The Living Murray
One River. One Life. Our Future.

The Department of Water, Land and Biodiversity Conservation



Salinity impacts of River Murray weir pool lowering in SA – Phase 1

Steve Barnett

David Cresswell

Mark Walter

Wei Yan

Report DWLBC 2003/26

Government of South Australia

Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation
Level 11, 25 Grenfell Street, Adelaide
GPO Box 2834, Adelaide SA 5001

Telephone	+61 8 8463 6947
Fax	+61 8 8463 6999
Website	www.dwlbc.sa.gov.au

Foreword

South Australia's natural resources are fundamental to the economic and social well being of the State. One of the State's most precious natural resources, water, is a basic requirement of all living organisims and is one of the essential elements ensuring biological diversity of life at all levels. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between rainfall, vegetation and other physical parameters. Development of these resources changes the natural balance and may cause degradation. If degradation is small, and the resource retains its utility, the community may assess these changes as being acceptable. However, significant stress will impact on the ability of the resource to continue to meet the needs of users and the environment. Understanding the cause and effect relationship between the various stresses imposed on the natural resources is paramount to developing effective management strategies. Reports of investigations into the availability and quality of water supplies throughout the State aim to build upon the existing knowledge base enabling the community to make informed decisions concerning the future management of the natural resources thus ensuring conservation of biological diversity.

Bryan Harris

Director, Knowledge and Information

Department of Water, Land and Biodiversity Conservation

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

A weir pool lowering (WPL) exercise in order to improve wetland and ecosystem condition in the River Murray floodplain will induce increased saltloads to the river from several sources – groundwater (floodplains and cliff), backwaters and anabranches. As part of this project to predict the salinity impacts of WPL, the factors controlling salt discharge to the river were described, the processes modelled and uncertainties in the prediction methods outlined.

Prediction tools for the estimation of the magnitude of saltload increases were made using a combination of different techniques (indicative of varying degrees of information quality and management tools available in different areas). These techniques include calibrated groundwater models, GIS models, spreadsheets using Darcy's Law and backwater salinity measurements.

Saltloads predictions in the various reaches enabled prioritisation of reaches (based on low salinity impact) for further work. These results show that Lock 1 to 2 and Lock 5 to 6 have the lowest impact, Lock 6 to 7 showing good potential, but will need more investigation involving both Victoria and NSW.

The complex relationship between flow and salinity and the uncertainties in estimating both, mean that the salinity impact from WPL events may be difficult to distinguish from other natural events, and that the actual impact may be difficult to measure.

Further work on priority reaches should include bathymetry and regular salinity monitoring of backwaters, ground EM traverses and possibly drilling in key locations, groundwater modelling and an instream EM survey to locate areas of high salinity adjacent to the river. To enable better estimates of river flow in these reaches, bathymetry of the river should be refined.

1 INTRODUCTION

The Department of Water, Land and Biodiversity Conservation (DWLBC) is planning to establish weir drawdown trials along the length of the River Murray in South Australia (Fig. 1). It is expected that these trials will not only introduce water users and the wider community to River Murray water level variation as a means of improving the health of the River, but will also reinstate elements of natural water level fluctuations in order to improve wetland and River ecosystem condition.

The development of a river level and groundwater/salinity response prediction tool, which will be the outcome of this investigation, will enable the prediction of impacts associated with a range of potential river weir pool lowering (WPL) scenarios. This tool will contribute to determining the benefits and costs of river level drawdown, which will be assessed through a combination of monitoring, investigations and modelling.

This report describes the key processes and driving factors (surface water and groundwater) which may result in salinity impacts in the river, and also reviews and analyses previous WPL trials and periods of natural low river levels (including the 2002/03 drought-induced WPL below Lock 1).

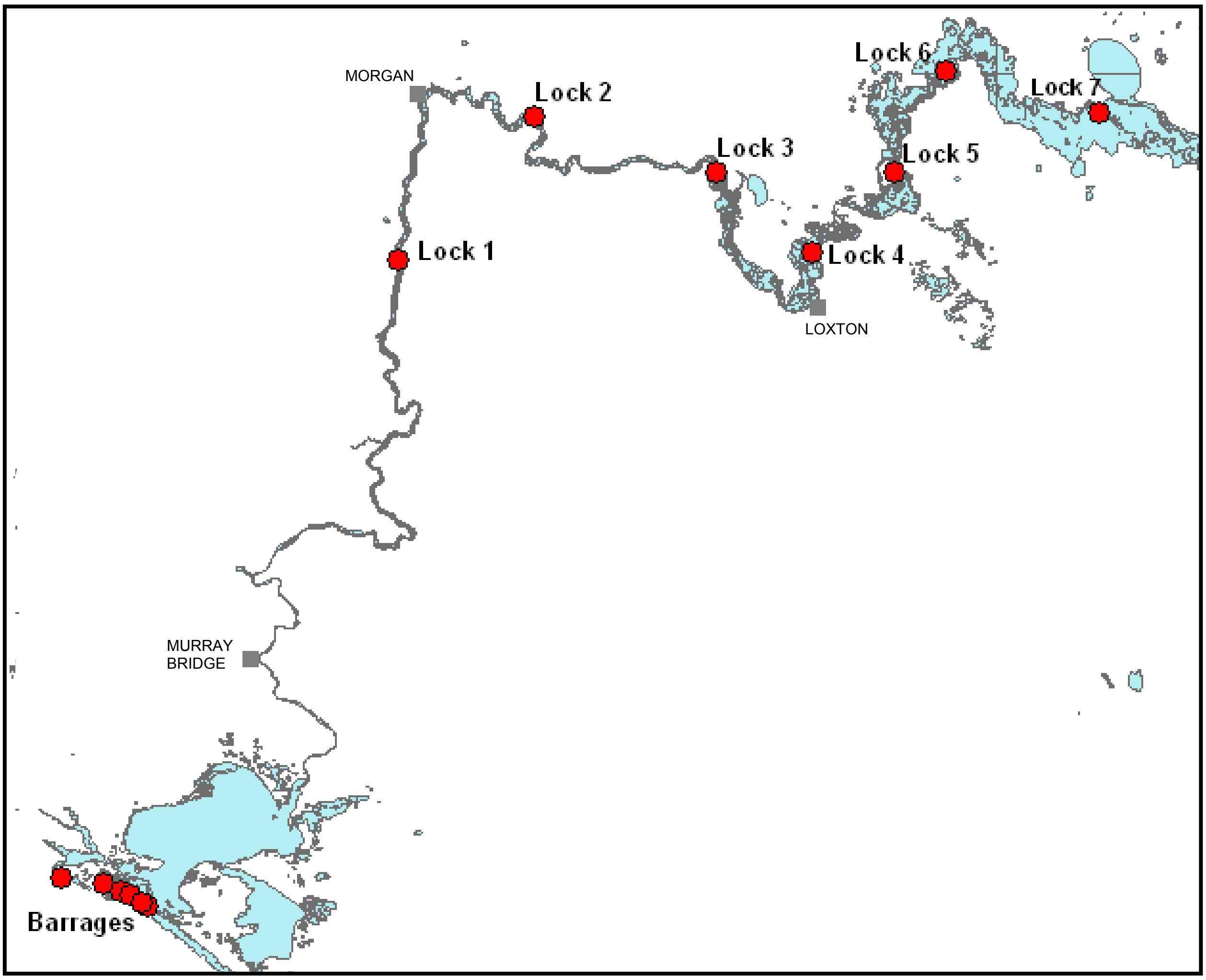


Figure 1. Location of locks and weir pools.

2 GROUNDWATER FLOW PROCESSES

Previous investigations of the regional hydrogeology of the Murray Basin in South Australia confirmed the River Murray and its valley as the discharge point not only for the regional watertable aquifers that are often saline, but also the underlying confined aquifers by way of upward leakage. There are several inter-related driving factors controlling groundwater discharge to the river, both from cliff sections and in the floodplain environment, which have been outlined by previous work (Barnett and Marsden, in prep) and are listed below.

(1) river regulation by locks and levees

(2) depth of the watertable below the ground surface of the floodplain

(3) regional watertable gradients towards the river valley

(4) presence of anabranches and billabongs.

Each of these factors will be discussed together with their management applications for WPL.

2.1 River regulation by locking

This process has imposed a permanent stepped increase in river levels upstream on what was previously a continuous and gradual rise. This has raised river levels upstream of locks, promoting groundwater recharge to the floodplain and cliff sections, and has lowered river levels downstream of locks which encourages groundwater discharge back into the river (Fig. 2). The extent of the zone of recharge from the river upstream of any lock is variable and not known with certainty. Within this zone, WPL would have minimal salinity impact (if any) because groundwater flow may still be away from the river.

Another effect of this stepped rise in river level is on the size and frequency of billabongs. The sudden rise in river level immediately upstream of a lock will result in inundation of much of the floodplain in the form of large billabongs. The ground level of the floodplain gradually rises upstream because it reflects the natural gradient of the pre-regulated river and consequently, the size and frequency of the billabongs will decrease (Fig. 2) upstream within the reach bounded by locks.

Downstream of Mannum, reclaimed polders with levees holding the river level above ground level, result in discharge to the floodplain, both from regional groundwater and the river. WPL would have no impact adjacent to these swamps.

2.2 Depth of the watertable below the floodplain

This is probably the strongest influence on whether groundwater discharge takes place to the floodplain or to the river. If the watertable is two or three metres below ground level, discharge will take place by evaporation (and transpiration if the floodplain is vegetated and groundwater salinity is low). The resultant lowering of the watertable will capture the regional groundwater inflow as well as induce outflow from the river (eg. Berri & Morgan).

The shallow depth of the watertable may result from the rising of the river level due to locking, or the geomorphology of the floodplain in the form of low-lying areas such as dry lagoons and channels.

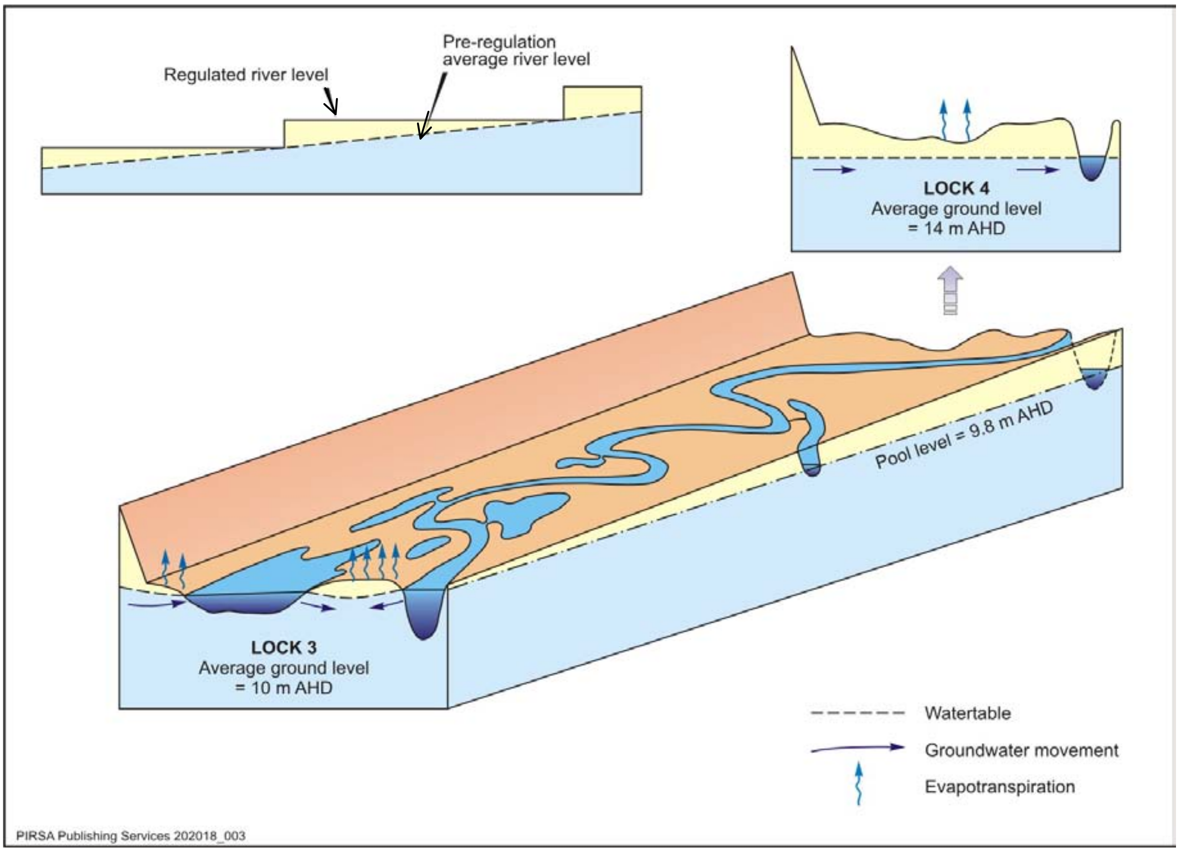


Figure 2. Effect of river regulation on groundwater processes.

2.3 Regional watertable gradients

These gradients are an important factor only when they are high and promote strong groundwater discharge from cliff sections as well as across the floodplain towards the river eg Woolpunda. In this situation, evaporative discharge, when it occurs, is insufficient to reduce the groundwater head enough to lead to outflows from the river to the floodplain. Consequently, WPLs would almost certainly lead to increased saline inflows to the river.

2.4 The presence of anabranches or billabongs

These may reduce the watertable gradient across the floodplain by intercepting the regional groundwater inflow, especially when they are close to the side of the valley eg as occurs at Morgan and Berri. More groundwater will be intercepted with a greater depth of penetration of the watertable, especially if the billabong is connected to the permeable Monoman Sands. These billabongs are mostly connected to, and are at the same level as the River Murray.

3 SURFACE WATER PROCESSES

The floodplain has the ability to mitigate a proportion of the effects of regional groundwater inflow to the river due to its low elevation with respect to river pool level. Interception occurs by a process of evaporation and evapotranspiration that stores salt on and within the soils of the floodplain and within the backwaters. In summer when evapotranspiration rates are high, these processes may reverse the groundwater gradients and induce flow toward the floodplain from the river and halt groundwater inflows to the river. Conversely, the low evaporation in winter may allow the flows to the river to recommence.

Backwaters can also act as groundwater flow interceptors, especially if they are disconnected from the river. This is due to the lowering of the water level within the backwaters by evaporation, which may induce groundwater flow toward them. However, backwaters connected to the river can continually return a proportion of this intercepted groundwater back to the river, depending on the efficiency of the connection between them.

Under normal conditions where the river pool levels are held relatively stable, wind action in the Lakes and lower reaches of the river will initiate an interchange of water between the river and backwaters. The wind can influence pool levels by up to 0.15 m. A more efficient connection between river and backwater will result in greater interchange and more salt returned to the river.

As the river level falls during a WPL event, surface water held within the backwaters will flow back into the river until they are isolated from the main channel or reach equilibrium with the river level. Saline concentrations within these backwaters are invariably higher than the river although in general, extremely high concentrations only occur in those backwaters already completely isolated and therefore unable to return any surface water directly to the river.

4 FACTORS CONTROLLING SALT LOADS TO THE RIVER

Notwithstanding the above driving factors controlling regional and floodplain groundwater flow, and interchange between backwaters and the river, there are several immediate controls of salt loads entering the river during WPLs.

4.1 Salinity of the groundwater adjacent to the river

Obviously, groundwater salinity adjacent to the river is a major factor. If regional salinities are high (eg over 20 000 mg/L above Lock 2), salt loads to the river will be higher for a given lowering, than if regional salinities are low (eg below 10 000 mg/L below Lock 1). Although regional salinities are reasonably well known, the groundwater salinity distribution on the floodplain is complex due to the number of processes operating and little is known along large stretches of the river.

4.2 Watertable gradients adjacent to the river

This is perhaps the biggest control of impacts due to WPL. If locking or interception scheme pumping has resulted in a gradient away from the river, a WPL may not be large enough to change this gradient and minimal salinity impacts from groundwater would be expected. Conversely, if regional or irrigation induced gradients are strongly toward the river, a WPL could have significant salinity impacts.

4.3 Aquifer permeability adjacent to the river

Although the previous two controls of WPL impacts are very important, the aquifer permeability controls the rate and magnitude of the impacts, as well as the extent of watertable lowering in response to WPL. A low aquifer permeability would dampen the impact with a slower response and lower fluxes, compared with high permeabilities. This parameter, although variable, is known reasonably well and comes into play when the river channel is wholly enclosed by the low permeability Coonambidgal Formation.

4.4 Rate of WPL

Because of evaporative losses, there is a net inflow of water to connected backwaters at normal pool levels. If the rate of drawdown is less than the fall induced by evaporation, the influence of WPL will be minimal. Conversely, a rapid fall in water level would reverse the natural net inflow to the backwaters and return significant volumes of salt rapidly to the river. An understanding of the quantities of salt held within the backwaters will provide an upper limit to the potential impact of rapid drawdown.

4.5 Connection of backwaters with watertable

The salinity of water held within backwaters is a function of the rate of salt entering from groundwater and the river, the evaporation from it and the wind induced mixing with the river. Shallow backwaters will have a poor connection with the often saline groundwater, especially if they are underlain or enclosed by the low permeability clays of the Coonambidgal Formation. Deeper backwaters may intercept the permeable Monoman Sands which would maximise groundwater inputs, depending on gradients. However, some backwaters may be too shallow to intercept groundwater, although if located close to the cliff edge, they may intercept seepage from watertable mounds beneath irrigation areas.

4.6 Sill level of the backwater connections

The continued lowering of the river pool will eventually lead to the stranding of the backwaters, which may have a positive or negative effect on saltloads. As backwaters become stranded or the connections become constrained, the wind interchange rates and therefore saltloads to the river will reduce. However, if the pool lowering is rapid, stranded backwaters may maintain a level higher than the river, resulting in steep groundwater gradients toward the river. This could increase saltloads to the river significantly, especially where floodplain salinities are high.

5 MODELLING OF PROCESSES

5.1 Groundwater

In order to examine groundwater flow processes occurring during a WPL event, and also to test the relative importance of the above factors controlling salt loads, a groundwater slice model with a width of 1 km was constructed using MODFLOW. Four hydrogeological settings were modelled, using typical aquifer parameters derived from previous investigations. These settings include the river channel located against a cliff section of the regional watertable aquifer (either Murray group Limestone or Pliocene Sands) and various combinations of floodplain sediments (Coonambidgal Formation clays and Monoman Sands) as shown in Figure 3.

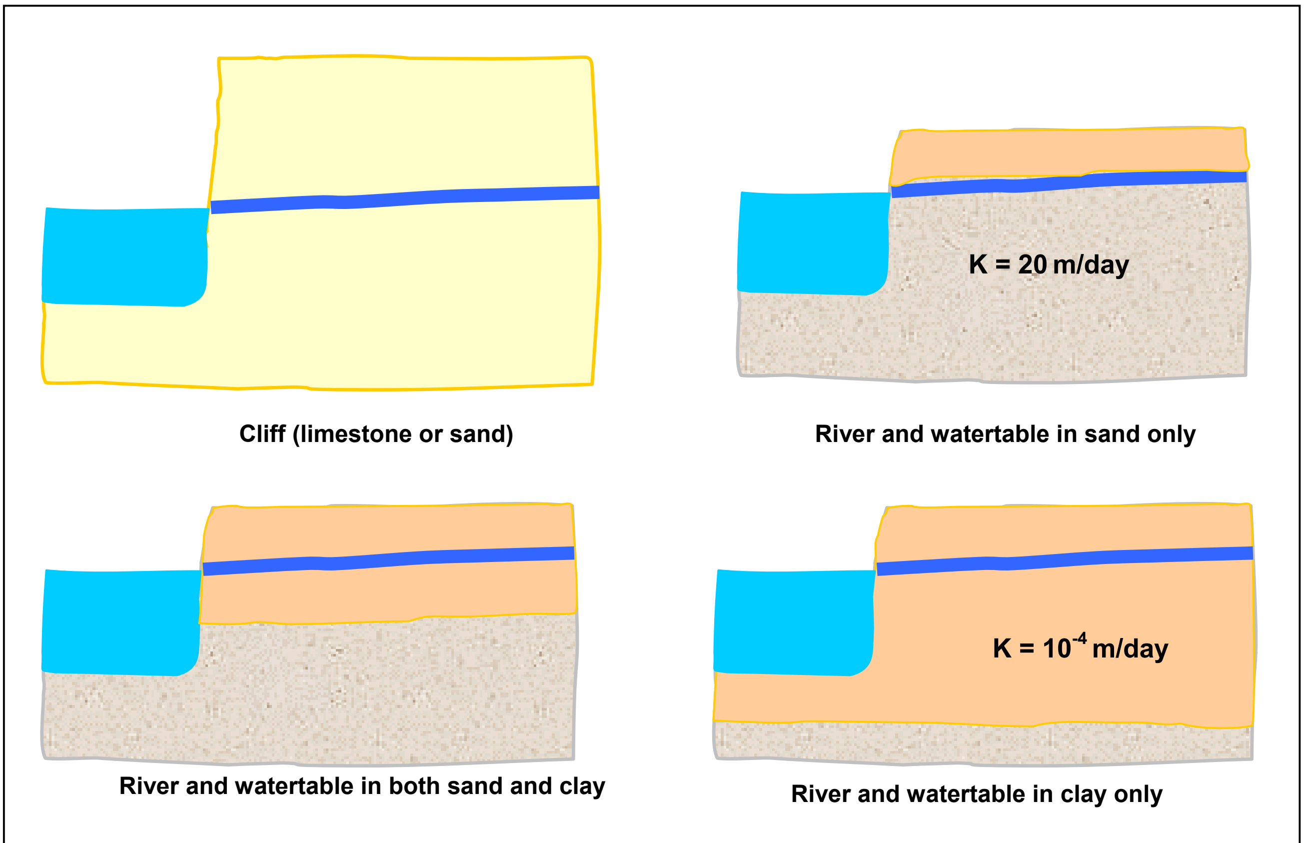


Figure 3. Modelled hydrogeological settings.

The WPL events were assumed to commence on 15 April with rates of lowering of 2 and 5 cm/day to maximum levels of 0.5 and 1 m below normal pool level. Recovery commenced on 1 October. The model calculated groundwater discharge to the river both as a rate and a total volume. A typical discharge curve and groundwater flow response to a WPL event (in this hypothetical case, a lowering of 1.5 m) is shown in Figure 4.

a – normal pool level with small groundwater inflow

b – drop in river level increases gradient toward river and increases discharge

c – when pool level stable, gradient and discharge gradually decrease

d – as river level rises, it recharges the aquifer (zero discharge)

Groundwater discharge to the river is re-established 3 – 4 months after the river has recovered back to normal pool level.

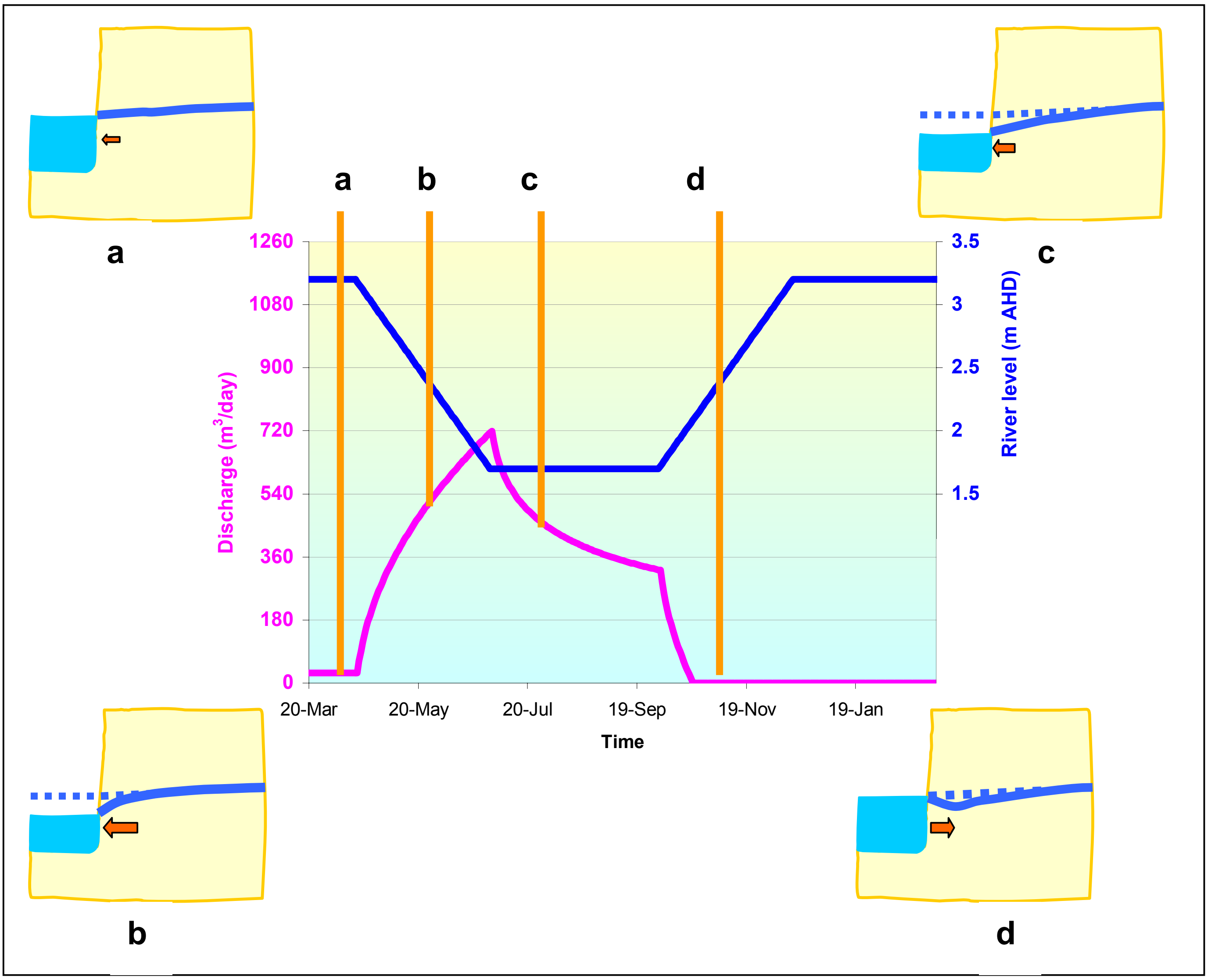


Figure 4. Groundwater discharge curve and flow response.

A number of scenarios were modelled to test the sensitivity of groundwater discharge to the river to variations in aquifer hydraulic conductivity, regional watertable gradients toward the river, and the rate and magnitude of WPL. Results are presented in Table 1 for the cliff section only. The volume stated is the total discharge for the WPL exercise from a one kilometre section.

Some immediate observations are that the volume of discharge does not vary with the rate of lowering (however this rate may be determined by other factors eg bank slumping), and that discharge is not overly sensitive to regional gradients (which is ironic given that this is one of the better known factors that control groundwater discharge). A doubling of the WPL from 0.5 m to 1.0 m will on average, result in an increase in discharge by 75%. Similarly, a doubling of hydraulic conductivity will increase discharge by about 50%.

Table 1. Groundwater discharge to river from cliff section (ML)

Scenario		WPL of 0.5 m	WPL of 1.0 m
Rate of pool lowering -	2 cm/day	31.2	55.3
	5 cm/day	31.8	57.4
Hydraulic conductivity -	1 m/day	21.1	39
	2 m/day	31.2	55.3
	5 m/day	54.4	94
Regional gradient –	0.00016	31.2	60.1
	0.00032	37.8	55.2

It can be observed that the increase in discharge with WPL is not linear, ie the discharge for 1 m is not quite double the discharge for 0.5 m. This is because the watertable gradient close to the river does not increase in a linear fashion in response to WPL.

A comparison of the four different aquifer sections, each one kilometre wide, shown earlier in Figure 3 for a WPL of 0.5 m is shown in Table 2. Not only is the total discharge volume shown, but also the area of influence (distance back from the river that the watertable has been affected by WPL), and the capture zone (distance back from the river that groundwater actually enters the river).

Table 2. Comparison of different aquifer sections

Aquifer section	Discharge (ML)	Area of influence (m)	Capture zone (m)
Cliff	40.1	1500	7
Floodplain sand only	82.8	1500	15
Floodplain sand and clay	63.5	1500	11
Floodplain clay only	11.0	30	0.2

Table 2 shows some interesting numbers. Although the watertable is affected some considerable distance from the river by WPL, the actual distance from which groundwater enters the river is limited. This is especially the case when the river is enclosed by the clays of the Coonambidgal Formation – discharge volumes are small with a very restricted capture zone. Not surprisingly, the Monoman Sands contribute more discharge because of their higher permeability.

5.2 Surface water

The response from backwaters to a WPL event is quite different to that from groundwater. The response is immediate and continues at a constant rate until the WPL stabilises at the new river level.

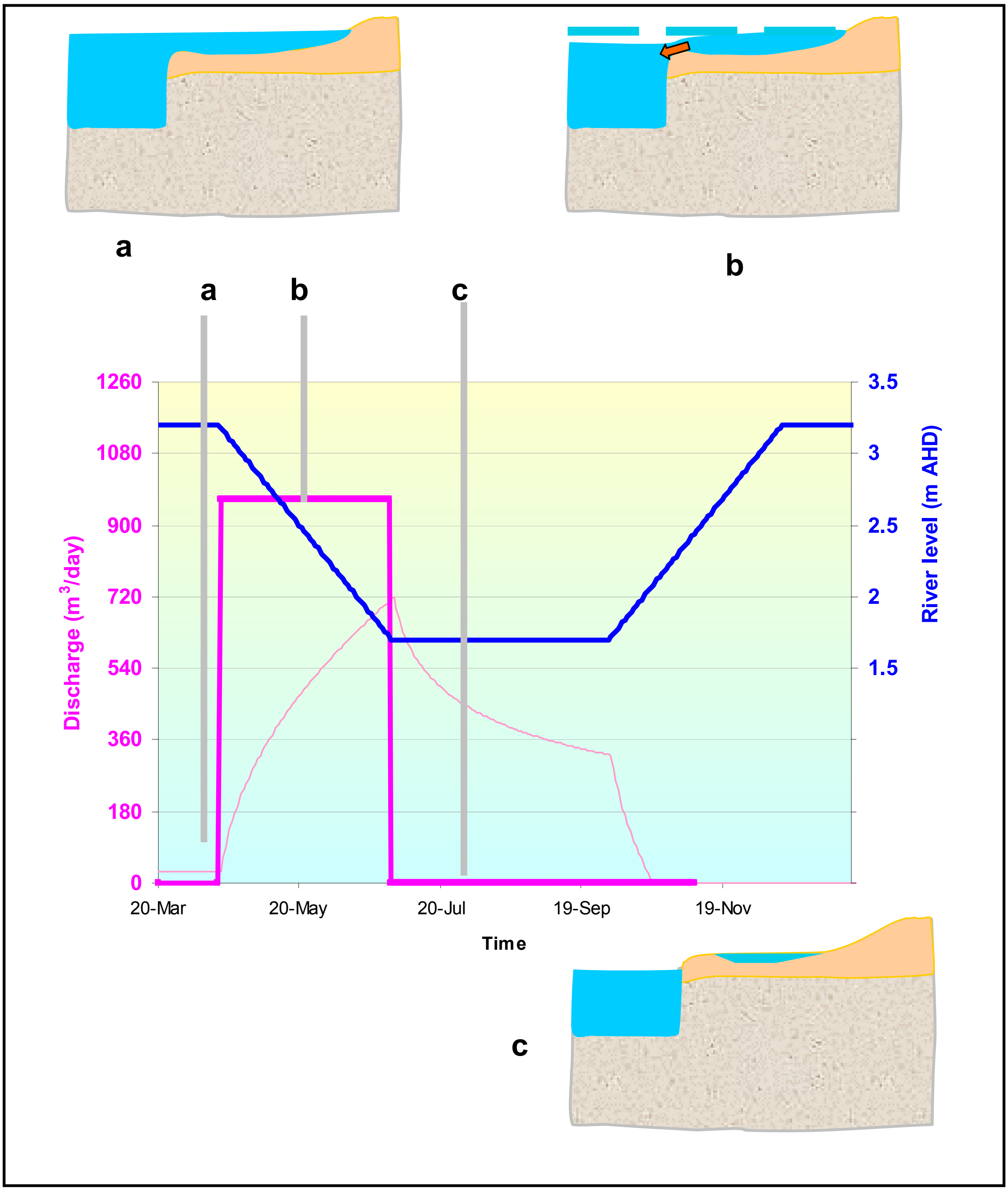


Figure 5. Backwater discharge curve.

Figure 5 shows that as the river falls, discharge from a backwater rises immediately to a certain level that is maintained while the WPL event is in progress. As soon as the river stops falling, discharge from the backwater ceases.

6 METHODOLOGY AND UNCERTAINTY

6.1 Groundwater contribution

6.1.1 METHODOLOGY

The methodology adopted in any reach is obviously dependent on the availability of information and the degree of understanding of the processes operating. In some areas, numerical groundwater models have been constructed where there are important management issues and the understanding of groundwater processes is reasonably well known. These models were used to determine the impacts of WPL where appropriate.

In areas where there are no suitable groundwater models, a simple spreadsheet and Darcy's Law (Q = KiA) were used to calculate inflows from cliff sections and areas around the lower lakes. Estimates of hydraulic conductivity and measurements of aquifer thickness and groundwater elevations from observation bores close to the river or lakes were incorporated. There were no overlaps between the different models used. Again, a rough calibration against observed run of river salt loads was attempted. However, these critical parameters controlling salt loads to the river have large variability.

For inflows from the floodplain, the Floodplain Impacts Model (FIP) was used (Overton et al, 2003). FIP is an analytical model, implemented within a GIS framework, that distributes floodplain groundwater inflows to the River Murray valley into discharge into seepage at the break of slope, evapotranspiration across the floodplain and as base flow to the river.

6.1.2 UNCERTAINTIES

Regional salinities are reasonably well known, although the salinity distribution close to the river may vary due to irrigation drainage or evaporative concentration on the edge of the river bank. The groundwater salinity distribution on the floodplain is complex due to the number of processes operating and little is known along large stretches of the river. Based on the observed variation ranges from 1000 to 100 000 mg/L, the error is assumed to be – 50% to + 200%.

Regional watertable gradients are well known, but few bores exist with values in the critical zone within a kilometre of the river. The uncertainty is assumed to be +/- 25%. Hydraulic conductivities are known reasonably well in a regional context with assumed values already having a conservative bias, but again they may have significant local variations close to the river. An increase of only 1 m/day could result in a doubling of calculated salt loads. The error is assumed to be – 50% to + 150%.

Because regional groundwater models have been calibrated against observed salt loads in the river, the uncertainty of their results is lower than other methods. The FIP model does not attempt to simulate floodplain wetlands, backwaters or oxbows, because the role that these water bodies play in intercepting saline groundwater flowing towards the river is unknown.

Taking into account the above factors and their relative importance, an uncertainty value for estimates of salt load based on best judgement has been decided as – 50% to + 50%.

6.2 Backwater contribution

6.2.1 METHODOLOGY

The method employed to estimate increased saline returns from backwaters during a WPL exercise involved the mapping of the extent of backwater pools and measurement of the mean depth and salinity to determine the salt stored within the system. The methodology, while not ideal as it suffers heavily from lack of specific site data, will at least provide an order of magnitude estimate as to the likely salinity impact.

The field survey included backwaters below Morgan to provide information for this study on weir pool lowering, and the majority of those within the Lock 1 to Lock 2 reach. Using GIS data and 1:50,000 topographic maps, those wetlands considered reasonably large and that demonstrated connection to the river at normal pool level were then selected for survey.

At each site, EC and temperature, and when in open water, a depth reading were taken. Also in sites where it was possible to boat across a large area of the backwater, running observations were taken. A brief description of each backwater sampled is contained in Appendix B, together with a map of sampling sites and estimated salt returns associated with a set WPL.

From this backwater data, the volume and salt returned for a WPL from normal pool level can be calculated and the additional salt returned above current river salinity deduced. These values were then summed and factored up to include all of the backwaters not included in the survey. As the river level fall continues, the actual salt returned would be likely to reduce as backwaters become isolated. Without a detailed survey, it is not possible to accurately consider the depth at which any given backwater would become isolated from the river. Based upon data collected for a small number of backwaters, it would appear that in some of the better connections, it would take a WPL of between 0.5 to 1 m for them to become isolated. Of course, some of the shallower backwaters would be cut off much earlier.

The results show that the majority of backwaters return relatively small amounts of additional salt which is due to low salinity concentrations recorded in them. Such low backwater salinities are probably due to a combination of the good mixing occurring between the river and backwaters and a low groundwater connection.

6.2.2 UNCERTAINTIES

Unfortunately the shallow conditions under low river pool prevented effective access to the majority of backwaters by boat. As a result, most of the readings were taken where road access was possible. Obviously, the accuracy of the data collected could be improved by increasing the area sampled in many of the backwaters which would be quite a lengthy process.

However where boat access was possible, or where readings were taken from substantially different locations, results generally indicated relatively homogenous conditions across the entire waterbody. Of concern was the presence of any salinity edge effect. Although many of the readings were taken from small piers, jetties and causeways, a considerable number of readings could only be taken from the bank. At some sites where it was possible to take both an edge reading and a deeper water reading further out, it appeared that the edge reading could be up to 100 EC higher than the deeper one. While this indicates that some measurements could be exaggerated at particular backwaters, over the entire reach any error is likely to be small.

The volume calculations are currently quite approximate as there is very little bathymetric data for the backwaters themselves, and only some have data defining how well they are connected to the river.

6.3 Estimation of river saltloads

6.3.1 METHODOLOGY

Saltloads entering the river are estimated by measuring the salinity of a body of water at one point, and comparing it to the salinity of the same body of water measured at a point further downstream. It is vital for an accurate estimate that the same two bodies of water are compared, especially when the inflowing river salinity is not stable (for example, it could be rising due to post flood saline return, or falling due to increased dilution flow).

It is therefore important to know the travel time for the paricular body of water between the two measuring points. This travel time will obviously vary according to the river flow, for instance the travel time between Lock 1 and Murray Bridge may vary from two days during a high flow, to over 40 days when on entitlement flow.

To convert the salinity data (recorded as a concentration) to estimates of salt inflow to the river in tonnes per day, an estimate of river flow is required. Flow is not measured directly at any site in SA, but must be calculated using the River Murray Hydraulic model (Water Studies Pty Ltd) which provides an estimate of flow through any reach on a daily basis.

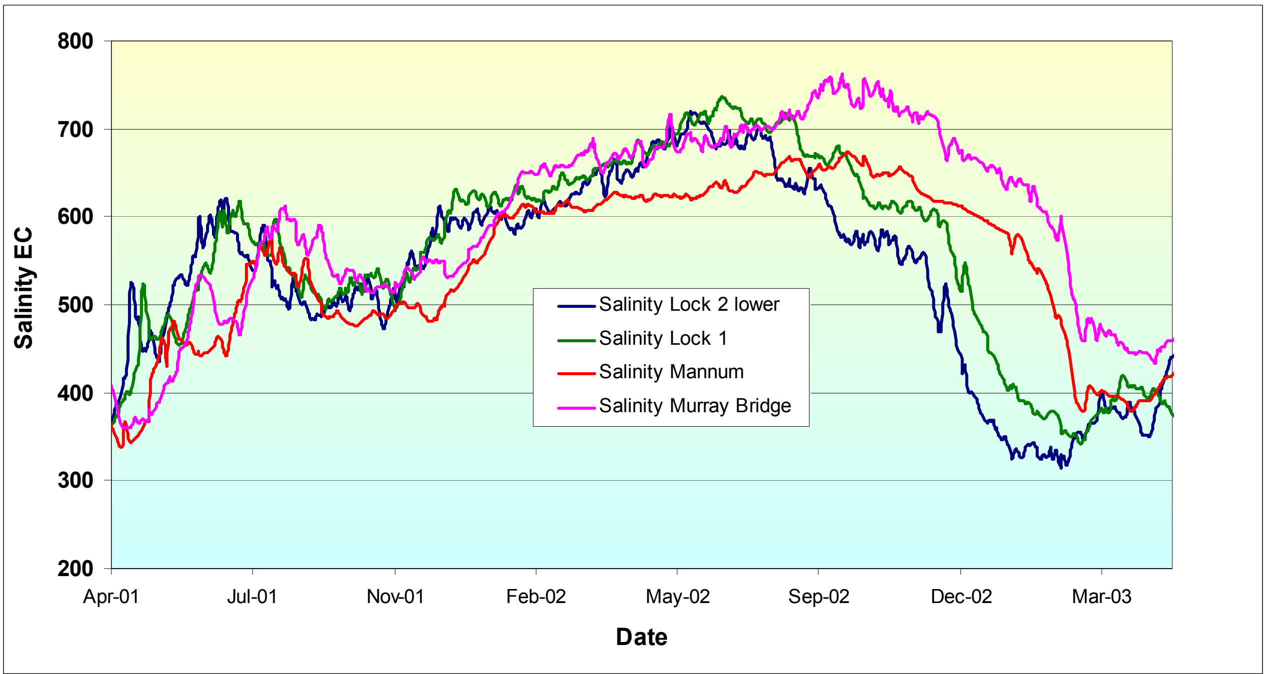


Figure 6. Recorded salinity between Lock 2 and Murray Bridge.

6.3.2 UNCERTAINTIES

The accuracy of estimating salt inflow to the river is determined by:

- the quality and consistency of the available recorded salinity data
- the ability to estimate the travel time between the salinity recording locations

Logically, river salinity should increase downstream but such obvious responses are not always observed even with the best quality data available. Incorrect travel times between recording stations is often identified as a cause of inconsistency, but inaccuracy in data recording can be the main cause. This is certainly the case in Figure 6 that shows that the salinity recorded at Mannum (in red) is consistently lower than the upstream stations. Needless to say, salinities recorded at Mannum were not used in this study.

6.3.2.1 River Salinity

The errors in salinity recording encountered could be caused by a combination of factors including:

- inaccuracies or slight variation between recording instruments used
- poor sampling procedures, ie recording too close to the bank or varying the location of the sample
- poor choice or limitations of sampling location. This may be caused by the site being placed close to a source of salt that is not fully mixed before the recording site. In addition, it is possible that water quality at an individual site may vary in relation to the flow in the river.

Some of these problems may be able to be alleviated for future studies, but it is likely that expectations of the current monitoring system are too high, and alternative procedures will be required in the future.

6.3.2.2 Travel time

The importance of travel time cannot be understated. There are several factors that influence travel time which are unfortunately, not being measured. These include:

- continuous river flow volumes - is the most obvious, yet it is one variable that is not routinely collected
- wind action - plays a significant role in the movement of water, especially below Lock 1
- reach volume – as pool level falls, the velocity of flow must increase to compensate
- rising or falling river levels – if rising, backwaters would be filling and therefore presenting a greater loss of flow and a resultant increase in travel time. Conversely if falling, water will be discharged from backwaters and travel time will decrease.

Without knowledge of these influences, travel times can be best estimated by correlating the natural peaks of salinity that pass down the river.

6.3.2.3 River flow

Flow is calculated using the River Murray Hydraulic model (Water Studies Pty Ltd) whose inputs are:

- river flow to SA measured at Lock 7
- irrigation use upstream of the site in question
- backwater and river evaporation and evapotranspiration upstream of the site

The model provides an estimate of flow through any reach on a daily basis. The model output indicates that an entitlement flow below Lock 1 would typically vary between 3300 and 3800 ML/day in February, and 2000 to 2500 ML/day in June. This result confirms that the flow of 3000 ML/day, as measured during the run of river surveys on June 2001 and Feb 2003 is a reasonable estimate, but also provides guidance on the likely error introduced when estimating salt inflow.

It should be noted that the computer model has limited (at least un-calibrated) accuracy in this flow range. This is because little monthly diversion information is available and estimates for evaporation and evapotranspiration loss could not have been calibrated against any known river flows within SA.

It is clear that consideration and resources will have to be given to implement methods to measure flows if accurate salt tonnage returns are required in the future.

6.4 Run of River Surveys

6.4.1 METHODOLOGY

Run of river salinity surveys providing a rapid assessment, or “snapshot”, of the changes in salinity and salt load on a kilometre basis along the river (Porter, 2001). The results are used to calibrate the groundwater models used in this report. Prior to commencement of a survey, river flows were stabilised at the entitlement flow to SA (3000 ML/day in June) and maintained throughout the survey period. This pre-survey stabilization period is required to enable river levels to settle and to minimize any in-flows from backwaters and lagoons.

Samples were taken at one kilometre intervals along the length of a sampling run using an intake tube attached to the deepest part of the hull of the 5.5m survey boat. The sampling boat speed is set to 40 km/hour. River water from a depth of 50 cm passes through a continuous salinity measuring cell which houses a standard Tetracon salinity probe attached to a WTW 325 salinity instrument connected to a portable computer (Porter, 2001). Every 20 kms or at certain defined points, a manual sample from the water pickup circuit is taken and used to verify the accuracy of the continuously collected data and check for any possible drift in instrument calibration.

6.4.2 UNCERTAINTIES

Two salinity surveys are available, one completed in February 2003, at the time of the current drawdown, and the second in June 2001. The results of these are shown in Figure 7.

The results of the surveys are seen to contradict the assumptions underlying this report, that salt export will increase as the pool level of the river is drawn down. The surveys show a drop in the salt inflow in February 2003 of nearly 40% compared to June 2001, as shown in Table 10.

Table 3. Salt export tonnages recorded from Run of River surveys

Survey	Lock 1 - Mannum (Tonnes/day)	Mannum – M Bridge (Tonnes/day)	Total (Tonnes/day)
June 2001	77.3	37.9	115.3
Feb 2003	39.5	32.3	71.9

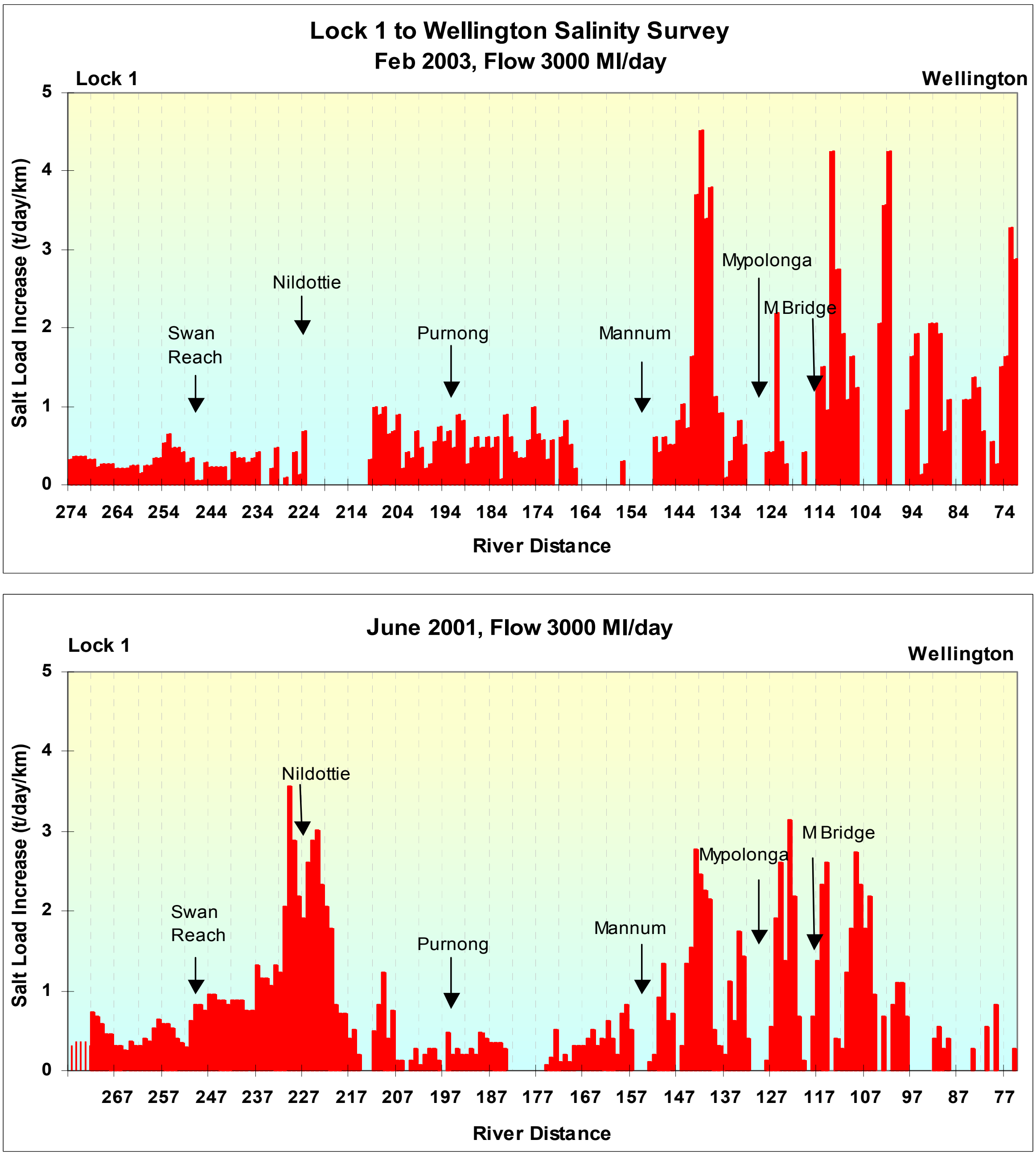


Figure 7. Comparison of Run of River surveys.

Of particular interest is the deviation of the two surveys around Nildottie (river distances 200 to 250 km), indicating the reverse of what was expected. Conversely salt inflows in the lower section (downstream of 150 km) remain relatively constant.

To explain the inconsistency, two observations can be made about the surveys. Firstly, the time of year they were taken is significant. Surveys conducted in summer will probably record lower saltloads as the floodplains could be acting as salt interceptors due to their high evapotranspiration loss. Summer surveys might then be expected to underestimate saltloads.

The second and perhaps more important factor is the timing of the survey with respect to river flow conditions. Examination of flow conditions indicates that the June 2001 survey was conducted following a significant high river flow (Fig. 8).

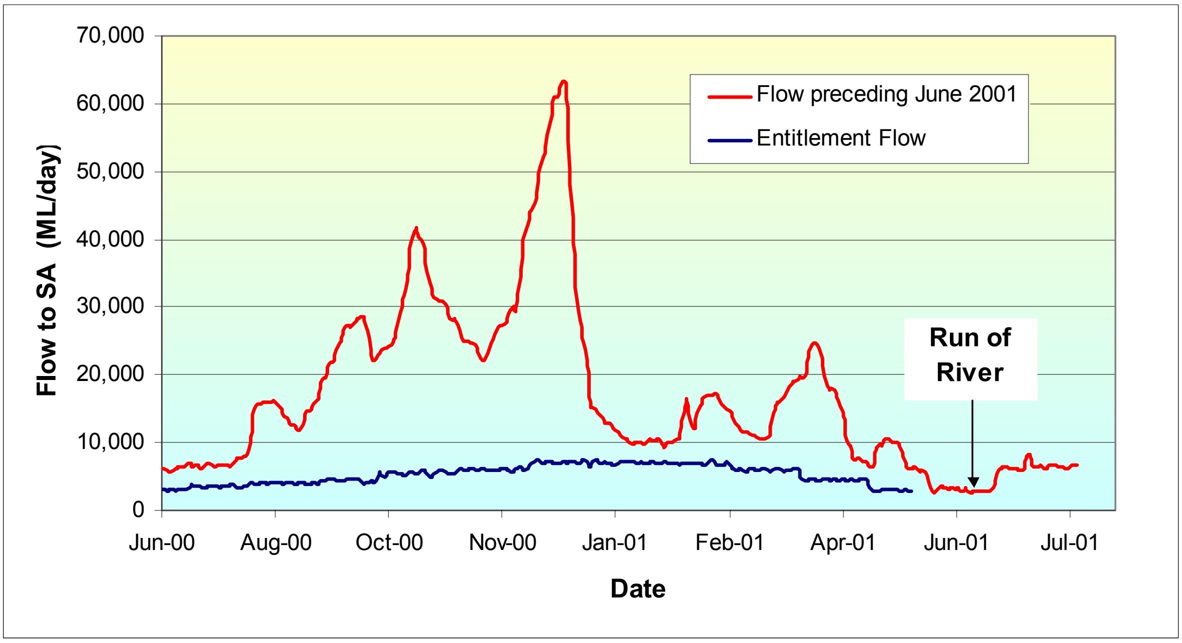


Figure 8. Flow to SA preceding the June 2001 Run of River sampling.

Apart from the high flow recorded toward the end of 2000 (which would have induced higher than average saltloads during the recession), there are also significant flow fluctuations much closer to the survey period in the early months of 2001. Such flow peaks, although small, would initiate a rise in water level and a subsequent drop following the passing of the event. This would have the effect of inducing a saline flow back to the river from backwaters. In addition, these backwaters may have recorded above average salinity due to the flood recession earlier.

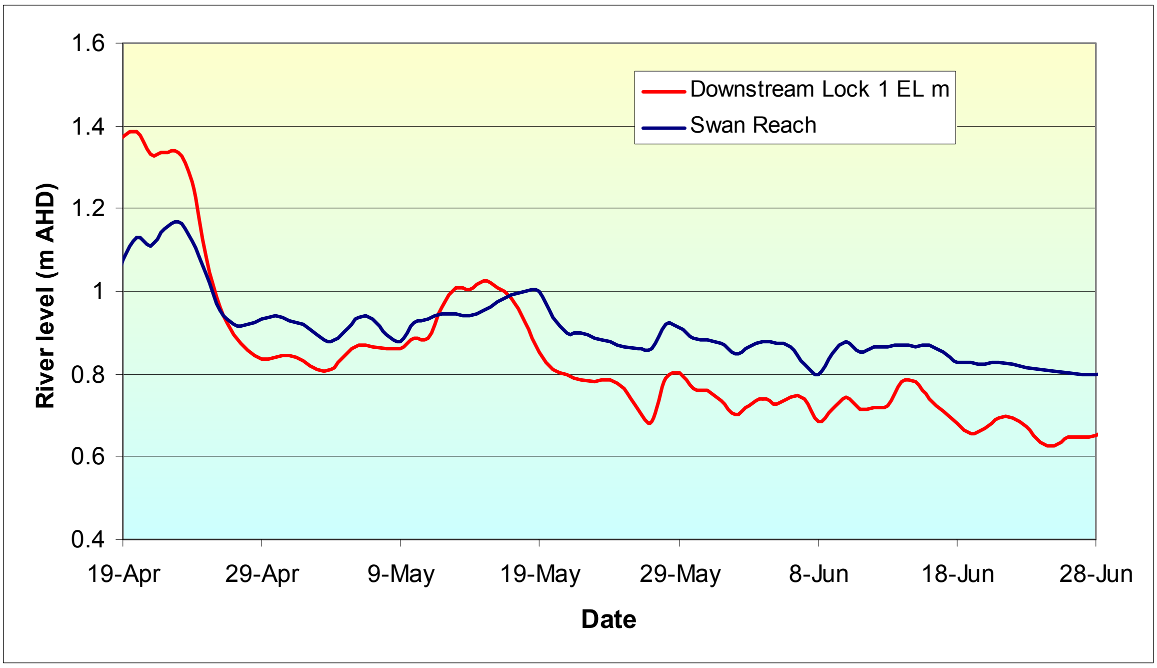


Figure 9. River levels just before June 2001 Run of River Survey.

Figure 9 indicates a significant fall in river level was recorded at the end of May 2001. As travel time between Lock 1 and Murray Bridge is around 35 days under winter entitlement flow, the salt return peak at Nildottie could have been caused by this fall.

6.5 Summary

The complex relationship between flow and salinity and the uncertainties in estimating both, mean that the salinity impact from WPL events may be difficult to distinguish from other natural events, and that the actual impact may be difficult to measure. The variation in 'natural' river salinity depends on several factors, including the upstream source of the flows and recent flooding history. Therefore the impacts of WPL will be expressed as an increase above an unspecified baseline salinity, rather than an absolute salinity value.

7 PREVIOUS WEIR POOL LOWERING EVENTS

7.1 Mildura 2001

In 2001, the Mildura weir pool was lowered for maintenance purposes, beginning on 12 May 2001. Before lowering, the upstream weir pool level was 34.39 mAHD upstream and 30.88 mAHD downstream. The pool level was lowest on 21 May at 30.97 mAHD. This represents a lowering rate of 38 cm/day to a maximum of 3.4 m, values far higher than would be expected for a WPL exercise in SA. Measurements of salinity showed a maximum increase of 275 EC during the exercise. The weir pool was raised from 22 May 2001 and brought back to normal on 31 May 2001. The final level was 34.46 mAHD upstream and 30.91 m downstream. The actual distance to which the Mildura weir pool extends is around 58 river km upstream of the weir (McCarthy et al, 2003).

7.1.1 REGIONAL HYDROGEOLOGY

The Mildura weir pool is flanked by a highly altered hydrogeological regime. Irrigation occurs on both sides of the river with associated watertable mounds, and groundwater interception schemes also operate on both sides of the river but downstream of the weir. Regional groundwater salinities are high (up to 35 000 mg/L) although watertable gradients (distant from irrigated areas) are parallel to and sometimes away from the river as shown in Figure 10 (Rural Water Commission, 1991).

In the vicinity of the weir, the 3.5 m differential between upper and lower pool levels exerts a strong influence on groundwater movement, with predominantly lateral flow on the northern side in a westerly direction from the upper pool through the alluvium to the lower pool under the Buronga meander. The Buronga salt interception scheme intercepts most of this flow. There is strong evidence of fresh water flushing the alluvium aquifer on the northern side, from observed salinities and groundwater flow directions, not only in the vicinity of the weir (Williams and Erny, 2003), but for considerable distances upstream (~ 10 km), as indicated by the salinities and groundwater elevations in paired bores 87122 and 87123, and 87640. This has resulted in a gradient of increasing salinity away from the river to the north.

The hydrogeology of the southern side of the river is dominated by a large watertable mound generated by drainage beneath the irrigation areas at Mildura and Red Cliffs (Fig. 10). This mound is up to 8 m higher than the upstream pool level, and would restrict any flushing due to the higher upstream pool level. The Mildura – Merbein groundwater interception scheme only protects the river downstream of the weir, and consequently there are no impediments to increased discharge to the floodplain/river as a result of WPL upstream of the weir.

7.1.2 GROUNDWATER RESPONSES TO WPL

The watertable response to the WPL was monitored by a total of 33 observation bores, with 17 located adjacent to the Mildura weir pool (Fig. 11). Another 16 bores were located downstream of the weir in the vicinity of the groundwater interception scheme and were excluded from this study.

Groundwater levels presented have not been corrected for salinity and serve to illustrate gross groundwater changes in response to WPL.

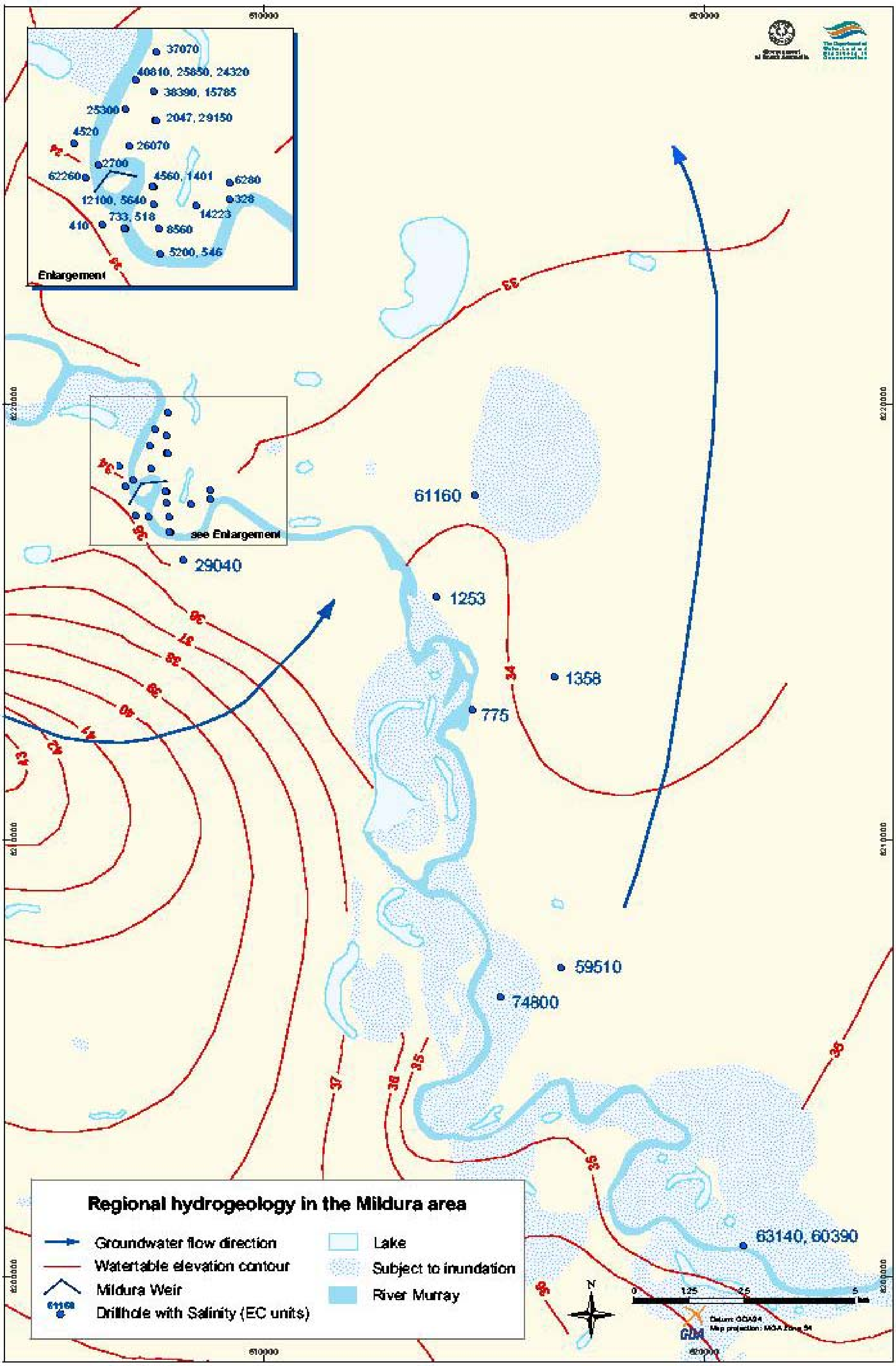


Figure 10. Regional hydrogeology in the Mildura area.

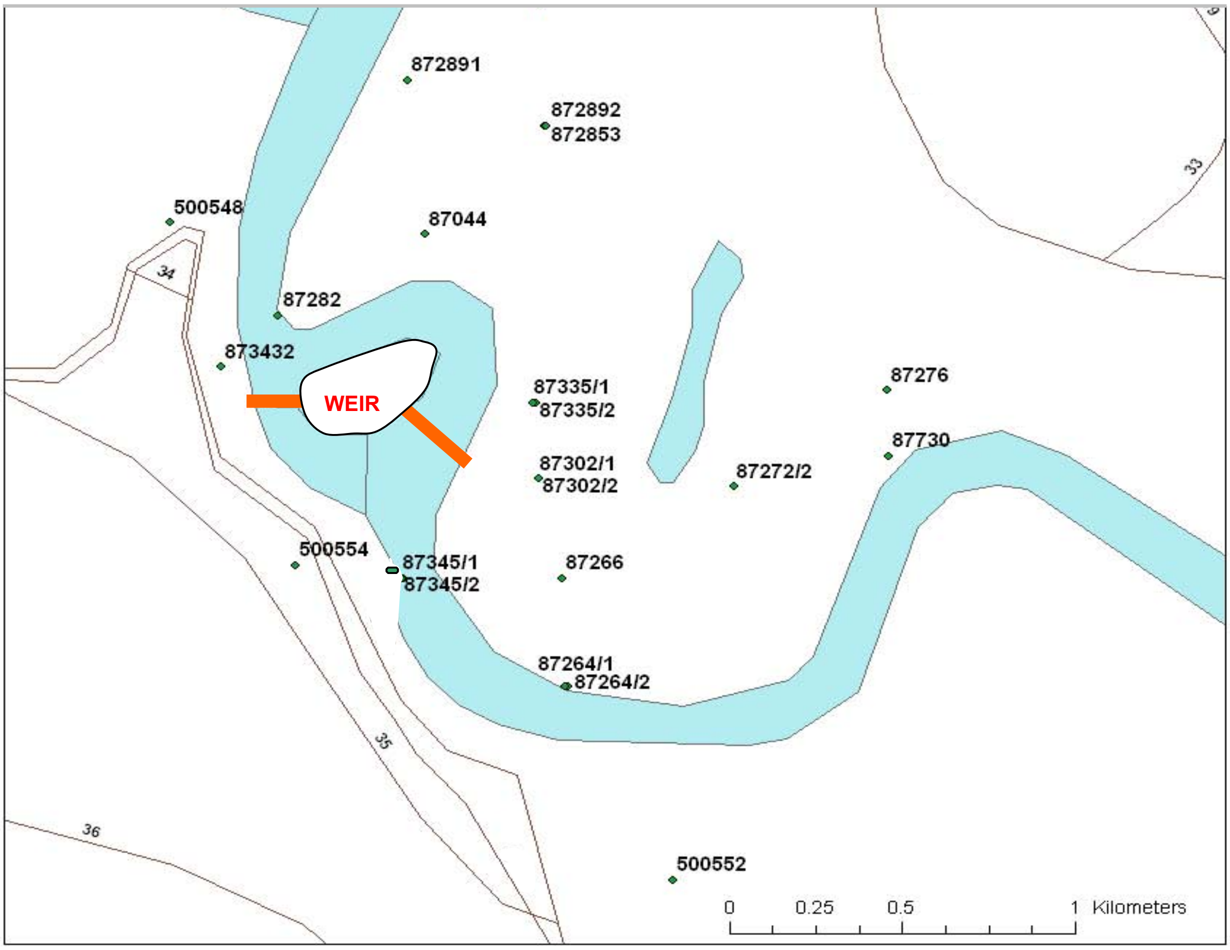


Figure 11 Location of bores adjacent to weir pool.

Eleven bores adjacent to the Mildura weir pool were monitored manually by the NSW DIPNR (Fig. 12), with six monitored with data loggers every three hours. Decreases in groundwater levels occurred in almost all of the 17 bores. Groundwater levels dropped by more than 0.4 m in seven bores located within about 200 m of the river (McCarthy et al, 2003). The WPL influenced groundwater as far as 1.85 km from the river. The groundwater levels were lowered by up to 0.7 m at a distance 41 river km upstream of the Mildura weir.

The groundwater levels in most bores reached their lowest levels on 21 May 2001 (9 of 17 bores), which correlated with the lowest river level stage. Six bores reached their lowest levels on 24 May after refilling of the weir pool had commenced, one on 28 May and one on 31 May. The short lag in the patterns of water level fall and rise between the surface and groundwater systems, along with magnitude of groundwater level change and the increase in river salinity, demonstrates a strong hydraulic connection between the systems (McCarthy et al, 2003).

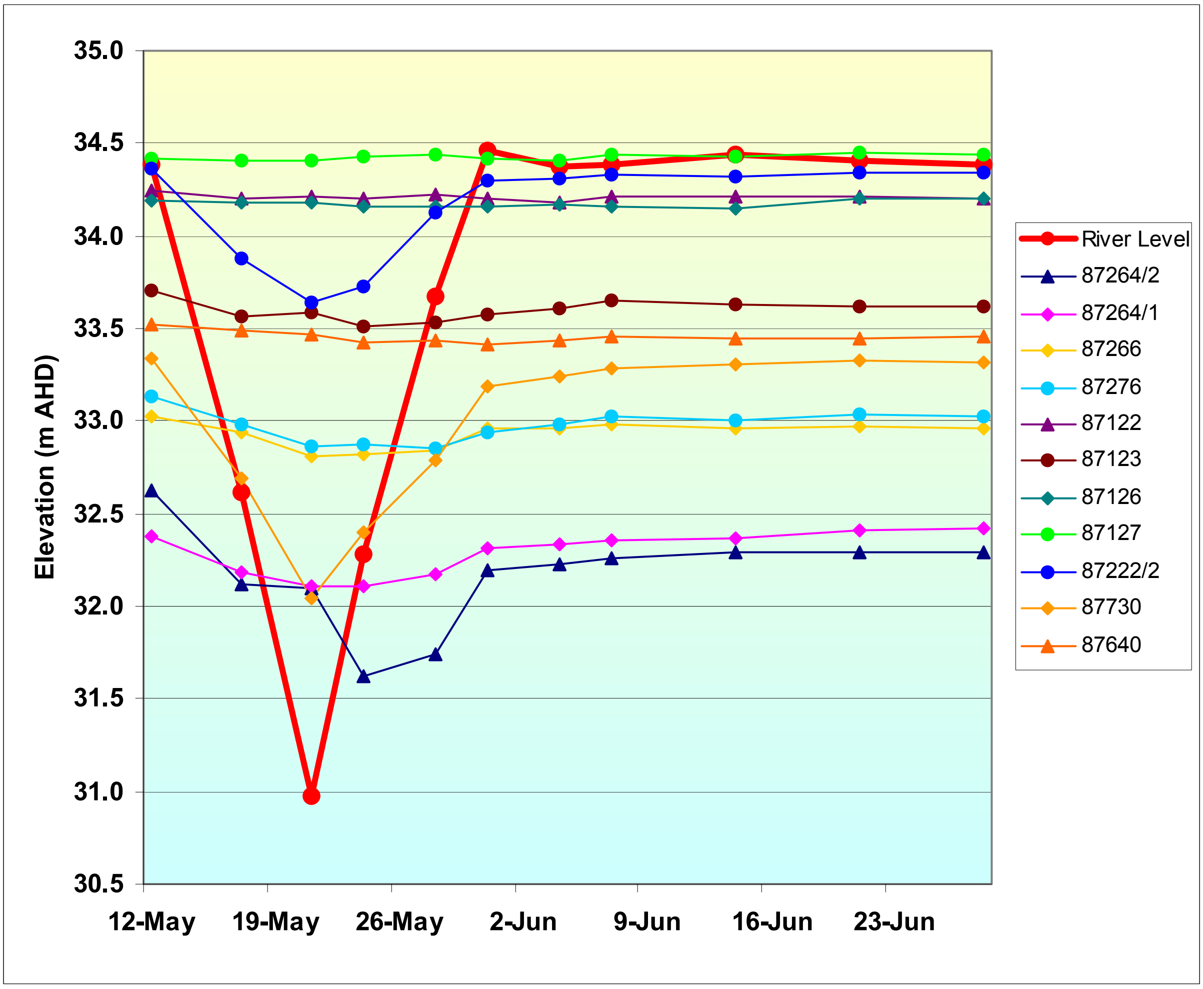


Figure 12. Groundwater levels adjacent to Mildura weir pool (after McCarthy et al).

Highly variable changes in groundwater salinity were observed within individual bores. For the 17 bores located adjacent to the Mildura weir pool, groundwater salinity increased in 13 (maximum increase of 6050 EC) and decreased in 4 (maximum decrease of 660 EC) (McCarthy et al, 2003).

The salinity increases were caused by groundwater flow reversal when the river level was lowered eventually below the groundwater level after about seven days. This induced flow of slightly more saline groundwater back toward the river and the boreholes. Bore 500552 showed a slight decrease because the increased gradient toward the river would have bought lower (but still relatively high) salinity irrigation mound groundwater toward the bore from the south.

7.1.3 CONCLUSIONS

The reversal of flow from the north is unlikely to contribute much salt as a result of WPL, with the most likely source of saline inflows from the irrigation mound to the southwest of the river. The delay in detecting an increase in river salinity which did not occur until about seven days after lowering commenced, as shown in Figure 13, could reflect the time taken for saltloads to flow downstream from the mound which extends 26 km upstream of the weir.

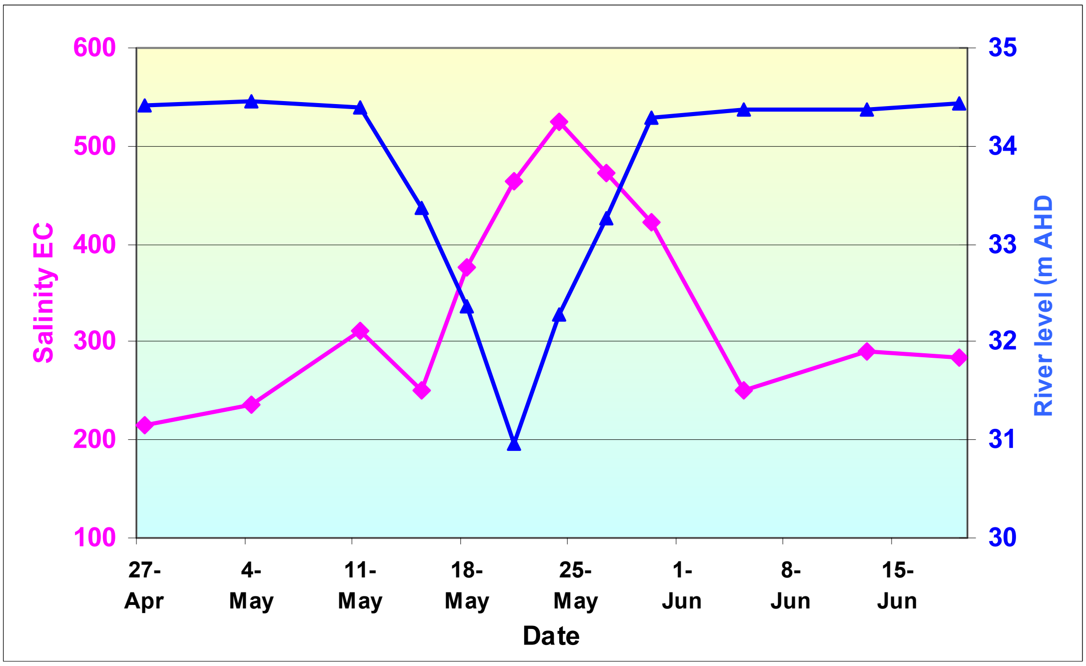


Figure 13. EC response in river to WPL.

Bore 500552 indicates high salinities beneath the floodplain with groundwater levels that are almost as high as the river level (when density corrections are made) before the WPL took place (Fig. 14). Despite a fall in groundwater level during the WPL, the levels are higher than the river from the start.

The marked increase in turbidity and TSS in the river is most likely a direct result of the rapid rate of lowering of 38 cm/day that is far higher than the proposed rate in SA. This would have probably promoted bank slumping and also an increase in flow velocity and a resultant increase in scouring.

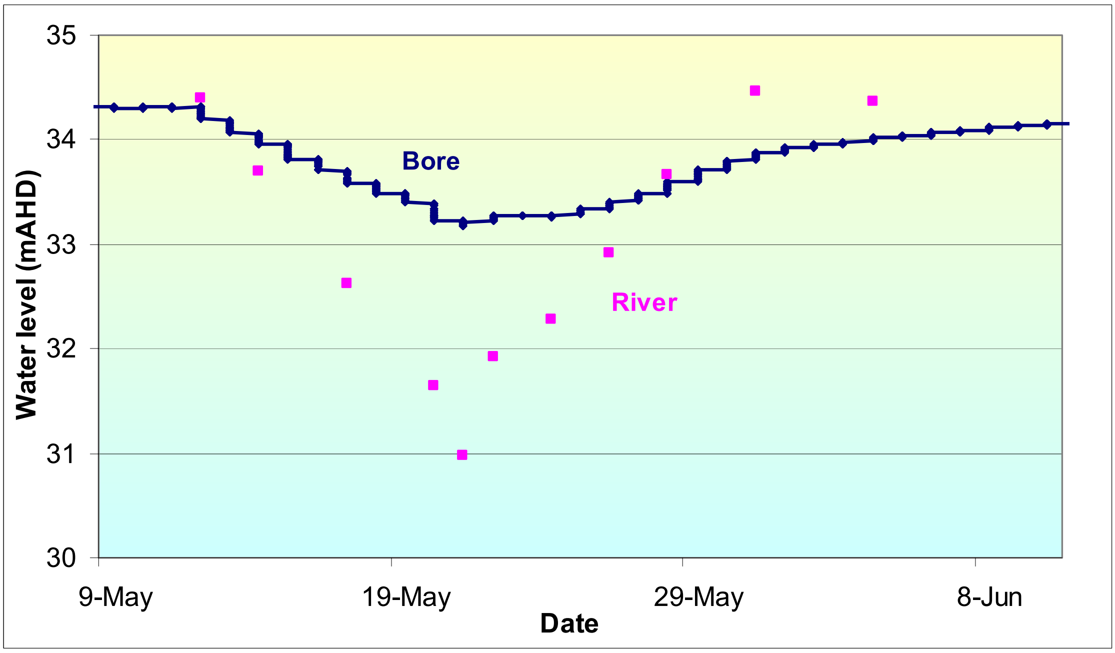


Figure 14. Groundwater levels in Bore 500552.

7.2 Lake Bonney 1989

Lake Bonney is a shallow off-river lake covering an area of 21 km^2. It is connected to the River Murray upstream of Lock 3 via Chambers Creek. The constant pool level, combined with the inefficient single inlet/outlet channel in the northwest corner, has led to restricted flushing and salinity levels as high as 6500 EC (Stace, 1990). It was proposed to lower the Lock 3 upper pool level by 0.5 m, which would have lowered the lake level by an estimated 0.3 m.

Lowering commenced on 23 May from 9.78 mAHD and was stopped due to strong community reaction on 26 May at 9.33 m when refilling commenced. This resulted in a WPL of 0.45 m at a rate of 0.15 m/day. Flow at Overland Corner at the commencement was 28 500 ML/day. Figure 15 shows the continuously recorded EC at Lock 3 during the WPL event.

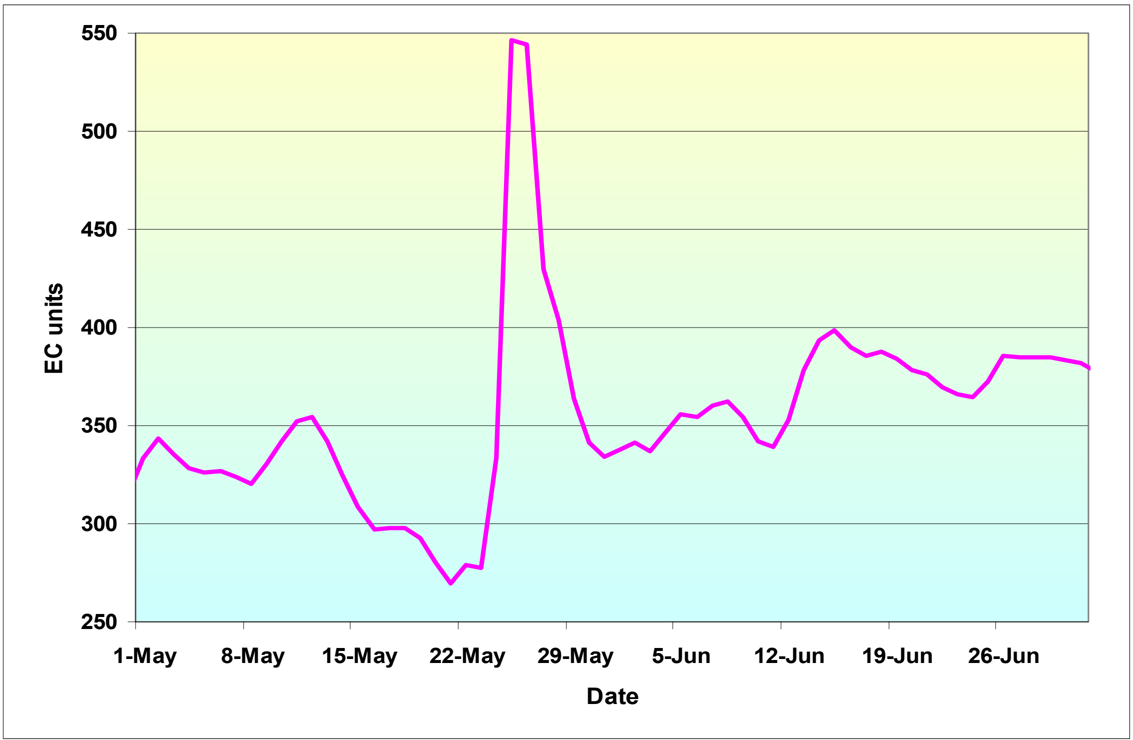


Figure 15. EC levels at Lock 3 during Lake Bonney WPL trial.

As can be seen, the salinity doubled from about 275 EC to 550 EC. There was minmal impact on river salinity at Loveday Pumping Station, so it was deduced that there was little contribution from backwaters upstream of this point (Stace, 1990). The level in Wachtels Lagoon fell about 0.32 m, resulting in “vast areas dried out into muddy islands”. The saltload contribution from Wachtels Lagoon was not monitored.

7.3 Natural

There have been several low flow periods in the past that have resulted in WPL events. In 1978, a pool levels were about 0.25 m below normal but unfortunately, this event followed a 34 000 ML/day high flow in the spring of 1977 and the salinity response to the flood recession would have overwhelmed the response to the WPL below normal pool level. Another WPL event occurred in autumn 1983 when flows reduced to about 1000 ML/day. The actual drop in pool levels are shown in Table 4.

Table 4. Weir pool lowerings in 1983

Reach	Below L1	L1 – L2	L2 – L3	L3 – L4	L4 – L5	L5 – L6
WPL	0.35 m	0.03 m	0.1 m	0.05 m	0.05 m	0.1 m

As can be seen, the only significant lowering occurred below Lock 1 because of the large evaporative losses from the lakes. Upstream, there was sufficient flow to maintain close to normal pool levels. There was no discernable change in salinity levels in response to lowering. Consequently these natural events cannot be used above Lock 1 for predictive purposes for future WPL events. However there are two events below Lock 1 that can provide some useful information.

7.3.1 THE JAN 1997 – SEPTEMBER 1998 EVENT

Detailed water level and salinity traces for this period are shown on Figure 16.

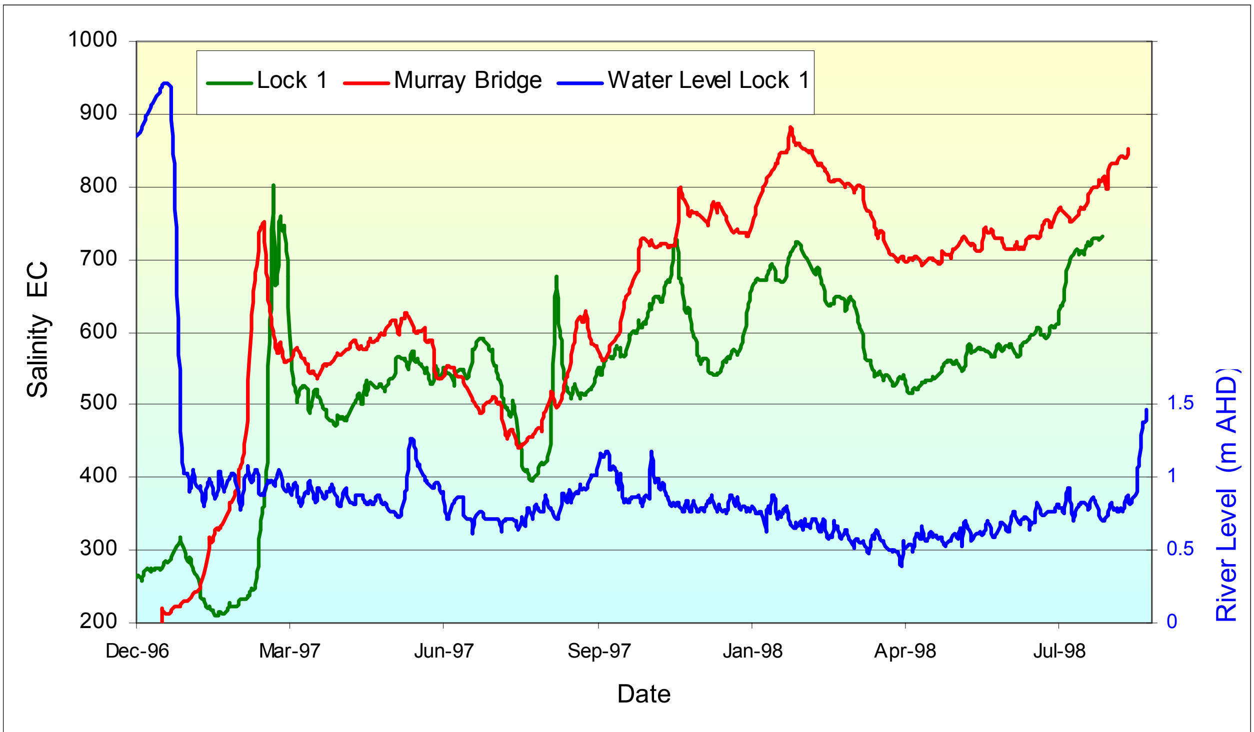


Figure 16. Recorded salinity Lock 1 and Murray Bridge corrected for travel time.

A constant flow of 3000 ML/day was assumed for the calculation of salt tonnage entering the reach. The early part of this graph is complicated by above average flows recorded entering the reach which initiated a large saline return as water drained from the backwaters. This post "high flow" saline return was somewhat masked by further above average flows peaking numerous times prior to November.

The resulting salt inflow between Lock 1 and Murray Bridge is shown in Figure 17 reaching over 300 tonnes/day under entitlement flow conditions. Negative saltload values remain common indicating the recording and travel time errors as alluded to earlier.

The rate of lowering for this 1997/98 event was 0.32 cm/day for 184 days to a minimum of 0.45 m AHD, resulting in a WPL of 0.585 m. Despite the considerable variation in calculated saltload, the resultant saltload increase of 270 tonnes/day above the nominal baseline of 100 tonnes/day is derived.

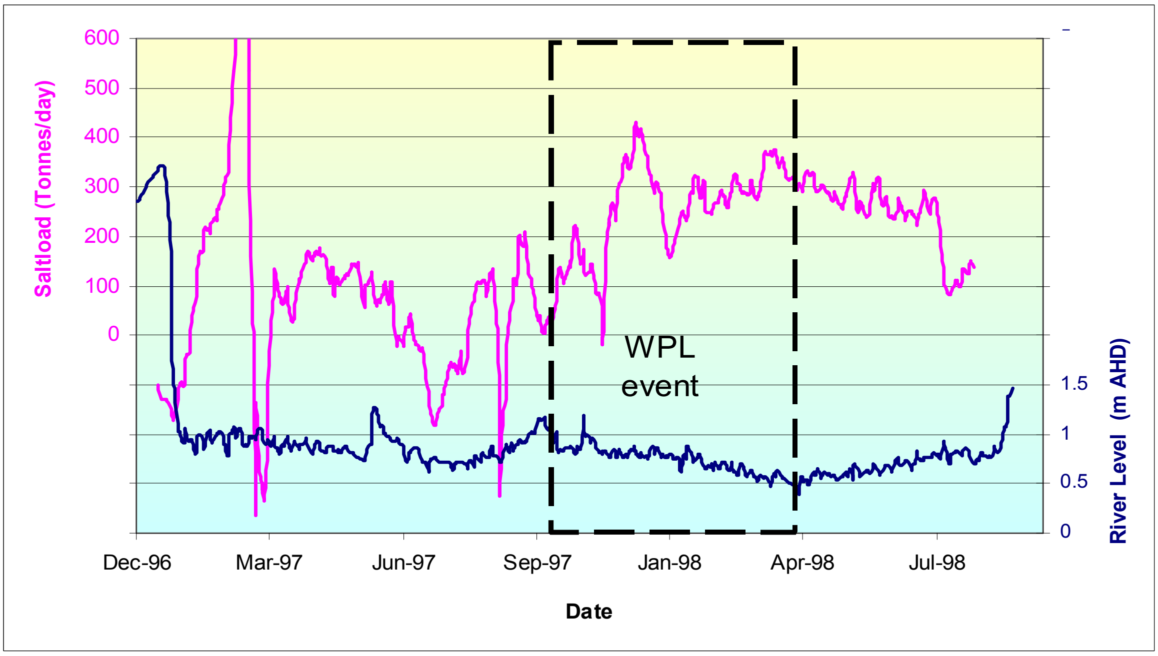


Figure 17. Estimated saltload between Lock 1 and Murray Bridge (Jan 97 – Sept 98).

7.3.2 THE APRIL 2001 – MARCH 2003 EVENT

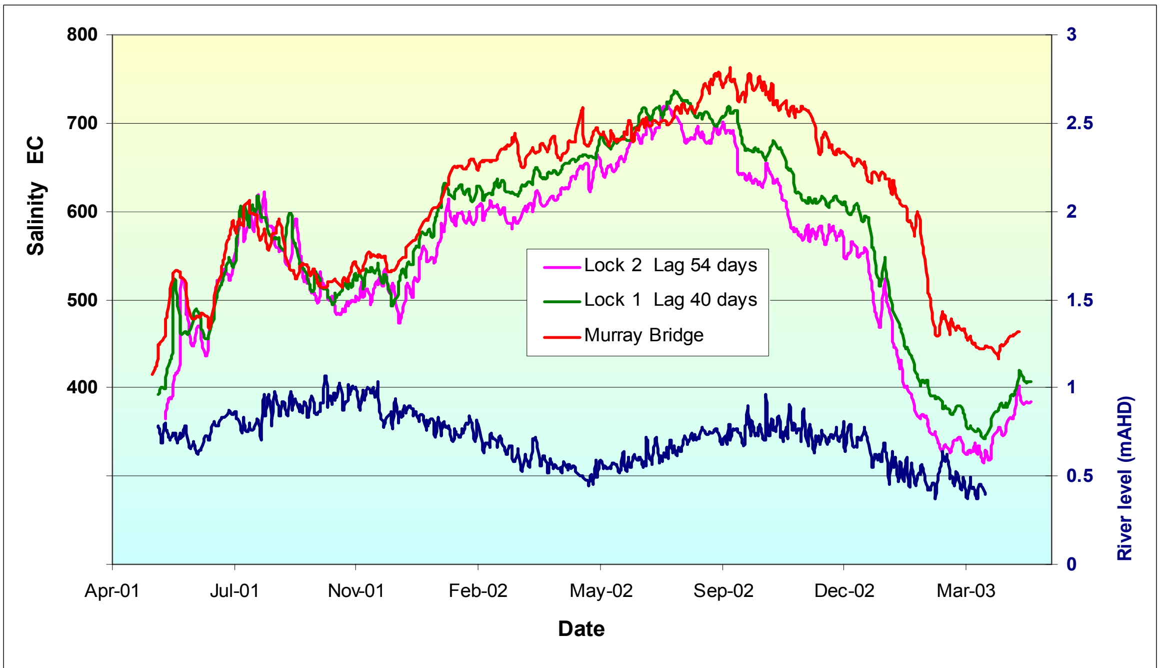


Figure 18. Recorded salinity Lock 2 to Murray Bridge corrected for travel time.

After removing the time lag due to travel times, Figure 18 shows the salinity recorded between Lock 2 and Murray Bridge, with the river level recorded below Lock 1. For this exercise, 3000 ML/day was adopted as the flow to calculate the salt inflows in Figure 19 based on the River Murray flow model results. Salt inflow between Lock 1 and Lock 2 was also included.

Caution should also be taken when viewing the peak salt loads estimated in early 2003. Figure 18 suggests that the salinity traces may not be entirely correctly aligned with respect to travel times. The consequence of this is, as the trace is falling rapidly, any translation to the right due to incorrectly estimating travel time has the effect of exaggerating salt return estimates.

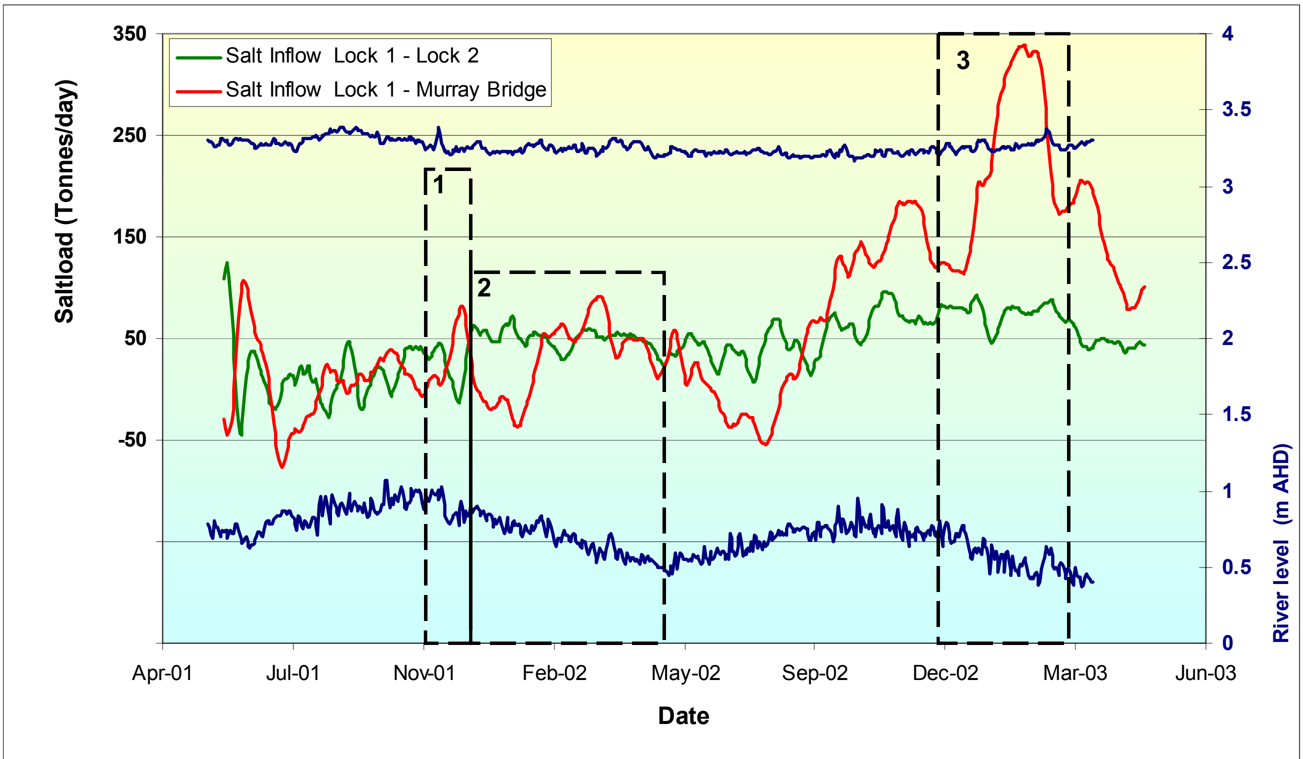


Figure 19. Estimated saltload between Lock 2 and Murray Bridge (May 01 – May 03).

There are three WPL events discernable in Figure 19 that have an interpretable increase in saltload below Lock 1.

- Event 1 – shortlived, WPL of 0.25 m at 4 cm/day resulting in saltload increase of 50 tonnes/day
- Event 2 – very gradual, WPL of 0.5 m at 0.3 cm/day resulting in saltload increase of 57 tonnes/day
- Event 3 - gradual, WPL of 0.43 m at 1.7 cm/day resulting in saltload increase of 212 tonnes/day

These results indicate that the rate of lowering may have an influence on saltloads, especially if it is quite low. Event 2 with only 0.3 cm/day, resulted in a quarter of the saltload of Event 3 with 1.7 cm/day, even though the WPL was similar. This very low rate minimises the impact of backwater contributions, but does not change the groundwater contribution. The Morgan water level shows very little change, but a small WPL of about 0.2 m is evident. The rate of lowering was very slow, at 0.05 cm/day, with a resultant increase in saltload of 53 tonnes/day.

8 THE BARRAGES TO LOCK 1

In this reach, not only are the impacts of WPL being investigated, but the impacts of the observed and predicted lowering due to the current drought will also be estimated. The reach below Lock 1 has a total river length of 274.3 km, 70.95 km of which represents the Lower Lakes. Although the lakes only represent roughly a quarter of the length of this reach, they clearly cover the majority of the area inundated. The Lower Lakes cover an area of approximately 814 km^2, backwaters an area of 45 km^2, while the River itself only covers around 35 km^2.

The preliminary estimates of impact for Lock 1 to the Barrages reach will be divided into three major segments which are based on different geomorphology and hence, different hydraulic and groundwater processes.

8.1 Lower Lakes

The Lower Lakes are surrounded in part by areas of low permeability lacustrine sediments inundated by previous high sea levels ~6000 years BP. Because these extensive areas are low lying, they have been salinised and are the sites of regional groundwater discharge by evaporation leading the very high salinities (~250 000 mg/L). These areas act like an interception scheme and encourage groundwater flow away from the lake (Barnett, 1992). There is limited potential for increased groundwater discharge to the Lake due to WPL because of the low permeabilities and the existence of a possible flushed zone. The exceptions are the small areas where the ground elevation is higher than 5 m AHD.

Because there are no suitable groundwater models of aquifer systems around the lakes, the spreadsheet model was used.

8.2 Wellington to Mannum

This reach is dominated by the irrigated reclaimed river flats cover about 5 300 ha and are about 1.5 m below the river which is contained within levees. Within this reach, there are virtually no anabranches or isolated backwaters as a consequence of the extensive reclamation.

Drilling on the reclaimed swamps at Mypolonga, Toora and Mobilong has shown artesian pressures in the deeper Monoman Sands with extensive drainage maintaining the watertable in the stiff clays of the Coonambidgal Formation to a metre or so below ground level, and consequently well below river level. The river therefore loses water to the reclaimed swamps at normal pool levels, but receives groundwater inflows from the cliff sections. Consequently, cliff inflows will be the main contributor to WPL impacts.

A groundwater model constructed previously by DWLBC to calculate impacts on river salinity due to clearance of native vegetation (Barnett et al, 2000), was to used to calculate inflows from cliff sections due to WPL.

8.3 Mannum to Lock 1

The region upstream of Mannum is commonly known as the Murray Gorge, as the river courses through a narrow and sharply defined valley, generally 1.5 to 2 kilometres wide and 30 to 40 m deep. This section of the valley is characterised by relatively straight stretches often abutting vertical cliffs along one side. A gentler slope generally represents the opposing side or large elongated backwaters separated from the main channel by low levees (MDBC, 1990).

8.3.1 GROUNDWATER

As in the previous section, a groundwater model was used to calculate inflows from cliff sections. Groundwater contributions from the floodplain are more difficult to determine. This is a segment of abundant backwaters that may, or may not intercept the regional groundwater inflows. If they maintain a level similar to the river, they may offer some protection by keeping groundwater gradients beneath the floodplain relatively flat. In this case, any groundwater use by evapotranspiration on the floodplain may be sufficient to induce flow out of the river instead of into it.

However, because of their probable shallow depth, and the fact they are underlain by the low permeability Coonambidgal Formation, they probably do not intercept significant groundwater inflows. The survey of backwater salinity tends to verify this conclusion.

From Lock 1 to Swan Reach, CSIRO drilling encountered relatively fresh groundwater in the floodplain adjacent to the river. Further downstream, as the floodplain elevation slowly decreases and approaches the river and floodplain watertable level, groundwater salinities increase as evaporative discharge processes predominate. This will induce flow out of the river and reduce the potential for significant inflows as a result of WPL.

The Bigmod modelling package predicted lake level responses for various river flow regimes. These levels were applied for the whole Lock 1 to Barrages pool level for the purpose of groundwater modelling. Backwater curves suggested minimal change to this scenario (a maximum of 5 cm within 50 km of Lock 1).

Figure 20 shows the modelled groundwater discharge from cliff sections from Lock 1 to Tailem Bend. Obviously, discharge will increase at lower river levels and vice versa. Salt loads were obtained by applying estimated salinities to this discharge.

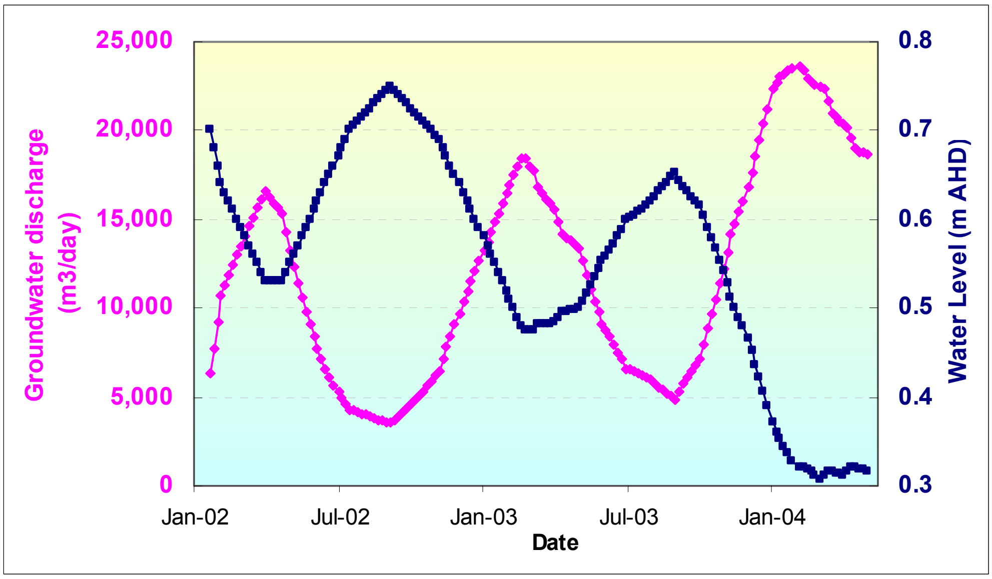


Figure 20. Groundwater response to river level changes - Lock 1 to Tailem Bend.

Groundwater discharge was modelled for various river/lake level scenarios that could occur in the summer of 2004, namely 0.3m (Fig.20), -0.2 m and –0.4 m AHD. In addition, the spreadsheet 'model' was used to calculate inflows for a lowering of 0.5 and 1.0 m in lake levels. Output from the FIP model suggests minimal floodplain contribution between Lock 1 and Mannum.

Predictions of the increase in saltloads due to a controlled WPL exercise as previously described were carried out, with results shown in Table 5. Also shown is the comparison between the natural saltloads over the exercise timeframe, and those induced by the WPL event.

Table 5. Saltload increase from groundwater due to WPL – Barrages to Lock 1

WPL	Saltload Increase (T/day)		Difference from no-WPL (Tonnes)	Average Saltload Increase from Lakes (T/day)
	Peak	Average		
0.5 m	140	100	11 000	35
1.0 m	250	180	24 000	65

Figure 21 depicts the total response from groundwater for the river below Lock 1 and the lakes, as an increase above saltloads at normal pool level, for a weir pool lowering of the river/lakes below normal pool level. This graph represents the average saltload over the period of the WPL event when the river level is stabilised at the lower level, and contributions from backwaters cease. The observed WPL events discussed previously in Figure 19 are plotted and show good agreement. It appears that backwater contributions were minimal in these events.

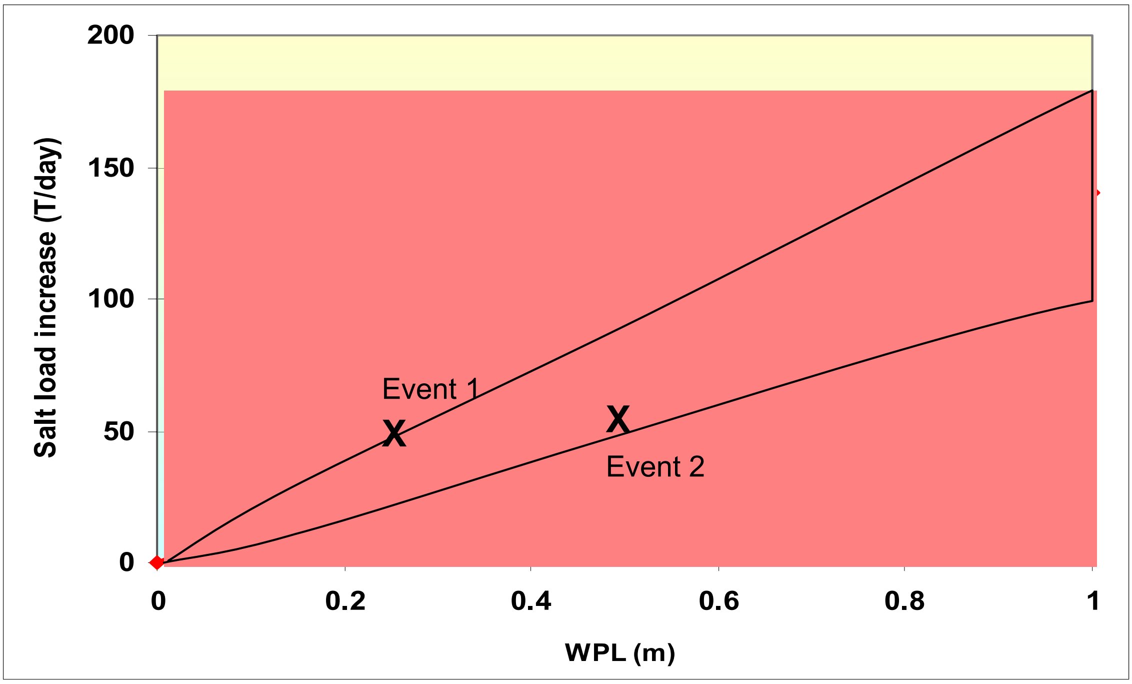


Figure 21. Groundwater saltload prediction tool - Lock 1 to Barrages.

Saltloads to the river can only be measured upstream of Murray Bridge. The salinity monitoring stations around the shores of the lakes are not representative of lake salinity, and consequently the saltload prediction tool to the barrages cannot be verified. Predictions of actual salinity levels are impractical because the salinity level at the start of the WPL can be quite variable depending on flow conditions.

8.3.2 SURFACE WATER

Calculations of the saltload contribution from individual backwaters based on surveys detailed earlier, are shown in Figure 22, with the totals for the reach in Table 6. The highest return is near the Swan Reach ferry is due to the local backwaters having much higher saline concentrations than the majority of others in the reach.

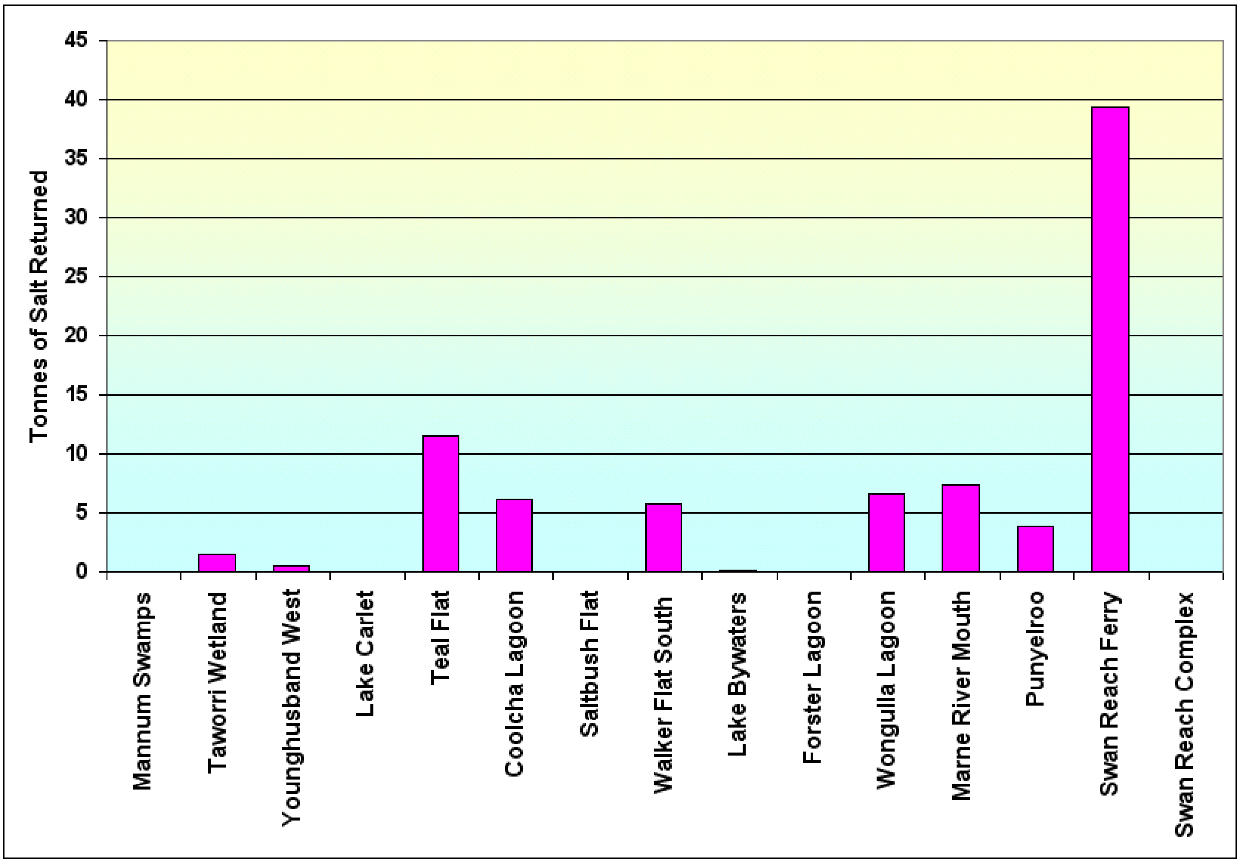


Figure 22. Salt increase from backwaters due to WPL of 0.1 m – Mannum to Lock 1.

Table 6. Salt increase from backwaters due to WPL – Mannum to Lock 1

WPL	Approximate Volume Returned (ML)	Saltload Increase (Tonnes/day)
0.1 m	2894	47
0.5 m	9705	32

Figure 23 shows the combined impact from surface and groundwater for the initial peak inflows that occur during the lowering phase of the WPL event. The backwater contribution decreases above 0.5 m, beyond which most of them would be drained or disconnected from the river.

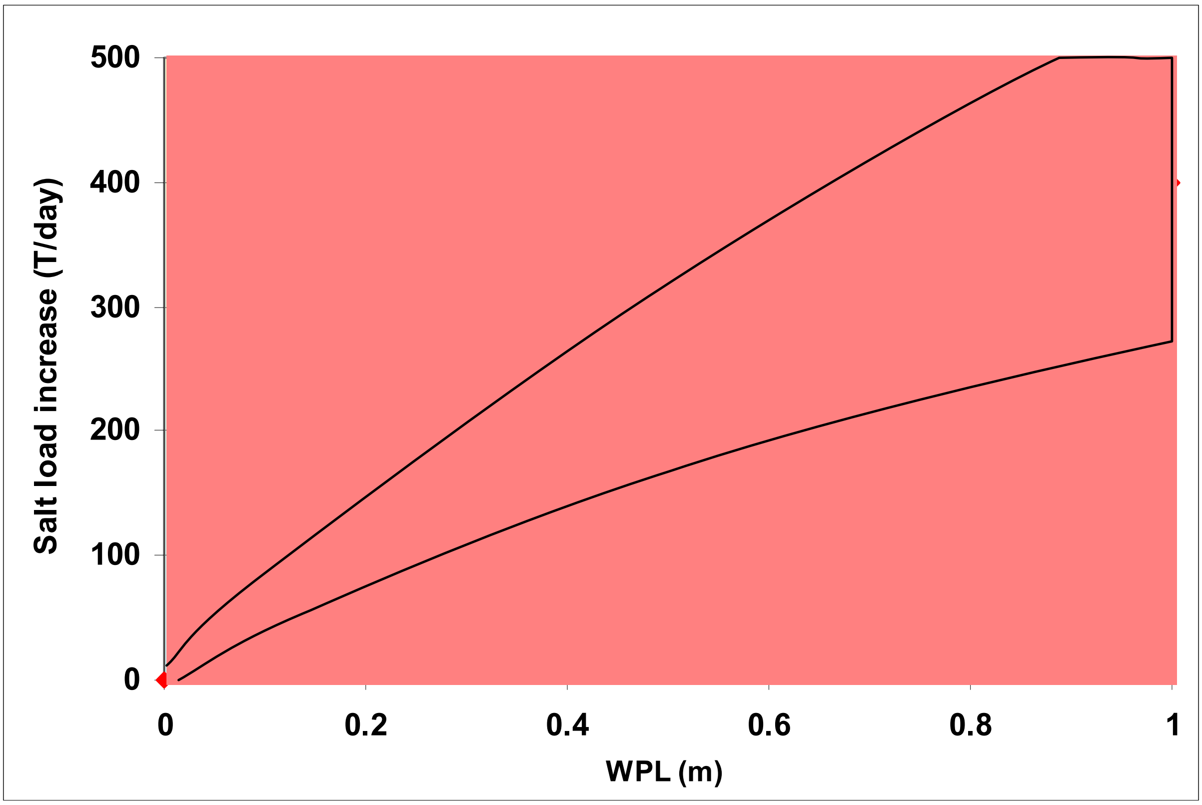


Figure 23. Drawdown saltload prediction tool - Lock 1 to Barrages.

Saltloads to the river can only be measured upstream of Murray Bridge. The salinity monitoring stations around the shores of the lakes are not representative of lake salinity, and consequently the saltload prediction tool to the barrages cannot be verified. Predictions of actual salinity levels are impractical because the salinity level at the start of the WPL can be quite variable depending on flow conditions.

9 LOCK 1 TO 2

The effect of the permanent rise in pool level above Lock 1 to 3.1 m AHD seems to extend a considerable distance upstream, with the run of river survey carried out in 2001 detecting an increase of only 2.4 tonnes/day between Lock 1 and Morgan (Porter, 2001). There are several reasons for this low accession. Observation wells in the regional limestone aquifer to the east of the river have indicated a regional watertable gradient away from the river, and also recharge from the river to the floodplain. To the west of the river, the Morgan Fault lies about three kilometres from and parallel to the river and acts as a barrier to regional groundwater inflows from the west. Also, the limited number of backwaters that occur between Lock 1 and Pelican Point have restricted connections to the river and would have to be 3 – 4 m deep to intersect the permeable Monoman Sands aquifer.

9.1 Groundwater Impacts

A DWLBC traverse comprising two sites was drilled on the heavily vegetated floodplain at Pelican Point (10 km south of Morgan), including a shallow backwater close to the western bank that is connected to the river. Salinity profiles obtained during drilling show a similar pattern to that at Blanchetown, with high salinities away from the river and a zone of low salinity adjacent to the river.

Examination of the flow nets indicate that, even at entitlement flows with the river at normal pool level, the river is recharging not only the alluvium but also the Murray Group limestone beneath the river valley. This suggests that evapotranspiration is again discharging groundwater from the floodplain, this time in sufficient quantities to lower the watertable below river level. The watertable is within three metres of the ground surface right across the floodplain which is heavily wooded.

The backwater adjacent to the western bank may intercept regional groundwater inflow from the west and may also lose water by recharging the alluvium. However it appears to be wholly enclosed by clay that may restrict interchange with the watertable.

Upstream of Morgan, the average floodplain level rises to about 8 m AHD whilst pool level remains at 3.1 m AHD. There are very few backwaters being deep enough to hold permanent water. From the northern side of the river, the regional watertable gradients are moderate (1:700), but the high groundwater salinities encountered on the floodplain (together with the significant degradation of tree health), suggest evapotranspiration intercepts much of this inflow. However, on the southern side, groundwater gradients are parallel to or away from the river. The FIP model shows negligible groundwater flow through the floodplain to the river.

Away from the influence of the Morgan Fault, there are only 10 km where the river is abutting the western/northern cliffs. The 2001 RoR found 9.6 tonnes/day between Morgan and Qualco that confirms the relatively low inputs from the regional groundwater flow system. The Cadell IA has minimal impact due to floodplain interception (and degradation) of irrigation drainage return flows and the low topography that precludes the formation of a large watertable mound.

The Qualco-Sunlands IA has a significant impact downstream of Lock 2 due to the steep watertable gradients toward the river. The 2001 RoR encountered 54.3 tonnes/day in this reach. The Qualco-Sunlands Groundwater Control Scheme would have slightly reduced this saltload since the survey was carried out, and will eventually reduce it even further.

The spreadsheet model was used to determine likely groundwater impacts as shown in Figure 24. This graph represents the average saltload over the period of the WPL event when the river level is stabilised at the lower level.

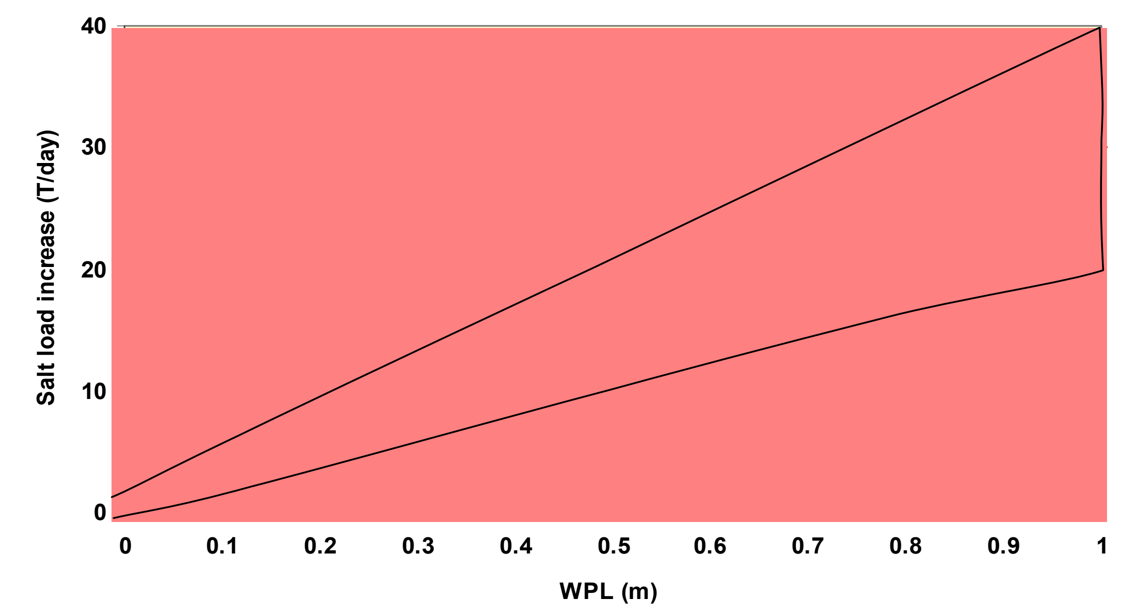


Figure 24. Groundwater saltload prediction tool - Lock 1 to 2.

9.2 Surface Water Impacts

The limited number of backwaters that occur between Lock 1 and Pelican Point have restricted connections to the river and would have to be 3 – 4 m deep to intersect the permeable Monoman Sands aquifer. Calculations of saltload contribution from individual backwaters based on surveys detailed earlier, are shown in Figure 25, with the totals for the reach in Table 7.

Table 7. Salt increase from backwaters due to WPL – Lock 1 to Lock 2

WPL	Approximate Volume Returned (ML)	Saltload Increase (Tonnes/day)
0.1 m	1257	6
0.5 m	4164	4

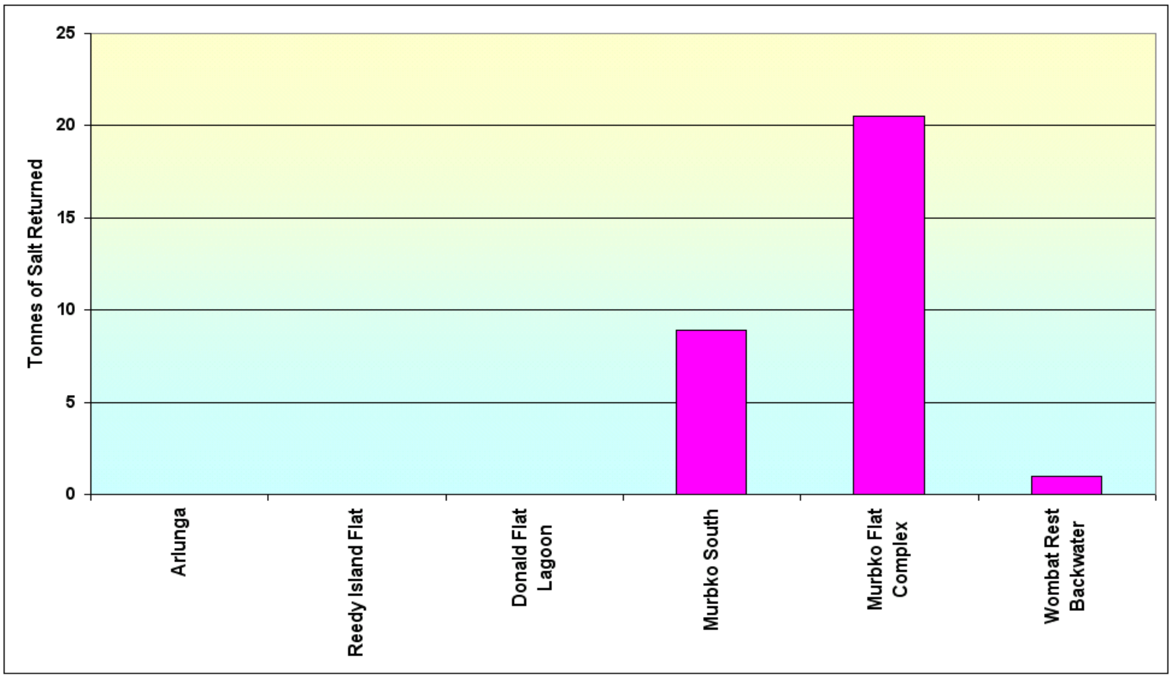


Figure 25. Salt increase from backwaters due to WPL of 0.1 m – Lock 1 to 2.

Figure 26 shows the combined impact from surface and groundwater for the initial peak inflows that occur during the lowering phase of the WPL event. The backwater contribution predominates up to about 0.5 m, beyond which most of them would be disconnected from the river. The actual salinity response to various WPL events in this reach will be discussed later.

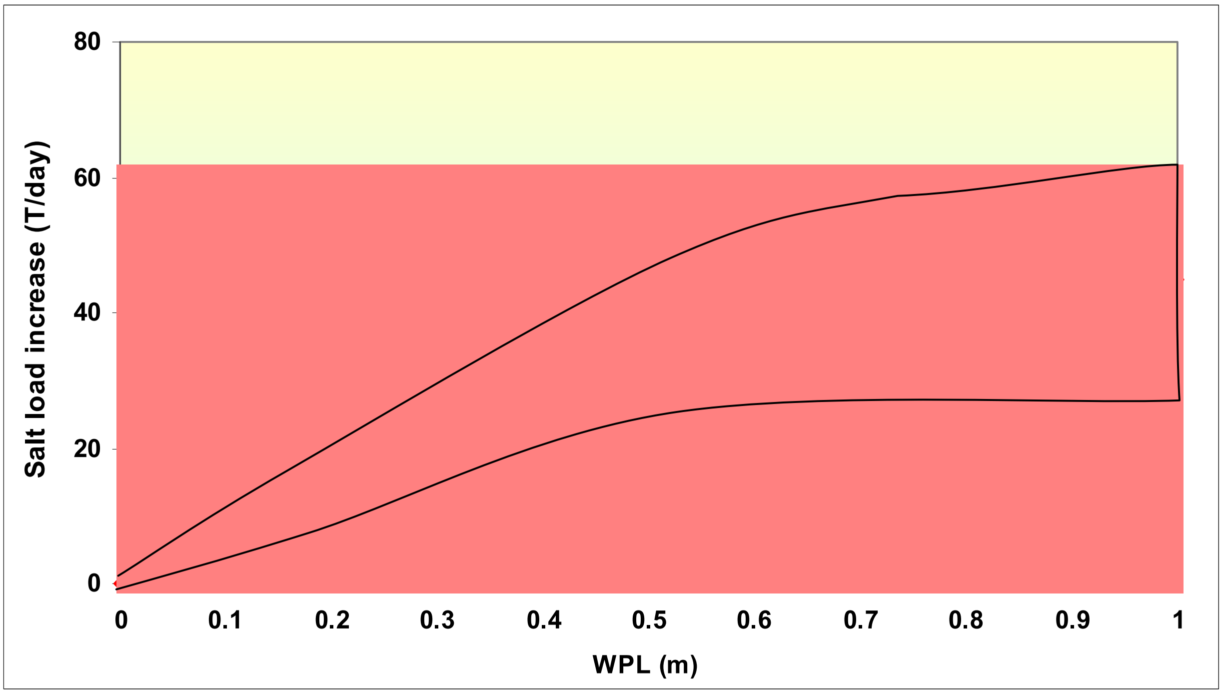


Figure 26. Peak saltloads during lowering - Lock 1 to 2.

10 LOCK 2 TO 3

Almost the whole length of this reach is an area of strong groundwater discharge toward the river from both north and south. These inflows are both man-induced (Waikerie and Sunlands Irrigation Areas) and natural (Woolpunda), and contributed a total of about 300 tonnes/day salt to the river before the Waikerie and Woolpunda interception schemes were constructed. The steep watertable gradients would have overwhelmed any attenuation effects from backwater interception or evapotranspiration from the floodplain.

10.1 Groundwater Impacts

A DWLBC traverse 15 km east of Waikerie near The Yarra billabong showed high groundwater salinities throughout the alluvium reflecting the regional values with no evidence of residual freshening due to recharge from the river. A strong vertical gradient exists, due to upward leakage from the Renmark Group. These flow nets were constructed before the Woolpunda Interception Scheme became operational and reflect pre-pumping conditions. The Yarra is a deeply incised backwater that is isolated from the river during low and entitlement flows. During these periods, it intercepts some of the groundwater inflow from the north and discharges it by evaporation, resulting in salinities of up to 19 000 mg/L.

The 2001 RoR shows a reduction from 300 to 70 tonnes/day due to interception between Lock 2 and 3. The question remains as to whether the watertable lowering due to interception is sufficient to protect the river from salt inflows during any WPL exercise. There is no groundwater model of any parts of the reach, and monitoring data is sparse or absent close to the river and on the floodplain. Upward leakage is an important process, rather than just lateral flows being a major contributor.

Because of the generally saline environment on the floodplain, this reach is considered high risk for WPL, even though the impacts are difficult to quantify.

10.2 Surface Water Impacts

There is no information on the few backwaters that are connected to the river in this reach.

11 LOCK 3 TO 4

The average floodplain level rises from about 10 m to 14 m AHD along this reach with a pool level of 9.8 m AHD. The regional groundwater gradients toward the river are generally low with local areas of moderate to steep gradients associated with irrigation areas at Kingston, Cobdogla, Moorook, New Residence and Loxton.

11.1 Groundwater Impacts

The presence of groundwater flow away from the river to the floodplain is supported by relatively low salinities in CSIRO floodplain bores close to the river between Lock 3 and Yatco Lagoon. Further upstream however, the high groundwater salinities encountered on the floodplain away from the river suggest evapotranspiration intercepts much of the inflow from the north, with the exception of the irrigation inflows at Gerard. The FIP model produced estimates of groundwater flow through the floodplain to the river (Table 8).

Total inflows between Lock 3 and Pyap were 36.3 tonnes/day in 2001, which is relatively low due to the low groundwater salinities beneath New Residence (probably due to flushing by drainage water), and the thin watertable aquifer in connection with the river at Pyap.

The major impacts on river salinity are the Loxton and Bookpurnong IAs where investigations are being carried out for the design and construction of an interception scheme. Obviously, an operating scheme would significantly reduce the impacts of a WPL event, however it is too early to estimate what these reductions would be, and when they would be achieved.

A calibrated groundwater model of the Loxton – Bookpurnong IAs was used to calculate the increase in inflows as a result of WPL. Again, construction of an interception scheme will significantly reduce inflows, but the timing and magnitude of these reductions is uncertain.

Table 8. Saltload increase from groundwater due to WPL – Lock 3 to 4

WPL	Saltload Increase – cliffs (T/day)		Saltload Increase from FIP (T/day)
	Peak	Average	
0.5 m	50	25	20
1.0 m	100	50	32

Figure 27 shows likely impacts of groundwater inflows to the main channel (pre-interception) between Lock 3 and 4 using the combined totals in Table 8. About 90 % of this impact is from the Loxton – Bookpurnong IAs.

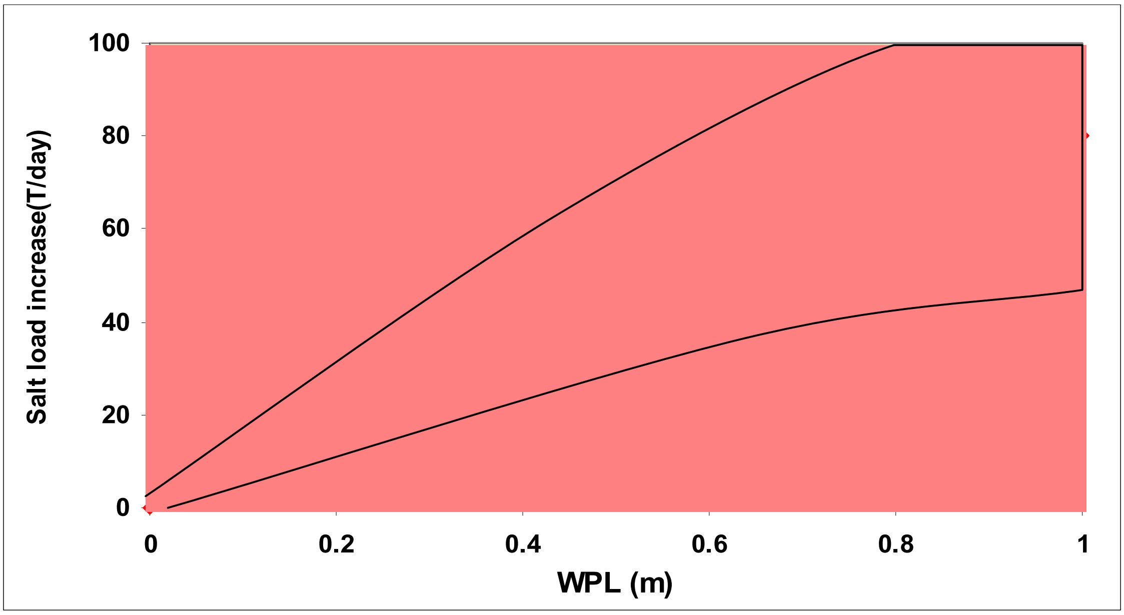


Figure 27. Groundwater saltload prediction tool - Lock 3 to 4.

11.2 Surface Water Impacts

Although groundwater impacts are relatively mild, surface water impacts from the broad floodplain are more significant than from the narrow gorge section downstream of Lock 3. The shortlived Lake Bonney lowering trial (Stace, 1990) demonstrated the profound impact of a three day WPL event that drained Lake Bonney water back into the river causing an increase of 360 EC at Lock 3. Calculations of salt contributions from individual backwaters based on surveys detailed earlier are shown in Figure 28, with the totals for the reach in Table 9.

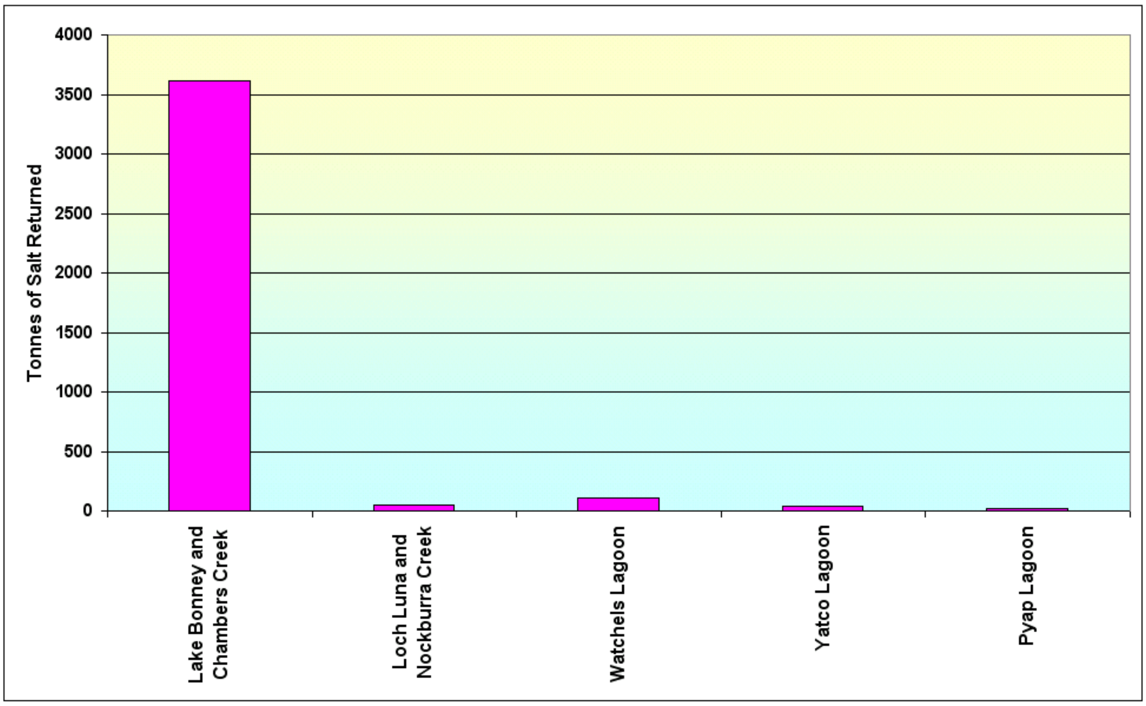


Figure 28. Salt increase from backwaters due to WPL of 0.1 m – Lock 3 to 4.

Table 9. Salt increase from backwaters due to WPL – Lock 3 to Lock 4

WPL	Approximate Volume Returned (ML)	Saltload Increase (Tonnes)
0.1 m	5565	831
0.5 m	23 150	713

As expected, Lake Bonney and Chambers Creek have the greatest contribution to saltloads. Figure 29 shows the estimates of the peak loads during the lowering phase of a WPL event, and is considered an overestimate because most of the backwaters would be disconnected or dry before a lowering of 0.5 m is reached. This contribution far outweighs the groundwater saltloads shown in Figure 27.

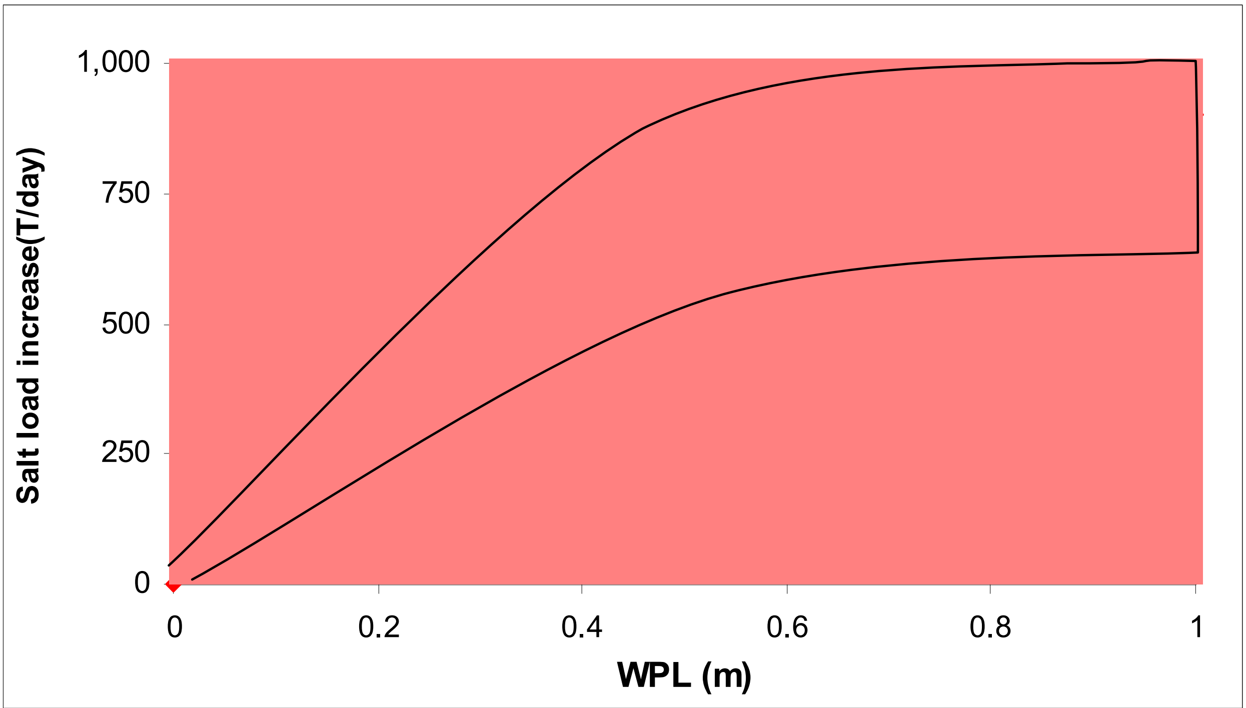


Figure 29. Peak saltloads during lowering - Lock 3 to 4.

12 LOCK 4 TO 5

A rise from 14 m to 17 m AHD occurs in the average floodplain level. A pool level of 13.2 m AHD is maintained with similar trends as described in the previous reach. This reach is more complicated than previous ones because of the Pike River anabranch that connects the upper and lower pool levels around Lock 5. This provides a gradient for surface flow that intercepts natural inflows as well as irrigation return flows with the salt load being returned to the river.

12.1 Groundwater Impacts

A DWLBC traverse drilled on the very wide floodplain opposite Berri that is characterized by anabranches, arcuate lagoons and extensive samphire flats. The river valley has been cut down into the sandy clays and silts of the Bookpurnong Beds and hence fully penetrates the Pliocene Sands watertable aquifer.

The salinity distribution shows a freshening of groundwater by recharge from the river with very high salinities elsewhere on the floodplain due to evaporative concentration. The flow net for entitlement flows confirms that, similar to Morgan, evaporative discharge from the low-lying floodplain has lowered the watertable sufficiently to allow recharge from the river as well as Salt Creek. The raising of the pool level by the establishment of Lock 4 may also have contributed to the observed water table gradient away from both the river and Salt Creek. Recharge from Salt Creek is much lower due to its shallow depth, resulting in minimal dilution of the saline groundwater at Site 2.

The level of the Berri Evaporation Basin on the floodplain is maintained below river level (by pumping to the Noora Evaporation Basin) and consequently, it intercepts groundwater outflows from the watertable mound beneath the Berri IAs.

Because of the raising of river level due to locking, the main inflows downstream of the Pike River would be from the Bookpurnong and Berri IAs. As in the previous reach, a calibrated model was used to estimate inflows for the Bookpurnong IA. After extensive drilling and testing, Howles (1986) calculated inflows from the Berri watertable mound using a similar spreadsheet method, and his parameters were used calculate WPL impacts.

The Pike River system is complicated by the presence of the Col Col embankment which maintains upstream water levels at a higher level than the normal Lock 4 – 5 pool level, but lower than the Lock 5 – 6 pool level. Therefore any WPL for Lock 4 – 5 will increase the head difference at the embankment and increase groundwater flows through the floodplain to the downstream reach. Naturally, inflows to the Pike River from the watertable mound beneath the highland will also increase.

Resource and Environmental Management (2002) carried out a flow tube analysis of these processes, including discharge from the floodplain to the river, before constructing a groundwater model of the area. These parameters were used to deternine the WPL impacts.

Again, the FIP model was used to estimate contributions for the floodplain. The totals, which represent the average saltload over the period of the WPL event when the river level is stabilised at the lower level, are presented in Table 10 and Figure 30.

Table 10. Saltload increase from groundwater due to WPL – Lock 4 to 5

WPL	Saltload Increase – cliffs (T/day)		Saltload Increase from FIP (T/day)
	Peak	Average	
0.5 m	60	30	14
1.0 m	130	65	25

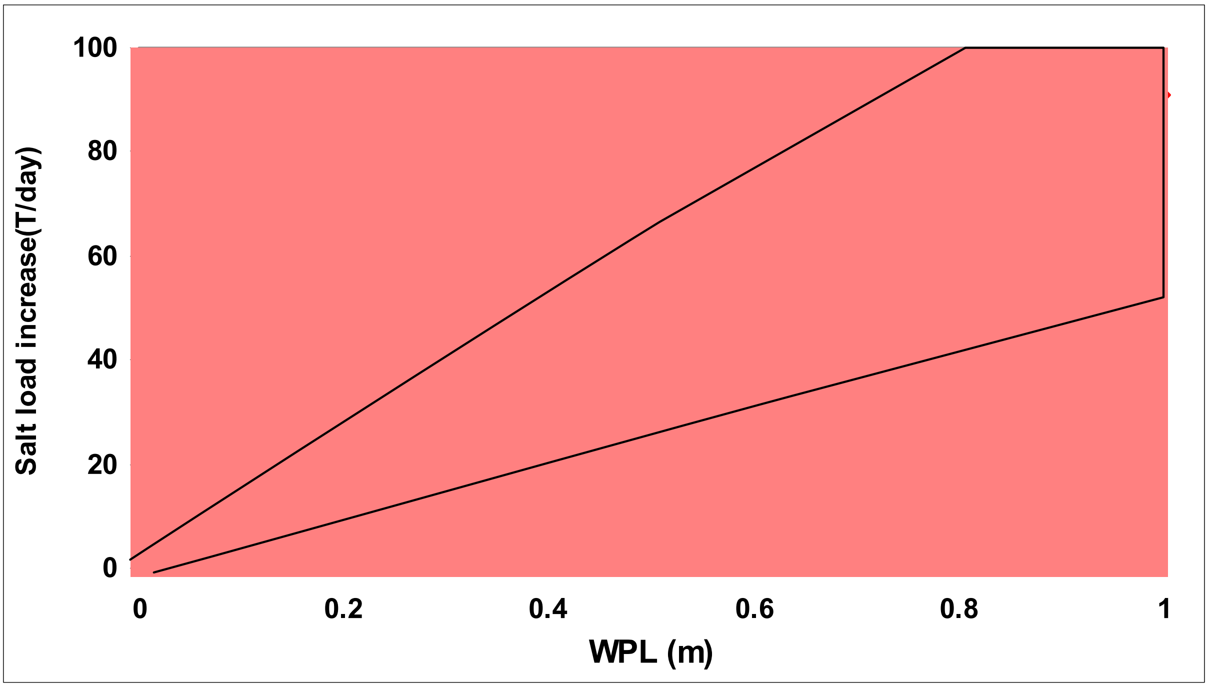


Figure 30. Groundwater saltload prediction tool - Lock 4 to 5.

12.2 Surface Water Impacts

There was not enough information on backwaters available to conduct a detailed analysis of their saltload contribution. The contributions from Pike River due to a WPL event are included in the above graph. Significant saltloads could be expected from the Gurra Gurra Lakes and Salt Creek system.

13 LOCK 5 TO 6

This reach displays similar trends to the previous reaches. Ground level rises from approximately 17 m to 20 m AHD with a pool level of 16.3 m AHD. Again, the presence of anabranches that flow around Locks 5 and 6 complicates the response to WPL and also the determination of the impacts. Compared to other reaches, there are few large backwaters or lakes in direct connection with the river that could make large salinity contributions.

13.1 Groundwater Impacts

In common with other reaches, observation wells in the vicinity of the Jane Eliza Landing marina development immediately upstream of Renmark and Lock 5, showed a watertable gradient away from the river due to evapotranspiration from the broad floodplain and raising of the pool level by locking. Similarly, bores in the vicinity of Lakes Woolpolool and Merreti display watertable elevations below that of the river.

The influence of Lock 5 appears to extend as far upstream as the Templeton wetland where piezometers indicate a gradient away from the river.

Some enhanced inflows as a result of WPL may occur from the eastern side of the river adjacent to the Murtho - Paringa area, although watertable gradients toward the river are currently relatively low compared to other older irrigation areas.

Table 11. Saltload increase from groundwater due to WPL – Lock 5 to 6

WPL	Saltload Increase – cliffs (T/day)		Saltload Increase from FIP (T/day)
	Peak	Average	
0.5 m	20	10	16
1.0 m	40	20	32

13.2 Surface Water Impacts

There was not enough information on backwaters available to conduct a detailed analysis of their saltload contribution. The contributions to Chowilla Creek from groundwater beneath the floodplain due to a WPL event are estimated using a calibrated groundwater model of the Chowilla area. These saltloads are surprisingly small (2 tonnes/day for 0.5 m lowering) due to the current very low groundwater levels resulting in flow away from the creeks.

Investigations in the Ral Ral Creek area (Woodward Clyde, 2000) found that saltloads of 34 tonnes/day entered the floodplain to the east of the small irrigation mound beneath the Renmark IA. Of this load, only 16 tonnes/day discharged to the River Murray via Ral Ral Creek due evaporative discharge from the salinised floodplain. A conservative estimate of a doubling of the saltload for a WPL of 0.5 m is assumed. A groundwater model of the area may be used for more refined estimates if needed.

Figure 31 shows the combined estimates of all of the above impacts from surface and groundwater for the average saltload over the period of the WPL event (excluding the peak).

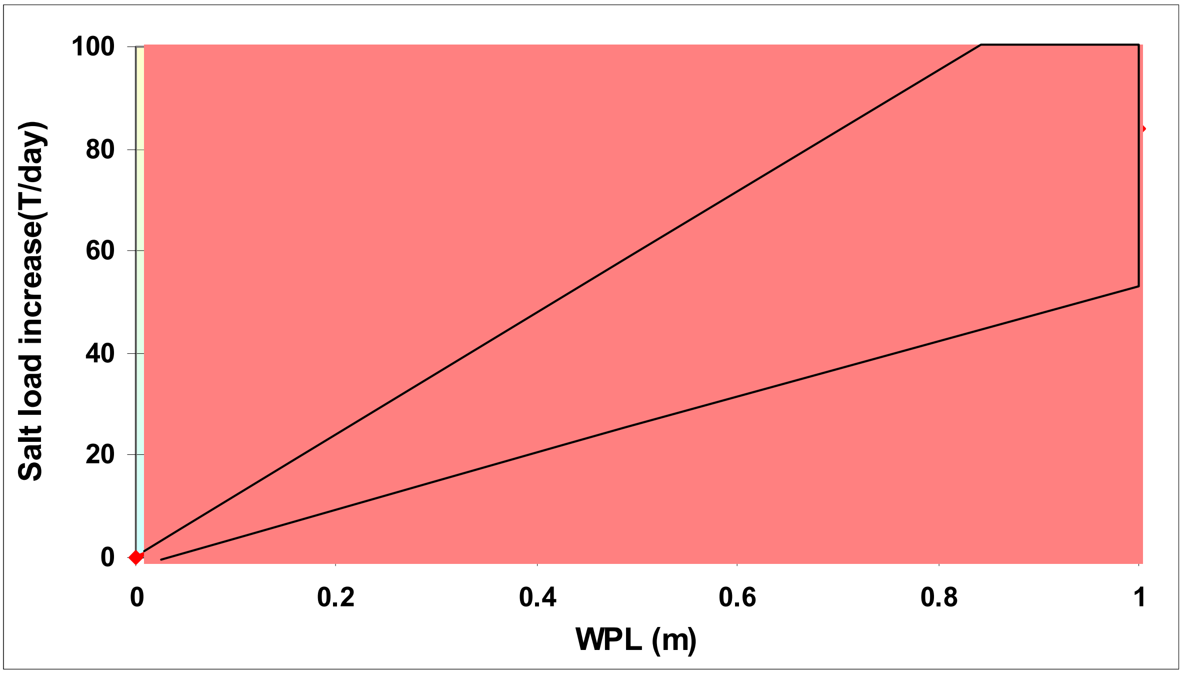


Figure 31. Groundwater saltload prediction tool - Lock 5 to 6.

14 LOCK 6 TO 7

Although not in SA, this reach was included because some groundwater information was available as an output from the Tri-State hydrogeological project. Again, this reach has complications due to the Lindsay River anabranch, and a lack of data on the NSW bank of the river. Obviously, the appropriate NSW and Victorian authorities would have to be involved in further work before this reach could to be selected for a WPL trial. A regional groundwater model has been constructed by SKM for the Lindsay River area south of the River Murray between the State border and Lock 7, and could be used for more detailed investigations on the Victorian side of the River Murray.

14.1 Groundwater Impacts

The impact of raising the watertable on the Chowilla floodplain due to the Lock 6 weir pool is understood and is being further investigated. An east to west regional watertable gradient exists from the upper Lock 6 pool level at Lindsay Point, to the lower pool level in the Murtho area, indicating groundwater flow away from the river for some distance upstream, despite the presence of a small watertable mound beneath irrigation at Lindsay Point. Return flows would only be expected with WPL events approaching 1.0 m.

Dudding and Evans (2001) found that after several years of entitlement flow (unaffected by flood recession), groundwater discharge occurs to the upper Lindsay River from regional groundwater at a rate of 17 tonnes/day. Evapotranspiration from the large area of floodplain induces flow away from the river and anabranches into the floodplain.

Although there is insufficient information to determine impacts from the NSW side of the river, the impacts from a WPL event in this reach are expected to be relatively small.

14.2 Surface Water Impacts

There is insufficient readily available information to determine impacts from backwaters in this reach.

15 PREDICTED SALINITY IMPACT FROM A WPL SCENARIO

A series of scenarios were run to estimate the salinity impact of a WPL at a rate of 2 cm/per day in various reaches of the river. The reaches chosen represent both the narrow gorge section (Tailem Bend to Lock 1, Lock 1 to 2), and the broad valley section (Lock 3 to 4). These impacts were calculated for the first month of a typical WPL event and consider the likely range of salt returned to the river from the backwaters as well as groundwater from both the cliff sections and the floodplain. WPL events of 0.25 m, 0.5 m and 1.0 m were used as a basis for calculations. An entitlement flow of 3000 ML/day was assumed below Lock 2.

While these graphs show a very clear delineation between when the river is falling and backwaters are returning salt, and when this process stops, in reality this is likely to be an ongoing process of mixing until the river and backwaters reach equilibrium. The salinity response in reality would resemble a smooth curve rather than the linear one depicted in the following graphs.

15.1 Tailem Bend to Lock 1

Figure 32 shows the salinity increase for a WPL event of 0.5 m and combines the saltload impacts from Figures 22 and 24. A 2 cm/day drawdown is likely to result in maximum increases of around 160 EC, although this could be as high as 220 EC if the upper groundwater return estimate is used. Once the river stops falling these salt returns are likely to stabilise at salinity levels of between 40 and 80 EC higher than normal.

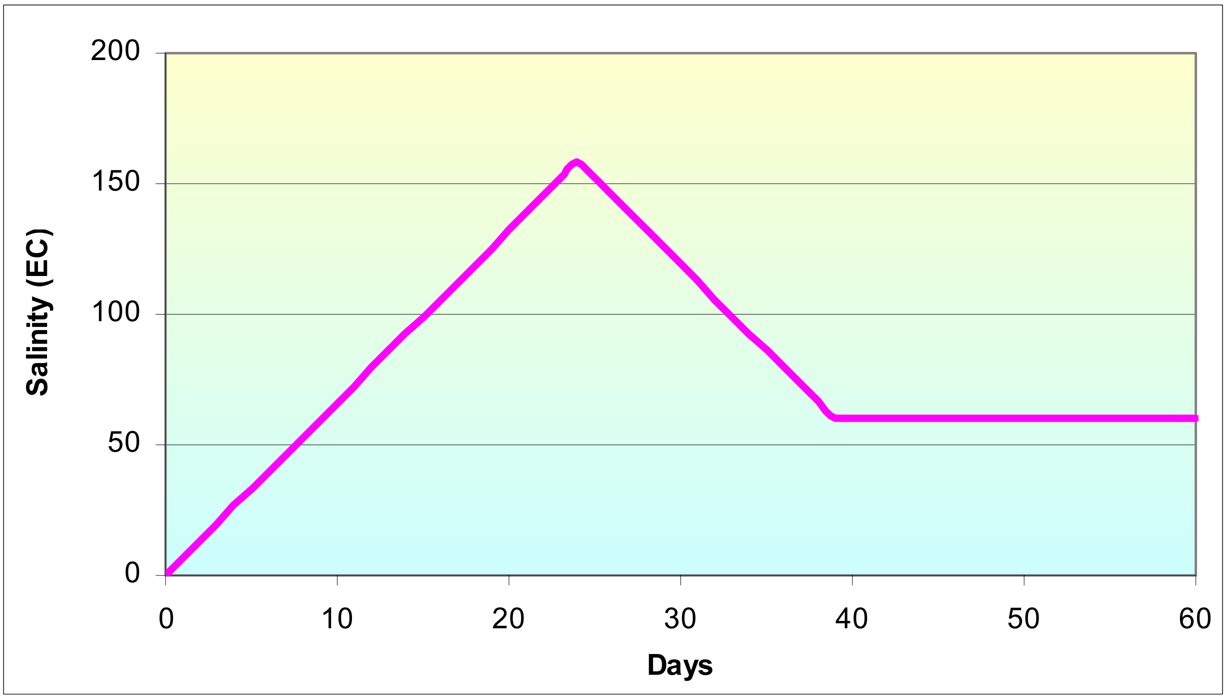


Figure 32. Salinity increase for WPL of 0.5 m - Tailem Bend to Lock 1.

This graph excludes the impacts of the lakes which as mentioned previously, have complex salinity responses to evaporation, surface water inflows, leakage beneath barrages and so on.

15.2 Lock 1 to 2

The response in this reach is much lower than below Lock 1 with again, a 2 cm/day drawdown. Figure 33 shows the response for various magnitudes of WPL and combines the impacts shown in Figures 24 and 26. The response 'flattens out' above 0.5 m as the backwater contribution decreases due to drying or disconnection from the main channel.

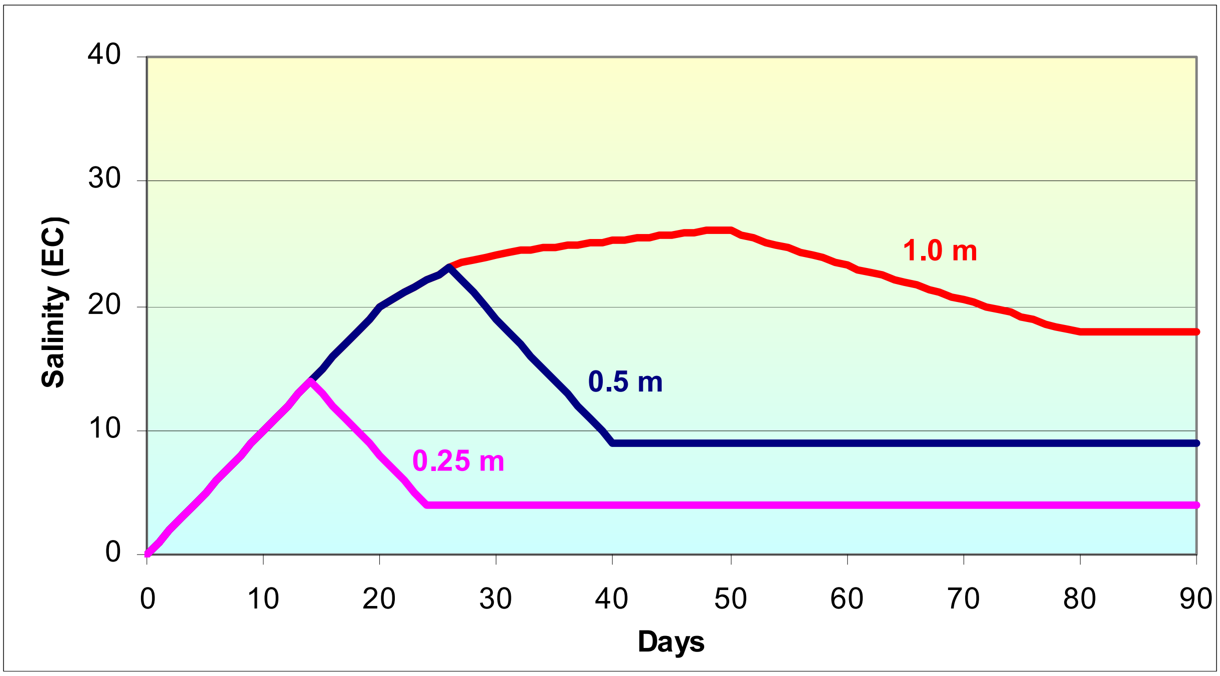


Figure 33. Salinity increase for WPL - Lock 1 to 2.

The salinity response is quite low compared to other reaches. For a WPL of 0.5 m, the peak salinity increase would be expected to be in the range 18–30 EC before stabilising at 5–12 EC above previous levels for the duration of the WPL event.

15.2 Lock 3 to 4

The salinity increase from Lock 3 to 4 as shown in Figure 34 is very dramatic and combines the impacts of Figures 27 and 29. The impact from backwaters, particularly Lake Bonney overwhelms that from groundwater as discussed previously. Obviously, these rises would be unacceptable. Figure 34 shows good agreement with the observed rise of 360 EC at Lock 3 due to the previous WPL of 0.45 m.

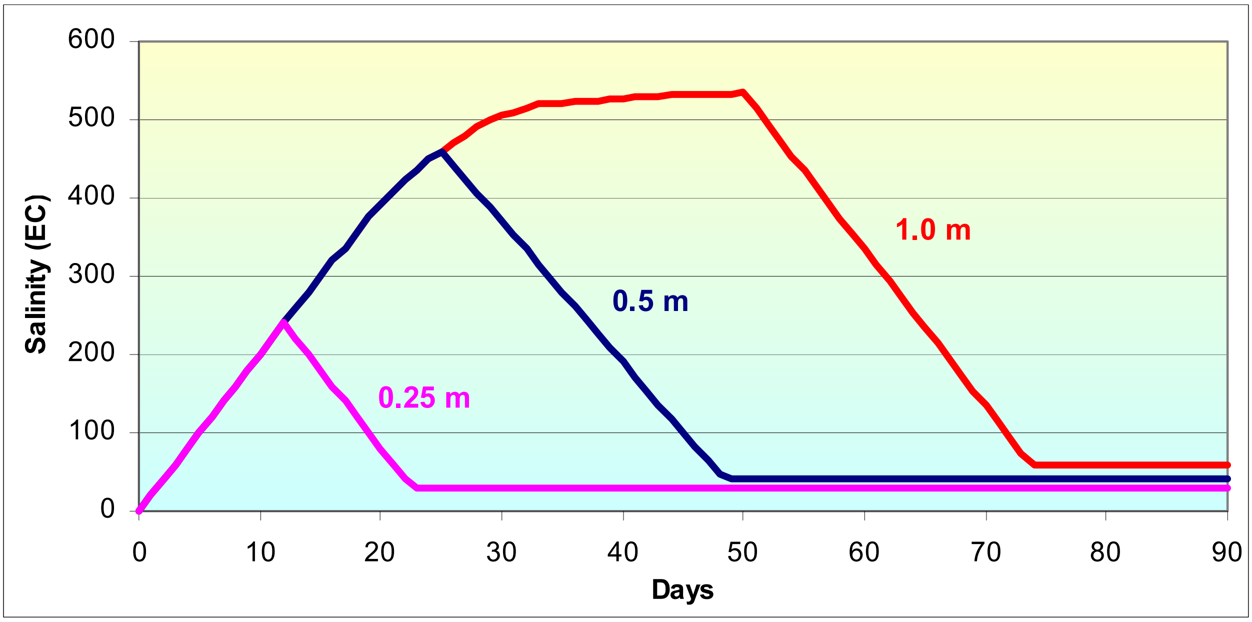


Figure 34. Salinity increase for WPL - Lock 3 to 4.

16 CONCLUSIONS & RECOMMENDATIONS

A weir pool lowering exercise in order to improve wetland and River ecosystem condition will induce increased saltloads to the river from several sources – groundwater (floodplains and cliff), backwaters and anabranches. The relative contributions from these sources depend on the geomorphology of the river valley. In the narrow gorge section below Overland Corner, groundwater contributions predominate due to the river channel being adjacent to the cliffs for significant distances. In the broad valley upstream of Overland Corner, contributions from large shallow lakes and lagoons predominate.

Prediction tools for the estimation of the magnitude of saltload increases were made using a combination of different techniques (indicative of varying degrees of information quality and management tools available in different areas). These techniques include calibrated groundwater models, GIS models, spreadsheets using Darcy's Law and backwater salinity measurements.

Estimates of saltloads from WPL events in various reaches enabled prioritisation of reaches based on low salinity impact for further work. A summary is presented in Table 12.

Table 12. Summary of saltload increases due to WPL of 0.5 m (tonnes/day)

Reach	Groundwater		Backwaters
	Peak	Average	
Barrages to Lock 1	210	135	30
Lock 1 to 2	30	15	4
Lock 3 to 4	90	45	713
Lock 4 to 5	88	44	?
Lock 5 to 6	52	25	?

Conversion of these saltloads to estimates of salinity responses for a WPL event of 0.5 m, range from a peak increase of only 23 EC for Lock 1 to 2, 160 EC for Lock 1 to Tailem Bend, and an enormous 450 EC for Lock 3 to 4. These results show that Lock 1 to 2 and Lock 5 to 6 have the lowest salinity impact. Lock 6 to 7 has good potential, but will need more investigation involving both Victoria and NSW.

The complex relationship between flow and salinity and the uncertainties in estimating both, mean that the salinity impact from WPL events may be difficult to distinguish from other natural events, and that the actual impact may be difficult to measure.

Further work on priority reaches should include bathymetry and regular salinity monitoring of backwaters, ground EM traverses and possibly drilling in key locations, groundwater modelling and an instream EM survey to locate areas of high salinity adjacent to the river. To enable better estimates of river flow in these reaches, bathymetry of the river should be refined.

17 REFERENCES

Barnett, S.R., 1992. Regional hydrogeology of the Cooke Plains – Coomandook area, Murray Basin. *South Australia*. *Department of Mines and Energy. Report Book,* 92/14.

Barnett, S., Yan, W., Watkins, N.L., Woods, J.A. and Hyde, K.A., 2002. Murray-Darling Basin Salinity Audit — groundwater modelling to predict future dryland salt loads to the River Murray in South Australia. *South Australia. Department for Water Resources. Report,* DWR 2001/017.

Barnett, S.R. and Marsden, Z.E., 2003. The hydrogeology of the River Murray alluvium. South Australia. *Department of Water, Land and Biodiversity Conservation. Report* (in prep).

Dudding, M. and Evans, R.S., 2001. Salt discharge mechanism into the Murray River floodplain at Lindsay Island. 8th Murray-Darling Basin Groundwater Workshop, Victor Harbor, September 2001.

Howles, S.R., 1986. Berri East groundwater interception scheme, hydrogeological investigation. *South Australia. Department of Mines and Energy. Report Book,* 86/59.

McCarthy, B., Ellis, I. and Gawne, B., 2003. Drawdown of the Mildura Weir Pool 2001, 2002 & 2003: Water Quality Responses. *Murray Darling Freshwater Research Centre, Lower Basin Laboratory, Mildura. Report No*. 8/2003.

Murray Darling Basin Commision, 1990. The Murray, ed. Norman Mackay and David Eastburn, CSIRO Publications, East Melbourne, Victoria.

Overton, I.C., Jolly, I.D., Holland, K.L. and Walker, G.R., 2003. The Floodplain Impacts Model (FIP): A tool for assisting the assessment of the impacts of groundwater inflows to the floodplains of the lower River Murray. CSIRO Land and Water.

Porter, B., 2001. Run of River salinity surveys - A method of measuring salt load accessions to the River Murray on a kilometer by kilometer basis. 8th Murray-Darling Basin Groundwater Workshop, Victor Harbor, September 2001.

Resource and Environmental Management, 2002. Hydrogeological assessment of the Pike River and Murtho Land and Water Management Plan areas. *for* Renmark to the Border Local action Planning Association.

Rural Water Commission, 1991. *Mildura Hydrogeological Map* (1:250 000 scale). Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

Stace, P.M., 1990. Lake Bonney lowering and filling trial, May 1989 to Jan 1990. Technical report – hydrological activities. *Engineering and Water Supply Department*.

Williams, R.M. and Erny, M., 2003. Conceptual model for the Buronga salt interception scheme, NSW. *In: Balancing the Groundwater Budget,* International IAH Groundwater Conference, Darwin, 2002.

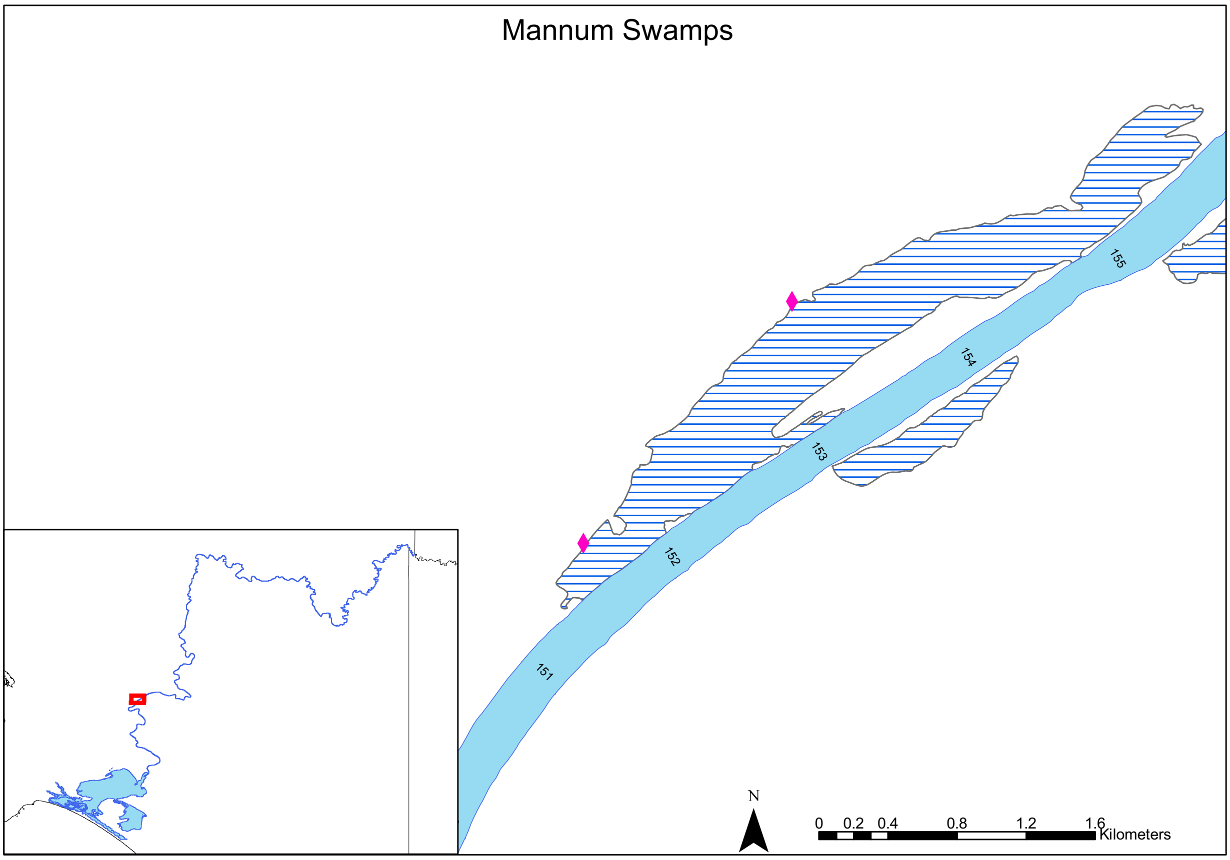
Woodward – Clyde, 2000. Ral Ral saline groundwater control options investigation. Renmark to Border Local Action Planning Association.

18 APPENDIX A



INDIVIDUAL BACKWATER DATA

Mannum Swamps



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
South	555	10.1	0.4	11/08/2003
South Bottom	570	10.1		11/08/2003
West	505	10.9		11/08/2003

Notes

Although not possible to get into the backwater itself, inroads were made at the connections where the readings where consistently between 500-515 EC. The bottom reading will not be included in the average salinity value as this is likely to give an inappropriately high reading.

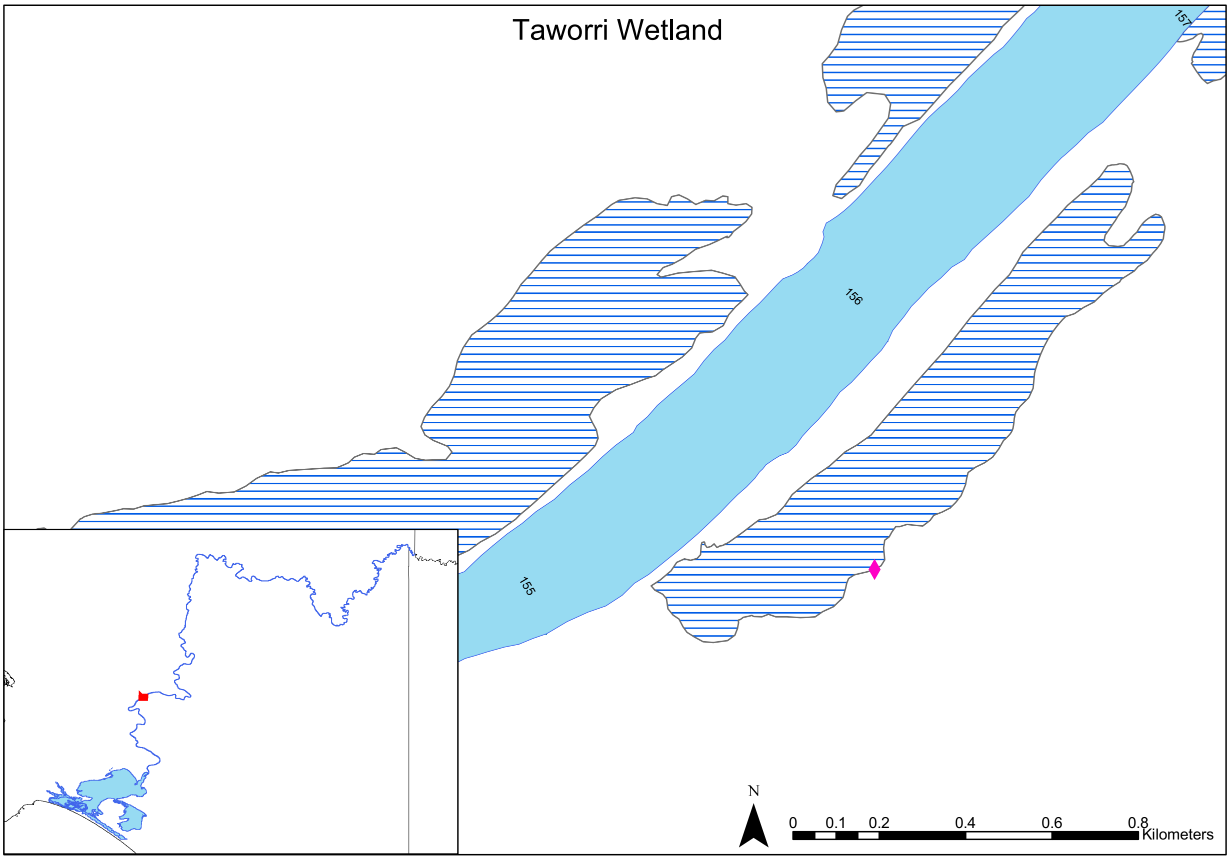
Average Salinity (uS/cm) = 530

Total area (SgM) = 1973570.27

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	179565.52	negligible

Taworri Wetland



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
South-East	660	9.3	0.5	12/08/2003

Notes

Although not shown on the above map, there does appear to be some connection with the river although this is likely to be cut of fairly rapidly with any decrease in river height.

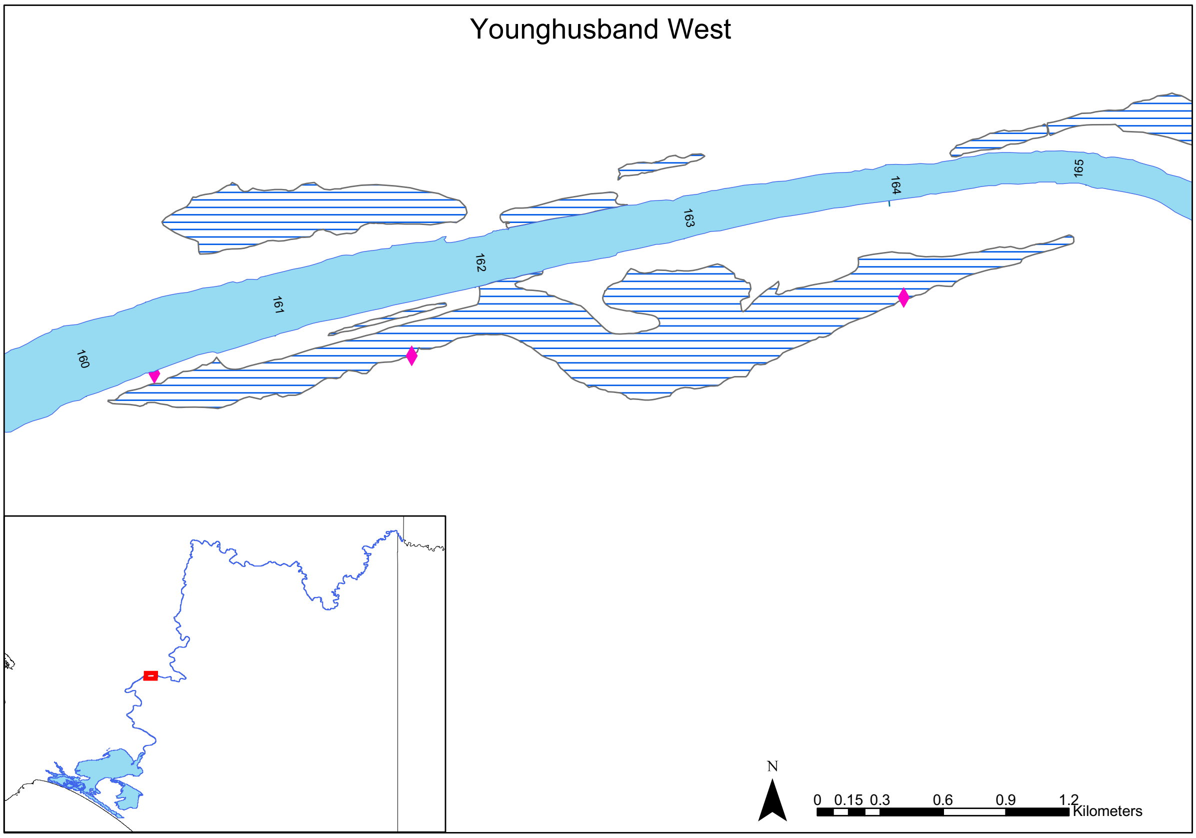
Average Salinity (uS/cm) = 660

Total area (SgM) = 311651.66

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	24627.59	1.55

Younghusband West



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
West	534	11	0.4	11/08/2003
South @ Bank	650	10.4		12/08/2003
South 5-6m out	540	10.5	0.5	12/08/2003
East in Pump Channel	635	11		12/08/2003
East Top of Pump Channel	590	10.8		12/08/2003

Notes

Where possible, the central region of this backwater was boated taking a number of spot readings, all ranging between 545-534 EC. Due to what appears to a fairly strong edge effect, the two highest readings have not been included in deriving an average value as these were felt not to be indicative of the entire waterbody.

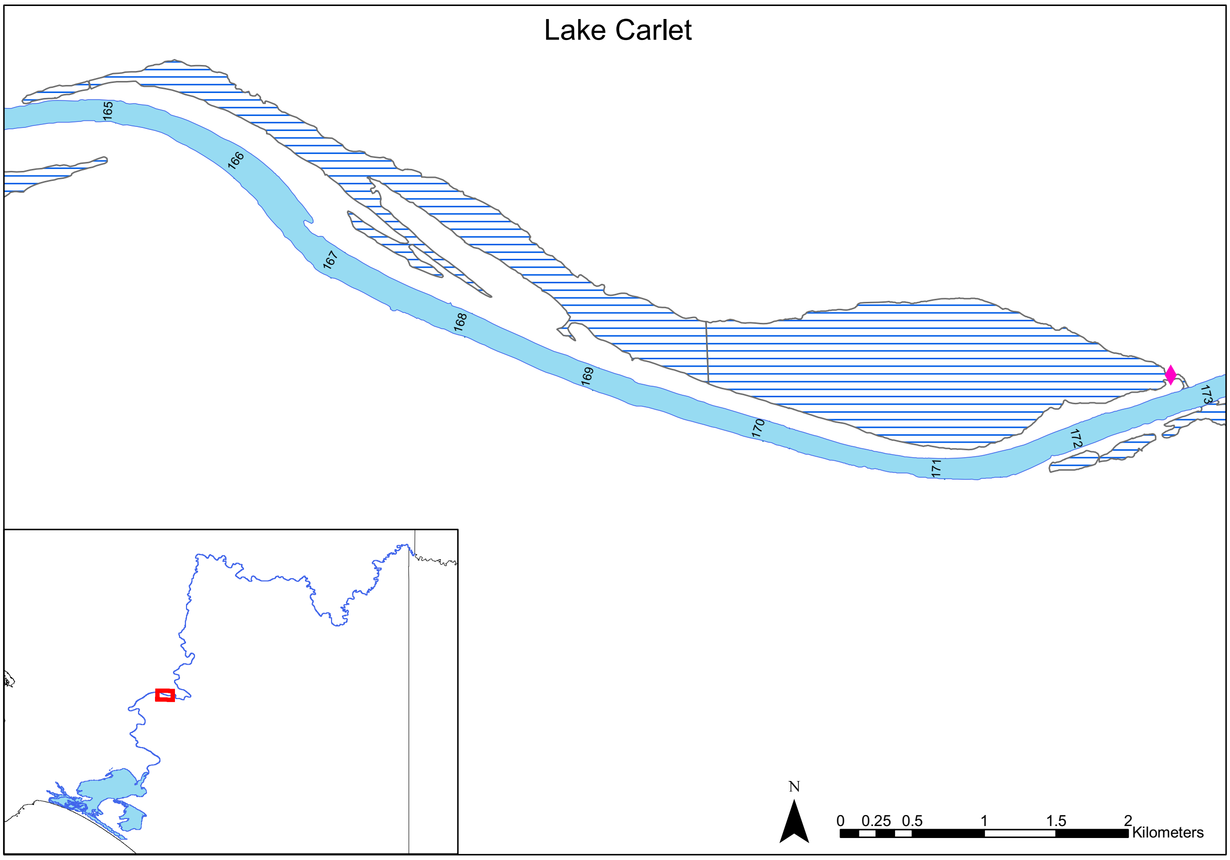
Average Salinity (uS/cm) = 554.67

Total area (SgM) = 1098780.85

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	96827.15	0.48

Lake Carlet



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
Eastern Inflow	535	11.2		11/08/2003

Notes

There was a very strong inflowing current at this site indicating that this was primarily river water. It was also strong enough however, to indicate that flow through this backwater was generally high, and in fact was likely to flow through exiting at a downstream connection. It was likely that there was a reasonable degree of mixing, keeping salinity values down.

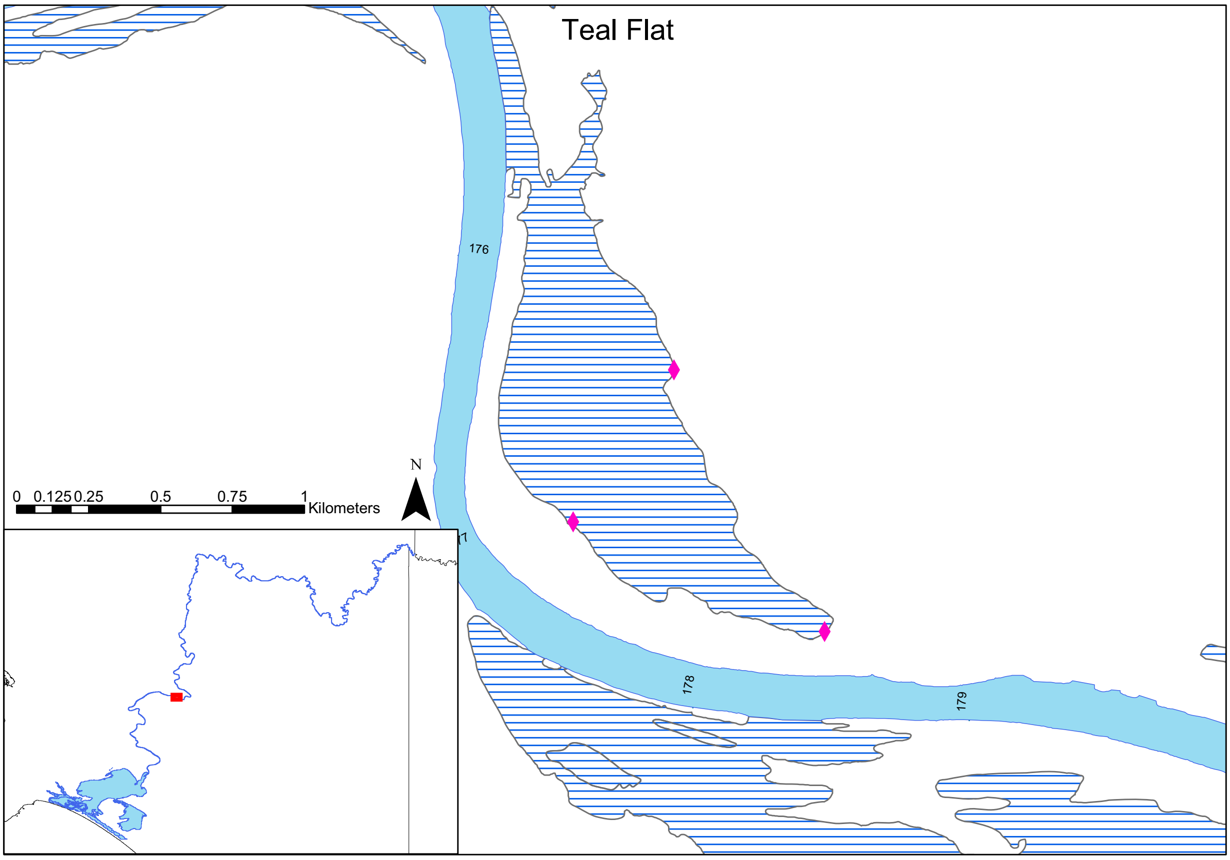
Average Salinity (uS/cm) = 535

Total area (SgM) = 3477845.57

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	323877.28	negligible

Teal Flat



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
East	720	13.6		11/08/2003
East Bottom	760	14.6		11/08/2003
West	730	13.7		11/08/2003
South	1150	13.5		11/08/2003

Notes

The highest reading of 1150 EC in the southern region was taken amongst reeds in fairly shallow water, which is representative of much of this southern region. Due to the large degree of visible aquatic vegetation and snags, it is estimated that this backwater would in general only have a depth at this time of between 20 and 30 cm. Due to the shallowness of the backwater it was felt appropriate to include the bottom reading.

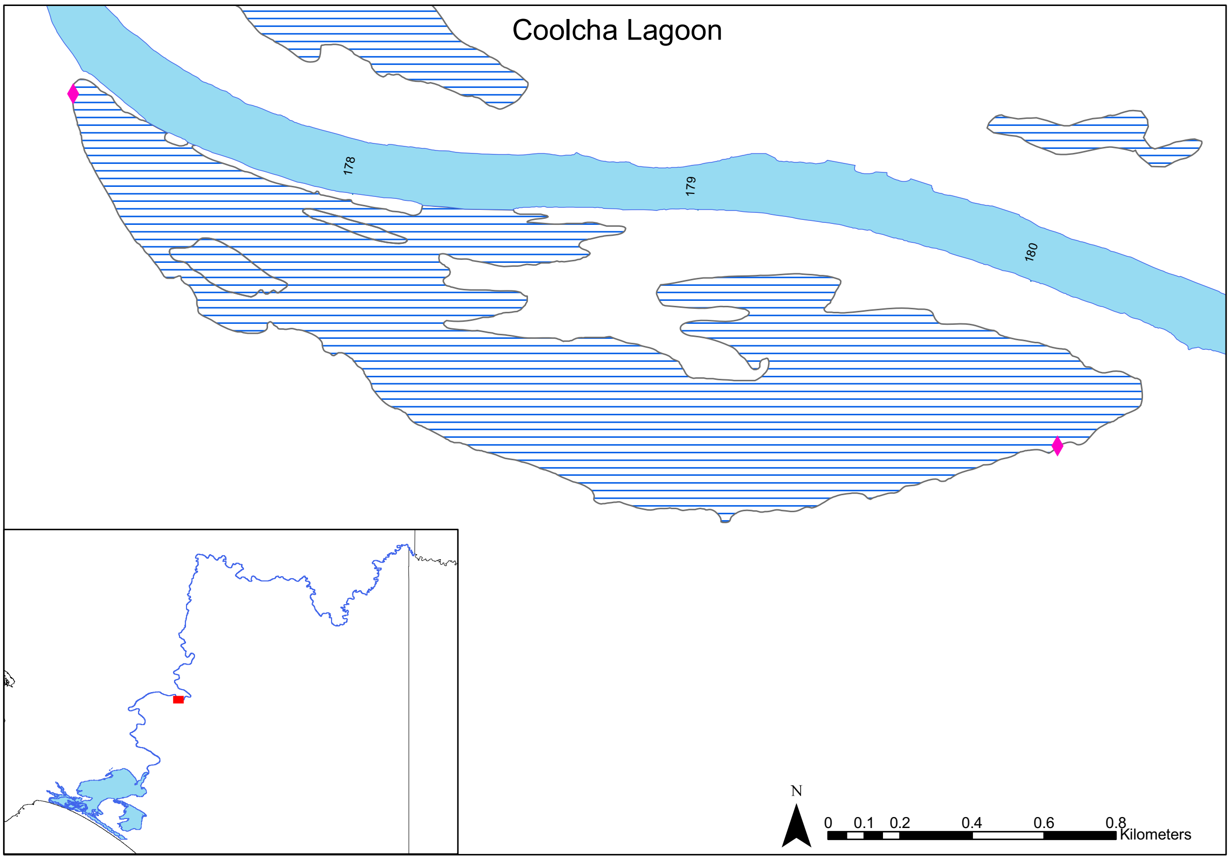
Average Salinity (uS/cm) = 840

Total area (SgM) = 818853.06

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	70739.61	11.46

Coolcha Lagoon



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
West	550	10.3		12/08/2003
East	730	11		12/08/2003

Notes

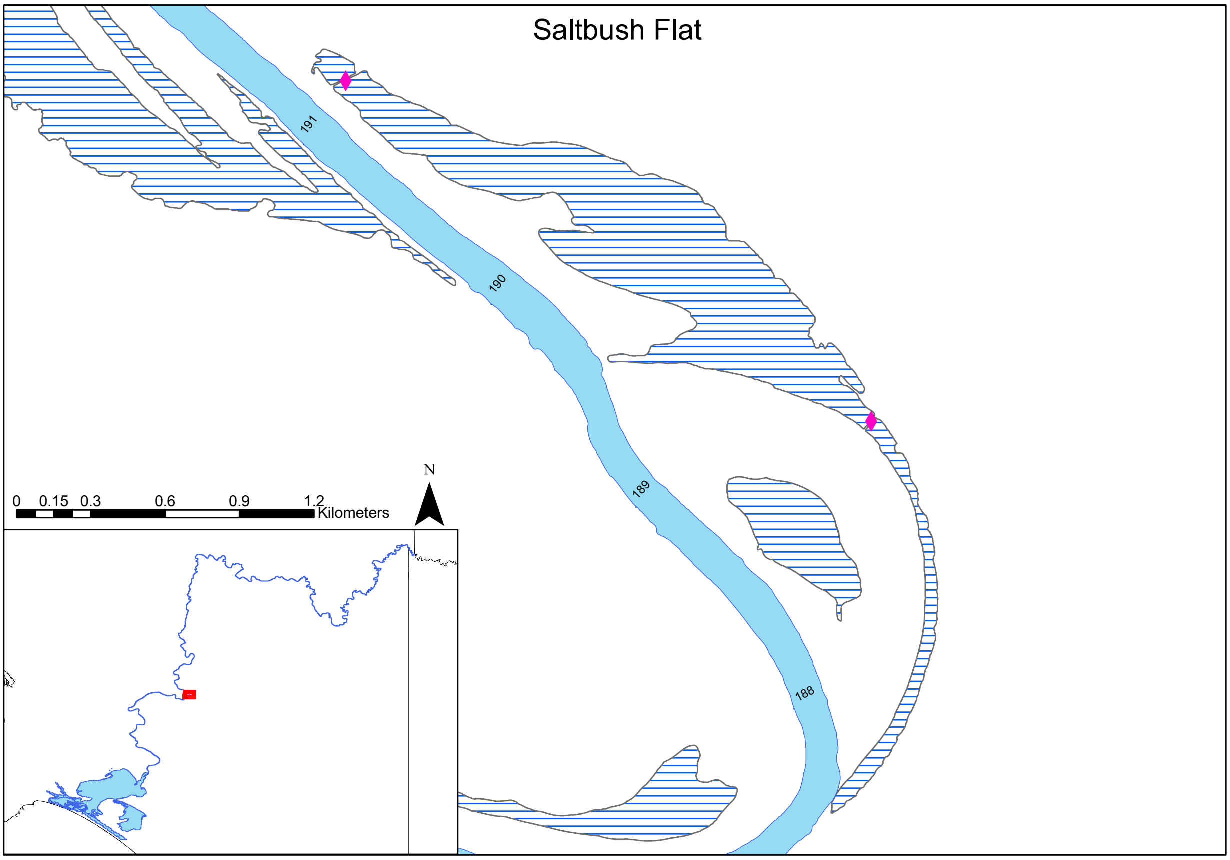
Average Salinity (uS/cm) = 640

Total area (SgM) = 1314950.28

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	117134.88	6.09

Saltbush Flat



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
North	2920	13		12/08/2003
South	4880	12.1		12/08/2003

Notes

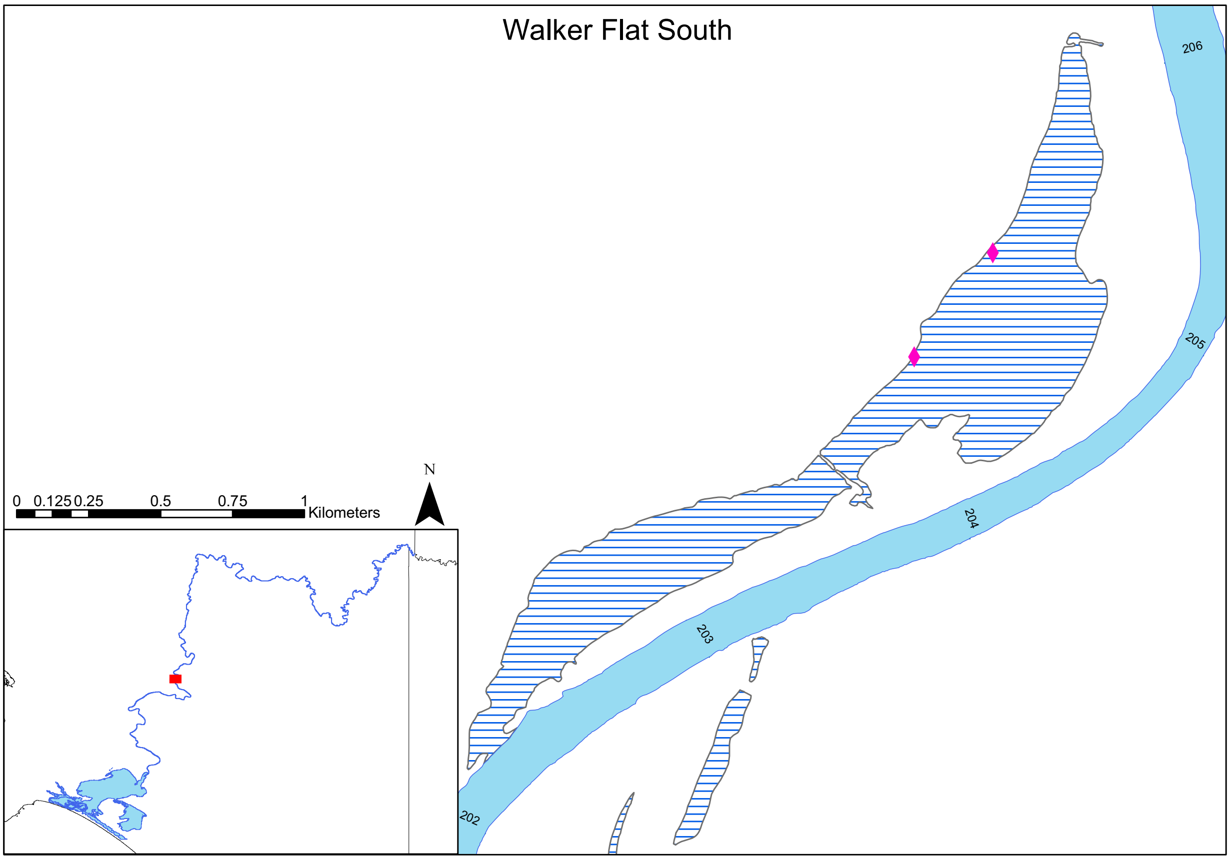
This backwater appears to be currently isolated from the river although there may be some small wind-induced exchange at the channel located towards the centre of the backwater. It is unlikely that this backwater will contribute any surface water to the river due to lowering.

Average Salinity (uS/cm) = 3900
Total area (SgM) = 853632.44

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	73964.74	Not Connected

Walker Flat South



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
North	690	12.8		11/08/2003
South	670	12.3		11/08/2003

Notes

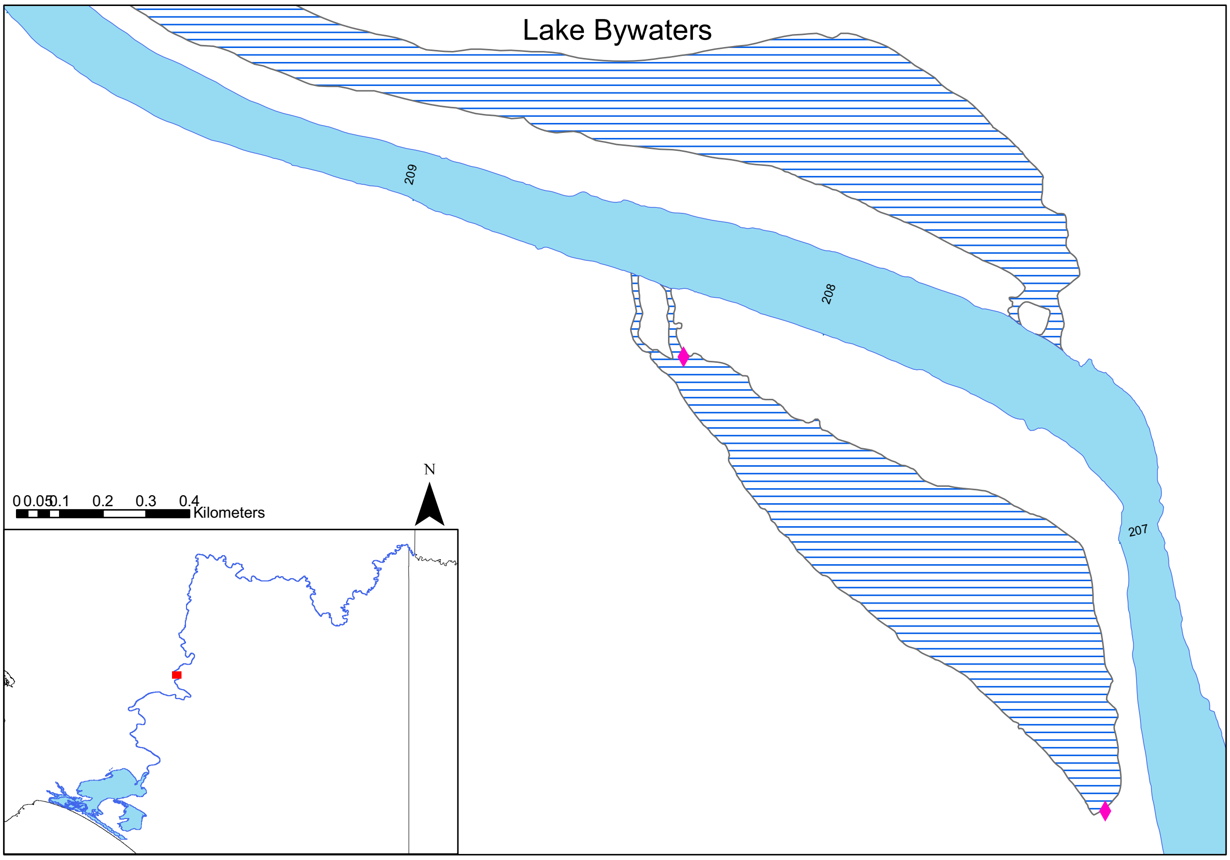
This backwater appears to be quite shallow from the bank, between 20-30cm in average depth at the time of the survey.

Average Salinity (uS/cm) = 680
Total area (SgM) = 886098.4

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	76979.96	5.7

Lake Bywaters



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
South	565	14.2		11/08/2003
North	540	11.2		11/08/2003

Notes

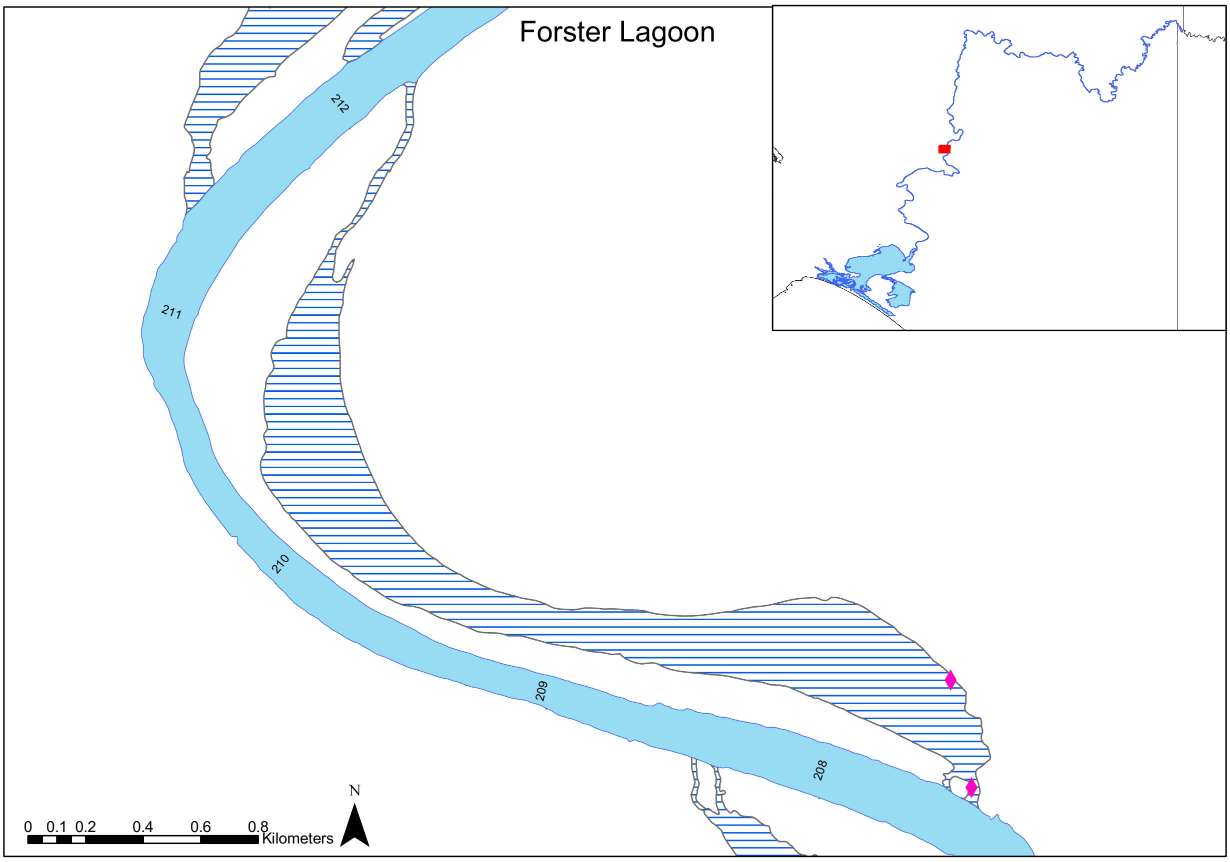
It appears that this backwater flows out of the southern end at the south site (this is a causeway) into a small channel ultimately flowing into the Walker Flat South Backwater from the previous page.

Average Salinity (uS/cm) = 552.5
Total area (SgM) = 387012.73

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	31314.97	0.09

Forster Lagoon



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
South	544	11.6	1	11/08/2003
North	545	12.6		11/08/2003

Notes

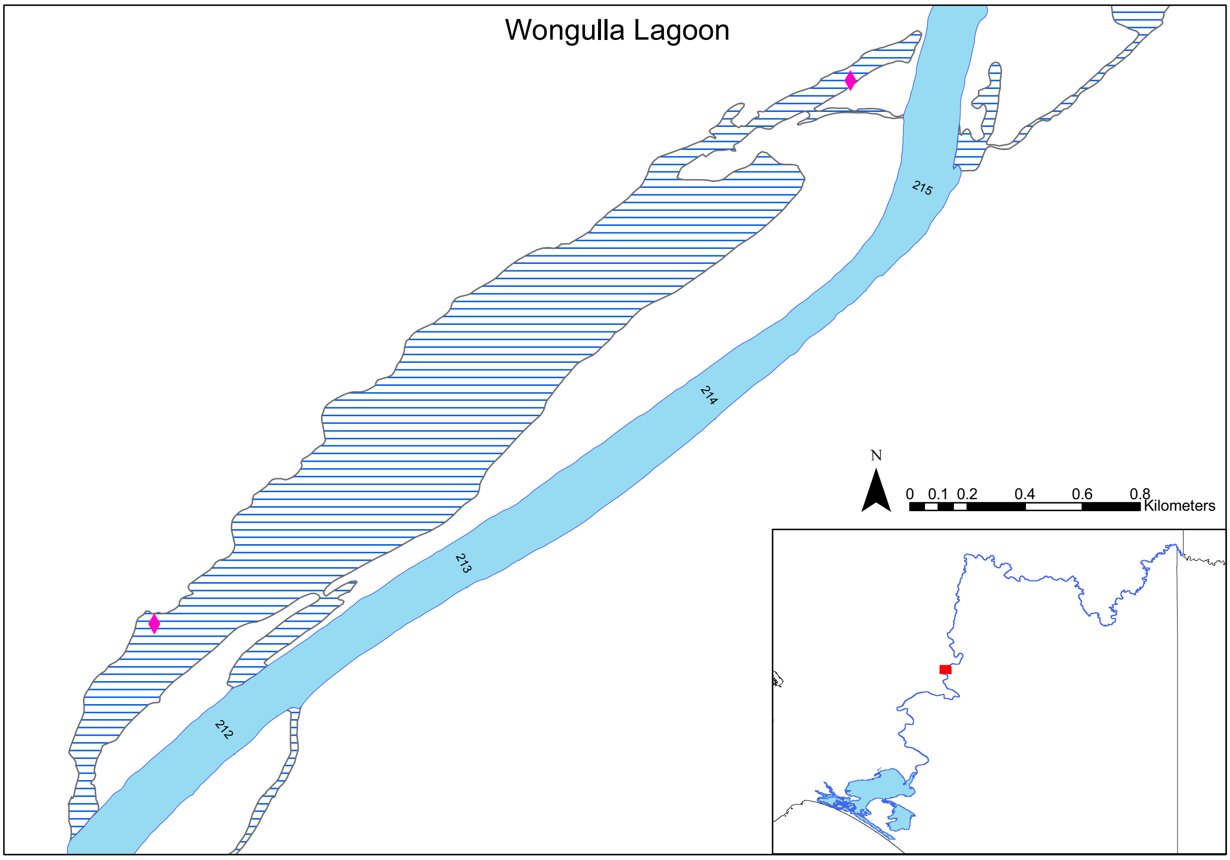
Most of lower region accessible by boat appears to have consistent readings.

Average Salinity (uS/cm) = 544.5
Total area (SgM) = 793747.51

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	68414.9	negligible

Wongulla Lagoon



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
SouthWest	555	11.5		11/08/2003
NorthEast	2000	11.8		11/08/2003

Notes

The NorthEast reading was located on the southern side of a causeway in a shallow swampy region. This area appeared not to be connected currently to the rest of the wetland and will not be included in the average salinity calculated for this backwater. This reading is likely to indicate that the upper reaches of this backwater would be higher that 555 EC and as such, the average salinity of this backwater will be defined as being 100 EC above the SouthWest value. This appears to be quite a shallow lagoon eg. 20-30cm in depth during survey.

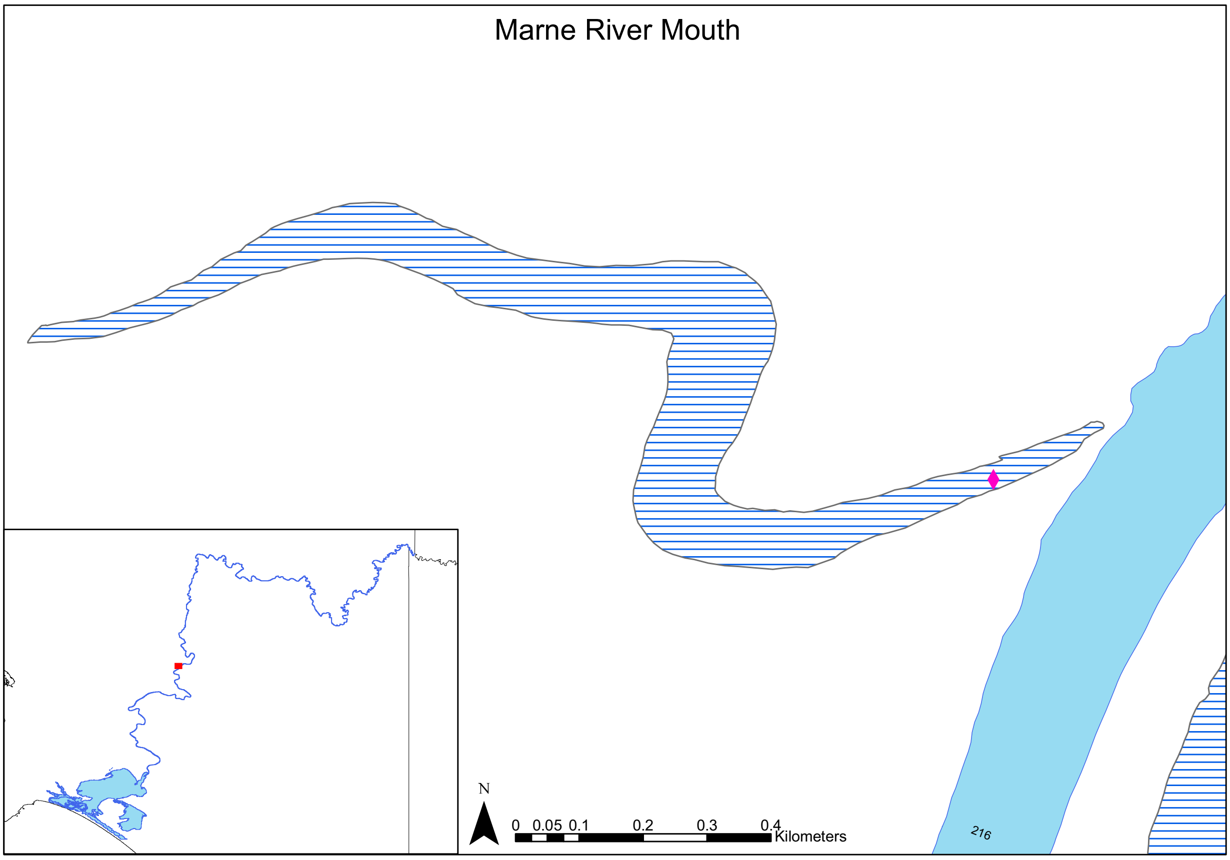
Average Salinity (uS/cm) = 655 (Estimated - see above)

Total area (SgM) = 1237558.74

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	109851.12	6.59

Marne River Mouth



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
East (Shown)	1614	11.8		11/08/2003
West (Not Shown)	5850	7.3		12/08/2003

Notes

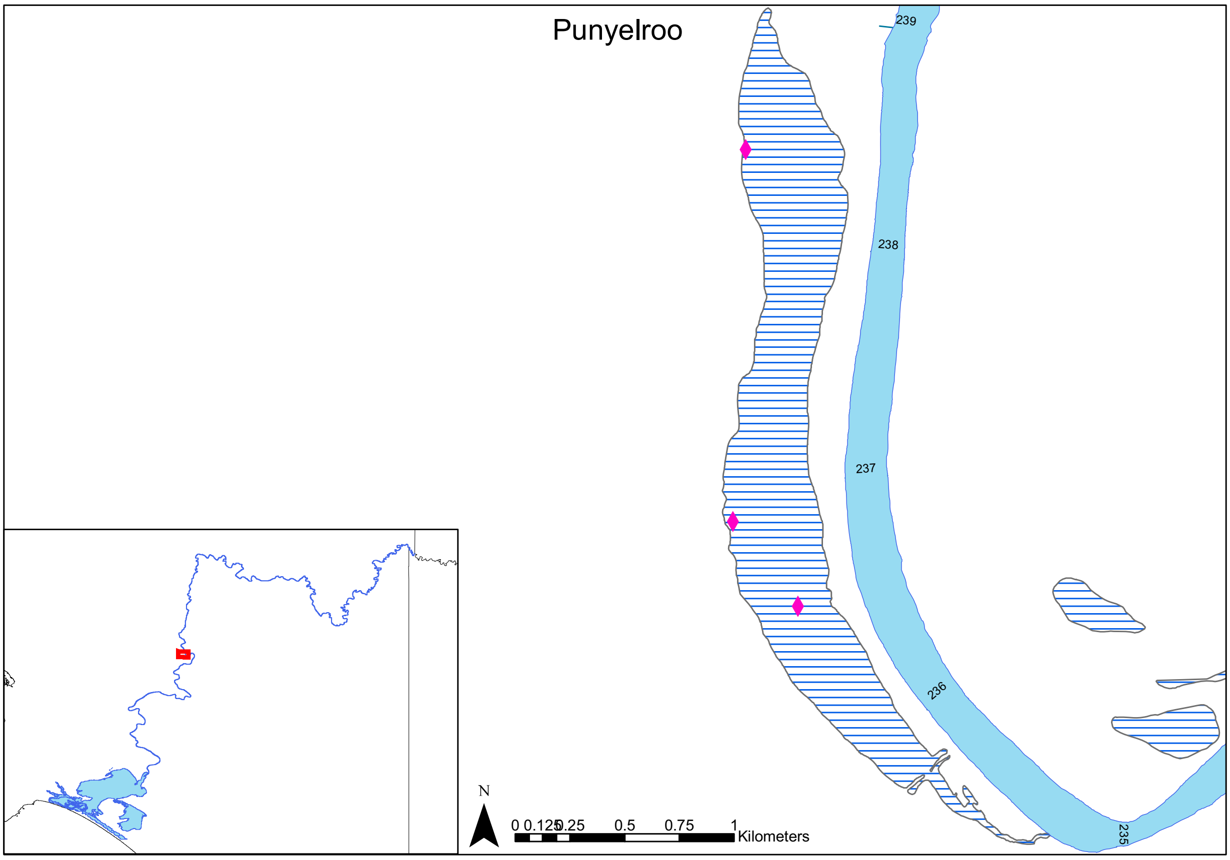
The west value is further upstream along the Marne River, however this is not likely to connect to the lower backwater, and will not be used to calculate the average salinity. It is however likely to be indicative of the salinity values that could regularly be expected through this region.

Average Salinity (uS/cm) = 1614
Total area (SgM) = 170641.46

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	12456.38	7.35

Punyelroo



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
North	620	14.3		12/08/2003
West	620	15		12/08/2003
South (N Causeway)	590	12.7		12/08/2003
South (S Causeway)	607	13		12/08/2003

Notes

The South site is located on a causeway with pools either side connected by a large pipe. On the northern side of this causeway, a channel to the river has been dug giving a very good connection at this point.

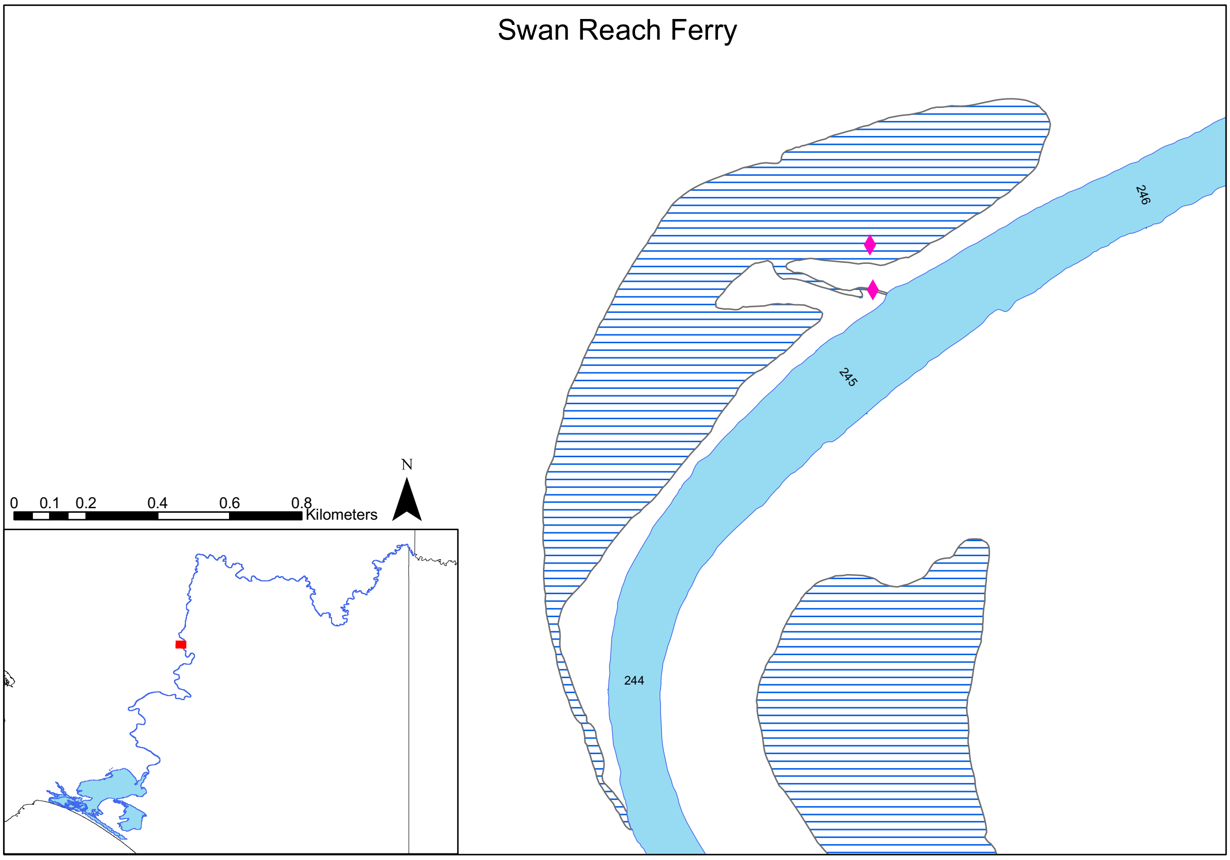
Average Salinity (uS/cm) = 609.25

Total area (SgM) = 1250737.16

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	111090.42	3.89

Swan Reach Ferry



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
South	563	12.1		12/08/2003
North (amongst vegetation)	2200	14.6		12/08/2003
North (open water)	1780	14.6		12/08/2003

Notes

The South site was located as far up this channel as it was possible to boat. Unfortunately this was not far and the water appeared to be fairly still. This reading probably is a better indicator of river salinity than backwater salinity. At the North site, two readings were taken, one at the waters edge amongst some fairly dense vegetation, while the second reading was taken further out. This may indicate that the salinity is less in the more open water. Only this last value will be used to define the average salinity backwater.

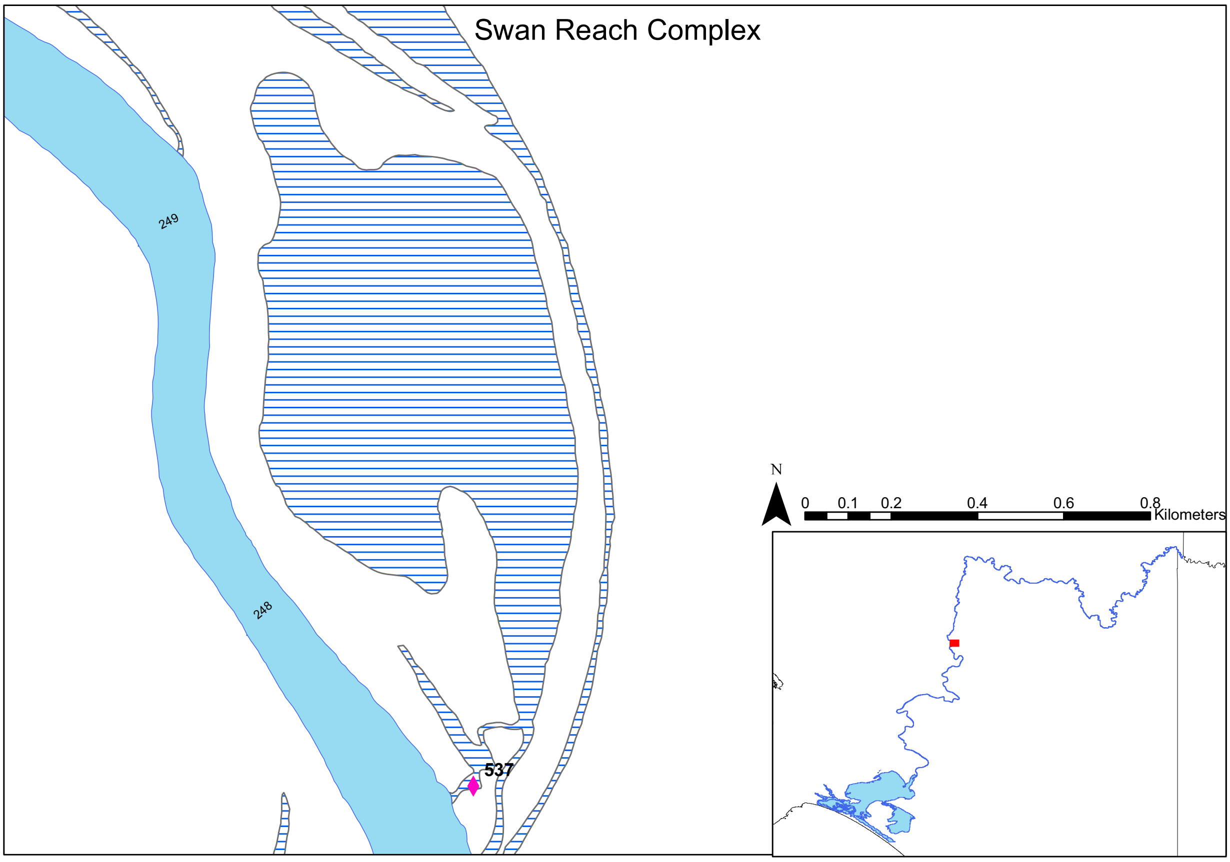
Average Salinity (uS/cm) = 1780

Total area (SgM) = 677445.52

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	57686.71	39.34

Swan Reach Complex



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
South	537	14.6		12/08/2003

Notes

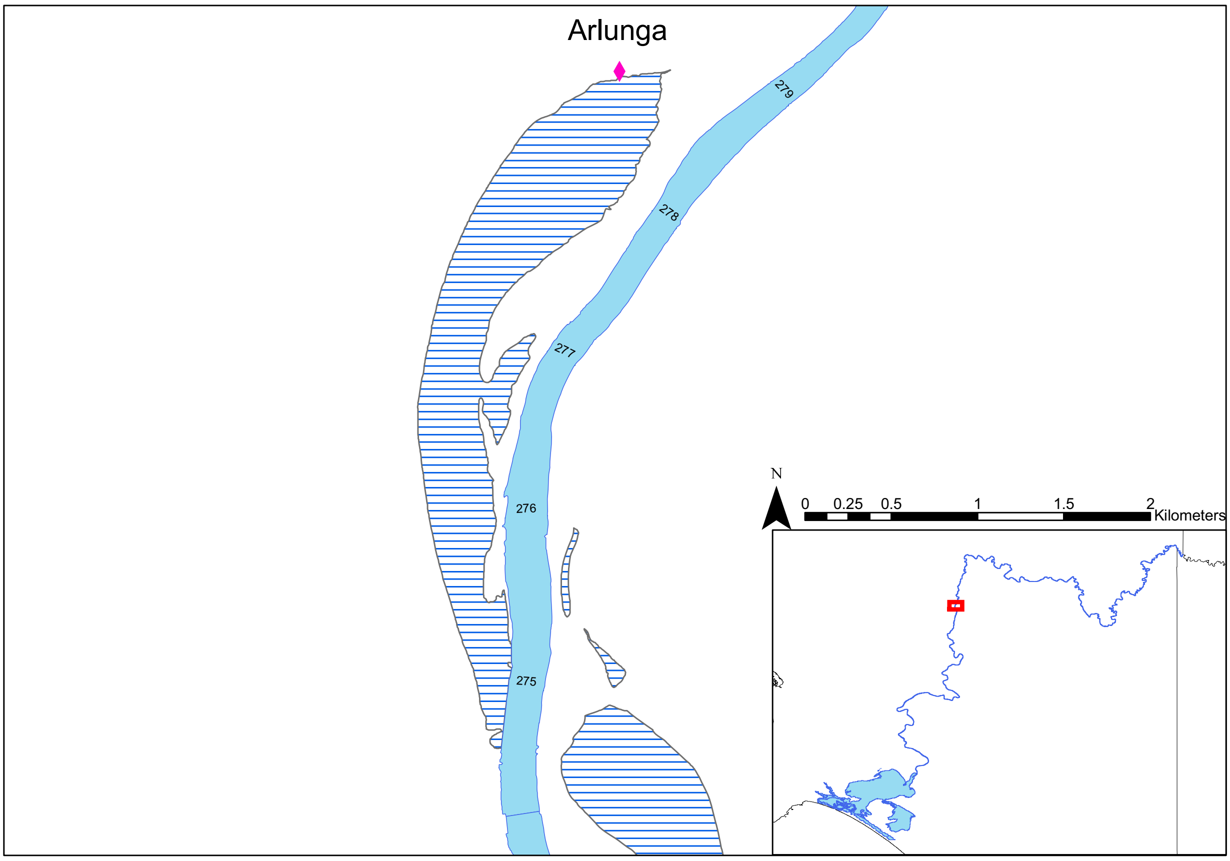
It was not possible to gain access further into this backwater, however water was flowing strongly back to the river from it. Tthis was felt to be a reasonable estimate of the average salinity for the entire backwater.

Average Salinity (uS/cm) = 537
Total area (SgM) = 672609.31

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	57242.22	negligible

Arlunga



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
North	539	11.3		12/08/2003

Notes

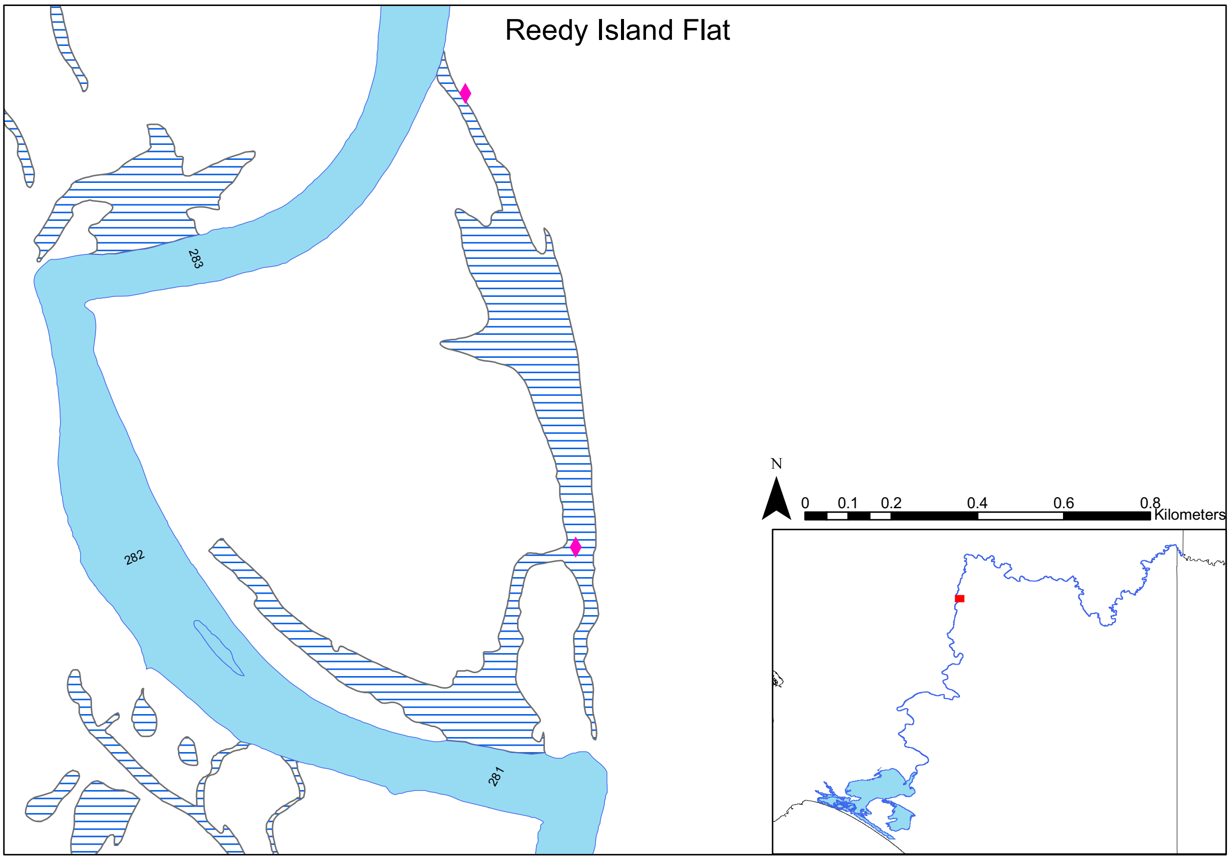
Average Salinity (uS/cm) = 539

Total area (SgM) = 1658973.34

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	149658.85	negligible

Reedy Island Flat



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
South	571	11.5		13/08/2003
North	551	11.6		13/08/2003

Notes

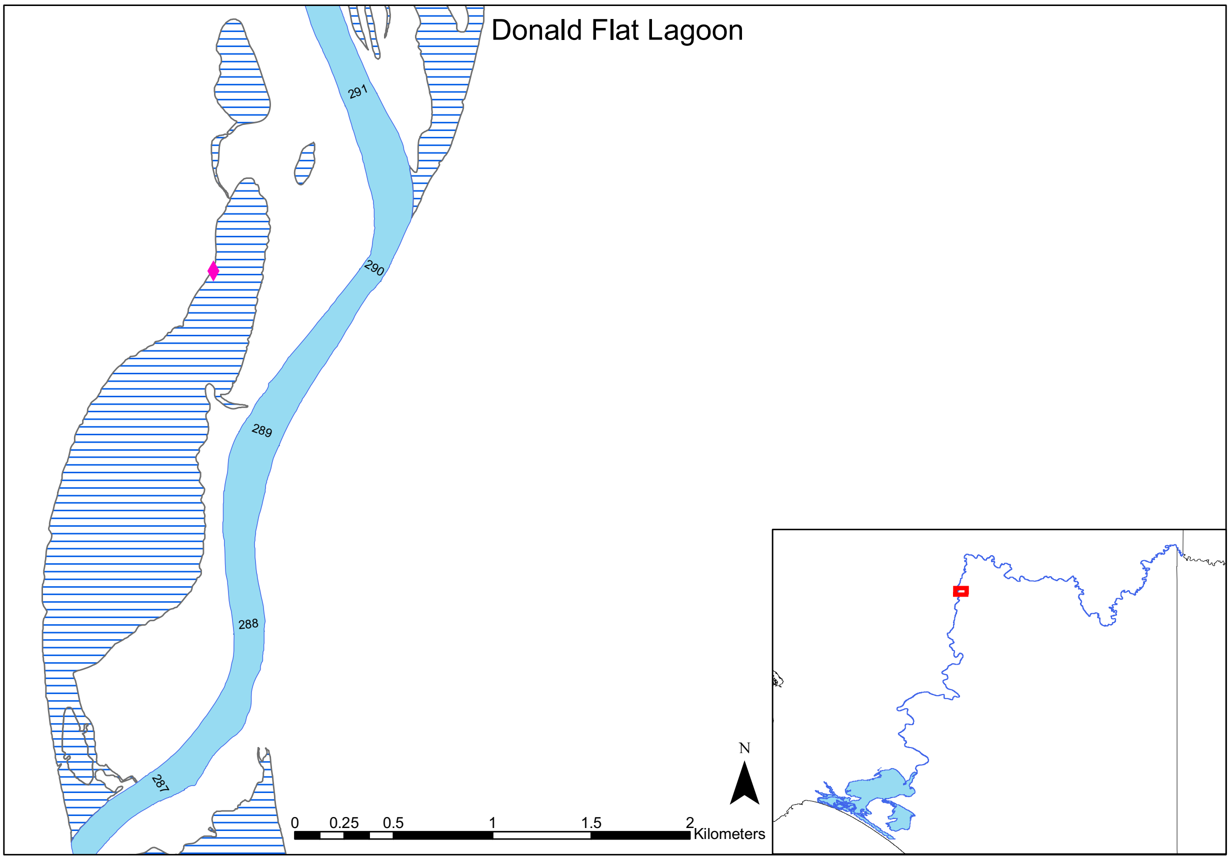
This backwater was clearly set up for skiing and was assumed that much of the central region of this backwater would be around 1m in depth or greater on this date. Interestingly when the North site was sampled, water was actually flowing out of this channel and back to the river.

Average Salinity (uS/cm) = 561
Total area (SgM) = 221839.06

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	16806.31	negligible

Donald Flat Lagoon



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
North	580	13.4		12/08/2003

Notes

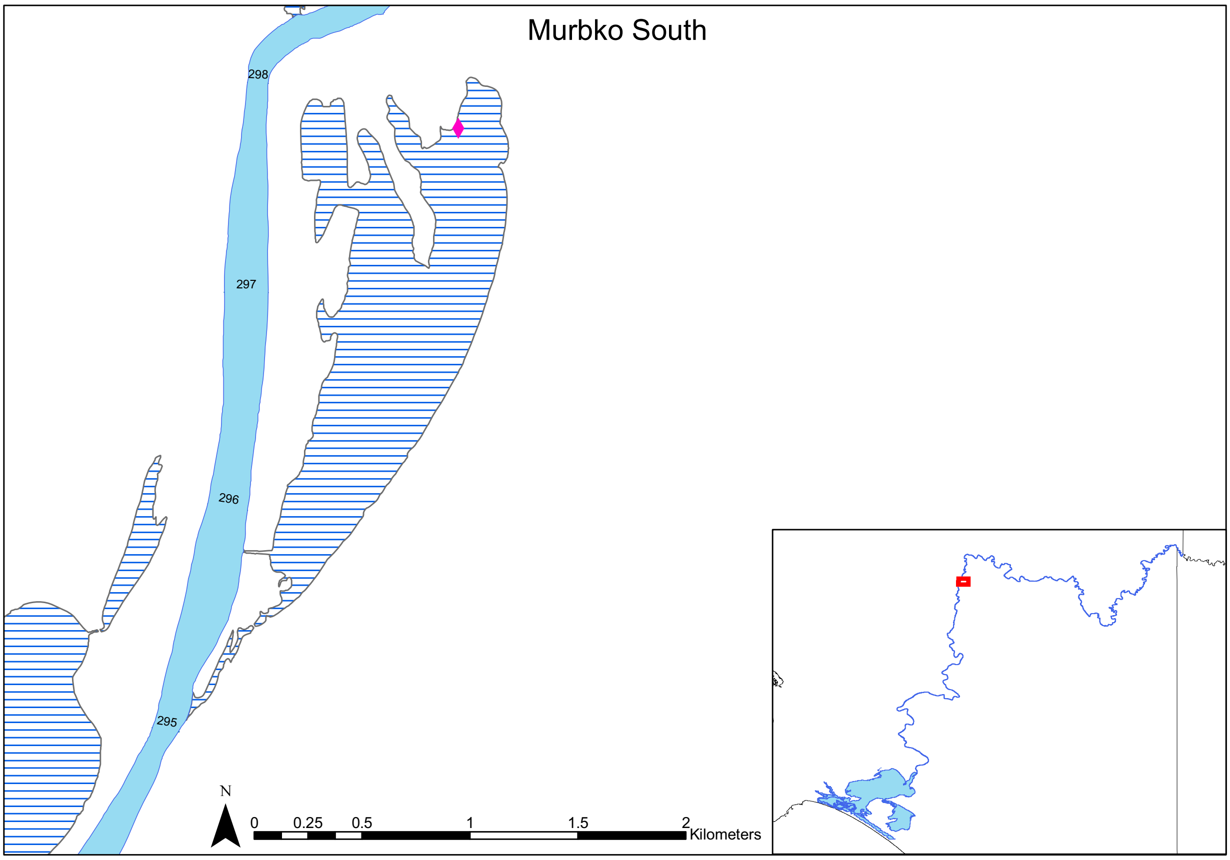
Average Salinity (uS/cm) = 580

Total area (SgM) = 1404068.24

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	125538.59	negligible

Murbko South



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
North	739	11.3		13/08/2003

Notes

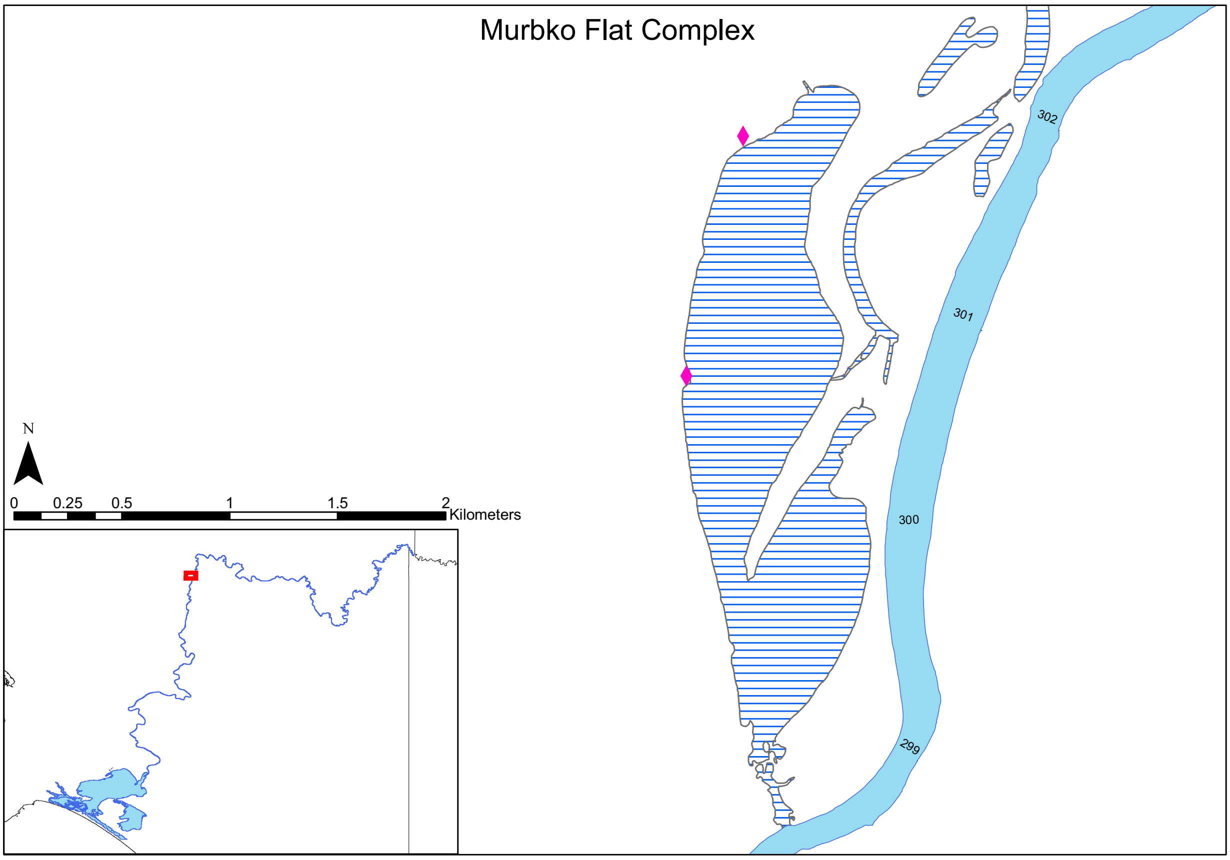
This reading was taken in the northern region above any apparent connections to the river and consequently, this reading may be higher than the actual average salinity for this backwater.

Average Salinity (uS/cm) = 739
Total area (SgM) = 1270850.32

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	112982.69	8.93

Murbko Flat Complex



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
West	850	12.6		12/08/2003
North	852	11.6		12/08/2003

Notes

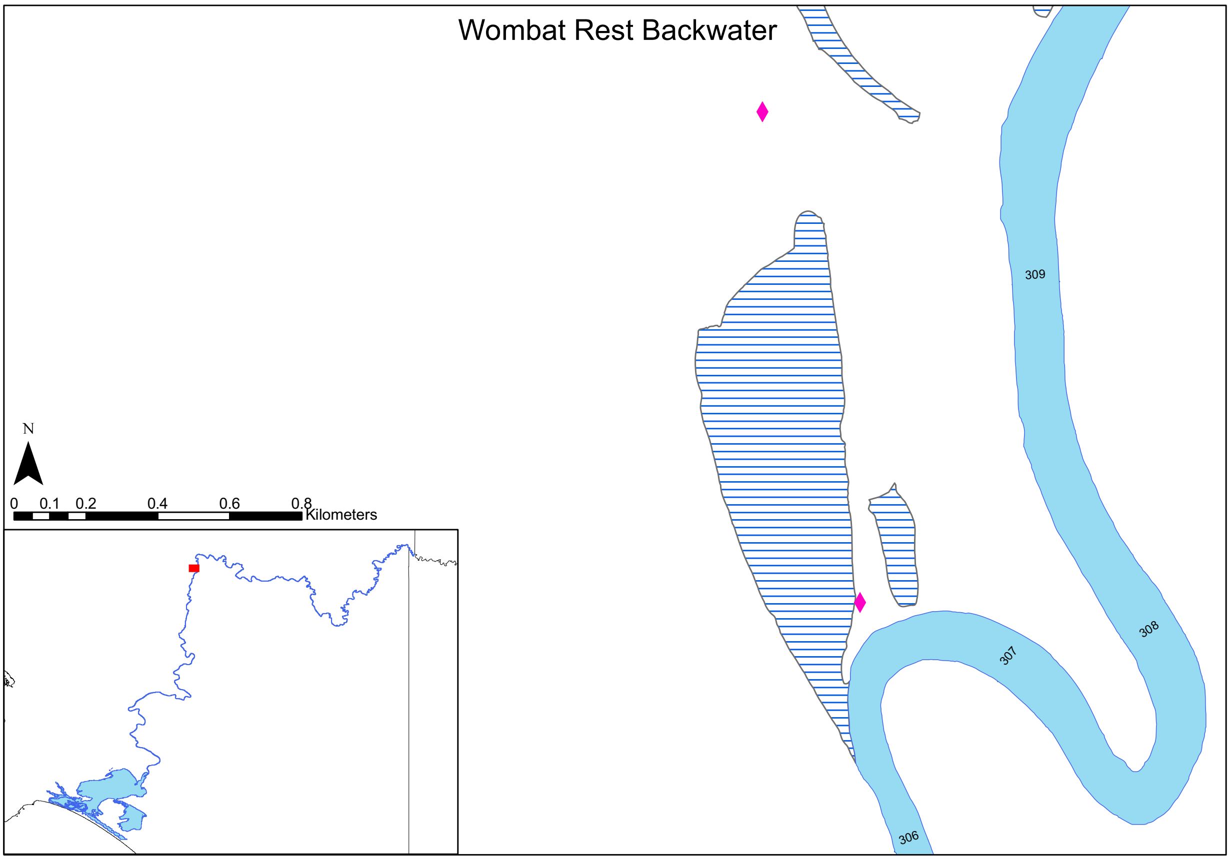
The total area listed below is for this specific backwater, although the inflow channel (not considered in calculation) is fairly long and may also hold a reasonable volume of water that could be returned to the river.

Average Salinity (uS/cm) = 851
Total area (SgM) = 1617423.07

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	145719.6	20.55

Wombat Rest Backwater



Site Details

Location	Salinity (uS/cm)	Temperature (deg C)	Depth (m)	Date
North	733	11.8		12/08/2003
West	575	11.4		13/08/2003

Notes

The North site is in fact, a causeway crossing over an inflow channel to this backwater. It is assumed to be indicative of the water in the more northern reaches of this backwater.

Average Salinity (uS/cm) = 654
Total area (SgM) = 376129.67

Increased salt load returned to river

River Fall	Volume Returned (ML)	Increased Salt Load Returned (Tonnes)
0.1m	30343.77	0.97