Ecological Justification for the South Lagoon Salinity Reduction Scheme

A Discussion Paper

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Executive Summary

The two most important ecological drivers in the Coorong are salinity and water level. The absence of adequate freshwater inflows from the River Murray to the Coorong during much of the last decade has led to excessive salinity and low water levels at critical times of year. Consequently a well documented collapse in ecosystem health has occurred, particularly in the South Lagoon. Key flora and fauna have disappeared from the South Lagoon and will not return until conditions improve.

For recovery to the 1985 (Ramsar listed) ecological state, as defined by the Ecological Character Description (ECD) for the site, both salinity and water levels need to be restored to their appropriate regimes. Management influence over water levels in the Coorong can be achieved via flows over the barrages. This requires improved management of water resources throughout the Murray-Darling Basin. However, if barrage flows adequate to restore appropriate water levels to the Coorong are achieved, the ecological health of the Coorong is not likely to be readily improved because flows are unlikely to be large enough to reduce salinity in the South Lagoon and therefore salinity will remain excessive. The lowering of Coorong salinity is therefore an essential first step to restoring the Coorong ecosystem. Given that salinity in the South Lagoon is currently greatly in excess of defined “limits of acceptable change”, as defined by the ECD for the site, a strong case for lowering salinity exists, irrespective of the status of Coorong biota.

The South Lagoon Salinity Reduction Scheme (SLSRS) has the following objectives:

- to reduce salinity in the Coorong by pumping hypersaline water out of the South Lagoon and discharging it into the Southern Ocean;
- to ensure the South Lagoon ecosystem is “flow ready”, primed to take advantage of barrage flows when they return;
- to provide immediate benefits for species that are relatively independent of water levels including some mudflat invertebrate species (chironomid larvae and Capitellid polychaetes) and small-mouth hardyhead fish, species for which the current salinity is near or above physiological tolerance. An increase in the abundance of these species in the South Lagoon is anticipated in the first year or two of pumping, irrespective of barrage flows. These species are an important food resource for waterbirds, which are therefore anticipated to benefit also.

Restoration of the formerly expansive and ecologically important beds of aquatic plants (*Ruppia tuberosa*) in the South Lagoon is more problematic. Translocation of *R. tuberosa* propagules from elsewhere is likely to be necessary to promote timely recolonisation. The return of appropriate spring water levels via adequate barrage flows is likely to be necessary to restore the historic extent of *R. tuberosa* beds in the South Lagoon. However, in the absence of barrage flows, a restricted extent of *R. tuberosa* is anticipated to re-establish in the South Lagoon following the SLSRS. Another critical benefit of the SLSRS will be to protect remnants of the former South Lagoon ecosystem currently restricted to the Murray Mouth and North Lagoon. The SLSRS will reverse the northward expansion of excessively saline water and thereby prevent the elimination of mudflat macroinvertebrate communities and *Ruppia tuberosa* beds in the North Lagoon. The elimination of these currently shrinking remnants would make the ecological restoration of the Coorong much more difficult.

1. Current Ecological Status of the Coorong

The Coorong, Lake Alexandrina and Lake Albert were designated as a Wetland of International Importance under the Ramsar Convention on 1 November 1985 (Phillips and Muller 2006). Contracting parties to the Ramsar Convention, of which the Australian Government is one, are obliged to manage Ramsar sites so as to retain their "ecological character". Ecological character is "the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time" (Phillips and Muller 2006). In this context, the given point in time is the time of designation, i.e. November 1985 for the Coorong and Lower Lakes.

Excessive Salinity

Salinity is a primary determinant of the ecological character of the Coorong and Lower Lakes Ramsar site (Phillips and Muller 2006). The Coorong features a gradient of salinity along its length such that salinity increases as distance from the Murray Mouth increases (Brookes *et al.* 2009, Phillips and Muller 2006).

The salinity of the Coorong fluctuates naturally over an annual timescale, being lowest in late winter/early spring and highest in late summer/early autumn (Phillips and Muller 2006). The suite of flora and fauna that characterise the Coorong can only exist within a particular range of salinity. If the salinity of the Coorong waterbodies moves outside its optimal range changes to the ecosystem are likely, with important species reduced in abundance or lost completely. The upper and lower bounds of the optimal salinity range are referred to as the "limits of acceptable change" (Phillips and Muller 2006). Based on the annual salinity range considered typical for different parts of the Coorong at the time of Ramsar designation, the Ecological Character Description for the Coorong and Lower Lakes (Phillips and Muller 2006) proposed the following limits of acceptable change for salinity in the Coorong (note: salinity units have been converted from EC to g/L using the equations described by Williams (1986)):

- North Lagoon
  - Whole lagoon: salinity within the range 4.5 to 40.1 g/L most of the time;
  - Northern end: salinity not to exceed 32.9 g/L at Long Point during the summer peak;
  - Southern end: salinity not to exceed 69.9 g/L at McGrath Flat in the summer peak.
- South Lagoon
  - Whole lagoon: salinity around 18.9 g/L in some parts during the winter minimum;
  - Northern end: salinity not exceeding 69.9 g/L at Villa de Yumpa during the summer peak;
  - Southern end: salinity not exceeding 93 g/L at Sandspit Point during the summer peak.

More recently, a revised target band of 60 – 100 g/L "on average" for the South Lagoon as a whole has been proposed (Paton *et al.* 2008), informed by the findings of the CSIRO CLLAMMecology Research Cluster. This revised target has been adopted for the SLSRS. It should be noted that the "ideal" salinity for the Coorong is an issue of considerable debate. There is evidence indicating that prior to European colonisation salinity was at times much lower than the above targets. For example, it has been suggested that the southern end of the South Lagoon periodically had a salinity less than 35 g/L (seawater) and that the prominence of hypersaline salinities (i.e. those >35 g/L) in this area is a recent (20^{th} century) phenomenon brought about by reduced freshwater inflows to the system (Fluin *et al.* 2009, Gell and Haynes 2005, Tomlinson 1996). Even under a regulated Murray-Darling Basin with a high level of extractions, barrage flows have occasionally caused salinity to drop below the targets proposed by Phillips and Muller (2006) and Paton *et al.*(2008). For example, in September and October 1984, salinity in the South Lagoon dropped to 50 – 70 g/L in response to above average barrage flows (Geddes 1987). In November 1975 salinity in the South Lagoon was 30 – 40 g/L following a major flood in the River Murray (Geddes and Butler 1984).

Since 1998 water quality data have been collected quarterly from 12 sites along the Coorong (EPA 2010). Summer/autumn maxima and winter/spring minimum salinity data for the North Lagoon at Long Point (Figure 1) and for the South Lagoon near Jack's Point are shown in Figure 2. These data clearly show that salinity has been increasing during the monitoring period. They also show that salinity has exceeded the limits of acceptable change (or target band) at both sites for much of the monitoring period, with the magnitude of that exceedence increasing steadily since 2000. The total area of the Coorong that is seasonally higher than the target upper limit for salinity (100 g/L) has been expanding from south to north since 2000 (Paton 2010). In the absence of freshening flows, this expansion is anticipated to continue. The expansion will progress in a northerly direction towards the Murray Mouth and the area that key flora and fauna are able to occupy will continue to shrink.

Based upon salinity alone, responsible agencies have a legal obligation to act to reduce salinity in the Coorong. In addition, the increase in salinity has, predictably, corresponded with the ecological degradation of the Coorong, particularly the South Lagoon, further strengthening the case for immediate action.

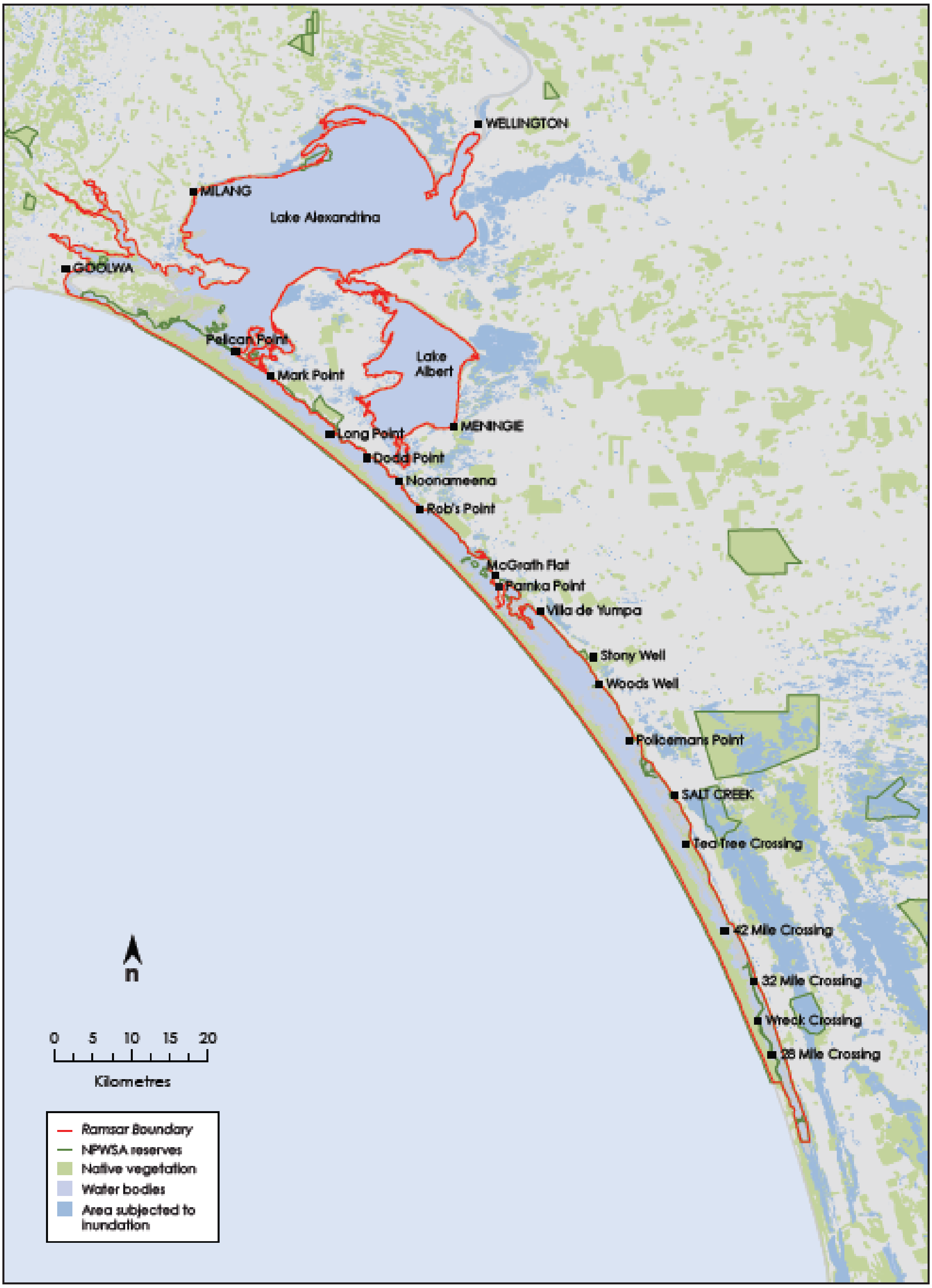
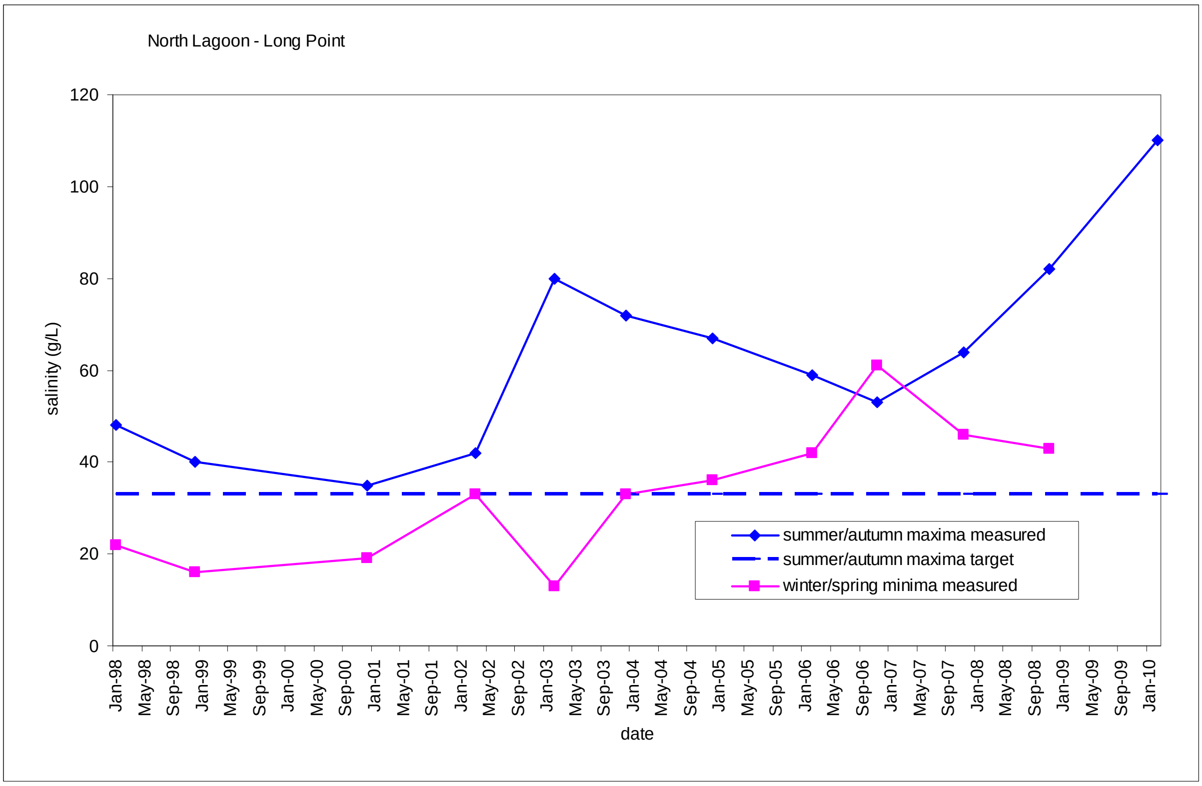


Figure 1. Map showing the boundaries of the Coorong and Lakes Alexandrina and Albert Ramsar site and other key landmarks (source: Phillips and Muller 2006).



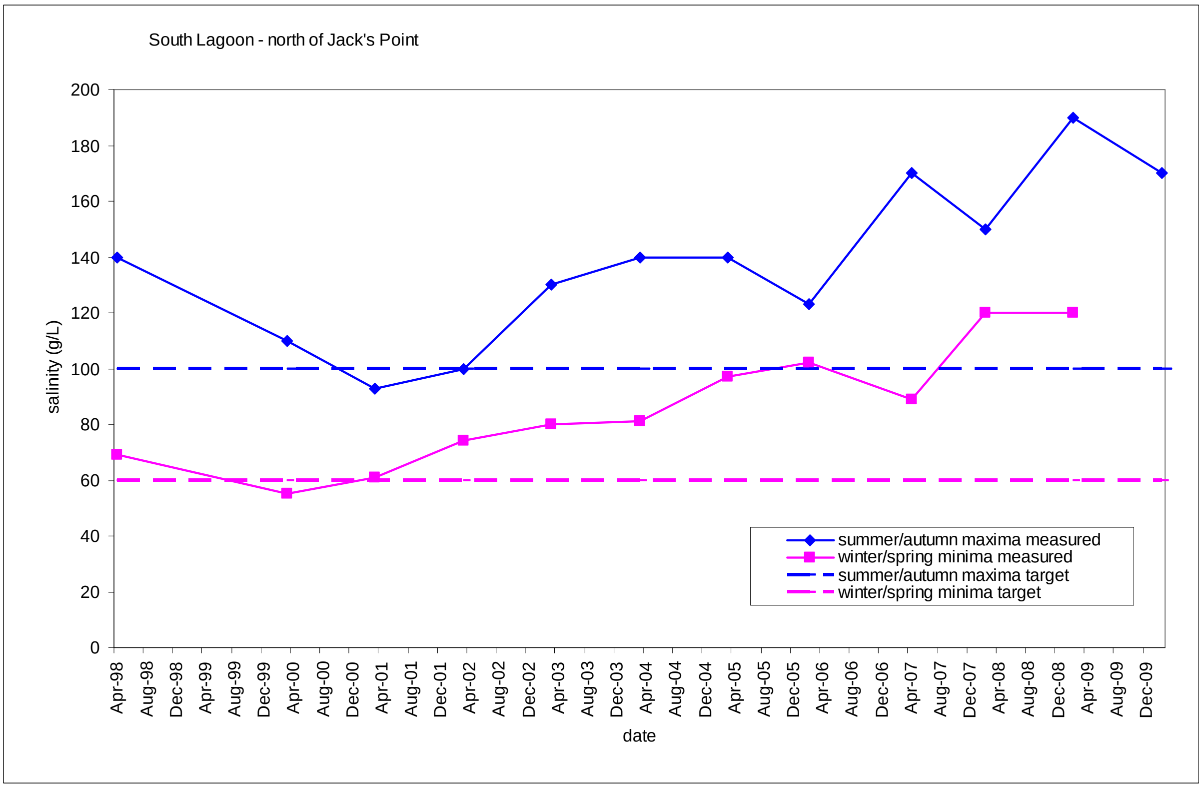


Figure 2. Salinity at two locations in the Coorong from January 1998 (data source: EPA 2010). Location-specific salinity targets are indicated as defined by Phillips and Muller (2006) for North Lagoon and Paton *et al.* (2008) for South Lagoon Sites. Note data are not continuous and therefore actual values in the Coorong may have exceeded recorded values during the monitoring period.

Loss of "Keystone" Aquatic Plants

At the time of Ramsar designation in 1985 both lagoons of the Coorong featured extensive beds of aquatic plants, with two species of the genus *Ruppia* particularly abundant and widespread (Geddes 1987). *Ruppia* spp. are considered "keystone species" in the Coorong ecosystem, that is, species whose loss from the ecosystem would precipitate the loss of many other species due to direct or indirect dependence upon the keystone (Phillips and Muller 2006). *Ruppia* provides food, in the form of shoots, seeds and turions, for waterbirds; provides nesting material for waterbirds; provides habitat for fish and invertebrates; provides a source of organic matter for mudflat detritivores; controls water temperature; prevents the erosion of sediments; influences nutrient cycling and likely provides other benefits for the ecosystem (Carpenter and Lodge 1986, Geddes *et al.* 2009, Paton 2010). At the time of Ramsar designation the dominant species of *Ruppia* in the South Lagoon was *R. tuberosa*, while *R. megacarpa* was abundant in the North Lagoon. These two species have different tolerances to salinity and their 1985 distribution reflected the different salinities of the two lagoons.

Ruppia tuberosa is an annual species that forms beds of foliage on seasonally inundated mudflats (Brock 1982). Being annual, the species relies on a viable bank of seeds and turions (asexual propagules) to maintain its presence in an area. Therefore, the success of annual seed set and turion development are important for the persistence of the species.

Salinity appears to influence the distribution of *R. tuberosa* in the Coorong. Historical data collected since the early 1990s indicate a salinity range of 32 - 110 g/L over which *R. tuberosa* re-established following annual re-inundation of mudflats in the Coorong (Paton and Bailey 2010). Rogers and Paton (2009a) predicted the highest cover of *R. tuberosa* would occur at sites with salinity ranging between 72 and 98 g/L from May to November. Based on these and other data, CLLAMMecology Research Cluster (2008) proposed an optimal salinity for *R. tuberosa* of 60 – 120 g/L. The species is capable of surviving in water of salinity outside this range (e.g. Brock 1982), however its growth and reproductive performance is likely to be sub-optimal (Paton and Bailey 2010) and its long term persistence under such conditions is unlikely. Research suggests that seeds and turions germinate/sprout at high salinities (up to 140 g/L) (Paton and Bailey 2010) but growth, flowering, seed set and/or turion development may be inhibited. It is important to note that another mechanism by which *R. tuberosa* can be prevented from producing seeds and turions is via the truncation of its growing season. This occurs when growing beds of *R. tuberosa* become exposed and desiccated by falling water levels before flowering and turion development has occurred. Such events can occur in the South Lagoon of the Coorong when there are no, or very low, flows over the barrages in spring (Webster 2005, Webster 2007). Paton (2010) proposed that the spatial and temporal patterns of decline of *R. tuberosa* from the South Lagoon are more likely to be the function of inappropriate spring water levels than excessive salinity. However, excessive salinity and low water levels are correlated and salinity clearly plays a role in the performance of *R. tuberosa* in the Coorong. It has been theorised that higher salinities may slow growth rates and delay the timing of reproduction, thus exacerbating the impact of inappropriate spring water levels (Geddes *et al.* 2009).

Ruppia tuberosa abundance has been monitored at five sites in the southern Coorong since 1998 (Paton and Bailey 2010). These data show that in 1999 *R. tuberosa* was present throughout the South Lagoon and absent from the North Lagoon (Figure 3). By 2008 it had disappeared from all four sites in the South Lagoon but had established in low abundance in the North Lagoon. Monitoring also shows that the species is currently absent from the southern parts of the North Lagoon (e.g. Magrath Flat) where it was prominent less than five years ago (Paton and Bailey 2010).

Ruppia tuberosa has almost certainly been declining in the southern Coorong prior to monitoring commencing in 1998. Comparable sampling at three of the four monitoring sites in the southern Coorong over three years from 1990 to 1992 revealed that *Ruppia tuberosa* was substantially more abundant at each of the sites in the early 1990s than at any time during the monitoring of the last twelve years (Paton and Bailey 2010).

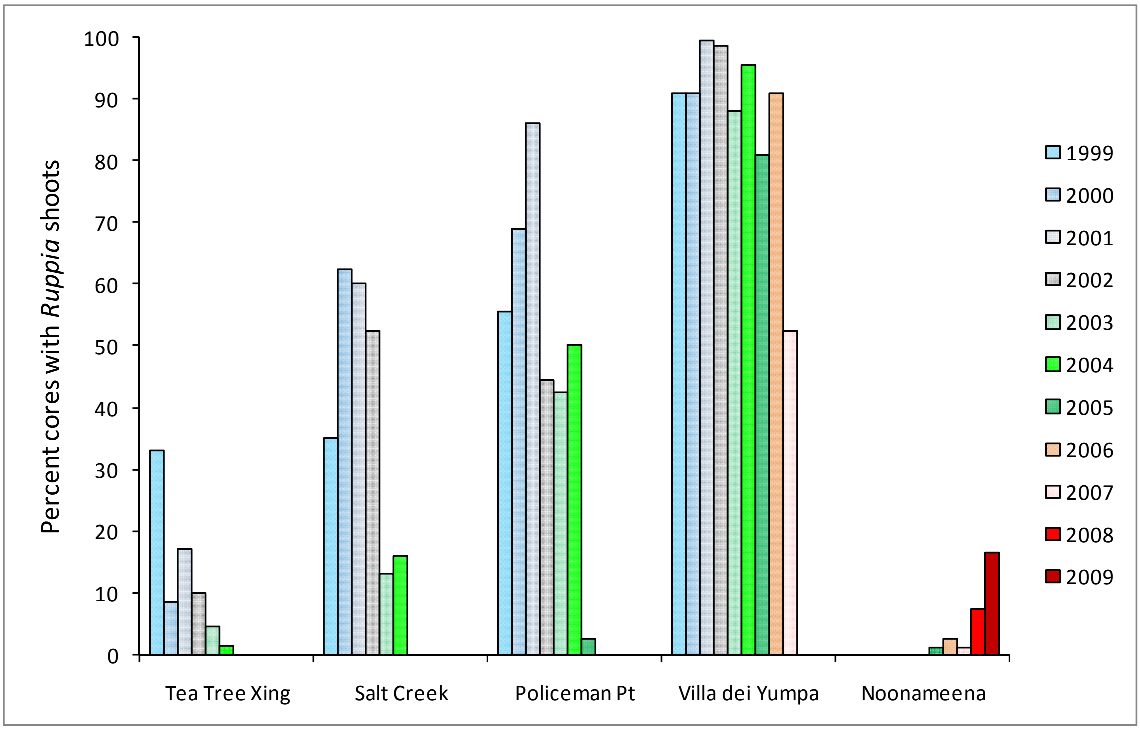


Figure 3. The percentage of 200 core samples that contained *Ruppia tuberosa* shoots in July at each of 5 sites in the Coorong from 1999 to 2009. Left to right along the x-axis corresponds with south to north. Noonameena is located in the North Lagoon while the other sites are in the South Lagoon (source: Paton and Bailey 2010).

The *Ruppia tuberosa* population crash observed in the South Lagoon over the last decade is not restricted to adult plants but also includes the propagule bank (seeds and turions) for this species. Paton and Bailey (2010) estimate that the current density of viable propagules is much less than 1% of that which existed in the 1990s. Even at the one site in the Coorong where *R. tuberosa* was prominent in July 2009 (Rob's Point in the North Lagoon) there were negligible propagules remaining in the sediments (0.18 propagules per core compared to ~20 propagules per core at some sites in the late 1990s) (Paton and Bailey 2010). This highlights the current vulnerability of *R. tuberosa* within the Coorong as a whole. If *R. tuberosa* fails to set propagules during spring then the species is also likely to rapidly disappear from the North Lagoon (Paton and Bailey 2010). The presence of *R. tuberosa* in the Coorong, therefore, remains precarious. The successful recolonisation of the South Lagoon by *R. tuberosa*, should favourable conditions return, is likely to require additional intervention such as translocation of material from elsewhere (Paton and Bailey 2010).

Ruppia megacarpa has been reported growing in water with a salinity ranging from 12 to 50 g/L (Brock 1982). An optimal salinity of <60 g/L has been proposed for the species (CLLAMMecology Research Cluster 2008). Geddes (in Phillips and Muller 2006) states that in 1985 *Ruppia megacarpa* "was along the inland side of the North Lagoon from north of Mark Point to south of Dodd Point, almost to Noonameena. There were dense stands to 60 cm tall along the littoral zone to a water depth of about 1 metre. This represented a band of *Ruppia* 100 to 200 metres wide. In my sampling since 2003 I have not seen any *R. megacarpa* growing in the North Lagoon".

As indicated by Figure 2, the summer/autumn salinity maxima in the North Lagoon at Rob's Point has exceeded the 60 g/L upper limit for *R. megacarpa* regularly since mid-2002. The 60 g/L upper limit has been exceeded throughout the entire year since early 2004. Brock (1982) found that germination of *R. megacarpa* seeds declines with increasing salinity such that at a salinity of 42 g/L no *R. megacarpa* seeds germinated. Brock suggested that germination requires a drop in salinity, such as occurs when freshwater inflows dilute saline waterbodies. *Ruppia megacarpa* is a perennial plant that occurred at permanently inundated elevations in the North Lagoon at locations that remained inundated even in the absence of spring barrage flows. Therefore a likely explanation for the loss of *R. megacarpa* from the North Lagoon is the persistence of salinity levels excessive to the physiological tolerance of adult plants and the germination of seeds.

Reduced Diversity and Abundance of Macroinvertebrates

A number of studies indicate a strong link between salinity and the diversity and abundance of macroinvertebrates in the sediments of the Coorong (Dittman *et al.* 2008, Dittman and Nelson 2007, Dittmann *et al.* 2006a, Dittmann *et al.* 2006b, Dittmann *et al.* 2006c, Dittmann *et al.* 2010, Geddes 1987, Geddes 2005, Geddes 2003, Geddes and Butler 1984, Geddes and Hall 1990, Kangas and Geddes 1984, Rolston and Dittman 2009). The salinity gradient along the length of the Coorong, whereby salinity increases with increasing distance from the Murray Mouth, corresponds with patterns in the distribution and abundance of the macroinvertebrate community. The highest macroinvertebrate abundances in the Coorong tend to occur in areas where the salinity is maintained between 30 and 45 g/L (Dittmann *et al.* 2010).

In the South Lagoon, larvae of the chironomid (midge) *Tanytarsus barbitarsus* are an important component of the mudflat macroinvertebrate community and an important food source for waders and fish (Paton 2010, Phillips and Muller 2006). Chironomid larvae live on the surface of submerged sediments and graze on surface algae (Paton 2010, pg. 134). In the mid 1980s *T.barbitarsus* was the dominant littoral and benthic macroinvertebrate in the South Lagoon and generally occurred throughout the lagoon (Geddes 1987). Winter monitoring commencing in 1998 has shown that *T.barbitarsus* larvae were prominent in the South Lagoon in winter from 1998 to 2006 but since then have declined dramatically (Paton and Bailey 2010). Neither *T. barbitarsus* larvae nor any other macroinvertebrate species were detected in the mudflats of the South Lagoon in January and March 2007 (Rolston and Dittman 2009). However low abundances of *T. barbitarsus* larvae were detected in the northern and southern ends of the South Lagoon in February 2010 (Dittmann *et al.* 2010). Based on observed distribution and abundance in the Coorong *Tanytarsus barbitarsus* has one of the highest salinity tolerances of the previously abundant macroinvertebrates of the Coorong, with an optimal salinity of <90 g/L, although it has been recorded in salinities up to 120 g/L (CLLAMMecology Research Cluster 2008). Figure 2 shows that salinities of greater than 120 g/L have regularly been experienced in South Lagoon since early 2003, corresponding with the decline of *T. barbitarsus*. The current status of macroinvertebrates in the mudflats of the South Lagoon is indicative of extreme ecosystem degradation.

The beds of *Ruppia megacarpa* that were extensive in the North Lagoon between Mark Point and the Needles in the early 1980s (Paton 2010) supported substantial abundances of aquatic invertebrates. In autumn 1981 Snoejis and van der Steer (cited by Paton 2010) recorded invertebrate densities within *R. megacarpa* beds of up to 35,000/m² for *Hydrobia buccinoides* (a snail), 1,100/m² for *Salinator fragilis* (a snail), 1,900/m² for *Arthritica helmsi* (a bivalve), 1,000/m² for *Simplisetia aequisetis* (a polychaete), 35,000/m² for *Capitella* sp. (a polychaete), 2,100/m² for *Tanytarsis barbitarsus* larvae and 3,800/m² for the larvae of two unidentified species of brine fly. These *R. megacarpa* beds have subsequently disappeared completely, with the most likely explanation being excessive salinity (see above), and much of the invertebrate community they supported has disappeared with them (Geddes and Francis 2008). Recent macroinvertebrate sampling in the Coorong (Dittmann *et al.* 2010) found a maximum density of ~35,000 individuals/m² (at Mark Point), with an average across all sampled sites (in the Murray Mouth, North Lagoon and South Lagoon) of 3552 individuals/m². Thus macroinvertebrate abundance has declined markedly since the early 1980s. Macroinvertebrate diversity was also much lower than that described by Snoejis and van der Steer, with counts in 2010 dominated by only two groups; chironomids and Capitellid polycheates (Dittmann *et al.* 2010). At sites with salinity greater than 70 g/L only chironomids were recorded, with annelids, molluscs and crustaceans all absent from the sediments.

Excessive salinity appears to be directly responsible for the ongoing loss of macroinvertebrates from the North Lagoon. For example, the disappearance of polychaetes (*Capitella* sp.) that were once prominent at Noonameena in the North Lagoon is likely to be due to elevated salinities (Paton and Bailey 2010). The salinities at Noonameena in winter in 2007 and 2008 approached the upper limit at which this genus has been recorded in the Coorong, which is typically less than 90 g/L, infrequently as high as 138 g/L (CLLAMMecology Research Cluster 2008, Rolston *et al.* 2010). In February 2010 a salinity of ~125 g/L was measured at Noonameena and the only macroinvertebrates present in the mudflat were a very small number of chironomids (Dittmann *et al.* 2010).

Increased salinity and increased exposure both result in reduced diversity and abundance of macroinvertebrates in the Coorong (Rolston and Dittman 2009). These outcomes are currently being observed in the North Lagoon under the present flow situation as salinity increases and water levels fall. If current conditions persist with no freshening influence, the distribution of macroinvertebrates will continue to recede northwards towards the Murray Mouth region, creating a reduced area of refuge where conditions remain within the physiological tolerances of species (Rolston and Dittman 2009). Recent monitoring indicates that macroinvertebrate abundance in the refuge area close to the mouth is continuing to decline (Dittmann *et al.* 2010).

Macroinvertebrates are important as a food source for higher trophic organisms (e.g. fish and birds) in the Coorong. Their currently reduced abundance and diversity, compared to the mid 1980s, has likely contributed to the declines observed in higher biota.

Reduced Abundance of Fish

Small-mouthed hardyhead were widespread and very abundant in the South Lagoon in the mid 1980s (Geddes 1987). Small-mouthed hardyhead are an important food source for piscivorous birds in the Coorong. Lui (1969) reported a lower and upper LD_{50}[1] for salinity for small-mouthed hardyhead of 3.3 and 108 g/L

[1] Lethal dose, 50%. The concentration of a substance (in this case total dissolved solutes) required to kill 50% of a test population of a species (in this case small-mouthed hardyhead).

respectively. Molsher *et al.* (1994) found no influence of salinity upon the size, condition or reproductive performance of small-mouthed hardyhead in the Coorong for salinities between 9 and 94 g/L. Salinities less than ~100 g/L can be considered optimal for the species, although it is capable of existing in higher salinities (CLLAMMecology Research Cluster 2008, Molsher *et al.* 1994). As shown in Figure 2, the salinity of the South Lagoon was generally below 100 g/L in winter/spring prior to 2007. Since 2007 salinity has remained above 100 g/L throughout the year, often markedly so. The establishment of year-round salinities higher than those optimal for small-mouthed hardyhead has corresponded with a dramatic decline in the abundance of this species in the South Lagoon (Paton 2010) and the species is now essentially absent from this part of the Coorong. The absence of small-mouthed hardyhead from the South Lagoon is likely due to salinity being consistently above its physiological tolerance, combined with the loss of its macroinvertebrate food resources and the structural habitat provided by beds of *Ruppia tuberosa*. The loss of macroinvertebrates and *R. tuberosa* are also linked to excessive salinity (see 'Reduced Diversity and Abundance of Macroinvertebrates' and 'Loss of "Keystone" Aquatic Plants' sections).

Changes to the Distribution and Abundance of Waterbirds

Most waterbirds that utilise the Coorong do so on a seasonal basis. Wetlands and other habitats beyond the Coorong, some as far away as the arctic, are also utilised. Therefore the abundance of waterbirds at the Coorong does not necessarily reflect conditions in the Coorong, it may reflect conditions at other sites. Nevertheless, changes to the abundance of waterbirds in the South Lagoon in the last 30 years do correlate with changes to the abundance of their preferred food resources (Rogers and Paton 2009b).

The abundance of piscivorous birds in the South Lagoon has declined steadily during the last 10 years (Paton 2010) as the abundance of small-mouthed hardyhead has declined. Affected species include Australian Pelican, Fairy Tern (SA: E) [2], Whiskered Tern, Common Greenshank and White-faced Heron (Paton 2010). Other piscivorous birds have changed their foraging areas and feeding habits, a likely response to the loss of fish and the South Lagoon, which must now be considered sub-optimal habitat for them. These species include Caspian Tern (AUS: M), Hoary-headed Grebe and Great-crested Grebe (SA: R) (Paton 2010).

The plight of the south-eastern Australian subspecies of the Fairy Tern (*Sternula nereis nereis*) is particularly illustrative of the relationship between conditions in the Coorong and waterbird abundance. In the mid 1980s there were ~1500 Fairy Terns in the South Lagoon alone. The global population is 2,580 individuals, thus the Coorong can be considered the traditional stronghold for the subspecies (Paton and Rogers 2009). By the 1990s numbers in the entire Coorong region had dropped to ~700 and by 2010 the population was around 350 individuals (Paton 2010), a decline of ~75% since the mid 1980s. The reduced abundance of Fairy Terns in the Coorong cannot be accounted for by increased abundance at other sites in south-eastern Australia but represents a net loss to the total population (Paton 2010). Paton (2010, pg. 182) states: "The dilemma for Fairy Terns in the Coorong is that their traditional [fox-free] breeding islands in the South Lagoon no longer have a reliable source of fish anywhere near them and will not have a supply of fish near them until the high salinities in the South Lagoon are eliminated".

Over the last 10 years, there have been declines in the abundances of Black Swan and Grey Teal in the South Lagoon, both species that historically fed on *Ruppia tuberosa* there (Paton 2010). Chestnut Teal and Australian Shelduck have responded to the changed conditions by feeding on Australian brine shrimp (*Parartemia zietziana*) (Paton 2010), which now flourish in the South Lagoon due to the very high salinity combined with the absence of their key predators, small-bodied fish. Australian brine shrimp were first recorded in the Coorong in 2006 (Mike Geddes, pers. com., 23/07/10).

The food resources for small and large-bodied waders in the South Lagoon were historically mudflat invertebrates and the seeds and turions of *Ruppia tuberosa*. With these food resources now largely absent from the South Lagoon there have been dramatic declines in the abundance of Curlew Sandpiper (AUS: M), Red-necked Stint (AUS: M), Red-capped Plover, Pied Oystercatcher (SA: R) and Red-necked Avocet (Paton 2010). In contrast, Sharp-tailed Sandpiper (AUS: M) abundance has been relatively stable (Paton 2010), an observation not easily explained, particularly given the declines in closely related species (e.g. Curlew Sandpiper). The abundances of Silver Gull and Masked Lapwing have been stable probably due to their relative independence from food resources within the lagoon. Banded Stilt (SA: V) have increased dramatically in abundance in recent years due to the sudden increase in brine shrimp abundance in the

[2] Conservation ratings (legislation: rating):

Legislation:

- SA = listed as rare or threatened in South Australia under the schedules of the South Australian *National Parks and Wildlife Act 1972*;
- AUS = listed as threatened or migratory in Australia under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

Ratings:

- R = rare, M = migratory, V = vulnerable, E = endangered, CE = critically endangered, EX = extinct.

South Lagoon, which these birds are able to utilise as a food resource (Paton 2010). The high abundance of brine shrimp in the South Lagoon is a symptom of the very high salinity now present. Brine shrimp and Banded Stilt are species more typical of extremely saline inland salt lakes such as Lake Eyre.

2. Conceptual Model for the Coorong South Lagoon

The conceptual model for the South Lagoon shown in Figure 4 was developed by Souter (2009). It is a control model depicting (Souter 2009):

- Drivers - major external factors that have large-scale effects on the ecosystem;
- Stressors – physical, chemical or biological agents that cause significant changes in ecological components, patterns and relationships;
- Ecosystem attributes – complex ecosystem components that respond to drivers/and or stressors (these can also act as stressors);
- Control points – points where management intervention can mitigate a stressor to have an impact upon the conservation priority species; and
- Summing points – points were a number of conditions must be met before a phenomenon can occur. For example a number of conditions may need to be met before breeding can occur i.e. for birds sufficient food in the appropriate season with available nest sites.

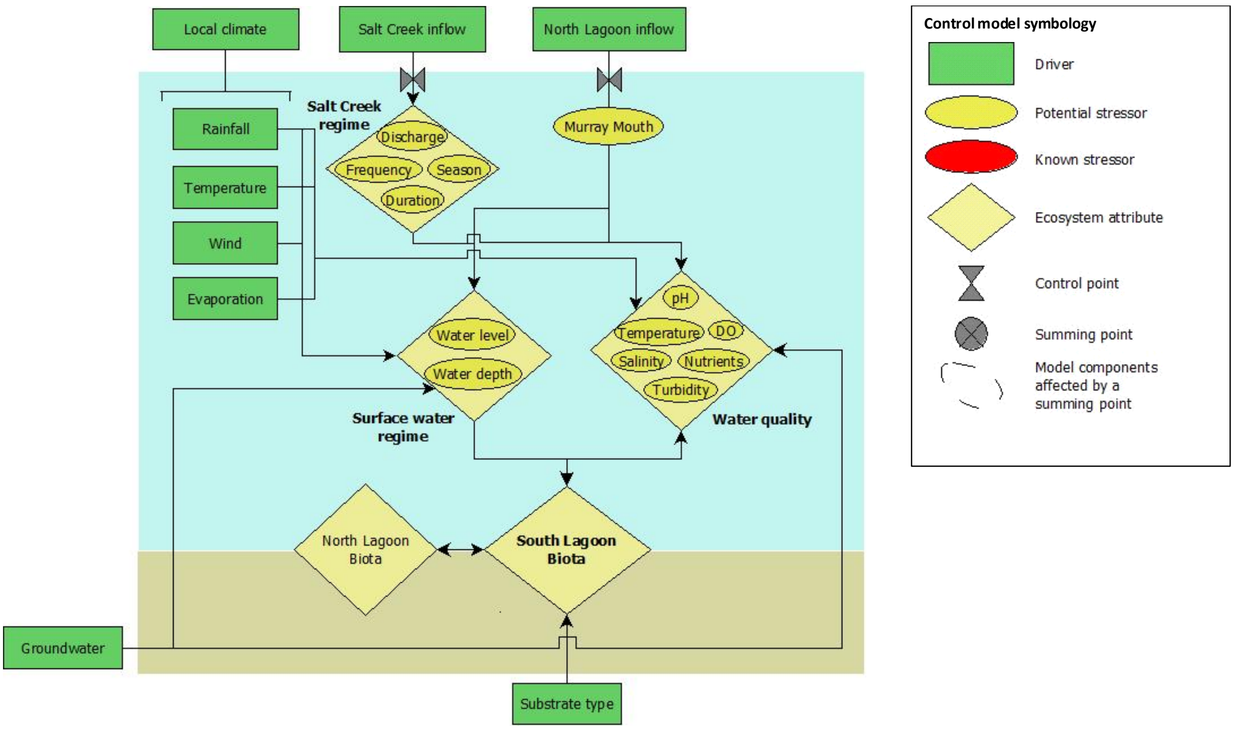


Figure 4. Control model for the Coorong South Lagoon (source: Souter 2009).

The model is described as follows by Souter (2009):

> "The South Lagoon control model has three drivers associated with inflow of water: Salt Creek inflow, North Lagoon exchange and groundwater. Water from Salt Creek includes redirected groundwater and surplus surface water from the Upper South East Drainage Scheme. North Lagoon inflow is dependent upon freshwater flow from Lake Alexandrina and tidal exchange of seawater through the Murray Mouth. … the requirement for an open Murray Mouth in allowing variation in South Lagoon water levels is depicted in the control model as a potential stressor linking North Lagoon inflow with the Surface Water Regime and Water Quality ecosystem attributes. Historically inflow of fresh regional groundwater is believed to have provided an important supply of freshwater to the South Lagoon. The current importance of this groundwater is not well known but included in the model for completeness. The South Lagoon will exchange biota with the North Lagoon depending on environmental conditions. The recent increase in South Lagoon salinity has seen a movement of biota from South to North following the diminishing salinity gradient. The colonisation of the previously South Lagoon species *Ruppia tuberosa* into the North Lagoon provides an example of this. Local climate plays an important role in the South Lagoon with local rainfall, lower temperature and evaporation in winter increasing water level, whilst the converse occurs during summer."

3. Anticipated Ecological Benefits of Pumping

Salinity Reduction

The South Lagoon Salinity Reduction Scheme (SLSRS) aims to rapidly reduce salinity in the Coorong South Lagoon from its current excessive levels down to the target range of 60 – 100 g/L defined by Paton *et al.*(2008). The SLSRS will lower salinity by exporting salt via mechanical pumping of hypersaline water from the South Lagoon to the Southern Ocean through pipes installed across Younghusband Peninsula. The hypersaline water of the South Lagoon will be pumped at a rate of 250 ML/day. The pumping rate was determined by modelling the salinity reduction achieved under different pumping rates (Lester *et al.* 2009a) whilst aiming to minimise cost and potential impact to the marine environment. The water pumped out will be replaced by seawater inflows through the Murray Mouth (combined with River Murray flows over the barrages if these occur during the pumping period).

Several alternative approaches to addressing excessive salinity in the Coorong have been assessed including the following (DEH 2010a):

- Do nothing. Twenty-year hydrological scenario modelling of a continuation of drought conditions and no freshwater inflows (CLLAMMecology Research Cluster 2008) shows that the salt concentrations in the South Lagoon would continue to fluctuate between 120 – 140 g/L (winter) and 170 - 220 g/L (summer). These conditions would result in a continuation of the current status of the ecology of the South Lagoon, i.e. a degraded unhealthy hypersaline ecosystem.
- A gravity reliant pipe between the Coorong and the Southern Ocean, rejected due to the inefficiency of salinity reduction relative to cost (DEH 2010b).
- The pumping of seawater from the Southern Ocean into the South Lagoon. This has been rejected because it would be relative inefficient at lowering salinity (compared to pumping in the reverse direction).
- Large flows of freshwater over the barrages. Because the Coorong has become so saline a return of 'average' barrage flows will not have the ecological benefit they once did. The salinity of the system needs to be reset so that when barrage flows do resume they provide the critical ecological benefit to the Coorong that they have historically. A barrage release in the order of 3,000 GL would be required to reset Coorong salinity to the extent that will be achieved by the SLSRS . Such barrage flows are unlikely in the foreseeable future given the status of water storages in the Murray-Darling Basin. In the meantime salt will continue to accumulate in the South Lagoon and the ecosystem will continue to deteriorate, potentially to a state where the damage is irreversible.
- Excavations at Parnka Point to increase mixing between the two Coorong lagoons. This proposal is still being considered and would be complimentary to but not a replacement for the pumping scheme (Lester *et al.* 2009a). Recent modelling (Figure 5) indicates that, combined with pumping, such excavations may not provide additional salinity reduction benefit to that of pumping alone.
- Increased freshwater flows from the South East into the South Lagoon. This proposal is being considered and would be complimentary to the pumping scheme (Lester *et al.* 2009b). However, even if initiated immediately, it would be several years before increased flows to the Coorong would occur. In the meantime salinity in the Coorong would continue to increase and the ecosystem continue to deteriorate.

Lester et al. (2009a) modelled the effect of a range of different pumping rates upon Coorong salinity and the ecosystem of the Coorong. Ultimately, the 250 ML/day modelled scenario was considered the optimum pumping rate. This pumping volume was further tested by subsequent updated modelling (BMT WBM 2010). Time-series showing predicted salinity in the South Lagoon at Policeman's Point is shown in Figure 5 and in the North Lagoon at Rob's Point is shown in Figure 6. Assumptions used to generate this model are:

- Zero barrage flows for the duration of the modelled period;
- Pumping commences 1/1/2011 and continues uninterrupted at 250 ML/day until 1/1/2014;
- Dredging of Parnka Point is instantaneous and occurs on 1/1/2012;
- For the "base case" and "pumping but no UPSE Scheme" scenarios, modelled inflows from the South East to the Coorong for the period 2010 to 2016 are 15, 10, 10, 15, 15 and 15 GL/year; and
- For the other three scenarios inflows from the South East to the Coorong for the period 2010 to 2016 are 15, 10, 10, 60, 60 and 60 GL/year, with the last three years reflecting the anticipated average inflows following the re-direction of South East drain flows towards the Coorong (the Coorong South Lagoon Flows Restoration Project (CSLFRP)).

Figure 5 clearly shows the beneficial impact that pumping has on salinity within the South Lagoon, with peak summer salinity reduced from 200 g/L to approximately 150 g/L within a year. By the end of the three year pumping program, assuming increased inflows from the South East via the CSLFRP, peak summer salinity is expected to be approximately 100 g/L. Even without the CSLFRP the figure is approximately 120 g/L. If pumping is not undertaken, peak summer salinity (at Policemen's Point) within the South Lagoon is anticipated to reach 250 g/L by April 2013. A salinity this high is approximately 2.5 times higher than the recommended upper limits for several key species that were abundant and widespread in the South Lagoon in the mid 1980s, including small-mouthed hardyhead, the chironomid *Tanytarsus barbitarsus* and *Ruppia tuberosa* (CLLAMMecology Research Cluster 2008, Lui 1969). The longer pumping is delayed the greater the salt accumulation in the South Lagoon will be and therefore the greater the volume required to be pumped, or volume released through the barrages, to reduce salinity back to target levels.

Figure 6 shows the beneficial impact of the SLSRS upon salinities in the North Lagoon. All pumping scenarios have a similar effect upon salinity. At the cessation of pumping peak summer/autumn salinity will have been reduced to ~100 g/L compared to ~230 g/L without pumping (base case). The winter minima is marginally lower under the proposed pumping scenarios compared to the base case; ~40 g/L versus ~50 g/L. The target for this part of the North Lagoon is that salinities remain below 70 g/L at all times (Phillips and Muller 2006). The target is not achieved throughout the year under the proposed pumping scenarios, however the duration and magnitude of its exceedence is greatly reduced compared to the base case. It is important to note that without pumping the summer/autumn maximum salinity at Rob's Point in the North Lagoon will greatly exceed the target for the South Lagoon. This situation is likely to eliminate crucial refuge areas of *Ruppia tuberosa*, mudflat macroinvertebrates and other biota from the North Lagoon in the next few years under current conditions of zero or very low barrage flows. The complete loss of these species from the Coorong will make ecosystem rehabilitation much more difficult and potentially impossible. The SLSRS prevents North Lagoon salinities exceeding tolerance thresholds for these biota and thereby helps to ensure these crucial remnants are preserved and able to act as a source of propagules for the recolonisation of the South Lagoon.

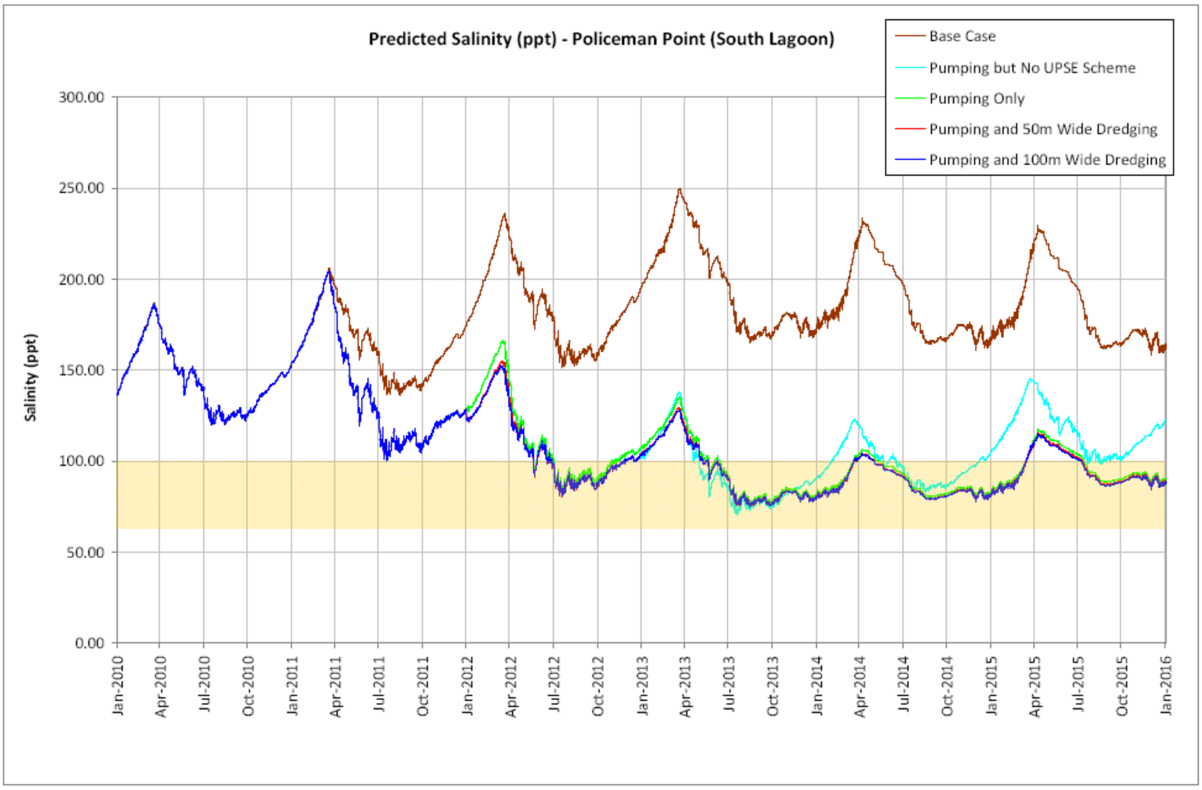


Figure 5. Predicted salinity in the South Lagoon at Policeman Point under "do nothing" (base case) scenario and various combinations of pumping at 250 ML/day, dredging at Parnka Point and increasing inflows from the South East (source: BMT WBM 2010). The target salinity band at this location (Paton *et al.* 2008) is shown in orange. Note: ppt = g/L.

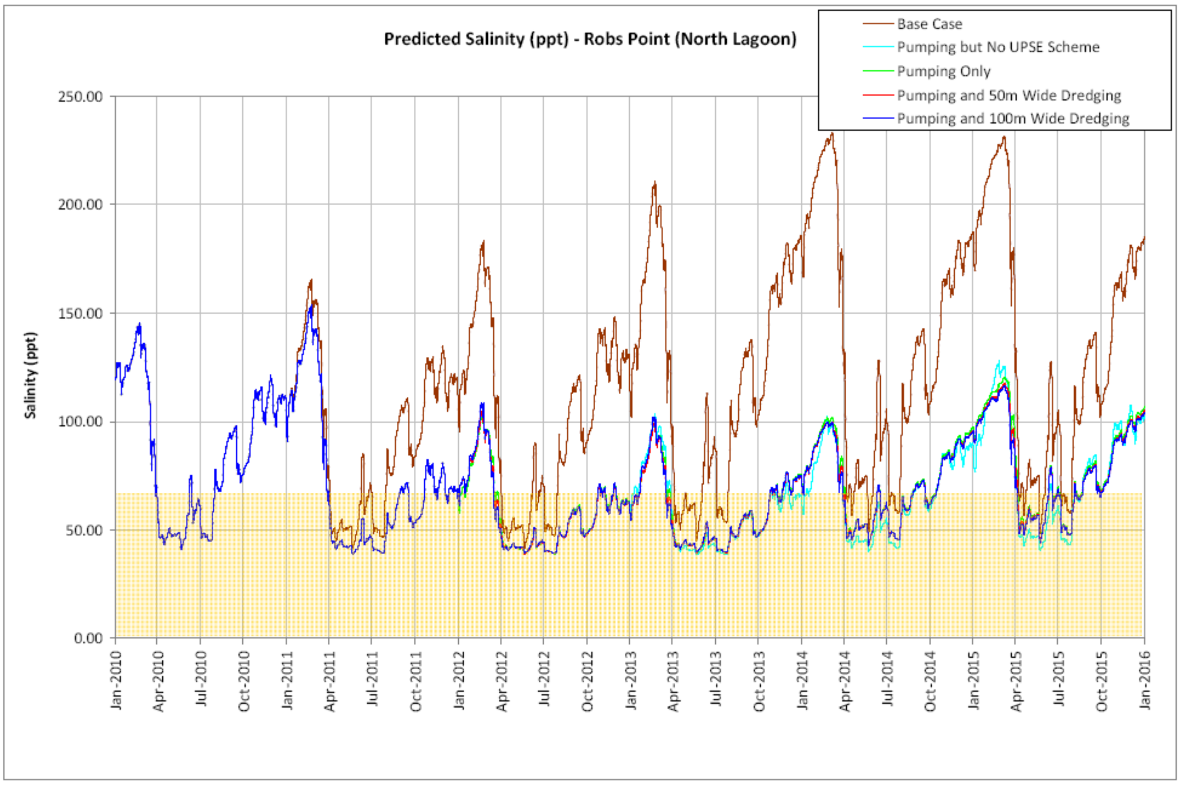


Figure 6. Predicted salinity in the North Lagoon at Rob's Point under "do nothing" (base case) scenario and various combinations of pumping at 250 ML/day, dredging at Parnka Point and increasing inflows from the South East (source: BMT WBM 2010). The target salinity band at this location (Phillips and Muller 2006) is shown in orange. Note: ppt = g/L.

Keystone Aquatic Plant Response to Reduced Salinity

Various attempts have been made to define suitable conditions for *Ruppia tuberosa* in the Coorong. The general consensus is that salinities should typically be managed between 60 g/L and 100 g/L between late winter and early summer and that the typical water depths over the beds of *R. tuberosa* need to be in the range of 0.3 - 0.9m (Paton and Bailey 2010). The 60 – 100 g/L salinity range fits within the published range of salinities in which *Ruppia tuberosa* exists (Brock 1981, Brock 1982), matches salinities that used to exist across the southern Coorong when *Ruppia tuberosa* was still extant, and importantly sits below the upper threshold salinities for two key aquatic organisms that were characteristic of the South Lagoon prior to its recent ecological collapse (chironomids, small-mouthed hardyhead) (Paton and Bailey 2010). Thus the SLSRS, by reducing South Lagoon salinity to within this target range, will address one of the key requirements for *R. tuberosa* - namely that of salinity. However, pumping will have no impact on water levels (except for minor, temporary effects (BMT WBM 2010)) and will therefore not address all of the issues currently limiting the distribution of *R. tuberosa*. It may be that only with both reduced salinity and appropriate barrage flows in spring, at the volumes known to maintain the water levels required (Geddes *et al.* 2009, Webster 2005, Webster 2007), will *R. tuberosa* recover its former extent in the South Lagoon. However, it is anticipated that with appropriate salinities in the South Lagoon, favourable conditions for *R. tuberosa* will exist, albeit with a reduced extent than would be the case if spring barrage flows were also provided.

It is important to note that, based on our current understanding, there would be little to no ecological benefit from appropriate spring water levels being restored to the South Lagoon via barrage flows if salinity had not first been reduced to target levels. Salinities would remain outside the physiological tolerances of key species, including *R. tuberosa*, and these species would therefore be unlikely to re-establish. Thus, salinity reduction is a necessary first step in the restoration process.

Unlike small-mouthed hardyhead fish and chironomids, *Ruppia tuberosa* is unlikely to re-colonise the South Lagoon quickly because of the loss of its propagule banks from this area of the Coorong over the last five or so years. Additional on ground works will be required to facilitate the timely re-establishment of this plant across the South Lagoon (Paton and Bailey 2010). Investigations into the most effective way to promote re-establishment via the translocation of *R. tuberosa* propagules have been completed and further work is planned (Paton and Bailey 2010).

The response of *Ruppia megacarpa* to the SLSRS is likely to be minimal. All that currently remains of this formerly abundant species in the North Lagoon is an extremely depleted seedbank, with approximately one viable seed per 20 m² (Paton 2010). With an optimal salinity range of <60 g/L, salinities in the North Lagoon are likely to remain sub-optimal for the species for much of the year (Figure 6). A sudden drop in salinity from the upper tolerance to estuarine/brackish conditions, such as that provided by an influx of freshwater, may be required to stimulate the germination of *R. megacarpa* (Brock 1982). Thus regular barrage flows are likely to be necessary to re-establish and maintain populations of *R. megacarpa* in the North Lagoon.

Mudflat Macroinvertebrate Response to Reduced Salinity

The success of the SLSRS at re-establishing macroinvertebrate populations in the South Lagoon requires the following (Dittmann *et al.* 2010):

a) the existence of source populations for recolonisation;

b) the ability of macroinvertebrates to disperse and reach the newly available habitat; and

c) appropriate water quality and sediment in re-establishment areas.

By reducing salinity in the South Lagoon, the SLSRS is anticipated to partly achieve requirement (c). By reducing salinity in the South Lagoon to 60 – 100 g/L, salinities will remain largely within the physiological tolerance range for the key mudflat macroinvertebrate *Tanytarsus barbitarsus* (chironomid) and at the upper tolerance level of *Capitella* sp. (polychaete) (CLLAMMecology Research Cluster 2008). The SLSRS will have no impact on sediments in the South Lagoon and it is assumed that it will similarly have no impact on the capacity of these sediments to support macroinvertebrates, provided water quality and depth considerations are met.

The recently documented increase in *T. barbitarsus* larvae abundance in both the central North Lagoon and northern end of the South Lagoon (Dittmann *et al.* 2010, Paton and Bailey 2010) provides confidence that requirements (a) and (b) above will be met for this species when the SLSRS is implemented. Clearly the species is capable of recolonising mudflats in the South Lagoon from which it was absent two to three years previously. This is likely to be related to its highly mobile (non-aquatic, airbourne) adult phase. It is therefore anticipated that *T. barbitarsus* abundance in the South Lagoon will increase relatively quickly in response to the SLSRS, perhaps within the first year of pumping. In addition to the population recently observed in the South Lagoon, remnant populations are thought to remain in close proximity to freshwater soaks peripheral to the South Lagoon (D. Paton. pers. com., 11/6/10) and these will provide an additional source population for recolonisation. For other invertebrate groups such as polychaetes, crustaceans and molluscs, the presence of juveniles in the Murray Mouth and northern end of the North Lagoon throughout the year suggests that colonisation of new, suitable habitat is possible, given the right environmental conditions (Rolston and Dittman 2009). However the current low abundances, greatly restricted distributions and modes of dispersal of these groups suggests that the southward expansion of their distributions may be slow (Dittmann *et al.* 2010).

Importantly, the SLSRS will prevent the further northward encroachment of excessive salinity within the North Lagoon. In doing so it will help ensure that the remnant populations of invertebrates (and other biota) in this lagoon, which provide potential source populations for recolonisation of the South Lagoon, are conserved. If these remnant populations are lost from the entire Coorong system, restoration of the former ecosystem becomes much more difficult.

Fish Response to Reduced Salinity

Achievement of the 60 – 100 g/L target salinity range for the South Lagoon via the SLSRS will bring the salinity back within the physiological tolerance range of small-mouthed hardyhead (Lui 1969). Increased abundance of this fish in the South Lagoon will require appropriate salinities and adequate food resources. The re-establishment of beds of *Ruppia tuberosa* is likely to provide further benefits, in the form of structural habitat and a greater abundance and diversity of food resources. However the presence of *Ruppia* is not a pre-requisite for an increase in fish abundance in the South Lagoon. Small-mouthed hardyhead have been recorded in abundance in the North Lagoon at locations devoid of submerged aquatic vegetation (e.g. Geddes and Francis 2008). A recent pilot study of the trophic ecology at Pelican Point in the North Lagoon found that the epibenthic amphipods *Paracorophium* and *Megamphopus* dominated the diet of small-mouthed hardyheads (Geddes and Francis 2008). Salinities at this location were around 36 g/L during the study (EPA 2010). Key amphipod species in the Coorong do not typically occur at salinities above ~60 g/L (Kangas and Geddes 1984), thus even when salinities in the South Lagoon are within the target range, conditions are sub-optimal for amphipods. Clearly, the diet of small-mouthed hardyhead in the South Lagoon prior to their decline cannot have been dominated by amphipods. It may have been dominated by the zooplankters copepods and ostracods, some species of which have an upper salinity tolerance of greater than 100 g/L, and by the chironomid *Tanytarsus barbitarsus* (Mike Geddes, pers. com., 19/7/10). The SLSRS will restore the salinity of the South Lagoon to within the physiological tolerance of these food resources for small-mouthed hardyhead. An increase in zooplankton and chironomid abundance and consequent increase in fish abundance is anticipated. Additionally, the very high abundance of the Australian brine shrimp *Parartemia zietziana* in the South Lagoon is anticipated to provide a food resource for small-mouthed hardyhead when salinity is restored to within the physiological tolerance range of this fish species (i.e. 3.3 to 108 g/L (Lui 1969)).

In conclusion, an increased abundance of small-mouthed hardyhead in the South Lagoon in response to the SLSRS, even in the absence of spring barrage flows, can be anticipated. Abundance may not increase to the levels it could if extensive beds of *R. tuberosa* were re-established, because these provide shelter, nursery habitat and additional food resources for small-mouthed hardyhead (Phillips and Muller 2006), however salinity and food resources are likely to be more favourable once salinities are reduced below ~100 g/L.

Waterbird Response to Reduced Salinity

The response of waterbirds to the SLSRS will depend upon how successfully the project increases waterbird food resources in the South Lagoon. Food resources for small and large-bodied waders include mudflat invertebrates and the seeds and turions of *Ruppia tuberosa* (Paton 2010). Given that increased abundance of mudflat invertebrates (chironomids) and limited re-establishment of *R. tuberosa* is anticipated, the SLSRS should enhance conditions for those waders that have declined in recent years as their food resources have declined. Thus, even in the absence of spring barrage flows, the SLSRS should provide benefits for Curlew Sandpiper, Red-necked Stint, Red-capped Plover, Pied Oystercatcher and Red-necked Avocet in the South Lagoon. If the SLSRS is complemented by spring barrage flows, the abundances of all of these species are anticipated to increase further.

The increased abundance of small-mouthed hardyhead in the South Lagoon anticipated as a consequence of the SLSRS is likely to provide benefits for piscivorous waterbirds. Benefits for species in decline, namely Australian Pelican, Fairy Tern, Whiskered Tern, Common Greenshank and White-faced Heron, are anticipated. For Fairy Tern, a timely increase in the abundance of small-mouthed hardyhead in close proximity (within ~2 km) of their historic breeding islands in the South Lagoon is critical to preventing local extinction (Paton and Rogers 2009).

The limited re-establishment of *Ruppia tuberosa* anticipated as a consequence of the SLSRS may have limited benefits for waterfowl. The species most likely to benefit are Black Swan and Grey Teal, species that have declined over the last 10 years as their chief food resource in the South Lagoon, *Ruppia tuberosa*, has declined. Because the SLSRS will prime the Coorong in readiness for the return of barrage flows, when such flows return a much more favourable response from waterfowl is anticipated than if the SLSRS were not implemented and salinity remained excessive.

Because the improvement to waterbird food resources likely as a consequence of the SLSRS cannot be confidently quantified, neither can resultant change to waterbird abundance be quantified. However, it is highly likely that at a minimum, declines in the abundances of most species will be halted. Increased abundances of most of the waterbird species discussed above is quite likely.

An important consideration regarding waterbirds is habitat availability when the Lower Lakes are refilled. A number of species may have responded to the degradation of the Coorong by shifting their foraging activities to the mudflats that have become exposed around the margins of the Lower Lakes as water levels have dropped. Migratory waders appear to be one such group, with more than 23,000 Red-necked Stint observed in the Lower Lakes in 2009 (Paton 2010). Previously, when the Lower Lakes were maintained within their normal operating water levels, no more than "a few thousand" Red-necked Stint have been recorded there (Paton 2010). The refilling of the Lower Lakes would render them far less favourable habitat for waders because most of the mudflat area would be too deeply inundated. The birds so displaced would need alternative foraging habitat. Without the SLSRS the South Lagoon will not provide that habitat because food resources for waders will be absent even if barrage flows accompany the refilling of the Lakes. However, with implementation of the SLSRS the South Lagoon ecosystem will be primed to respond more favourably to barrage flows and the loss of foraging areas in the Lower Lakes may be offset, at least partially, by improved foraging conditions for waders in the South Lagoon.

It is important to note, as stated previously, that waterbird abundance in the Coorong is influenced by a variety of factors in addition to local conditions. This makes any prediction regarding future waterbird abundance in the Coorong less certain than predictions for permanently resident species.

4. Ecological Risks of Pumping

Risks to the Coorong

As previously discussed, beds of R*uppia tuberosa* have recently established in the North Lagoon. These areas provide critically important remnants of the ecosystem that formerly dominated the entire South Lagoon and is now absent from it. The *R. tuberosa* and other biota that inhabit these beds provide source material likely to be important in the recovery of the South Lagoon ecosystem. The SLSRS poses a potential threat to these areas because it will lower salinity in the North Lagoon, potentially to levels below the optimal for *R. tuberosa*. It has previously been observed that at salinity below ~60 g/L beds of *R. tuberosa* become smothered and ultimately displaced by filamentous green algae (*Enteromorpha* sp.) (D. Paton, unpublished data). If the SLSRS reduces salinity to <60 g/L where *R. tuberosa* currently exists before the species has successfully re-established in the South Lagoon there is a chance *R. tuberosa* could be eliminated from the entire Coorong. To prevent this the rate of salinity reduction can be slowed if necessary by slowing the pumping rate. Both salinity and *R. tuberosa* abundance throughout the Coorong are regularly monitored and will remain so during the SLSRS and thereafter. Note that further investigation of the relationship between Coorong salinity and *Enteromorpha* abundance is proposed (Paton and Bailey 2010).

The risk of acid sulfate soil exposure posed by SLSRS has been assessed (Fitzpatrick *et al.* 2008) and has been deemed very low. However, regular water level and water quality monitoring of the Coorong will occur during the pumping phase and will inform any need to slow or cease pumping in order to prevent acidification of surface waters.

Risks to the Marine Environment

The risks posed to the marine environment by the SLSRS are not the focus of this discussion paper, however in summary they are anticipated to be minor, temporary, recoverable and to be greatly outweighed by the likely ecological benefits the program is anticipated to provide for the Coorong (DEH 2010a). Risks to the marine environment are summarised by Lester and Fairweather (2010). For further information see Pirzl (2010) for risks to southern right whale, Wiltshire *et al.*(2009) for risks to Goolwa cockle, Rowling *et al.*(2010) for a description of the marine environment adjacent to the ocean outfall and Aurecon (2010) for modelling of the outfall plume.

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