey organisms).

In response to the current environmental conditions, there have been significant changes in the biological communities of the Coorong. Lack of flows over the barrages has lead to the establishment of marine communities in the former Murray estuary, where traditionally estuarine-specialist species once flourished. The hypersaline conditions of the South Lagoon have led to the development of new communities that were not present in the ecosystem even five years ago, that are more characteristic of inland, ephemeral salt lagoons than estuarine or coastal lagoons. Brine shrimp have flourished, fish are largely absent and Banded Stilt populations have bred for the first time in the last four years. The North Lagoon provides an ecological transition between the Murray Mouth and the South Lagoon, with salinities increasing sharply with distance from the Mouth. The North Lagoon has developed into a refuge for many of the species that were previously found in the South Lagoon (such as *Ruppia tuberosa* and Smallmouth Hardyhead *Atherinosoma microstoma*), but are unable to survive the current extreme conditions. While these refugia currently exist in the Coorong North Lagoon, their distribution is restricted, a situation that will increase as extreme salinities continue to expand northwards.

The current conditions in the Coorong are not suitable for supporting the diverse ecological communities for which the system is renowned. The Ramsar and Icon Site status of the region means that there is an obligation to address the hydrological and ecological declines currently being experienced. However, to effectively evaluate alternative management options, a desired endpoint for the system needs to be identified. This includes specifying the desired ecosystem states and key biological assets, and the conditions that enable these to be productive. A common stated objective for the system is to return it to conditions that were present at the time of Ramsar listing in 1985. At this time, there was a combination of estuarine, marine and hypermarine (but with lower salinities than the current hypersaline conditions – see Figure 1) conditions, which supported a diverse range of ecological communities. We therefore consider a return to this combination of states a desirable goal for the management and restoration of the system.

The aim of this discussion paper is to investigate a series of flow scenarios that have been proposed under The Living Murray program, and explore the likely response of the Coorong ecosystem to each scenario, based on the key drivers of water level and salinity. We will establish which species and communities are likely to be present, those that may be lost and identify the relative ecological benefits of each flow scenario. We will also speculate on other management actions, such as rehabilitation strategies that may enhance the recovery of the system.

Figure 1. A comparison of the salinity gradient along the Coorong, between January 1985, January 2001 and January 2007. While a difference in the shape of the gradient existed between 2001 and 1985, the dramatic salinities observed today were not observed until after 2001 (particularly since 2006 – not shown).



Description of Alternative Flow Scenarios

Five alternative scenarios were assessed for hydrological and ecological responses. Four of these require at least minimum annual flows from the MDB via the barrages; the fifth, described as a 'do nothing' scenario, assumes no significant inflows. Each of the scenarios (with the exception of the 'do nothing' scenario) use a combination of the following four flow categories. Additional information regarding the amount of water per day crossing individual barrages is in Appendix 1 (note Appendix 1 shows flows as ML per day, not GL).

Flow categories

Category 1 – Minimum fishway flows

Category 1 flows involve the release of 31 GL of water between March and August in order to keep the fishways operational. The 31 GL is divided between the fishways at Boundary Creek, Mundoo Channel, Hunters Creek, and Tauwitchere. For the months between September and February, additional water is released through the fishways as attractant flows to induce fish spawning. During these months, 273 GL is released, giving a total of 304 through the year. Ideally this flow category would be the minimum flow each year.

Category 2 – Moderate fishway flows

Category 2 flows have the same flow regime as Category 1 between March and August, with 31 GL crossing the barrages. Between September and February, larger flows are released as attractant flows through the fishways, resulting in 823 GL entering the Coorong during those months and 854 GL annually. This flow category has an ideal return interval of 1 in 2 years.

Category 3 – Moderate fishway flows and moderate barrage release

Category 3 flows use the moderate fishway flows of 823 GL over six months described in Category 2 for the entire year (1,646 GL per annum). In addition to these flows, an additional 1,654 GL of water crosses the barrages during September and February, in a moderate barrage release. This results in a total of 3,300 GL per annum. This flow category has an ideal return interval of 1 in 4 years.

Category 4 – Moderate fishway flows and large barrage release

Category 4 flows also include moderate fishway flows of 1,646 GL per annum, spread evenly across the year. In addition to the fishway flows, a large barrage release of 8,354 GL occurs throughout the year. This is a total of 10,000 GL over the year. This flow category has an ideal return interval of 1 in 5 years.

Flow scenarios

The above flow categories describe the water entering the Coorong over the barrages (including the fishways) over a one year period. In order to model these flows over a 20 year period, four flow scenarios have been devised, using various combinations of these flow categories (and an additional scenario with no flows). This allows the return intervals to be taken into account, and provides information on the cumulative benefit of each additional flow category over 20 year flow regime. Table 1 summarises the flow categories used and the return time of each for the various scenarios.

Scenario 1 -'Do Nothing'

This scenario represents the continuation of current drought conditions, with no inflows of freshwater from the Murray-Darling Basin over the barrages or the Upper South East Drainage Scheme through Salt Creek.

Scenario 2 - 'Minimum flow'

This scenario models Category 1 flows each year for 20 years.

Scenario 3 - 'Low flow'

This flow scenario assumes that Category 2 flows will meet their ideal return interval of every second year, with Category 1 flows for the alternating years.

Scenario 4 - 'Medium flood'

The 'Medium flood' scenario involves a more complex combination of flows. It uses a repeating pattern of categories as follows: Category 1, 2, 1, 3. These four years are then repeated until the 20-year flow regime is constructed.

Scenario 5 - 'Large flood'

The 'Large flood' scenario also uses a repeating sequence of the flow categories. A sequence of Category 1, 2, 1, 3, 4 is repeated to construct the 20-year flow regime.

Modelling assumptions

The calculations of flow amounts assume that South Australia receives its entitlement allocation of 1850 GL, and that the Lower Lakes are held above 0.5m above Australian Height Datum (AHD) to enable the delivery of water into the Coorong via the barrages. The Medium and High flow scenarios assume that TLM water allocations are supplemented by surplus unallocated flows. The modelling also assumes that there is no significant flow into the system via the Upper South East Drainage scheme through Salt Creek, and assumes that the system begins in the condition it was in as at March 2007. Modelling was conducted using a one-dimensional hydrodynamic model that is described in Webster (2007)

Table 1. Description of flow scenarios modelled

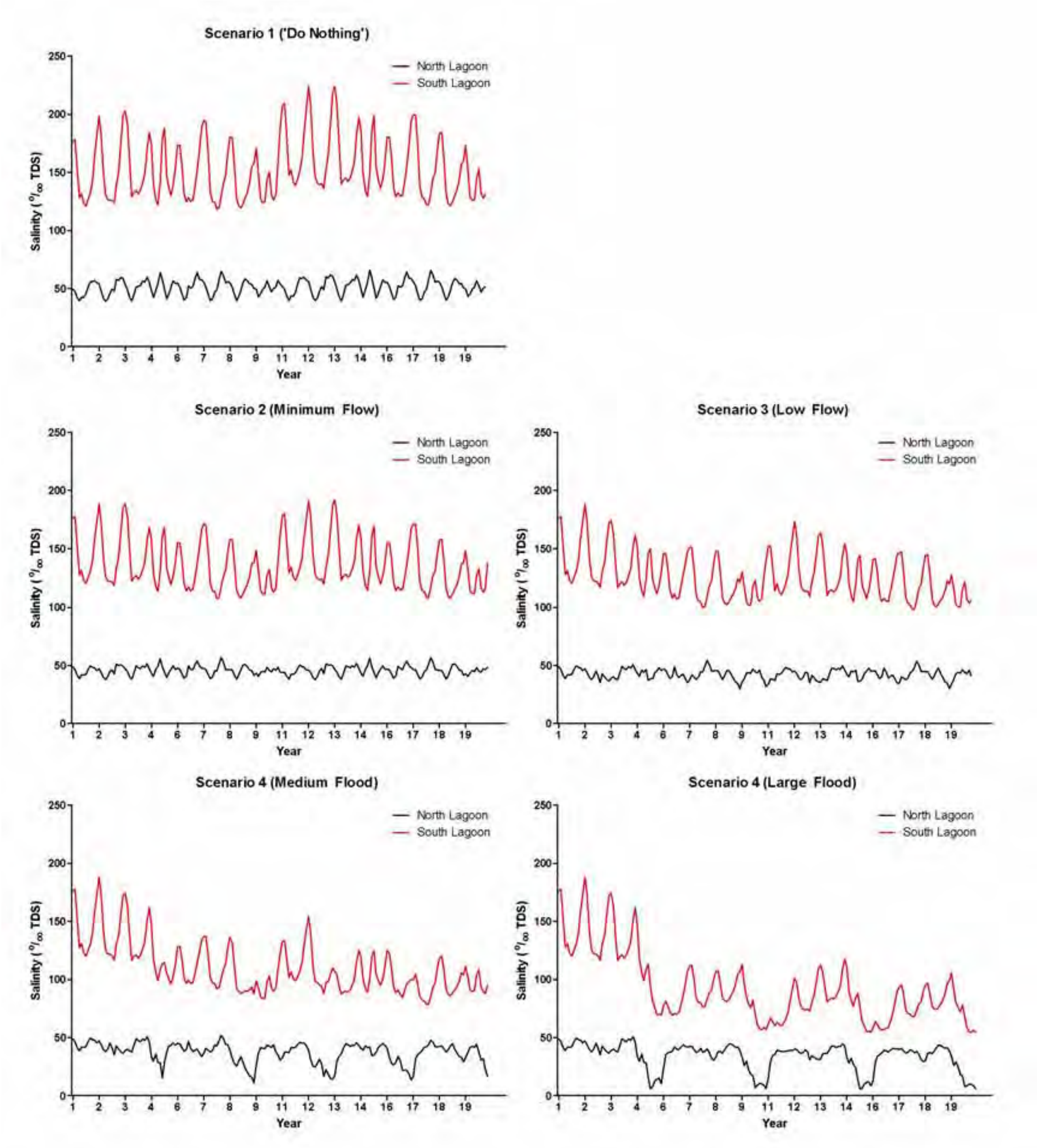
	Return time				Average flow over barrages (GL/yr)
Scenario	Category 1	Category 2	Category 3	Category 4	
1 -'Do Nothing'	-	-	-	-	0
2 - 'Minimum flow'	1 in 1	-	-	-	304
3 - 'Low flow'	1 in 2	1 in 2	-	-	579
4 - 'Medium flood'	2 in 4	1 in 4	1 in 4	-	1,190
5 - 'Large flood'	2 in 5	1 in 5	1 in 5	1 in 5	2,952

Hydrological Responses to Alternative Scenarios

Salinity Responses

The range of salinities predicted in the North and South Lagoons in response to alternative flow scenarios are presented in Figure 2.

Figure 2. Predicted salinity responses in the Coorong North Lagoon and South Lagoon under five alternative flow scenarios over a 20-year period from March 2007.



In the North Lagoon, significant changes in salinity regime (when compared to the 'Do Nothing' scenario) do not appear until medium-large floods are experienced. Under the 'Minimum Flow' and 'Low Flow' scenarios, average North Lagoon salinities are ~45 $^{o}/_{oo}$, while the average salinity over the 20 years for the 'Do Nothing' scenario is 51 $^{o}/_{oo}$. Minimum salinities for the North Lagoon under these scenarios are between 30 and 40 $^{o}/_{oo}$, and maximum salinities are predicted to be between 54 and 66 $^{o}/_{oo}$. For the first three scenarios, in the North Lagoon, the predicted minimum and maximum salinities decrease with increasing water within the ranges given. However, even at these moderate amounts of water, the average salinity range exhibited in the North Lagoon falls within the typical physiological tolerance limits for many of the Coorong's biota (although low salinity pulses are often required to complete key life stages – see below). A comparison of the salinities ranges under each scenario and typical physiological tolerance limits for key taxa is given in Figure 3.

Under the higher flow scenarios of the 'Medium Flood' and the 'Large Flood', average salinities in the North Lagoon decline to around that of seawater. The minimum salinity predicted for the North Lagoon is 11 $^{o}/_{oo}$ for the 'Medium Flood' scenario and 6 $^{o}/_{oo}$ for the 'Large Flood' scenario, demonstrating that both have the capacity to generate truly estuarine conditions in the North Lagoon over the 20 year period. The level of variability in the salinity level also increases dramatically for these flow scenarios, from a variance of 20-40 for Scenarios 1 to 3, to 80 and 130 for Scenarios 4 and 5.

The South Lagoon shows larger differences between the scenarios. Here, salinity is an important constraint on many organisms' physiology, diversity and habitat distribution. Under a 'Do Nothing' scenario, average salinities in the South Lagoon range from a *minimum* of ~120 $^{o}/_{oo}$, and a maximum of ~225 $^{o}/_{oo}$, with an overall average of 152 $^{o}/_{oo}$ over the 20 years. Under a 'Minimum Flow' regime, the maximum and average salinities experienced over the 20 years are significantly lower (but still high at 190 $^{o}/_{oo}$ and 136 $^{o}/_{oo}$ respectively), while the minimum salinities are only marginally lower (107 $^{o}/_{oo}$). A similar small decrease in salinity range is also experienced under a 'Low Flow' regime and, as with the North Lagoon, a biologically relevant salinity response is not observed in the South Lagoon until the medium and large flood regimes are experienced. For the 'Medium Flood' scenario, the average salinity over the 20 years in the South Lagoon is 110 $^{o}/_{oo}$ and for the 'Large Flood', it is 92 $^{o}/_{oo}$ both of which are within the salinity tolerances of biota previously characteristic of the South Lagoon (Figure 3a).

Furthermore, Figure 2 shows that, under any regime, a significant drop in South Lagoon salinities are not observed until at least three and up to five years from the start of the modelling run, reflecting the current poor condition of the system and the interval between large flow events. The salinity modelling presented here highlights the need to undertake remedial action in the South Lagoon, both to enhance the positive effects of medium-large flow events, and to sustain a functioning ecosystem until significant flows are available, and their effects manifest through the system. The opportunities for possible remedial actions are presented in the Discussion, and include an option to pump hypersaline water from the South Lagoon to the sea.

Figure 3a. Salinity tolerance ranges (‰ TDS) for key species and ecosystem states in the Coorong. Dark green indicates the preferred range of salinities; light green indicates where a species may be found but where conditions are suboptimal (sub-lethal effects may be observed)

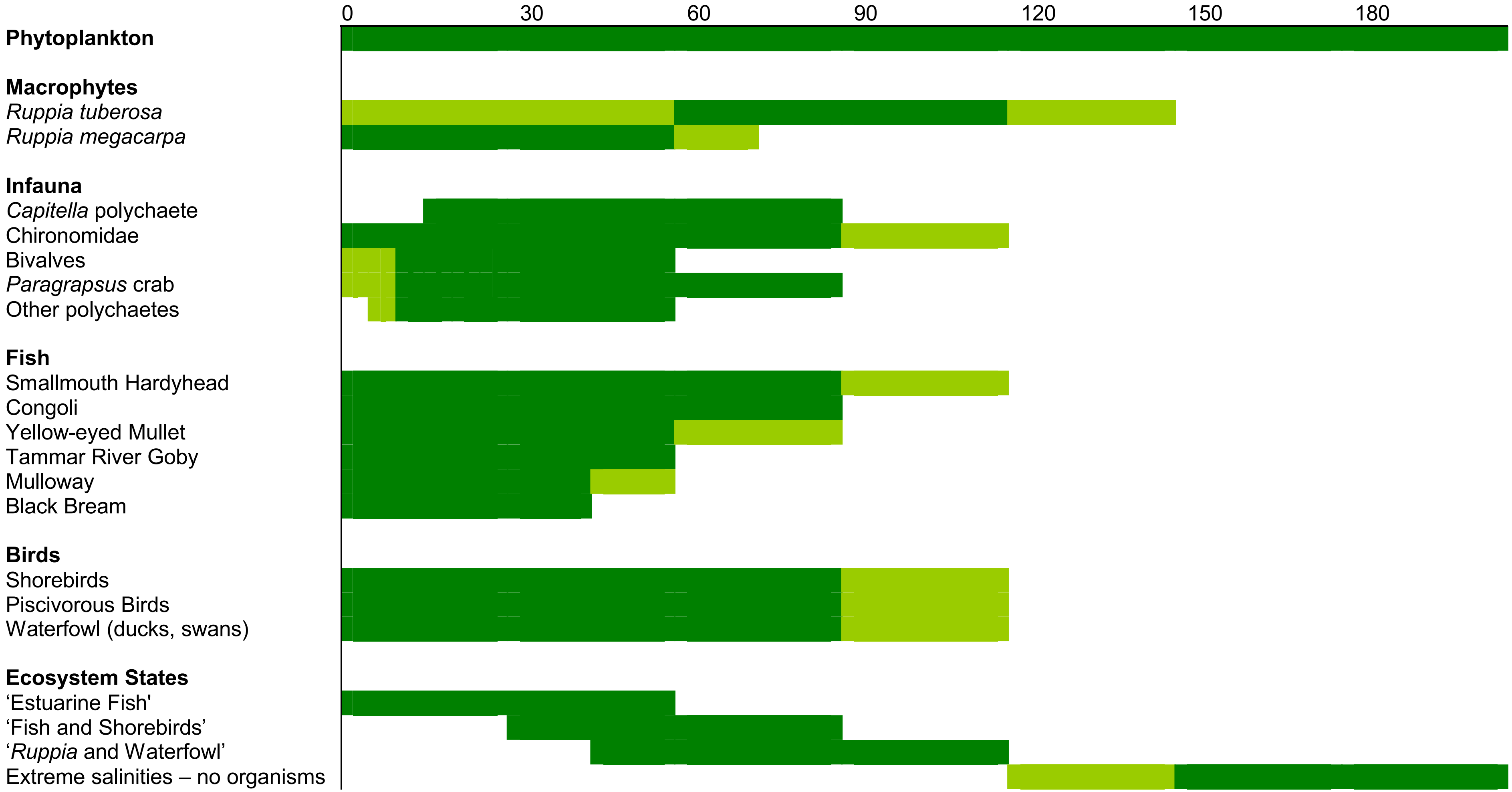
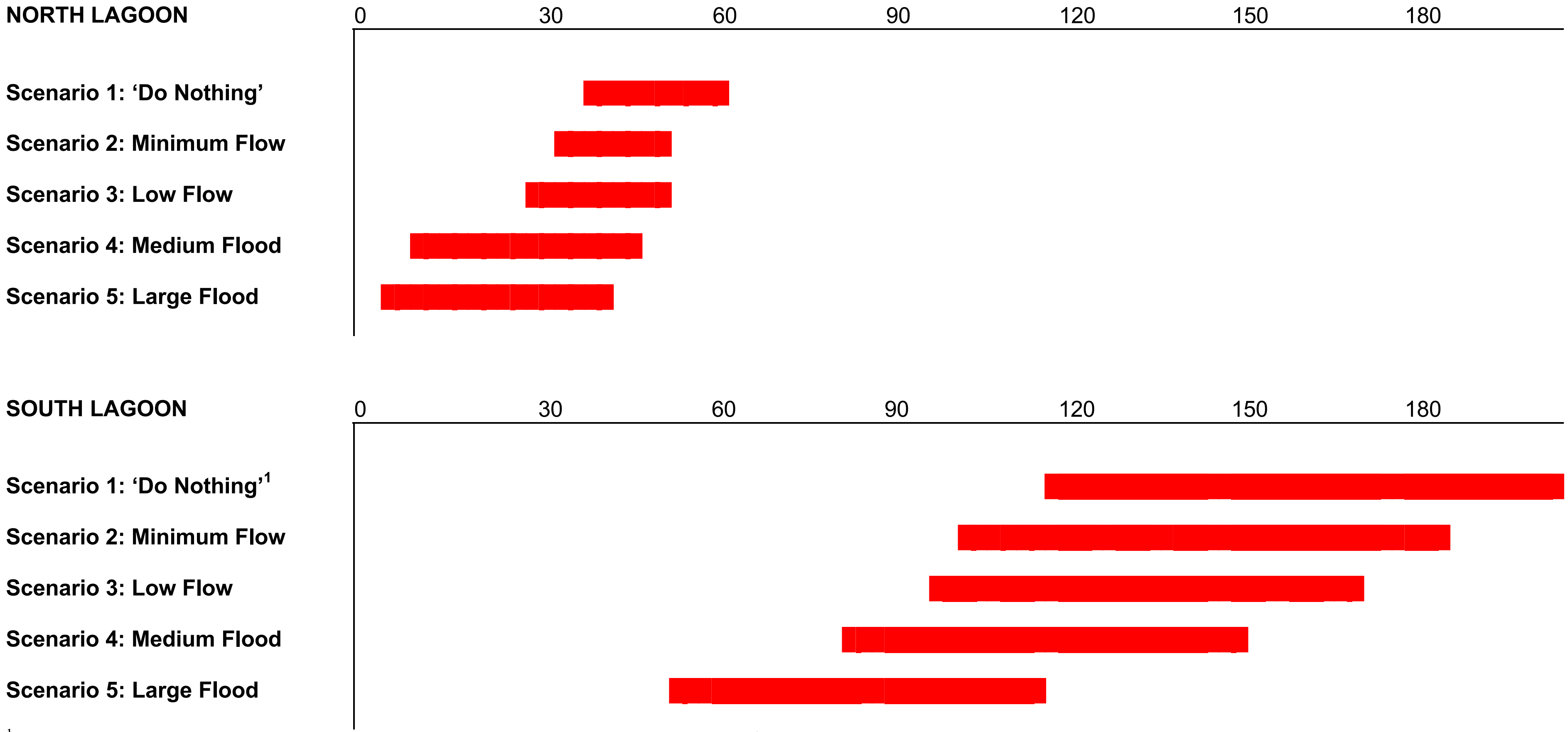


Figure 3b. The range of average salinities (°/oo TDS) experienced by the Coorong North Lagoon and South Lagoon under the alternative flow scenarios. Salinity ranges were taken from five years from the start of a modelled flow regime, to 15 years from the start of the modelled flow regime (Years 5-15 in Figure 2).

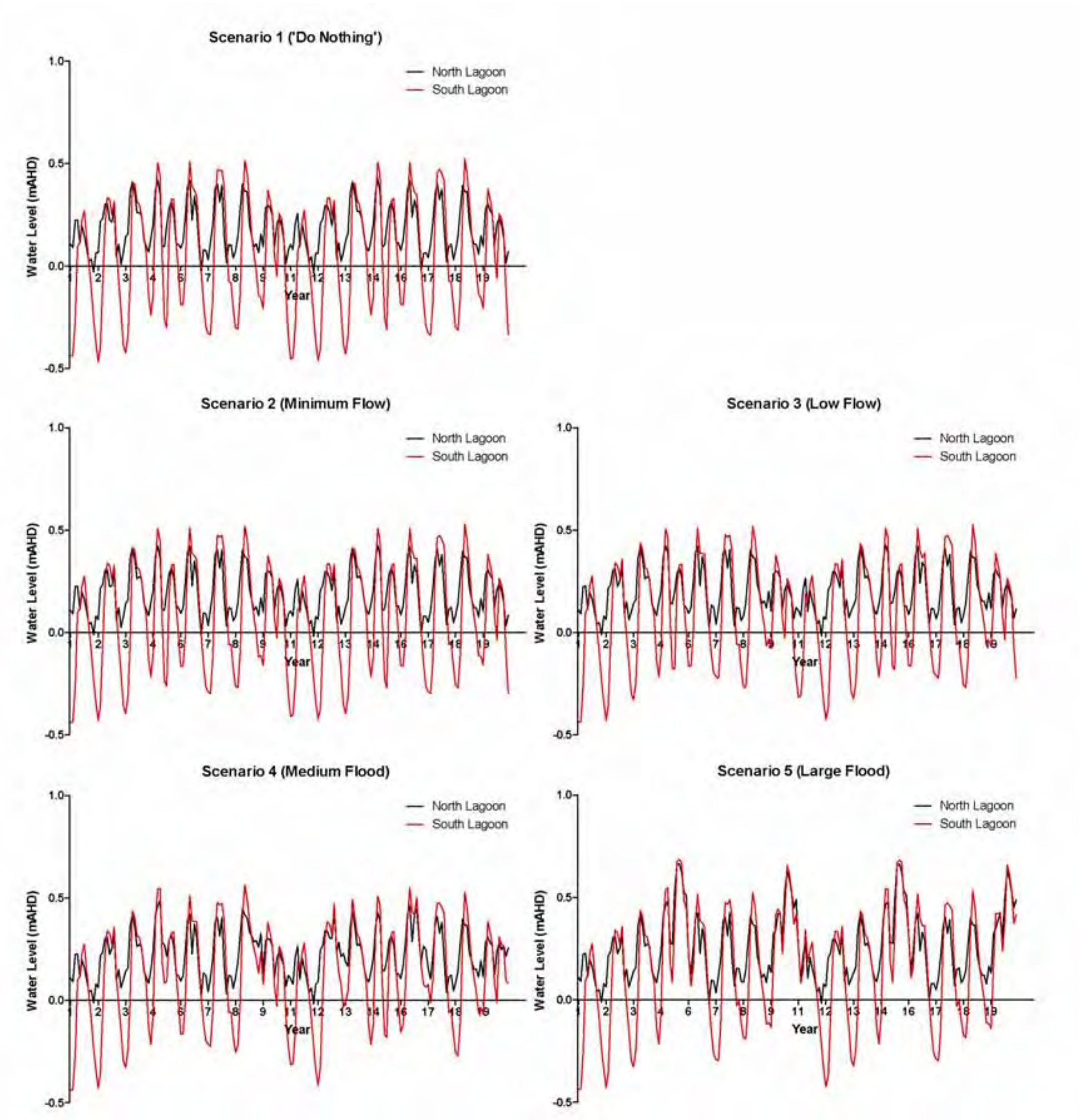


[1] – South Lagoon salinities under a 'Do Nothing' scenario reach a maximum of 225 °/oo TDS.

Water Level Responses

The response of water level regimes to the alternative flow scenarios are presented in Figure 4.

Figure 4. Predicted water level responses in the Coorong North Lagoon and South Lagoon under five alternative flow scenarios over a 20-year period from March 2007.



As with the salinity responses, there was little difference in South Lagoon water level regimes, between the first three scenarios. The South Lagoon experienced a minor increase of minimum (summertime) water levels (~0.04m difference) under a 'Minimum Flow' regime compared to a 'Do Nothing' regime. While the overall minimum water levels under a 'Low Flow' regime did not differ from Scenarios 1 and 2, there were larger changes in those years when the slightly larger flows were delivered (differences of ~0.15m in minimum summertime water level). As with salinity, the big differences in South Lagoon water level are seen when comparing Scenarios 1-3 with the medium and large flood scenarios. In those years when floods occur, minimum (summertime) water levels in the South Lagoon can be greater than

0m AHD, a situation that does not occur under the other flow scenarios. These floods, although not occurring every year, are likely to be important recruitment events for species such as *Ruppia tuberosa*, allowing the species to persist and thrive in the South Lagoon, as long as there are functional populations available to take advantage of the improved water level conditions.

Water level conditions in the North Lagoon do not vary as much seasonally as those in the South Lagoon, rarely dropping below 0m AHD under any flow scenario. Again, the significant changes in water level regime are only seen under those scenarios that include medium-large flood events, where water levels spike in direct response to the timing of large flows over the barrages.

Responses of Key Biological Assets to Alternative Scenarios

A general summary of the range of salinities over which key ecological assets in the Coorong are likely to be found is presented in Figure 3, alongside the range of salinities predicted under the various flow regimes. The salinity limits experienced by different species are typically – but not exclusively - related to the physiological limits of these species. A notable exception is the range of salinities over which different bird species are found, which is indirectly linked to salinity through the physiological tolerance limits of each species' food source.

The expected range of salinities that would be experienced in the North and South Lagoons under different scenarios are presented in Figure 3b. The minimum and maximum values presented for each scenario are the minimum and maximum average values (averaged across all sites in each lagoon). Minimum values are typically experienced in Winter-Spring, while maximum values are typically experienced in Summer-Autumn. When the salinity tolerances for each of the key ecological assets (Figure 3a) are compared with these alternative salinity regimes (Figure 3b), we can see that the salinity tolerances of most organisms are currently met in the North Lagoon, and that the salinity benefits of medium-large floods provide the most benefit to estuarine specialists, such as Black Bream and Mulloway. These salinity ranges are averaged across the entire spatial range of each lagoon, however, and we must consider that species that benefit at higher salinities (eg ~ sea water) will expand in their distribution in response to an overall drop in the average North Lagoon salinity (the same principle applies to the South Lagoon). In the South Lagoon, while minimum and low flow scenarios decreased the minimum and maximum average salinities slightly, these were still higher than either the preferred or maximum salinity tolerances of most species – *from the current conditions in the South Lagoon, a small decline in salinity, in response to small flow events, provides little ecological benefit.* Only under medium-large flood scenarios do we see significant drops in South Lagoon salinities, that are meaningful to the biota (with regard to salinities being within most species' tolerance range, at least during parts of the year).

While salinity is regarded as a primary driver for the distribution and abundance of many key ecological assets in the Coorong, for some key species (particularly *R. tuberosa* and many macrobenthic invertebrates), water level regime can be at least as important, and these two features can interact. Furthermore, complex biological interactions among organisms will also be important determinants. More detailed descriptions of key asset responses to each of the alternative scenarios are presented below.

For each key asset, we present a table that compares the response of the species or community to the alternative flow scenarios, compared to the 'Do Nothing' scenario (which, therefore, is not presented in each response table). The responses in the North Lagoon and South Lagoon are presented separately. The response descriptions are defined in Table 2.

Table 2. Definitions of the categories used to describe the response of key biological assets to alternative flow scenarios.

Descriptor	Response
⇓	Significant negative response to scenario in abundance, distribution and/or diversity
↓	Small negative response to scenario in abundance, distribution and/or diversity
-	No response to scenario in abundance, distribution and/or diversity
↑	Small positive response to scenario in abundance, distribution and/or diversity
⇑	Significant positive response to scenario in abundance, distribution and/or diversity

Changes in the Distribution of 'Ecosystem States'

One method of assessing the ecological condition of the region is to consider the gradient of ecosystem states that it supports. An ecosystem state is a combination of environmental conditions that occur at a given time and location, and the biological community that is best suited to those conditions. Analysis to characterise the ecosystem states of the Coorong is currently ongoing. These analyses are based on ten years of data, from 1998 to 2007, using the 12 CLLAMMecology study sites spread along the salinity gradient. The biological dataset includes information about *Ruppia tuberosa*, bird abundance and commercial fish catch data. Environmental variables included are modelled water levels and flows over the barrages, meteorological data and water quality data.

Analyses to date indicate that the ecosystems in the region can be divided into three ecosystem states, which vary in their distribution and prevalence through time. The first of these ecosystem states can be thought of as an 'Estuarine Fish' state. This state is likely to occur where salinities range from less than 15 ppt to approximately 60 ppt and is characterised by high numbers of estuarine and diadromous fish and good numbers of piscivorous, and shore birds (Figure 3a). The second state can be considered to be a 'Fish and Shorebirds' state, existing in salinities of between around 30 and 90 ppt. This state has the good abundances of fish such as Yellow-eyed Mullet and Mulloway, with high numbers of shorebirds. The last state is a '*Ruppia* and Waterfowl' state, with a salinity range of approximately 45 to 120 ppt, and communities of *Ruppia tuberosa* and high numbers of waterfowl like teal and shelducks. More recently, another state has become apparent, the 'Extreme Salinities' state. This state may occur at a salinity range of between 90 and >200 ppt, and is generally a degraded state, supporting Brine Shrimp and Banded Stilts, but little else. How the distribution of these four states would change under alternative flow scenarios is presented in Table 3.

Table 3. Response of ecosystem states to alternative scenarios. For a natural ecosystem state, a positive response is defined as an increase in its distribution along the Coorong, and a negative response as a contraction. For the 'Dead Sea Downunder' a positive response is defined as a contraction, as it represents a degraded system.

	'Estuarine Fish'	'Fish and Shorebirds'	'Ruppia and Waterfowl'	'Extreme Salinities'
2 Minimum Flow	↑	-	↑	↑
3 Low Flow	↑	-	↑	↑
4 Medium Flood	⇑	-	⇑	⇑
5 Large Flood	⇑	↑	⇑	⇑

Note: See Table 2 for category descriptions. States are described in the text above.

Changes in the Distribution of Ecosystem Components

The individual species that make up these ecosystem states will respond in different ways to the alternative scenarios, and some detailed knowledge of how these key assets will respond are presented below.

Responses of Planktonic Communities

The limited freshwater inflows to the Coorong has not only resulted in the increased salinity in the system but has also significantly reduced the importation of limited nutrient resources, which are vital for primary and secondary production. Since water in the Coorong has been sourced from the marine environment in recent years, it can be assumed that the system is nitrogen limited. In the past the Lower Lakes have been a source of nitrogen to the Coorong. The major form of this nitrogen is organic nitrogen and so initial benefits to the Coorong ecosystem are likely to be observed in the first order consumers and heterotrophic microbial community. Consequently, it is unlikely to result in an initial increase in dominance of phytoplankton communities. These benefits will cascade through the ecosystem and thus increase the overall productivity. The benefits provided by a substantial flow through the Lower Lakes and over the barrages are likely to be much greater than a 'release'. Firstly, a substantial flow-through event will result in larger amounts of organic material being exported to the Coorong simply because of the increased volumes. However, it will also result in a larger amount of organic material per unit volume, as a substantial flow will bring with it deposited and benthic organic material, as well as allocthonous material.

The increasing salinity gradient along the Coorong has resulted in a change to the diversity, composition and abundance of the phytoplankton community, while also limiting their productivity. The extreme salinities experienced within the Coorong have resulted in the dominance of one planktonic species. Thus the application of freshwater inflows will reduce this dominance, and increase diversity and productivity throughout the system.

Table 4. Response of plankton communities to alternative scenarios. For the plankton communities, a response is defined as change in community structure (particularly diversity) that has positive or negative flow-on effects for the broader ecological community.

	North Lagoon	South Lagoon
2 Minimum Flow	-	↑
3 Low Flow	↑	↑
4 Medium Flood	⇑	⇑
5 Large Flood	⇑	⇑

Note: See Table 2 for category descriptions.

Response of *Ruppia tuberosa*

Ruppia tuberosa is regarded as a keystone species in the hypersaline components of the Coorong, providing a key food resource and habitat for higher trophic organisms. The persistence and sustainability of the species in the Coorong should be seen as a primary restoration objective for any future management plans.

The critical hydrological parameter for the persistence and sustainability of *Ruppia tuberosa* populations is the maintenance of suitable water levels to allow for the completion of life cycle. Specifically, *R. tuberosa* requires continual inundation until the completion of flowering and seed set, which, in the Coorong, typically occurs in January. In the absence of continuous inundation over this period, plants become exposed prior to seed-set, and the existing seed bank thus becomes depleted through time, reducing population persistence and sustainability. A key hydrological feature to identify when assessing alternative flow scenarios is therefore the maintenance of high water levels – particularly in the South Lagoon – through January.

Salinity has a secondary impact on *R. tuberosa* distribution. Both the timing of germination, and germination success, are affected at salinities greater than $100^{o}/_{oo}$, and can potentially reduce growth rates, thus extending the length of time required to complete the life cycle. Higher salinities thus lead to an extension of the required period of mudflat inundation. While *R. tuberosa* prospers at lower salinities in *ex situ* trials, the species is unlikely to persist at continuously low salinities ($<60^{o}/_{oo}$) *in situ*, due to exclusion by other species, particularly the filamentous algae *Enteromorpha* sp.. Habitat that supports *R. tuberosa* is likely to decline with increasing flows in the North Lagoon, however, is more than offset by the increase in habitat quality in the South Lagoon, where the species was historically abundant.

Table 5. Response of *Ruppia tuberosa* to alternative scenarios. For the *R. tuberosa*, a response is defined as change in the distribution and quality of habitat that can support the species through its complete life cycle.

	North Lagoon	South Lagoon
2 Minimum Flow	-	-
3 Low Flow	-	↑
4 Medium Flood	↓	⇑
5 Large Flood	↓	⇑

Note: See Table 2 for category descriptions.

Response of Macroinvertebrate Infauna

Additional freshwater input into the Coorong over the barrages will result in an increase in the abundance of species tolerant to low salinities close to the site of water release. Further from the barrages, within the Murray Mouth region, there is unlikely to be significant changes from the current macroinvertebrate community composition, as estuarine conditions will prevail. The addition of freshwater is unlikely to adversely affect the current macroinvertebrate community to the point where species would disappear from the system as a whole, but specific sites close to the flow points may show changes in the macrobenthic community structure. As the salinity levels decline along the Coorong, the distribution of individual species will change as the conditions improve with respect to their individual salinity tolerance. This will mean increased invertebrate diversity and abundance throughout the North Lagoon, and for 'Medium Flood' and 'Large Flood' scenarios the recovery of species with higher salinity tolerances, such as *Capitella*, in the South Lagoon is likely. The probable response of the macroinvertebrate infauna community in the North and South Lagoons under each flow scenario is shown in Table 6.

Current low water levels have left large areas of mudflat exposed which are then unsuitable for macroinvertebrates. Increased water levels will inundate these presently exposed areas, and potentially make the habitats suitable for colonisation. The period until colonisation of newly inundated mudflats will vary between species and will depend on the water level and salinity of individual sites. However, juvenile infauna are currently present within the Coorong (Murray Mouth and North Lagoon) throughout the year, meaning that colonisation of new habitats should be relatively rapid: Colonisation by juveniles may occur in a matter of a few weeks, but the establishment of significant adult/reproductive populations or communities may take up to a year or more. Availability of suitable habitat for macroinvertebrates is primarily dependent on frequent water inundation, in addition to tolerable salinities. Macroinvertebrate infauna have been shown to survive for less than one week without inundation. For macroinvertebrates, the longer a mudflat is inundated, the more accessible it is for recruitment. The permanent inundation of mudflat habitats due to increased water levels as a result of the different flow scenarios is likely to benefit macrobenthic invertebrate populations. Water levels will also vary with wind strength and direction, the opening of the Murray Mouth, tidal flushing and other water movements at the Northern end of the North Lagoon. The availability of this habitat to predators of the infauna (ie fish and wading birds) is highly dependent on the water level throughout the system and as a result could have significant consequences for these predator populations.

Factors other than water level and salinity that are also important in determining macroinvertebrate recruitment include sediment grain size and sediment organic content. Both of these are likely to be affected in the Murray Mouth region by additional flows over the barrages due to changes in flow velocity, direction and sediment deposition rates, but the effects in the North and South Lagoon are likely to be minor.

If salinities in the South Lagoon can be reduced to below 80 ‰, the potential for the colonisation of suitable mudflats by higher salinity tolerant macroinvertebrates (such as the polychaete family Capitellidae and larvae of insect families like Chironomidae) is increased, provided connectivity with the North Lagoon is maintained. The greater the reduction in salinity, the greater the diversity of colonists is likely to be. A change in the distribution of Capitellidae and Chironomid larvae, which are key food sources for a variety of birds and fish in the region, will be one of a series of positive effects on these key predator populations.

Table 6. Response of macroinvertebrates infauna to alternative scenarios. For infauna, a response is defined as change in the distribution and quality of habitat that can support the species through its complete life cycle.

	North Lagoon	South Lagoon
2 Minimum Flow	-	-
3 Low Flow	-	-
4 Medium Flood	↑	↑
5 Large Flood	↑	⇑

Note: See Table 2 for category descriptions.

Response of Fish Communities

The responses of fish communities to freshwater flows across the barrages and fishways can be described by examining species of commercial importance that exhibit a range of life-history characteristics and dependency on estuarine conditions and habitat. The following summarises the predicted responses of four key species in the Coorong: 1) black bream, 2) greenback flounder, 3) yellow-eye mullet, and 4) mulloway.

1) Black bream populations are likely to be highly responsive to freshwater inflow to estuaries because: (i) they reside in estuaries and can complete their entire life-cycle within these systems (i.e. 'estuarine resident'); (ii) their spawning movement and location is likely related to freshwater flows that create an area with the appropriate environmental conditions (e.g. salinity, dissolved oxygen content and habitat); (iii) survival and development of larvae and growth of juveniles are significantly affected by environmental conditions (i.e. salinity, water quality, food availability) on which freshwater flows have direct influence; (iv) the amount of 'favourable littoral habitat' for the settlement of post-larvae and juveniles may be affected by freshwater flows (i.e. water levels, optimum water quality - temperature, salinity, turbidity); (v) thus their recruitment success varies with the timing and level of freshwater flow to the estuary; and (vi) freshwater inflow could affect catch rates in the fishery as the spawning aggregation, movement and distribution of black bream is likely responsive to reduced salinity.

2) Greenback flounder populations are likely be affected by freshwater flows to estuaries, as this species: (i) is an 'estuarine migrant'; (ii) spawns during winter before the high flow season; and (iii) larval and juvenile growth would potentially take advantage of any enhanced biological productivity (i.e. food availability) related to freshwater flows to estuaries and this might result in faster growth rates (and therefore survival rates) thus higher level of recruitment success.

3) Yellow-eye mullet populations are likely be affected by freshwater flows to estuaries, as this species: (i) is a 'marine migrant', which spawn in marine conditions

but regularly utilises estuaries as juveniles and/or adults; (ii) the early life-history stages (post-larvae/juveniles) have a strong preference to shallow estuarine habitats; (iii) reduced freshwater flow causing a closure of the entrances of estuaries by sandbar formation could impede fish spawning until subsequent opening of estuaries by heavy freshwater discharge, when movement of juveniles are supported into the protected estuaries for their first year of life. Restriction of the mouths of estuaries also limits the passage/movement of adult fish; (iv) fish growth would potentially take advantage of any enhanced biological productivity (i.e. food availability) related to freshwater flows to estuaries and this might result in faster growth rates (and therefore survival rates) thus higher level of recruitment success.

4) Mulloway populations are likely to be highly responsive to freshwater inflow to estuaries because: (i) they make extensive use of estuaries during juvenile life stage (at least up to 5 years) as nursery grounds (i.e. 'marine migrant'); (ii) spawning occurs in the near-shore environment with spawning aggregation or pre-spawning feeding aggregation near estuary mouths, which may be promoted by freshwater attraction flows. This may, in turn, place larvae close to suitable nursery habitat; (iii) freshwater inflow may affect recruitment success by: directly providing attractant flow for larvae and early juveniles to locate favourable habitat; affecting the extent of quality nursery/refuge habitat (i.e. creating low salinity environments where juveniles are protected from predators; increasing turbidity which may provide protection from visual predators; increasing food availability through increasing abundance and growth of smaller prey species; consequently creating a high growth environment for juveniles); (iv) closure of estuary entrances causing by reduced flow will directly affect the immigration/emigration of juveniles and adults, particularly the recruitment of juveniles; and (v) fishery catches are well correlated with freshwater inflows (with no time lag for adults and lags for juveniles).

In addition to the benefits described above for selected estuarine-resident, estuarine-migrant and marine-migrant species of commercial importance, the operation of fishways (as part of the scenarios presented in this paper) would provide unrestricted fish passage between the Lower Lakes, Murray estuary and the sea for a number of diadromous species, e.g. congolli, common galaxias, short-headed lamprey and shortfin eel, all of which migrate between marine and freshwater environments to complete their life cycle. Fish passage is critical in allowing adult fish access to and from spawning habitats, dispersal of juvenile fish to new habitats, access to feeding habitats, re-colonisation of new habitats, exploratory movements and habitat selection, and access to and from refuge areas during droughts or floods.

Table 7. Response of Fish Communities to alternative scenarios. For the fish species, a response is defined as change in distribution and quality of habitat that can support the species through its complete life cycle.

	North Lagoon	South Lagoon
2 Minimum Flow	-	-
3 Low Flow	-	↑
4 Medium Flood	↑	⇑
5 Large Flood	↑	⇑

Note: See Table 2 for category descriptions.

Response of Bird Communities

The principal response of the Coorong birds to hydrological change is related to the distribution of their food resources. For example, the distribution of Black Swans in the Coorong, a species which relies almost exclusively on aquatic vegetation for food, is strongly related to the distribution of *Ruppia tuberosa* (although other aquatic vegetation, including macroalgae near the Murray Mouth, can also be exploited), and Black Swans will thus respond to hydrological changes in a similar way to *Ruppia*. Other waterfowl such as Grey and Chestnut Teal may not be as sensitive, as they are able to exploit a wider range of resources, particularly Chironomid larvae and pelagic invertebrates.

The response of some fish-eating species, such as Australian Pelican and Fairy Tern, relates almost directly to the distribution of their fish prey. However, breeding success for many fishing species is restricted by the availability of suitable nesting habitats. For pelican, the only suitable nest sites in the Coorong are in the South Lagoon. As a result, the current loss of fish from the South Lagoon has disassociated breeding sites from food sources for this species, leading to a historic decline in the size of the breeding colony. The nationally threatened Fairy Tern is similarly restricted, although suboptimal nesting opportunities do exist near the Murray Mouth for this species.

For shorebirds such as the migratory Calidrine waders (Red-necked Stint, Curlew Sandpiper, Sharp-tailed Sandpiper), the ability to access food sources becomes as important as the abundance of the food species in the environment. Across the majority of the Coorong, shorebirds have relied heavily on the most saline-tolerant epibenthic and infaunal invertebrates, namely Capitellid polychaetes and Chironomid larvae, as well as the seeds and turions of *R. tuberosa*. These birds should thus primarily respond to hydrological change in a similar way to these organisms. However, water level regimes play an equally important role, in that shorebirds are extremely sensitive to water depth when foraging. For the three species mentioned above, mudflats become inaccessible at water depths greater than ~5-7 cm. While increased flows (and thus higher water levels and lower salinities) will benefit the food sources for migratory shorebirds over summer, a risk associated with these higher water levels is that there will be lower areas of recently exposed and shallow water habitat available to these birds. This could be a particular concern if mudflats in the northern parts of the Coorong were completely inundated, as the current poor state of the South Lagoon might not allow this possible alternative habitat to be useful to the birds. Care must be taken to ensure that, in any one year, appropriate habitats are available in some locations across the system, while also ensuring that populations of food items are sustained in the long-term (through appropriate water levels for mudflat inundation, and physiologically appropriate salinity regimes).

Table 8. Response of bird species to alternative scenarios. For the birds of the Coorong, a response is defined as change in the distribution and quality of habitat that can support the species through its complete life cycle.

	North Lagoon	South Lagoon
2 Minimum Flow	-	-
3 Low Flow	-	↑
4 Medium Flood	↑	⇑
5 Large Flood	↑	⇑

Note: See Table 2 for category descriptions.

Discussion

The unique ecological character of the Coorong resulted in it becoming an internationally recognised wetland of ecological importance. This character was largely driven by the spatial and temporal heterogeneity that existed. Under natural conditions, much of the heterogeneity would have been associated with inputs of freshwater, creating gradients in salinity within the physiological limits of the range of biota. In addition, freshwater inputs altered water levels, continually inundating vast areas of mudflats, providing habitat for the establishment of infauna and *Ruppia*, and so food sources for higher trophic levels. Freshwater inflows also bring inputs of nutrients and allochthonous organic material that are essential for the primary and secondary productivity of the system. In addition, flows across the barrages keep the Murray Mouth open, thus improving the exchange between the Coorong and the Southern Ocean, essential in preventing the build up of salts during periods of low flow, and providing a tidal inundation cycle for mudflats in the Murray estuary.

The heterogeneity that existed within the Coorong created significant ecosystem resilience: each component of the ecosystem was able to find suitable conditions within the Coorong at any one time. However, with the absence of significant freshwater inputs for a number of years, the resilience of the Coorong ecosystem has been compromised. A large proportion of the Coorong now experiences salinities that are outside the salinity tolerance of many of the organisms that once thrived within the system. Consequently, the area of habitat available for these organisms has been severely reduced and many of these organisms are now restricted to small areas. As the boundary of this hypersaline water continues to move northwards, the encroachment of coarse-marine sediments, brought in through dredging, is further restricting the habitable area of many organisms. Without immediate and proper management, components of the system will be completely lost from the Coorong. However, the fact that most components of the Coorong ecosystem are still present provides hope for the restoration of the system, if immediate action is taken.

This study aimed to predict the likely ecological response to a range of flow scenarios across the barrages (MDB) that separate the Coorong and the Lower Lakes. This was a significant task since there is only evidence of how biota and ecosystems have declined through time with the absence of significant freshwater inputs and not how they respond to improved conditions. Iit was therefore necessary to make the assumption that the biota will follow the same but reverse path in recovery. A majority of the results presented in this document, represent expert opinion based on results obtained from the CLLAMMecology Research Cluster. Prior to completion of CLLAMMecology, in June 2009, several tools will be developed that will provide a more powerful means of assessing the likely ecological responses to various flow regimes and management interventions, enabling more robust predictions of the ecological benefits of water addition.

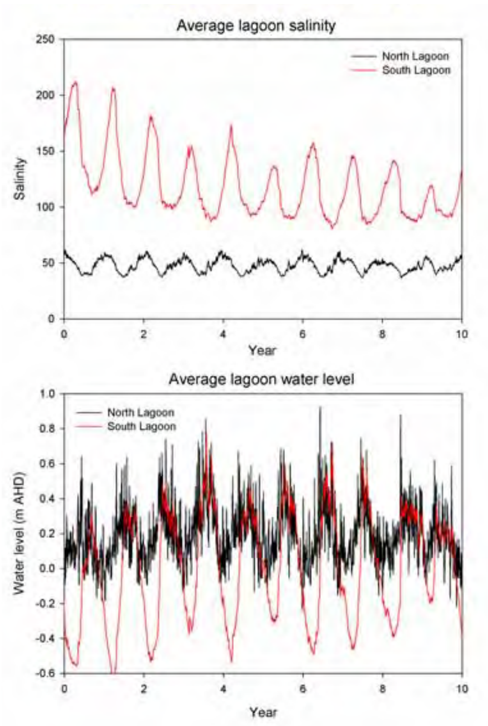
It was clear from the results of this study that there would be a positive response from all components of the system to the freshwater inputs from the MDB. The apparent benefits would be more strongly observed in the South Lagoon, as the provision of flow would essentially provide re-colonisable habitat for many organisms that are now constrained within the North Lagoon. It is also clear that significant widespread benefits will not be achieved until substantial flows across the barrages are provided.

The provision of minimum flows (average of 304 GL/yr) would present very few benefits across the system. Although there may some localised benefits to fish communities there would be no apparent large-scale benefits for fish, invertebrates or *R. tuberosa*. The provision of low flow (average of 579 GL/yr) is likely to provide small ecological benefits in the South Lagoon for plankton, *R. tuberosa* and fish communities. In comparison, the provision of medium flows (average of 1190 GL/yr) is likely to result in much more substantial ecological benefits with significant improvements in plankton, *R tuberosa* and fish in the South Lagoon and plankton in the North Lagoon. It is probable that small positive responses would also be observed for invertebrate communities throughout the Coorong and fish communities in the North Lagoon. The apparent decrease in *R. tuberosa* distribution in the North Lagoon under the medium and high flow scenarios would be outweighed by the increased distribution in the South Lagoon, as well as the benefits for *R. megacarpa* in the North Lagoon. As expected, the most substantial improvements would be likely following the provision of the high flow scenario (average of 2935 GL/yr). Significant benefits would be observed for the plankton communities throughout the Coroong and invertebrates in the North Lagoon and fish in the South Lagoon. Positive benefits would also be observed for invertebrates and fish in the North Lagoon. These substantial benefits would also be transferred to higher trophic levels, most notably large-bodied fish and birds.

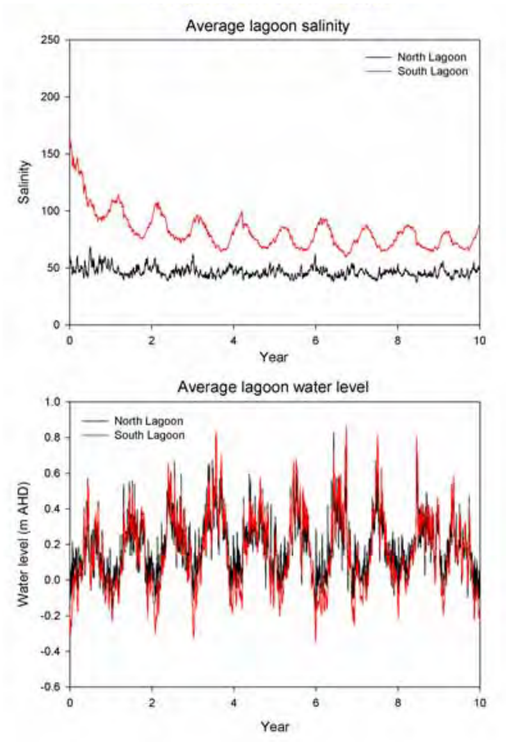
However, even under the highest flow scenarios, no benefits were seen until the first flood event, leaving the system (and particularly the South Lagoon) in decline until this event occurs. This lag highlights the importance of maintaining long-term flow/flood regimes, the success of which is measured at the timescale of decades (rather than years). In addition, this lag stresses the need for remedial action in the intervening period. This action is currently required as a matter of urgency: we simply cannot wait in hope for the next uncontrolled flood to provide the solution. This analysis also suggests that the minimum flow scenarios will not assist in the recovery or maintenance of the South Lagoon while we wait for this flood. While the most desirable action is the delivery of both medium- and large-volume flows, at appropriate frequency, from the MDB via the barrages, in their absence, interim action is required to maintain suitable water level and salinity regimes in all parts of the Coorong. One such strategy being explored is to pump hypersaline water from the South Lagoon into the Southern Ocean, over the Younghusband Peninsula. Preliminary hydrodynamic modelling (Figure 5) suggests that this solution will go some way to controlling the extreme salinities currently experienced, and create conditions within the salinity tolerances of the key species. Such strategies will allow for the maintenance of functional populations of key organisms until the next uncontrolled flood becomes available. If such actions are not taken soon, the key ecological assets of the Coorong will continue to decline, such that recovery will become increasingly difficult and improbable. The analysis presented here also suggests, however, that while the key components of a functioning Coorong ecosystem are still present, opportunities exist to restore the system such that it supports the values for which it is renowned.

Figure 5. Predicted salinity and water level responses in the Coorong North Lagoon and South Lagoon. a) Scenario pumping 100 ML/day from South Lagoon. b) Scenario pumping 200 ML/day from South Lagoon, with deepening of channel between North and South Lagoon to depth of 1m.

a)



b)



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Appendices

Appendix 1. Distribution of flows over the barrages for each of the four flow categories. Flows are described as ML/day. Category A for each flow represents the flow between March and August, and B represents the flow between September and February.

	Goolwa	Mundoo	Hunters	Boundary	Tauwitchere	Total
Category 1a	50	2	7	2	89	150
Category 1b	415	102	7	32	689	1,245
Category 2a	50	2	7	2	89	150
Category 2b	1,245	329	7	100	2,053	3,734
Category 3a	1,245	329	7	100	2,053	3,734
Category 3b	4,274	329	7	100	8,112	12,822
Category 4a	8,895	329	7	100	17,353	26,685
Category 4b	8,895	329	7	100	17,353	26,685