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Appendix E (3)

An evaluation of three management strategies for the mitigation of high salinities in the Coorong

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EXECUTIVE SUMMARY

A series of possible strategies for alleviating the present high salinities in the Coorong have been evaluated including pumping brine from the South Lagoon and increasing the dredging effort at the Mouth. Here, the hydrodynamic model developed previously for the Coorong is used to investigate the salinity and water level responses in the Coorong for three additional sets of scenarios that extend the work that has already been undertaken. The scenarios examine the impacts of varying the location of the intake for South Lagoon pumping, of short term modification of Upper Southeast Drainage (USED) discharges, and of constructing a pipe connection between the South Lagoon and the sea to facilitate exchange.

The intake location considered for pumping brine from the South Lagoon in order to lower salinities there has been approximately mid-way along the Lagoon. An alternative site close to the northern end of the South Lagoon has the substantial advantage of requiring a relatively short pipe connecting to the sea. Model simulations of pumping from both locations suggest that salinities would be reduced about 2/3 as much in the South Lagoon for pumping from the northern site compared to the mid-lagoon site, but water level responses in the Lagoon would be little different from one another.

Model simulations were undertaken to assess the impacts of increasing inflows to the South Lagoon from the USED scheme. Inflows through the drought years 2001-2008 have averaged ~7 GL/year. Approximately doubling this drought inflow has a modest effect on South Lagoon salinities, but increasing the inflow to 60 GL/year causes average salinity in the Lagoon to reduce from ~150 g/L to less than 90 g/L. The imposition of median barrage flows on top of the enhanced USED inflows causes further major reduction in South Lagoon salinity.

The third scenario type investigated is the potential benefit of a pipe connecting the South Lagoon with the sea which would be flushed naturally by flows driven by water level differences across the pipe ends. Such differences would arise due to due to wind set-ups and evaporation in the Lagoon and to the tides and other longer term level variation in the sea. The hydrodynamic simulations showed that the effect of a 2-m diameter pipe would be to cause a salinity reduction in the South Lagoon of ~40 g/L which is similar to pumping brine from the Lagoon at 250 ML/day. However, it is probable that the benefit of the pipe would be much less than this in reality as the model does not properly account for ponding around the pipe outlets and the likelihood that this water would flow back through the pipe when the flow reverses.

1. INTRODUCTION

A series of possible strategies for alleviating the present high salinities in the Coorong have been evaluated. These strategies include pumping water from the South Lagoon and changing the dredging regime of the Mouth as well as longer term strategies for maintaining its ecological health. The latter include modification to the drainage systems in the Upper Southeast drainage (USED) area as well as the provision of extra flows at times to allay the development of unfavourable conditions.

The approach taken has been to couple an ecological state model to a hydrodynamic model. The hydrodynamic model simulates the salinity and water levels along the Coorong as these respond to the drivers of barrage flows, flows from the USED, wind, evaporation, precipitation, and water levels in the sea. Here, the hydrodynamic model is used to investigate the salinity and water level responses in the Coorong for three additional sets of scenarios that extend the work that has already been undertaken. The scenarios examine the impacts of varying the location of the intake for South Lagoon pumping, of short term modification of USED discharges, and of constructing a pipe connection between the South Lagoon and the sea to facilitate exchange. Each of these sets of scenarios is described more fully and examined in turn.

The description of the hydrodynamic model and its application is described in Lester et al. (2009) which examines the benefits of pumping options for the South Lagoon. The model implementation is designed to simulate present conditions and the next few years assuming that drought conditions continue. The simulations commence in 8 March 2005 and utilise measured sea levels and meteorological conditions where available (for the first few years) and continue with repeats of level and meteorological time series thereafter. Generally, barrage flows are considered to be zero through the simulations and the Mouth channel is dredged to a defined depth to maintain openness. Prescribed flows into the south end of the South Lagoon from the USED are mostly based on measured flows during the period 2000-2008.

2. ALTERATION OF PUMPING LOCATION

It is has been suggested that pumping from the Coorong from a location in the channel near Parnka Point may be advantageous as the distance between the Coorong and Endeavour Bay is relatively small at this location. How pumping in this channel would affect salinity mitigation in the Coorong is tested here. In the pumping scenarios investigated to date, the model has simulated pumping from cell 76 which is located in the centre of the South Lagoon to the west of Woods Well. Here, the impact of pumping from cell 61 is assessed. Cell 61 is ~0.5km to the north of Parnka Point (Figure 1). The pumping rate for all scenarios is specified to be 250 ML/day and continues for 3 years after commencement. Three 2010 start dates were tested namely 1 January, 1 April, and 1 July. Figure 2 shows the comparison between the average simulated salinities in the North and South Lagoons for the baseline case (no pumping), pumping from cell 76, and from cell 61 starting on 1 April 2010.

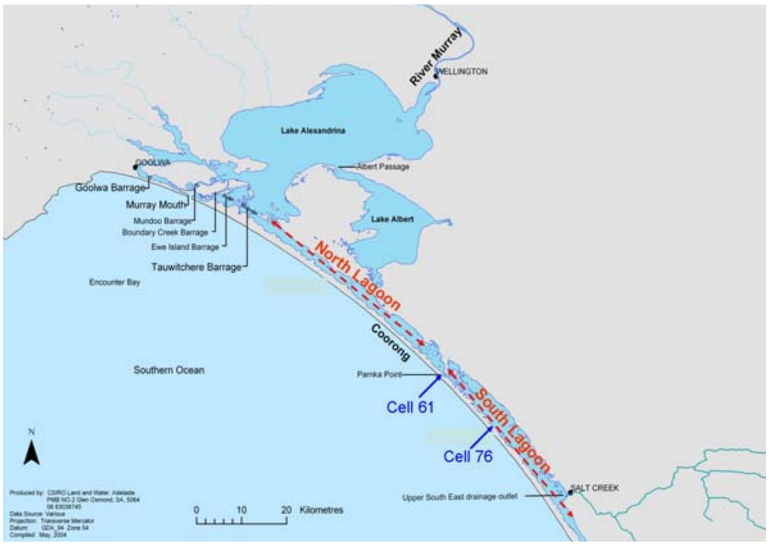

Figure 1. Map of Coorong showing the locations of the cells considered in the pumping and pipe connection scenarios.

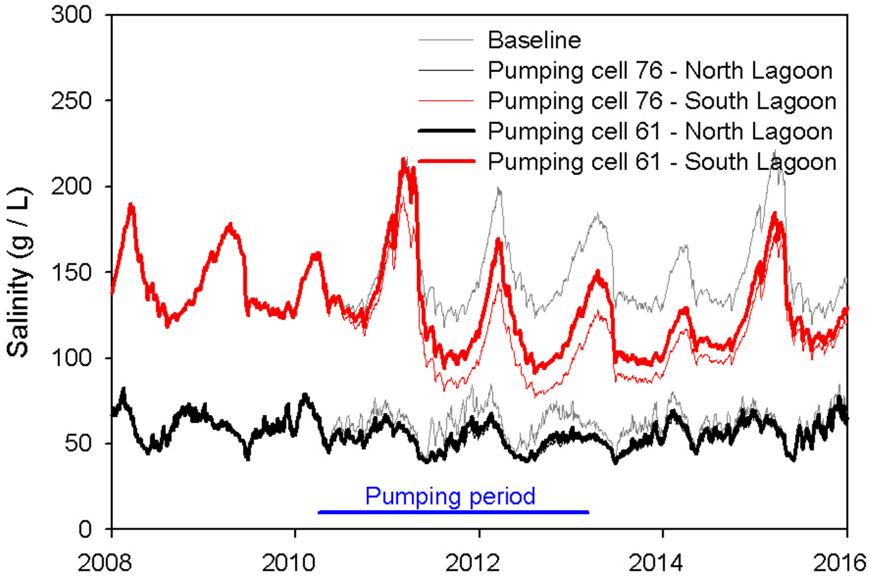

Figure 2. Comparison between average simulated salinities in the North and South Lagoons for the baseline scenario, pumping from cell 76, and pumping from cell 61.

It is apparent that pumping from cell 76 reduces salinity in the South Lagoon compared to the baseline significantly more than does pumping from cell 61. For the years 2012 and 2013 which are the years showing the greatest benefit from pumping, the average baseline salinity in the South Lagoon is 150.0 g/L. Pumping from cell 76 reduces this to 99.7 g/L, whereas pumping from cell 61 shows an average salinity of 116.7 g/L. Thus, pumping from cell 61 is ~2/3 as effective at reducing salinity in the South Lagoon as pumping from cell 76.

The reductions in salinity of the North Lagoon associated with pumping are more modest and are fairly similar to one another. Average salinity in the North Lagoon is 60.8 g/L for the baseline through 2012 and 2013, whereas pumping from cells 76 and 61 reduces salinity to 49.3 and 51.1 g/L, respectively. The results for starting pumping at the other times of 1 January 2010 and 1 July 2010 show substantially the same relative benefit of pumping cell 76 versus 61 in both the North and South Lagoons as for commencing pumping on 1 April.

Figure 3 shows the impacts on average water levels in the South Lagoon of pumping cells 76 and 61. Although there is a substantial reduction in summertime levels during the pumping period compared to baseline, pumping cell 76 versus pumping cell 61 causes a virtually identical water level response. This occurs because the main constriction for exchange between the two lagoons occurs further to the north of Parnka Point.

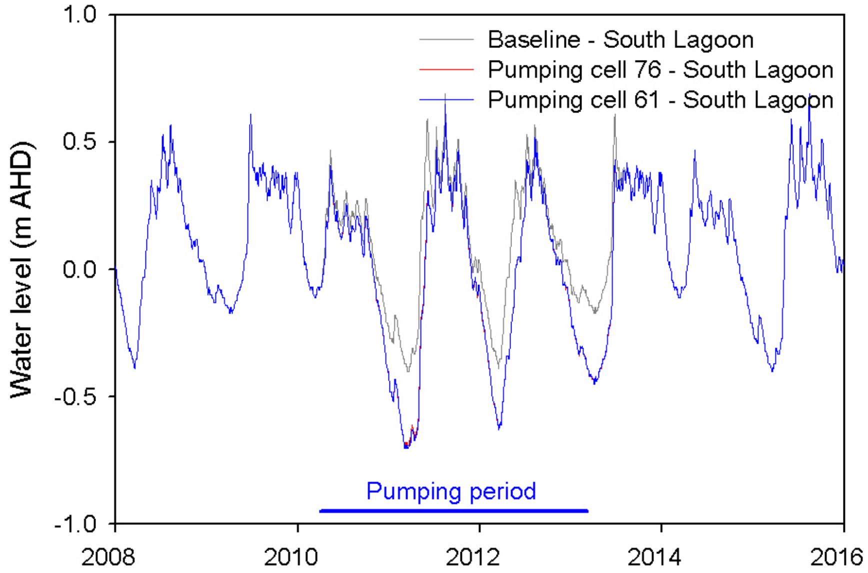

Figure 3. Comparison between average simulated water levels in the South Lagoon for the baseline scenario, pumping from cell 76, and pumping from cell 61.

3. MODIFICATION OF USED INFLOWS

Modification of the drainage system of the USED is being considered to increase the freshwater inflow to the south end of the South Lagoon. An analysis of the impacts on the Coorong of the modelled flows from a number of possible drainage designs has been reported by Lester et al. 2009. Here the impacts of a hypothetical sequence of USED discharges through the coming years are considered. Also considered is the impact of the return of significant flows through the barrages after 3 years.

In modelling of the Coorong response so far, a hypothetical sequence of USED discharges has been used which is based on measured discharges at Salt Creek in the period 2000-2008. These flows should be generally representative of drought conditions. This USED discharge is specified as the average of measured flows on each day of the year between 2001 and 2008. The discharge pattern is shown over a year in Figure 4. It represents a total flow volume of 7 GL over the year. To construct multi-year time series of USED discharges, the flow pattern shown is repeated.

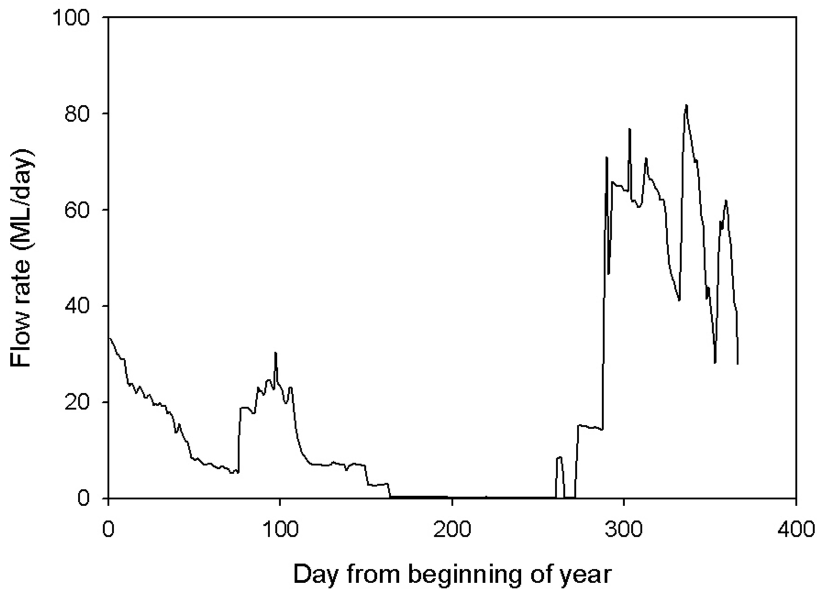

Figure 4. USED flow sequence constructed from the average measured Salt Creek flows 2000-2008.

The USED discharge pattern that is investigated here considers flow volumes of 15 GL this year, 10 GL for the next 2 years and 60 GL/year thereafter. The year considered is the hydrological year that starts at the beginning of July and runs to the following June. To construct the USED time series, the discharge pattern shown in Figure 4 is scaled up by a factor that produces the desired volume over each hydrological year. This strategy is applied from 1 July 2009 onwards. Between the beginning of the simulation (March 2005) and this time, measured USED discharges at Salt Creek are available and are used instead (Figure 5).

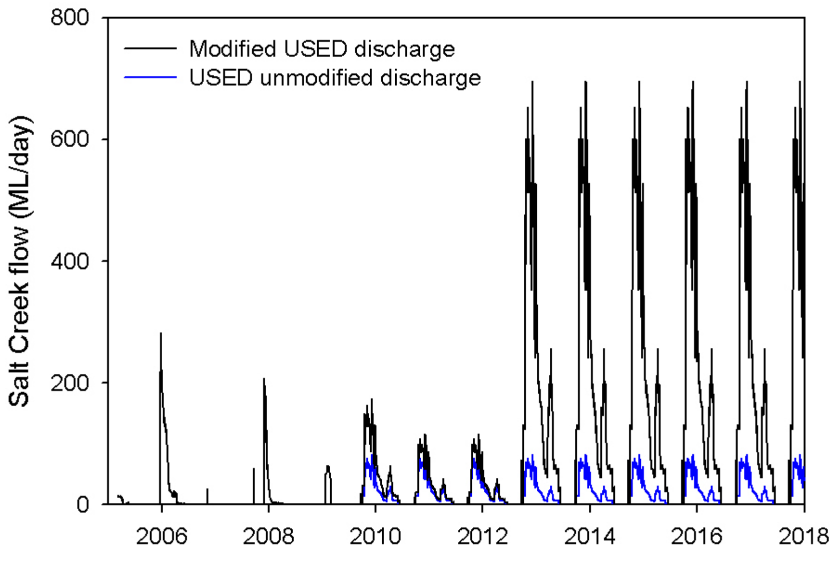

Figure 5. Time series of discharge from Salt Creek used in model simulations to investigate impact of modifying USED flows. Also shown are 'unmodified' discharges.

Most of the analyses considered here assume an ongoing drought condition in which barrage flows remain effectively zero. An additional simulation is run to assess the impact on salinity and water levels of the return of significant barrage flows after 3 years (mid 2012). The barrage flows for the hydrological year 1969-1970 have an average of 8.6 GL/day which is closest to the median discharge of 8.3 GL/day for the period 1963-2008. These flows are shown in Figure 6.

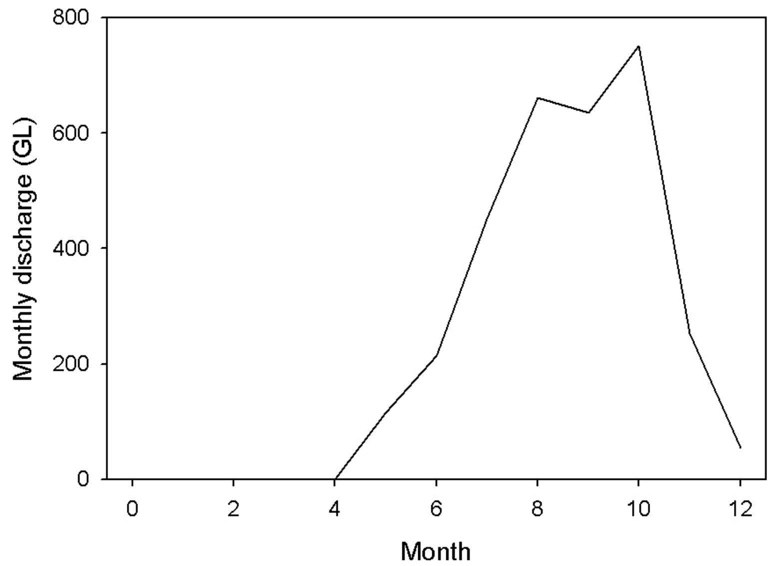

Figure 6. Monthly barrage flows for the 1969-1970 hydrological year. Note that the graph wraps around July 1969. Thus, Month 8 is August 1969, but Month 2 is February 1970, for example.

Figures 7 and 8 show the simulated average salinity in the North and South Lagoons for the modified USED discharges with and without barrage flows returning after 3 years. Also shown are the salinities obtained when the USED discharges are assumed to be the continued repetition of the 2000-2008 averages shown in Figure 4. These are referred to as the ‘unmodified’ discharge.

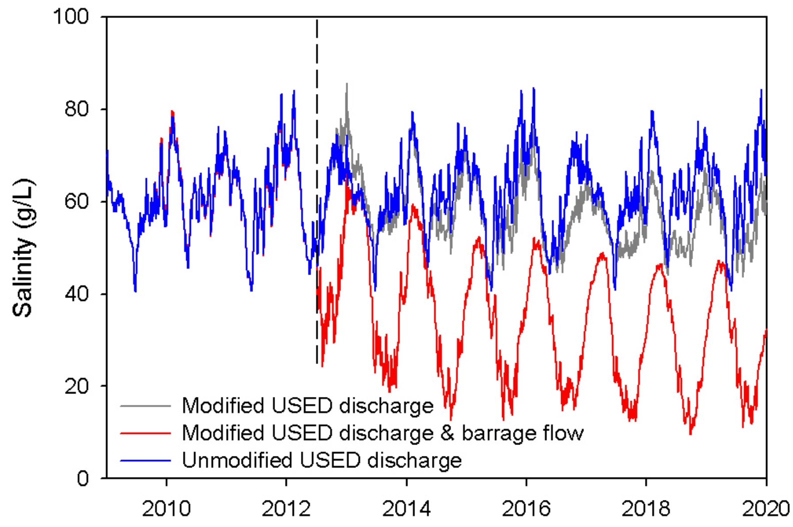

Figure 7. Average salinity across the North Lagoon for three USED discharge simulations. The dashed line shows the onset of barrage flows for the second scenario and the switch to 60 GL/year USED discharge for the two scenarios having modified USED discharge.

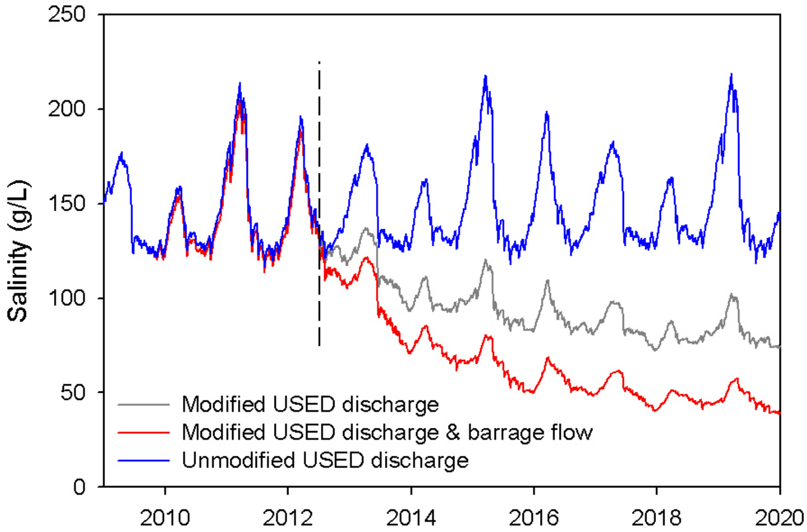

Figure 8. Average salinity across the South Lagoon for three USED discharge simulations. The dashed line shows the onset of barrage flows for the second scenario and the switch to 60 GL/year USED discharge for the two scenarios having modified USED discharge.

Up to July 2012 when the USED discharge is increased to 60 GL, the salinities in the North and South Lagoons are little different from one another. After this time, increasing the USED discharge to 60 GL causes some reduction of salinity in the North Lagoon, but it has a major impact in reducing salinity in the South Lagoon. It takes several years for the full benefit of the enhanced USED flows to be realised as the system adjusts, but between 2016-2020 the average salinity in the South Lagoon reduces from 150.9 to 84.9 g/L with the increased USED flow volume.

It is not surprising that an annual inflow to the South Lagoon of 60 GL makes a substantial difference to salinity in the South Lagoon. Fundamentally, salt is carried into the South Lagoon with the flow that is necessary to replace evaporative losses. The annual loss of water due to evaporation is estimated to be ~150 GL (~4.2 mm/day) so a 60 GL inflow from the USED means that the flow from the North Lagoon required to replace evaporative losses is reduced to 90 GL which results in a lot less salt being transported into the South Lagoon.

When median barrage flows commence after July 2012, the impact on salinity in both lagoons is dramatic. Whereas the unmodified USED flows show average salinity in the North and South Lagoons for 2016-2020 to be 65.5 and 150.9 g/L, respectively, barrage flows cause these averages to drop to 33.0 and 50.3 g/L, respectively. The full adjustment of the salinity regime to barrage flows only takes about 2 years in the North Lagoon, whereas full adjustment in the South Lagoon takes ~5 years. A second feature to note is the change in the amplitude of the seasonal variation in salinity. Without barrage flows, the seasonal variation in salinity is ~20 g/L, but this approximately doubles with barrage flows. By contrast, the South Lagoon shows seasonal variations of ~50 g/L with unmodified USED discharges, but this reduces to~15 g/L with modified USED discharges and barrage flows together.

Figure 9 shows the simulated water levels in the South Lagoon for the three cases considered. The enhanced USED discharges reduce the degree to which wate r levels drop due to evaporation over summer compared to the unmodified discharge. Overall, the seasonal variation in water level is reduced. The impact of barrage flows after July 2012 is to raise winter water levels as water is backed up due to the flow constriction in the Mouth channel. Summer water levels are little changed for the modified USED discharge with or without the extra barrage flow. Overall, the effect of barrage flows is to raise the average water level in the South Lagoon and increase the amplitude of the seasonal variation in South Lagoon water levels to some degree.

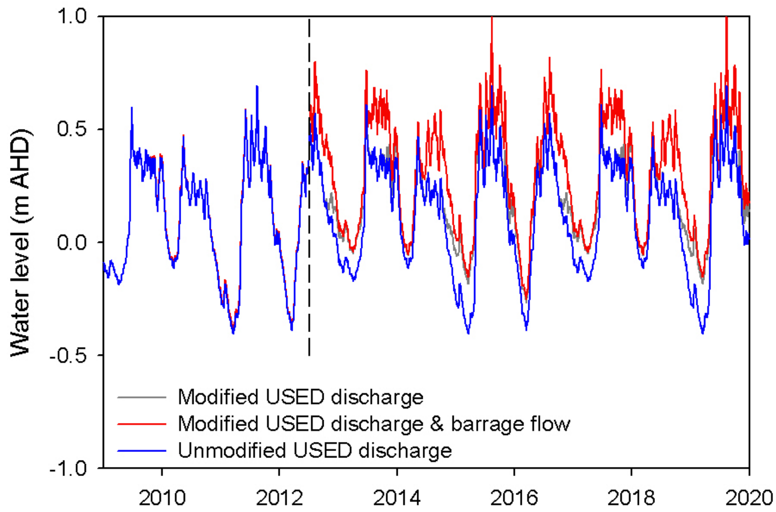

Figure 9. Average water level across the South Lagoon for three USED discharge simulations. The dashed line shows the onset of barrage flows for the middle simulation and the switch to 60 GL/year USED discharge for the first two scenarios.

4. PIPE CONNECTION TO SEA

The third variation investigated is the potential benefit of a pipe connecting the South Lagoon with Encounter Bay (the sea) which would be flushed naturally; that is flows through it would occur as a consequence of the water level difference between the ends of the pipe. Water level differences between the South Lagoon and Encounter Bay vary due to wind set-ups and evaporation in the South Lagoon and to the tides and other longer term sea level variation in Encounter Bay and these would cause back and forth water exchanges through the pipe depending on whether water level is higher in the Coorong or in the sea (Figure 10).

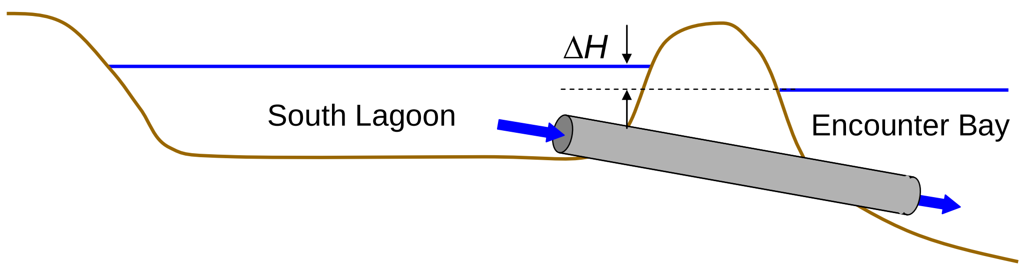

Figure 10. Schematic cross section of the South Lagoon showing a pipe connection to the sea.

The flow within a pipe is derived using the pipe-flow calculator available at: http:/www.pipeflowcalculations.com. The calculator solves the following equations which also appear in engineering textbooks such as Duncan et al. (1970). The equation for steady flow in a pipe is given by:

$$Q = \pi\sqrt{\frac{D^5 g \Delta H}{8\lambda L}},$$

where Q is the flow rate (volume per time), D is the pipe diameter, g is gravitational acceleration, ΔH is the head difference between the Coorong and the sea (Figure 10), λ is a friction parameter, and L is the length of the pipe. The friction parameter depends on the flow conditions and properties of the pipe walls.

The Reynolds Number of the flow is defined as:

$$\mathrm{Re} = \frac{VD}{\upsilon},$$

where V is the flow speed (= flow rate / cross-sectional area) and υ is kinematic viscosity (~10^{-6} m^2/s). The boundary layer thickness (δ) can be calculated based on the Prandtl equation as:

$$\delta = 62.7 \frac{D}{\mathrm{Re}^{7/8}}.$$

When δ is bigger than pipe roughness (k), then the flow can be considered as flow in a hydraulically smooth pipe and the Blasius equation is used for λ :.

$$\lambda = \frac{0.3164}{\sqrt[4]{\mathrm{Re}}}.$$

If $\delta < k$ and if Re < 10^5 then the Prandtl equation is used to define λ :

$$\frac{1}{\sqrt{\lambda}} = 2.0 \log\left(\frac{\mathrm{Re}\sqrt{\lambda}}{2.51}\right),$$

whereas if $\delta < k$ and if Re > 10^5, then the Karman equation is used:

$$\lambda = \left(2.0 \log\frac{D}{k} + 1.14\right)^{-2}.$$

In this analysis, the pipe is assumed to have a length of 1 km, a diameter of 2 m, and a roughness of 1 mm. This roughness is the middle of the range for a concrete pipe. The relationship between flow rate and head difference for these pipe parameters is shown in Figure 11.

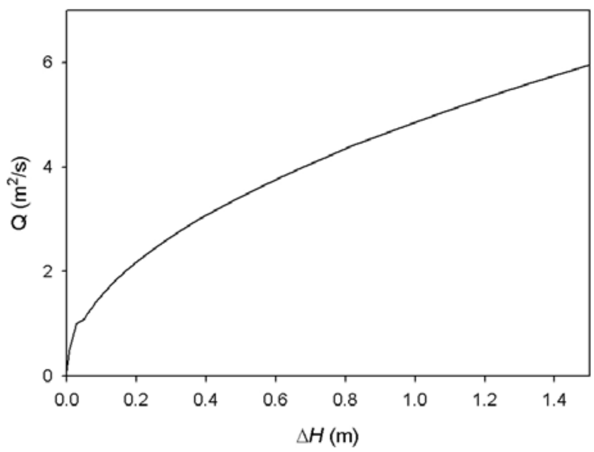

Figure 11. Flow rate versus head difference for a pipe 1000-m long, 2-m diameter, and 1-mm roughness.

For modelling salt transport through the pipe, the pipe is divided into 10 cells, and the transfer between consecutive cells is assumed to occur as the flow carries the salt from one cell to the next. The salinity at the seaward end of the pipe in Encounter Bay is assumed to be 36.7 g/L as it is in all the hydrodynamic simulations that have been undertaken. The salinity of the water at the pipe inlet in the South Lagoon is assumed to be that of the appropriate salinity cell in the hydrodynamic model.

As with previous scenarios, the impact of a pipe installed during continuing drought conditions in the MDB in which there are no further barrage flows is considered. In the pipe scenarios, the pipe is installed and operational starting on 1 April 2010. The impacts on salinity in the South Lagoon are compared in Figure 12 for the cases of no pipe installation, a pipe inlet in cell 61 at Parnka Point and a pipe inlet in cell 76 near the middle of the South Lagoon (Figure 1).

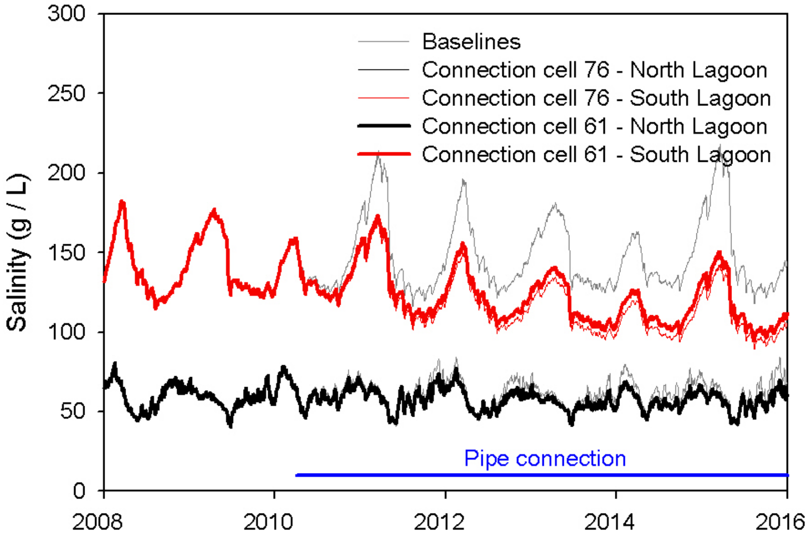

Figure 12. Comparison between average salinity in the North and South Lagoons for baseline scenario and for pipe connections between cells 76 and 61 and the sea.

The results show that the installation of the pipe is expected to cause considerable salinity reductions in the South Lagoon and a modest reduction of salinity in the North Lagoon mainly through summer. The full benefit in reducing salinity in the South Lagoon takes several years to achieve. For the years, 2013-2015, the baseline salinity in the South Lagoon has an average of 148.2 g/L versus averages of 109.7 and 115.9 g/L for pipe connections to cells 76 and 61 respectively. These are similar reductions to those achieved by pumping at 250 ML/day from these locations after 2 years. A pipe connection to cell 95 near Salt Creek was also tested and shows a salinity reduction to 106.6 g/L which is a little lower than that for the pipe connection to cell 76.

Figure 13 compares the water level responses in the South Lagoon of the baseline scenario to those of the pipe scenarios. The pipe connection has little affect on water levels for most of the year, but in summer water levels do not decrease quite so far due to evaporation as they do for the baseline case.

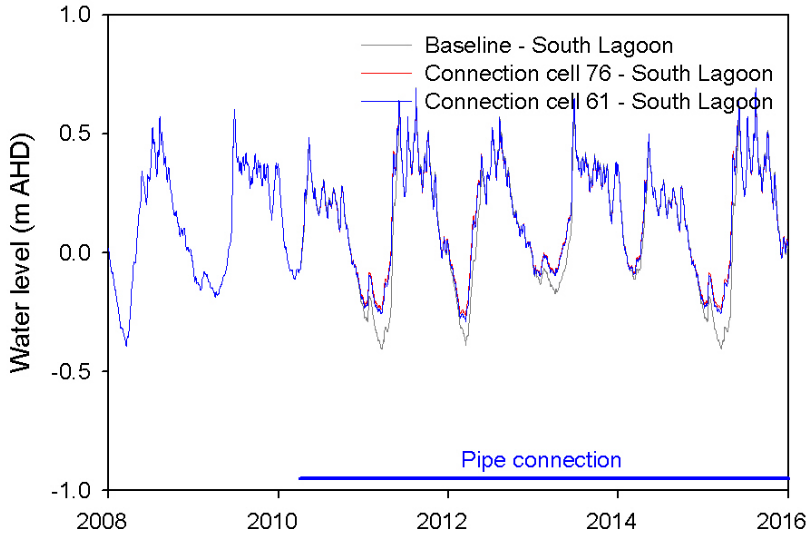

Figure 13. Comparison between average water levels in the South Lagoon for baseline scenario and for pipe connections between cells 76 and 61 and the sea.

It is certain that the salinity reductions with a pipe connection would be substantially less than what is achieved in the scenarios presented here. Much of the benefit of removing salt from the South Lagoon is achieved by oscillatory flows induced by the tides in Encounter Bay. In the simulations water of low salinity introduced to the system by a flooding tide is spread throughout the salinity cell in which the pipe inlet is located (~7 km long). In reality, much of this water would pond in the vicinity of the inlet and would flow out again on the ebbing tide.

The median flow rate through the pipe for the simulation having D = 2 m, L = 1000 m, and k = 1 mm is 2.4 m^3/s which corresponds to a hydraulic head of 0.25 m. The impact of varying pipe characteristics by calculating the flow rate when each of these parameters is varied in turn is shown in Table 1. The small value of roughness (k = 0.3 mm) considered in Table 1 corresponds to smooth concrete, whereas the large one (k = 3.0 mm) corresponds to rough concrete. Decreasing the pipe diameter decreases flow rate, whereas decreasing pipe length and roughness both increase flow rate.

***D* (m)**	***L* (m)**	***k* (mm)**	***Q* (m^3/s)**	**Ratio**
2	**1000**	**1**	2.43	1.00
1.5	1000	1	1.15	0.47
2.5	1000	1	4.36	1.79
2	**500**	1	3.44	1.42
2	**2000**	1	1.72	0.71
2	1000	**0.3**	3.47	1.43
2	1000	**3.0**	2.13	0.88

Table 1. Flow rate through pipe with the prescribed properties calculated using the Pipe Flow Calculator. The last column presents the ratio of the flow rate to the flow rate for the baseline properties (first row). The bold type indicates the parameters that have been varied.

Figure 14 shows the effect of varying the relative flow rates through the connection pipe on the average salinity in the South Lagoon between 2013-2015. Here a relative flow rate of 1.0 refers to the hydrodynamic simulation for the baseline pipe configuration with D = 2 m, L = 1000 m, and k = 1 mm. A connection to cell 76 is assumed. A relative flow rate of 0.5 for example means that for all hydraulic heads, the flow rate is half what it would be for the baseline configuration with the same heads. A relative flow rate of zero refers to the case with no pipe connection between the Coorong and the sea.

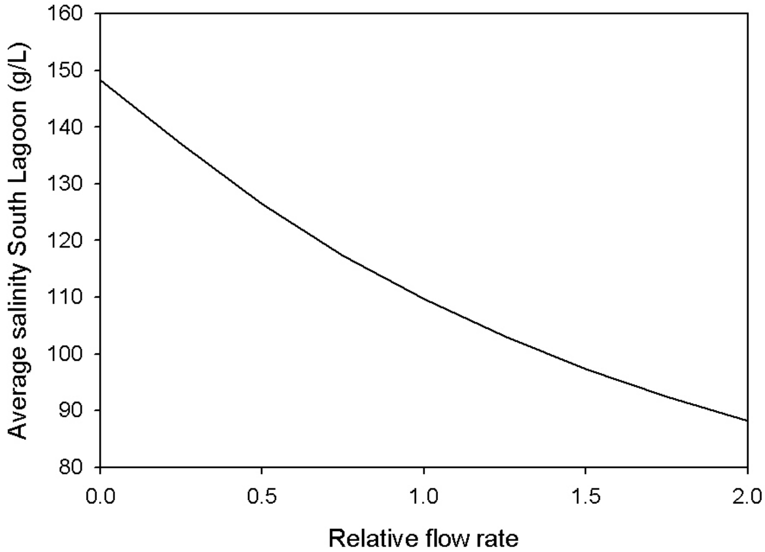

Figure 14. Impact of altering the relative flow rate through a pipe connecting the Coorong to the sea.

Increasing the flow rates through the pipe connection results in a steady decline in the simulated average salinity in the South Lagoon. One might use these results in conjunction with Table 1 to provide an indication of the benefits of altering the configuration of the pipe. For example, reducing the pipe diameter to 1.5 m reduces the expected flow rate through it by a factor of about 2.0 (Table 1). Reducing the relative rate by a factor of 2 to 0.5 results in an average South Lagoon salinity of 126.4 g/L, whereas average salinity for the baseline configuration is 109.7 g/L. An important caveat on using this approach is that it does not consider the impacts of larger flow rates on the efficiency of mixing of inflowing water from the sea. Due to ponding effects around the pipe outlet in the South Lagoon, one might expect that the larger flow rates would result in less efficient removal of high salinity water to the sea. The one-dimensional hydrodynamic model for the Coorong can't resolve the details of the mixing processes around the pipe ends. To evaluate these properly, a 3-dimensional hydrodynamic model of much higher spatial resolution would be required.

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